Challenges to Implementing Microreactor Technologies in Rural and Tribal Communities

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Abstract

Microreactors are an emergent technology providing nuclear-powered energy production facilities that boast portability, modularity, robust operational capacity, and carbon-free baseload electricity generation. While the exact operational and maintenance requirements are currently unclear, most platforms aim to have similar features, such as minimal required operational staff, portability via standard shipping vectors, and high availability factors. Proposed areas for deployment include remote military installations, community disaster relief and recovery operations, and electricity resource supplementation in rural communities, among others. Successful deployment would secure critical, vulnerable infrastructures, and alleviate resource scarcity in historically disadvantaged communities. Rural and Tribal communities are uniquely poised to benefit due to increased vulnerability to—and disproportionately negative outcomes caused by—power disruptions, infrastructure gaps, and critical service disruptions. However, successful deployment to these areas will depend on the careful consideration of current barriers, opportunities, and unique impacts of energy transitions to the respective local communities; as such, implementation and technology must be considered jointly.

As microreactors have not been widely studied in multiscale policy spheres, nor as a typical context for emergent technologies, this article will examine existing regulatory scope, energy infrastructure, ecological capacity, natural resource impacts, and community buy-in as a measure of a community's adoption capability for this technology. Using the Institutional Analysis and Development (IAD) Framework introduced by Elinor Ostrom, we will provide a context for micro- and meso-scale adoption of this technology that is reliant on the nested federal political, social, economic, and

doi: 10.18278/jcip.3.2.7

regulatory climate surrounding the use of nuclear technology, microreactors, and their deployment to address climate change and its associated needs at the local scale. We will address municipal, county, state, and Tribal perspectives; current policies; and ongoing efforts, as well as ecological and social costs associated with transition to a carbon-free national energy position.

Keywords: Small modular reactors, SMR, energy policy, environmental justice, rural communities, Tribal communities, Institutional Analysis and Development, energy transitions, coupled human systems, nuclear

Introduction

Recent global and national disruptions of energy supply, diminished energy resources, environmental degradation, and extended controversies over energy technologies have revived interest on the topic of energy transitions. Renewables and other emerging technologies, such as nuclear energy and advanced nuclear reactors, have been advanced to address these current and expanding challenges. For their part, the nuclear energy industry has proposed the deployment of small modular nuclear reactors to support local power provision—particularly in cases of natural disasters and frequent outages.

Small modular reactors (SMRs) are portable nuclear facilities that serve the same basic function as larger scale nuclear power plants, but they produce a fraction of the power that prototypical plants can produce due to their reduced scale. According to the United States (U.S.) Nuclear Regulatory Commission (NRC), SMRs produce 300 megawatt electrical (MW_e) or less power. This reduced scale also reduces the design component options and footprint requirements in electricity generation.

Presently, the most common model for SMRs are light water reactor (LWR) facilities, but there is a catalog of alternate nuclear reactor designs using various working fluids, which includes liquid metals (e.g., sodium, sodium-potassium alloys, or lead-bismuth eutectic), high temperature gas in the form of helium, or molten salts. SMRs are intended to be scalable to meet existing or growing power demands and may even be further optimized for civilian use. The SMR concept diverges from current nuclear reactors by: (1) increasing safety and reliability through reduced componentry; and (2) reducing the overall facility size. To accommodate this technology, a community must be able to provide a skilled workforce that can operate and maintain these reactors, as well as potentially build additional reactors to meet future power demands.

Proposed Communities for SMR Deployment

Mehta (2005), Wellock (1998), Sovacool (2009), Sovacool and Valentine (2012), and Jasper (1990) all describe national nuclear policy stating that nuclear development is not merely an economic or technical challenge, but also dependent on the cultivation of broader social conditions. Conversations about proposed communities often center around urban areas with industrial colocation. However, this technology is particularly attractive to chemical and agricultural producers in rural and remote communities where a significant amount of heat, and subsequently atmospheric carbon, is currently generated through fossil fuel combustion, as an externality of agriculture. Here, these innovations aim to address critical gaps in service for rural and remote communities.

The size and modularity of SMRs allow siting in areas with common challenges in remote energy provision—particularly following catastrophic natural disasters, such as wildfires—and to provide more reliable energy service to residents and remote localities. In the presence of new technologies such as SMRs, foreseen challenges by designers and policymakers often focus on the economic viability of such technologies. However, communities at the margin—particularly U.S. rural and Tribal communities—may face more challenges in siting and implementation than their urban counterparts. This is due to the nature of their lessened capacity at both the institutional and infrastructure levels. Other issues deemed as important by marginalized communities may take precedence over new power generation using SMRs.

US Rural Communities

Rural communities are characterized by conditions that disqualify them from being classified as metropolitan areas—such as counties consisting of countryside or woodland areas where the presence of rural localities consisting of fewer than 2,500 people and urban areas with populations less than 49,999 that do not contribute to 'larger labor market areas'—or what are commonly thought of as bedroom or suburban communities (USDA ERS 2021). Resources flowing from these rural counties, then, may have some variance — with larger communities in the county being the center for shopping, medical, governmental, career, and job locations, and other services. These communities often are the county seat. For less densely populated communities of rural towns, the prevalence of infrastructure and government institutions, including street-level services such as police, fire fighting, and local representation, may have limited capacity compared to their slightly less rural counterparts (Mockrin et al. 2014).

Individual rural communities are often characterized by their close-knit populations, where 'everyone knows everyone,' their limited services, and long distances from city centers or services. Many rural communities have depended on natural resource extraction industries or agriculture to support their economies. Some of these include timber, critical minerals mining, crop farming, and fishing, among others. Rural communities across the West are often characterized by proximity to the wildland-urban interface (WUI) and subsequently studied for their challenging experiences during and after recurring natural disasters, such as wildland fire and tornadoes, among others (Mockrin et al. 2018). In past years, recurring natural disasters, such as the wildfires in California, Oregon, and surrounding states, have left rural counties with mass infrastructure damage, as well as mid- and long-term disruptions in power provision for both rural and urban localities. Other outages, such as those caused by the 2021 winter storms in Texas, or Hurricane Ian in 2022 in much of Florida, among others have exacerbated the challenges of rural communities in receiving power, water, and aid. these communities may be less accessible, have a much lower population, and have less infrastructure to tend, they are often the last ones to come back online following a natural disaster or outage (Mockrin et al. 2022).

In addition to outage experiences during catastrophic events, many rural areas are already classified as disadvantaged communities (DOE 2022a), meaning that critical service gaps in education, medical service provision, Internet, and energy, among others, exist and can be exacerbated by such events. Rural community capacity hinges on the availability of infrastructure and institutional inputs—such as those from local government, street-level bureaucrats, job opportunities, and available industry, among others. Challenges to new technology adoption may stem from the current lack of infrastructure; issues with quality provisions or the availability of food, water, and electricity; low median income and home ownership; a legacy of land or environmental degradation with resource extraction and other natural resource-based industries; and a diminished tax base from which to derive funding for capital improvements.

