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Citizen-Led Community Innovation for Food Energy Water Nexus Resilience

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Food-energy-water (FEW) resources are necessary for the function of multiple socio-natural systems. Understanding the synergies and trade-offs in the FEW nexus, and how these interconnections impact earth's systems, is critical to ensure adequate access to these resources in the future; an essential component for achieving the Sustainable Development Goals (Scanlon et al., 2017). Although, over the last decade, the identification of FEW nexus complexities has increased at a global (Intergovernmental Panel on Climate Change [IPCC], 2018; D'Odorico et al., 2018), national (Lant et al., 2019), and city scale (Rushforth and Ruddell, 2018), these findings are yet to be adequately translated into "on the ground" action due a lack of technical and political capacity (Weitz et al., 2017). Specifically, local FEW systems have been overlooked in these analyses (Scanlon et al., 2017; Lant et al., 2019), thus leaving small and medium towns vulnerable due to a lack of data and inadequate FEW system management. Building on 3 years of field-tested FEW nexus research in the Ruddell Lab, we argue that participatory citizen science projects, such as our FEWSION for Community Resilience initiative, can bridge the data-policy gaps that exist within local FEW system management by: (1) providing last mile data on the FEW system, and (2) translating local data into evidence-based solutions at a grassroots level. Thus, we present a broadly applicable framework and call to action for local scale participatory citizen science to solve complex FEW nexus issues at a local, regional, and national scale.

Keywords: participatory science, citizen science, resilience, food energy water, nexus, vision

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INTRODUCTION

Policy and decision making at all levels of government, and within the non-profit and private sectors, is increasingly focused on supply chain and network issues which transcend disciplinary, governance, and jurisdictional boundaries. Following the 2011 World Economic Forum address (World Economic Forum Water Initiative [WEF], 2012), the food-energy-water (FEW) nexus has

emerged as an exemplary network concept representing the need for cross-cutting policy in an interconnected world. A nexus perspective focuses on the interconnections between food-energy-water resources, and now appears on political agendas as a component of sustainable development. For instance, it is a foundational element in the achievement of the United Nations' Sustainable Development Goals and the implementation of the 2030 Agenda for Sustainable Development (Bleischwitz et al., 2018; Liu et al., 2018). The FEW nexus faces increasing strain from globalization, growing consumption, competition for scarce resources, climate change, and urbanization. These strains compound individual resource implications across an interdependent and global network; creating uncertainties for effective decision making. Proponents of nexus thinking have called for sustained research into FEW networks, frameworks, and governance structures to manage the unpredictable consequences of decision making (Scanlon et al., 2017).

Whilst significant research has been devoted to overcoming these issues at a national (Lant et al., 2019) and global scale (Hoekstra and Mekonnen, 2012; Intergovernmental Panel on Climate Change [IPCC], 2018), action and data at the local level remains elusive. Nexus research, whilst proliferating analysis on critical FEW questions, has not provided adequate frameworks to translate complex systems thinking concepts into effective policy. Moreover, there is a need to understand how nexus resources and stakeholders interact across scales (Daher et al., 2018). At the root of this issue is a fundamental lack of actionable information about how the nexus functions and who influences it at the local level, which limits the capacity of local decision makers to understand and manage FEW networks. In the US, for example, the availability of FEW nexus data is geographically, and temporally, limited (at best) to large cities and national-scale analyses (Romero-Lankao and Norton, 2018; Marston et al., 2018). The local level, such as the median small city or rural community, which provides critical food and water resources to larger municipalities, is left relatively uninformed and vulnerable (Rushforth and Ruddell, 2018).

Adopting a local lens for the management of the FEW nexus is a necessary step in ensuring the sustainable management and resilience of these systems at the tactical, local level (Yung et al., 2019). We believe that *local* capacity and information is the most fundamental challenge facing sustainable development and FEW systems resilience. Citizen-led solutions are the most direct method to provide researchers with critical last mile data for the networks they inhabit, especially in the median community which may lack local professional science support. Our research over the past 3 years suggests that the solution is to deploy participatory citizen-led initiatives which directly collect the missing "last mile" FEW data while simultaneously building local political capacity to manage complex systems through education, data collection and visualization, networking, and conversation. In this Perspective, we outline how citizen-led initiatives can build evidence-based conversation and data-driven capacity to solve complex local FEW nexus issues.

