BRIDGING PHYSICAL AND SOCIAL SCIENCES TO UNLOCK NEW POTENTIAL FOR ADDRESSING INTERCONNECTED RESOURCE CHALLENGES

A Dissertation

by

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ABSTRACT

As urbanizing cities work toward sustainable resource planning, particular attention must be given to the interdependence of interconnected resource challenges. Coherent policies, strengthened by and consistent with, the research understanding of the challenges and their interdependencies, are necessary for sustainable resource allocation. Enabling Environments must be created that allow: 1) development of interdisciplinary research, 2) cross-sectoral stakeholder cooperation in planning resource allocations, and 3) appropriate levels of engagement and exchange of information between researchers and related stakeholders. This dissertation focuses on opportunities for bringing together the knowledge accumulated in understanding and quantifying the interconnections between resource systems with theories in social science and their application.

Building on common pool resources and collective action theory, the work uses social network analysis to understand the interactions between stakeholders governing interconnected resource systems. Using convergence theory, a methodology and criteria are developed for assessing the extent to which researchers and stakeholders tend to converge on topics related to the resource challenges, thereby reducing feedback cycles and increasing information exchange and support. This is accomplished through two surveys, in the context of a model resource hotspot in San Antonio, Texas: a growing, urbanizing population with major agricultural activity, situated above the Eagle Ford shale play's growing hydraulic fracturing development.

The study's main outcomes follow. 1) *Identification of challenges faced in developing an interdisciplinary research team*, i.e. defining the study region's physical boundaries, establishing dependency relations between sub-groups, data incompatibilities, varying data access, and funding. 2) Modest *levels of communication* exist between water institutions, but very low levels of communication exist between water institutions and those responsible for food and energy decisions. Frequency of communication among officials at different water institutions was higher among those who participated in stakeholder engagement activities: significant only in the communication among water officials themselves. Main institutional barriers to higher levels of communication between cross sectoral stakeholders include finance, structure, capacity, or differences in language, interest and value systems. 3) *Aspects of convergence* were identified between the perspectives of researchers and regional stakeholders on issues of water, energy, and food in the San Antonio Region. Similar aspects of convergence were found in the perspectives of both groups regarding the Texas Water Development Board strategies with the greatest or least potential. Both groups converged on water as a first priority, but not on their perspective of the direction of future regional priorities: they differed in their rankings of energy and food (second and third priorities). The study also indicated convergence regarding potential roles of "increased communication" and "information sharing between agencies" as a means to improve cooperation and address interconnected resource challenges. To realize these potentials, institutional mechanisms and finances for such activities should be revisited: addressing communication barriers is critical to developing cooperative stakeholder environments that allow long-term planning for resource allocation that avoids potentially unintended consequences.

In an effort to work towards the globally agreed upon water, energy, and food Sustainable Development Goals (SDGs) within urbanizing cities, and at different scales, we need to develop research that better understands and quantifies the interconnections between the goals, and to develop coherent, consistent policies strengthened by the research understanding of the challenges and their interdependencies. This could be accomplished by creating the necessary environments to allow development of the necessary research, cross-sectoral cooperation in planning for the future of resource allocation, and appropriate levels of engagement and exchange of information between researchers and related stakeholders. While the 2030 Agenda is global, localization of its goals, indicators, critical questions, solutions, and involved stakeholders must be contextualized. This is essential to the potential success of any plan, at any scale, to achieve the goals.

This dissertation offers lessons learned from a case study of the resource hotspot of San Antonio, Texas in the US. The overall approach, methodologies, and lessons learned from this study could be customized and contextualized to better understand and address other resource stressed regions globally.

DEDICATION

I dedicate this dissertation to

the 844 million humans who still lack access to safe drinking water,

the 815 million humans who still lack access to food, and

the 1.1 billion humans who still lack access to energy…

…and to

each human making a contribution to push the needle towards a world that is more

equitable,

sustainable,

and resource secure

for all.

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CONTRIBUTORS AND FUNDING SOURCES

This work was supervised by a dissertation committee led by Professor Rabi H. Mohtar of the Department of Biological and Agricultural Engineering and Zachry Department of Civil Engineering at Texas A&M. The committee included Professor Kent E. Portney, Director of the Institute for Science, Technology and Public Policy of the Bush School of Government and Public Service, Texas A&M University; Professor Efstratios N. Pistikopoulos, Director of the Texas A&M Energy Institute, of the Artie McFerrin Department of Chemical Engineering; and Professor Ronald Kaiser of the Department of Recreation, Park, and Tourism Sciences at Texas A&M.

Chapter 2 was coauthored with all committee members and published in *sustainability* in February 2018. Chapter 3, co-authored with Professors Mohtar and Portney, and Dr. Hannibal, was published in *Science of the Total Environment* in February 2019. Chapter 4, also co-authored with Professors Mohtar and Portney, and Dr. Hannibal, is currently undergoing peer-review. The social network analysis in chapters 3 and 4 was conducted with the support of Dr. Bryce Hannibal, of the Bush School of Government and Public Service.

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NOMENCLATURE

NGO	Non-Governmental Organization
NPO	Non-Profit Organization
R	Researchers
RS	Regional Stakeholders
STEP	Socio-Techno-Economic-Political
WC	frequency of communication between water and cross-cutting organizations
WE	frequency of communication between water and energy organizations
WEF	Water, Energy, and Food
WEFNI	Water-Energy-Food Nexus Initiative
WF	frequency of communication between water and food organizations
WW	frequency of communication between water and other water organizations
SDGs	Sustainable Development Goals

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1. INTRODUCTION

With projections for global populations to reach 8.6 billion in 2030 (United Nations, 2017), alarms of exceeding an additional 1.5^{o}C warming globally (IPCC, 2018) and its implications on resource securities, accompanied by projected demand for water (+55%), energy (+80%), and food (+60%) by 2050 (IRENA, 2015), resource systems face considerable stresses which threaten their sustainability. These projections come at a time when 844 million people lack access to safe drinking water (WHO, 2017); 1.1 billion lack access to energy (50% of whom are on the continent of Africa) (IEA, 2017); and about 815 million lack secure access to food (FAO, 2017; Stephan et al, 2018). The challenges of meeting increasing water, energy, and food needs are linked not only to growing demands globally, but also to the growing interdependencies between the interconnected resource systems. Pressures on these systems emerge to become hotspots, each with distinct characteristics that require a fresh look at the challenges that arise from within each resource system individually, and at their respective interfaces. Solutions to address resource hotspots must be multi-faceted, acknowledge the multiple dimensions of the biophysical water, energy, and food systems, and include the stakeholders connected with each of them.

In 2015, representatives of 193 United Nations member states announced their commitment to align policies towards a list of 17 Sustainable Development Goals (United Nations, 2015). The Goals constitute an ambitious agenda that carry quantifiable targets to be achieved by 2030 (Figure 1.1). These include a vast array of goals ranging from alleviating extreme poverty, improving water access and sanitation, improving access to reliable and affordable clean energy, achieving food security and sustainable agriculture, among others. We find ourselves at a unique point in history, with a global political commitment and momentum to work towards addressing these challenges. However, achieving those goals requires the participation of diverse groups of actors and decision makers, at multiple scales, including researchers, and stakeholders working in areas which affect theses interconnected resource systems, in order to arrive sustainably to year 2030. **An enabling *environment* which allows for developing research, and appropriate planning and decision making mechanisms, that are consistent with our understanding of the complexity and interconnectedness of the challenges at hand, will be essential to the successful achievement of these goals.**

Figure 1.1 United Nations Sustainable Development Goals (United Nations, 2015)

This dissertation builds upon the existing literature of the water-energy-food nexus accrued since 2011 (Bonn Conference, World Economic Forum; 2011), and focuses on the opportunities for bringing together the knowledge accumulated in understanding and quantifying the interconnections between resource systems with theories in social science and their application. The goal of this work is to provide a more complete picture of the multi-faceted challenges facing us, and the existing potential opportunities, as we plan for a future that achieves sustainable resource use and allocation.

The dissertation identifies three areas, or '*environments*' of focus, that could especially benefit from improved understanding of resource interconnections and the diverse set of stakeholders and decision makers connected with them (Figure 1.2). **Focus area one** is linked to research environments and mechanisms that allow the development of interdisciplinary research to advance our knowledge and preparedness to address the resource challenges. **Focus area two** is the environment of cooperation between the various stakeholders in the water, energy, food, and other interconnected domains: it explores ways in which to allow cooperation to occur and to address the barriers that hinder it. The **third area focuses** on the way in which the research environment and the stakeholder environment are evolving, with their understanding of issues related to interconnected resource challenges, and the level of convergence between their respective perspectives. **The dissertation is founded in the understanding that addressing the challenges that face each of these three focus areas will contribute to enabling the development of relevant and necessary interdisciplinary research that addresses the**

trends facing interconnected resource systems, and then operationalizes the solutions that arise therefrom.

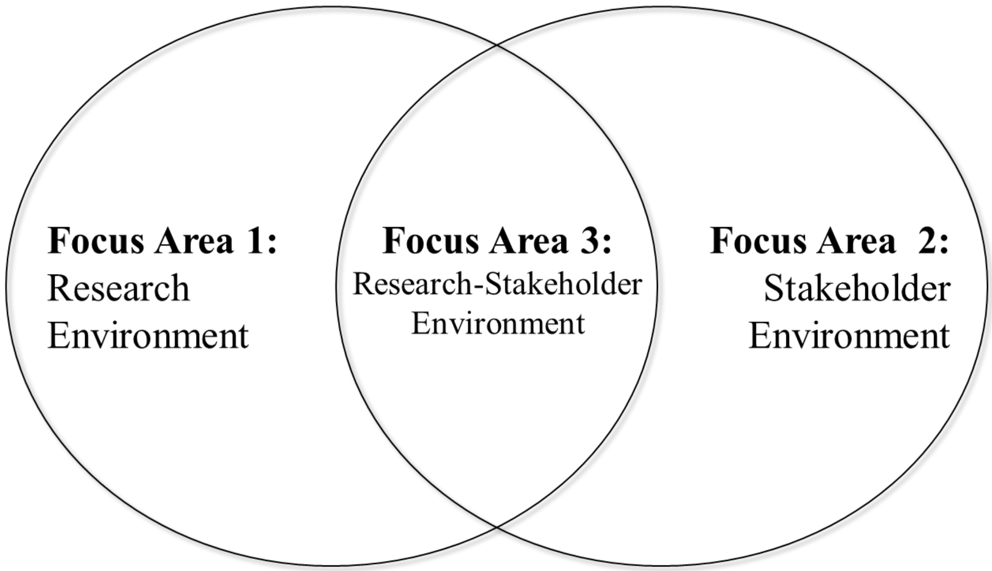

Figure 1.2 Dissertation focus areas (Source: Author)

The following three chapters specifically address the following **overarching objectives**:

1- Explore critical questions at the interfaces of interconnected resource systems and propose a mechanism to facilitate *interdisciplinary research* that builds on both the social and the physical sciences to enhance the development of multifaceted solutions, capable of addressing the complexity of current and future resource challenges.

2- Build on *common pool resources* and *collective action theory* to understand the interactions between managing common resource pools and ways to understand institutional barriers that lead to low levels of communication and coordination between stakeholders who govern these interconnected resource systems.

3- Use *convergence theory* to develop a methodology and criteria for assessing the extent to which researchers and stakeholders tend to converge on topics related to the interconnected resource challenges, thereby reducing the feedback cycle and increasing the exchange of information and relevant support.

Chapter 1 outlines the dissertation and introduces the contents of each of its subsequent chapters, which present three distinct, yet complimentary, articles that address different aspects of physical and social sciences as these are used to better understand interconnected resource hotspots.

Chapter 2 explores the multiple dimensions of water, energy, and food systems as these relate to government, business, and society. It then identifies contemporary critical questions at the interface of these stressed resource systems. A 3-filter framework is introduced for vetting the feasibility of proposed resource allocation scenarios, to account for bio-physical resource interactions and trade-offs, stakeholder interactions and trade-offs, and to address governance and financing schemes for the implementation of those scenarios. (Daher et al., 2018). To improve our ability to understand and address complex resource challenges, we must improve the compatibility of existing tools for addressing different aspects of resource interfaces. There is also a need for better quantification of the interactions between stakeholders and for identifying solutions consistent with the stakeholder landscapes. Given that stakeholders and resource systems interact across scales, solutions must be implemented through policies that are also coherent across scales. There is no "one size fits all" tool for assessing physical resource interactions, stakeholder interactions, and policy and governance challenges: quantification and assessments must be localized and contextualized. Feasible, implementable, sustainable solutions require truly inclusive and transdisciplinary conceptualization, quantification, and assessment of current and projected resource hotspots. The 3-Filter STEP framework proposed in this chapter offers guidance in accounting for the different elements that need to be accounted for while assessing and promoting a nexus solution.

Chapter 3 introduces the case of the San Antonio (Texas, USA) Region. This region is home to a rapidly growing population with developing energy and agricultural sectors that compete for water, land, and financial resources. Despite the tight interconnectedness between water, energy, and food challenges, little is known about the levels of communication and coordination among the various officials responsible for making the decisions that affect the management and planning of the three resource systems. It has been postulated that efficient communication is a prerequisite to developing resource allocation strategies that avoid potentially unintended, negative consequences that may result from inefficient allocation of natural resources and competing demands. Factors that could impact communication are identified and their potential roles are considered in improving existing levels of communication between San Antonio's water officials and those at other energy, food, and water institutions in the Region. A questionnaire, designed to gather information on stakeholder concerns, frequency of communication, and participation in engagement forums, was sent to public water officials in the Region. Chapter 3 focuses on this regional water-energy-food hotspot: developing an understanding of the physical resource competition that results from its growing municipal, agricultural, and energy sectors. It then tests hypotheses related to 1) current levels of communication between decision makers within the water, energy, and food domains; 2) impact of water officials' perception of future water challenges; 3) participation of these decision makers and officials in stakeholder forums that are related to resource planning; and 4) impact of the scale at which they govern, upon that level of communication (Daher et al., 2019).

Chapter 4 explores the degree of convergence of perspectives between the researchers and the stakeholders in the San Antonio Region with regard to various aspects of water, energy, and food security (Daher et al, in review). The past decade witnessed growth in research on interconnected resource challenges, and primarily focused on quantifying the physical resource interconnections, and more recently, also including the social, economic, and policy dimensions of these interconnections. Despite the move towards inter- and trans-disciplinary research that has fostered increased collaboration between research groups in same or similar areas of study, little work was done regarding the convergence of perspectives between those research groups and their respective stakeholders, particularly on issues related to resource challenges.

A questionnaire was sent to 370 researchers and other regional stakeholders who represent governmental, non-governmental, and business organizations working in the water, energy, or food sectors in the Region. The intent of the exercise was to better understand the level of convergence between the perspectives of both groups with regard to various resource related issues in the Region. Seventy-one responses were received: 31 from researchers, and 40 from other regional stakeholders. Chapter four 1) evaluates the *level of convergence* between perspectives of researchers and regional stakeholders regarding the region's water, energy, and food challenges. It then 2) quantifies the existing *level of communication* of both individual groups of respondents (researchers and regional stakeholders) with identified WEF organizations in the region; and 3) identifies *barriers to and opportunities for improving communication* among WEF organizations and with the researchers involved.

Chapter 5 presents the overall conclusions and lessons learned, including discussions of suggested areas of research for moving forward.

2. DEVELOPING SOCIO-TECHNO-ECONOMIC-POLITICAL (STEP) SOLUTIONS FOR ADDRESSING RESOURCE NEXUS HOTSPOTS[1]

2.1. Introduction

We live in a world of non-uniform resource distribution and uneven resource demands. This results globally, in the emergence of resource nexus hotspots each with distinct characteristics and gap projections. A "resource nexus hotspot", or more specifically, a "water-energy-food (WEF) nexus hotspot" could be considered as "a vulnerable sector or region at a defined scale, facing stresses in one or more of its resource systems due to resource allocation at odds with the interconnected nature of food, energy, and water resources" (Mohtar and Daher, 2016). Given the tight interconnectedness between water, energy, and food resource systems, the proposed solutions and interventions for addressing these hotspots need to be holistic. Whether policy, technological, or social interventions are considered, these need to be localized and contextualized. In addition to the diversity of resource constraints and interlinkages across cases, the nature of stakeholders, the difference in their goals, value systems, decision making power, and the way in which they interact, changes from one hotspot to another. Furthermore, the implementation of proposed interventions, and the success of that implementation, are subject to their modes of governance and their interactions at multiple

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[1] Reprinted with permission from "Developing Socio-Techno-Economic-Political (STEP) Solutions for Addressing Resource Nexus Hotspots" by Bassel Daher, Rabi H. Mohtar, Efstratios N. Pistikopoulos, Kent E. Portney, Ronald Kaiser, and Walid Saad, 2018.Sustainability, 10(2), 512. Copyright 2018 by mdpi.

scales. In order to properly assess and evaluate alternatives and possible interventions that may reduce pressures in a particular hotspot, we need to also ensure the feasibility of those scenarios within the boundaries and interactions of the physical resource system constraints, and their compatibility and suitability with involved stakeholders and governance systems. The growing body of literature related to WEF nexus research (The Water, Energy, and Food Security Resources Platform, 2018) has evolved since 2011, in Bonn (Bonn Conference, 2011) and the World Economic Forum (2011), up until today, where we see resource interconnectedness and trade-offs present in many global discussions, including in the agendas of climate change and sustainable development goals.

Different conceptualizations and approaches have transpired as part of this growing movement of holistic water-energy-food resource systems thinking. Examples include some that are focused on modeling water, energy and food systems (Bazilian et al., 2011; Daher and Mohtar, 2015; WEF Nexus Research Group, 2018), others that have an additional focus on climate and land use systems (Howells and Rogner, 2014; Howells et al., 2013), and multi-scale analysis of socio-ecological systems (Giampietro et al., 2015). These are in addition to the adoption of a water-energy-food nexus approach to addressing food security and sustainable agriculture challenges by the Food and Agriculture Organization of the United Nations (FAO, 2014), the World Bank's (2017) water-energy nexus modeling for energy planning, the water, food, energy, and ecosystems approach of the Global Water Partnership (GWP, 2017) and United Nations Economic Commission for Europe (UNECE, 2015), as well as the United Nation University's water-soil-waste nexus framework (Avellán et al., 2017). Furthermore, there is a common push toward developing and evolving these models by focusing on resource efficiency, as well as resource productivity (Yu et al., 2017; Mohtar, 2017; Rasul and Sharma, 2015).

In light of the current, growing WEF nexus research activity on several thematic and geographic fronts, this chapter highlights the multidimensionality of resource systems and the multifaceted nature of stakeholders; it outlines ways in which these multidimensional players and resource systems interact across scales. The resulting challenges for governance and policy coherence are elaborated and discussed. This paper will specifically: (1) explore the multiple dimensions of water, energy, and food systems, as these relate to government, business, and society; (2) identify contemporary critical questions and interlinkages across resource systems; (3) present a 3-Filter framework for vetting the feasibility of proposed resource allocation scenarios, through accounting for physical resource interactions and trade-offs, stakeholder interactions and trade-offs, and addressing governance and financing schemes for carrying forward the implementation of those scenarios.

2.2. Resource Systems: Not Just Interconnected, but Also Multidimensional

Drawing from systems theory, which describes a system as an organized entity (natural or manmade), made up of interrelated and interdependent parts, this chapter describes water, energy, and food as a system of interconnected resource systems.

2.2.1. Water Coordinates: From W (m3) to W (m3, X:Y, Time, Source, Quality)

Discussions of projected water gaps across different regions are common in the literature. These projected water gaps often illustrate the difference between projections of water supply and demand. Addressing such gaps usually focuses primarily on identifying new alternative sources of water to boost supply, while also reducing demand within different water consuming sectors. While the availability of specific volumes of water (m3) is a critical determinant to our ability to produce food, cool energy-generating power plants, and provide water to our cities, it is not the only dimension to be considered (Figure 2.1): there is also a spatial dimension to water. The physical location of water is important: how far is it from its final use; is the future availability of one body of water more vulnerable to future climatic changes because of its location; is the same body of water subject to quality threats due to potential industrial leaks or intensified agricultural activity upstream; and, is it subject to future scarcity threats due to increased water demanded for economic activity upstream? There is a temporal dimension to water. Water availability varies with the time of the year: planning its allocation varies with the seasons. Climate change has an effect on rainfall patterns, causing intensification of rain events in shorter periods of time. Different sources and types of water come with different energy and carbon footprints. Is the water present at the surface, or part of a ground water aquifer? How much energy is required to treat, desalinate, pump or convey a needed amount of water to its final use? What is the impact on neighboring ecosystems? There are different qualities of water, which determine its suitability for different end uses: for example, water of certain levels of salinity might be suitable for salt resistant crops; urban waste water could be treated and allocated for different uses, including agriculture, landscaping, and others. Thus, allocating water (m3) by considering only demand and supply of its volumes, misses the bigger picture and the larger implications on the resource systems connected to water. This allocation model unravels once we also consider water in relation to those additional “coordinates”, W (m3, X:Y, Time, Source, Quality). The decisions made for the amount, time, location, source, and quality will, in turn, dictate the energy and carbon footprints, and the cost. Similarly, energy and food have multiple dimensions.

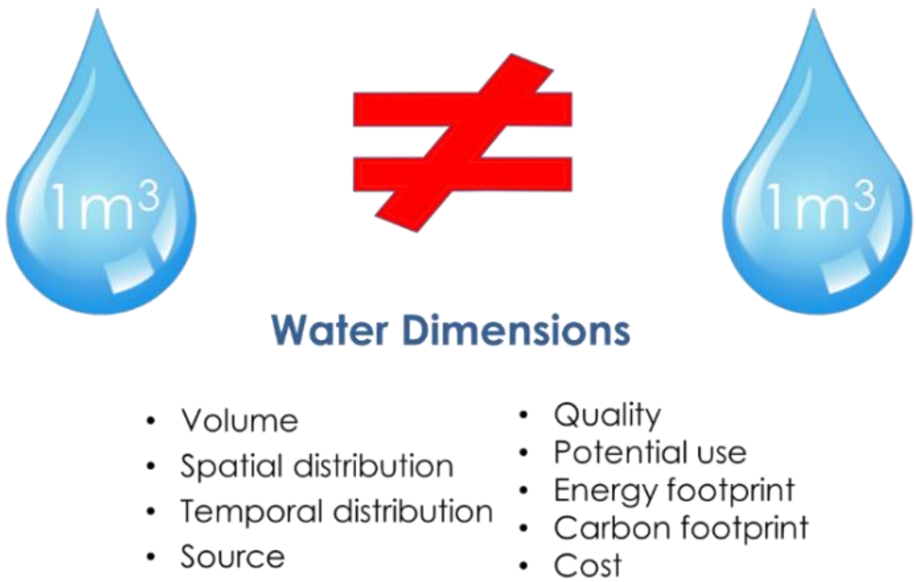

Figure 2.1 The multiple dimensions of water (Daher et. al, 2018)

2.2.2. Food Coordinates: From F (Ton) to F (Tons, Source, X:Y, Time, Kcal)

Meeting municipal or energy demands from agriculture (tons) dictates what types, and in what amounts, specific crops need to be grown or imported. The nature of the diet and the standard of economic well-being of a given nation or community plays a role in shaping these demands. For example, a nation or region with a growing middle class is likely to experience increasing demand for meat-based diets. It also is a function of energy policies, which might offer incentives or disincentives for using biofuels for energy generation. The source and way in which crops and food products are grown are a function of available technologies and farmers' capacities. The resources required for traditional open agriculture, green house agriculture, aquaponics, or hydroponics, all differ. The type of irrigation technology and fertilizer additive required to produce a given food product impacts energy consumption, carbon emission, and total production costs. Growing food also has a spatial component (X:Y): food production depends on climate, soil quality and suitability, water availability, and other factors. It depends on proximity and access to markets and consumers. There is also a temporal dimension (X:Y) to food production: what time of the year (season) is best for certain crops; what specific crop rotations ensure the long-term soil health and future productivity; what are the more favorable seasons to grow given products in a way that lowers the requirements for water, fertilizer, and energy? Further, the dietary and nutritional requirements of the growing population impact the type of food products necessary for inclusion in the local food basket (Figure 2.2).