U.S. Tribal Communities

Across the U.S., Tribal communities—including those on or off reservations—suffer disproportionately from health impacts, food and water insecurity, housing insecurity, and energy poverty, among many other environmental injustices and disparities in social and economic wellbeing. Environmental challenges, such as a history of mining on sacred ancestral lands, unregulated waste, and failure to properly clean up natural resource extraction areas, have led to further mistrust and strained relationships between Native American peoples and current energy suppliers. These include but are not limited to industry and the U.S. Department of Energy (DOE). These challenges compound historical social injustices endured by Tribal communities during the periods of colonization and expansion of settlements across the US, but particularly in the West.

In September 2021, the U.S. Department of Defense (DoD) issued a draft environmental impact statement regarding the Project Pele Mobile microreactor and its ongoing consultations with state, local, and Tribal stakeholders—particularly insight shared from the Shoshone-Bannock Tribes of Fort Hall, ID. Due to the Tribes' deep cultural heritage and strong historical ties to the land, their insight is very valuable to the Strategic Capabilities Office.

Notably, the Land Back Movement, which has been gaining traction among Tribal communities and progressives across North America since 2020, has focused on the sovereignty of indigenous peoples over their historic lands. Centered on environmental stewardship and the rights of nature, the Land Back Movement examines the role of Tribal communities in preventing further destruction of ancestral lands and combating climate change through grassroots conservation and guardianship of the environment (NDN Collective 2020).

The Biden Administration's 2021 executive order, the Justice40 Initiative (DOE 2022b), outlines stipulate that projects funded by the federal government must consider the environmental and energy injustices experienced by marginalized communities, such as rural and Tribal communities. The Tribal experience of health disparities, food insecurity, and energy poverty, among many others, highlight the need for solutions to social science's 'wicked' problems, or large-scale, multifaceted societal challenges imposed by the current institutional structure. However, current resource extraction practices for energy provision and other infrastructure across the US has led to a history of land degradation and disruption of sacred Tribal lands, cultural resources, and biodiversity.

Community Linkages

Linkages between rural and Tribal communities are often reflected in the types of resources, community capacity, and generalizations regarding remote living and access to critical services such as education, medical care, high-speed Internet, and energy equity, among others (DOE 2022a). It is important to note that many social science studies consider Tribal entities in the studies of rural communities—particularly in the American West. Similarities between natural resources, industry, natural amenities, and environmental and energy injustices—including gaps in service — are unique to each individual community context. Studies on rurality across the U.S. necessarily strive to include Tribal perspectives, particularly since federally recognized Tribes and reservation lands as managed by the Bureau of Indian Affairs, are largely remote and rural in nature, thereby experiencing the same challenges as their other rural community counterparts. For our analysis, we will consider the resources and capacity of rural and Tribal communities to be similar, yet governed by sets of contrasting sociocultural, economic, political, and institutional norms. Citizens and other members of these communities are assumed to have a different set of values regarding their community, the land, its stewardship, and priority needs, wants, as well as for the outcomes of new technologies and interventions.

Regulatory and Licensing Processes for Small Modular Reactors

Current principles of nuclear regulation and safety have evolved due to technical understanding of the strengths and weaknesses of existing plant designs and public concerns related to the safety of nuclear power plants. The role of nuclear reactor safety regulation and licensing is for the government to review and independently verify that nuclear reactor systems perform safely with reasonable assurance that the public and environment are protected (Deutch et al. 2003). Safety functions include controlling nuclear fission, heat and coolants, and the managing of any chemically reactive or radiological materials. Additionally, licensing challenges and requirements for SMRs are derived from frameworks and features that are significantly different from traditional LWR-based plants, making the licensure case for SMRs non-standard when compared to the current nuclear power fleet.

The licensing process for new reactors, in broad terms, is the process by which a civilian organization receives authorization to conduct any or all the following activities:

1. Construct, operate, and decommission commercial reactors and fuel cycle facilities.
2. Possess, use, process, export, and import nuclear materials and waste.
3. The management and transportation of nuclear materials and waste.
4. Site, design, construct, operate, and retire nuclear waste disposal sites.

Proper execution of these activities requires forthright dealings with regulatory organizations, community involvement and support, proper engagement with reactor vendors and construction firms, and the establishment of an adequate technical workforce. Current rural and Tribal communities may not be well-suited to meet these demands, given their geographical isolation, lack of centralized infrastructure, public apprehension towards unfamiliar or external influences, etc., described in earlier sections of this paper. Providing guidance on how to overcome these challenges is a major objective of this work—particularly in the context of the adoption of advanced technologies, when disparities in accessing current technologies and historical gaps in resources and infrastructure exist today.

Challenges to Adoption of New Technologies

Tribal and indigenous ways of life, as well as rural community values and norms, may pose challenges to the acceptance of SMR adoption at a local level. Federal and state regulatory processes have been thoroughly examined. Social science may focus on market support for adoption of these technologies for supplemental, emergency, and day-to-day energy provision. There is a need for community-led buy-in for the adoption of technologies, including support for nuclear power. In addition, to an understanding of unique community conditions, needs, and wants, is crucial in the promotion of SMR adoption.

Therefore, for the adoption of SMRs and new energy transitions in general, industry should consider the ways not only that regulatory bodies and markets interpret what is allowable, safe, and innovative, but also how these new technologies align with or defy social norms, expectations, and common values at multiple scales before determining the target site for the implementation of projects. Rural and Tribal communities possess unique and localized community networks, contexts, and sets of inherent rules and norms. These exist alongside regulatory practices, infrastructure availability, and economic feasibility. This can produce unforeseen and unstudied challenges in the siting and adoption of SMRs and other energy innovations.

Literature Review

An interdisciplinary Massachusetts Institute of Technology (MIT) (Froese et al. 2020) study on the future of nuclear power linked the "limited prospects for nuclear power today" to "four unresolved problems: Costs, Safety, Waste, and Proliferation" (Deutch et al. 2003). It is important to note that these problems are ultimately social in origin and the recognition by nuclear reactor vendors that these are problems to be dealt with reflects popular struggles (Ramana and Mian 2014). The social science literature on many of these restrictions about nuclear technology proliferation is vast. For example, Ishiyama (2003) analyzed an environmental justice study evaluating long-term nuclear waste, Greenberg (2014) studied trust in nuclear institutions, Greenberg (2009) focused on risk perception to understand the public preferences for risk perception in the U.S., and Downer (2014) and Hagmann (2012) questioned the risk complexity and problematic nature of the production of 'expert knowledge' about reactor accidents.

At a micro-level of analysis, adopting more pro-environmental choices and behaviors is possible, but this adoption is not occurring to the extent necessary to stem the increasing flow of greenhouse gases and other environmental damage because there are limits on the part of individuals that prevent the widespread adoption of new technologies (Gifford 2011). Some barriers are recognized in psychological research, but others are considered only marginally (Kollmuss and Agyeman 2002; Lorenzoni et al. 2007).