BUILDING LOCAL RESILIENCE: CITIZEN-LED SOLUTIONS

Current research into the food-energy-water nexus has overlooked the local level; compounding the vulnerability of FEW nexuses at local, regional, and national scales. Considering the importance of food-energy-water resources for the sustainability of socio-natural systems, developing the resilience of local nexuses is critical. Local resilience requires the community to have adequate technical and political capacity to map, monitor, and manage the local FEW nexus (Yung et al., 2019). However, current research has failed to provide sufficient local, or "last mile," data to help communities identify their complex local FEW nexuses (Rushforth and Ruddell, 2018). Moreover, insufficient data has compounded political capacity issues which exist in small and medium sized towns. Local institutions are seldom the case study for large-scale research projects which develop governance frameworks for the FEW nexus, and they often lack the resources necessary to effectively implement governance frameworks which have been designed for large municipalities. Building local resilience, therefore, requires an approach which can suitably develop both political and technical capacity at the local level.

Outside of the food-energy-water research field, studies have adopted engagement methods – such as *public participation in scientific research* (PPSR) (Shirk et al., 2012) – to build local scientific and political capacity and thus improve the community's resilience (Grossberndt and Liu, 2016; Newman et al., 2017). PPSR approaches recognize that varying degrees of participation and methods for engagement may be used to achieve the social, political, or economic goals of a community. These approaches have been widely adopted in the fields of environmental science and conservation to build resilience by engaging with citizens to produce "last mile" data on local socio-environmental systems, including marine conservation (Cigliano et al., 2015) and sustainable water management (Buytaert et al., 2016). In these studies, citizens were involved in the process of scientific research through citizen science (Buytaert et al., 2016); building the community's scientific capacity by providing information on critical systems which can be used to inform the modelling of local socio-environmental systems (Bodin, 2017), and thus improve the identification of threats to those systems.

Alongside the collection of local data, PPSR approaches strengthen a community's policy making capacity through increased scientific literacy and analytical skills, an improved understanding of the uncertainty and complexity inherent in the local system being studied, and stronger social networks to generate data-centered conversations (Bonney et al., 2009). Engaging local citizens and nexus stakeholders in the process of scientific research develops the capacity of local political institutions to manage their local socio-environmental systems through (Bonney et al., 2009; Shirk et al., 2012; Haywood, 2014):

1. Awareness – by engaging citizens in the scientific process, local communities become aware of the nexus thinking concepts which have been difficult to translate into policy.

2. Education – understanding and adopting nexus thinking approaches is supported through training during the PPSR process.
3. Engagement – involving local stakeholders across all levels to the process supports the adaptive and flexible governance required.
4. Empowerment – vulnerable people are often most negatively influenced by threats to socio-environmental systems, and it is therefore important that their voices are equally heard in the management process. PPSR focuses on achieving empowerment by arming citizens with analytical tools and data to add evidence to their voice.

Clearly, PPSR approaches have significant advantages for generating resilience as these methods can be used to build a community's political and technical capacity. For example, Daher et al. (2020) emphasizes stakeholder engagement in city FEW nexus problem solving. Whilst citizen-led solutions for improving research and political capacity are common in the field of environmental management and conservation, their potential has not been exploited for nexus management. In the next section, we outline how PPSR approaches can be used to improve local food-energy-water nexus resilience with reference to our 3-year participatory study – FEWSION for Community Resilience (F4R) – which implements a citizen-led approach.

APPLYING PPSR FOR THE LOCAL FOOD-ENERGY-WATER NEXUS

PPSR attends to both social and scientific goals, and this makes it a powerful tool for building local resilience in socio-natural systems like the food-energy-water nexus (Markolf et al., 2018). In line with the findings of previous PPSR studies, engaging citizens in the process of data collection generates data which informs and reveals both a community's unique issues and specific pathways to sustainable FEW nexus management. This approach directly overcomes the massive hurdles of privacy regulation, data aggregation, and data distribution faced by larger-scale governmental data collection efforts. Thus, local PPSR approaches increase both the resolution and accuracy of FEW nexus data.

Concurrently, holding a data-centered conversation with local policy makers and private stakeholders like utilities or grocers enhances the opportunity and capacity for evidence-based decisions related to the local, collectively managed FEW nexus. Researchers in the Cambodia LIVES project (Yung et al., 2019), for example, noted that a lack of local data hindered policy makers from establishing adequate management structures for their local FEW nexus. Issues of political capacity follow a similar pattern, in which institutions used to traditionally managing resources through silos are struggling to adopt flexible approaches. PPSR projects utilize the strength of volunteers as citizen scientists to provide local data for policy makers through conversation. Helpfully, the involvement of community members in collecting and analyzing data on their community's FEW nexus simultaneously builds the social networks needed to actualize policy for the FEW network. Using the social networks and local knowledge of citizens provides researchers, and policy makers, with access to improved understanding of the FEW nexus.

