



FEW and Far Between

Rebalancing Research and Training Priorities at the Food-Energy-Water Nexus

Ellen J. Platts¹ · Bridget Kerner² · Nick Adams³ · Jan-Michael Archer³

Accepted: 13 April 2022

© The Author(s), under exclusive licence to Springer Nature B.V. 2022

Abstract

The food-energy-water (FEW) nexus framework calls for a systems perspective on addressing complex sustainability challenges. As a sustainability science field, nexus research should in theory bring together transdisciplinary approaches drawing from a range of stakeholder knowledge and experiences. This approach would align with the competence-based training for future sustainability leaders advocated for in sustainability education literature. In practice, the field is dominated by techno-scientific approaches with superficial or peripheral attention paid to issues of social justice and community engagement. In this article, we explore how this imbalance in the literature reflects a breakdown between the ideals of sustainability training and the reality of training at the nexus and describe obstacles that may be contributing to this breakdown, including a prejudice towards the idea of “objective” science, institutional incentives, and disciplinary culture. To address these concerns, we introduce a research project focused on assessing the training of future researchers at the FEW nexus and exploring how these programs train students in particular views of what is important at the FEW nexus, such as technological solutions, stakeholder collaboration, and/or issues of equity and justice. It will also provide recommendations for creating open learning environments that are competence-based, and that incorporate multiple methods, acknowledgments of limitations, and alternate ways of knowing.

1 Introduction

The food-energy-water (FEW) nexus, which has grown from a niche sustainability concept to an expansive research field in recent decades, is a globally recognized strategy for addressing “wicked” problems. Wicked problems are those known for their complex

✉ Ellen J. Platts
ejplatts@umd.edu

¹ Department of Anthropology, University of Maryland, College Park, MD, USA

² Urban and Regional Planning and Design Program, School of Architecture, Planning & Preservation, University of Maryland, College Park, MD, USA

³ School of Public Health, Maryland Institute of Applied Environmental Health, University of Maryland, College Park, MD, USA

interdependencies that span disciplines and scales and that have no simple solutions (Balint et al., 2011). Scholars researching the FEW nexus have oriented their work toward forecasting the ongoing functionality of food, energy, and water systems in the face of worldwide challenges (e.g., climate change and overconsumption) and developing new methods for ensuring resource security (Allouche et al., 2015). While research focusing on food, energy, and water systems has occurred in silos for decades, only recently has a field encompassing the intersections and cascading interactions of all three been taken up as a governance tool and preeminent research agenda.

The term “food-energy-water nexus” (also referred to as the “water-energy-food” nexus) came to prominence in international policy circles in the aftermath of the 2008 financial crisis (Cairns & Krzywoszynska, 2016; Schmidt & Matthews, 2018). During the 2008 World Economic Forum, conversations on limited water resources and potential limits on economic growth launched the FEW nexus as a systems approach to water scarcity that considered the interconnectedness of food, energy, and water systems (Allouche et al., 2014). The Bonn2011 Nexus Conference indicated continued attention and advancement for the nexus approach, jumpstarting nearly a decade of the concept’s use in global political forums, international development, and conservation organizations, and justifying significant amounts of funding for research and training (Belmont Forum & Joint Programming Initiative Urban Europe, 2016; Economic Social Research Council, 2015; National Science Foundation, 2020; Opejin et al., 2020). Since 2016, in the USA alone, the National Science Foundation has invested over \$100 million in funds for graduate research training programs focused on the FEW nexus, a telling commitment to the future of this work (USA Spending, 2022). As sustainability science has expanded as a field in response to the complex challenges of climate change, poverty, and pandemics as well as FEW nexus issues, the university has taken on a larger role in addressing these challenges. However, this role is not a solitary one but rather a collaborative undertaking. Co-creating knowledge and solutions between university researchers, including graduate students, and other partners such as government, industry, and civil society is necessary to work towards sustainable transformations (Trencher et al., 2014, 2017).

As graduate student fellows within a National Science Foundation-funded Research Traineeship, the University of Maryland Global STEWARDS (STEM Training at the Nexus of Energy, WAtter Reuse and Food Systems), we propose that graduate student training functions to shape how future scholars think about and approach the FEW nexus and solutions to nexus challenges. Graduate students trained in these areas are expected to be future change agents and sustainability leaders capable of addressing challenges such as climate change, biodiversity loss, and resource insecurity, requiring them to undertake transformational projects and embody transformational characteristics that move beyond the status quo (Redman & Wiek, 2021). Graduate programs provide the setting where many students begin to link together the systems that underpin the FEW nexus, and are trained in the practices, customs, and requirements of academic knowledge production. Transformational education for graduate students at the FEW nexus, itself a boundary-spanning field, presents an opportunity to provide future leaders with the kind of transdisciplinary, value-laden, and competence-based training required to face these challenges (Wiek et al., 2016). Furthermore, it is an opportunity to participate in the kind of cross-sector stakeholder engagement that is understood to be necessary to successfully advance sustainable transformation, and to fulfill the goals of transdisciplinarity.

Yet despite these expectations for what future sustainability scholars should be able to do, much of the FEW nexus literature does not reflect a similar perspective, indicating a breakdown between the ideals of sustainability training, the materials and scholarship

that graduate students are familiarized with, and how particular kinds of scholarship are rewarded in graduate school and beyond. In this article, we explore the dissonance between the emphasis on transdisciplinary approaches in educating future sustainability leaders and the content of FEW nexus literature, drawing also upon sustainability education literature and our own experience in receiving training at the FEW nexus. We propose that this dissonance provides the impetus for further research on how graduate students in sustainability fields are trained, from the perspective of graduate students themselves. We introduce such a research project that aims to examine how particular graduate fellowship programs train students in particular views of what is important at the FEW nexus, such as technological solutions, stakeholder collaboration, and/or issues of equity and justice, and to make recommendations to improve the scope and breadth of this training.