Additionally, communication is critical for community support for nuclear technology adoption. A social comparison between one house and its neighbors is one of the most efficient ways to change energy use. The way a message is delivered can influence how people react and behave, according to Thaler and Sunstein (2008). In this way, the authors' ideas about nudging and behavioral economics are critical. They demonstrate how one of the most common economic models are wrong in predicting what people do. Cognitive limitations, information bias, emotions, and an unknown future are commonalities among individuals who try to make decisions related to the environment and energy conservation.

The authors present a series of experimental results based on Kahneman (2011) regarding how people sometimes prefer the certainty of a decision even when the final benefit of that decision measured in monetary values is smaller than other options. In other words, monetary incentives are not the only ones that matter.

Health and environmental messages are vital to consumer buy-in, particularly in areas of environmental injustice and critical service gaps in healthcare, broadband, and in areas of land degradation and natural resource extraction. In the literature, there is not a common agreement regarding the reasons that lead people to accept specific technologies or innovations over others. However, vast literature exists regarding measurable psychological factors that could explain 'consumers' decisions, but only considers quantifiable factors, rather than qualitative data or robust sentiment analyses. The rapid development of new technologies makes it impossible for consumers to adapt quickly enough. In addition, researchers have yet to develop a model understanding the adoption behavior of consumers (Boserup 1981; Rezvani, Jansson, and Bodin 2015).

Adoption behaviors of communities vary, including both subjective and objective reasoning, measurable and quantifiable behaviors, and those currently unobserved. A significant share of the current empirical behavioral analysis is inclined to measurable factors. The most classical model includes aspects that can be measured numerically, narrowing its scope. An excellent example of this is Froese et al. (2020), Locatelli et al. (2014), and Macdonald and Parsons (2021). Furthermore, most studies focused on a limited quantitative set of psychological factors, thus failing to include a comprehensive set of critical factors influencing technology acceptance. If variables cannot be measured quantifiably, they are not included in the analysis. It is critical to note that a vast share of studies only considers factors that can be formalized in mathematical terms.

Thus far, there is no consensus on what framework to use to explain technology acceptance and consumer behavior related to new technologies such as SMRs. In a recent survey conducted by the Pew Research Center (2022), a third of U.S. adults (35%) said the federal government should encourage the production of nuclear power, while about a quarter (26%) said the government should discourage it. Another 37% said the federal government should neither encourage nor discourage the production of nuclear power. (The authors note that the survey was fielded before the 2022 Russia's military invasion of Ukraine and following discussions related to nuclear safeguards and security.)

Specifically, we argue that there are more important social restrictions than NIMBY opposition concerning the deployment of SMRs. Specifically, cultural, psychological, and political barriers (Sovacool 2009) affect the deployment of new energy technologies. Additionally, at the micro-level, behavioral psychology and communication play a role in public policy related to energy. Many psychological scientists now assume that emotions are a dominant driver of meaningful decisions in life (Lerner et al. 2015; Keltner et al. 2014; Keltner and Lerner 2010; Ekman 2007). And as we described before, energy decisions have been critical through human history, its evolution, and quality of life. Furthermore, the importance of emotions relating to energy decisions cannot be ignored.

Another vital attribute of SMRs to be considered is concern about risks. Most of the energy technology developed in the last few decades has some degree of risk and diverse consequences on natural systems. A significant share of these technologies also has destructive potential on both human and natural systems. From a broader perspective, a nuclear plant is imbued with complex and interrelated human and natural systems where we cannot think about technological artifacts in isolation. Pritchard (2013) argues that government regulators and industry officials often focus on fixing the technology in question and attempting to reduce the likelihood of future human error. A complementary approach should ask about whose goals these technologies serve, as well as the needs of the communities they will serve. The implementation of new technologies could be disruptive and radical for an entire socioeconomic system due to interdependence among actors and technologies.

In terms of nuclear reactors, due to complicated technological designs, we cannot anticipate all the possible interactions or inevitable failures (Pritchard 2013). The solutions to addressing these risks are unclear because of the varied types of system failures like design, equipment, procedures, operators, material input, and environment. Uncertainty about a safety outcome fosters social rejection (Kahneman 2011). Additionally, Perrow (1984) states that risks seem to appear faster than the capacity to reduce risks. Barriers include limited cognition about the problem, ideological worldviews, sunken costs and behavioral momentum, and dis-credence towards experts and authorities, among others. It is critical to note that engineers often evaluate the safety of a design using the Probabilistic Risk/Safety Assessment/Analysis (PRA/PSA) methodology. However, a risk assessment is not enough to reach a successful deployment of SMRs and a widespread implantation of this technology across different scenarios. Compounding this issue, the general population, which may be hesitant to adopt nuclear technologies (Boudet 2019), may not fully grasp the intricacies of PRA/PSA, thus escalating challenges in influencing positive sentiments to adoption of SMRs or other energy advancements not reliant on fossil fuels—particularly post-Fukushima and the war on Ukraine, where news media and conversations interacted with the perceived lack of safety and reliability of nuclear power, rather than statistical probabilities of incidents related to day-to-day operations.

Even so, behavioral studies aimed towards the adoption of new energy technologies may not capture rural and Tribal values and norms, or those uniquely held by close-knit communities such as these. Additionally, the traditions of both rural communities and Tribal entities may present challenges that go beyond those quantifiably measurable. Studies regarding the adoption of nuclear technologies center around the public's environmental and safety concerns for operations and waste, regulatory challenges, and economic feasibility. However, additional challenges exist at the periphery, particularly in elements of rural and Tribal communities' potential issues regarding the externalities of SMR siting and implementation. For example, issues of greater priority might be more prudent to address – such as equitable provision of education, food, and water, among others and resistance to government and institutional interventions in tight-knit and localized social networks—both formal and informal.

Policy Framework

Traditional economic frameworks following a rational choice model assume that all parties have perfect information about the context in which decisions are made. Pure economic theory dictates the examination of prediction of future supply and demand of individualized or collective systems to predict outcomes related to these energy markets. However, unobserved, or non-quantifiable factors (i.e., historical, sociocultural, psychological, and inter and intrapersonal factors of community members and environments) may not be examined in the proposal and adoption of new technologies.

The Institutional Analysis and Development (IAD) Framework (Ostrom 2007) has been used to examine both formal and informal rules that govern decisions and outcomes both within and among institutions. This framework has commonly been employed in public policy spheres to understand how institutions operate and interpret situations and actions of themselves and one another at multiple scales. Institutions, here, are regarded as any type of collective decision-making and acting body, such as local communities, government, industry, non-governmental organizations (NGOs), schools, and interest groups, among others.

As economic and regulatory models may not capture a community's true willingness-to-adopt these new technologies, and while formal regulations govern siting and operations, other aspects of implementation—localities are often governed by informal networks of community leaders, influence, social norms, and collective values (Fishler 2017). However, their desired implementation at the micro-scale—specifically in municipal, Tribal, or rural contexts localities—necessarily depends on the analysis of local sociocultural, economic, environmental, and political contexts, as well as the presence and quality of proximal infrastructure.