2.2.3. Energy Coordinates: From E (kWh) to E (kWh, Source, X:Y, Time)

Energy (Kwh) is a critical input across different economic sectors: it is required for food production, treatment and conveyance of water, transportation, and powering cities, among others. The choice of an energy portfolio is dependent on locally available energy sources (conventional, non-conventional) and access to energy markets, each of which results in different impacts on water demands and quality, cost, emissions, etc. Energy has a strong spatial component (X:Y). A decision to invest in solar or wind energy, for example, is highly dependent on the suitability and potential yield of these energy sources in a given land area. A major and persistent challenge facing the energy system, particularly with regard to non-conventional sources, is energy storage. The mismatch between peak demand and peak production of some sources, solar for example, points to the risks in relying solely on such energy sources to meet demand (time).

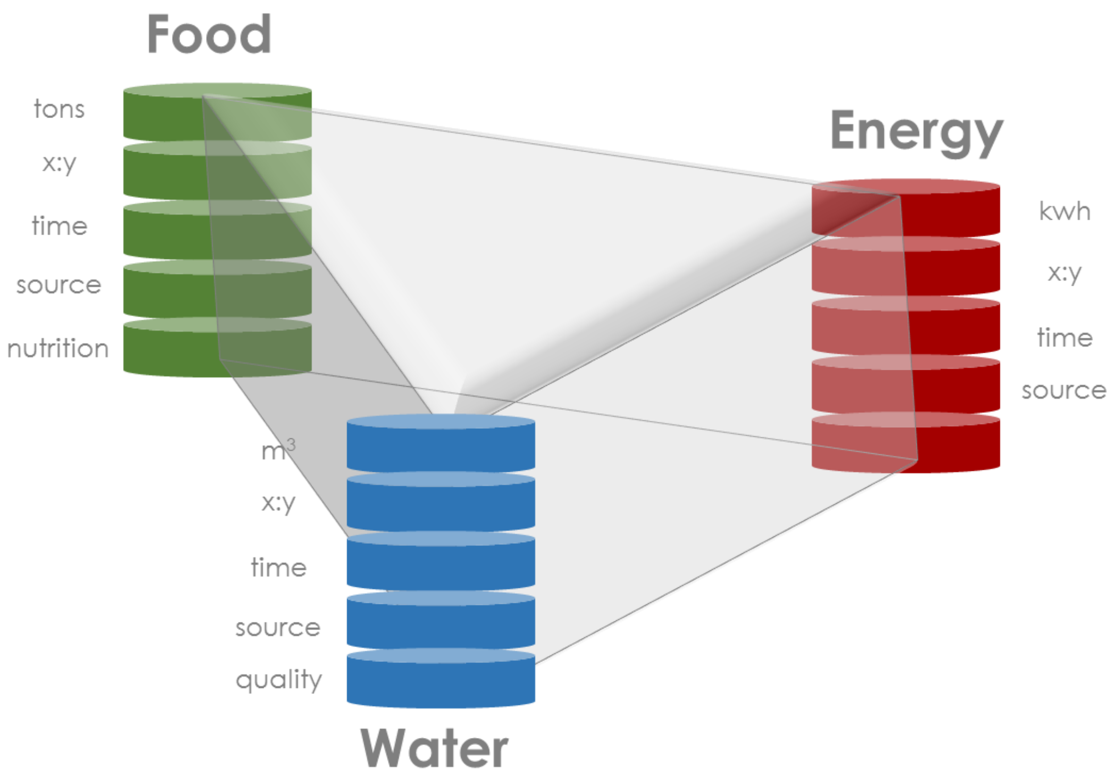

Figure 2.2 Resource systems and their interactions are multidimensional (Daher et. al, 2018)

A ton of rainfed wheat harvested and processed using diesel powered power plants is different from a ton of wheat grown in a drier region that relies on irrigation from ground water aquifers dependent on solar powered technologies through its production supply chain. This is one of many examples of how producing the same quantity of wheat might exert very different stresses on the interconnected resource systems. Similarly, a kWh of energy produced from natural gas, using a steam generator with a cooling technology that depends on neighboring surface water, differs from a kWh of energy produced by concentrated solar power (CSP), with a cooling tower that depends on groundwater. It is also worth noting the important role of trade and cooperation in alleviating the stresses facing these interconnected resource systems. These could be in the form of food imports and exports, virtual water trade through importing and exporting the water embedded in products, energy trade, technology and knowledge transfer. Diversifying an energy portfolio could consist of exploring different energy sources within a given country, for example, but it should also extend beyond that to assess the risks associated with producing that energy nationally, as opposed to importing it. The case with food production is similar.

2.3. Critical Questions and Interlinkages

Global population will continue to increase for the foreseeable future. The middle class is rapidly growing, especially in developing regions of the world. Global threats, including climate change, the increasing vulnerability of global financial systems, inequity of resource distribution, and growing resource scarcity, among others, make the assessment of resource allocation alternatives at different scales ever more critical. Asking the right critical questions at the interface of these stressed resource systems and accounting for their multi-dimensionality becomes instrumental in effectively addressing the allocation challenges as we move forward.

Figure 2.3 illustrates the critical questions schematically. These questions are aimed at the main interlinkages and interfaces across the different resource systems.

Municipalities and urban settings are areas within which most of our population growth is concentrated. This makes these areas a source of increased pressures on resources, yet with a potential to contribute towards reducing them as well. For this reason, questions relating to the interaction between the water, energy, and food resource systems within these areas have been included. Our ability to model these questions, while holistically accounting for the influences and trade-offs associated with decisions made within various sectors, is a precursor to identifying synergistic interventions that reduce the extent of their interdependencies. Stresses resulting from the availability and quality of water are affected by decisions made within the different systems: what crops to grow and when; what choices of energy should constitute an energy portfolio; how are urban areas projected to expand?

Given the various dimensions of water, the main question becomes one that explores water allocation scenarios to reduce competition between resource systems and reduce stress within the water system itself, while ensuring that environmental flows and quality limits are not exceeded. Similarly, demand for energy is driven by decisions and projections made within water, agricultural, and urban centers. The choice of different energy portfolios directly impacts requirements for water, land, and financial resources, as well as carbon emissions. Decisions made within those same resource systems could have a role in releasing stresses facing the energy system through the use of water to generate hydropower, biomass to produce energy, and utilization of urban areas to harness solar energy at the household level.

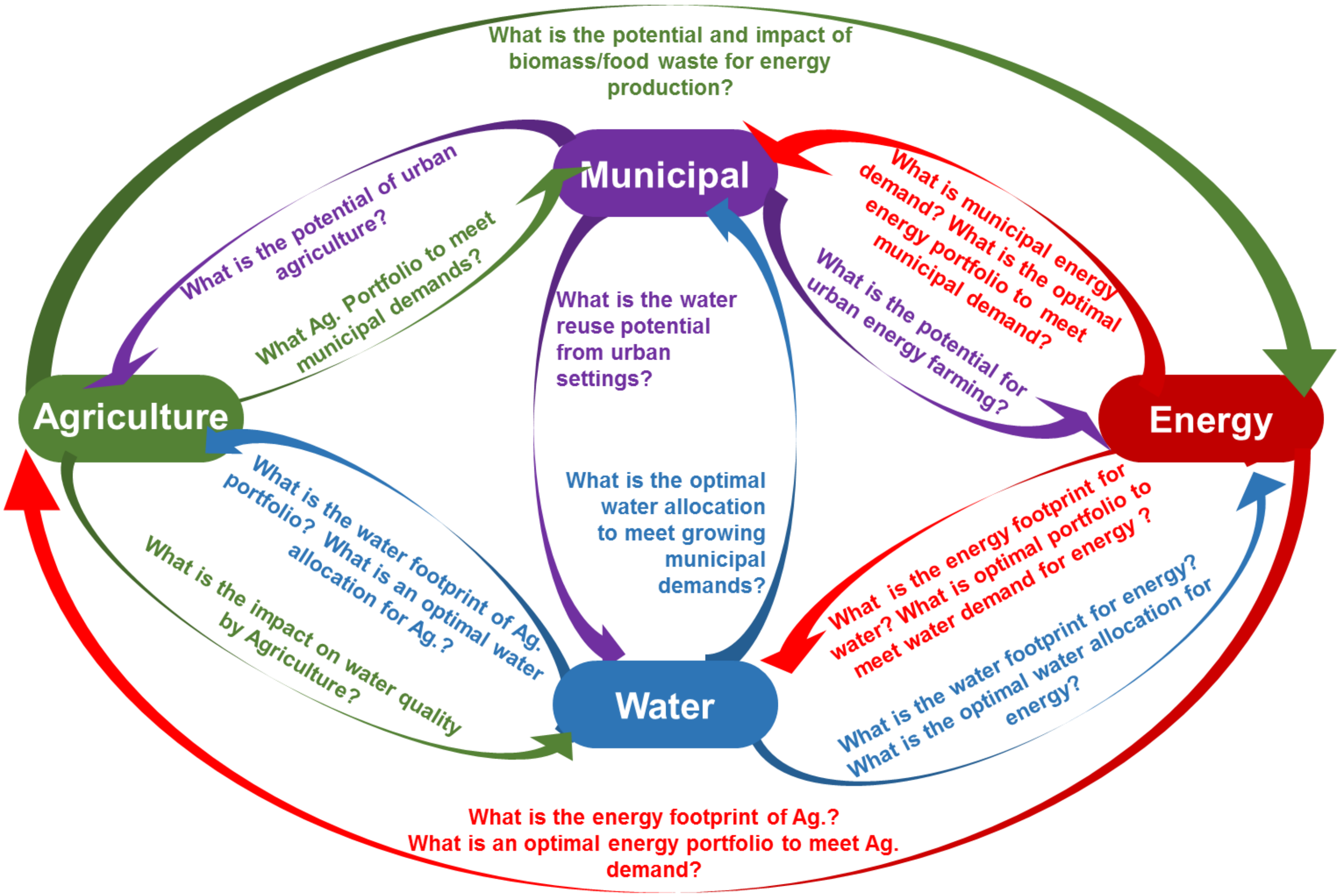

Figure 2.3 Overarching critical questions across resource systems (Daher et. al, 2018)

A holistic assessment and quantification of these energy portfolios will contribute to identifying the trade-offs between the alternative pathways moving forward. There is also a need to assess different scenarios for agriculture and food production (water, energy, land, emissions, and financial needs) in light of the different variables and responses to the demands of a growing population. In addition to viewing and modeling urban areas as “resource sinks”, the potential for growing cities to become larger resource producers could play a role in alleviating pressures on resource systems. Related questions need to be captured to effectively model the impact of specific interventions, future scenarios, and the impacts of these on this system of systems: what is the water reuse potential from urban settings; what is the potential of harvesting solar energy from rooftops and how much would it cost and who will pay for it? What infrastructure would be needed? What is the potential of urban agriculture; could it reduce some of the stresses that face the agricultural system? How might urban agricultural centers increase the resilience and food security of city residents? Is current city infrastructure able to support it?

More integrative modeling of these interconnections is needed to assess and evaluate future interventions and scenarios: it is necessary to capitalize on existing tools and to modify and develop others where needed. Several tools are available in the literature that explore aspects of these questions. For example, the Catchment Water Allocation Tool by IWMI (2017) allows assessment of different interventions that support integrated irrigation and aquaculture in watersheds. Similarly, SEI’s (2014) water evaluation and planning system (WEAP) supports the allocation of water between agricultural, municipal, and environmental use. Both LEAP (long range alternatives planning system) (SEI, 2013) and WEAP analyze the interactions between water and energy uses. CROPWAT by FAO (2017) assists in calculating water requirements and irrigation needs for crops based on soil climate and crop data. Many other tools exist that could be used to answer some of the questions addressed above including, CLEWS (KTH, 2013), MuSIASEM (Giampietro et al., 2013), and the WEF Nexus Tool (Daher and Mohtar, 2015; WEF Nexus Tool, 2018). More tools can be found in FAO (2014) and IRENA (2015). However, moving forward, one of the main challenges of such tools within an integrative platform is the incompatibility of inputs and outputs, the differing scales, and establishing uniformity in assessment criteria across tools.

2.4. Players Are Interconnected and Multi-Dimensional

In addition to the complexity of the multidimensional physical resource interconnections, one must also deal with the reality that these common resources are consumed, regulated, and impacted by different stakeholders and decision makers (Figure 2.4). The concept of "tragedy of the commons" was first introduced by Hardin (1968), who described the "commons" as any shared and unregulated resource. According to the "collective action problem", people acting independently will result in a worse outcome than if they coordinate. Individuals will work towards maximizing their own utility, making everyone, including themselves, worse off compared to when they act cooperatively (Hardin, 1971). Ostrom (1990), one of Hardin's critics argued that humans are more complex than he assumed and that resources can be managed through local contextualized governance solutions to local problems within local communities, thus avoiding the "tragedy" (Ostrom et al., 1999). Her studies showed examples of how local communities successfully managed common resource pools, including forests and fisheries. Further research in recent years focused on the importance of understanding the interactions between natural and human systems [Kurian et al., 2017; Lubell, 2013; Lubell et al., 2012;2010; Scott et al., 2015). Ostrom (2009) introduced a multi-tier framework for analyzing interactions among linked social-ecological systems. Madrid et al. (2013) applied concepts to the social-ecological system to develop a multi-scale integrated assessment of interactions between ecosystems and societal “metabolisms”.

This chapter builds on a wide body of literature that focuses on the interactions between government, business, and society; and it categorizes these players into three types, accordingly (Lussier and Sherma, 2013; Steiner and Steiner, 2012; Doppelt, 2010; Dentchev et al., 2015; Aßländer and Curbach, 2017; Dahan et al., 2014). The chapter highlights the way in which a better understanding of those interactions can be useful in the context of addressing resource hotspots. The following section explores those dynamics. We acknowledge that this representation is a simplification of complex categories of players and interactions which this chapter will not expand on.

The three types of players are driven by different goals as they interact with each other. “Society”, includes among others, the general public, NGOs, youth organizations, academia, families, religious groups, individuals, unions, and online communities. Players within “society” make decisions regarding the consumer products they utilize, and where they come from. In democratic societies, individual members of this group have the right to vote and to protest against what they perceive to be unjust or inequitable laws and regulations, which may also occur informally in others.

“Businesses” are profit or ‘value’ generating bodies that respond to society’s demands for goods and services. Businesses are also entities that provide employment in society: an intimate demand-supply relation exists between the two. Different types of businesses exist across sectors: the ability to make a change, whether through improving technological efficiencies in the supply chain or through their role in social/corporate responsibility, directly impacts the different resource systems and their future allocations. Businesses have an increasing stake in being better stewards of resources, perhaps water, which is a result of encountered disruptions due to water supply challenges (Newborne and Dalton, 2016). “Government” is a series of constructs and processes that make laws and regulations, represented (in democratic societies) by legislative, judicial, and executive branches. Depending on the scale considered, government includes ministries, river water authorities, ground water districts, local governments, and city councils, among others. The way in which water, energy, and food are governed may vary at different scales, from centralized to decentralized or other, hybrid, forms of governance. Players within “government” interface and interact with players from “business”. Public-private partnerships are increasingly popular for financing long term infrastructural projects, such as support for particular research aimed at improving a technology in which the private sector provides financial support and the government sector provides facilities (such as National Labs in the USA). Government players, at a specific scale, have the ability to incentivize the use of specific technologies, thereby impacting the “promoted” businesses.

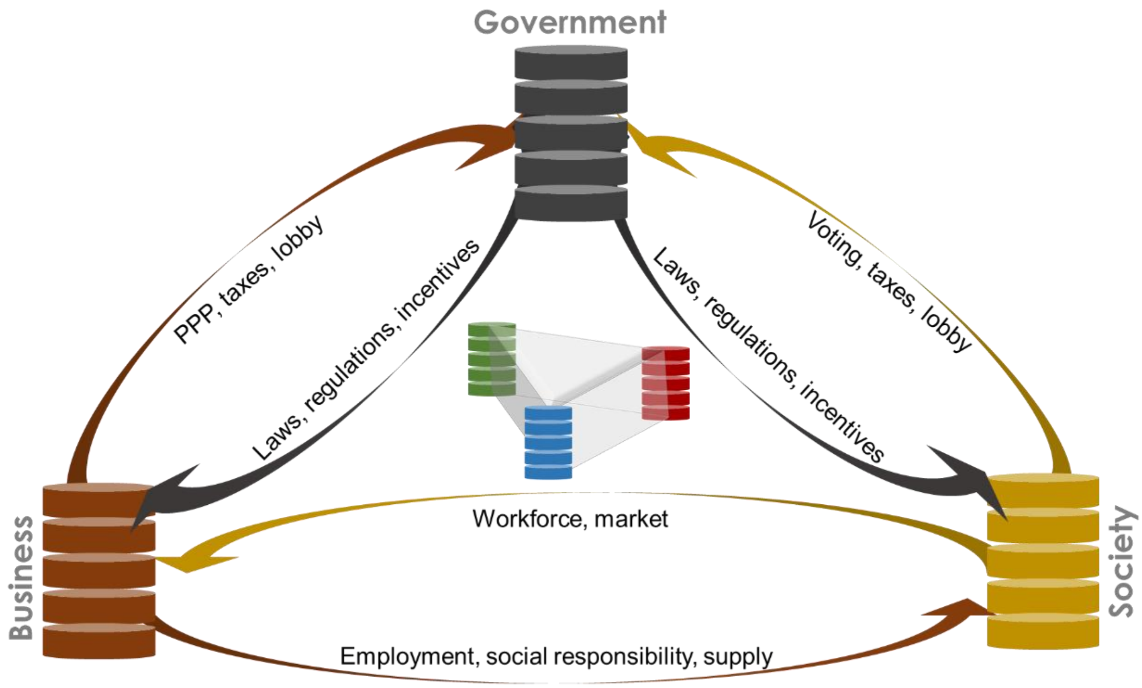

Figure 2.4 Multidimensional resource systems and players and their interconnections (Daher et. al, 2018)

They interact with and are dependent upon one another. Further, government investment in infrastructure that facilitates transportation is good for businesses: it facilitates supply chains. Governmental players also have a role in incentivizing specific consumption behaviors within society and for businesses, which may be effected through subsidies. Government players, especially those in elected positions, want to ensure they maintain public support to remain in power, which also factors into their decisions.

2.5. Resource Systems and Players Differ and Interact within and across Scales

Government, business, and societal players across the water, energy, and food systems have differing goals, value systems, and decision-making powers, at differing scales. Decisions made by one within a specific resource system and at a specific scale, could have implications for another within a different resource system or scale. Such interactions are potentially complex, for example, a decision made to subsidize electricity or the installation of solar pumping stations for farmers at the national scale, might incentivize those farmers to pump more water in order to increase their food production. While this would create positive economic impact for farmers, and a carbon benefit when compared to diesel pumping, it might also result in increased risk of groundwater depletion or degradation at the municipal scale (Figure 2.5).

Another challenge is policy incoherence across scales: while those same farmers receive electricity subsidies from the federal government to encourage increased production, they might also be faced by groundwater laws at the basin scale that limit water pumping. In light of our growing understanding and knowledge of the extent to which physical resource systems are interconnected, there is a need for a better understanding of how decisions and players interact and share risks (Gallagher et al., 2016) across scales: this points to the need for better identification of synergies between different decisions, and for avoiding the potential competition that might result from incoherent policies. Policies created to incentivize a specific action at a specific scale could conflict or compete with other actions at different scales. Specifically, there is a need for developing mechanisms for quantifying policy coherence through quantifying the impact of proposed policies across different sectors, within the same scale, and across scales. There is also a need to identify the compatibility of "current institutional setup" and "cross-sectoral interaction" with the nature of physical resource systems and their interconnections.