2 Student Competencies and Transdisciplinarity in Sustainability Education

Within sustainability science, several ideas have developed on what future sustainability leaders, today's students, should be able to do to address complex challenges. These are referred to as competencies, defined as the “functionally linked complex[es] of knowledge, skills, and attitudes that enable successful task performance and problem solving” (Wiek et al., 2011). Educational literature on competencies in sustainability emphasizes their boundary-spanning, interdependent, and forward-looking nature. In order to be the leaders and change agents seen as necessary to address sustainability challenges, students should be exposed to education that enables them to acquire these competencies. In this literature, major competencies in sustainability training includes systems-thinking competence, futures-thinking competence, values-thinking competence, strategies-thinking competence, implementation competence, interpersonal competence, and intrapersonal competence (Redman & Wiek, 2021; cf. Wiek et al., 2011; Wiek et al., 2016). These competencies are similar to the concept of expertise in sustainability research integration and implementation that incorporates thinking beyond the status quo, prioritizing collaboration, and creativity in integrating insights beyond one's own discipline or lived experience (Bammer et al., 2020).

Without fully reiterating the content of these competencies here, the skills, knowledge, and attitudes considered to be critical for future sustainability leaders and researchers are not only the systems-oriented approach that may be more familiar to environmental researchers, but simultaneously the people-oriented, social skills that emphasize concerns around justice, equity, collaboration, and integration of multiple points of view (Brundiers et al., 2021; Wiek et al., 2011). The values-thinking competence is explicitly normative, requiring students to think about and take a position on particular sustainability actions based on concepts of equity and ethics (Wiek et al., 2011). These values-laden positions connect to other competencies as well; for example, Brundiers and colleagues indicate that strategic-thinking competency includes a capacity to undertake radical change to “dismantle oppressive power structures” (Brundiers et al., 2021: 18).

These ethically oriented competencies extend beyond the student themselves, as the interpersonal competence requires collaboration and engagement with both teammates in a university setting, and stakeholders beyond those walls. Stakeholder engagement is seen as a “must have” in sustainability science research (Brundiers et al., 2021), especially

research that positions itself as transdisciplinary. There is a widespread acknowledgement that wicked problems require an interdisciplinary or transdisciplinary approach to create sustainable solutions. Frameworks of transdisciplinarity call for the integration of knowledge from communities affected by interventions to create research questions, generate new knowledge, and re-integrate findings into policies and solutions (Bammer et al., 2020). This definition moves past the consideration of breaking down academic silos and requires researchers to accept and include traditional and other stakeholder knowledge in all stages of the research process (Trencher et al., 2017). Stakeholder engagement plays a key role in the transdisciplinary process, as engaging with a diverse group helps to elicit novel ideas, which contributes to the expansive reach that is necessary to develop solutions to the world's wicked problems (Boone et al., 2020). By engaging stakeholders within and outside of the academic field, the transdisciplinary approach promotes the co-creation of knowledge between researchers and those who will be directly affected by the solutions developed in the research process.

3 Identifying Imbalance in FEW Nexus Literature

As a sustainability field, it would be reasonable to think that research at the FEW nexus would reflect the emphases discussed in the literature on sustainability education. However, this is not often the case. In our experience receiving training at this nexus, we identified an imbalance between the goals and expectations of transdisciplinarity laid out in the sustainability education literature and the context of the research we were exposed to in the FEW nexus literature. Expanding upon this observation, we conducted a literature review to further understand the scope of FEW nexus literature and consider the implications of our own exposure to limited elements of this literature. The literature review is based on peer-reviewed journal articles, books, and grey literature (reports and white papers). It is not a comprehensive review of the entire field, but does include several systematic reviews, bibliometric reviews, and discourse analyses of nexus scholarship (Albrecht et al., 2018; Newell et al., 2019; Opejin et al., 2020; Wiegbleb & Bruns, 2018). The literature search was conducted in *Google Scholar* using the keywords “FEW Nexus” and additional sources were included from the content of systematic and bibliometric reviews. This literature review includes 36 documents that represent several different approaches to FEW nexus research. After reading, we characterized each reference for inclusion in one of the sections of the review below. The analysis of the literature was interpretive rather than mechanical, guided by our experience and with exchange among our group, with fellow trainees, and with advisors engaged in sustainability research.

3.1 Characterizing FEW Nexus Research

FEW nexus research is dominated by concerns for natural resource security, efficiency, and sustainable development (Wiegbleb & Bruns, 2018). Researchers have tried to address these concerns from a primarily quantitative, “Science, Technology, Engineering, and Mathematics” (STEM) approach to nexus research. In a recent systematic review, Albrecht et al. (2018) discovered that many of the 245 articles and book chapters reviewed do not address the linkages between FEW systems. About three quarters of the studies reviewed relied solely on quantitative methods, and only one quarter incorporated social science methods. The dominant discourse lacks human-oriented, social science perspectives that are critical

when developing solutions to wicked nexus problems. Alternative ways of thinking, however, flicker around the edges of this leading approach to nexus research. This alternative approach challenges the dominant techno-managerial framings of the field, its ambiguous use as a “buzzword,” and the relative dearth of attention paid to issues of social justice and inequality, public health, and the energy sector in nexus research (e.g., Allouche et al., 2014, 2015, 2019; Cairns & Krzywoszynska, 2016; Leese & Meisch, 2015; Middleton et al., 2015). It highlights the tensions produced by the institutional, economics-driven creation of the FEW nexus research paradigm (Allouche et al., 2014; Schmidt & Matthews, 2018), and the effects this perspective of the FEW nexus have on local communities. Addressing nexus challenges without considering the political implications, social–historical context, and economic feasibility of potential solutions may lead not only to ineffective recommendations (Märker et al., 2018; Schlör et al., 2018), but also to perpetuating longstanding inequities across lines of race, gender, class, and ethnicity (Leese & Meisch, 2015).

3.2 Techno-Scientific Approaches to the FEW Nexus

The current FEW nexus framework largely focuses on the scarcity of natural resources which constrain global capacity for the delivery of clean water and the production of food and energy. Resource scarcity has driven researchers to view nexus challenges through a lens of risk and security (Wiegbleb & Bruns, 2018). This lens highlights how a failure in the systems that deliver any one of these resources could cause severe disruptions to the others, and consequently, to human life. Leese and Meisch (2015) suggest that the threat in the FEW nexus is imminent and, considering the expected impact of climate change and rapid population growth, likely to worsen in the future. While risk may be present in the current moment, these authors suggest that a “security lens” notion in the nexus is not limited to only taking sweeping action to address a current and dire threat, but also allows for development strategies which help to manage and mitigate the threat’s impact on future generations. Prioritizing resource risk and security leads to research in the FEW nexus field being largely solutions-oriented. Nexus researchers commonly rely on the concept of ecological modernization, using economic analysis to assess the effectiveness of sustainable methods for using and recycling FEW resources (Wiegbleb & Bruns, 2018). Theories from STEM fields and engineering techniques are drawn upon to create technological innovations which, alongside market instruments, are used by decision makers to maximize resource efficiency and reduce waste.

