

Article

Stakeholder Analysis for the Food-Energy-Water Nexus in Phoenix, Arizona: Implications for Nexus Governance

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Abstract: Understanding the food-energy-water nexus is necessary to identify risks and inform strategies for nexus governance to support resilient, secure, and sustainable societies. To manage risks and realize efficiencies, we must understand not only how these systems are physically connected but also how they are institutionally linked. It is important to understand how actors who make planning, management, and policy decisions understand the relationships among components of the systems. Our question is: How do stakeholders involved in food, energy, and water governance in Phoenix, Arizona understand the nexus and what are the implications for integrated nexus governance? We employ a case study design, generate qualitative data through focus groups and interviews, and conduct a content analysis. While stakeholders in the Phoenix area who are actively engaged in food, energy, and water systems governance appreciate the rationale for nexus thinking, they recognize practical limitations to implementing these concepts. Concept maps of nexus interactions provide one view of system interconnections that be used to complement other ways of knowing the nexus, such as physical infrastructure system diagrams or actor-networks. Stakeholders believe nexus governance could be improved through awareness and education, consensus and collaboration, transparency, economic incentives, working across scales, and incremental reforms.

Keywords: nexus approach; water-energy coupling; food-water coupling; food-energy coupling; governance

1. Introduction

Understanding the linkages and interdependencies in the food-energy-water nexus is necessary to identify risks and inform strategies for integrated nexus governance that supports multi-sector resiliency, security, and sustainability [1]. Despite current understanding about interrelationships between the elements of food, energy, and water systems, policy, planning, and management decisions for each sector are typically made in isolation, without full consideration of tradeoffs and interactions. This is primarily because of the complexity of each individual system and difficultly identifying the

interconnections, which makes it challenging to assess multiple systems in an integrated manner, especially with current scientific methods and modeling capabilities [2].

Despite these challenges, it is necessary to understand these intricacies because the interactions between these systems may lead to new and complex societal risks. For example, cascading failures may occur when failure in a component of one system (e.g., electricity generation) leads to increased risks of failures in a component of another system (e.g., water treatment) [3]. Food, energy, and water resources are increasingly linked, for instance through global markets, as illustrated by joint price movements between world food and oil prices [4]. Furthermore, changes in components of one system may alter thresholds and tipping points in the other systems [5]. As these systems feedback on one another, the behavior of the overall system is difficult to predict based on an understanding of the individual components [6]. Finally, the scale and scope of these systems-of-systems means that they are together subject to a wider range of stressors from, for instance, global climate change impacts, such frequency and intensity of droughts and floods, or economic or political shocks. Thus, knowledge of the linkages, synergies, and conflicts in the food-energy-water (FEW) nexus is urgently needed to provide evidence-based decision-making for policies in each sector that are most likely to produce positive effects in the other sectors as well as for developing innovative approaches to nexus governance [7]. To achieve such integration, policy makers need to incorporate information about impacts of FEW interactions and the robustness of policy decisions across a range of future conditions [8]. A nexus perspective thus requires new tools and methods to improve risk management.

To manage risks in coupled FEW systems and enhance resilience, security, and sustainability, we must understand not only how these interconnected systems are physically connected but also how the systems are institutionally linked. Furthermore, it is important to understand nexus governance at spatial and temporal scales at which actors make planning and policy decisions, such as infrastructure investments, which have lasting implications. To date, however, few studies have examined empirically how governance actors understand the nexus concept, how these actors are linked, and what policy actions they recommend. To study these governance issues, which tend to be highly context specific, qualitative and place-based case studies are required.

To address these challenges, in this paper we present a stakeholder identification and analysis for the food-energy-water nexus in Phoenix, Arizona. Given its desert setting, and dominance of irrigated agriculture, which relies on energy-intensive pumping of water from deep aquifers as well as highly variable and climate-sensitive surface water, Phoenix presents an interesting case to study the institutional linkages and emergent risks, as well as the barriers to and opportunities from policy coherence. Using a case study design, we generate qualitative data through focus groups and interviews with regional stakeholders representing a broad cross-section of governance actors, including participants from agriculture, water, and energy sectors. Our analysis reveals, from the point of view of the stakeholders themselves, the linkages and interconnections between sectors, the current actors in FEW nexus governance in the Phoenix region, and recommended policy actions to enhance nexus governance. The long-term goal of this research is to contribute to an interdisciplinary understanding of nexus dynamics to inform integrated modeling, visualization, and decision support infrastructure for FEW systems at decision-relevant temporal and spatial scales.

1.1. Food-Energy-Water Nexus Research

The origins of food, energy, water nexus research have been traced to at least the mid-1980s, stimulated in part by the Food-Energy-Nexus Programme of the United Nations University. Influential U.S. government reports by the Department of Energy on water-energy nexus articulated national priorities for science, modeling, and policy [9,10]. Furthermore, the World Economic Forum focused global attention on the nexus by consistently identifying FEW issues, such as water crises, extreme weather events, food shortages, and failure of climate adaptation and mitigation efforts as major global risks to security in need of immediate attention [11,12]. In addition, in the international development context, the United Nations Sustainable Development Goals (SDG) framework aims to integrate

environmental, social, and economic goals and recognize tradeoffs and synergies between objectives for food, energy, and water sustainability [13].

Meanwhile, academic interest in the nexus has increased considerably in recent years. A search of Web of Science records shows that articles with the topic “food-energy-water nexus” increased from just four papers published in 2011 to more than 80 in 2016. As Scott et al. [14] noted in their thorough review, explicit consideration of multiple interactions within the FEW nexus emerged in the late 2000s with research in India [15,16] and the Western U.S. [17–19], including studies documenting the water-use implications of energy production and agriculture [14]. Several academic journals have devoted Special Issues to the FEW nexus, including *Water Policy*, which examined the implications of hydropower for agriculture, energy prices for energy-intensive water practices, and biofuel production for the agricultural sector [15]. A 2015 Special Issue of *Water International* emerged from a conference on sustainability in the water, energy, and food nexus held in Bonn, Germany, and the resulting papers focused on tools, solutions, and governance at multiple scales [7].

In this literature, scholars have proposed a number of integrated or coupled approaches to analyze the energy-water nexus [8], food-energy-water nexus [1,20,21], and the climate-energy- water-land nexus [22]. These approaches vary widely in terms of conceptual and modeling sophistication. One example is the Transboundary River Basin Nexus Approach (TRBNA), a method to identify trade-offs and impacts of the FEW nexus across sectors, establish socio-economic and geographical context, and engage participant stakeholders in the nexus assessment process through discussion of transboundary issues [23]. While this approach is flexible, adaptable, and participatory, the authors noted limitations including lack of focus on economic constraints, cultural differences, or power imbalances, and it significantly emphasizes water over the other sectors. Another example is the Water-Energy-Food Nexus Tool, a simple application for scientists and policy makers to explore and visualize resource consumption scenarios and compare outputs against a sustainability index [20]. An interdisciplinary team led by the U.S. Department of Energy Pacific Northwest National Laboratory developed the Platform for Integrated Modeling and Analysis (PRIMA), a sophisticated multi-model tool linking a regional earth system model, an integrated assessment model, and several individual sector models of energy, water, land use, and crop productivity. The authors identified research on stakeholder engagement, visualization, and decision support as key future priorities.

A prominent theme in the social sciences literature on the FEW nexus is the importance of moving towards an integrated policy approach that considers all three sectors to maximize gain, optimize trade-offs, and reduce negative impacts [24]. For instance, Scott et al. advocate an institutional perspective, focused on groupings created from social structure [14] examining institutions at multiple scales and functions of public and private institutions, while considering and prioritizing human wants and needs. Others have pointed to the contested nature of the nexus framing, and thus the need for understanding the underlying politics and the potential value of approaching the nexus through an environmental justice lens [25].