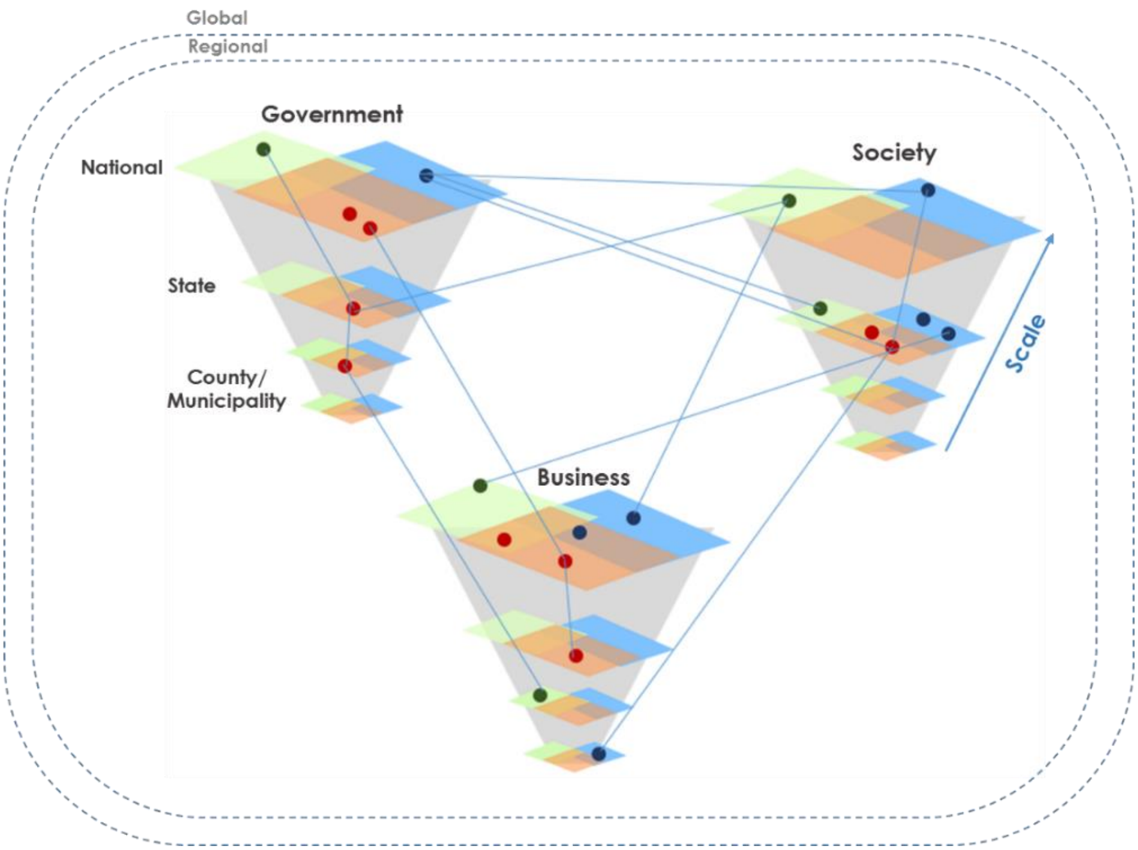

Figure 2.5 Interaction between different players across scales (Daher et. al, 2018)

2.6. An Iterative 3-Filter STEP Framework for Vetting WEF Nexus Scenarios

There are risks associated with planning and managing resource systems within silos. Solutions for such complex, interconnected, and uncertain problems cannot be only technical; they cannot account only for physical resource constraints, or offer only socio-economic, technological, political, or financial interventions. Proposed scenarios must be multi-faceted, and represent a complete package including an understanding of the resource systems, their interactions, and the biophysical and economic trade-offs between different projected pathways forward. Scenarios must be vetted with consideration of the nature of different stakeholders, their interactions, and the trade-offs that become apparent during dialogue, in negotiation, and through conflict. Once the bio-physical resource and stakeholder landscapes are understood, several potentially feasible scenarios are likely to emerge: these need proper governance structures and financing schemes to be realized and sustained.

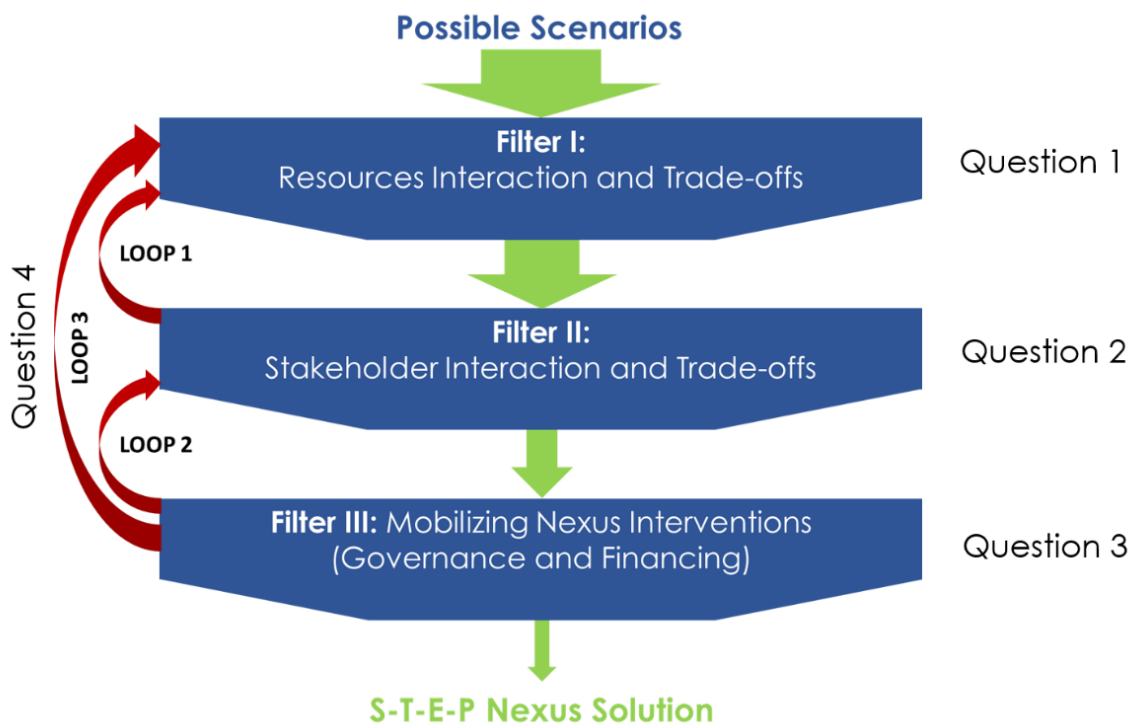

Figure 2.6 Iterative socio-techno-economic-political (STEP) nexus solution guiding framework (Daher et. al, 2018)

Thus, we can arrive at a STEP nexus solution: a proposed scenario vetted from socio-techno-economic-political (STEP) perspectives. Different suites of tools, models, and instruments are available to support researchers across disciplines in prescribing contextualized, holistic, STEP nexus solutions for a given resource challenges or nexus hotspots. Figure 2.6 presents a 3-Filter framework. The presented framework is intended to offer analysts, modelers, “nexus tool” developers, engineers, and social and policy researchers working towards addressing resource nexus hotspots—while each focus separately on vetting different aspects of proposed scenarios—a conceptual guideline with a suggested structured stepwise approach, and iterative feedback cycles, to guide their collaboration as they work towards arriving at STEP nexus solutions.

This framework requires that all three “filters” be checked before a proposed scenario is prescribed as a nexus solution that addresses a specific critical question. It is worth mentioning here that the goal of the outlined questions, or suite of questions, is to act as a guide towards the choice of different tools, models, and instruments to help holistically vet a proposed scenario. The answers to those questions might not be a clear Yes or No. That will depend on the availability of needed data, reliability of the used tools, as well as the nature of the critical question being addressed. In order to briefly demonstrate the framework, we will refer to the earlier example of proposing a future energy portfolio scenario at a national scale.

Feedback Loops and Cross-Thematic Interactions

a. **Filter I: Resources interaction and trade-offs**

Question #1: *Are the proposed resource allocation scenarios moving forward within the physical resource constraints at the given operational scale? Is there sufficient water, land, financial, and human capital resources for the given scenario?*

If **YES:** Move to Filter II.

If **NO:** Develop new scenarios that do not require resources that exceed available limits.

Specific to our example on identifying a future energy portfolio, we need to assess the resource needs (water, land, financial, environmental, and others) associated with business-as-usual, as opposed to those needed for different proposed portfolios. How much more, or less, water and land would be needed if reliance on solar energy is increased by 20%, for example? Which solar energy technology is most suitable? How do the resources needed for this shift affect and compete with resources needed for agriculture? Will we have competition with agriculture over the same available land, or is the land suitable for solar energy but not arable? Providing a quantification to answer these questions is facilitated by using, or customizing, existing integrative resource assessment tools from the literature. That quantification needs to be done while capturing the interconnections between the multi-dimensional system of systems (Section 2). The choice of tools would depend on the critical question in hand.

b. **Filter II: Stakeholder interaction and trade-offs**

Question #2: *Given the nature of the involved stakeholders, their interactions, power relations, value systems, and goals, which of the scenarios identified as 'feasible' in Question 1 could be implemented? Are there challenges beyond physical resource constraints that relate to understanding the realities of the stakeholder landscape?*

If **NO:** Move to Filter III to check governance structures and financing schemes for scenario.

If **YES:** Return to Filter I (**Loop 1**) to explore different scenario possibilities.

In this filter, we need to identify who are the stakeholders (governmental, business, and societal) connected with a decision to shift to an additional 20% solar energy. How well would households respond to government incentives for installing roof top solar panels? What role do conventional energy producers have in affecting such a decision? How encouraging are market entry conditions for new solar panel manufacturers to start operating? Are there any imposed barriers that might make the 20% goal an ambitious one to reach within a specified timeframe? How much do farmers have a say in making such a decision? What level of coordination and cooperation exists between energy and other water and agricultural planning institutions? To address these questions, we might need instruments like game theory, direct engagement with stakeholders through questionnaires, surveys, workshops, focus groups, and other participatory approaches to help with understanding these interactions and the feasibility of proposed scenarios (Section 4).

c. **Filter III: Governance and Financing**

Question #3: *If the scenario clears **Loop 1**, through Filters I and II, who would govern the implementation of the scenario moving forward, and who will finance it? Is this consistent with the stakeholder involvement and the interactions presented in Filter II? Does implementing the given scenario result* *in policy coherence? Does the existing governance structure allow for implementation?*

If **YES: Loop 2** clears, the proposed scenario could be promoted.

If **NO:** we have the option of investigating other scenarios identified as 'feasible' from both the physical resource and the stakeholder perspective, though **Loop 2**. We could also go through **Loop 3** and investigate other scenarios in **Filter I**.

Are there any budgetary limitations that would not allow a government to invest in solar farms, or provide subsidies for solar panels at a household level and within a given timeframe? Would implementation of the 20% goal be centrally led by the government or through a more decentralized approach? Will the company providing solar panels be government-owned? Would panels be sold at a predetermined price or will price be determined by a free market approach? Are there any policies at the local levels (municipal land zoning regulations for example) that might challenge a federal goal of switching to solar? (Section 5).

Question #4: *Does a proposed governance structure ensure that the scenario provided by Filter I can be implemented? Are there any limitations/constraints?*

If **YES: Loop 3** clears.

If **NO:** Revisit the solution portfolio in **Filter I** and propose another solution; one that fits **Filter III** limitations.

Finally, we must check whether any of the limitations that may have emerged from Filter III would challenge the implementation of the initially proposed scenario from a bio-physical and technical perspective. This would serve as a final cross-check before promoting a nexus solution.

Using the outlined guiding framework, a suggested scenario undergoes rigorous trial and error and checks to ensure that:

a. long term sustainability of the physical resource is not compromised (Filter I);
b. stakeholders are effective partners in the solution (Filter II);
c. implementation and long-term governance of the solution are feasible (Filter III).

2.7. WEF Nexus, Government, Business, Society and Sustainable Development Goals (SDGs): Capitalizing on Existing Momentum

In the coming 15 years, 193 United Nations member states are committed to work toward achieving a set of 17 sustainable development goals (SDGs) (United Nations, 2015). These goals include specific targets and local indicators for monitoring progress on water, energy, and food securities, and others related to economic growth, and sustainable consumption, among others. The water-energy-food nexus research community has a unique opportunity to leverage the momentum toward these goals. Figure 2.7 shows a preliminary mapping of some of these goals that are directly related to the interconnected resource systems, the players, and the interactions between them (Figure 2.4 with mapped SDGs). As nations work toward the 17 goals, they need to be aware of the extent of their interconnectedness and the potential competition among them (International Council for Science, 2017).

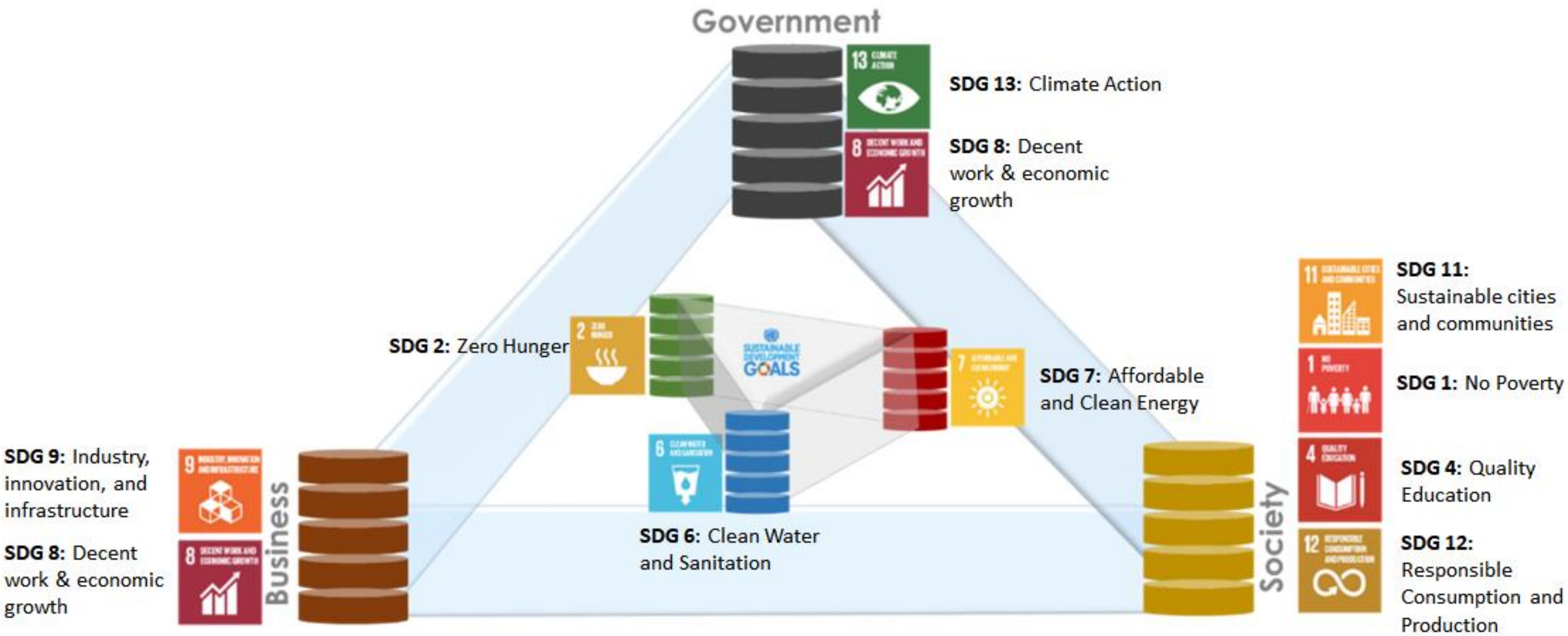

Figure 2.7 Role of water-energy-food (WEF) nexus and government-business-society interactions towards achieving sustainable development goals (SDGs) (Daher et. al, 2018)

In order to ensure arrival at these goals by 2030 and without unintended consequences, action plans must be developed with an understanding of the interconnections between the physical resource systems and the players involved with them. Achieving these goals requires innovative plans across different scales and could benefit from a framework that provides a structured approach for guiding collaboration across disciplines. As we continue to investigate and quantify the critical questions identified in Figure 2.3, through case studies at different scales and across a variety of eco-zones, political, market, and social environments, we are guided by the framework outlined in Figure 2.6. We will learn lessons that would result in revisiting and refining our approaches for addressing complex resource hotspots, thus enabling us to more effectively work toward achieving the Sustainable Development Goals.

2.8. Concluding Remarks

Moving forward, and as part of finding solutions for complex resource hotspots, several challenges exist that must be addressed. With regard to integrative resource assessment tools, there is a need for improving the compatibility of different tools that address critical questions guided by the interactions presented in the overarching WEF platform (Figure 2.3): this enables building on existing tools and avoiding duplication of effort. There is also a need for better quantification of the interactions between different players in order to identify implementable solutions. Given that players and resources systems interact across scales, there is a further need of better understanding and quantifying those interactions and ensuring solutions are implemented through policies that are coherent across scales. There is no one size tool that fits all for assessing physical resource interactions, stakeholder interactions, and policy and governance challenges. Therefore, localized and contextualized quantification and assessment is necessary. The 3-Filter STEP framework offers guidance through the different elements that need to be accounted for while assessing and promoting a nexus solution. Proposing feasible, implementable, sustainable solutions requires truly inclusive transdisciplinary conceptualization, quantification, and assessment of current and projected resource hotspots.

3. TOWARDS CREATING AN ENVIRONMENT OF COOPERATION BETWEEN WATER, ENERGY, AND FOOD STAKEHOLDERS IN SAN ANTONIO[2]

3.1. Introduction

Demand for resources is projected to increase as populations and economies around the world continue to grow (Bazilian et al., 2011; Hoff, 2011; World Economic Forum, 2011; Mohtar and Daher, 2012): by 2050, populations around the world will need 55% more water, 60% more food, and 80% more energy (IRENA, 2015). The pressures facing the resource systems and the extent of their interdependence, vary from one location to another, often emerging as hotspots (Mohtar and Daher, 2016) of varying characteristics and requiring unique sets of solutions to address them. Our growing understanding of these interlinkages, and the development of different methods for their quantification (Howells et al., 2013; Giampietro et al., 2013; FAO, 2014; Daher and Mohtar, 2015; Khalkhali et al., 2018), is an initial step in reducing stresses on these resource systems and their interdependence (Mohtar and Daher, 2017). While methods in WEF nexus research have focused to a large extent on quantifying the interlinkages between physical resource systems and trade-offs evaluation (Webber, 2016), the literature is still lacking in incorporating the political and institutional context to water, energy and food sector (Albrecht et al., 2018; Hagemann and Kirschke, 2017). Despite our growing

[2] Reprinted with permission from "Toward creating an environment of cooperation between water, energy, and food stakeholders in San Antonio " by Bassel Daher, Bryce Hannibal, Kent E. Portney, and Rabi H. Mohtar, published in Science of the Total Environment, Volume 651, Part 2, 15 February 2019, Pages 2913-2926. Copyright 2019 by Elsevier.

understanding of the level of interconnectedness between resource challenges, we know little about the level of communication and coordination between those making decisions within the different resource domains (Hoolohan et al., 2018; Portney et al., 2017a). Without sufficient communication, inefficient and competing resource allocation strategies and policies could be developed, resulting in unintended negative consequences to the sustainability of the resource systems. White et al. (2017) cite lack of communication and collaboration as one of four main barriers to making decisions to address water-energy-food shocks. Pittock et al. (2013) and Pahl-Wostl (2017) further attribute policy incoherence across different sectors to lack of communication, and divergent targets and institutional frameworks. Harriss and Lyon (2014) additionally identify communication and collaboration across disciplines as one of the major practical challenges facing nexus-oriented research (Kurian, 2017).

Building on this body of literature, this article quantifies the level of communication between cross-sectoral stakeholders, considering it a precursor, for their cooperation on addressing interconnected resource challenges. The article specifically focuses on the water-energy-food hotspot in the San Antonio Region in Texas, USA, by first, understanding physical resource competition resulting of its growing municipal, agricultural, and energy sectors. Then it tests hypotheses related to 1) the current **levels of communication** between decision makers within the water, energy, and food domains; 2) the impact of water officials' perception of future water challenges, 3) their participation in stakeholder forums related to resource planning, and 4) the impact of the scale at which they govern, **on that level of communication.**

3.2. Common Pool Resources and Collective Action

Stakeholders within various resource domains have authority to make decisions that impact the way in which resources are allocated, supplied, used, consumed, and reused (Daher et al., 2018). Resources are finite and often common to multiple groups. The term "Social Dilemma" refers to situations in which individuals make independent choices about inter-dependent situations (Hardin, 1971). Social dilemmas occur when "individuals in interdependent situations face choices in which the maximization of short-term self-interest yields outcomes leaving all participants worse off than feasible alternatives" (Ostrom, 1998). According to Collective Action Problem, when people act independently of each other, this often results in a worse outcome than if they coordinate their actions. Individuals tend to maximize their own utility, which results in everyone, including the individual, becoming worse off when compared to a coordinated action (Feiock, 2013). The theory of collective action, first published by Mancur Olson, argues that any group of individuals attempting to provide a public good has difficulty in efficiently doing so (Olson, 1965). The example below illustrates a set of possible actions by water, energy, and food stakeholders and potential implications of that action on the same resources (Figure 3.1).

- **Water (W)** resources are finite, and under increasing pressure as a result of decisions made by a stakeholder, within or outside of, the water domain (including energy and food).

- **Energy (E)** is required for pumping, treating, and conveying water, and for food production. The choice of energy portfolio also impacts how much water, land, and financial resources are required.
- **Land (L)** is also limited, and is mainly shared between agriculture, energy, cities, recreational areas, forests and other public areas.
- **Financial (Fi)** resources are needed to subsidize, invest in, operate, and maintain different activities within water, energy, or food systems. These finances come from public or private sources; the focus here is on public budgets, which have limitations and must be prioritized in relation to various sets of competing expenditures.
- **Carbon emissions (C)** are produced or reduced depending on the decisions made by stakeholders within the three domains.

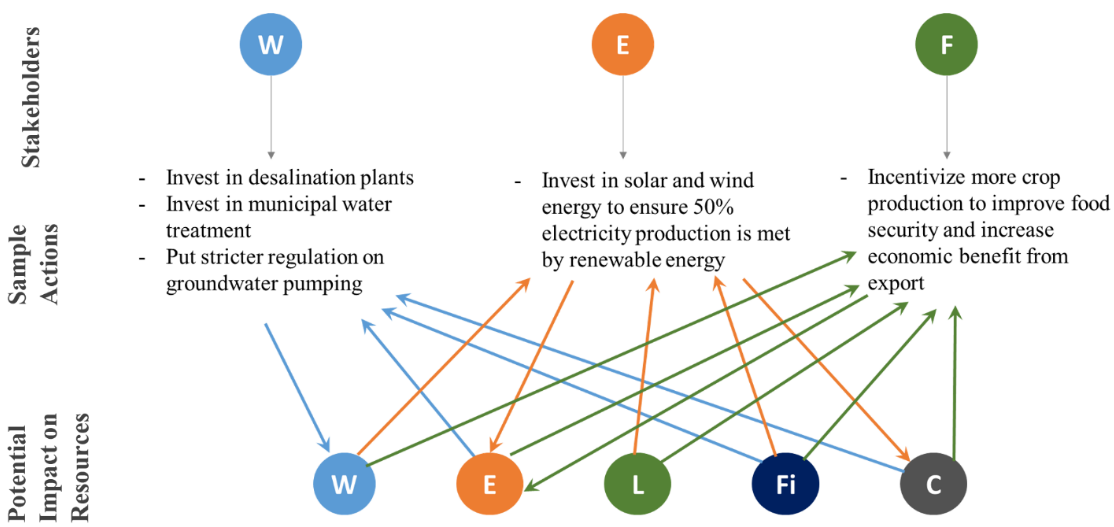

Figure 3.1 Example demonstrating the implications of different actions made by water, energy, and food stakeholders on water (W), energy (E), land (L), finances (Fi), and carbon emissions (C) (Source: Authors) (Daher et. al, 2019)

Decision makers within the public sector, with the authority to develop policies related to governing water, energy, and food resources, also have an important role to play in incentivizing different actions that could, potentially, result in reducing pressures on the resource systems (Portney et al., 2017a). An example of that could be through the implementation of subsidies, decisions to invest in different technologies, or changing trade policies, among others. In carrying out this role, decision makers must be aware of the extent to which the policies they develop might conflict with other stakeholders managing the same common resources. There is a need to provide a better understanding of the *potential* of translating solutions developed across resource domains into coordinated policies that are consistent with the degree of resource interconnectedness and the manner in which they affect the long-term sustainability of the resource systems. However, this must done with an understanding of the public policy process and its potential role in ensuring effective implementation of proposed policies and for a given environment with identified biophysical conditions, community attributes, rules, and action situations (Ostrom, 2011). The analysis that follows will build on common pool resource and collective action theory to explore ways that highlight the added value of communication and coordination among public policy officials within water, energy, and food domains.