The techno-scientific approach that is typical of the leading discourse focuses heavily on quantitative methods (Albrecht et al., 2018). Many studies in this area have adopted integrated assessment models to represent the interconnected dynamics of food, energy, and water systems (Larkin et al., 2020). To understand the FEW nexus, researchers use stock-and-flow models, which assess the outputs of the connected systems (Berardy & Chester, 2017; Daher, Lee, et al., 2019; Markantonis et al., 2019; Mroue et al., 2019; Siddiqi and Anadon, 2011), and dynamic models that integrate the effect of policy on resource consumption and output (Brouwer et al., 2018; Martinez-Hernandez et al., 2017). As technological advancements have increased the complexity of the interactions at the FEW nexus by erasing the geographical boundaries of system interactions, concepts like virtual water and the supply chain are focuses of nexus researchers. Virtual water is a term developed to describe the water used to produce commodities (e.g., crops) that are then exported from their source country and distributed globally (Oki & Kanae, 2004). Researchers are using the modern supply chain infrastructure to model how distribution of food allows the

transfer of water resources across traditional geographic boundaries, creates pressure on systems in vastly different regions, and drives the need for energy-intensive technological solutions like large-scale desalination and long-distance transportation systems (Scanlon et al., 2017; Siddiqi and Anadon, 2011; Ramaswami et al., 2017). Research framed around the supply chain is still largely quantitative in nature, focusing primarily on inputs and outputs that are not human-centric.

In sum, the leading approach to nexus research emphasizes a solutions-oriented perspective, technological innovation, and quantitative methods including integrated assessment modeling. The dominant approach focuses on the natural food, energy, and water systems, assessing how they may be better controlled and managed to achieve resource security and avoid future global crises. The position of FEW nexus research within STEM fields structures approaches to the nexus in ways that reinforce ongoing inequities in access by students, researchers, and community stakeholders from underrepresented populations. Stakeholders are considered when presenting potential technological solutions to issues in the FEW nexus, but this is largely centered around policy makers, economics or “ability to pay,” and environmental stewards.

3.3 Alternative Approaches to FEW Nexus Research

While the above framework makes up the bulk of FEW nexus scholarship, alternative approaches exist, some that even critique the FEW nexus concept itself (Wiegbleb & Bruns, 2018). These alternative approaches focus on examining how the nexus concept is similar to concepts used by indigenous peoples (i.e., traditional ecological knowledge), incorporating social theory, community participatory research methods, and practical scalable solutions.

The conceptual development of the FEW nexus has been criticized for being both unoriginal and unattainable. While the nexus concept was introduced at the 2008 World Economic Forum as new, go-to vocabulary for policy makers addressing sustainable development, critics argue that the connections between food, energy, and water systems have long been understood as a singular system by communities (Allouche et al., 2015; Benson et al., 2015; Williams et al., 2019). Governance at local scales in farming, hunting, and fishing communities has always incorporated all three elements, evident by the traditional knowledge, stories, and lessons of these groups. Cairns and Krzywoszynska (2016) argue that the term’s newfound fame as a policy and research buzzword re-appropriates existing academic, policy, and community approaches to resource management, raising it above critical engagement and restricting nexus approaches to those that can be easily digested by funders and policymakers. Taking this even further, Schmidt and Matthews (2018) argue that the nexus concept is a tool developed and used by global financial giants to financialize environmental resources, turning the challenges of climate change and resource scarcity into opportunities for capitalization and profit.

The FEW nexus concept emphasizes integration and has been touted as a comprehensive, interconnected approach to (a) solving resource challenges in the face of a growing global population that consumes evermore resources and (b) balancing the impacts of global climate change. However, the expansion of nexus research, policy, and practice has revealed areas that dominant research frameworks and methodological approaches generally fail to integrate. A central focus on water systems (Beck & Villarroel Walker, 2013: 632; Benson et al., 2015; Opejin et al., 2020), coupled with the emphasis on quantitative,

STEM fields, has led to limited integration of human health, social science, and critical theory perspectives in the development of the nexus concept. Along these lines, Allouche et al. (2019) and Simpson and Jewitt (2019) rebuke the disproportionate emphasis of current FEW nexus approaches being placed on STEM fields and highlighting technological solutions to nexus problems. Indeed, much of the early research on the nexus was void of social science theory, creating a misconception that technology and innovation will solve encroaching resource problems and that governance, politics, and local context serve a secondary role. The dominant nexus approach has been challenged for failing to adequately address issues of poverty and resource distribution (Foran, 2015; Mdee, 2017). This treatment of human concerns as the motivation for—but not the focus of—nexus research is reflected in interviews with research funders who recognize that social science is often understood to be an “add-on” to natural or physical science projects (Cairns & Krzywoszynska, 2016).

The emphasis placed on techno-scientific solutions and developing new technologies and market instruments for solving problems at the FEW nexus overshadows the primacy of integrating stakeholders into sustainability research. A subset of FEW researchers has attempted to understand the forces that dictate the decision-making processes of key stakeholders (e.g., Bonatti et al., 2018; Covarrubias et al., 2019; Larkin et al., 2020; Rasul, 2014; White et al., 2017). Adding dedicated community- and stakeholder-engaged research techniques to the current dominant approaches has a multitude of benefits. Bergendahl et al. (2018) state clearly that stakeholders (e.g., individual farmers) make important technical, social, and economic decisions, arguing for a transdisciplinary approach to include these decision-makers in the creation of interventions to promote sustainability at the nexus. Many of the articles which use a FEW nexus approach to analyze the impact of scenarios and policies on individual regions have no assessment of feasibility in the eyes of policymakers or community stakeholders (Berardy & Chester, 2017; Daher, Hannibal, et al., 2019; Kulat et al., 2019; Markantonis et al., 2019; Mroue et al., 2019). These articles analyze the resource and economic responses to individual scenarios excellently, but there is still a need for qualitative research to ensure that social aspects of these regions are considered when moving forward with sustainability initiatives. Importantly, policymakers are not the *de facto* proxies for the vast range of community needs. While it is important to engage policymakers when designing multi-scale, interdisciplinary, and trans-sector solutions, it is critical to recognize that policymakers represent only a calculated majority of their constituents—at best. In stating this, we stress the need for more substantive inclusion of social justice (particularly distributive and restorative justice) and environmental justice frameworks throughout the FEW nexus, relating to the values-thinking competence described in sustainability education literature. Striving towards this balance through the inclusion of justice frameworks respects the knowledge, efforts, and actions of indigenous communities and other communities of color, recognizing that none of these concerns, ideas, or goals is new. As Allouche and colleagues note, “For many rural communities, however, food, water and energy has never been conceptually separated in the way that experts have sought to understand them. Indeed, it may be that the water-energy-food nexus is the (re)discovery by experts working in silos of what practicing farmers and fishers already know” (Allouche et al., 2014, 23).