To have an impact on integrated nexus governance and, ultimately, resilience, security, and sustainability outcomes, research must move from conceptualizing and documenting FEW interactions to specifying actionable strategies for enhancing policies. To date, most literature focuses on the theoretical importance of an integrated approach to governance, with minimal emphasis on how to implement nexus research to achieve this goal [2]. Recently, however, social science researchers have begun to develop approaches for engaging stakeholders in FEW research with the aim of co-developing knowledge and solutions. In one such example, a team of UK researchers used semi-structured interviews to engage stakeholders from a range of professions within the food, water, and energy sectors including academics, policy makers, private sector interests, and funders [26]. They suggest that social sciences can be useful in creating so-called “nexus forums” where participants of diverse backgrounds can debate ways of defining, understanding, and acting upon the FEW nexus. In another example, researchers held workshops including stakeholders from academic, practitioner, and policy groups, using a knowledge co-production approach to encourage the participants to share their

specific expertise, engage and challenge other's views, and contribute to constructive dialogue [27]. The results revealed four main barriers to decision-making in the context of FEW nexus shocks: (i) lack of communication and collaboration; (ii) decision-making processes; (iii) social and cultural dimensions; and (iv) uncertainty about the nature of responses to nexus shocks. Our study is informed by and contributes to this literature using similar methods to engage governance stakeholders in a participatory process to develop common conceptual understandings of the nexus and identify strategies for knowledge co-production and policy reforms.

1.2. Stakeholder Identification and Analysis in Environmental Management

Stakeholder analysis has become increasingly popular within environmental social sciences literature and environmental management. While definitions vary, the process typically involves identifying, categorizing, and investigating relationships among stakeholders [28]. Definitions of stakeholders also vary, but most include actors and organizations with vested interest, power and influence, and those who are affected by the decisions and actions taken by participants involved in governance [28,29]. Stakeholder analysis, drawing from management research [29,30] and policy analysis, "focuses on the interrelations of groups and organizations and their impact on policy within a broader political, economic, and cultural context" [31] (p. 240). Three complementary approaches to stakeholder analysis rely on descriptive, normative, and instrumental rationale [28]. The descriptive approach defines the relationship between a central issue or phenomenon and its stakeholders. The normative approach engages stakeholders to document their perspectives and enhance the legitimacy of knowledge used for decision making, incorporating the views of representative actors within a specific moral, legal, and institutional context. The instrumental approach is said to enhance salience and usability of knowledge and technologies developed for use by those stakeholders.

In their influential article, Reed et al. developed a typology of research methods for stakeholder identification and analysis [28] including three stages: (i) identifying stakeholders; (ii) differentiating between and categorizing stakeholders; and (iii) investigating relationships among stakeholders. The authors discuss focus groups, semi-structured interviews and snowball sampling as techniques for identifying stakeholders. To differentiate and categorize stakeholders, methods include top-down or analytical categorizations or reconstructive or bottom-up (stakeholder-led) categorizations. Finally, to investigate relationships among stakeholders, the methods include actor—network linkages, social network analysis, and knowledge mapping.

Drawing from the stakeholder analysis literature, our study is guided directly by descriptive and instrumental approaches and indirectly by the normative approach. The descriptive and instrumental goals are to identify and engage stakeholders and solicit their critical feedback on the co-production, testing, and implementation of knowledge, complex system models, simulations, and visualizations for decision support for FEW nexus in Arizona and beyond. From a normative perspective, this research functions as one technique to engage a broad cross-section of societal interests in nexus governance. Our methods, described later, include interviews and focus groups for identification and reconstructive categorization of stakeholders. While much of the research focuses on global or national scale, our focus is on the sub-regional scale, where many decisions are made.

2. Study Context

2.1. Phoenix Active Management Area

The location of our study is central Arizona, USA. Specifically, we focus on the Phoenix Active Management Area (AMA), which is a political/hydrological boundary created by the passage of the 1980 Arizona Groundwater Management Act (Code). The Code, which is administered by the Arizona Department of Water Resources (ADWR), was established to control severe overdraft of groundwater resources in the state and to create a mechanism for allocating limited groundwater resources to meet the state's changing water needs. There are currently five AMAs within Arizona,

with boundaries generally defined by groundwater basins and sub-basins. The Phoenix AMA includes seven groundwater sub-basins and covers an area of approximately 14,500 km² mostly located within Maricopa County (Figure 1). The AMA includes most of the Phoenix metropolitan area, a desert metropolis with a current population of 4.57 million people, which has been one of the fastest growing areas in the U.S., and is projected to rise to some 7 million by 2050.

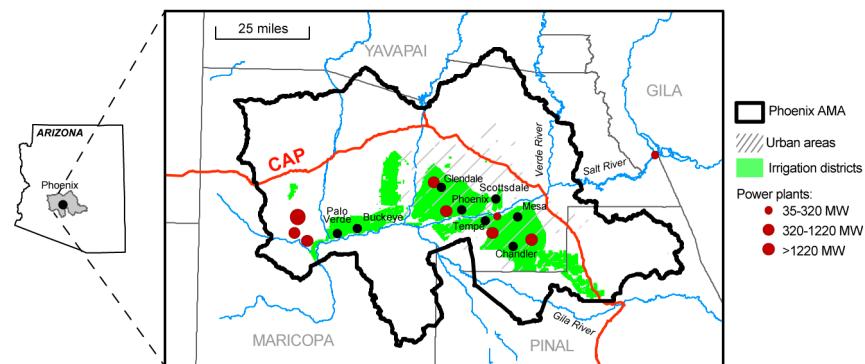


Figure 1. The Phoenix Active Management Area, including the main cities, rivers, irrigation districts, large-scale power plants, and the Central Arizona Project aqueduct.

Population and economic growth in the Phoenix AMA has led to dramatic changes in the water and energy demand as well as food production over the last 30 years. Much of this growth has been made possible by availability of water supply through the Central Arizona Project (CAP), the system of canals diverting water from the Colorado River into central and southern Arizona. According to one credible estimate, CAP contributes to about 23% of the cumulative Gross State Product [32]. However, CAP holds a junior priority water entitlement among the Lower Colorado River Basin states (Arizona, California, and Nevada), making it vulnerable to reductions in Colorado River water [33,34]. Thus, climate represents a critical stressor for the FEW nexus in Phoenix AMA. For example, a recent analysis of Colorado River shortages found that as CAP supplies are cut, water supplies to non-Indian agricultural customers would be severely impacted since they have limited rights to CAP. Consequently, these customers are likely to shift to pumping groundwater, leading to an increase in electricity demand. Currently, the coal-fired Navajo Generating Station (NGS) is the major source of pumping energy for CAP, but recently it has faced a lot of pressure under the Clean Air Act for its emissions. Given the environmental concerns at the NGS, serious water and energy shortages could occur under various policy futures, leading to a series of cascading effects on the local economy.

2.2. Overview of Water, Energy, and Food Components in the Phoenix AMA

Phoenix presents a compelling case study for examining the food-energy-water nexus. The semi-arid environment inherently water limited and currently faces management challenges associated with competing demands among urban and agricultural users, effects of climate change, long-term drought, population growth pressures, and uncertainty associated with surface water shortages and groundwater depletion. In addition, there are competing narratives about the appropriate role for irrigated agriculture and the associated water and energy demands [35].