Thus, in theory, PPSR approaches offer benefits for improving resilience and helping communities to solve complex FEW nexus issues. Building upon these theoretical assumptions, we developed the F4R initiative: a 3 year participatory study which implements a PPSR approach to build the capacity of a small town to identify and manage its local FEW nexus. In the F4R initiative, PPSR techniques were used to generate last mile data on the local FEW nexus, identify citizen knowledge regarding the critical content most relevant for citizen training, identify methods for engaging stakeholders at multiple levels of organizations, and build connections between diverse representatives of public and private organizations in the community (**Figure 1**). The PPSR approaches adopted were designed to build the community's technical and political capacity by focusing on data collection and strengthening social networks.

In the F4R process, social networks were strengthened as citizen scientists helped to connect the theory of the project with applications and practitioners from emergency management and food bank networks. First, our initial partners – the city and university sustainability programs – connected community participants with stakeholders working on local food access and waste. These initial connections led us to engage with local food banks who were interviewed by participants; leading to food access for vulnerable populations becoming the focal point of initial community action plans. Secondly, our first cohort of community participants were able to initiate conversation with a local emergency manager who subsequently saw potential areas for community action. As a result, the second cohort of community participants connected with the county-level "Volunteer Organizations Active in Disasters" (VOAD) group who were then involved in our next round of engagement. Conversations with the VOAD group linked community participants back to food banks, but with expanded access to representatives and facilities at the regional and state level.

In line with previous studies (Shirk et al., 2012; Newman et al., 2017; Yung et al., 2019), implementing an effective PPSR approach to build local food-energy-water nexus resilience requires the engagement of participants, community leaders, and FEW providers. In our 3-year study – the F4R initiative – we developed a process anchored by three central activity types: learning, scientific research, and action (**Figure 2**). In the first (*learning*) phase we ran full day workshops with community participants which provided structured learning on systems thinking and national and local FEW nexuses. It also incorporated opportunities to learn about community resources through guest speakers and field experiences, as well as brainstorm and discussion sessions focused on participants identifying the questions and tools most relevant for local FEW issues. Following these learning sessions we held meetings every other week to discuss and enact the data collection process (*scientific research phase*). In the final (*action*) phase we hosted work sessions where community participants engaged with other stakeholders across a variety of sectors. During the work sessions, stakeholders suggested