Prioritizing and accepting these alternative perspectives and various ways of knowing re-politicizes scientific research, and reveals the cultural orientation of researchers, which itself generates more effective science that is reflective of the world and its inhabitants (Medin & Bang, 2014). In addition to these concerns of justice, stakeholder involvement throughout the conduct of FEW nexus research accomplishes one of the defining tenets

of the transdisciplinarity that is so often called for: dissemination of findings and capacity building beyond the confines of academia (Hoolohan et al., 2018). We note that there is a relevant difference between community stakeholders (e.g., impacted residents and end-users) and stakeholders from academia, agency, and industry; each having unique (and sometimes dueling) motivations and needs (Bielicki et al., 2019). Using transdisciplinarity as both a goal and a guiding principle, several researchers have used stakeholder involvement to reevaluate the success of quantitative strategies at the FEW nexus. Sperling and Berke (2017) highlight that stakeholders' lack of awareness of FEW issues and needs contributes to a reluctance to act on established solutions, leading to an implementation gap where developed techno-scientific strategies go improperly tested or untested altogether. Particularly when developing decision-support tools, stakeholder involvement must be applied early and often throughout modeling processes (Guan et al., 2020). Given the sheer vastness of FEW problems, governance and policymaking alone cannot fill the implementation gap (Daher, Hannibal, et al., 2019). Community, and even individual, stakeholder buy-in is crucial.

4 Implications of Imbalance: Blocks to Transdisciplinarity and Competence-Based Education

In reviewing literature at the FEW nexus, we found that our primary exposure to certain quantitative, techno-scientific approaches during our traineeship was reflective of the field as represented in the literature. The kind of transdisciplinarity that is central to the success of sustainability science is not apparent in FEW nexus literature broadly. For example, while projects using techniques such as integrated assessment models include qualitative information such as policy concerns or potential societal impacts, they do not necessarily include stakeholders in the development of the project or proof of concept, or make use of the knowledge base held by stakeholders through their lived experience. Within the literature, FEW nexus research projects often do not live up to the standards of interdisciplinarity, let alone transdisciplinarity. The disproportionate dominance given to techno-scientific approaches in FEW nexus research is fundamentally at odds with the goals of—and potential for—transdisciplinarity. Many FEW nexus research programs enjoy a kind of “quasi-interdisciplinarity,” whereby disciplinary silos are less distant from each other but still far from being integrated. This is not a novel criticism (as Albrecht et al., 2018, Wiegble and Bruns, 2019, and many others explain); however, we find it salient. The gap between the rhetoric of transdisciplinarity and the reality of mismatched collaboration reemphasizes the problems that emerge from addressing the FEW nexus from a strictly techno-scientific perspective, one that fails to theorize and thoroughly describe the on-the-ground situations of climate change and resource scarcity (Foran, 2015).

Furthermore, some of the competencies described as important for successful sustainability researchers are not reflected in the types of research that make up the bulk of the field; indeed, a lack of prioritization of interpersonal competence can be seen in the issues surrounding stakeholder engagement in the literature. While systems-thinking is reflected in most nexus research, other competencies such as values-thinking or interpersonal competence are not. Critiques of the leading FEW nexus approaches emphasize a lack of critical perspectives on issues of justice and disparities in resource allocation, as discussed above. The values-thinking competence is explicitly oriented towards these kinds of concerns. Sustainability education experts have even advocated for treating values-thinking

as the lead competency in order to provide a normative and applied focus to sustainability research that supports justice work, ecosystem integrity, and regenerative economies (Brundiers et al., 2021).

That there exists an imbalance in the literature such that several articles have been published to highlight this disparity indicates the tenacity of blocks to the kind of transdisciplinary, competence-based training and research needed for transformational sustainability work. These blocks are well documented in sustainability education literature. Perhaps the most insidious is the positivistic idea that science ought to be value-free and “objective,” a widely held prejudice that sustainability science must overcome (Brundiers et al., 2021). Acquiring normative knowledge in order to make value-laden decisions is crucial for sustainability scientists and trainees in this field, for as Wiek and colleagues (Wiek et al., 2011: 209) argue, “The concept of sustainability is unavoidably value laden and normative, since it addresses the question of how social-ecological systems ought to be developed... This quest is challenged by critical issues of dissent and unbalanced power relations that jeopardize principles of socio-ecological systems integrity, intra- and inter-generational equity, and democratic governance.” The idea that scientists should not imbue their research agendas with specific values such as justice, equity, and ethics in order to be “objective” blocks the development of the transformational research necessary to address complex challenges. As Nasir and Vakil (2017: 401) ask in the context of computer science, sustainability researchers should be also asking questions like, “Code for what? For whom? For which purposes? Whose problems are being coded for? Which questions are being asked?” In some educational settings focused on the FEW nexus, STEM fields and scientific perspectives, including biological, physical, engineering, and social and behavioral sciences, are framed as the place where answers to these complex problems will be found (Murray et al., 2021; Rodríguez et al., 2019; Wade et al., 2020). This centering of STEM fields does not address the documented role of STEM in maintaining disparities across race and gender that have structured how “objective” scientific solutions are created, presented, and implemented. This culture of seeing science as value-free simultaneously permits bias against students from underrepresented groups as a “combination of historical patterns of scientific racism, academic disciplinary cultural assumptions of meritocracy, and norms and behaviors that privilege some groups and marginalize others” (Carter et al., 2019: 87). Integrating a values-laden approach not only improves the quality of transdisciplinary research and meets the goals of the competencies described in sustainability education research, but also improves the quality of the educational experience itself for marginalized students.