3.3. San Antonio Region Case Study: Resource trends

3.3.1. Overview of population, water, energy, and food production trends in the San Antonio Region

The San Antonio Region, for this study, includes the city plus those counties comprising Planning Region L (Figure 3.2), as defined by the Texas Water Development Board (TWDB) in the Texas State Water Plan. San Antonio is one of the fastest growing cities in the U.S. (Forbes, 2017), and the Region has a rapidly developing energy industry, particularly hydraulic fracturing in the Eagle Ford Shale, and a burgeoning irrigated agriculture sector. The competition for water between the agricultural, energy, and municipal sectors can be exacerbated by climate change, which further threatens the availability and distribution of water resources. The economy and environment of southeast Texas were transformed when the Eagle Ford shale play became a major producer of shale oil and gas, much of which production occurs above the Carrizo Aquifer. Texas accounts for nearly 23% of the total natural gas production of the United States (USEIA, 2017). While the Texas Railroad Commission, the regulatory agency for this production, does not require companies to report the quantity or sources of water used for production, based on voluntary reporting, the average amount of water used per fractured well in the Eagle Ford Shale is 13.7 million liters (Kondash and Vengosh, 2015).

As more wells are permitted, and as technology continues to advance toward greater lateral length per well, it is projected that more water will be consumed in energy production. Agriculture is most present in the Wintergarden area, west of Region L, and includes LaSalle, Frio, Dimmit, and Zavala counties. The Texas Water Development

Board (2017) predicts that water used for irrigation will increase by 47% between 2015 and 2020. However, water stress from irrigation is projected to decline by 8% in the period 2020-2070 as a result of the anticipated increase in irrigation technology efficiency. The Eagle Ford shale play, located under the vegetable growing Wintergarden area, means direct competition for water between the agriculture and energy sectors.

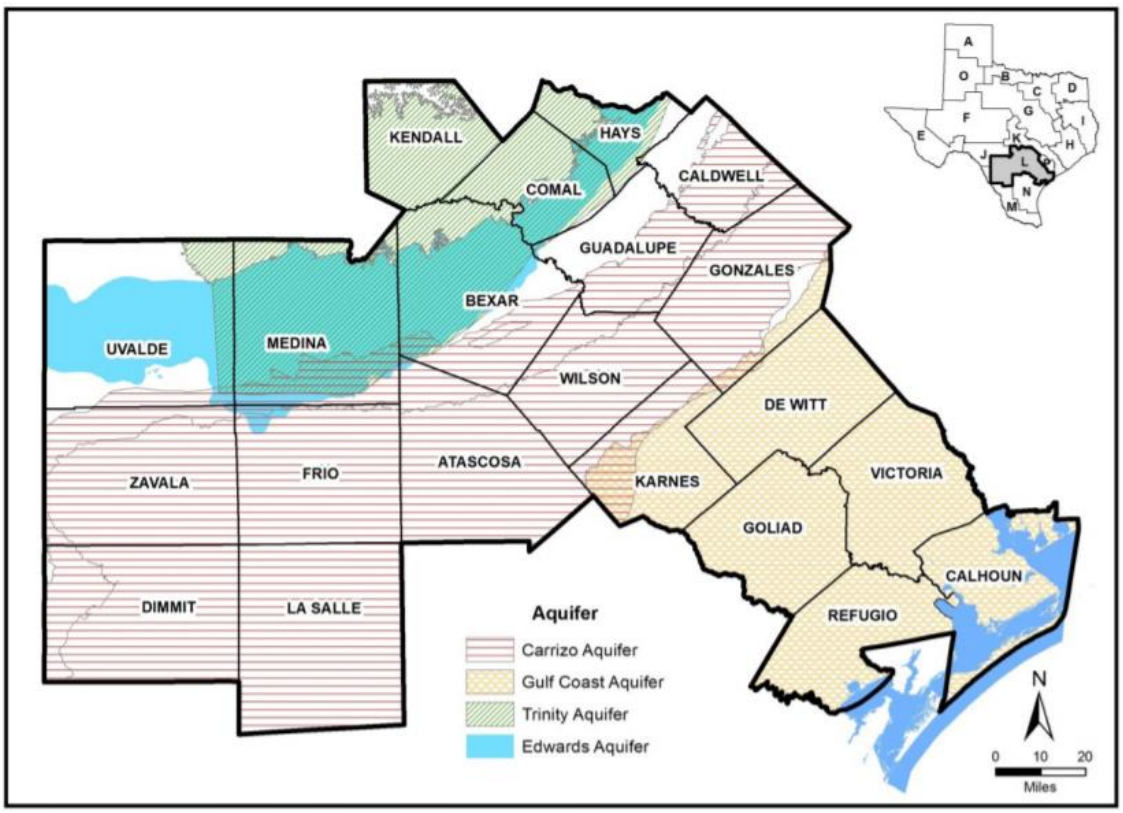

Figure 3.2 Texas Water Planning Region L (TWDB, 2017)

3.3.2. San Antonio Region: A Water-Energy-Food Hotspot

The growth trends of the municipal, industrial, and agricultural sectors are expected to continue to exert increasing pressure on the limited water resources in the Edwards and

Carrizo-Wilcox aquifers. As population grows and climate uncertainty continues, the water system faces increasing stresses. Water, energy and food are highly interconnected resource systems: planning future management pathways to allow their mutual development and limit competition that infringes a single sector makes it important to better understand and quantify those interlinkages.

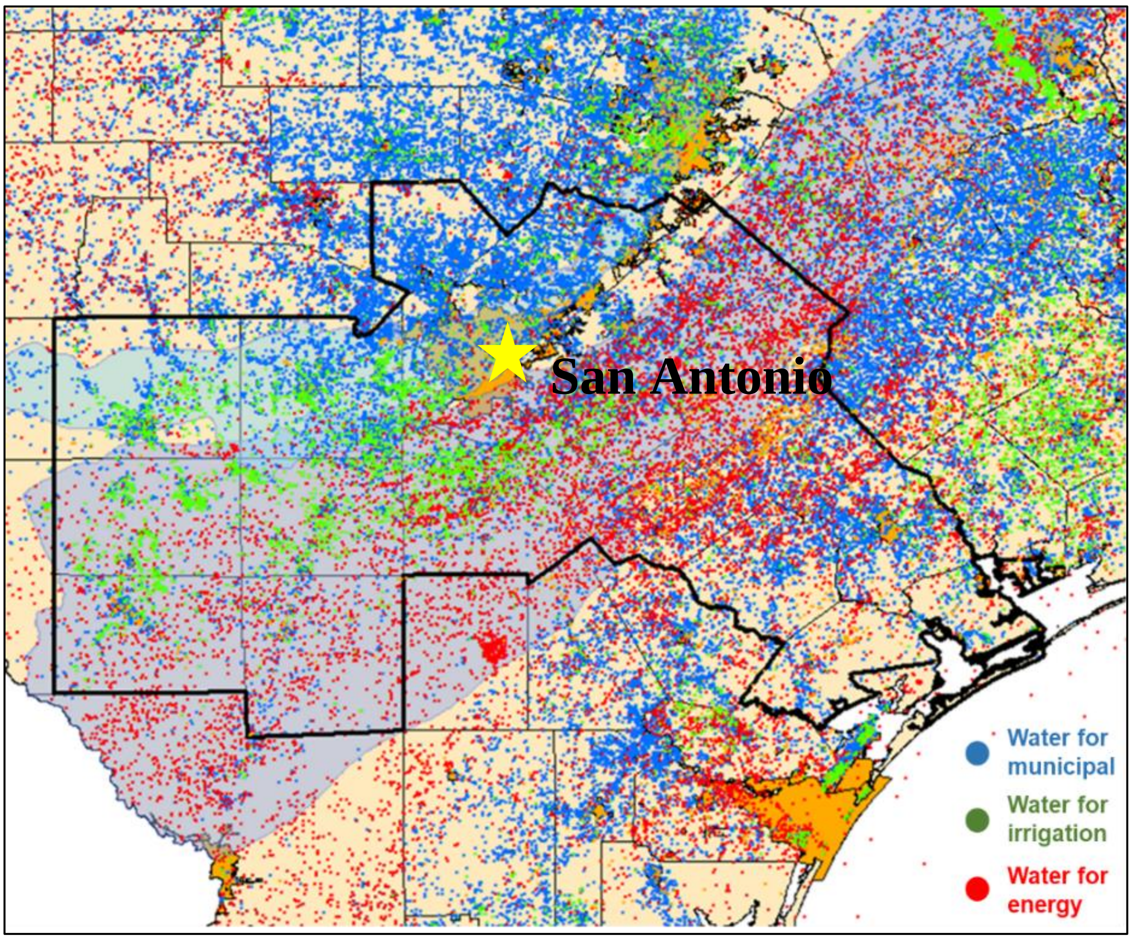

Figure 3.3 Map showing water wells for agriculture, oil &gas, and municipal use in the San Antonio Region. Source: Figure developed by authors using Geographic Information System (GIS) and TWDB (2017) data. (Daher et. al, 2019)

Figure 3.3 shows the groundwater wells of the San Antonio region: the green, red, and blue dots respectively represent groundwater wells whose water is used for agriculture, oil

& gas, or municipal purposes. The figure also illustrates the “nexus hotspot” (Mohtar and Daher, 2016) created by the competition between these sectors for the water. Addressing such hotspot requires holistic, yet localized, transdisciplinary, multi-stakeholder approaches. While plans for strategic water reserves exist, these are very costly (TWDB, 2017): solutions for better resource allocation requires that we build on our understanding of the interconnections of these resource systems, and strive to reducing projected resource gaps through cooperative, synergistic solutions that cost less and have a greater likelihood of implementation.

3.4. Hypotheses and Rationale

This section introduces several hypotheses being tested in this paper and the rationale behind each.

Hypothesis 1: Individuals at water institutions in the San Antonio Region engage in higher levels of communication with individuals at other water institutions, than with individuals at food or energy institutions.

Rationale 1: Drawing from the theory of homophily (Katz et al., 2004; McPherson and Smith-Lovin, 1987; McPherson, Smith-Lovin and Cook 2001), hypothesis 1 suggests that people at water institutions with public authority are more likely to communicate with people at other water institutions, compared to others from energy or food institutions, regarding addressing similar goals or challenges facing water resources in the San Antonio region. The rationale underlying this hypothesis is linked to the opportunity of people at those water institutions to communicate at water planning meetings at which representatives from different water institutions are present, or through different correspondence to coordinate and establish common regional goals, perhaps within the same water planning region, such as Region L. Such communication might be less present with other food and energy institutions. Testing hypothesis 1 will provide an indication of the level of communication between water institutions, and the way in which it compares to those with energy and food institutions.

Hypothesis 2: The frequency of communication of people at water institutions with people from water, energy, and food institutions is improved as a result of their participation at stakeholder cooperative planning efforts.

Rationale 2: The rationale behind this hypothesis is that people who attend such meetings have a greater chance to meet people from other institutions in the water domain, and/or from the food and, or energy domains (Hamilton et al., 2018). The assumption is that people who are exposed to and trained on the importance of integrative planning while dealing with water issues are likely to see increased value in having such communication. This could result in them being more likely to reach out to those from other water, energy, and food institutions when attempting to address the challenges within the mandate of their own water centric institutions. Integrative planning is referred to as the process of coordination with other stakeholders regarding setting priorities and developing resource allocation plans for the region.

Hypothesis 3: People at water institutions who are less concerned about water future availability are less likely to communicate with people from different water, energy, and food institutions.

Rationale 3: According to Portney et al. (2017b), the potential to coordinate across domains could be viewed as a function of the perception of existing public policy and management officials regarding the urgency of the resource challenges and of resource interconnectedness. The rationale underlying this hypothesis is that people with a higher sense of urgency toward future water availability are more aware of the need to communicate and coordinate with other water institutions. They are more likely to be aware that solutions to water challenges will not come exclusively from within the water sector itself, but will come through coordination with others interconnected with the sector.

Hypothesis 4: People at water institutions having authority at a larger scale are more likely to communicate with people from other water, food and energy organizations.

Rationale 4: The underlying rationale for this hypothesis is that people working at institutions with a broader governance authority (geographical, institutional) are more likely to intersect with a greater number of other institutions, thereby increasing the likelihood of communications with these institutions (Mullin, 2009; Newig and Fritsch, 2009). The standard orthodoxy from administrative theory is that higher level organizations in the "hierarchy" should perform coordinating functions among lower level organizations. The practical implication is that if there is greater contact with these higher level organizations, in this case state agencies, then perhaps some level of coordination is actually taking place. If there is not, then the standard view of public administration isn't working and changes need to be prescribed (Kok and Veldkamp, 2011).

3.5. Methodology

3.5.1. Stakeholder definition, identification, classification, and investigating relationships

3.5.1.1. Stakeholder Definition: Who are the "Stakeholders"?

It is important to clearly define who is meant by "stakeholder". A wide body of literature proposes different ways for defining stakeholders. Some approaches are more pragmatic, attempting to classify stakeholders according to a set of attributes: those who affect an action, and those who are affected by an action (Freeman, 1984), or those whose involvement is a "pragmatic requirement" to achieving a successful outcome (Miles, 2015), or whoever causes a problem needs to be considered as a stakeholder and co-owner in the process of addressing that problem (Checkland, 1991). Others promote greater inclusiveness of all types of stakeholders, whether closely or remotely connected with the given issue (Bryson 2004; Grimble and Wellard, 1996; Nutt and Backoff, 1992; Johnson and Scholes, 2002; Lebacqz 1986; Lewis 1991). In addition to these methods of identifying stakeholders, expert opinion is also recognized as important tool for achieving the same goal (Kumar et al, 2016; Schiller et al., 2013). In this study, a stakeholder is defined as a person at an entity, organization, or institution, who makes decisions that impact the water, energy, and food sectors of the San Antonio Region; stakeholders may be employed at units working centrally on related water, energy, or food issues. The survey was distributed to those stakeholders who are public officials with legal authority, and who work at water organizations in the San Antonio Region. The survey sent to the stakeholders gave them the chance to self-identify (Crane and Ruebottom, 2010) as "water stakeholders" through asking the following question: "Do you currently work for an agency or department that deals with water issues in the San Antonio Region?**"**

3.5.1.2. Stakeholder Identification and Classification

A list of water institutions with legal authority and other major energy and food stakeholders in the San Antonio Region has been identified extant research (Portney et al. 2017a). This document formed a base from which to identify key stakeholders. Additional literature and web searches were used to identify different organizations and key personnel actively working in areas related to water, energy, and food. In the end, the survey was distributed to 257 identified people who work at water organizations in Region L. Stakeholders in this study were classified by the domain in which they were employed at the time; namely water, energy, food, and "cross cutting". The category of "cross-cutting" includes offices with mandates that likely extend beyond water management, such as state representatives, senators, the Railroad Commission of Texas, and others. The identified sample cosists of 57 water, 14 energy, 10 food, and 12 cross-cutting organizations in the San Antonio Region from Portney et al. (2017a), in addition to research on the scope of the different organizations to identify their category. The list of water, energy, and cross-cutting stakeholder organizations is presented in **Appendix A.**

3.5.1.3. Stakeholder Relationships – Social Network Analysis

In this study, Social Network Analysis (SNA) is used to provide an understanding of the relations between stakeholders (Scott, 2000; Wasseman and Faust, 1994). Rogers (1986) characterizes a communication network as consisting of "interconnected individuals who are linked by patterned communication flows". The strength of the tie between different stakeholders, according to Prell et al. (2009), is representative of the influence one has upon another in comparison to those who share weaker ties. It also can be an indication of similar views, effective communication of complex information and tasks, and a higher likelihood of trust between stakeholders (Coleman, 1994; Crona and Bodin, 2006; Cross and Parker, 2010; Friedkin, 1998; Kadushin, 1966; Newman and Dale, 2004; Wellman and Frank, 2001). In the context of resource management, Crona and Bodin (2006) refer to stakeholders with strong ties as those more likely to influence one another and for whom there is a greater likelihood of mutual learning and resource sharing. On the other hand, weaker ties[3] are indicative of less frequent communication, and might imply a lower likelihood of resource sharing or influencing one another's decisions. In Prell et al. (2009), the tightness of the links between a network of stakeholders was identified with the question: "Do you communicate with anyone from [stakeholder category named here] on upland management issues in the Peak District National Park?"

[3] Here, weaker ties are characterized by infrequent communication. We are not referring to a bridging tie as elaborated in Granovetter (1973).

If the respondent answered "yes," the follow-up "How often do you communicate with this person? (Daily, Weekly, Monthly, 1–2 times=year)" was asked. In this study, the level of communication between water, energy, and food organizations in the San Antonio Region is measured through a survey which included a roster of other organizations involved with resource management. The results from the network question were organized into a communication network matrix which is used to test hypotheses listed below.

3.5.2. The Survey and Questionnaire

Of the 257 surveys distributed, 28% of recipients work at Groundwater Conservation Districts, 16% work at River Authorities, 9% work at state agencies, 10.4% work at municipal service providers and 36.6% work at other water related organization. The questionnaire displayed a web address that the respondents could use to answer the questions on a computer or handheld device. A total of 101 responses were received by mail or online, yielding a response rate of 39.3%. Table 3.1 identifies the specific questions used to test these hypotheses. The detailed list of questions is available in **Appendix B**.

The 101 respondents indicated the frequency of their communication with individuals from other water (W), energy (E), food (F), or "cross-cutting" (C) institutions in the San Antonio Region (Figure 3.4). Respondents indicated the frequencies with which they communicated with each of the institutions: ***4*= *Once a week or more;* *3*= *Monthly;* *2*=** *Once every 3 months; 1= Once a year;* ***0*=** *Not at all*

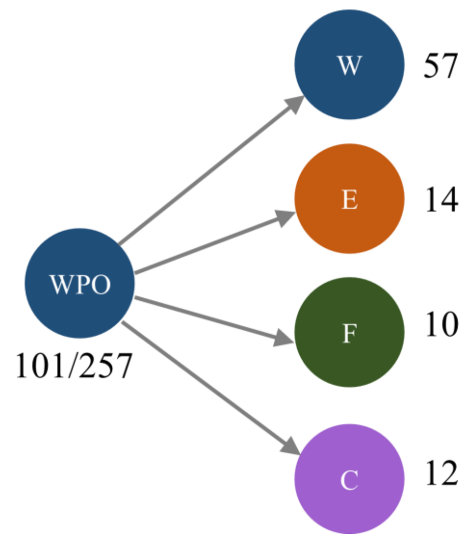

Figure 3.4 The distribution of the number of water, energy, food, and cross-cutting stakeholders (Daher et. al, 2019)

Throughout this discussion, the response to the questions addressing frequency of communication are shown as percentages indicating: “no communication” (0’s) or “some communication” (sum of 1, 2, 3, and 4’s). More details on these questions in the conducted surveys are elaborated in the following sections. The operationalization of “low levels of communication” generally consists of contacting behavior “once a year” or “not at all.”

Throughout the analysis, the level of communication indicated by a given respondent in the questionnaire is represented by the **average** of the responses to their frequency of communication with the different institutions. A larger number of 0’s (meaning, no communication at all) indicates a lower level of communication with other institutions. The average value representing that level of communication can be between 0 and 4. The closer that number is to 0, the less communication that respondent has with others from different institutions. Conversely, the higher that average, the greater the communication.

Table 3.1 Methodology Summary (Daher et al., 2019)

	Methodology Summary
Population	- Public officials with legal authority, who work at water organizations in the San Antonio Region.
Methods for Stakeholder Identification and classification	- Portney et al. (2017a) list of water institutions with legal authority in San Antonio Regions - Scoping – Literature and web searches - Self-identification: ***Q1.*** *Do you currently work for an agency or department that deals with water issues in the San Antonio Region?*
Methods for Stakeholder Relations	Social Network Analysis
Hypothesis 1: *Individuals at water institutions in the San Antonio Region engage in higher levels of communication with individuals at other water institutions, than with individuals at food or energy institutions.*	***Q9, 10, 11, 15.*** *Over the last year, as part of your job,* ***how often have you communicated*** *with any of these organizations, or decision makers from these organizations,* ***about water issues affecting the San Antonio Region?***
Hypothesis 2: *The frequency of communication of people at water institutions with others from water, energy, and food institutions is improved as a result of their participation at stakeholder cooperative planning efforts in San Antonio.*	***Q12.*** *Over the last year, as part of your job, have you* ***personally participated in any kind of stakeholder forum*** *or* ***cooperative planning*** *effort with organizations or agencies other than your own?* with Q 9, 10, 11, and 15
Hypothesis 3: *People at water institutions who are less concerned about water future availability are less likely to communicate with others from different water, energy, and food institutions in San Antonio.*	***Q13.*** *Overall, how concerned are you about* ***future water availability*** *in the San Antonio Region?* with Q 9, 10, 11, and 15

Table 3.1 Methodology Summary (Continued)

Hypothesis 4: *People at water institutions having authority at a larger scale are more likely to communicate with people from other water, food and energy organizations.*	***Q2.*** *What* ***agency or department*** *do you work for?* with Q 9, 10, 11, and 15
Methods for Statistical Analysis to examine significance of results	**H1**: t-tests; **H2, H3, H4**: Bivariate regression analysis (OLS Regression)
Outcomes	- Identify level of communication between governmental water stakeholders and other water, energy, food, and "crosscutting" C stakeholders in San Antonio - Identify potential correlation between attending stakeholder engagement meetings and level of communication - Identify potential correlation between perception towards the urgency of water scarcity challenges in the region and the level of communication with other stakeholders - Identify potential correlation between the scale at which stakeholders operate and the level of communication

Other measures are included as predictor variables. The first, forum attendance, asked about their participation in stakeholder forums or cooperative planning efforts. Respondents were asked if they attended a forum or cooperative planning effort and were given the answer options "**yes**", "**no**", or "**not sure**". We also asked about the stakeholder's level of concern about future water availability. When asked about their level of concern about future water availability in San Antonio, respondents were asked to rate their level of concern about future water availability and give a 0 to 10 point range as answer options, where 0 is not concerned at all, and 10 is extremely concerned.

3.6. Results and Analysis

Hypothesis 1 aims at obtaining two main pieces of information about the communication levels of the different stakeholders: 1) the overall level of communication existing between the 101 surveyed water officials and other water, energy, and food institutions in San Antonio, and 2) the likelihood of higher levels of communication between water officials among themselves, than with those from energy or food domains. Throughout the remainder of the analysis, communications by the 101 surveyed people from water institutions with the other water institutions are referred to as WW. WE, WF, WC refer to the communication of those water officials (W), with other identified energy (E), food (F), and cross-cutting institutions (C), respectively.