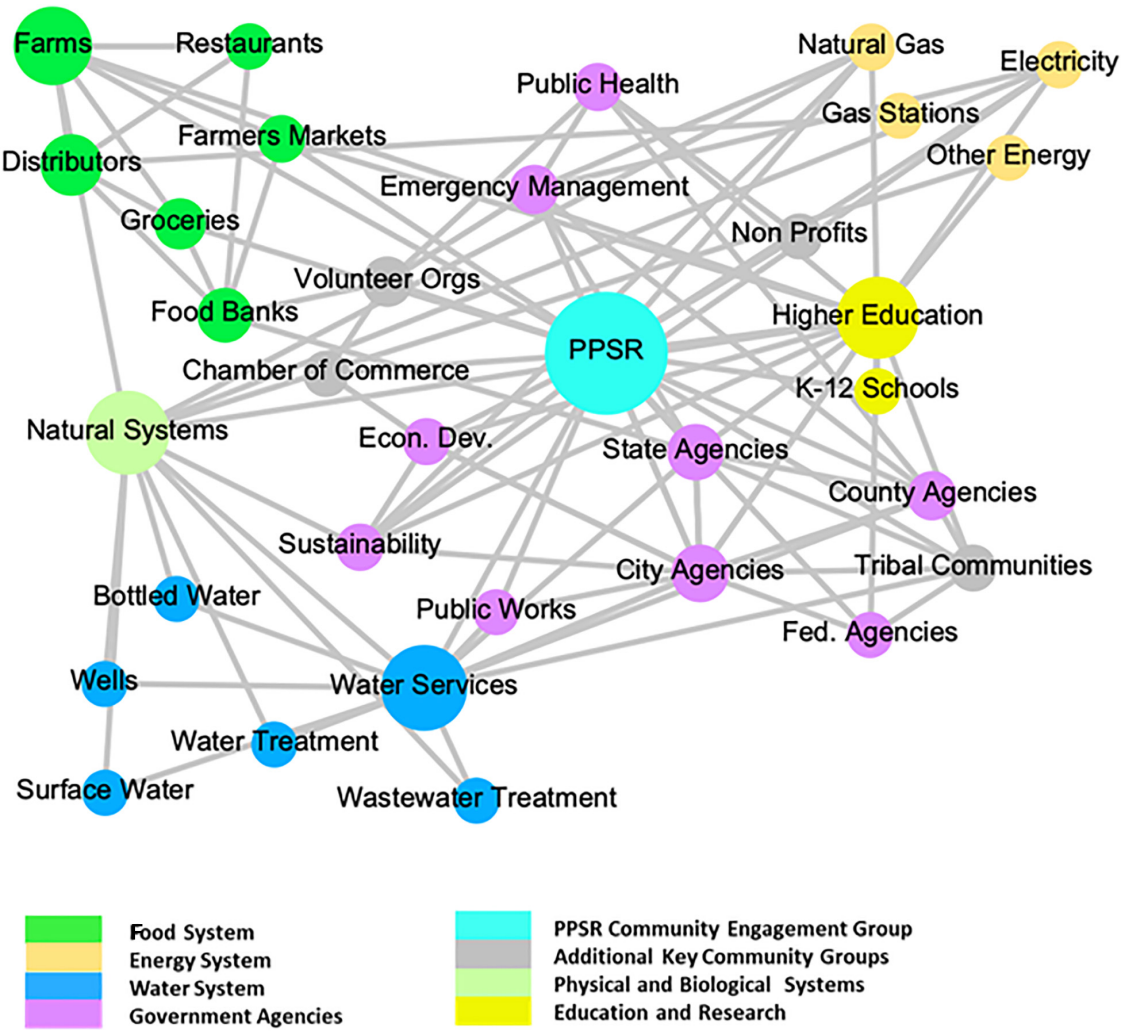

FIGURE 1 | Citizens building a network for community resilience around FEW. This figures shows stakeholder groups engaged in a pilot community in the Southwest US. Citizen volunteers and project coordinators worked with stakeholders to develop tools, content, and identify key contacts and potential community applications.

recommendations which were incorporated into local FEW nexus action plans.

In the PPSR process, local community members are recognized as experts of their communities, and they have the opportunity to engage and establish a network with subject matter experts and providers in the local food-energy-water nexus. Citizens receive training for data collection, and community engagement strategies while learning about, and contributing to, data focusing on the FEW nexus. Citizens then analyze the vulnerability and resilience of local FEW supply chains, providing essential information for the latter stages. Through this process, a community co-creates research questions, collects and communicates food-energy-water data, analyzes this data, evaluates the impacts of local decisions, and identifies actions that build the community's capacity for resilience (**Figure 2**). Ensuring that communities are at the center of FEW nexus management improves their capacity to understand, and solve, complex nexus challenges by generating locally appropriate data, and supporting evidence-based policy making.

It is essential to acknowledge and discuss trade-offs when working to identify solutions to problems and positive community actions related to complex natural-human coupled systems like FEW. Our process was designed to initiate discussions by presenting visualization of national and mesoscale data and analytics, encourage identification of dependencies and trade-offs, and provide an opportunity for participants to collect additional local scale data that can be analyzed and presented for potential community action. Examples of trade-offs between competing objectives include cost, security, socio-environmental quality, trade network dependence, vulnerability, resilience, jobs, profitability, equity, and self-sufficiency of food vs. energy vs. water supply chains.