In studies of energy policy, particularly in the context of SMRs, a comprehensive review of both regulatory processes and projected market demand is critical to understand the processes by which innovative technologies are implemented in communities. However, in policy studies, the need to acknowledge the multiple actors, sectors, and factors exist that play in certain spheres, including local community development and acceptance of new policies, norms, and infrastructure.

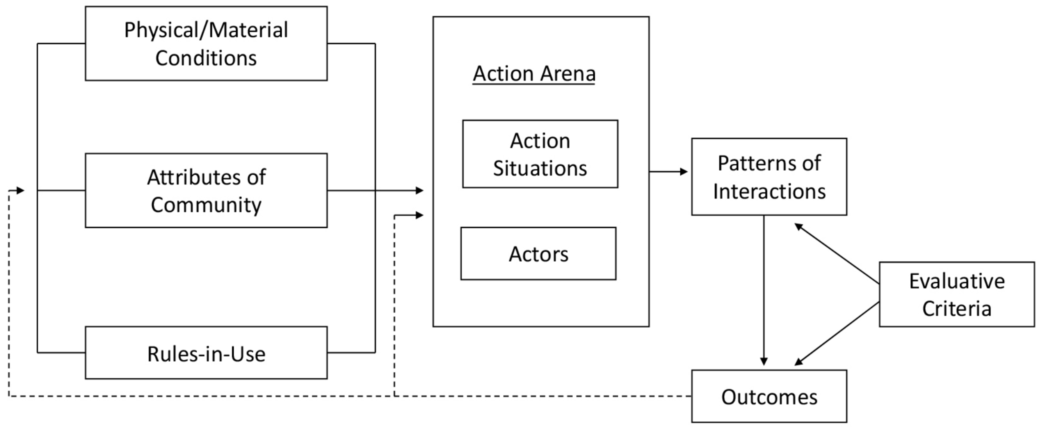

Figure 1: **A Framework for Institutional Analysis**

Adapted from E. Ostrom, Gardner, and Walker (1994). From: Institutional Rational Choice, (Ostrom 2005), in Theories of the Policy Process, Paul Sabatier

In Ostrom's IAD, as observed in Figure 1, physical and material conditions in accordance with attributes, demographic elements, social norms, inherent and implied rules in use, and current institutional capacity determine actions and decisions for the adoption of new policies, norms, and technologies. These decision-making spaces (e.g., action arenas) are the spaces in which the actors within institutions and communities consider conditions, attributes, and rules of their contexts alongside new or changing policies, infrastructure, technologies, and other proposed communal change-agents.

The resulting patterns of interactions relate to how these proposed alterations will be interpreted, simultaneously with existing beliefs, attitudes, and criteria regarding the evaluation of that which is proposed. This is relevant to the determination of willingness-to-adopt these new or changed policies or technologies within their unique contexts. It is important to note that outcomes are inherent agents of shifts in attributes, rules, and conditions of a community (Ostrom 2007; Fishler 2017).

Here, actors and stakeholders in communities may not necessarily act in a rational or formal manner, as they are acting based on sociocultural norms of their communities as decision-making bodies. For those that act according to economic principles/rational choice model of utility maximization, the decision to adopt new technologies or new sets of norms should not only consider the tradeoffs between goods and services, but also established inherent rules and values governing their patterns of interactions both within and outside their communities.

Discussion

Most studies of emergent technologies, like disaster mitigation, focus on one point in time adoption of innovations through an economic and technical lens (Mockrin et al. 2016). These studies may consider the availability of current infrastructure, resources, and challenges with program management, mitigation techniques, and practices meant to support adoption and deployment strategies as they relate to initial siting and implementation. In this context, regulatory challenges are navigated through formal decision-making bodies. However, while formal governance structures are certainly present in both rural and Tribal communities, it is misleading to assume that the same institutional resources and capacity exist within these types of communities as they do within those of higher capacity, greater population, greater infrastructure locales with numerous formal decision-makers, enforcers, and economic, policy, and technological spaces among other complexities. Tribal communities are often set within rural contexts, particularly in the case of federally recognized Reservations, and present further disenfranchisement by way of institutional capacity, infrastructure, funding, citizen resources, and greater disparities in health, socioeconomics, and quality of life (DOE 2022a). It may be beneficial for innovators in industry and government to understand the barriers and opportunities for SMR adoption in Tribal communities. These advanced technologies are aimed at addressing energy needs, including peak hour cost, availability, and accessibility for the disenfranchised. The creation of tailored approaches toward SMR implementation in Tribal communities—many of which are considered the most disadvantaged in the US—may be scaled upward to ensure success in additional areas, especially those communities or localities with less disadvantages, greater resources, and greater capabilities to adopt to these innovations.

Thus, the consideration of economies-of-scale are critical in understanding how communities and the institutions embedded within them will adopt new policies, technology, and infrastructure (Ostrom 2007). The study of civilian microreactor implementation exists largely within regulatory spaces at the federal and state levels, and at the meso-level and macro-economic scales. Current studies of these technologies focus largely on market demand, economic feasibility, and regulatory policy conditions that may create barriers or opportunities for adoption in the broad sense.

However, for rural and Tribal communities, policy research and environmental justice critiques, would indicate that there are complex sociocultural and informal considerations that this emergent industry may wish to consider prior to SMR siting and deployment. The goals of SMR implementation outside of military contexts may not necessarily align with the adoption of other new technologies, and not simply in urban areas. A new more nuanced frame may be needed for rural and Tribal communities, where populations may be hesitant to accept the influence of outsiders, industry, and federal government interventions.

With criticism of adoption of these technologies in urban areas, citing safety and waste concerns (Boudet 2019), the challenges in deploying SMRs in civilian context may go beyond these aspects. In truth, rural and Tribal communities often lack capacity and institutional availability that their metropolitan, suburban, and exurban counterparts may hold. The lessened institutional capacity, as well as remote geography, have inherently exacerbated challenges to rural and Tribal qualities of life—including decreased access to quality food, hospitals, education, Internet/broadband access, safe drinking water and water treatment provision, and the availability of affordable efficient home energy service, among other critical service gaps.

Because proposed communities for SMR adoption vary widely in their contexts, norms, composition, environment, and available institutions for governance checks and balances, there is a need for consideration of future challenges to adoption at the institutional level. Institutions, here, are defined as informal or formal decision-making bodies—including federal, state, and local governments (formal), as well as community groups, norms and beliefs, and conditions of the environment (informal), among others (Fishler 2017). Additionally, these institutions, their rules, standards, norms, culture, as well as material and physical conditions, are nested within one another. This implies a scaffolded approach to how regulations, changes, and operations are determined and interpreted within and among institutions (Ostrom 2007), as shown in Figure 2.