Using social network analysis techniques, we create a visual representation of the information described above. Figure 3.5 illustrates the communication network between the 4 categories of organizations. The tie represents any level of communication, or if the organizations communicated at least once per year. The grey circles are those who received and responded to the aforementioned survey of San Antonio water organizations. The blue squares represent water organizations, the red squares are energy organizations, the green squares are food organizations and the orange squares are crosscutting institutions.

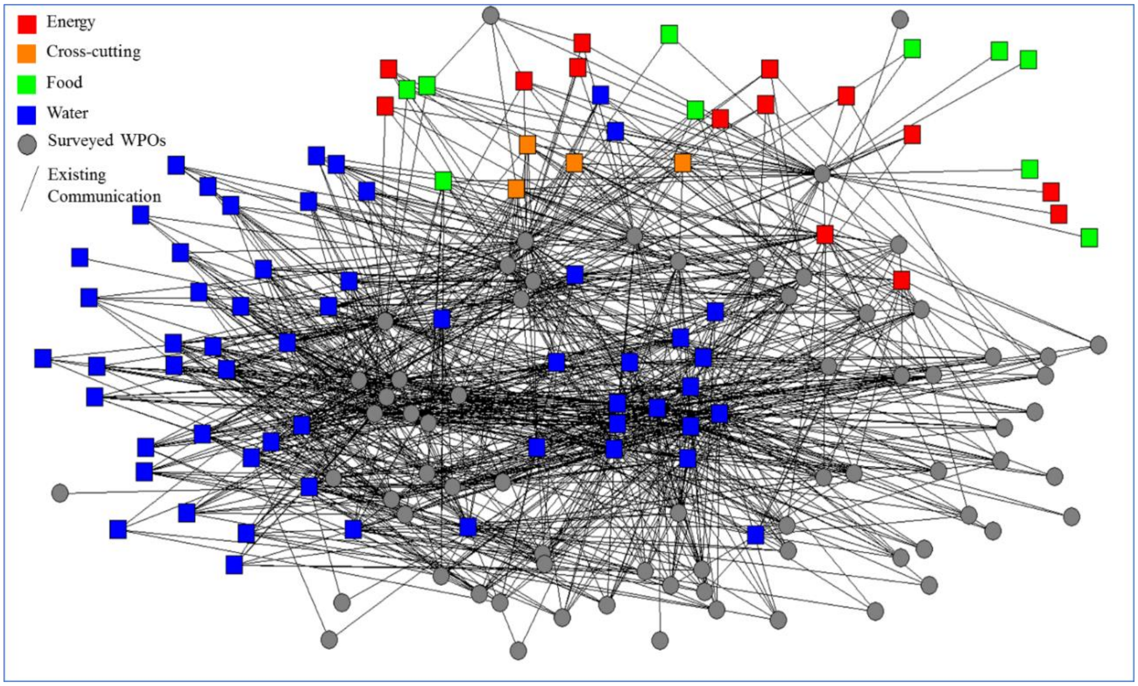

Figure 3.5 Network map depicting any level of communication between water, energy, food, and crosscutting organizations in the San Antonio Region (Daher et. al, 2019)

It is fairly clear to see that the majority of the ties in the figure are to water organizations. The cluster of water organizations in the center portion of the map as well as the numerous ties to the water organizations on the left of the figure demonstrate that there is more connectivity to those groupings of water organizations. The presence of connectivity to water organizations is also highlighted by the sparseness of connections to other types of organizations. Again, it is notable from the figure that, on average, there are fewer connections to both energy and food organizations. A number of those organizations are pendants (only one connection) or have a small number of ties to other water organizations.

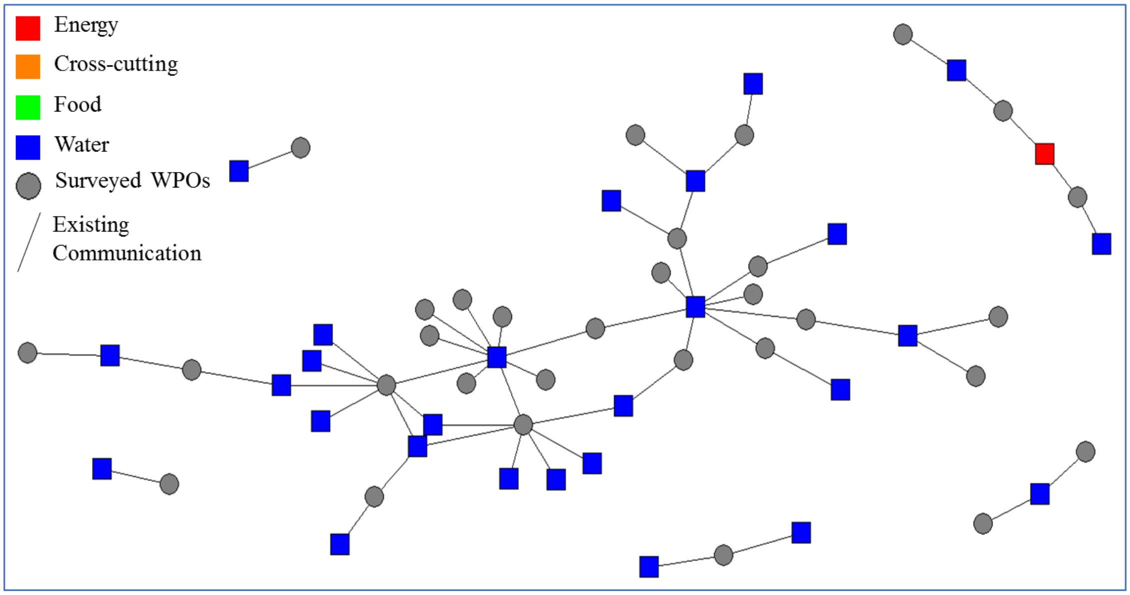

Figure 3.6 Network map depicting weekly communication between water, energy, food, and crosscutting organizations in the San Antonio Region (Daher et. al, 2019)

Figure 3.6 illustrates weekly communication between survey respondents and other organizations. This figure provides good visual evidence of what is being examined in Hypothesis 1. As frequency of communication increases, many of the food, energy, and crosscutting organizations drop from the network because of the very infrequent communication. In fact, only one energy organization (CPS Energy, the San Antonio city-owned utility) remains in the weekly communication network.

Table 3.2 Communication between the 101 officials at water institutions with other water, energy, and food institutions (Daher et al., 2019)

	WW	WE	WF	WC
NO Communication	80%	93%	96%	83%
some communication	20%	7%	4%	17%

The results about communication, displayed in Table 3.2, show low levels of communication are reported between water officials and other stakeholders in San Antonio Region. Only 4% of the responses indicate some communication with food institutions, 7% with energy institutions, and 17% with cross-cutting institutions. The highest level of communication was reported with other water institutions: 20% of responses indicate some communication. Figure 3.7 shows a breakdown of the different levels of communications reported.

Even among those who reported "some level of communication", most indicated a low frequency (once a year). Only 8 percent communicated with other water institutions yearly, 7% every 3 months, 4% monthly, and only 1% communicated at a frequency of once a week or more often. These percentages are lower for communication with people from energy and food institutions. A similar higher level of communication is reported between WW and WC (19.7% and 16.8%), compared to those with WE and WF (6.8% and 4.2% respectively).

While the percentages displayed in Table 3.2 provide basic information about level communication, they do not suggest whether communication within one sector is statistically different from another. To address this, we examine the results from a paired sample, or dependent, t-test. The paired sample t-test is used to determine whether the means of two variables are not independent from each other. Table 3.2 summarizes the p-values from the respective t-tests.

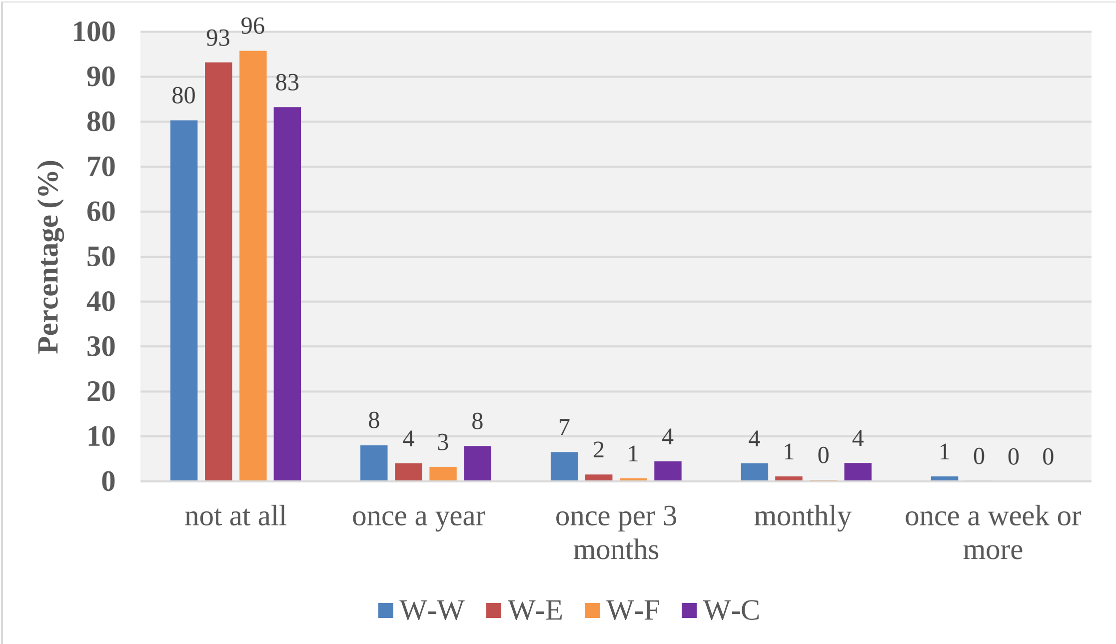

Figure 3.7 Breakdown frequency of communication with other water, energy, food and cross-cutting institutions in San Antonio (Daher et. al, 2019)

As seen in Table 3.3, we find mixed support for H1. Specifically, we find that water managers have more communication with other water managers than individuals from energy institutions. This result is statistically significant at the p<0.001 level. The results for WF and WC do not support H1, meaning that the levels of communication between WF and WC are not statistically different from WW.

Table 3.3 P-value results for t-test for WW vs WF, WW vs WE, WW vs WC averages (Daher et al., 2019)

Comparisons	***Hypothesis***	***P-value (t-test)***	***Decision***
WW vs WF	H1: μ (ww) > μ (wf)	p<0.967	No Support for H1
WW vs WE	H1: μ (ww) > μ (we)	p<0.001	Support for H1
WW vs WC	H1: μ (ww) > μ (wc)	p<0.998	No support for H1

Hypothesis 2 investigates the relation between participation in stakeholder forums and cooperative planning efforts, and the effect of such participation on frequency of communication. The results for whether or not an individual attended a forum are split nearly identically between "yes" and "no," with **50.6% attending a forum and 46.4%** not attending a forum. Out of the 46 people who answered "yes," **77%** of their possible interactions with different water, energy, and food stakeholders, showed no communication at all (Table 3.4). This number was higher among those who indicated not participating in any stakeholder forum or cooperative planning effort as part of their job (total 36 who answered "no")

Table 3.4 Percentages of frequency of communication between water officials who have or have not participated in integrative planning workshops, with all stakeholders from San Antonio (Daher et al., 2019)

	No Participation	**Participation**
No Communication	**91%**	**77%**
Some Communication	9%	23%

To investigate whether this change is statistically significant, we examine the relationship between forum participation and communication in a bivariate regression. We estimate and ordinary least squares (OLS) regression where the dependent variable measures levels of communication between water, energy, food, and crosscutting. The bivariate regression results are presented in Table 3.5.

Table 3.5 Results from Bivariate Regression Predicting the Influence of Stakeholder Forum Participation on Communication (Daher et al., 2019)

	Model 1: WW	Model 2: WE	Model 3: WF	Model 4: WC
Participation in Stakeholder Forum	0.283**	0.050	-0.392	-0.061
	(0.089)	(0.043)	(0.450)	(0.364)
Constant	0.270***	0.082**	0.830*	0.821**
	(0.063)	(0.030)	(0.320)	(0.259)
R-squared	0.099	0.015	0.008	0.000

* p<0.05, ** p<0.01, *** p<0.001

N=95

These results offer partial support for hypothesis 2. We find that attending a stakeholder forum is positively related to the levels of communication between water organizations; however there is no relationship with attending a forum and communication between water and any other groups. Based on these results, it is probable that the forums attended were directed at water managers. If this is the case then forums directed at a broader audience may influence breaking down institutional silos and promote communication across areas of specialty. Further research on this topic is important and warranted.

As stated above, **Hypothesis 3** examines levels of communication in relation to concern about future water availability. Specifically, the question asked, "…on a scale of 0-10, with 0 being not concerned at all, 10 being extremely concerned, how concerned are you about the water availability in the future." We estimate an OLS regression for this variable as well, similar to H2. Results are shown in Table 3.6.

Table 3.6 Results from Bivariate Regression Predicting the Influence of Concern about Water Availability on Communication (Daher et al., 2019)

	Model 1: WW	**Model 2: WE**	**Model 3: WF**	**Model 4: WC**
Concern for Future Water Availability	-0.014 (0.019)	-0.002 (0.008)	0.010 (0.064)	-0.013 (0.060)
Constant	0.501*** (0.137)	0.125* (0.061)	0.307 (0.470)	0.699 (0.442)
R-squared	0.007	0.001	0.000	0.001

* p<0.05, ** p<0.01, *** p<0.001

N=88

As with hypothesis 2, we looked for a relation between levels of concern about water availability and the frequency of communication between water-water, water-energy, water-food, water-crosscutting. As our results do not show support for the hypothesis, we learn that there is insufficient evidence to conclude that people at water institutions in San Antonio Region have a higher frequency of communication with other water, energy, and food stakeholders, as a result of being more concerned about future water availability.

Hypothesis 4 examines the influence of "scale" or region of governance on the level of communication among stakeholder groups. We measure scale by geographic governance responsibilities or area of jurisdiction. We divide organizations into 2 categories which seek to capture horizontal and vertical communication. There are different levels of governance being addressed by this hypothesis. Specifically, this hypothesis captures horizontal communication among regional institutions such as cities, counties, groundwater conservation districts, river authorities, and utilities as well as vertical communication between these institutions and state governing bodies (including Texas Water Development Board, Texas Commission on Environmental Quality, and Texas Water Resources Institute). Certainly, there may be other classifications of scale that researchers could define and our measurement provides a baseline level of communication.

Table 3.7 Results from Bivariate Regression Predicting the Influence of Scale on Communication (Daher et al., 2019)

	Model 1: WW	**Model 2: WE**	**Model 3: WF**	**Model 4: WC**
Scale	-0.059	0.081	1.311	1.237
	(0.163)	(0.071)	(0.890)	(0.769)
Constant	0.411***	0.094***	0.745**	0.920***
	(0.049)	(0.021)	(0.266)	(0.229)
R-squared	0.001	0.013	0.021	0.025

* p<0.05, ** p<0.01, *** p<0.001

N=101

The results for H4 are presented in Table 3.7. Again, we estimate an OLS regressions to determine the impact of “scale” on levels of communication. The results in suggest that geographic scale may have little influence on levels of communication among the stakeholder groups. Further investigation into different treatments of scale categories yielded similarly insignificant results.

3.7. Discussions

In this paper, we investigated the level of communication that exists among different water institutions, and between water, energy, food, and cross-cutting institutions in San Antonio. We also investigated the potential role concern about future water challenges, participation in engagement activities, and the scale of organization, play in improving those levels of communication. Results from the statistical analysis offer several conclusion and offer useful insights into further examination of stakeholder an polycentric governance studies (Berardo and Lubell 2016; Mewhirter, Lubell, and Berardo 2018).

3.7.1. On the overall level of communication

We conclude that the overall level of communication of water institutions with other water, energy, food, and crosscutting institutions is low. However, we also notice and conclude that people at water institutions in San Antonio have a higher frequency of communication with people at other water institutions, than with people at energy and food institutions. Low communication could be attributed to institutional or financial constraints, as well as time limitations. Without specific agreements or contractual obligations towards cooperation or coordination with the different institutions in place, water officials might find themselves unable to take steps toward improving levels of communication with other institutions. The various responsibilities water officials at different institutions have as part of their mandate, may leave little time to effectively engage with others through cooperative planning workshops, for example. This low level of communication might also be a result of the officials' perception toward the limited role or value of increased communication in addressing the resource challenges faced, lack of common goals and collaborative projects, a lack of incentives to collaborate, and a lack of institutional mechanisms to cooperate (Rosen et al, 2018). Even though our study results showed higher levels communication between people at different water organizations, compared to their communication with people at food and cross-cutting organizations, that difference was not statistically significant. This could mean that people at water organizations communicate more with people at food and cross cutting organizations, compared to energy. Additional effort needs to focus on addressing the barriers resulting in low overall levels of communications, particularly with energy.

3.7.2. On the role of stakeholder forums in increasing communication

We conclude that the frequency of communication among water officials who attended stakeholder forums is higher than that of those who have never attended such a forum with other water, energy, food or crosscutting institutions in San Antonio. To clarify, representatives from water institutions who attend forums have a higher level of communication with other water institutions than those who do not attend the forum. We also find that there is insufficient evidence to suggest that attending stakeholder engagement activities improves the frequency of communication by water stakeholders with stakeholders at food, energy, and crosscutting organizations. One reason behind the increased communication among officials from water institutions but not others, might simply be the fact that such meetings are largely attended by people from water-centric institutions, or the forums are oriented toward water managers. Even though such forums promote integrative planning, they largely remain to be done within the same "silo", with weaker agriculture or energy presence. Therefore, assuring food/agriculture and energy are represented at such meetings could play a role in improving current levels of communication, potentially contributing to an improved environment for cross-sectoral cooperation.

3.7.3. On the role of concern regarding future water availability in the region

We conclude that there is insufficient evidence to allow us to conclude that people at water institutions in the San Antonio Region would have a higher frequency of communication with other water, energy, and food stakeholders as a result of being more concerned about future water availability. One potential factor contributing to this result is not perceiving the resource systems and their challenges to be as interconnected as they are. Viewing these resource systems as siloed could potentially cause officials to not realize the need for greater communication across resource domains, regardless of their concern toward future water availability. Raising awareness and building institutional capacity towards the importance of cross-institutional and cross-sectoral cooperation and coordination on resource allocation challenges could play a positive role in improving those levels of communication.

3.7.4. On the differing scales of organizations

From the data presented in this study, we conclude that the frequency of communication among organizations charged with differing governance scales does not vary significantly. Future research could delve deeper into analyzing specific strategies and tasks in natural resource governance among these organizations and develop theory about levels of communication. Given the conflicting ideal or optimal level of communication, it is unclear what research might expect to uncover regarding communication among these categories of organizations. Future research in the areas of nexus governance may focus on this area of research.

3.7.5. Limitations and Future research

This first hypothesis gave us an overall indication of the low level of communication among people from different institutions in San Antonio, and the relatively higher level of communication among water institutions, compared to that with other food, energy, and cross-cutting institutions. In reality, these 101 water officials come from different types of organizations with differing scopes and scales of authority. Further, this study does not identify the quality of communication being surveyed. This study only scratches the surface of the research possibilities in the communication between organizations across interconnected resource domains. It is important to note that the results presented here should be taken as preliminary to a more thorough and robust analysis which would be worthwhile. A comparative study, done at a region with similar resource stresses, could investigate trends in cross-sectoral levels of communication, and reasons behind similar or different results, compared to those reported by this case study in San Antonio. Further research also needs to be done on the type and quality of communication that might result in cooperation or coordination between institutions. Also capturing the perspective of energy and food officials from San Antonio, would increase the sample size and type, and could yield new insights to better describe the network and levels of communication.

3.8. Conclusions

Given the tight interconnectedness between resource challenges facing the San Antonio Region, a certain level of communication, coordination, and cooperation is needed between officials across these resource domains. Collective action dilemmas and issues must be confronted by polycentric, or network governance systems (Feiock 2013). The social relations and dense connectivity among stakeholders can reduce transaction costs that may impede collective and effective governance of common pool resources. If a siloed mentality and governance system progresses, the region may be subject to competing resource allocation strategies and policies that result in unintended consequences. An environment that incentivizes increased levels of communication, coordination, and cooperation is needed. This could be partly be achieved through investing in cross-institutional mechanisms which promote higher levels of cooperation, and that work towards improving the compatibility of differing planning horizons, and common goal setting activities across sectors. This could also be facilitated through the organization of integrative planning workshops, forums, and moderated dialogues which bring officials representing institutions from different resource domains to discuss future resource strategies. Such dialogue and exposure to different viewpoints would facilitate better understanding the reality of the resource challenges facing the region, and of the innovative cross-disciplinary and cross-institutional solutions necessary to effectively allocate and distribute resources to society.

4. TOWARD UNDERSTANDING THE CONVERGENCE OF RESEARCHER-STAKEHOLDER PERSPECTIVES RELATED TO WATER-ENERGY-FOOD (WEF) CHALLENGES: THE CASE OF SAN ANTONIO, TEXAS

4.1. Introduction

In the past decade, the scientific community has witnessed a growth in water-energy-food nexus related literature (Albrecht et al., 2018; Dai et al., 2018; Zhang et al., 2018; Kaddoura and El Khatib, 2017), which primarily focused on the quantification of the bio-physical interconnections and trade-offs between the three resources systems (Bazilian et al, 2011; Giampietro et al, 2013; Howells et al, 2013; FAO, 2014; Daher and Mohtar, 2015; IRENA, 2015). More recently, there is growing interest in complementing that focus with social sciences research to better understand the policy processes and implications for different resource allocation pathways (Kurian, 2017; Portney et al., 2017a; Pahl-Wostl, 2017; Artioli et al., 2017, Daher et al., 2019, White et al., 2017, Bunakov et al., 2017, Hannibal and Vedlitz, 2018). While much of the growing scientific literature comes from within cross-disciplinary research groups (Mohtar and Daher, 2019; Endo et al., 2018) that build on interconnected resource system frameworks and theories, little is known about the extent to which that research is a reflection of the actual perspectives of the stakeholders in the regions studied.