2.2.1. Water-Food

Food production in the Phoenix AMA requires water to irrigate agricultural fields and dairy industry operations. This water is currently supplied by groundwater (37%), CAP (27%), and other surface water sources (30%). Note that while irrigated acreage in the region has declined, agriculture still accounts for around 47% of the total water demand. Furthermore, agriculture has also begun shifting production to forage crops. The shift to such forage crops (specifically alfalfa) has been associated with the growth of local dairy. However, this trend has also raised concerns as alfalfa is

a highly water intensive crop. Moreover, exports of alfalfa to Gulf countries and China have raised public concern over virtual water exports from a water scarce region during a long-term drought. While a dominant narrative of planned agricultural obsolescence has persisted in the region over the last several decades, as reflected in and reinforced by state policy, counter narratives about agricultural value and resilience have emerged strongly in recent years [35].

2.2.2. Water-Energy

Thermoelectric plants in the region use water for operating purposes, which is mainly obtained from groundwater (55%) and reclaimed (39%) sources. Part of the energy generated is then used for water infrastructure to enable conveyance and distribution pumping, groundwater pumping, and drinking-water and wastewater treatment [36]. It is also critical to mention that the Navajo Generating Station (NGS), located in northeastern Arizona (an external input to the AMA FEW system), provides the energy required for the CAP aqueduct, one of the main water sources for our system. CAP is estimated to be the single largest user of electricity in Arizona, demanding 2.8 TWh of electricity per year to pump 500 billion gallons of water up its 336-mile long course from Lake Havasu to Phoenix and Tucson [37]. The coal fired NGS plant, which has been a vital part of Arizona's economic growth, accounts for 29% of Arizona's energy emissions and has come under repeated pressure from the Environmental Protection Agency and environmental groups to reduce emissions or close. The uncertainties surrounding environmental regulations related to NGS have been identified by regional stakeholders as an important example of the challenges surrounding the FEW nexus in our study area.

2.2.3. Energy-Food

The year-long growing season in Arizona provides a comparative advantage in growing food crops, particularly head lettuce and cabbage. However, due to the dry conditions, energy costs embodied in irrigation are quite high. Fuel is also required for land preparation and growing operations. A recent study on energy use in growing food in Arizona found embodied energy from "seed to farm edge" in cabbage to range from 9054 to 12,061 kcal/head while in head lettuce it ranges from 6488 to 7877 kcal/head [38]. These estimates were based on calculation of energy use in each farm operation (including on-farm machine use and irrigation) obtained from the AZ Crop Budget tables prepared by University of Arizona Cooperative Extension.

3. Research Method

In this research, we employ a case study design, which is an in-depth and detailed exploration of a bounded system over time, incorporating multiple sources of data [39]. Our case is focused the food, energy, and water nexus in the Phoenix, Arizona metropolitan region. The question guiding our research is: *How do stakeholders involved in food, energy, and water governance in Phoenix, Arizona understand the FEW nexus and what are the implications for integrated nexus governance?* All procedures were reviewed and approved by the Institutional Review Board at the lead author's university and conformed to APA ethical standards.

3.1. Participant Selection

We used a nonprobability sampling strategy to identify key informants with significant professional experience and in-depth firsthand knowledge of food, energy, and water systems in the Phoenix AMA. Our sampling design included elements of expertise-based, purposive, stratified, and snowball sampling strategies [40,41]. We generated a sampling frame from several sources including: (i) a database of approximately 400 contacts, provided by a university research center in the Phoenix area that is actively involved with water, agriculture, and energy stakeholders; (ii) a list of approximately 300 participants from a conference on climate change impacts and agriculture in Arizona; and (iii) a list of approximately 75 participants in a Phoenix-area workshop on the water-energy nexus in the Southwest. To ensure that we included a broad range of interests, we classified the individuals by sector (i.e., food, energy,

and/or water), assigning each a primary, secondary, and tertiary interest, as appropriate, based on their organizational affiliation. To ensure a broad range of perspectives, we also classified the individuals by environmental governance sector (i.e., public, private, nonprofit) [42].

3.2. Data Collection and Analysis Procedures

We generated qualitative data between March 2017 and August 2017 through moderated focus groups and semi-structured individual interviews. We conducted five focus groups, each lasting two hours, held at the ASU Decision Theater in Tempe, a resource that provides expertise in collaboration, computing, and display technologies for modeling, simulation, and visualization. The Decision Theater provides an immersive environment for collaboration that features a seven-screen panoramic ultra-high-definition display as well as state-of-art video conferencing and audio recording technology. For the focus groups, the project team used the display technology to provide a brief overview presentation of the long-term research program and capture participant responses in real time. For participants who could not attend one of the Decision Theater sessions, we offered individual interviews at a convenient location, typically the participant's office, and we completed 14 individual interviews, each lasting approximately one hour. We continued sampling until we reached theoretical saturation for key concepts [43]; that is, we continued to conduct focus groups and interviews until each additional interview produced little to no new information [44].

The interview and focus group protocol were identical and included three sections. The first section elicited participants' understandings of the concept of the food-energy-water nexus including major linkages, tradeoffs, and cross-sector impacts. The second section focused on identifying FEW stakeholders in the Phoenix AMA and the level of interest and influence of various actors and institutions. The third section prompted discussion about major policies affecting the FEW nexus and potential reforms or new policies to reduce risks across interdependent systems or to enhance efficiencies or co-benefits between sectors. Interviewees represented a broad range of FEW stakeholders including representatives of local governments, water and power utilities, agricultural interests, and environmental advocacy groups.

We used a professional service to transcribe the audio data, imported the documents into MAXQDA V12 (VERBI GmbH, Berlin, Germany) qualitative data analysis software and used a content analysis approach to interrogate the data [45]. Content analysis is a research method that seeks to understand the intrinsic meaning of a person or group's written or verbal communication [45]. Our first step was to identify key concepts from the literature related to each major topic area in the protocol: (i) food-energy-water nexus interactions and linkages (e.g., benefits the water sector, co-benefit, negative trade-off); and (ii) FEW stakeholders (e.g., Agribusiness and Water Council of Arizona and Arizona Public Service) and FEW nexus policies (e.g., Groundwater Management Act). Next, we created code definitions that enabled us to identify, in reliable and valid ways, the presence or absence of theoretically meaningful topics in focus group and interview text we collected from respondents [40]. Our codebook defined each code using a theoretically-informed definition, inclusion criteria, and exclusion criteria [46]. In addition to the deductive codes developed from the literature, we created inductive codes based on occurrence in the data. The coding unit for this study was at the statement level. After pretesting and refining the codes, we tested interrater reliability using Cohen's kappa [47], and demonstrated acceptable reliability (>0.80). The final completed sample for our study included 39 participants (Table 1).

Table 1. Study participants.

Organization	N	Nexus Sector(s)	Organization Type
Salt River Project	12	W, E, F	Utility Cooperative (Salt River Valley Water Users' Association) and State Agency (Salt River Project Agricultural Improvement and Power District)
Central Arizona Water Conservation District	1	W, E	Municipal Corporation

Table 1. *Cont.*

Organization	N	Nexus Sector(s)	Organization Type
Arizona Department of Water Resources	1	W	State Agency
City of Tempe	1	W, E, F	Municipal Government
City of Phoenix	12	W, E, F	Municipal Government
Arizona Municipal Water Users Association	1	W	Nonprofit Corporation
City of Peoria	1	W, E, F	Municipal Government
Lincoln Institute of Land Policy	1	W, F	Nonprofit Private Operating Foundation
Arizona State University	1	W, F	State of Arizona Public University
Audubon Society	1	W	Nonprofit Organization
Maricopa Stanfield Irrigation and Drainage District	1	F, W, E	Municipal Corporation
Arizona Cattlemen's Association	1	F, W	Nonprofit Organization
Maricopa County Food System Coalition	1	F	Nonprofit Organization
Arizona Power Authority	1	E, W	Body Corporate and Politic of the State of Arizona
Queen Creek Irrigation District	1	F, W, E	Municipal Corporation
US Geological Survey	1	W, E	US Federal Agency
Agribusiness and Water Council of Arizona	1	W, E, F	Nonprofit Trade Association

4. Findings

We present the findings in four complementary sections, following the structure of the interview and focus group protocol: (i) perceptions of the salience and utility of the FEW nexus concept; (ii) understandings of the linkages and interactions among FEW systems; (iii) identification and analysis of stakeholders; and (iv) nexus policy recommendations. The findings include detailed interview and focus group excerpts as well as conceptual diagrams derived from the empirical content analysis.