While the idea that science is a value-free endeavor is a foundational block to the transdisciplinary, competence-based sustainability research we advocate for here, additional obstacles include traditional incentives for professors and students that discourage transdisciplinary work in the pursuit of dissertations, degrees, and tenure (Bammer et al., 2020; Boone et al., 2020; Brundiers et al., 2021; Trencher et al., 2014, 2017). Traditional disciplinary cultures have their own set of approaches, methodologies, and ways of doing work (Bammer et al., 2020); transdisciplinary research requires what Boone and colleagues (2020) call a “sharing” attitude that moves beyond the idea of science as an individual pursuit. For students, a particular block to the development of transdisciplinary perspectives is that their mentors, advisors, and professors may not have received competence-based, transdisciplinary training themselves (Brundiers et al., 2021; Wiek et al., 2016). Redman and Wiek (2021) argue that while many university programs address sustainability problems, they do not usually fully prepare graduates for doing the work of sustainability.

The techno-scientific slant of much FEW nexus research may be related to these blocks, which impact the state of the literature as researchers write publications and conference presentations that will support them in graduating, becoming employed, or gaining tenure. However, the alternative approaches to the FEW nexus described above do provide a pathway for pursuing the kinds of value-driven, interpersonal, and engaged research called for in the sustainability education literature. There is an educational challenge inherent in this imbalance and in current approaches to transdisciplinary training at the FEW nexus—are new forms of training, such as the NSF NRT INFEWS programs, providing students with the knowledge, values, skills, and opportunities to overcome these challenges?

5 Assessing Educational Priorities for FEW Nexus Research Training

In the last 5 years, the NSF has spent \$115,720,491 through the Innovations at the Nexus of Food, Energy and Water Systems (INFEWS) program to fund research traineeships (NRTs) for graduate students at 17 universities across the USA (USA Spending, 2022; National Science Foundation, 2020). This is a significant investment in the future of sustainability research and has created a pool of students trained in different ways to think about sustainability and FEW nexus research. These programs train future generations of FEW nexus researchers and present them with tools to conceptualize, imagine, and work towards future solutions to current problems.

Inspired by our observations of the dissonance between the values we hold as social scientists and public health scholars, those same values that are emphasized in sustainability education literature, and the research we were exposed to during our training program, we are currently conducting a mixed-methods assessment of student and faculty participation in National Science Foundation (NSF) Research Traineeship (NRT) programs focused on the FEW nexus. The purpose of our project, funded itself by the NSF, is to study the experiences of students and faculty of INFEWS NRT programs in an effort to (1) understand how NRT programs train students in particular views of what is important at the FEW nexus, such as technological solutions as well as issues of equity and justice, as they relate to competence-based ideals; and (2) make recommendations to improve the scope and breadth of this training. Specifically, we examine whether (and if so, how) the syllabi of courses in NRT programs, the learning techniques presented in these courses, and the disciplinary diversity of these programs incorporate competence-based training, as well as whether they foster an emphasis on values of equity and distributional justice. This will contribute to a better understanding of how the nexus can be used as a tool not only to develop scientific solutions to sustainability problems but also to ensure distributional justice in terms of the future benefits of sustainability. This project will make use of semi-structured interviews with NRT principal investigators, focus groups held with student participants from diverse disciplinary backgrounds, and a survey for both student and faculty members of NRT programs. NRT faculty and students will be surveyed for perceptions on curriculum development, goals for the students in each program, and understandings and perceptions of interdisciplinarity and transdisciplinarity. We will include the 12-item Transdisciplinary Orientation Scale, a measure of readiness to collaborate in transdisciplinary research, in the survey (Misra et al., 2015) to see if this measure correlates with perspectives and/or program design. The research will increase understanding of if and how certain approaches to the FEW nexus continue to be prioritized, why particular visions of

future FEW functionality are being pursued, and what methods are used to maintain and reproduce the current priorities of FEW nexus research.

The original idea for this project emerged from our own experiences in the NRT program at the University of Maryland. While we had the opportunity to hear from many different practitioners and researchers at the FEW nexus, we were only briefly exposed to social science methodologies. The notion of justice frameworks and stakeholder engagement was brought into our courses primarily through the work of our student group, which was formed by the students with previous experience in social science and public health backgrounds. We were drawn to work together through our shared questioning of the way that the FEW nexus was presented through our coursework. We asked ourselves why frameworks such as the OneHealth approach that connects the health of people, animals, and environment (Center for Disease Control, 2018) or well-established social science methodologies such as semi-structured interviewing or participant observation were not included in our training. We remain extremely grateful to our instructors in the NRT program, who supported us in our reading, learning, and critiquing of our program and research at the FEW nexus, and in no way intend for this paper or the research described here to reflect poorly upon our training. They, alongside the NSF, continue to support us in pursuing the project described here and have encouraged us to continue to probe into how fellow students are being trained at the FEW nexus, to better work towards transformational sustainability solutions.

Our research project assesses the curriculum, disciplinary representation, and skill development opportunities offered to the students and young researchers who will frame the next generation of nexus scholarship and direct thinking possibilities for sustainable futures. Similar to reviews of the literature that aim to assess the various discourses that orient a field of research, this project will examine the FEW training that is occurring before journal articles and white papers are published. Understanding the ways that graduate students are being trained will provide a head start for understanding how the next generation of policymakers, scholars, and funders will conceptualize and tackle the nexus in the future. Ultimately, the findings may provide opportunities for nexus researchers to reflect and refocus future research to address the identified gaps in the truest sense of transdisciplinary research projects and take a more holistic approach to FEW problem-solving. Such a refocusing may help to identify practical, people-oriented solutions that are able to combat the complex challenges at the heart of sustainability research.

6 Conclusion

Throughout this article, we have explored the ways that FEW nexus research is represented in much of the literature, critiques of these approaches, and highlighted the ways that the transdisciplinary and competence-based training hailed in sustainability education literature is not reflected in much of the FEW nexus literature. The research project introduced here aims to further understand how the imbalance between techno-scientific “quasi-interdisciplinary” and truly transdisciplinary research has come to be in the FEW nexus literature, and the potential for current training programs at the FEW nexus to address these challenges. While it may be the case that as a relatively new field, we simply need more time for current researchers, students, and future scholars to be adequately trained in a transdisciplinary, competence-based approach, the imbalance in the literature identified in this article presents a hefty obstacle to overcome. Through the study described here, we

will test whether the blocks to transdisciplinarity and competence-based training in sustainability are sufficiently overcome through training programs such as the NSF NRT and be able to make more specific recommendations for improving training outcomes. In this way, it will provide a baseline for ensuring future training of students is further rooted in transdisciplinarity and the ethically oriented competencies of values-thinking and interpersonal competence in the form of stakeholder engagement, as well as other key competencies discussed in the literature. While this training is US-focused, the model used here could be applied to a more global approach to training assessment.