Water, energy, and food resource systems are multi-dimensional and interconnected (Figure 4.1a). These resource systems do not exist in a vacuum, but are governed, managed, and consumed by various actors who in turn interact with one another. Said actors have different value systems and preferences that impact their decisions and actions (Daher et. al, 2018) (Figure 4.1b). In an effort to more fully understand the research methodologies in the nexus, Albrecht et al (2018) review and categorize 73 WEF nexus methods from the literature. They include methods focused on the biophysical resources and their interconnections, *with categories* including footprinting (Cottee et al, 2016; Rulli et al., 2016; Talozi et al., 2015), systems analysis (Al-Ansari et al, 2015; Li et al, 2016), spatial analysis (Daccache et al., 2014; Guipponi and Gain, 2016; Scott and Sugg, 2015), and material flows analysis (Villarroel Walker et al, 2012). Other categories focus on *social science* methods such as institutional analysis (de Strasse et al., 2016; Sharma, 2010), questionnaires, surveys and interviews (Portney et al. 2018, Cottee et al., 2016; Endo et al., 2015), and stakeholder analysis (Halbe et al., 2015; Karlberg, 2015). Further categories include those focused on bridging the biophysical and social dimensions through scenario analysis (Walsh et al., 2016; Ringler et al., 2016; Daher and Mohtar, 2015; Scott, 2011), trade-off analysis (Bonsch et al, 2016; Mayor et al, 2015), and integrated assessment models (van Vuuren et al., 2015; Yang et al., 2016a). Similar categorization was done by Galaitsi et al. (2018), who categorized 63 studies from the literature into those focused on modelling physical systems, analysis of governance and management systems, and direct support of decision or policy making.

Despite these recent developments in academic research emphasizing the biophysical and social sciences, relatively little is known about the extent to which the perspectives of researchers and stakeholders in a given hotspot converge over resource related issues (Figure 4.1). In this paper, we use the case of the water-energy-food nexus hotspot in the region of San Antonio, Texas, USA, and the research groups at Texas A&M's Water Energy Food Nexus Initiative (WEFNI, 2018), to develop a better understanding of the gap between researchers and stakeholders and identify areas in which convergence, or lack thereof, exists.

This paper specifically: 1) evaluates the *level of convergence* between researchers and regional stakeholders perspectives regarding San Antonio Region's water, energy, and food challenges; 2) quantifies the existing *level of communication* of both groups of respondents (researchers and regional stakeholders) with identified WEF organizations in the region; and 3) identifies *barriers to and opportunities for improving communication* between the WEF organizations and the researchers involved.

4.2. Convergence Theory

Convergence theory first originated in the 1960's, where it was suggested that as societies industrialize and grow, common societal patterns would emerge, eventually resulting a uniform global culture (Rostow, 1959; Kneissel et al., 1974). That discussion was especially present in the context of the evolution of socialist and capitalist economic systems (Tinbergen, 1961), and the prediction that revolutions at the time would not be able to create new economic systems, but rather that convergence would happen (Kneissel et al., 1974). Later research in new sociological institutionalism explored convergence and divergence in the context of institutional changes (Di Maggio and Powell, 1983), and explored different mechanisms including power, attraction and competition (Bechert, 2010) which argue to result in institutional isomorphism.

According to the body of comparative politics literature, one way convergence is defined is “the tendency of societies to grow more alike, to develop similarities in structures, processes, and performances” (Kerr, 1983). Subsequently, convergence between different groups was been examined in several topical areas, including natural resource governance. For example, Bergendahl et al. (2018) emphasize the importance of convergence of actions taken by engineering, science, and business partners to yield Food-Energy-Water technological innovations to address complex resource problems of the 21st century. Boon et al. (2014) highlight the importance of balancing convergence and divergence over different issues within transdisciplinary teams and emphasize the role of aligned incentive systems and low partner diversity to achieving higher effectiveness and satisfaction among those groups. Michaud-Létourneau and Pelletier (2017) investigate the areas in which key national leaders converge or diverge in relation to the coordination of a multi-sectoral plan for reducing chronic under nutrition in Mozambique. Their article is motivated by convergence as a prerequisite for coordination between multi-sectoral partners. Kronley and Kilgore (2016) examine the convergence of perspectives between students and faculty on issues related to student writing abilities using a survey sent to both groups and later quantifying the statistical significance of the differences in answers coming from the two groups to identify areas where gaps in perspectives exist. Convergence is considered to have a temporal dimension, reflecting movement from different positions to a common point over time (Bennett, 2018); although Bennett acknowledges that convergence is also used as a synonym for similarity or uniformity in comparative policy literature.

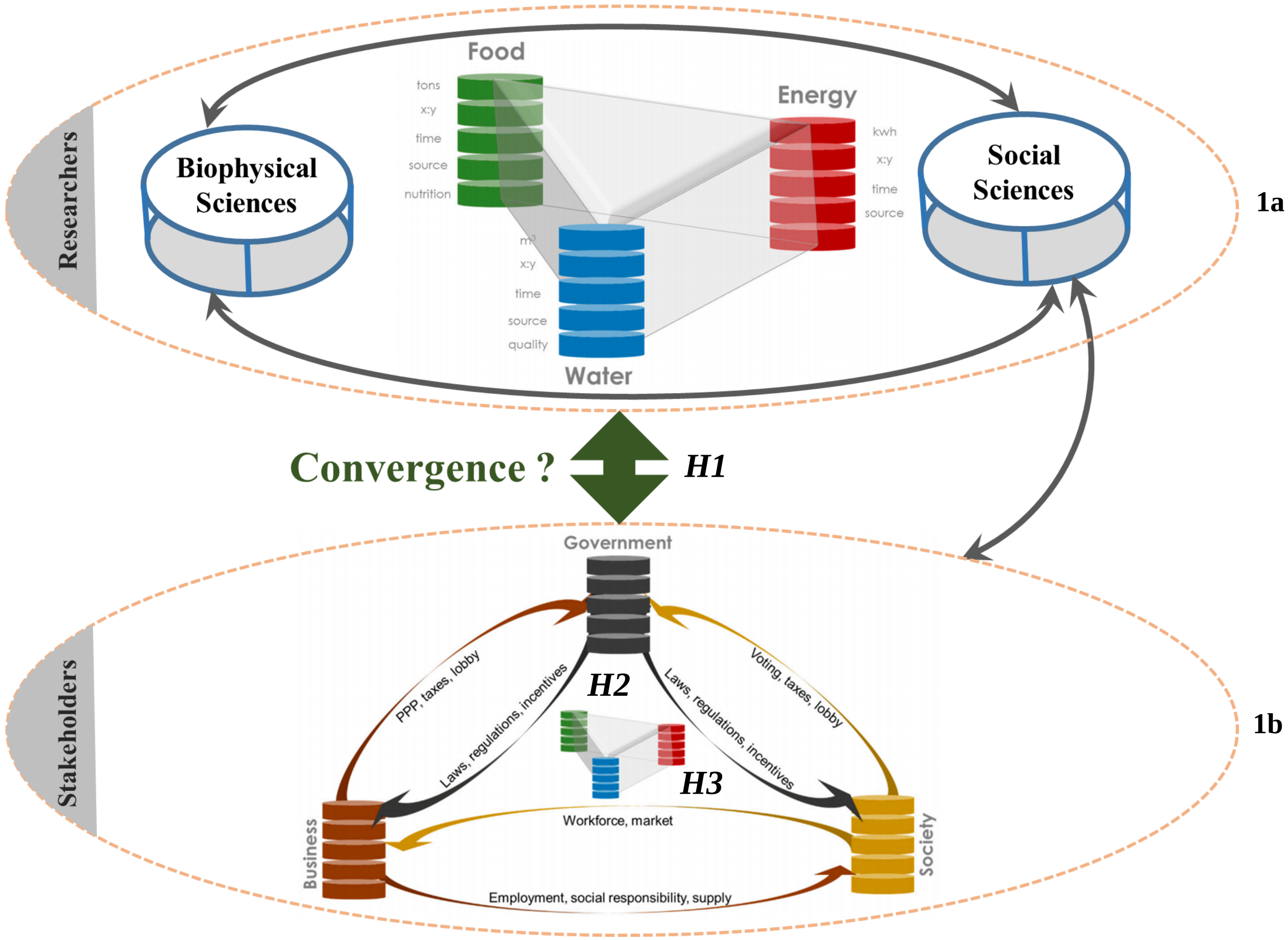

Figure 4.1 Gap in studies on difference in perspectives between academics and stakeholders on issues related to water, energy and food issues. Adapted from (Daher et al. 2018)

This paper will not look at the convergence between perspectives over different time periods, but rather a static reflection of the difference between perspectives at a point in time. In this paper, we also do not focus on the level of convergence within researchers, and within regional stakeholder's responses. The goal is to identify areas in which researchers and regional stakeholders do not converge, as reflected in a survey about their perspectives and preferences regarding issues related to managing water, energy, and food resources in the San Antonio Region. This considers that aspects of convergence exist between researchers and stakeholders over different topics in cases where no statistically significant difference exists between their responses. As researchers work towards operationalizing WEF nexus concepts and frameworks into technical and policy recommendations, it is important to engage the multi-sectoral stakeholders involved and ensure any research or recommendations are consistent with the nature of the challenges faced by the stakeholders. Furthermore, it is important for stakeholders to understand and be aware of the areas in which convergence of perspectives, or lack thereof, exist with researchers studying the issues related to the challenges they face as the stakeholders make decisions regarding future resource allocations. Having information on convergence of direction or perspectives would contribute to providing such insight for both groups.

4.3. Resource Hotspot: San Antonio Region, Texas

The San Antonio Region, also known as Region L, is one of 16 water planning regions in Texas (TWDB, 2017). It is home to a growing, rapidly urbanizing population (Zhao et al., 2016), has major agricultural activity surrounding the city (Odintz, 2010), and lies over the Eagle Ford shale play - with its growing production of oil and natural gas due to hydraulic fracturing technology (Mohtar et al., 2018). San Antonio region also represents a resource hotspot whose stakeholders compete across sectors for the same limited water, land, and financial resources (Daher et al., 2019) in a region whose projection trends indicate continued growth across those sectors (Portney et al., 2017b). To effectively address future resource challenges and ensure sustainable urbanization, it is essential that stakeholders are aware of the interdependence of their decisions. It is also important that stakeholders are able to evaluate the extent to which possible technological, policy, or social interventions can reduce resource stresses and address the complex resource challenges faced. Each sector must better understand the interlinkages and tradeoffs as they relate to their own sector, and must also contribute to catalyzing the initiation of dialogue among the stakeholders (Mohtar and Daher, 2016). Such dialogue creates opportunity for holistic, sustainable allocation decisions, while potentially reducing unintended consequences and competition across sectors.

The Texas A&M Water-Energy-Food Nexus Initiative (WEFNI) was created in 2015 with the goal of initiating such an effort to better understand the complexities of the regional resource hotspot (Mohtar and Daher, 2019). The initiative identified and developed six sub-groups to better understand the different dimensions of the hotspot: data and modeling, trade-off analysis, water for food, water for energy, energy for water, and governance and financing. Following the research activity of the interdisciplinary sub-groups and building on a series of research-based workshops, the initiative convened a "Stakeholder Engagement Meeting" in San Antonio. During the meeting, WEF stakeholders representing governmental, non-governmental, and business organizations from the Region received the preliminary findings and recommendations from the research (Rosen et al., 2018). The meeting also provided the opportunity to distribute a survey to researchers and invited regional stakeholders, in an effort to learn about their perspectives towards issues related to water, energy, and food security in the region. Gaining insight about the issues over which the perspectives of researchers and regional stakeholders converge or not, would allow researchers to identify areas in which they might be mischaracterizing the issues or challenges facing stakeholders from the region and would provide stakeholders needed information about the areas studied. Such information could potentially be considered while making decisions related to future resource allocation in the region.

4.4. Hypotheses and rationale

To elaborate the need to address various levels of convergence on water, energy, and food related issues, we examine the following hypotheses. "*Researchers*" (R) in this context are those who are part of the WEF Nexus Initiative, and are involved in studying the San Antonio region as a resource hotspot. *"Researchers"* also include other academics coming from different institutions in Texas and were on the WEFNI mailing list. "*Regional Stakeholders*" (RS) are the water, energy, and food actors from the San Antonio Region.

HYPOTHESIS 1: The perspectives of researchers and regional stakeholders from San Antonio converge over issues related to water, energy, and food in the region**.**

In the first hypothesis, we examine the extent to which there is convergence in perspectives between researchers and regional stakeholders over the following ***six elements***:

1. extent of interconnectedness between water, energy, and food in the region;
2. level to which local agencies need to cooperate across issues of water, energy, and food;
3. current relative priorities of water, food, and energy in the San Antonio region, and what they should be in the future;
4. level of concern towards future water availability, energy security, and food security in the region;
5. level of familiarity with the Texas Water Development Board's water supply strategies for the San Antonio Region in the 2017 State Water Plan; and
6. potential of different Texas Water Development Board strategies in meeting the Region's water needs in the coming 10 years.

This hypothesis and series of sub-hypotheses draw from the public policy literature, for the theory of convergence (Drenzner, 2001; Knill, 2005; Heichel et al., 2005). It assumes that researchers studying different resource challenges in the region have an understanding of those challenges and a degree of convergence due to input from different stakeholders through various formal and informal participatory and engagement processes over the years. This hypothesis also assumes that stakeholders in the region are aware the public research being developed within the academic sphere through different forms information exchange and this contributes to greater convergence over time.

HYPOTHESIS 2: Researchers have a lower level of communication with water, energy, and food stakeholders from San Antonio than do the stakeholders among themselves.

In the second hypothesis, we examine the extent to which the type of organization a respondent works in impacts the frequency of communication with different water, energy, and food stakeholders in the region.

H2a. Respondents who reported working at *non-academic organizations* have a higher level of communication with water, energy, and food organizations in San Antonio than those who reported working at *academic institutions*.

H2b. Respondents who reported working at *organizations with a single disciplinary focus* (water, energy, or food) have a lower level of communication than respondents who reported working at *organization with focus on a combination of two or three of the resources* (water, energy, and food).

H2c. Respondents who reported working at *governmental organizations* have a higher level of communication with stakeholders from San Antonio than those working at *businesses* or *non-profit organizations* in the region.

Hypothesis 2 draws on the theory of homophily (McPherson and Smith-Lovin,1987;McPherson et al., 2001) and its relation to communication (Rogers and Bhowmik, 1970), suggesting that people who work at similar type of organizations are likely to communicate among each other at a rate that is higher, than their rate of communication with those from different type organizations.

HYPOTHESIS 3: Researchers converge with regional stakeholders from San Antonio around ways in which greater cooperation might be achieved between water, energy, and food organizations in San Antonio Region.

While stakeholders within different cross-sectoral organizations might realize the need for better communication and cooperation as they plan for the future allocation and management of the region's resources, barriers at various levels may exist that challenge such communication and cooperation from happening. These barriers could be financial, legal, or the result of lack of proper institutional mechanisms that facilitate or improve cooperation (Daher et al., 2019). This hypothesis similarly builds on the theory of convergence, as in Hypothesis 1, exploring the extent to which researchers and regional stakeholders converge over what they view as the main barriers to better cooperation and ways in which it could be improved.

4.5. Methodology

4.5.1. Stakeholder identification, classification, and relationships

Different methods exist for stakeholder identification, classification, and analysis. In this study, we use a ***survey, snowball sampling*** and ***scoping studies*** to identify and classify stakeholders, and to seek their input. We also use ***social network analysis*** to understand stakeholder relations. The following section outlines the methods by which each was done (Figure 4.2).

4.5.1.1. Stakeholder Definition: Who are we considering as "Stakeholders"?

Several definitions exist for a stakeholder (Freeman et al., 2010). In this study a **stakeholder** is a person at an entity/organization/ institution who makes decisions that have impact on water, energy, and/or food/agriculture in the San Antonio Region. These can be governmental, business, or civil society organizations. Throughout this paper we refer to the stakeholders who responded to the survey as “regional stakeholders”. We refer to the 97 water, energy, and food organizations identified in the San Antonio Region as “WEF Organizations”.

4.5.1.2. Stakeholder Identification

Stakeholders were identified through input from the Organizing Committee for the WEFNI workshop, snowball sampling, and scoping:

WEFNI Workshop Organizing Committee Contacts: The Water Energy Food Nexus Initiative (**WEFNI, 2018**) at Texas A&M University with National Science Foundation sponsorship, organized a workshop titled: “Water-Energy-Food Nexus (WEF) Stakeholder Information and Engagement Workshop” (Jan 10, 2018). The workshop included invited leaders from diverse technical, academic, research, and business backgrounds in the water, energy, and food sectors and from the San Antonio Region. The workshop organizing committee included members of the WEFNI leadership team actively engaged in the San Antonio Region. A total of 370 names across different water, energy, and food institutions within governmental, business, and civil society, in addition to academia, were suggested. The researchers invited to participate included those actively involved in the research in the different WEFNI research subgroups, and others who had subscribed to the WEFNI mailing from different departments at the Texas A&M San Antonio, College Station, Kingsville, and Corpus Christi campuses and University of Texas San Antonio and Austin.

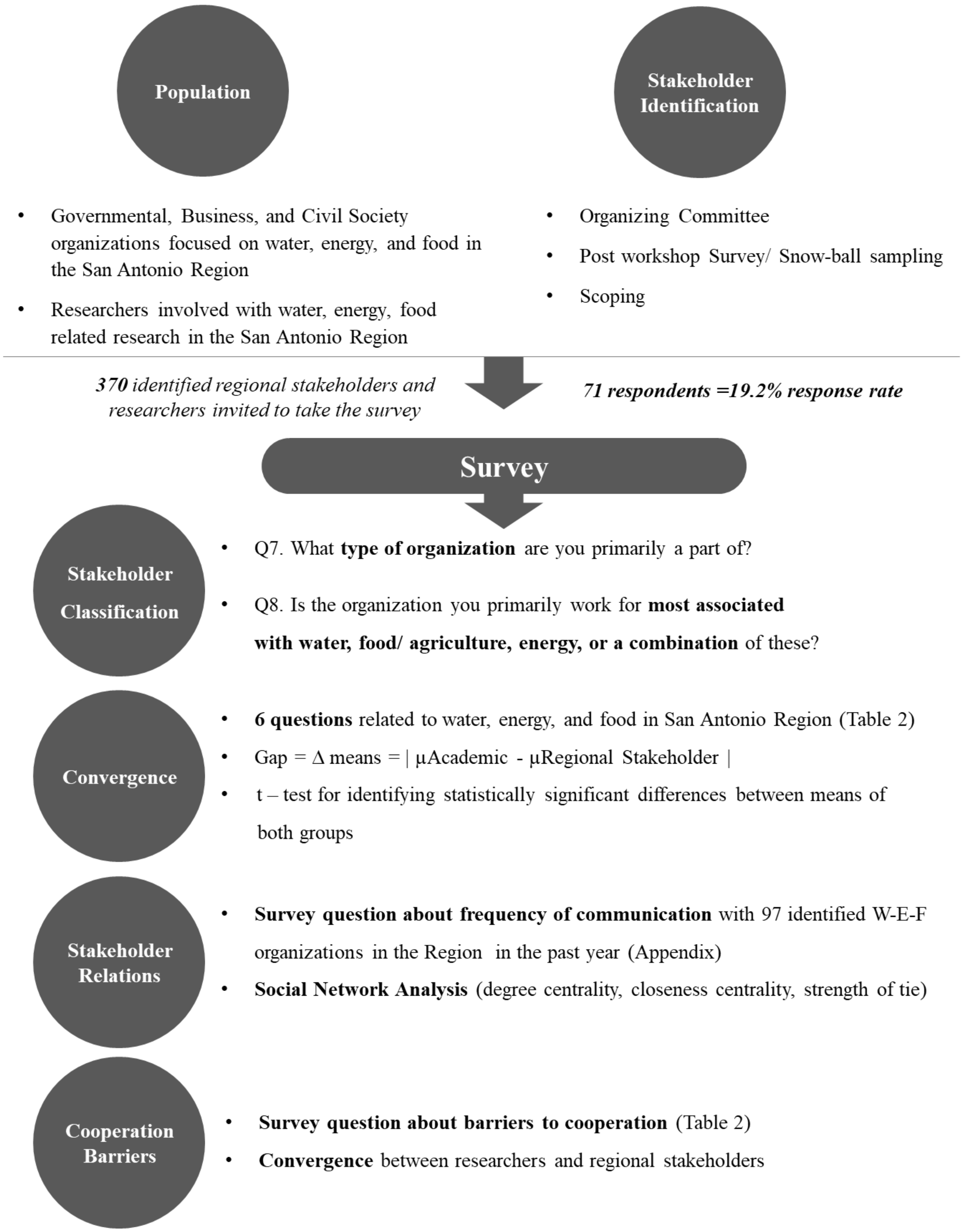

Figure 4.2 Methodology Summary

Web search for organizations and contacts – scoping: Additional water, energy, and food stakeholders from the San Antonio region were identified through a web search of organizations and key personnel actively working in related WEF areas supported the Organizing Committee in identifying the 370 invited people. Scoping was used to identify water, energy, and food stakeholders to be included in the survey. The list of 97 WEF Organizations in the survey (**Appendix E**) builds on a similar list developed by Portney et al (2017) that identifies major water, energy, and food stakeholders in the San Antonio Region.

Suggested stakeholders from survey respondents – snowball sampling technique seeks suggestions from existing study subjects to recruit future subjects (Goodman, 1961). This insures sample inclusivity by not missing unidentified stakeholders who should be included in the study. Those who attended the stakeholder engagement workshop were requested to complete a post workshop questionnaire that included a question about identifying names of other stakeholders not seen at the workshop but whom they consider important to be involved: *"Are there others whom you think we should add to our list of stakeholders?"* A total of 12 responses to the post workshop survey (response rate 13.6%) were received and included names of organizations already on the initial list of invitees, thus, no additional invitations were sent.

4.5.1.3. Stakeholder Classification

The list of stakeholders and their affiliated institutions were categorized as *researchers* and *regional stakeholders*. Regional stakeholders were later asked, as part of the survey, to self-identify the type of institution (governmental, nonprofit/nongovernmental, or business) and its focus (on water, energy, or food). Stakeholders at organizations with a focus that cuts across multiple resource systems where classified as “cross-cutting” and include, for example, the office of the mayor. The authors’ judgment was used to initially classify which category best represents each organization. As part of the survey, stakeholders were asked to self-identify how they best categorize their organization and their area of primary focus of work (Table 4.1). This was done using questions 7 and 8 (Table 4.2).

4.5.2. Survey

A survey was sent to WEFNI workshop invitees and 71 responses were received (19.2% response rate); 88 attended the workshop (24% attendance rate). Those who attended the workshop without responding to the survey were not included in further rounds of reminders. The authors did not want the stakeholders to respond to the survey after being influenced with the workshop discussions on the water-energy-food nexus in the region.