4.1. Salience and Utility of the Nexus Concept to Stakeholders

We first asked our participants if they found the food-energy-nexus concept meaningful, useful, and relevant to their work. Overall, they described the nexus as a new and generally meaningful concept but expressed significant reservations about how useful and understandable it is, especially when communicating with diverse audiences, as illustrated by the following excerpts. For example, a state-level water policy maker said:

No. Certainly Energy-Water Nexus has been out there for more than a decade as a major topic, but putting it together to say-taking the Energy-Water Nexus and saying the Food-Energy-Water Nexus, it seems to me to be a bit newer. It makes sense, but as a framing it's a newer—I see it as a newer perspective.

A city planner recognized the nexus concept in terms of connection of food and water with land but was less focused on the energy system:

We talk a lot about food and we talk a lot about water obviously, because of our environment here in Arizona. And maybe not so much about energy. I think we recognize that as an important component, but I don't know that it's—on a regular basis I don't think we necessarily talk about those three together. I think we generally talk about food, land and water.

Finally, an executive with a regional water and energy provider highlighted the need for clarity:

Yeah. You know, I think it would be better—you know, you hear a lot about the water energy nexus. And a lot of people don't understand what that means. You have to explain it. But I think when

you add the variable food, you get—food's such a general term. It gets a little bit muddled on what exactly it means, and what are you trying to get, what do you want to get accomplished? I'm very big on—and whether it's a map, or it's a phrase, it should tell you exactly what you're looking for and what you want, if you can. It's always easier for the audience.

Only a few participants said that they used the concept in their work, whereas most said that the nexus concept was not salient. For instance, the general manager of an irrigation district said:

I stay away from using the word nexus, because most of the people I work with are farmers, and they're like, 'Why are you using that term?' It's just connection. They're moving together. So, the concept, yes, the terminology, no.

Several participants said that the relevance of the concept was limited because their organization was focused on one sector. For instance, a federal agency water scientist said. "It may come up from time to time, but not typically, no, because we're more focused on just the water piece of it." Others said that the nexus is an academic concept not used by planners, managers or other stakeholders. A representative of an environmental nonprofit said simply, "Not particularly. That's a little wonky."

4.2. Stakeholder Understandings of Food-Energy-Water Nexus Interactions

In our study, participants identified a range of interactions between food, energy, and water systems, including two-way interactions between each system as well as three-way interactions.

4.2.1. Food-Energy-Water Interactions

Our analysis shows how regional stakeholders understand three-way interactions for the nexus. Figure 2 shows the linkages identified by the study participants and is derived by content analysis of the co-occurrence of codes.

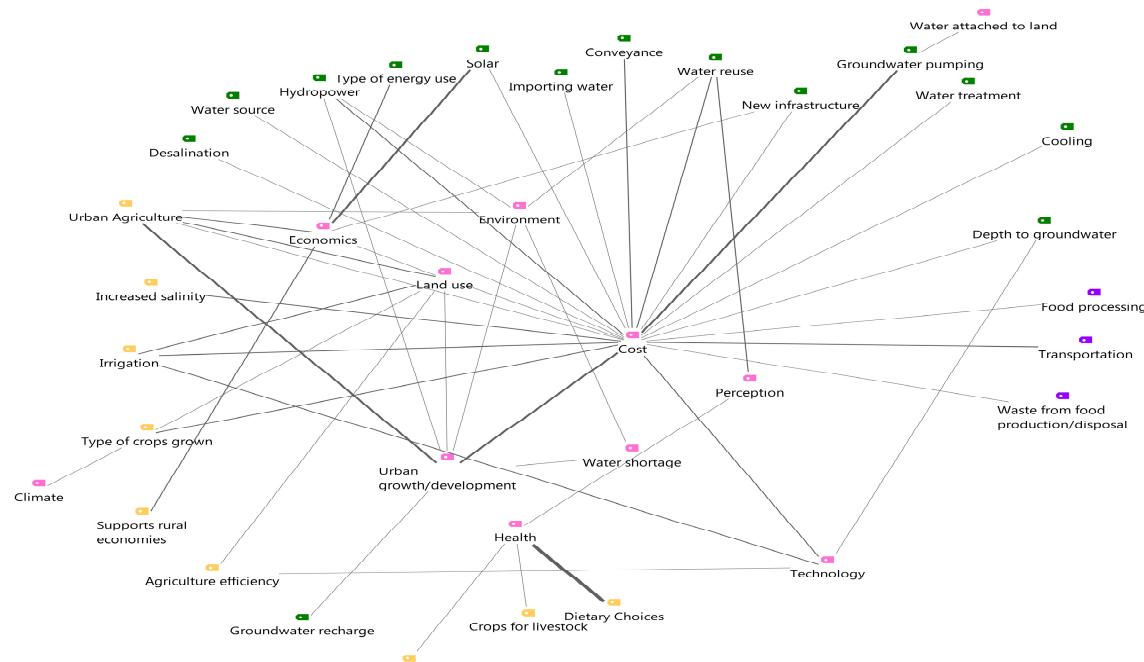


Figure 2. Code co-occurrence model of food-energy-water system interactions. The model illustrates the association and intersections among codes. The width of the line is dependent upon the number of intersections. Code tag color indicates interaction type with green representing energy-water interactions, yellow for water-food interactions, purple for food-energy interactions, and pink for three-way interactions.

We note two specific insights from this data visualization. First, economics are central to the stakeholders' understandings of the nexus, including costs and mechanisms for pricing and allocating scarce resources. The following excerpt from a municipal water policy advisor is illustrative:

Well, I think of it as a sustainability term that is talking about integrating or looking at the economic cost—a cost-benefit analysis for all three as an integrated unit . . . and then, in turn, one of the beauties of a reclamation system is that that particular energy water nexus was recognized right away, so not only do you develop—that's the word I've been looking for—develop water for agricultural uses, but you also create energy or generate electricity by developing the water itself. So it kind of is a little bit circular.

Second, stakeholders identified environment, land use policy, water shortage, urbanization, technology, and climate change as cross-cutting factors that affect the nexus through multiple linkages. This quotation from a focus group participant illustrates the stakeholders' views about the complexity and societal tradeoffs presented by a nexus perspective:

And in this case—with three components I think of kind of a three-dimensional production possibilities, and there are optimal points, depending on your combination. But it depends on what a society's preferences are for each one of those. So to me it's all tradeoffs. So you know, I'm sure that there are solutions that provide more benefit depending on the three that you choose. But I don't think you can have everything.

4.2.2. Water-Energy Interactions

Much of discussion centered upon the linkages, co-benefits, and tradeoffs between components of the coupled water-energy systems (Figure 3). This figure visualized the prominent direct water-energy nexus interconnections including groundwater pumping, conveyance, water importation, water treatment, water reuse, electricity generation, solar power, hydropower, groundwater recharge as well as indirect connections to other aspects of the FEW nexus.