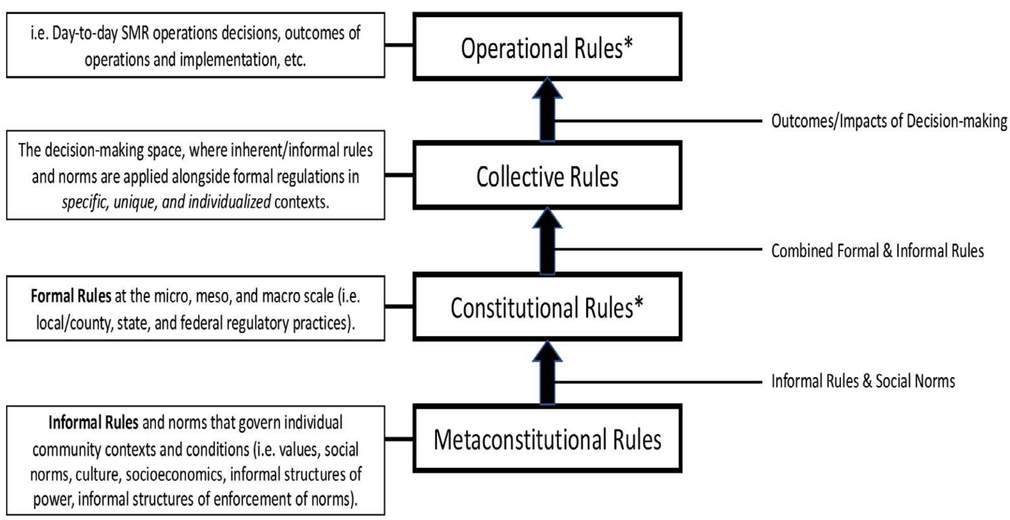

Figure 2: **Multiple Levels of Analysis – Scaffolded Rules-in-Use**

Adapted from E. Ostrom, Gardner, and Walker (1994). From: Institutional Rational Choice, (Ostrom 2005), in Theories of the Policy Process, Paul Sabatier.

Most current studies rely on notions of formal institutions or quantifiable data related to marketability and conditions under which SMRs are feasible under federal and state regulations, as well as economic feasibility. Additionally, they often depend on economics for social science determinants of adoption of these technologies. However, the process by which communities accept and adopt new technologies are more nuanced than these aspects (Boudet 2019).

Since all rules here are assumed to be nested within one another, these define how the previous set of rules will be interpreted or changed. While rules may be fixed, they may be interpreted differently by varied actors, sectors, agencies, and stakeholders. In the context of SMRs, this means that the community in which A facility is to be sited may view the introduction of new technology in a different light than industry professionals. Metaconstitutional rules provide the basis upon which all other rules are interpreted, adjudicated, and understood. These refer to those which are not commonly studied in policy spaces, as they rely on qualitative accounts of values, norms, culture, socioeconomics, inherent and contextual structures of power, and community context and the environment. Here, either informal or implicit rules based on the day-to-day experiences of living within the community and the beliefs and patterns-of-interactions between residents and street-level bureaucrats are of primary interest.

Informal rules flow upward to constitutional rules of operation, implying formal rules and regulations at the micro-, meso-, and macro-scales. In the context of SMRs, these may relate to local/county, state, and federal regulations surrounding the siting and externalities of these facilities and their implementation. In studies of SMR feasibility, the focus often draws in on federal and state regulations as nested within one another, yet, divorced from metaconstitutional rules and norms that may govern the regions and communities in which new technologies are introduced.

This framework can be used to examine a community's physical and material conditions—including existing infrastructure, availability of storage, and landscape and available space, among others. In previous studies of feasibility or willingness to adopt, the foci for this technology have existed largely in this space, as well as the formal rules employed for siting and certification purposes. These formal rules may relate to federal and state laws for reactor safety and operations, as well as economic feasibility.

Policy studies related to institutions, however, should consider attributes of the community as a crucial aspect of willingness-to-adopt. Oftentimes, these attributes are not or cannot be measured nor analyzed in quantifiable ways—yet they have impacts on the patterns of interactions between institutions, decisions of actors within these contexts, or the Action Arena itself, as seen in Figure 3. The nuances may not be captured in quantitative studies but may be observed in qualitative and social science research considering the context of the resulting impacts of sociocultural norms, environmental conditions, socioeconomics, familiarity with technology, political and policy views, and values, priorities, and genialness to and acceptance of influence from outsiders or institutions external to their communities or localities.

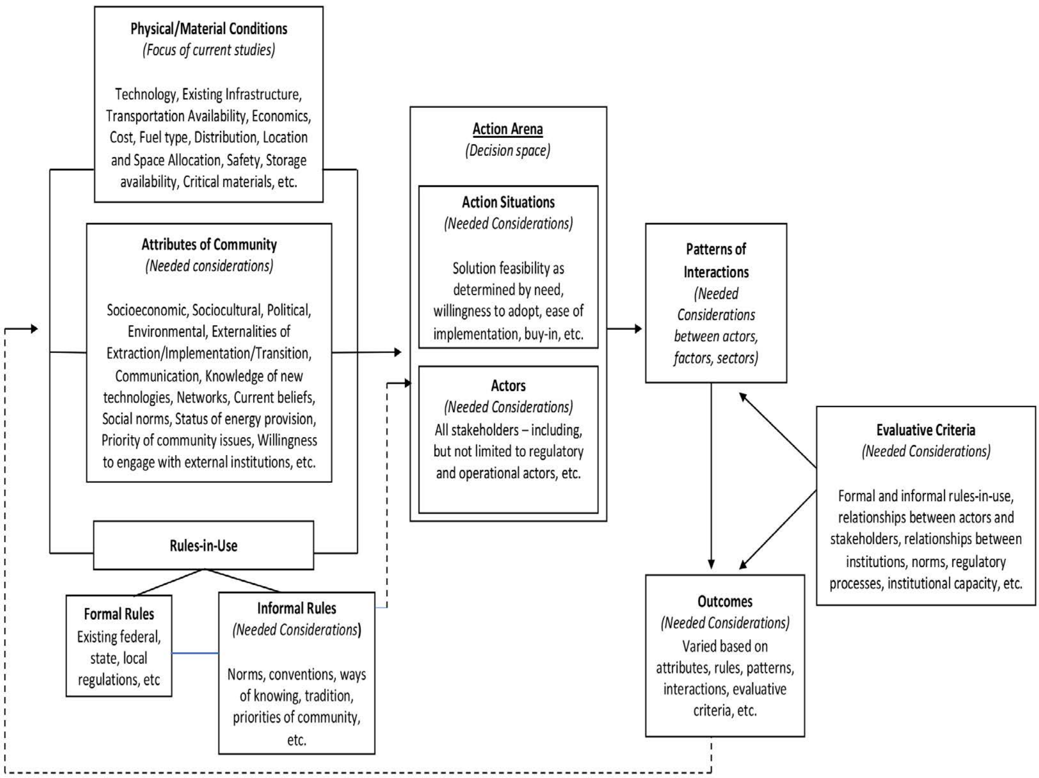

Figure 3. **Institutional Analysis of Small Modular Nuclear Reactors: Needed Considerations**

Adapted from E. Ostrom, Gardner, and Walker (1994)

Formal Regulatory Practices vs. Informal Rules and Norms

Current efforts towards examining willingness-to-adopt of these technologies does discuss the need for partnerships between government stakeholders in both local and regional contexts, as well as local government decision-makers. However, due to the limitations of institutional bandwidth and lack of willingness for most rural and Tribal communities to accept formal rules and regulation from those outside their communities, in addition to a lack of infrastructure enabled to implement and enforce these formal governance structures, there may be additional challenges that have previously not been considered in these spaces.