Table 4.1: Summary of self-identified categories for the type of institution of survey respondents and workshop attendees

		SURVEY RESPONDENTS	WORKSHOP ATTENDED BY
By type of organization	Governmental (G)	14	19
	Non Profit (N)	11	13
	Business (B)	14	15
	RESEARCHERS	32	41
By area of focus	Water	21	33
	Energy	4	6
	Food	5	13
	Cross-cutting	41	36
	Total	**71** /370 (19.2%)	**88** /370 (24%)

4.5.2.1. Measuring convergence

In this paper, we adopt a method similar to Kronley and Kilgore (2016) in examining the level of convergence between both groups.The difference in means of the answers by researchers and regional stakeholders to each of the six questions (Q1-1 to Q1-6) is quantified and compared. An independent samples t-test was conducted representing both sets of responses. If the difference in means is statistically significant for a specific question, we conclude that there is no convergence on that issue. If the difference between means is not statistically significant, we fail to reject the null hypothesis (i.e. that both perspectives converge). The answers to each question were first recoded. For exampe, in Q1-1, the answers “Very Low”, “Low”, “Moderate”, “High” and “Very High” were recoded into 1, 2, 3, 4, and 5, respectively. A similar recoding was done for Q1-2 and Q1-6. For Q1-4 and Q1-6, no recoding was needed, as respondents were given a 0-10 and 1-5 scale, respectively.

$$\textbf{Gap} = \Delta \text{ means} = | \mu_{\text{Academic}} - \mu_{\text{Regional Stakeholder}} |$$

4.5.2.2. Social network analysis metrics: measuring degree, closeness and strength of tie

Social network analysis was used to visualize and understand the strength of relations between different stakeholders. From the developed network, we leaned about the degree and closeness centrality of different stakeholders. *Centrality* provides information on stakeholders most connected with others and distinct aspects of connectiviety within the network. A highly centralized network is characterized by a few stakeholders with the majority of ties with others in the network (Prell at al., 2009; Zhu, B. and Chen, H., 2010). Bavelas (1948) introduced the idea of centrality as it applies to human communication. According to Prell et al (2009), stakeholders with high *degree centrality* can be looked at as key players to mobilize the network, with the ability to bring other stakeholders together (Proctor and Loomis, 1951; Freeman, 1978). Degree centrality is simply the sum of ego's, or the focal actor's, direct ties to other actors in the network. It is defined as:

$$\text{degree}_{\text{i}} = \sum_{j} x_{ij}$$

where *i* represents the actor and x_{ij} is the (*i*, *j*) entry in the adjacency matrix, or the value of the tie between *i* and *j*.

Closeness centrality is another measure for centrality in a network, and is calculated as the sum of the shortest paths between a given node and all other odes in the netowork (Bavelas, 1948). Closeness examines how "close" an actor is to all other actors in the network. Summing the total number of geodesic paths between a focal node and all other actors may be influential in the transmission of information because it is generally interpreted as an amount of time until whatever is flowing through the network arrives at the focal node (Borgatti 2005). Nodes that are closer (with lower scores) have short distances from others and may be well-positioned to obtain the information earlier than those on the periphery of the network.

$$C_c \ (i) = \sum_{j=1}^{n} d_{ij}$$

where d_{ij} is the distance to connect actors *i* and *j*. Closeness assumes that whatever flows through the network does so along the shortest path.

Strength of tie will be measured in the networks and represents the frequency of communication between different nodes (Sheng et al., 2013). The strength of tie is important: it allows us to gauge the level of connectedness in the network. Tie strength varies for a number of reasons. Here, very infrequent information sharing represents a weak tie and more frequent information represents a stronger tie. Strength of tie is represented as valued degree centrality, or the total number of connections for each actor in a given network. The frequency of communication indicated by respondents to Q2 is represented by the average of their frequency of communication with different institutions. A larger number of 0's (meaning, no communication) indicates a lower level of communication with other institutions. The average value representing that level of communication ranges between 0 and 5. The closer to 0, the less communication that respondent has with others from different institutions. Conversely, the higher the average, the greater the communication. (Daily: 5, Weekly: 4, Monthly: 3, Once every three months: 2, Once a year: 1). Statistical tests (t-test for two samples with unequal variances) were conducted to identify the sigificance of any difference in results between the researchers and regional stakeholder respondents.

Table 4.2 Summary of hypotheses and respective survey questions

Hypothesis 1: The perspectives of researchers and regional stakeholders from San Antonio converge over issues related to water, energy, and food in the region**.**	Q 1-1. ***To what extent*** *do you think water, energy, and food* ***resources are connected*** *to each other?* Q 1-2. *In general,* ***to what extent*** *do you think that agencies and* ***organizations should collaborate, coordinate, or cooperate*** *across issues of water, energy, and food?* Q 1-3. *What do you see as the* ***current relative priorities*** *of water, food, and energy in the San Antonio region? What do you think the* ***relative priorities*** *of water, food, and energy should be for the San Antonio region* ***in the future****?* Q 1-4. *Overall, how concerned are you about* ***future water availability*** *in the San Antonio Region? Overall, how concerned are you about* ***energy security*** *in the San Antonio Region?* *Overall, how concerned are you about* ***food security*** *in the San Antonio Region?* Q 1-5. *How* ***familia****r are you with the* ***Texas Water Development Board's water supply strategies*** *for the San Antonio Region in the 2017 State Water Plan?* Q 1-6. *Please indicate* ***how much potential*** *you think each* ***listed strategy has*** *for managing water to help the San Antonio Region meet its water needs over the next ten years?*
Hypothesis 2: Researchers have a lower level of communication with water, energy, and food stakeholders from San Antonio than that of stakeholders among each other.	*Q 2. Over the last year, about* ***how often have you communicated*** *with any of these organizations, or decision makers from these organizations,* ***on issues related to water, energy, and food/agriculture planning*** *in the* ***San Antonio region****?*
Hypothesis 3: Researchers converge with stakeholders from San Antonio over ways greater cooperation could be achieved between water, energy, and food organizations in San Antonio Region.	*Q 3. In your view,* ***how could cooperation*** *across issues of water, energy, and food best* ***be accomplished****?*

4.6. Results and Analysis

4.6.1. Level of convergence in perspectives between researchers and regional stakeholders

One of the main aims of Hypothesis 1 is to learn whether researchers and regional stakeholders converge over a series of issues related to water, energy, and food resources in the region. We are also interested in learning whether convergence exists within each of the groups, researchers and regional stakeholders. In order to do that, we investigate whether the responses coming from both groups are statistically different. At a first glance, there are no significant gaps in answers coming from both groups to the given questions (Figure 4.3). Researchers and regional stakeholders seem to be in agreement over the extent water, energy, and food (WEF) resources are connected (Q1a), and the extent to which oragnizations need to cooperate over WEF related issues in the region (Q1b).

Both groups appear to agree about the current relative priorities in the region, with water first, followed by energy, then food (Q1c). While both groups agree that water needs to remain the number one priority in the future, reserchers rank food, then energy, as second and third priority, and regional stakeholders ranked energy as second and food as third, showing some disagreement on priorities. Researchers and regional stakeholders also indicate higher levels of concern about future water availability, followed by food security, then energy security (Q1d). Both groups also indicate similar low-moderate familiarity with the Texas Water Development Board water supply strategies (Q1e). After conducting t-tests for the different responses for each of the questions, no statistical signifiance in the difference of perspectives was found, indicating that aspects of convergance do exist between both groups’ perspectives about these six topics.

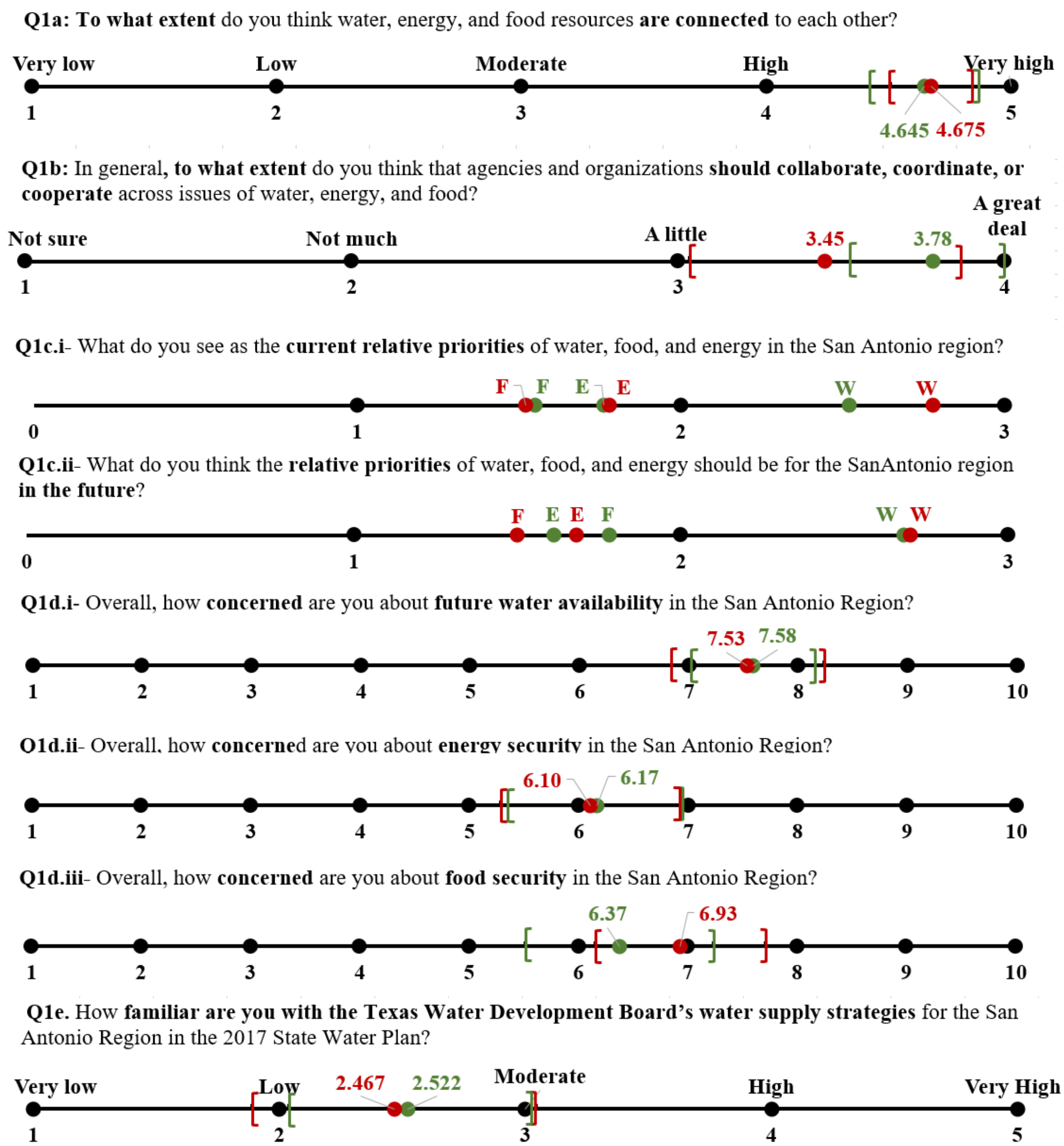

Figure 4.3 Summary of academic and regional stakeholder respondents to the survey questions

In addition to mapping the means of the responses of each of the researchers and the regional stakeholders, we calculate and map the 95% confidence interval for each, as shown in Figure 4.3. The confidence interval gives a rage of the most likey values for each group's responses. In addition to aiding in the identification of areas of convergence between both groups of respondents, the confidence interval also provides an indication of the level of convergence within each of the groups. A wider confidence interval is an indication of lack of convergence within the same group over a specific topic. For example, there seems to be more convergence within each of the regional stakeholder and researcher groups regarding their concern about future water availability, compared to concern about future energy and food security. This could be observed through the shorter confidence interval rage when asked about water availability, compared to others. Overall, given that the ranges of confidence intervals overlaps between both groups, and since those ranges are also within one answer difference (between 4 and 5 in Q1a, for example), we can conclude the presence of aspects of convergence within and between both groups over the six topics realted to water, energy, and food in the San Antonio Region.

The 2016 Texas Development Board Report outlines a list of water management strategies to meet projected water demands by 2070. It includes a list of strategies to increase supply and reduce demand in an effort to address challenges projected to face the water system in the coming decades. In response to this question, both groups indicated similar views about the potential of different strategies in the list (Figure 4.4).

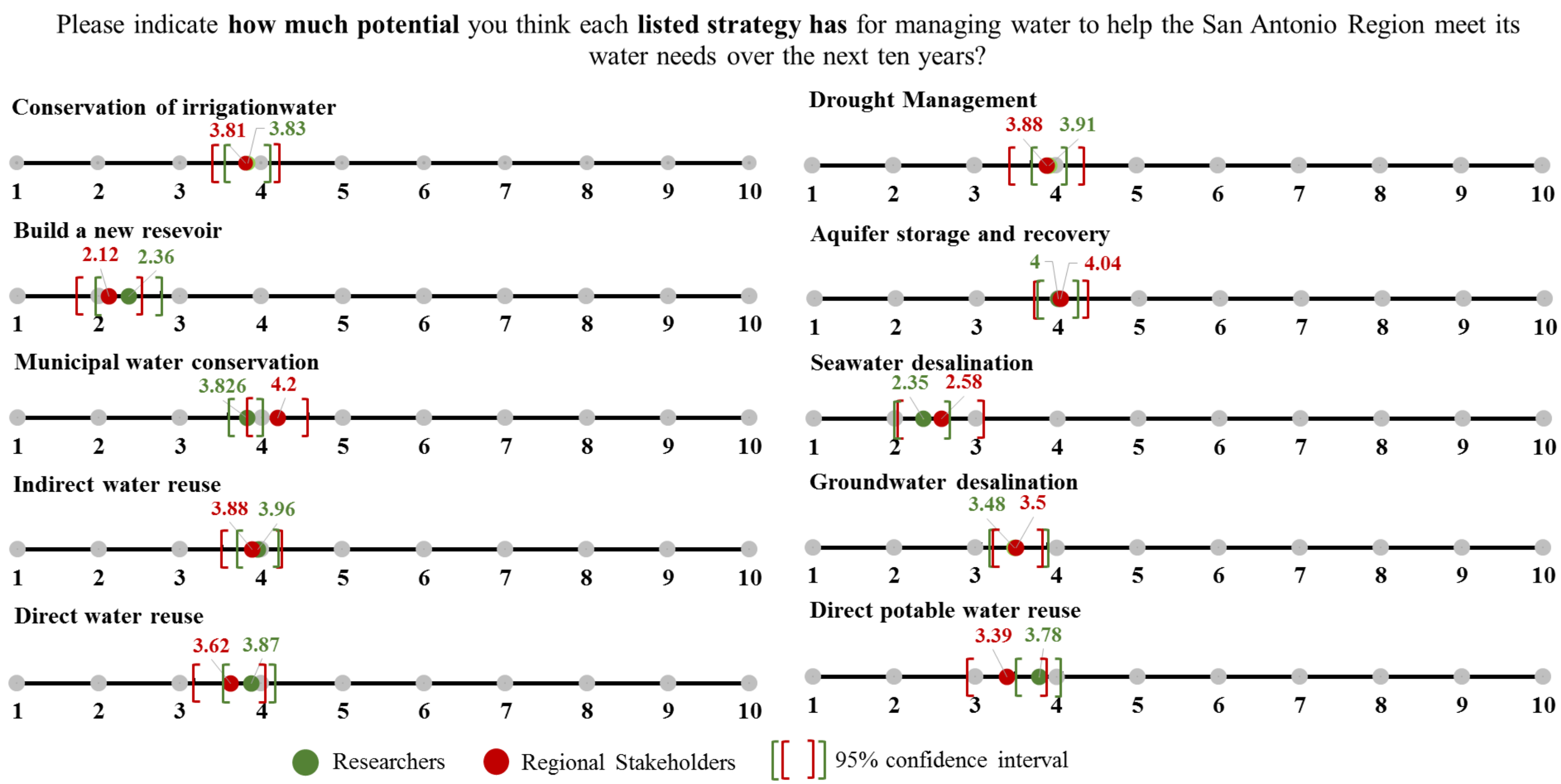

Figure 4.4: Summary of responses regarding the potential of different TWDB strategies

Researchers indicated *"aquifer storage and recovery"* followed by *"indirect water reuse"* as the top management strategies with greatest potential. Regional stakeholders indicated *"municipal water conservation"* followed by *"aquifer storage and recovery"*. Both groups agree that *"building a new reservoir"*, is a management strategy with the least potential in meeting San Antonio's water needs in the next 10 years. We similarly conduct two-sample t-tests to identify whether the differences in responses from both groups are statistically significant. For all strategies, we fail to reject the null hypothesis for equal means, at 95% confidence level. According to this analysis, there is insufficient evidence to conclude lack of convergence between both researcher and regional stakeholder groups regarding the potential of TWDB's regional water strategies.

4.6.2. Level of communication

Fifty five (55) of the 71 survey responses completed the network question (Question 2), asking about the frequency of the respondents' communication with the 97 identified water, energy, and food organizations from the San Antonio Region (**Appendix E**). In addition to responses to this question, we used network analysis metrics to identify central players and communications. In Figure 4.5, "communication" includes any frequency of communication (daily, weekly, monthly, once every 3 months, and once a year), compared to "no communication" at any frequency, in the past year. We notice an overall modest level of communication between different categories of respondents with the water, energy, and food organizations from the region. Twenty five (25) researchers and thirty (30) regional stakeholders answered the network question. A higher level of communication between regional stakeholders compared to that between researchers and the 97 water, energy, and food organizations was reported. This was confirmed after conducting a t-test showing a statistically significant difference between both ($p = 0.0461 < 0.05$).

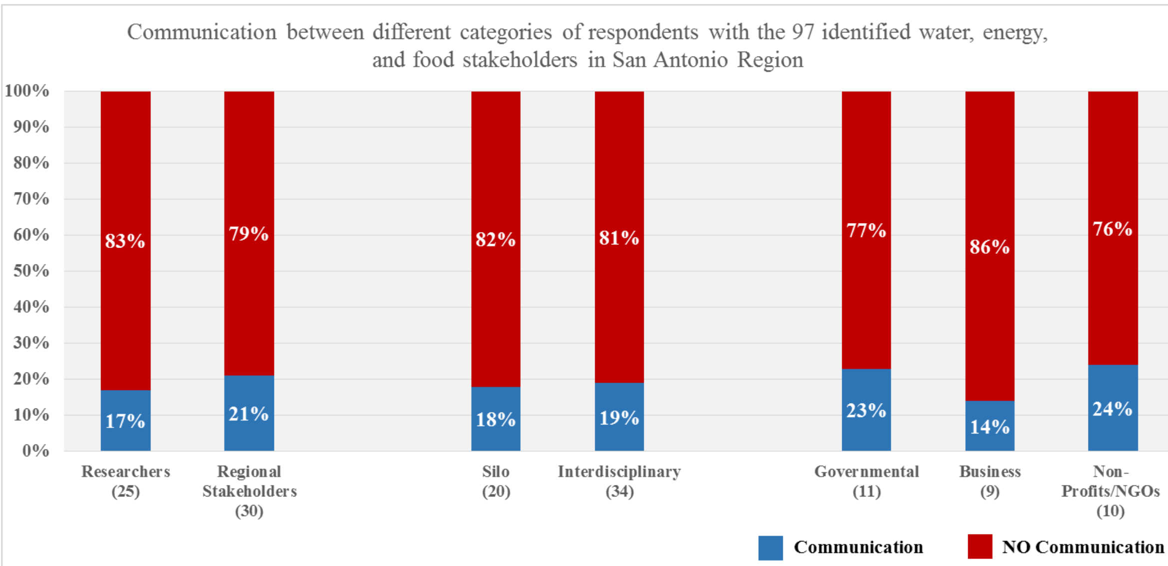

Figure 4.5: Communication between different categories of respondents with the 97 identified water, energy, and food stakeholders in San Antonio Region

The 20 respondents who self-identified in their answer to Q.8 (**Appendix D**) to be working for an organization with either a water, energy, or food focus were considered "silo" focused. The other 34 respondents who identified doing a combination of water, energy, and food were considered as "inter-sector/discipline" focused. A similar frequency of communication is reported by both groups (Figure 4.5), and was confirmed by the t-test, which indicated no statistically significant difference between both groups ($p > 0.05$).

In Q7 (**Appendix D**), respondents self-identify the type of organization they worked at. Here we see that those who work at business organizations have a lower level of communication with San Antonio stakeholders, compared to governmental and non-governmental/non-profit organizations. After conducting pair-wise t-tests between the three groups, we fail to reject the null hypothesis for equal means, and conclude no statistically significant difference between their responses.

4.6.2.1. Network Mapping and Metrics

In this section, the responses to Question 2 are used to identify central actors and visualize their frequency of communication with the 97 water, energy, and food organizations from the region. The visualizations below represents a bipartite network matrix of communication among involved organizations. Each survey respondent is represented by a different color circle, according to their respective category. The 97 WEF organizations in the survey are represented by grey squares. Each line connecting between two nodes, an edge, represents some level of communication. We distinguish the different frequencies of communication through line thicknesses (Figure 4.6). The size of the node (circle or square) is an indication of the centrality of the stakeholder: larger size signifies a higher number of connections or higher centrality.

As seen in Figure 4.6, there appears to be a higher number of regional stakeholders (red), compared to researchers, who are central to the network. A similar result is demonstrated in Table 4.3. Researchers show lower levels of monthly and weekly communication by both network measures (degree and closeness). San Antonio River Authority appears one of the most central and connected stakeholder in the network. Eco Centro - San Antonio

College also appears to be the most central research/academic player in the network. Some of the major stakeholders which emerge from this network are Texas Commission of Environmental Quality and River Authorities as well. We limit the network map to monthly, weekly, and daily communications in order to identify most frequent communicators in the network.