Our participants identified hydropower generation as the most significant linkage between water and energy in the Phoenix AMA, providing co-benefits to each sector. For instance, a state agency executive said, "So out of that roughly nine million acre-feet of water that gets run through the dam, it generates electricity, the state gets a percentage. We allocate that to customers." An executive with a regional water and power supplier said, "So for (organization), we have hydroelectricity. We generate energy by moving water. Fortunately, from our perspective, that water, our system is gravity flow. And so, we don't need a lot of energy necessarily to move the water." This same participant also noted the efficiencies in this system: "I think on the water savings side, there's always a level of savings when it comes to the energy."

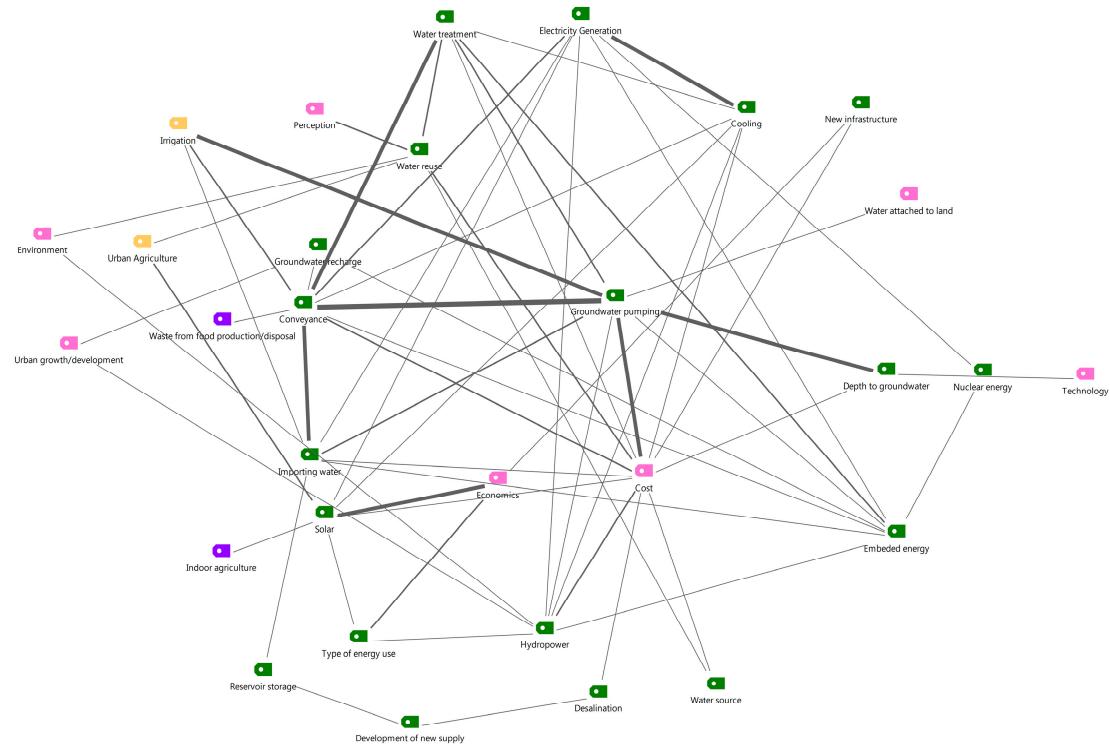


Figure 3. Code co-occurrence model of water-energy system interactions. The model illustrates the association and intersections among codes. The width of the line is dependent upon the number of intersections. Code tag color indicates interaction type with green representing energy-water interactions, yellow for water-food interactions, purple for food-energy interactions, and pink for three-way interactions.

4.2.3. Water-Food Interactions

Our participants also discussed interconnections inherent in the food-water nexus and this discussion focused mostly on water supply as an input into agriculture systems via irrigation as well as water quality impacts of irrigated agriculture (both positive and negative) and the implications of food production choices on energy demands (Figure 4).

The following excerpt from an interview with a city planner exemplifies the discussion about the water-agriculture nexus in the Phoenix region:

I think one topic that always seems to come up when we're talking about food production is the use of water. And people talk about water in a desert environment as a very precious commodity. So, I think there's going to be—it's probably occurring already, to a certain degree. But I think there's going to be more discussion about the use of water for agriculture and that the most appropriate use is—is the production of food the most appropriate use for or limited supply of water that we have in the Phoenix metro area as well as in Arizona? So I think that we're going to come to a point where—as we say we want to grow more food and we want to be more self-sufficient and more sustainable, but you're going to have the other side of that discussion coming back at us and saying, "Well, we can't be sustainable if we're using up our water." At some point there's going to be a discussion of, "How do we balance the two?" and maybe you accomplish both and hopefully keep everybody happy.

In another example of the discourse, a regional food policy association representative pointed to the possible water quality impacts of regional food production:

The little that I know about this is that producing food actually can clean soil. And if you limit the amount of poisonous chemicals that you put on your ground or in the food to take care of pests and

all that, you will have a lot cleaner water supply. And I know that microbial remediation can make a stark difference for the quality of our soil.

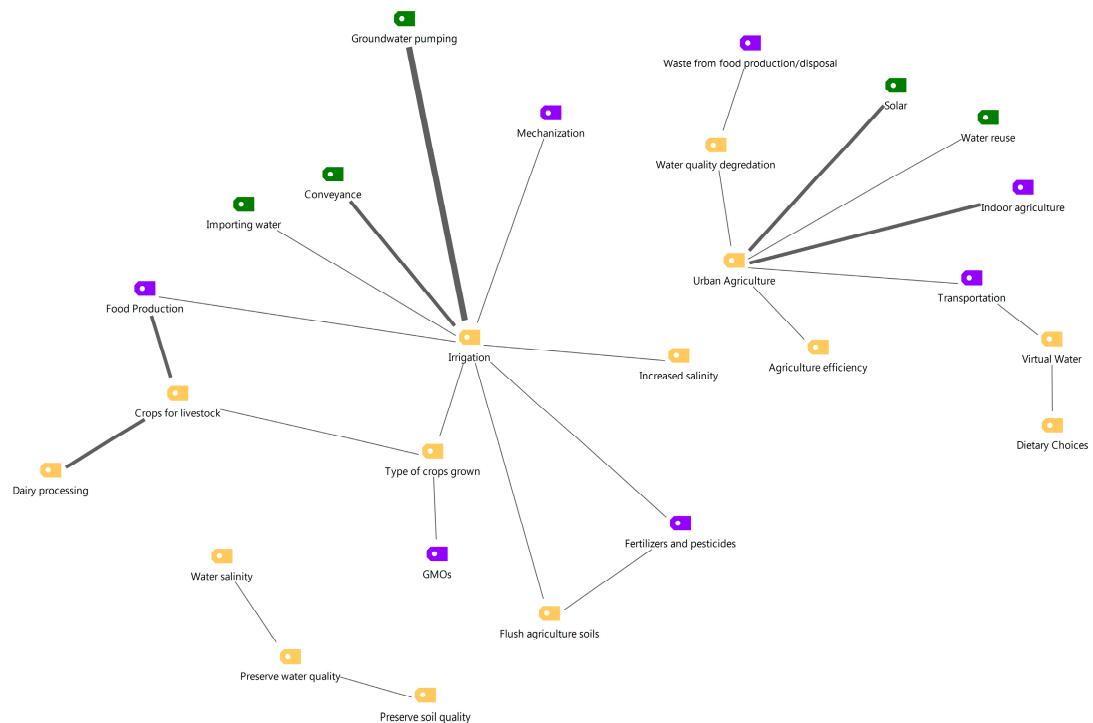


Figure 4. Code co-occurrence model of water-food system interactions. The model illustrates the association and intersections among codes. The width of the line is dependent upon the number of intersections. Code tag color indicates interaction type with green representing energy-water interactions, yellow for water-food interactions, purple for food-energy interactions.