Acknowledgements We would like to thank our Global STEWARDS cohort and faculty mentors for their feedback on this manuscript. We would additionally like to thank Kelsey McKee and Shirley Vincent for their generous feedback during the revision process.

Author Contribution All authors contributed to the study conception and design, literature review and analysis, drafting of the manuscript, and revision. All authors read and approved the final manuscript.

Funding All authors were supported by NRT-INFEWS: UMD Global STEWARDS (STEM Training at the Nexus of Energy, WAtter Reuse and FooD Systems) that was awarded to the University of Maryland School of Public Health by the National Science Foundation National Research Traineeship Program, Grant number 1828910.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

Albrecht, T. R., Crootof, A., & Scott, C. A. (2018). The water-energy-food nexus: A systematic review of methods for nexus assessment. *Environmental Research Letters*, 13(4), 043002. <https://doi.org/10.1088/1748-9326/aaa9c6>

Allouche, J., Middleton, C., & Gyawali, D. (2014). *Nexus Nirvana or Nexus Nullity? A dynamic approach to security and sustainability in the water-energy-food nexus* (p. 37). STEPS Centre.

Allouche, J., Middleton, C., & Gyawali, D. (2015). Technical veil, hidden politics: Interrogating the power linkages behind the nexus. *Water Alternatives*, 8(1), 17.

Allouche, J., Middleton, C., & Gyawali, D. (2019). *The water-food-energy nexus: Power, politics and justice*. Routledge, Taylor & Francis Group.

Balint, P. J., Stewart, R. E., Desai, A., & Walters, L. C. (2011). *Wicked environmental problems: Managing uncertainty and conflict*. Island Press.

Bammer, G., O'Rourke, M., O'Connell, D., Neuhauser, L., Midgley, G., Klein, J. T., Grigg, N. J., Gadlin, H., Elsum, I. R., Bursztyn, M., Fulton, E. A., Pohl, C., Smithson, M., Vilsmaier, U., Bergmann, M., Jaeger, J., Merkx, F., Vieni Baptista, B., Burgman, M. A., ... & Richardson, G. P. (2020). Expertise in research integration and implementation for tackling complex problems: When is it needed, where can it be found and how can it be strengthened? *Palgrave Communications*, 6(1), 5. <https://doi.org/10.1057/s41599-019-0380-0>

Beck, M. B., & Villarroel Walker, R. (2013). On water security, sustainability, and the water-food-energy-climate nexus. *Frontiers of Environmental Science & Engineering*, 7(5), 626–639. <https://doi.org/10.1007/s11783-013-0548-6>

Belmont Forum & Joint Programming Initiative Urban Europe. (2016). *Sustainable Urbanisation Global Initiative (SUGI)/Food-Water-Energy Nexus*. <https://jpi-urbaneurope.eu/calls/sugi/>

Benson, D., Gain, A., & Rouillard, J. (2015). Water governance in a comparative perspective: From IWRM to a “nexus” approach? *Water Alternatives*, 8(1), 756–773.

Berardy, A., & Chester, M. V. (2017). Climate change vulnerability in the food, energy, and water nexus: Concerns for agricultural production in Arizona and its urban export supply. *Environmental Research Letters*, 12(3), 035004. <https://doi.org/10.1088/1748-9326/aa5e6d>

Bergendahl, J. A., Sarkis, J., & Timko, M. T. (2018). Transdisciplinarity and the food energy and water nexus: Ecological modernization and supply chain sustainability perspectives. *Resources, Conservation and Recycling*, 133, 309–319. <https://doi.org/10.1016/j.resconrec.2018.01.001>

Bielicki, J. M., Beetstra, M. A., Kast, J. B., Wang, Y., & Tang, S. (2019). Stakeholder perspectives on sustainability in the food-energy-water nexus. *Frontiers in Environmental Science*, 7,. <https://doi.org/10.3389/fenvs.2019.00007>

Bonatti, M., Schlindwein, I., Lana, M., Bundala, N., Sieber, S., & Rybak, C. (2018). Innovative educational tools development for food security: Engaging community voices in Tanzania. *Futures*, 96, 79–89. <https://doi.org/10.1016/j.futures.2017.11.008>

Boone, C. G., Pickett, S. T. A., Bammer, G., Bawa, K., Dunne, J. A., Gordon, I. J., Hart, D., Hellmann, J., Miller, A., New, M., Ometto, J. P., Taylor, K., Wendorf, G., Agrawal, A., Bertsch, P., Campbell, C., Dodd, P., Janetos, A., & Mallee, H. (2020). Preparing interdisciplinary leadership for a sustainable future. *Sustainability Science*, 15(6), 1723–1733. <https://doi.org/10.1007/s11625-020-00823-9>

Brouwer, F., Avgerinopoulos, G., Fazekas, D., Laspidou, C., Mercure, J.-F., Pollitt, H., Ramos, E. P., & Howells, M. (2018). Energy modelling and the Nexus concept. *Energy Strategy Reviews*, 19, 1–6. <https://doi.org/10.1016/j.esr.2017.10.005>

Brundiers, K., Barth, M., Cebríán, G., Cohen, M., Diaz, L., Doucette-Remington, S., Dripps, W., Habron, G., Harré, N., Jarchow, M., Losch, K., Michel, J., Mochizuki, Y., Rieckmann, M., Parnell, R., Walker, P., & Zint, M. (2021). Key competencies in sustainability in higher education—Toward an agreed-upon reference framework. *Sustainability Science*, 16(1), 13–29. <https://doi.org/10.1007/s11625-020-00838-2>

Cairns, R., & Krzywoszynska, A. (2016). Anatomy of a buzzword: The emergence of ‘the water-energy-food nexus’ in UK natural resource debates. *Environmental Science & Policy*, 64, 164–170. <https://doi.org/10.1016/j.envsci.2016.07.007>

