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Transdisciplinarity and the food energy and water nexus: Ecological modernization and supply chain sustainability perspectives

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ABSTRACT

Successful Food-energy-water (FEW) nexus projects will be more likely to succeed if a transdisciplinary approach is used. Ecological modernization (ecological technology) policies and practices, and sustainable supply chains influence the FEW nexus from a commerce and industry perspective. Taking these perspectives and considering their intertwined linkages is important for advancing research and adoption of FEW nexus efforts. This paper provides an overview of these perspectives and interlinkages. A biosolids case study is used to exemplify the complexities and interactions of these four thematic perspectives: the FEW nexus, transdisciplinarity, ecological modernization, and sustainable supply chains. An integrative multi-level analysis scheme is used to analyze interrelationships. This analysis and the case study help to identify a series of research opportunities to further this nascent field. Research opportunities include methodological developments, attitudinal and social concerns, performance indicator systems, and meta-social evolutions in technology and policy.

1. Introduction

Sustaining global economic stability, nature, and quality of life requires improved understanding and management of interconnected food-energy-water (FEW) systems, the nexus. One of the most thought-provoking challenges is to feed 3 billion more people by 2050 and it must be accomplished by sustainably providing water and energy for all society's needs; while maintaining ecological quality.

The FEW nexus incorporates natural, social, and human-built components. The need to examine science, engineering, technology, industry, business, and social research agendas with a FEW nexus systems lens is clear. Many complex interactions are at play in FEW systems including changing land-use practices; increased urbanization; population growth and distribution; changing demand and consumer preferences; water, soil and air contamination; and climate variability.

The interactions within and between systems function according to fundamental scientific principles that govern the coupling of various physical, chemical, biological, economic, and social processes. Transdisciplinarity is the incorporation of a broad set of scientific and policy disciplines, including industries and actors, for addressing broad and complex problems, e.g. sustainability (Hadorn et al., 2006; Kurian, 2017). Transdisciplinarity is meant to address concerns of traditional scientific methods relying on reductionist, reasoned, studies that investigate a phenomenon or research question typically from a single disciplinary perspective (Max-Neef, 2005; Popa et al., 2015). For example, when chemical pesticides (e.g. DDT) in agriculture were introduced, food production capabilities increased. A broader perspective showed the ecological costs were immense, as discussed by Rachel Carson's 'Silent Spring' (Carson, 1962); which brought about a revolution in U.S. environmental policy. Transdisciplinarity may have addressed this issue before significant social and environmental concerns arose.

Transdisciplinary efforts can provide insights and guide research in the FEW systems field. A diverse (divergent), yet thematically-focused cluster of scientists, engineers, students, researchers, industry practitioners, and government officials can provide insights and progress within FEW nexus research to arrive at a common integrated output (convergence) (Boon et al., 2014).

Questions arise on the role of transdisciplinarity. How does transdisciplinary and cross-sector experience including physical, biological, natural, and social/behavioral processes comprising FEW systems help in identifying systems-level responses especially with respect to sustainable supply chain and technological perspectives? What might potentially be a research agenda at the center of this effort from a systemic supply chain and ecological technology perspective? These concerns are addressed in this perspectives article. Transdisciplinarity is introduced

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through a case study that considers various technical, economic, and social dimensions within the sustainable supply chain and ecological modernization perspective; evaluation of case studies has been encouraged as a technique to engage various transdisciplinary stakeholders (Kurian, 2017). Transdisciplinarity becomes an element of the problem solving process that has the potential to identify opportunities at the boundaries and interactions of traditional disciplines.

Transdisciplinarity, or *working collaboratively across traditional lines and with various stakeholders such as industry and government entities*, provides an opportunity to develop novel approaches to interpret and address complex environmental, infrastructure, and natural resource use issues. Integrating transdisciplinarity, sustainable supply chains, and ecological modernization theory[1] can provide insights into development and management of the FEW network. Understanding this linkage can inform researchers, practitioners and policy makers.

The remainder of the paper is structured to provide first some perspectives on the FEW nexus, transdisciplinarity, ecological modernization, and sustainable supply chains. A case study based on actual activities related to a bioenergy and biosolids supply chain with significant FEW influences is then presented. This case study sets the stage to help integrate the four thematic perspectives of the FEW nexus, transdisciplinarity, ecological modernization, and sustainable supply chain management in a multi-level analysis presented in tabular form. These perspectives present a set of emerging paradigms for FEW nexus analysis. This framework provides one way to help analyze and evaluate FEW projects. Research and practice directions and implications form the penultimate section, followed by a concluding section.

This paper is meant to contribute to the call for FEW nexus research as called for by the *Resources, Conservation, and Recycling* journal virtual special issue (Khanna et al., 2017). This paper provides an important and differing perspective of evaluating the FEW nexus not addressed in the literature.