4.2.4. Food-Energy Interactions

Participants also discussed interconnections inherent in food-energy nexus, albeit less frequently, with the most common linkages including biofuels, energy consumed for food transport, storage, and processing, as well as recovery of food waste for energy production (Figure 5).

A university food systems scientist discussed the impacts of high-protein diets on energy demands and downstream effects on supply chains:

So the trade-off for having high-quality protein foods, for example, in abundance and at will—you know, we can get them whenever we want—is an excessive demand on resources and fertilizers, for example, to produce more feed, more crops, corn, that kind of thing—soybeans—that requires then more energy to produce that. So the more high-quality but animal-based foods we want, the more we stress food systems here in the US, and, of course, in developing countries like China, that's becoming an issue too because demand for meat is growing and growing. So there are absolutely trade-offs for, like I said, on-demand access to high-quality nutritional foods.

Highlighting the opportunity for energy production from food waste, a representative of a cooperative association between a local city and participating restaurants focused on managing fats, oils, and grease said:

So, the average restaurant in the United States discharges between 517 pounds of fats, oils and grease in the sewer systems annually, and fats, oils and grease is by twofold the most energy-rich organic urban waste in the world and its lost. It not only is it expensive to remove at the end of the

line but it's lost if we allow it to enter our sewage systems from restaurants and ultimately, I think there are ways that we can facilitate its removal and its recovery as an energy source and energy feedstock and I think the next 10–15 years my industry will really, really focus on that.

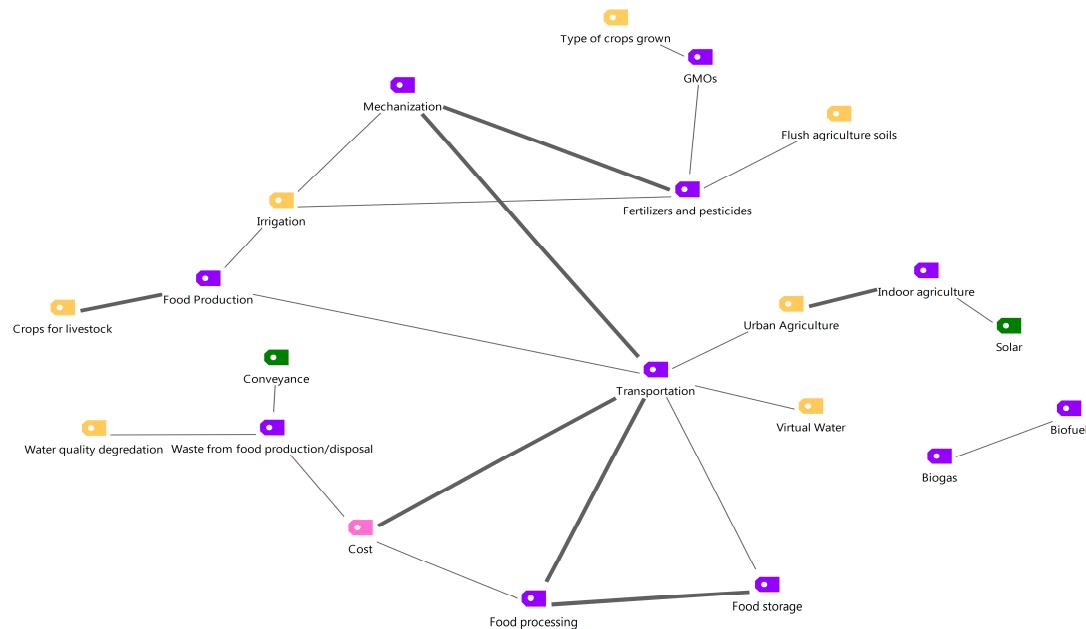


Figure 5. Code co-occurrence model of food-energy system interactions. The model illustrates the association and intersections among codes. The width of the line is dependent upon the number of intersections. Code tag color indicates interaction type with green representing energy-water interactions, yellow for water-food interactions, purple for food-energy interactions, and pink for three-way interactions.

As Figures 3–5 show the linkages within the nexus, they also imply different levels of complexity and interconnectedness within the participants' mental models. Figure 3 includes the most amount of linkages out of the figures, emphasizing that participants viewed the water-energy interaction as being highly complex. Participants were quick to identify the water-energy interaction, especially those who directly worked in the space between those two sectors. Figure 4, showing the water-food interaction, showed a moderate level of complexity but a strong emphasis on the link between groundwater pumping and irrigation. Many participants who had connections to the agricultural or food sectors tended to put an emphasis on irrigation-related interactions within the FEW system. Figure 5, showing the food-energy interaction, had the least number of linkages and the lowest level of complexity. Many participants had difficulty with this relationship, emphasizing the food-water nexus or the water-energy nexus more. The lack of attention on the food-energy interaction may be due to a lack of holistic understanding of the local nexus or to fewer linkages between energy and food within the study area. The levels of complexity within these figures is in line with the perceptions of the participants, who tended to state that the water-energy nexus was the strongest within the Phoenix area and that the food-energy link was the weakest.

4.3. Stakeholder Identification and Analysis

The second major aim of our research is to identify stakeholders for the FEW nexus in the Phoenix AMA and to illuminate the relationships among the actors and organizations involved in food, energy, and water systems. Our approach combines elements of the analytical and reconstructive methods [28]; we developed an initial scheme to guide the sampling strategy, as detailed earlier, and then asked those stakeholders to develop a reconstructive categorization. We asked participants to identify actors,

organizations, and institutions who have (or should have) interest, power, and influence for food, energy, and water systems and to specify those with the most power and influence and those most relevant to the nexus. Figure 6 provides an overview of the most identified stakeholders.

While our participants identified many public, private, and nonprofit organizations at federal, state, regional and local scales, with responsibilities across one or more sectors, a small number of organizations were consistently mentioned as the most powerful and influential. These include the Arizona Department of Water Resources, the Central Arizona Project, and Salt River Project. For instance, a state water policymaker said, "Well, I usually think of the 800-pound guerillas in the water management are the Department of Water Resources, the Central Arizona Project, and the Salt River Project. Those are really the three biggies." A representative of the state cattle industry agreed:

The ADWR, which is the Department of Water Resources which is obviously a huge one and their regulatory arm. I think you have the CAP is one because they're a major water deliverer and they kind of have that, an interesting mandate and challenges in front of them because they're directly tied to the Colorado River. You have SRP which fills both roles, I mean they deliver water, they have power, and it's on a different streamline than CAP is. But they are definitely a big portion of that.

This excerpt reinforces the finding that participants perceive ADWR and SRP to be influential:

Arizona Department of Water Resources. They're the enforcers of the groundwater code. I think they have a lot of influence, the Arizona Department of Water Resources, again, because of the groundwater code and the restrictions or controls put in place through the groundwater code and the enforcement of those particular regulations. Again, the Salt River Project. The Salt River Project is a very unique organization. I think they're referred to as a quasi-public or quasi-municipal organization. So it has a lot of independence that say for instance city governments don't have.

In addition to the influential water management agencies, participants identified several other stakeholders as relevant to the nexus including Arizona Public Service, Arizona Corporation Commission, Arizona Power Authority, Agribusiness and Water Council of Arizona, Arizona Cattlemen's Association, Arizona Cotton Growers Association, Arizona Farm Bureau, Irrigation and Electrical Districts Association, Native American tribes, local city governments, individual irrigation and electrical districts, and farmers in general.