Research shows that the prevalence of informal networks in these tight-knit communities are the most effective forms of political and sociocultural influence—

particularly in rural and Tribal communities (Fishler 2017). Here, social norms and identity, including neighbor-to-neighbor relationships, are often the determinants of success in both street-level citizenship and stakeholder engagement. In areas where there are current service gaps and a lack of infrastructure, grassroots organizations of informal leaders who may self-select based on their connectedness in the community can often complement and have as much influence as formal regulators, governance structures, or business owners and other stakeholders. In areas where enforcement of formal regulations at the county and local level are lacking due to the challenge in resource provision for such street-level bureaucratic processes, these communities may rely on a kind of informal network-driven approach to determining and enforcing social norms and accepted behaviors, as observed in Figure 4.

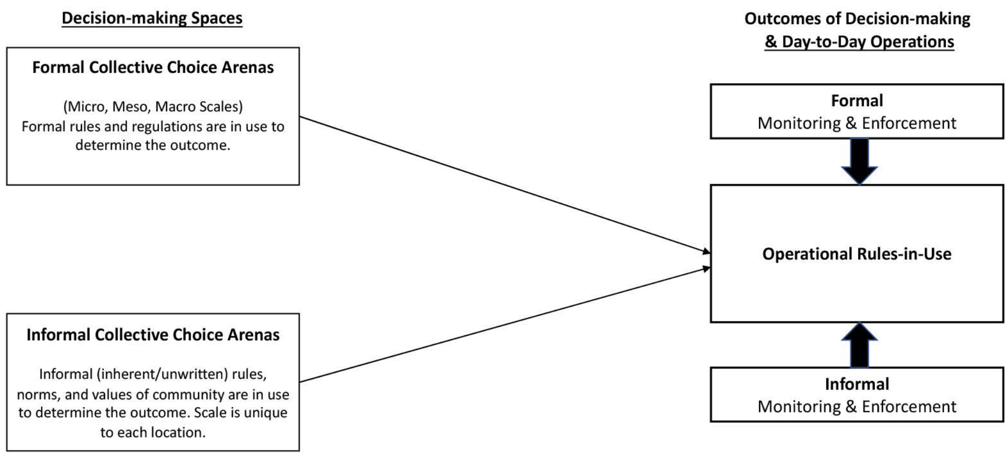

Figure 4. **Relationships of Formal and Informal Collective Choice Arenas**
Adapted from E. Ostrom, Gardner, and Walker (1994)

Formal institutions are the typically involved in analyses of SMR civilian deployment—such as regulatory bodies like the NRC, state governance, and local policies—regarding aspects of SMRs and their externalities (e.g., waste removal, water usage). They are geared more towards conformity to the norm, engaging the populace, and information provision to the commons (Ostrom 2007).

Formal collective choice arenas and decision-making spaces at the federal, state, county, and local level—or macro-, meso-, and micro-scales—include those agencies, bodies of governance, and other organizations where formal and explicit rules are used to describe and determine outcomes. At this time, those designing and siting SMRs are focused largely on overcoming only barriers located in the formal arenas to bring them to market.

However, informal collective choice arenas, where varied groups, cultures, inherent and unwritten rules, values, and norms are upheld should be a focus of siting and understanding potential barriers to community buy-in, willingness-to-adopt and willingness-to-pay, as well as availability of current infrastructure and community bandwidth. Informal monitoring and enforcement of these values will inherently align with proposed energy solutions that connect with community values, culture, norms, and the prioritized wants and needs as a precursor to formal regulations. These include legal operations, regulatory processes, and physical and material conditions. Here, the rules of day-to-day operations and successful implementation of SMRs in rural and Tribal communities should consider these informal and formal rules in tandem, which are checked and balanced not only by regulatory bodies, but also by keepers and enforcers of rules and norms within the localized context.

Safety

Safety practices and certifications are not necessarily enough to assuage community challenges in acceptance of nuclear technologies. In many cases, the distrust of nuclear technologies may stem from historical knowledge of nuclear disasters, environmental concerns about waste generation and storage, and the snowballing nature of negative sentiments surrounding the use of nuclear power, as well as the role of for-profit industry in communities. Some research suggests that education to increase awareness of reactor technologies and their inherent safety mechanisms may lead to greater social acceptance and willingness to adopt emergent and advanced technologies like SMRs (Choi et al. 2020). However, the hazards literature may indicate that education programs on best practices for safety and mitigation may not achieve long-range outcomes (Gil-Rivas and Kilmer 2016; Mockrin et al. 2018), while psychology studies suggest that acceptance of public education efforts depend on pre-existing attitudes about the particular topic, and therefore, may not assist in changing minds (Choi et al. 2020; Cho and Choi 2010).

Existing Critical Service Gaps

The prevalence of existing gaps in service and environmental and energy injustices in rural and Tribal communities may reduce the willingness to adopt new energy technology such as SMRs. Critical service gaps such as the lack of adequate medical care, Internet service provision, availability of nutritious food, proximity to disaster-prone landscapes, inequitable education, and lack of or unsafe/deteriorating infrastructure, may take priority over acceptance of new infrastructure that is time- and resource-intensive. If the immediate benefits of SMRs to the public are not clear, it may be especially challenging for these localities and groups to accept the benefits of energy transitions. It may not appear that the time-intensive and high-resource needs of SMRs will improve th quality of life for all members of the community. Since current environmental and energy injustices exist, particularly for these two community types, SMRs may not necessarily create the greatest impact on the largest number of people—particularly those that are currently disadvantaged because of existing infrastructure. Additionally, for existing disadvantaged communities, SMRs may not guarantee relief from energy and its cost burden, particularly in marginalized spaces, where the most vulnerable may still be at risk from resource extraction, space acquisition, and externalities of SMR deployment and implementation.

Rural Communities

Rural communities prefer that local governance, institutions, and rules enforcement be informal, depending mostly on their social norms. While rural residents are often subject to local building and zoning codes, they may put great stock in expressions of freedom (Kim and Marcoullier 2016; Miller and Rivera 2010; Mockrin et al. 2018; Nigg and Tierney 1993; Sumner 2005). These rural communities may value individuals embedded in the community creating and uplifting their networks, rather than acceding to the influence of outsiders or their formal rules. Additionally, because rural communities more heavily rely on informal networks than their urban counterparts (Gifford 2008; Gifford 2011; Sumner 2005), they may challenge the enforcement of formal rules that appear to violate community social norms. Achieving buy-in and support for new rules, institutions, and infrastructure may be grassroots-based through a bottom-up decision-making structure (Kapucu and Garayev 2011). The presence of an outside industry and an influx of "bureaucrats" to ensure compliance may not necessarily preserve agreed-upon social norms and conventions of these rural communities.