Carter, D. F., Razo Dueñas, J. E., & Mendoza, R. (2019). Critical examination of the role of STEM in propagating and maintaining race and gender disparities. In M. B. Paulsen & L. W. Perna (Eds.), *Higher Education: Handbook of Theory and Research: Volume 34* (pp. 39–97). Springer International Publishing. https://doi.org/10.1007/978-3-030-03457-3_2

Center for Disease Control. (2018). *One Health Basics*. <https://www.cdc.gov/onehealth/basics/index.html>

Covarrubias, M., Spaargaren, G., & Boas, I. (2019). Network governance and the Urban Nexus of water, energy, and food: Lessons from Amsterdam. *Energy, Sustainability and Society*, 9(1), 14. <https://doi.org/10.1186/s13705-019-0196-1>

Daher, B., Hannibal, B., Portney, K. E., & Mohtar, R. H. (2019a). Toward creating an environment of cooperation between water, energy, and food stakeholders in San Antonio. *Science of the Total Environment*, 651, 2913–2926. <https://doi.org/10.1016/j.scitotenv.2018.09.395>

Daher, B., Lee, S.-H., Kaushik, V., Blake, J., Askariyah, M. H., Shafeizadeh, H., Zamaripa, S., & Mohtar, R. H. (2019b). Towards bridging the water gap in Texas: A water-energy-food nexus approach. *Science of the Total Environment*, 647, 449–463. <https://doi.org/10.1016/j.scitotenv.2018.07.398>

Economic Social Research Council (ESRC). (2015). *Funding Call Centre for Evaluating Complexity across the Energy-Environment-Food Nexus*. <https://valuing-nature.net/news/funding-opportunity-centre-evaluating-complexity-across-energy-environment-food-nexus>

Foran, T. (2015). Node and regime: Interdisciplinary analysis of water-energy-food nexus in the Mekong region. *Water Alternatives*, 8(1), 20.

Guan, X., Mascaro, G., Sampson, D., & Maciejewski, R. (2020). A metropolitan scale water management analysis of the food-energy-water nexus. *Science of the Total Environment*, 701, 134478. <https://doi.org/10.1016/j.scitotenv.2019.134478>

Hoolohan, C., Larkin, A., McLachlan, C., Falconer, R., Soutar, I., Suckling, J., Varga, L., Haltas, I., Druckman, A., Lumbroso, D., Scott, M., Gilmour, D., Ledbetter, R., McGrane, S., Mitchell, C., & Yu, D. (2018). Engaging stakeholders in research to address water-energy-food (WEF) nexus challenges. *Sustainability Science*, 13(5), 1415–1426. <https://doi.org/10.1007/s11625-018-0552-7>

Kulat, M. I., Mohtar, R. H., & Olivera, F. (2019). Holistic water-energy-food nexus for guiding water resources planning: Matagorda County Texas Case. *Frontiers in Environmental Science*, 7, 3. <https://doi.org/10.3389/fenvs.2019.00003>

Larkin, A., Hoolohan, C., & McLachlan, C. (2020). Embracing context and complexity to address environmental challenges in the water-energy-food nexus. *Futures*, 123, 102612. <https://doi.org/10.1016/j.futures.2020.102612>

Leese, M., & Meisch, S. (2015). Securitising sustainability? Questioning the “water, energy and food-security nexus.” *Water Alternatives*, 8(1), 695–709.

Markantonis, V., Reynaud, A., Karabulut, A., El Hajj, R., Altinbilek, D., Awad, I. M., Bruggeman, A., Constantianos, V., Mysiak, J., Lamaddalena, N., Matoussi, M. S., Monteiro, H., Pistocchi, A.,

Pretato, U., Tahboub, N., Tunçok, I. K., Ünver, O., Van Ek, R., Willaarts, B., ... & Bidoglio, G. (2019). Can the implementation of the water-energy-food nexus support economic growth in the Mediterranean region? The current status and the way forward. *Frontiers in Environmental Science*, 7, 84. <https://doi.org/10.3389/fenvs.2019.00084>

Märker, C., Venghaus, S., & Hake, J.-F. (2018). Integrated governance for the food–energy–water nexus – The scope of action for institutional change. *Renewable and Sustainable Energy Reviews*, 97, 290–300. <https://doi.org/10.1016/j.rser.2018.08.020>

Martinez-Hernandez, E., Leach, M., & Yang, A. (2017). Understanding water-energy-food and ecosystem interactions using the nexus simulation tool NexSym. *Applied Energy*, 206, 1009–1021. <https://doi.org/10.1016/j.apenergy.2017.09.022>

Mdee, A. (2017). Disaggregating orders of water scarcity—The politics of nexus in the Wami-Ruvu River Basin Tanzania. *Water Alternatives*, 10(1), 16.

Medin, D. L., & Bang, M. (2014). *Who's asking? Native science, Western science, and science education*. The MIT Press.

Middleton, C., Allouche, J., Gyawali, D., & Allen, S. (2015). The rise and implications of the water-energy-food nexus in Southeast Asia through an environmental justice lens. *Water Alternatives*, 8(1), 627–654.

Misra, S., Stokols, D., & Cheng, L. (2015). The transdisciplinary orientation scale: Factor structure and relation to the integrative quality and scope of scientific publications. *Journal of Translational Medicine & Epidemiology*, 3(2), 1042.

Mroue, A. M., Mohtar, R. H., Pistikopoulos, E. N., & Holtzapple, M. T. (2019). Energy Portfolio Assessment Tool (EPAT): Sustainable energy planning using the WEF nexus approach – Texas case. *Science of the Total Environment*, 648, 1649–1664. <https://doi.org/10.1016/j.scitotenv.2018.08.135>

Murray, R. T., Marbach-Ad, G., McKee, K., & Sapkota, A. R. (2021). Experiential graduate course prepares transdisciplinary future leaders to innovate at the food-energy-water nexus. *Sustainability*, 13(3), 1438. <https://doi.org/10.3390/su13031438>

Nasir, N. S., & Vakil, S. (2017). STEM-focused academies in urban schools: Tensions and possibilities. *Journal of the Learning Sciences*, 26(3), 376–406. <https://doi.org/10.1080/10508406.2017.1314215>

National Science Foundation. (2020). *NSF Award Search: Advanced Search Results*. <https://www.nsf.gov/awardsearch/advancedSearchResult?ProgEleCode=1997>