When discussing the agricultural interests, and farmers specifically, our participants noted that power and influence comes from direct representation in the state legislature and through collective associations with access to legislators. An irrigation district manager said, "Yes, the Arizona Cattle Growers Association has a very strong representative in the state legislature." A university professor said, "Obviously, the major ag producers of cotton and the ranchers and things like that, that have very large-scale farms, industrial-size farms, are the ones who have the voice because they have the most economic impact." A city water policy advisor highlighted the relationships between agricultural businesses and the various levels of government as key to agriculture's influence:

I would say that agricultural businesses have a lot of interest in the governance systems, whether that's through their ties to reclamation projects through their ties to energy contracts, even, that they've received a lot of preference from, and their ability to have good access to both federal, state, and local governments—all three. I would say they are major players in that nexus.

That same water policy advisor identified irrigation districts as the stakeholders especially relevant to the FEW nexus in the Phoenix AMA:

They're (irrigation districts) the ones that usually are in many cases they have contracts for energy, so they should actually get the—you know, sometimes they're actually acquiring the energy on the open market. But then most importantly, they're actually moving the water. So they have real fingers in all three of those and have very close ties to all three sort of sectors. That's the one like the bull's eye.

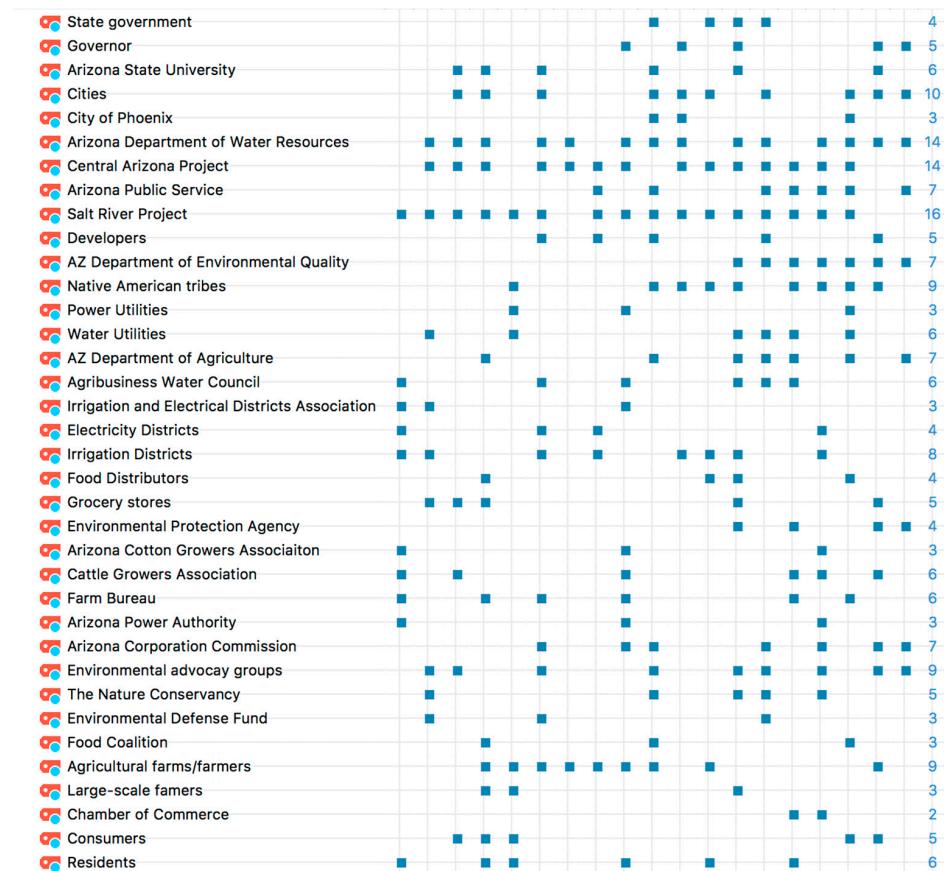


Figure 6. Chart of stakeholders that were identified in three or more interviews or focus groups. The columns indicate individual interviews or focus groups and the rows indicate the identified stakeholders. The numbers indicate the sum total of interviews and focus groups that mentioned each of the codes at least once.

4.4. Policies for the FEW Nexus

The final aims our study are to identify stakeholders' views on current policies relevant to nexus governance in the Phoenix AMA as well as their recommendations for policy reforms and new policies to promote integrated governance. Our participants discussed many laws, regulations, policies, and institutions at the national, state, regional, and local levels. Influential federal laws and policies include Endangered Species Act, Clean Water Act, National Environmental Policy Act, Farm Bill, Clean Power Plan, and Federal Land Management and Policy Act. Figure 7 provides an overview of the most identified policies and regulations that affect the FEW nexus in the Phoenix AMA.

At the state level, participants highlighted the 1980 Arizona Groundwater Management Act and specifically the Active Management Area (AMA) rules, AMA boundaries, and the irrigation grandfathered rights. An irrigation and drainage district manager said:

We have a Groundwater Management Act in the state of Arizona that very much is affecting how things operate. I think overall in a good way, because in the '60s and '70s a lot of the areas were relying on groundwater, overusing groundwater. So they put some management goals in those areas to make the groundwater supply more sustainable over a long period of time, which creates more security for water supplies for areas. So I would say it's a little bit of a loose tie to energy, but certainly for water supply.

In addition to the GMA, participants also pointed to the Central Arizona Project water subcontracting process, and the Arizona Power Authority's Hoover Dam long-term power contracting process.

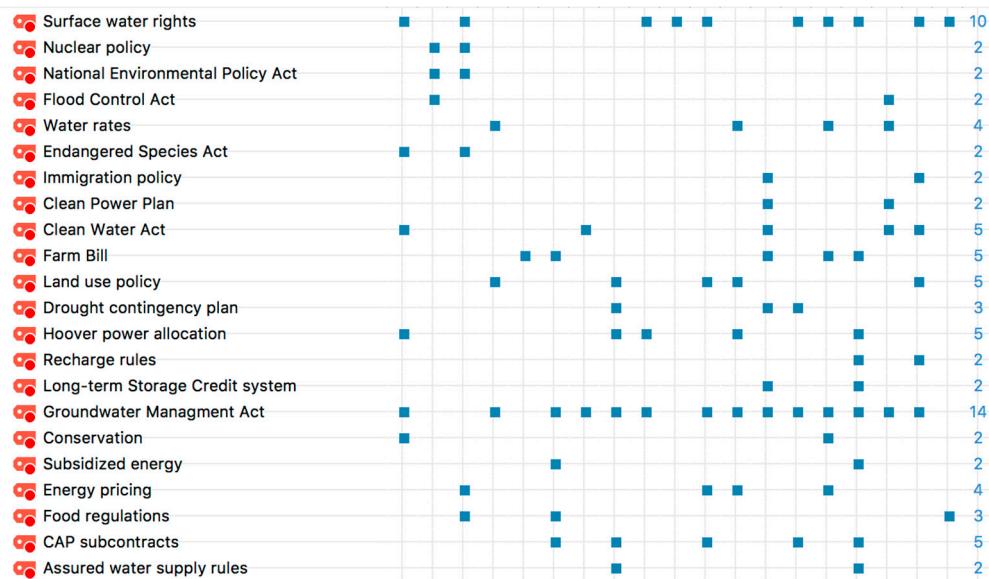


Figure 7. Chart of policies and regulations that were identified in two or more interviews or focus groups. The columns indicate individual interviews and focus groups and the rows indicate the identified policies and regulations. The numbers indicate the sum total of interviews and focus groups that mentioned each of the codes at least once.