Tribal Lands and Community Values

The preference for local governance of rural communities also apply to Tribal communities, but other pertinent factors can deter the willingness to adopt new or unfamiliar industries or technologies. For example, efforts toward the preservation of Tribal lands, resources, and values have become more mainstream since the media focus in 2015 on the Keystone XL Pipeline. This led to a call across North America for the restoration of traditional native lands and the protection of natural resources, biodiversity, and Indigenous ways of life—particularly through the Land Back Movement. In relation to SMRs, required critical materials, disruption of historic lands through extraction, standing up the facility, the use of water and water treatment, space needed for coolant storage, etc. may be at odds with Tribal values such as conservation and environmental stewardship.

At the same time, increased energy provision and the reduction of energy costs on Tribal lands—particularly on American Indian Reservations—are often needed in remote locations. The introduction of new industry within these communities, compared with sacred beliefs about the role of people on the land, may necessarily present tradeoffs that create misalignment in the retention of values and norms in the pursuit of SMR implementation in Tribal communities.

As previously noted, federally recognized Tribes are considered sovereign nations with their own governance bodies and decision-making. In addition to informal networks, industry and Federal entities should consider a government-to-government approach in the development of plans for the implementation of new technologies and infrastructures.

Governance and Social Networks

A focus on federal and state policies on nuclear energy to determine marketability may overlook informal governance structures driven by the public, particularly in arenas where community decision-making practices are determined by small groups of publicly minded residents. Local decisions may rely on complex social norms including groups of influential neighbors, rather than local ordinances (Aldrich and Meyer 2015; D'Agostino and Kloby 2011; Fishler 2017).

Energy and Environmental Justice

Under the Biden administration's Justice40 Initiative (DOE 2022b), 40 percent of funding is projected to impact disadvantaged communities experiencing environmental injustice under current infrastructure. Priorities for research and development under DOE prioritize the alleviation of service gaps and energy poverty. However, current data tools and collection may miss indicators and data points due to the lack of current institutional capacity to capture these underserved populations. Determining measurable success for alleviating energy poverty may inherently rely on robust community engagement strategies. These are consistent with traditional scholarship on environmental justice, which emphasize grassroots, community-driven action to meet a population's basic needs while abating environmental injustice (Mohai et al. 2009).

These challenges have been highlighted in publicly available databases, including DOE's Disadvantaged Communities (DAC) Reporter, which identifies areas where communities and quality of life indicators rank below median benchmarks for the country. It should also be noted that challenges exist in using this tool since the ability to undertake data collection and reporting varies between communities. Rural and Tribal regions may or may be challenged in this regard. Ongoing research efforts are aimed at quantifying potential shortcomings to identify meaningful solutions for incomplete data sets (DOE 2022a; Ross et al. 2022).

Importantly, true service gaps, particularly those related to energy provision, may not be adequately reflected in the data. This may pose challenges in determining the actual value of new technologies as well as quality-of-life improvements they may allow. Standard assessments of market demand in these contexts may not reflect actual ground level community benefits of technologies like SMRs.

Additionally, the presence of multiple informal decision-making networks and stakeholders that may influence formal actions and policy adoption by regulating bodies. This may further complicate a true understanding of the willingness to adopt regulatory processes and market demand. This follows traditional formal economic policy and rational choice models.

Other Externalities and Additional Considerations

Traditional micro-economic theory considers externalities to be inherent to the interplay of supply and demand of goods and services. However, the IAD favors viewing externalities as outcomes of the policy, decision-making, or adoption process. They may inherently change physical and material conditions, attributes, and rules in communities (Ostrom 2007). This feedback loop can influence future decision-making of actors and sectors, including amplifying challenges, decisions, and future externalities.

In the context of SMR implementation in rural and Tribal communities across the US, as presented in Table 1, we consider the complexities of resource provision for such technologies, implementation, and the resulting challenges that these localities may likely experience.

Table 1. Micro-scale community externalities of SMR implementation

Externalities	Description & Additional Considerations
Environmental	
Waste Disposal	Availability space and location for safe disposal of waste with least impact to humans and environment.
Water Quality/ Quantity	Available water for SMR use that may impact agriculture, drinking water availability, etc., in record drought areas.
Coupled Human-Environmental Systems	Potential impacts to environment and ecology from implementation of new infrastructure and/or resource extraction.
Natural Hazards	Future natural hazards and priority of remote community access.
Resource Extraction	Potential environmental and health hazards related to resource extraction for use in SMRs, including critical minerals. Potential degradation of historic Tribal lands. Impacts to other local and marginalized communities associated with mining and development.
Infrastructure	
Transportation	Available routes of transportation for SMR components, including to remote locations.

Water Treatment	Water treatment needs for SMR operations, including needed upgrades and upkeep of facilities, water reuse, and runoff, etc.
Location & Space	Available development space for SMR and associated infrastructure.
Existing Infrastructure	Existing power grid infrastructure and power distribution.
Existing Service Gaps	Gaps in energy or public utility provision that may take precedence over the desire for new technologies.
Socio-Cultural	
Tribal Resources	Potential impacts to biodiversity, historical/sacred Tribal ancestral lands, resource extraction, further development on Tribal lands, Issues of land sovereignty/Rights of Nature/Sacred resources.
Tribal Values	Tradeoffs between development of land, resource extraction, perpetuation of systemic environmental and energy injustices.
Rural Values	Tradeoffs between sustained power provision/costs/systems resilience and attitudes about government and industry interventions, attitudes towards outsiders.
Informal Networks	Power of citizen-led and street-level bureaucratic advocacy coalitions and/or influence over other residents, formal bodies of government.
Prioritized Needs	Potential conflict surrounding focus on new technologies as opposed to addressing current systemic environmental and energy injustices, as well as critical service gaps.
Economic	
Job Availability	Tradeoffs between current and/or previous industries in rural and Tribal areas, and limited available, family-sustaining jobs of SMR operations at the implementation site.
Benefits to Community	Area of opportunity for broader impacts to community development, rural, and Tribal energy and environmental justice.

Policy Recommendations

The following recommendations for institutional buy-in at the local level in rural and Tribal communities recognize the challenges and tradeoffs discussed above. These policy recommendations are non-exhaustive and may not apply to their urban counterparts, although environmental justice, water provision, and prioritized needs should be considered, where relevant, in all SMR sites and proposed projects.

Recommendation 1: *Embed local leaders in all planning, siting, and implementation phases, as well as in other deliberations as warranted*

Stakeholders should focus not only on regulatory processes, siting, safety, and storage and waste disposal, but also on the development of relationships with community leaders and high-profile members having influence with other residents—either formally or informally. Many infrastructure projects enable community engagement and outreach planning at the beginning and end phases of building or implementation. Involvement throughout the life cycle of the project and its day-to-day operations is also important. Community engagement and its willingness to adopt new technologies, particularly those that may disrupt the status quo or business-as-usual, may benefit from community residents becoming stakeholders and assisting the determination of benchmarks for success. In lieu of formal bureaucracies or institutional capacity in rural and Tribal environments, citizen-based qualitative data regarding current critical gaps and communal challenges can also assist in the alignment of stakeholders and community members. This is important where data is lacking on existing experiences of environmental and energy injustices under prevailing energy provision methods (Lach et al. 2003).