2. Background

The FEW nexus can be investigated from a broad variety of perspectives and disciplines. In addition to transdisciplinarity. FEW nexus research can be advanced through the thematic lenses of ecological modernization (technology and innovation) and sustainable supply chains. Each of these lenses provides different perspectives, and thereby are likely to lead to qualitatively different solutions even when applied to the same problem. Accordingly, this section sets the foundation with discussion and background of the FEW nexus, transdisciplinarity, ecological modernization, and sustainable supply chains.

2.1. The food-energy-water (FEW) nexus

The relationship between food (agriculture), energy, and water are intertwined in many ways. FEW nexus resources are at the core of numerous social concerns relating to security, technology, poverty, hunger, and environmental preservation. Over the years, studies at the individual topic level of concerns, e.g. energy research, have been pursued, with whole fields and disciplines dedicated to these topics emerging over time. The interaction of various dyadic nexuses, e.g. water-energy or food-water, have been investigated. Only recently, first mentioned in the late 1990s, has consideration of the triad of these issues and their nexus become more widespread by social and scientific institutions. More recently, researchers have proposed extension to the foundational FEW nexus to include such additional topics as climate or land or "x" (Ringler et al., 2013; Sperling and Berke, 2017). The FEW nexus has been strongly linked to issues surrounding development and sustainability (e.g. Biggs et al., 2015) in developed and developing nations (Ozturk, 2015).

To date, most research on FEWS has focused on technological solutions – e.g., the use of waste water for algae cultivation, followed by harvesting the algae as a food and/or energy resource (Zhu et al., 2013). There have been calls for extending the focus, as we do in this paper, to go beyond a single scientific perspective to incorporate the interdisciplinarity of science (Scanlon et al., 2017). Although technological considerations are important, without consumer and social behavior changes and support, broader acceptance will fail (Portney et al., 2017); thus the further need for transdisciplinarity, as described in the next section, to broaden the scope to stakeholder involvement.

2.2. Transdisciplinarity

Transdisciplinarity is an approach closely associated with addressing complex problems that require input from multiple disciplines and must consider the needs of multiple stakeholders. Attempting to investigate and pursue scientific and engineering research using a traditional reductionist scientific approach may not be feasible when the topic, typically of practical concern, becomes sufficiently complex (Popa et al., 2015). Thus, the development and application of evolving scientific transdisciplinary perspectives is necessary to more effectively address these complex systems that have also been defined as "wicked" problems. Wicked problems are multifaceted problems with no obvious, clear solution (Norris et al., 2016), one of which is coupling energy, water, and food to broader industry and social systems; these issues are especially prevalent in socio-ecological systems.

The wicked problems argument sets the foundation for a broader transdisciplinary perspective needed to address FEW concerns. In fact, Churchman establishes a moral principal for the research community when it comes to solving wicked problems. The moral principle states: "whoever attempts to tame a part of a wicked problem, but not the whole, is morally wrong." (Churchman, 1967, p. B-142).

Transdisciplinarity is a relatively fluid concept and its definition is continuing to evolve; a common thread is that transdisciplinarity addresses problems from the broadest possible scientific and practical perspective. Some researchers view transdisciplinarity as a process that begins with 'what exists', building to 'what we are capable of doing', then moving to 'what we want to do' resulting in 'what we need to do' (Max-Neef, 2005). It not only incorporates specific disciplines and fields such as mathematics, chemistry, and economics, but also professions, industries, and societal stakeholders. Various social systems and institutions, including their general values and norms, are also integrated. Transdisciplinarity focuses on expanding from concrete (abstract, analytical, and theoretical) scientific principles and technologies to less tangible philosophical and ethical mores and norms of society.

The traditional 'siloed' discipline focus begins with fundamental principles and scientific knowledge in scientific or academic disciplines. This specialization is needed to build strong disciplinary foundations, delving deeply into field specific knowledge. The next level of collaboration includes inter-disciplinary work. An example of inter-disciplinary work is given by the basic sciences of chemistry, biology, and physics working together; each sharing and building inter-disciplinary knowledge. In fact, inter-disciplinary work often spawns new sub-fields that exist at the boundaries of traditional disciplines – hence biochemistry and chemical biology now exist as distinct sub-disciplines at the chemistry-biology interface. Another level of collaboration would span even more disparate boundaries, by collaborating across knowledge fields to include, for example, the social sciences and humanities. This requires a multidisciplinary focus whereas the current emphasis in all disciplines at academic institutions may be in very divergent single-discipline programs and schools. The multidisciplinary focus then extends further to become transdisciplinary to incorporate higher levels of

[1] Supply chain functions within and between organizations are composed of purchasing, production, transportation and logistics, marketing, and returns activities. Sustainable supply chains include the management of these activities with environmental and social sustainability in mind. Ecological modernization theory posits that technology and innovation can decouple economic growth from environmental degradation. Both concepts are detailed later in the paper.