Newell, J. P., Goldstein, B., & Foster, A. (2019). A 40-year review of food–energy–water nexus literature and its application to the urban scale. *Environmental Research Letters*, 14(7), 073003. <https://doi.org/10.1088/1748-9326/ab0767>

Oki, T., & Kanae, S. (2004). Virtual water trade and world water resources. *Water Science and Technology*, 49(7), 203–209. <https://doi.org/10.2166/wst.2004.0456>

Opejin, A. K., Aggarwal, R. M., White, D. D., Jones, J. L., Maciejewski, R., Mascaro, G., & Sarjoughian, H. S. (2020). A bibliometric analysis of food-energy-water nexus literature. *Sustainability*, 12(3), 1112. <https://doi.org/10.3390/su12031112>

Ramaswami, A., Boyer, D., Nagpure, A. S., Fang, A., Bogra, S., Bakshi, B., Cohen, E., & Rao-Ghorpade, A. (2017). An urban systems framework to assess the trans-boundary food-energy-water nexus: Implementation in Delhi India. *Environmental Research Letters*, 12(2), 025008. <https://doi.org/10.1088/1748-9326/aa5556>

Rasul, G. (2014). Food, water, and energy security in South Asia: A nexus perspective from the Hindu Kush Himalayan region. *Environmental Science & Policy*, 39, 35–48. <https://doi.org/10.1016/j.envsci.2014.01.010>

Redman, A., & Wiek, A. (2021). Competencies for advancing transformations towards sustainability. *Frontiers in Education*, 6, 785163. <https://doi.org/10.3389/feduc.2021.785163>

Rodríguez, L. F., Marshall, A.-M., Cotton, D., Koelsch, R., Koziel, J., Meyer, D., Steward, D., Heemstra, J., Padmanabahn, A., Classen, J., Meyer, N. J., Ruddell, B. L., Ryan, S. M., Cai, X., Habib, E., & Saundry, P. D. (2019). The development of the INFEWS-ER: A virtual resource center for transdisciplinary graduate student training at the nexus of food, energy, and water. *Frontiers in Environmental Science*, 7. <https://doi.org/10.3389/fenvs.2019.00038>

Scanlon, B. R., Ruddell, B. L., Reed, P. M., Hook, R. I., Zheng, C., Tidwell, V. C., & Siebert, S. (2017). The food-energy-water nexus: Transforming science for society. *Water Resources Research*, 53(5), 3550–3556. <https://doi.org/10.1002/2017WR020889>

Schlör, H., Venghaus, S., Fischer, W., Märker, C., & Hake, J.-F. (2018). Deliberations about a perfect storm – The meaning of justice for food energy water-nexus. *Journal of Environmental Management*, 220, 16–29. <https://doi.org/10.1016/j.jenvman.2018.04.097>

Schmidt, J. J., & Matthews, N. (2018). From state to system: Financialization and the water-energy-food-climate nexus. *Geoforum*, 91, 151–159. <https://doi.org/10.1016/j.geoforum.2018.03.001>

Siddiqi, A., & Anadon, L. D. (2011). The water–energy nexus in Middle East and North Africa. *Energy Policy*, 39(8), 4529–4540. <https://doi.org/10.1016/j.enpol.2011.04.023>

Simpson, G. B., & Jewitt, G. P. (2019). The water-energy-food nexus in the Anthropocene: Moving from ‘nexus thinking’ to ‘nexus action.’ *Current Opinion in Environmental Sustainability*, 40, 117–123. <https://doi.org/10.1016/j.cosust.2019.10.007>

Sperling, J. B., & Berke, P. R. (2017). Urban nexus science for future cities: Focus on the energy-water-food-X nexus. *Current Sustainable/renewable Energy Reports*, 4(3), 173–179. <https://doi.org/10.1007/s40518-017-0085-1>

Trencher, G., Nagao, M., Chen, C., Ichiki, K., Sadayoshi, T., Kinai, M., Kamitani, M., Nakamura, S., Yamauchi, A., & Yarime, M. (2017). Implementing sustainability co-creation between universities and society: A typology-based understanding. *Sustainability*, 9(4), 594. <https://doi.org/10.3390/su9040594>

Trencher, G., Yarime, M., McCormick, K. B., Doll, C. N. H., & Kraines, S. B. (2014). Beyond the third mission: Exploring the emerging university function of co-creation for sustainability. *Science and Public Policy*, 41(2), 151–179. <https://doi.org/10.1093/scipol/sct044>

USA Spending. (n.d.). *Federal Awards*. Retrieved March 10, 2022, from https://usaspending.gov/keyword_search/NRT-INFEWS

Wade, A. A., Grant, A., Karasaki, S., Smoak, R., Cwiertny, D., Wilcox, A. C., Yung, L., Sleeper, K., & Anandhi, A. (2020). Developing leaders to tackle wicked problems at the nexus of food, energy, and water systems. *Elementa: Science of the Anthropocene*, 8(11). <https://doi.org/10.1525/elementa.407>

White, D. D., Jones, J. L., Maciejewski, R., Aggarwal, R., & Mascaro, G. (2017). Stakeholder analysis for the food-energy-water nexus in Phoenix, Arizona: Implications for nexus governance. *Sustainability*, 9(12), 2204. <https://doi.org/10.3390/su9122204>

Wieglob, V., & Bruns, A. (2018). What is driving the water-energy-food nexus? Discourses, knowledge, and politics of an emerging resource governance concept. *Frontiers in Environmental Science*, 6,. <https://doi.org/10.3389/fenvs.2018.00128>

Wiek, A., Bernstein, M., Foley, R., Cohen, M., Forrest, N., Kuzdas, C., Kay, B., Keeler, L., Barth, M., Michelsen, G., Rieckmann, M., & Thomas, I. (2016). *Operationalising competencies in higher education for sustainable development* (pp. 241–260). Routledge.

Wiek, A., Withycombe, L., & Redman, C. L. (2011). Key competencies in sustainability: A reference framework for academic program development. *Sustainability Science*, 6(2), 203–218. <https://doi.org/10.1007/s11625-011-0132-6>

Williams, J., Bouzarovski, S., & Swyngedouw, E. (2019). The urban resource nexus: On the politics of relationality, water–energy infrastructure and the fallacy of integration. *Environment and Planning c: Politics and Space*, 37(4), 652–669. <https://doi.org/10.1177/0263774X18803370>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.