Recommendation 2. *Consider Tribal communities to be sovereign nations and use government-to-government style communication and negotiations in developing buy-in*

A critical aspect of developing new infrastructure on Tribal lands and with Tribal partners, is for industry and others to respect the sovereignty of indigeneity and its values. These values may align or misalign with efforts to deploy new energy technologies. External partners should consider Tribal resources, lands, and biodiversity as inherent in these government-to-government interactions and should support the retention and sharing of this value. In addition to a government-to-government approach to value and information-sharing, allowing Tribal entities to have the option to engage on their terms is important. And respecting their style and willingness to communicate is a critical step in trust- and relationship-building. As Tribal communities identify barriers and opportunities to implement SMR projects and other advanced technologies, stakeholders should avoid prescriptive solutions. Collaboration should reflect the needs and wants defined by the community. The objective can be to take an integrated approach for energy provision while respecting the communities particular culture, values, and lived experiences.

Recommendation 3. *Understand current community needs and existing critical service gaps that may take precedence over the desire for new technologies*

Industry and government stakeholders should consider that community buy-in may not be easily won, and that they may need to contend with issues that have gone unaddressed or are of larger importance to community members. Additionally, the roles of influential informal leaders in the community – and their ability to garner support or opposition to changes in their community structure and norm – should not be ignored. Rather, these informal governance models and community groups should be considered to be members of an advocacy coalition that can influence official policies and changes within their localities. In the introduction of new technologies, those proposing projects should go beyond traditional economic models. Deliberations can reflect the view that SMRs can benefit the community, align with local values and needs, and can support an integrated-systems approach to energize community development through SMR deployment. In these communities, data-driven approaches to address important service gaps may transcend available data, since institutional capacity for data collection may be limited. This, in turn, can create challenges in the deployment of value-added integrated energy systems (Ross et al. 2022). Adequate data is fundamental to enabling individual communities integrate emergent technologies. Tools such as the DAC Reporter reflect qualitative and social science approaches that permit the identification of community priority needs under current infrastructure. It provides systematic approach to measure the needs of disadvantaged communities at a micro scale and in a sensitive manner while facilitating external financial investment.

Recommendation 4. *Consider energy and environmental justice, and develop a robust mitigation plan, including tradeoffs for sourcing materials and siting facilities*

SMRs have the potential to restore environmental and energy justice, particularly in times of uncertainty about energy provision and concern about adverse environmental impact. Project stakeholders have a role to play in addressing the unique challenges that exist within affected communities. This includes knowledge of current natural hazards, water provision, and strains on the community and its resources. Additionally, the development of a mitigation plan is critical for addressing issues that may be exacerbated by the introduction of new infrastructure and industry in the area. Relevant parties should base mitigation plans not only on quantitative data—noting that data collected in rural and Tribal areas may be incomplete or inadequate due to resource strain. Qualitative and social science data should capture the lived experiences and hardships of community members and recognize institutions at the local level. To create the desired impacts within disadvantaged communities, developers and stakeholders should seek to integrate multi-solution implementation of technologies that bring additional or value-added benefits to marginalized groups. These may include access to high-paying jobs, healthcare, and more equitable opportunities for education, among many others.

Recommendation 5. *Strategize with local communities on what successful energy transitions look like, and implement benchmark success measures that incorporate community values, wants, and needs*

Critical to a willingness-to-adopt and ongoing buy-in for new infrastructure, is the engagement of rural utilities, utility boards, and local actors, factors, and sectors to determine the roles of industry as outsiders to the community. Their role in stewardship of the area, and potential for service to the region in which SMR facilities are implemented are important. Outsider consideration of community members and garnering an understanding of demographics, trends, and qualitative data about the community may assist in the development of projects where community values are determinants of success. Additionally, treating these action arenas as unique locations with their own attributes, rules in use, and aspects of community will ensure responsible consent-based siting. A cardinal objective should be continued engagement of community members throughout the process, rather than simply the initial phases. Finally, in implementing these projects, industry and other stakeholders should consider a community development plan where citizens at large define the challenges and metrics for success. These would typically include creating more opportunities for community residents, particularly in disadvantaged communities. Care should be taken to avoid prescriptive solutions. Stakeholders can have a role in continually empowering communities to make decisions on behalf of themselves in addressing problems identified by community members.

Conclusion

Ostrom's IAD framework may provide insight in examining the actors, factors, and sectors involved in responding to challenges exacerbated by climate change. These include energy provision and transitions to a carbon-free economy. While SMRs are considered carbon-free, their inputs rely on a set of existing or developed systems to ensure their success in day-to-day operations. In SMR development, particularly in the rural and Tribal contexts, industry, and stakeholder partners should carefully consider the unique aspects of communities including current gaps in service, environmental and energy injustices, coupled human systems, and how the implementation of this technology can be used as an integrated solution to multiple community needs.

No matter the context, advanced technologies like SMRs rely on a set of resources for their componentry and deployment. Additionally, any new technology or transition from current infrastructure will inherently impact the environment. This includes physical and material conditions of the community in which it is implemented. Rural and Tribal communities may be disadvantaged and experience environmental and energy injustices, among other socio-economic disparities. This can compound challenges such as willingness-to-adopt in the implementation of SMRs. Where other equity gaps persist – such as an absence of critical services, the presence of food deserts, lack of quality education, limited access to medical care, issues with job availability, among others – a community's desire for immediate needs to be met ahead of energy transitions is an important consideration for developers.

While further research is needed on the relationship between rurality or Tribal-identification and views on SMR adoption, some research suggests that a lack of knowledge or mistrust of outsiders can create embedded challenges in the proposal of new energy infrastructure (Boudet 2019). As stakeholders consider a community's willingness to adopt and buy-in to SMRs, formal regulations and governance bodies should not be the sole players in decision-making related to energy transitions. Rather, informal networks of governance, citizen groups, and the inherent values, social norms, and cultural beliefs of each locality should be intentionally examined. This type of robust engagement and outreach can avert roadblocks in a mutually beneficial way.

By analyzing these rural and Tribal communities, including their values and norms and how their internal processes influence how formal regulations are interpreted and enforced, SMR developers can maximize the probability of project success. Messaging and solutions that acknowledge the unique conditions and attributes of these areas, make it easier to garner support from the community and create more willingness to implement solutions for equitable energy provision across a spectrum of local contexts.

Acronyms and Abbreviations

COL – Combined License

ESP – Early Site Permit

DAC – Disadvantaged Communities Reporter

IAD – Institutional Analysis and Development Framework

ITAAC – Inspections, Tests, Analyses, and Acceptance Criteria

LWR – Light Water Reactor

NRC – U.S. Nuclear Regulatory Commission

PRA – Probabilistic Risk Assessment/Analysis

PSA – Probabilistic Safety Assessment/Analysis

SMR – Small Modular Reactor

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