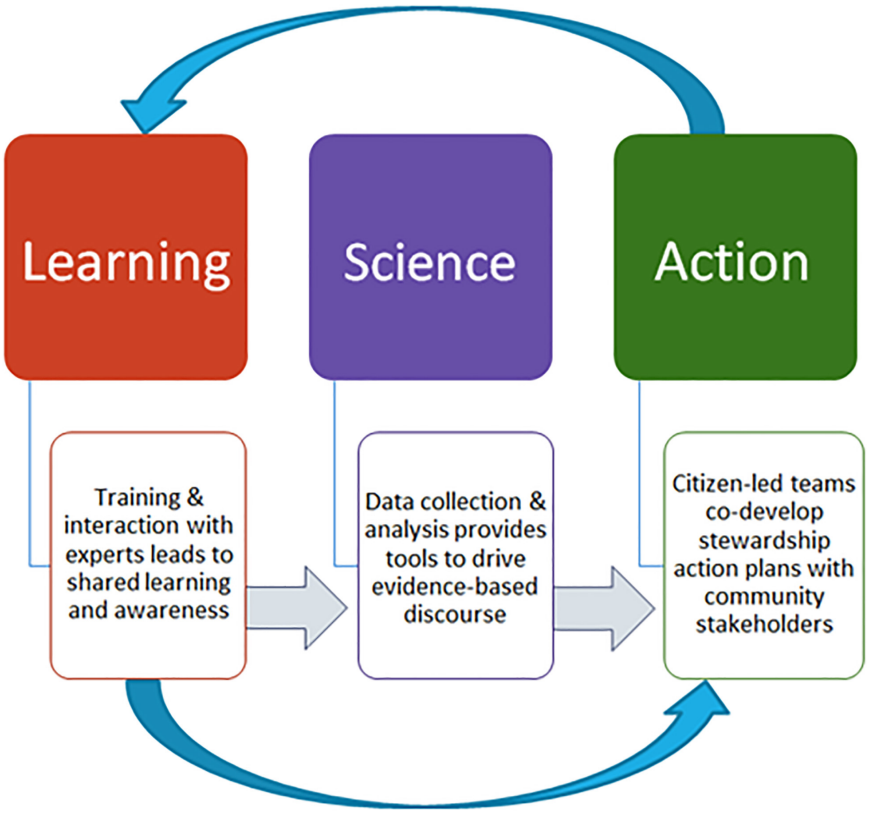

FIGURE 2 | Three areas of focus. PLACE4FEWS required a high level of participation. This figure shows the key pieces designed to engage citizen scientists (including students, retirees, and other stakeholders) to help develop a process and tools for learning about FEW nexus concepts, collecting and visualizing data, and identifying meaningful community applications and actions for FEW.

DISCUSSION: A CALL TO ACTION ON LOCAL FOOD-ENERGY-WATER NEXUS RESILIENCE

Small and medium sized towns need not be left vulnerable due to insufficient data and a lack of political capacity. Adopting a citizen-led approach can, we believe, overcome pervasive issues and establish resilience across the local FEW nexus. Implementing a citizen-led approach provides a host of benefits to stakeholders in the nexus, but also requires action and commitment at all levels:

1. *Citizens* have an opportunity to learn, contribute, and become leaders that drive action in their community. For example, data generated by citizen science programs can be utilized in hazard mitigation planning, climate action initiatives, and community master plans. They can make decisions that impact their personal FEW nexus while informing actions and decisions made by local policy makers and government staff.
2. *Policy makers and government staff* have the opportunity to obtain the data and community support needed to evaluate and communicate the impacts of their decisions. They can overcome many hurdles presented by boundary and capacity limitations by leveraging the power of a citizen-led process that can connect diverse groups and initiatives for public health, community planning, infrastructure development, water services, sustainability, and economic development.
3. *FEW system stakeholders* like grocers, utility operators, and representatives from facilities like food banks and hospitals, can benefit from data reports and tools provided that improve needs analysis and partnership development, while establishing their organizations as leaders who provide critical support that contribute to the resilience of the community.

Building resilience requires collaboration between a diverse set of stakeholders (Walker et al., 2002). Collaboration between stakeholders can be enhanced through the creation of a PPSR network, which enables stakeholders to effectively communicate and establish a community of best practice. Large scale disasters illustrate the necessity of both a PPSR approach and network. During a disaster, the emergency management community (EMC) often lack the capacity, and authority, to manage local FEW needs, let alone a whole state or region. While the EMC engages state and national resources, these mechanisms need

improvement, especially in light of recent emergencies such as COVID-19. If emergency managers had data tools and a communication network that connected last mile stakeholders and resources across boundaries of the private, public, and non-profit partners in a community, then they could better coordinate the actions needed to support critical FEW lifelines and supply chains in preparation for, and in response to, large scale disasters. In addition, many local partners, like food banks, often lack the capacity to meet hunger relief needs in their service areas, both short- and long-term. Implementing a PPSR process, using data and community engagement tools, can improve the last mile connections and capabilities of partners like food banks and emergency managers in local, regional, and state networks.

Building local FEW nexus resilience requires fundamental shifts in traditional approaches to management and research. As scientists, educators, and citizens, we have a critical role to play in guiding local political structures to undergo radical – but necessary – changes. We are calling for the creation of local PPSR approaches, which increase education and awareness about the FEW nexus, actively engage communities in citizen-led data collection that connects the local FEW nexus to the state and national level, and drives community leaders to build and improve the networks and policies linked to food-energy-water resources. Without this, a huge opportunity to creatively, and democratically, manage the food-energy-water systems will be lost, and issues attributed to top-down, siloed governance structures will prevail.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation, to any qualified researcher.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Northern Arizona University IRB. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

EH helped design the study and led the writing. RR, ER, SR, KP, and NB helped design the study and write the manuscript. BLR led the design of the study as Principal Investigator and helped write the manuscript. All authors contributed to the article and approved the submitted version.

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