Finally, when we asked participants about how to improve the governance system to address the nexus, several key themes emerged including awareness and education, consensus and collaboration, transparency, economic incentives, working across scales, and incremental reforms. Stressing the role of awareness and education, one of the focus group participants said, “So, somehow you’ll have to distill this down to something that a legislator can grasp or you know a city manager.” A focus group participant from the Arizona Department of Water Resources said:

I think they need to be aware that there is a nexus, first of all. That needs to be part of our everyday—the everyday conversations amongst the stakeholders as opposed to having their blinders on and saying well we just have to worry about water and where our policies are on water. We have to start our laundry list of things to do when we’re considering new approaches and new solutions. We need to consider all three of these and I don’t think that’s happening. It is between water and energy more so, I think.

The participants in our study stressed the need for collaboration and coordination across actors from the food, energy, and water sectors, and, notably they suggested that the stakeholders are increasingly engaged in such coordination. For example, an irrigation district manager discussed a stakeholder engagement process led by the Arizona Department of Water Resources that aims to improve regional planning and coordination, especially between urban water users and peri-urban and rural agricultural interests. He said:

Right now, we’re kind of in the process of actually doing that, what’s happening at the state level. Part of that is when the different user groups and stakeholders come together to understand what their needs and challenges are. In the old days, we didn’t know what the cities were doing. They didn’t know and lack of knowledge creates a fear. So when you operate out of fear and a lack of understanding, sometimes you do things that aren’t coordinated . . . There’s much more of those different user groups coming together to understand what their needs are, because agriculture can say, “Oh, you have that particular need. We can either give or shift what we’re doing to help that, if you can help us over here.” That integrated approach is being incorporated now. Now whether there’s enough of it or not, I think it’s much, much better now than it was maybe 30 or 40 years ago because there has been—there’s more of a, “We’re in this together”, attitude that is more helpful.

Stakeholders also stressed the need for transparency and openness in nexus governance and suggested a positive recent trend. A biologist working with an environmental nonprofit said:

There are still a lot of discussion that needs to go on. This is the first time in my career in this state as a wildlife biologist that I have seen the water managers more openly discuss the issues and potential solutions with the public. These have historically closed door, backroom deals. There's still a lot of that, however, there's a lot more transparency I think today than there was historically.

To achieve the reforms for integrated nexus governance, some of our participants, especially those in the farming and ranching interests, recommended economic incentives as the preferred policy instrument as opposed to regulation. A cattle ranching representative said, "So I would say for the large majority of everything there on the water and economic side, or water and food side, economics is the best way to drive policy changes rather than using the big stick of government."

Given the complexity of the governing the nexus and the far-reaching impacts of potential reforms across multiple social, economic, and environmental scales, Phoenix-area stakeholders recommended incremental reforms. A cattle ranching representative summarized it this way:

So, when we look at food energy and water nexus why can't we take small steps to make the water system more resilient? Why can't we take small steps to make energy more resilient? Same with food. It doesn't have to be overnight, but maybe the goal is really lofty but the small steps to get there is better, I think is a much better approach on the policy side rather than let's just do the lofty goal today. Let's fix is slowly over time.

Finally, with regards to nexus policy, our participants stressed the need for leadership at the state and regional level to promote coordination across multiple levels governance. While recognizing the importance of local actors, participants stressed the key role of the most powerful and influential actors. A municipal water manager summarized it this way:

Overall if you're going to look at the energy food water nexus, you have to bump it up a level. You have to bump it up to the level of state agencies, major regional wholesalers like SRP and CAP. The governor. You know. Things like that. The major regional—regional decision makers. Because it won't occur on a municipal scale.

5. Discussion

This study contributes to social science scholarship necessary to clarify and improve the relevance of food-energy-water nexus concepts for integrated nexus governance. Consistent with related research [26,27], our approach engages a diverse set of stakeholders in a collaborative setting to encourage participants to share expertise and contribute to constructive dialogue. The research provides an arena for stakeholders and scientists to come together to develop a common conceptual understanding of the linkages, interdependencies, and feedbacks in the food-energy-water nexus, within a specific geographic, social, and political context. This helps to build social capital between scientists and other stakeholders and increases the likelihood that policy concerns will inform the research as well as the relevance of research for decision making. To achieve the potential efficiencies and co-benefits promised by a nexus framing it is necessary that a broad range of stakeholders be involved and collaborate for effective multi-sector natural resource management [7]. Our research has several implications for research and integrated nexus governance.

First, scholars have consistently recommended an integrated policy approach considering all three sectors to identify and manage risk, achieve efficiencies, and enhance resilience, security, and sustainability [1,14,24,48] and our research demonstrates empirically the challenges of achieving this goal in practice. While stakeholders in the Phoenix area who are actively engaged in food, energy, and water systems governance appreciate the rationale for nexus thinking, they recognize practical limitations to implementing these concepts. The actors, organizations, and institutions involved in food, energy, and water governance each have a focus, guided by factors such as the specific function they serve

(service provision, regulation, or policy), their institutional legacies (history of legislations, court decisions, policies, and norms), and organizational cultures. While some individuals and organizations tend to focus on a single sector and view the other sectors as external inputs or constraints, others may have more overlapping functions. Through stakeholder analysis, policy researchers can help to identify specific actors and organizations that fall under these varied categorizations, including those with power and influence, such as Arizona Department of Water Resources (ADWR), Central Arizona Project (CAP) and Salt River Project (SRP), in our case where water scarcity is a central concern, or those that sit at the center of the nexus, such as irrigation districts in this study, as key nexus governance actors that may be crucial to integration. While not addressed directly in our study, this process could be used also to identify stakeholders who have been marginalized in the policy making process, thus contributing to environmental justice [25]. This is key as nexus policy may be enhanced through multi-level networked governance systems drawing upon sector-specific expertise with meta-governance achieved through strategic steering and coordination built upon multi-stakeholder collaborative processes.

Second, this study contributes to research on methods to develop shared conceptual models of interconnected complex systems, which can be useful to structure policy discourse and to inform the development of more sophisticated computer models, simulations, and decision support systems [49]. Methods for modeling and exploring interdependent systems have advanced substantially in recent years, but research is only beginning to illuminate the nature of these systems and implications for risk and management. Prior research has shown that conceptual maps, causal loop diagrams and similar tools can be effective for helping policy makers to consider a systems approach in decision-making and these conceptual models can be useful in designing more sophisticated computer models and decision support systems [50]. Complex systems models can be used within an anticipatory governance framework to explore interconnections among system components, create and evaluate scenarios, explore uncertainty, test management interventions, and evaluate the potential efficacy of various policy options [22,51]. The concept maps presented in our research provide one view of the system interconnections, derived from stakeholders, and maps can be used to complement other ways of knowing the nexus, such as physical infrastructure system diagrams or actor—networks.

Finally, our study shows that stakeholders believe nexus governance could be improved through awareness and education, consensus and collaboration, transparency, economic incentives, working across scales, and incremental reforms. We note the preference for policy instruments (regulatory versus market based) differs between stakeholders. For example, the food sector actors seem to prefer market based instruments much more than the other sectors, perhaps because of history of regulation, organizational culture, and political affiliation. Understanding such differences is a crucial step towards integrated governance. Reforms our participants suggested would seem to address several of the barriers to nexus decision-making identified by prior research [27]. It is interesting to note, however, that our participants did not suggest the need for any new significant federal or state laws or major policies, and, in several cases, recommended easing existing regulations, to allow for economic growth or future innovation. This view runs counter to the assertion by some scholars that significant, transformational changes are required to transition these interconnected socio-ecological-technical systems to more sustainable, resilient, and secure states, especially in the face of increased risks associated with climate change impacts [52]. Future research may focus more directly on the effects of increased risks, shocks, and cascading failures on stakeholders' perceptions on the need for and type of policies and reforms necessary to improve nexus governance.

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