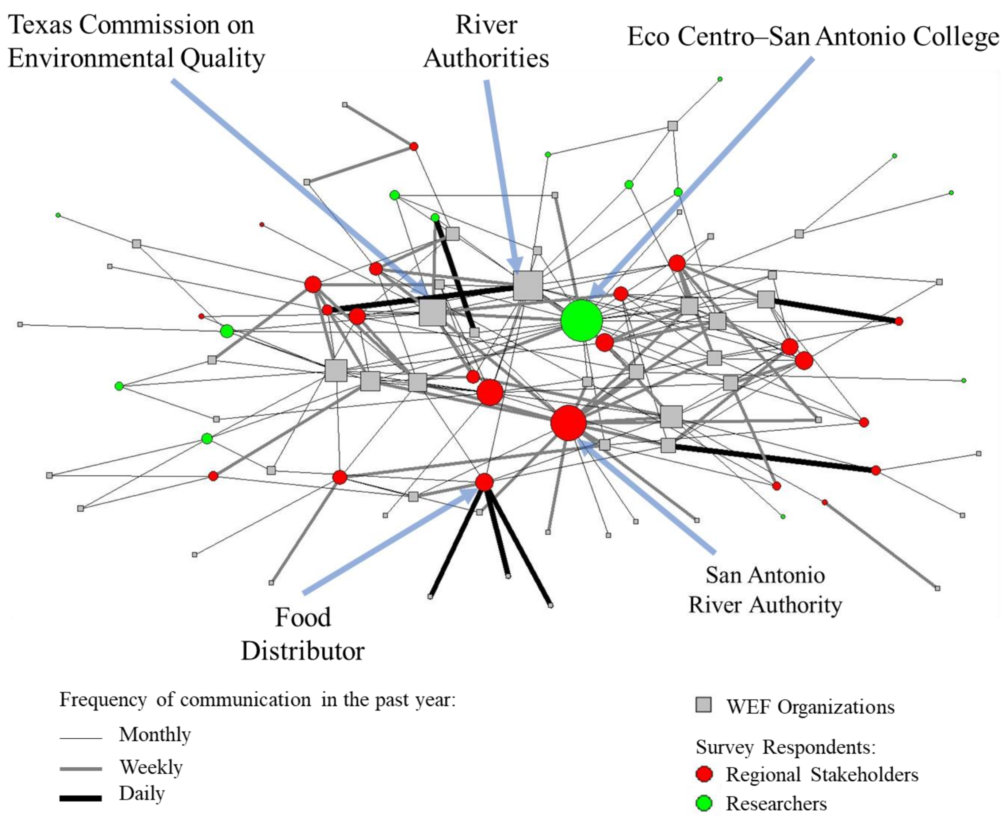

Figure 4.6: Network map for daily, weekly, and monthly communication of researchers and regional stakeholders with regional WEF stakeholders

Table 4.3 presents some descriptive characteristics from the network measures. The primary takeaway is that as frequency of communication increases, network structure dissipates or may begin to break down. The total number of ties in the communication network supports this statement, where the total number decreases from 422 to 112 from monthly to weekly communication. This is perhaps, expected, given there is no assumption or expectation that network actors should be communicating weekly or daily. As stated, the frequency of communication omits any details on the quality or qualitative aspects of the discussion. Figure 4.7 examines the communication network of those organizations who identified having a single disciplinary focus (Silo) and a multiple disciplinary focus (Inter) with other regional WEF stakeholders. As seen in the figure, there does not appear to be one centralized group in the network and this is reflected in monthly communication in Table 4.3, where there is very little difference between the monthly metrics.

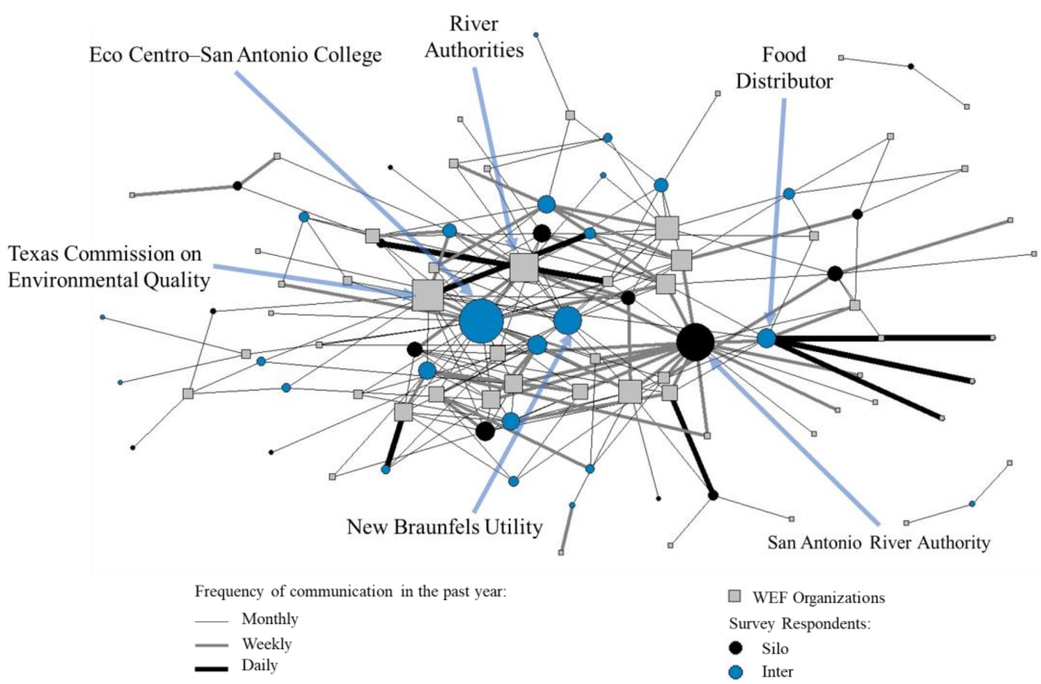

Figure 4.7: Network map for daily, weekly, and monthly communication of respondents self-identifying as working within a single disciplinary focus versus others who identified having interdisciplinary focus, with regional WEF stakeholders

Table 4.3 Mean Frequency of Monthly and Weekly Communication

	Degree		Closeness	
	Monthly	**Weekly**	**Monthly**	**Weekly**
Researchers	2.48	0.2	982	1208
Regional stakeholders	4.65	1.59	904	1146
Silo	3.93	1.67	905	1137
Inter	3.62	0.74	951	1186
Governmental	5.27	1.73	919	1131
Business	3.22	1.11	938	1168
Nonprofit/NGO	5.13	1.8	839	1150

For the weekly communication, however, “silo” organizations communicate with a higher number of other organizations as shown by the higher degree centrality. What is unclear however, is whether these silo-ed organizations are communicating with other silo-ed organizations or if they are reaching out to a broader pool of natural resource managers.

Figure 4.8 is a visual representation of the communication network for government, nonprofit, and business organizations. As also seen in Table 4.3, there does not appear to be a significantly higher level of communication for any singular category of organization. It is interesting to note that while some overall network measures are low, there are a few organizations involved in frequent communication with each other.

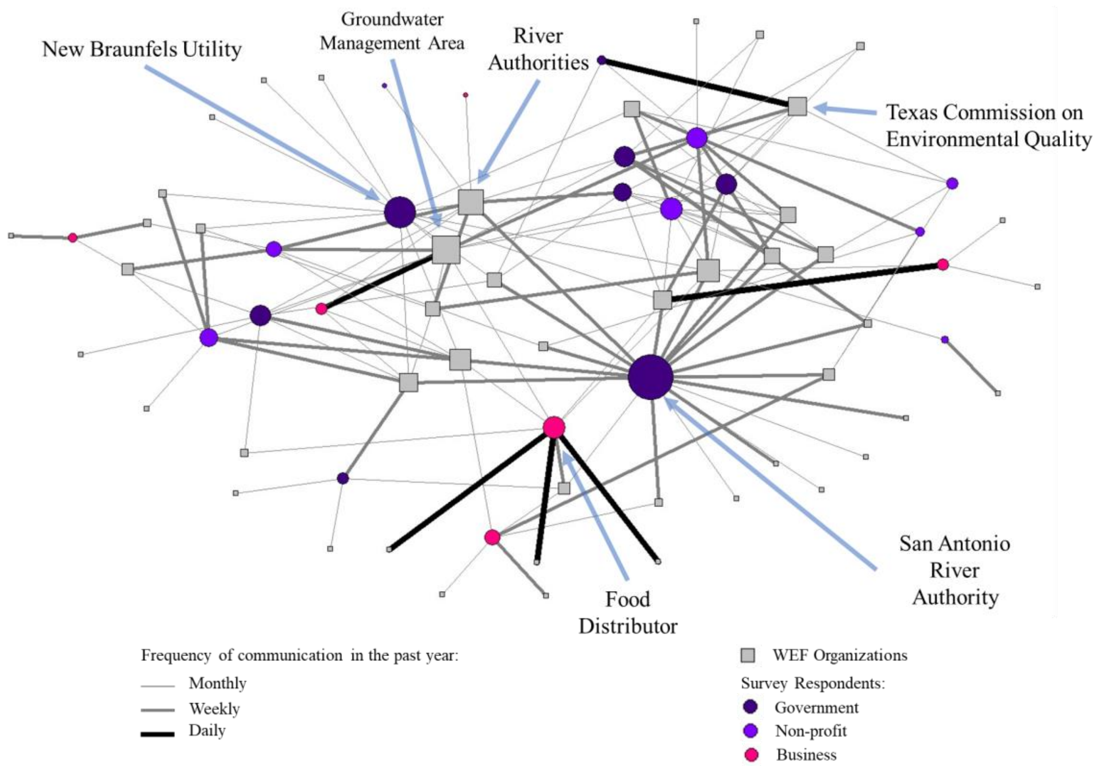

Figure 4.8: Network map for daily, weekly, and monthly communication of governmental, non-governmental/non-profit, and business stakeholders who respondent to the survey, with regional WEF stakeholders

For example, the food distribution service company in Figure 4.8 communicates weekly with aquifer authorities, as well as with the state general land and public utility offices. We further observe that weekly communication occurs between respondents and large engineering firms, the San Antonio Office of Sustainability, regional planning authorities, river authorities, groundwater conservation districts, Texas A&M extension services, among others. While we do not know the qualitative aspects of the communication and overall levels of communication are relatively low, we can suggest that there are some important organizations concerned with governing water, energy, and food in the region that are in frequent communication.

4.6.3. Identification of barriers for improved cooperation

As part of the Water-Energy-Food Nexus (WEF) Stakeholder Information and Engagement Workshop (WEFNI, 2018), participants were asked: *"In your view, how could cooperation across issues of water, energy, and food best be accomplished"?* 71 responses were recorded. Respondents were given the option of selecting multiple responses. The answers to this question tied between "sharing information" and "improving communication among existing agencies" (Figure 4.9). We noticed aspects of convergence between researchers and regional stakeholders over their perspectives on ways to cooperate across sectors. Another question asked participants about identifying 2 or 3 most important impediments to agencies and organizations collaborating over issues of water, energy, and food? Answers highlighted a lack of sufficient communication, silos mentality, lack of common goals and collaborative projects, lack of incentives to collaborate, and lack of institutional mechanism to cooperate. Specifically those answers included: "lack of understanding across the topic and a lack of understanding of what each organizations current or potential role", "bureaucratic silos, time and focus", "working in silos, not communicating enough, not speaking each other's language", "traditional silo mentality and organizational hierarchies", "lack of shared information and lack of incentives", "regulatory silos, territorial attitudes, lack of understanding", "lack of incentives to collaborate; lack of institutional mechanism to cooperate", "lack of communication and competing goals between agencies".

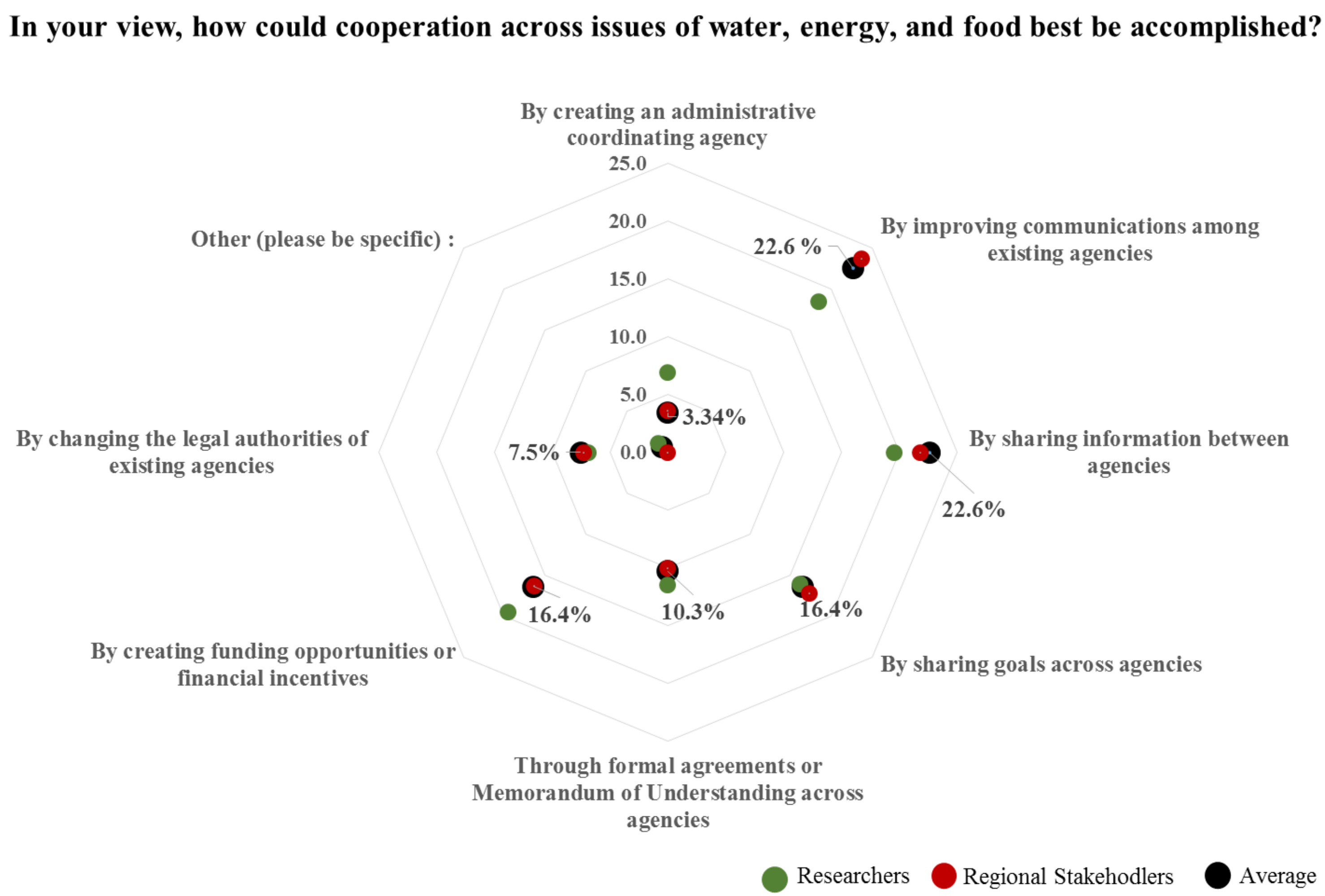

Figure 4.9: How cooperation could across issues of water, energy, and food best be accomplished

4.7. Discussion

In this section we discuss the main results from the analysis in the previous section. It may be worth emphasizing that the analysis and conclusions about convergence and communication discussed are specific to the context in this case study and not necessarily representative of the broader trends of convergence and communication within, and across, research and regional stakeholder groups elsewhere. However, the methods used in this study, could be replicated and customized, to learn about similar trends across different resource hotspots.

4.7.1. On the level of convergence between researchers and regional stakeholders

Survey results show aspects of convergence between researchers and regional stakeholder perspectives about the 6 investigated elements related to water, energy, and food in San Antonio. The group of responding researchers seems to differ with the group of responding stakeholders about the current and future priorities of the region, while agreeing that water is a top priority, currently and in the future. This could be attributed to a larger number of researchers coming with water and agriculture focus. This could also be a reflection of the stakeholders' views of the importance of the energy sector and its contribution to the state's economy, thus keeping it at a higher priority than agriculture and food security. Regarding the Texas Water Development Board strategies and their potential, Researchers identified "aquifer storage and recovery", followed by "indirect water reuse", while Regional Stakeholders identified "municipal water conservation", followed by "aquifer storage and recovery", as strategies with the highest potential to support San Antonio in meeting its water needs in the coming 10 years. We can conclude aspects of convergence over the high potential of "aquifer storage and recovery". Both groups also covered over the least potential of "building new reservoirs". As researchers work towards modeling and assessing the sustainability of future alternatives for bridging the water gap in Texas (Daher et al. 2019) and San Antonio, these inputs from regional stakeholders need to be taken into account. That would result in the development of recommendations and analytics which would support and catalyze a stakeholder dialogue around trade-offs resulting from different resource allocation pathways moving forward.

4.7.2. On the level of convergence within researchers and regional stakeholder groups

While analyzing the results of this survey, ***we noticed aspects of convergence, at varying levels, in the responses from within researchers and within regional stakeholders.*** That was represented by the 95% confidence interval that varied in range across different issues. Given the complexity and interconnectedness of the resource challenges facing the region, the diverse sets of goals and priorities, and the diversity within researcher groups and regional stakeholders, it is expected that some level of divergence is observed, even within the same *group*. This *inter-group* convergence within researchers could be improved by supporting further interdisciplinary projects and developing teams of researchers across different faculty and disciplines to allow the chance to debate, discuss and arrive to a consensus on ways to research and develop solutions to address the complex and interconnected resource challenges. *Inter-group* convergence among regional stakeholders could be improved by ensuring proper representation across sectors at resource planning meetings and stakeholder engagement activities, which could also be facilitated and supported by researcher groups.

4.7.3. On the level of communication of researchers and regional stakeholders

- ***Overall, modest levels of communication exist between respondents and regional WEF stakeholders***. The low levels of communication could be attributed to the lack of appropriate institutional mechanisms and resources that allow for improving those levels. The implications of not improving the levels of communication include incoherence within research and stakeholder environments, either of which may lead to the development of incoherent policies and strategies for managing resources in the region.
- ***A higher frequency of communication among stakeholder groups that is statistically significant, compared to that of researchers with stakeholders***. This result was expected and could be attributed to the fact that different governmental, business, or non-profit organizations have more opportunities to meet and engage, compared to those who are at academic and research institutions. One way to improve the level of communication between researchers and stakeholder groups is ensuring the presence of active engagement and outreach plan components, including capacity building seminar and dialogue forums (Rosen et al, 2019). Dedicating sufficient time and resources would contribute to increased potential usability and significance of the developed research, and improve the continuity and feedback relation and engagement of researchers with the stakeholders.

- ***Not enough evidence of a significant difference in the frequency of communication between respondents who reported working at organizations with a silo focus, compared to organizations with interdisciplinary focus.*** This could be a result of institutional barriers that do not allow further communication. It may be the case that people across different organizations do want to communicate more, or realize its importance, but are not doing so because it is not part of their organization's mandate, or that no resources are allocated for formal meaningful communication.
- ***No statistically significant differences between the frequency of communication of businesses, governmental, and non-governmental organizations with the different stakeholders in the region.*** This tells us that there is a limited link between the type of organization and the level of communication. This could be a sign that the institutional and financial challenges cut across different types of organizations and is not only limited to governmental institutions. An additional research question that stems from this paper and deserves attention is: with whom are these specific organizations communicating and the context of that communication. It is unclear what institutional boundaries may exist that could impede communication, or what institutional mechanism could be created to facilitate communication. These questions warrant additional research in this area.

4.7.4. Perspectives on ways to overcome barriers for improved cross-sectoral communication

Convergence exists between both groups sharing information between agencies and improving communication between existing agencies. Even if stakeholders realize the need to communicate more and share information across organizations, they often lack the institutional mechanisms allowing them to do so. They may also lack the dedicated resources and human capital to lead these activities.

4.7.5. Limitations and Future work

One limitation of this study is the number of responses. While we received a response rate close to 20%, a larger number of responses might have resulted in identifying some areas where convergence may not exist and where further attention is needed. Additionally, within our list of respondents, we had a lower number of nonprofit/non-governmental and governmental stakeholders from energy and food sectors, compared to stakeholders from other categories. We generally reported more responses from stakeholders within the water sectors compared to those from the food and energy sectors. Having a more even distribution of responses across different categories of stakeholders would also contribute to ensuring more representative results. Further studies could include the kind of impact on resources these regional stakeholders have. For example, food distributors and retailers are not necessarily involved in making decisions for increased agricultural growth or kind of technologies used. The case is similar with water and electricity utilities. This study outlines an example of a methodology for measuring convergence and communication between different groups. Future work could build on the provided methodology and uses within different contexts of consensus building where convergence between different actors is a goal. An example could be in transboundary water conflict settings and others were competition over common resource pools exists. There would also be value in building on this work by including elements which measure the quality of communication, in addition to its frequency. Having such information would provide additional insights on the potential of additional communication resulting in actual collaboration and coordination across different institutions. Future work could also be strengthened to include additional understanding and quantification of convergence within each of the researchers and stakeholder groups.

4.8. Conclusions

As researchers continue working toward better understanding the interconnected resource challenges and supporting stakeholders in addressing them, it is important to ensure a high level of communication and engagement between both groups at different stages of a project. That is especially useful in shortening the research-policy/strategy/decision feedback cycle when rapid recommendations to address timely challenges are needed. It is particularly important to have early on involvement of stakeholders in the process of developing new research work to ensure convergence of perspectives and the production of relevant research. In addition, increased communication between different cross-sectoral stakeholders and increased exchange of information would potentially allow for greater coherence among their strategies as they manage the future of their interconnected resources. The survey developed in this study allows for identifying possible areas of convergence or divergence between researchers and regional stakeholders, in an effort to make sure they are addressed early on, in order to create research and solutions that is of greater value to all. It further provides a method that could be replicated in areas with similar resource challenges within the United States, and elsewhere across different resource hotspots globally.

5. CONCLUSIONS AND MOVING FORWARD[4]

The resource challenges we face today will require the development of creative solutions that are consistent with our understanding of their complexities and interdependencies. Arriving at such solutions will require innovative thinking in the way we research and manage resources systems. There is also a need to be innovative in catalyzing a dialogue that fosters the essential communication, cooperation, and collaboration within the research and stakeholder communities, and between them both. This dissertation highlights some of the critical questions at the interface of interconnected resource challenges, and explores ways in which these questions could, potentially, be addressed within three enabling *environments:* 1) research, 2) stakeholders, and 3) research-stakeholders. The discussion is conducted in the context of a model resource hotspot: the San Antonio, Texas Region. A summary of the major conclusions and lessons learned are outlined below.

1- RESEARCH: Lessons learned from creating an interdisciplinary team and using a nexus approach to address a resource hotspot

To understand the resource hotspot of the San Antonio Region, aspects of the proposed STEP framework were expanded and put into action through the development

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[4] This section of the "Conclusions and Moving Forward" Chapter, entitled "RESEARCH: Lessons learned from creating an interdisciplinary team and using a nexus approach to address a resource hotspot", is adapted, with permission, from "Lessons learned: Creating an interdisciplinary team and using a nexus approach to address a resource hotspot" by Rabi H. Mohtar and Bassel Daher, published in Science of the Total Environment, Volume 650, Part 1, 10 February 2019, Pages 105-110. [doi:10.1016/j.scitotenv.2018.08.406] Copyright 2019 by Elsevier.

of an interdisciplinary team of researchers at the Water-Energy-Food Nexus Initiative at Texas A&M University. The interdisciplinary team consisted of six sub-groups (Figure 5.1), each of which identified their intended objectives, outcomes, and data collection needs. Following several months of work within the respective sub-groups, a Town Hall style meeting took place with the primary goals of sharing projects, research questions, and data. Potential synergies between sub-groups were discussed, and a roadmap of nexus interlinkages was developed for the overall project.

Figure 5.1 The subgroups of the interdisciplinary team working on the San Antonio case study (Mohtar and Daher, 2019)

Building on the discussions of the first Town Hall, the framework proposed in Figure 5.2 represents the interconnections and interdependencies between the 6 sub-groups. Progress on interlinkages, data and modeling, governance and tradeoffs were made during the first year, however it was concluded that further discussion of stakeholder engagement were necessary to develop a stakeholder engagement plan.

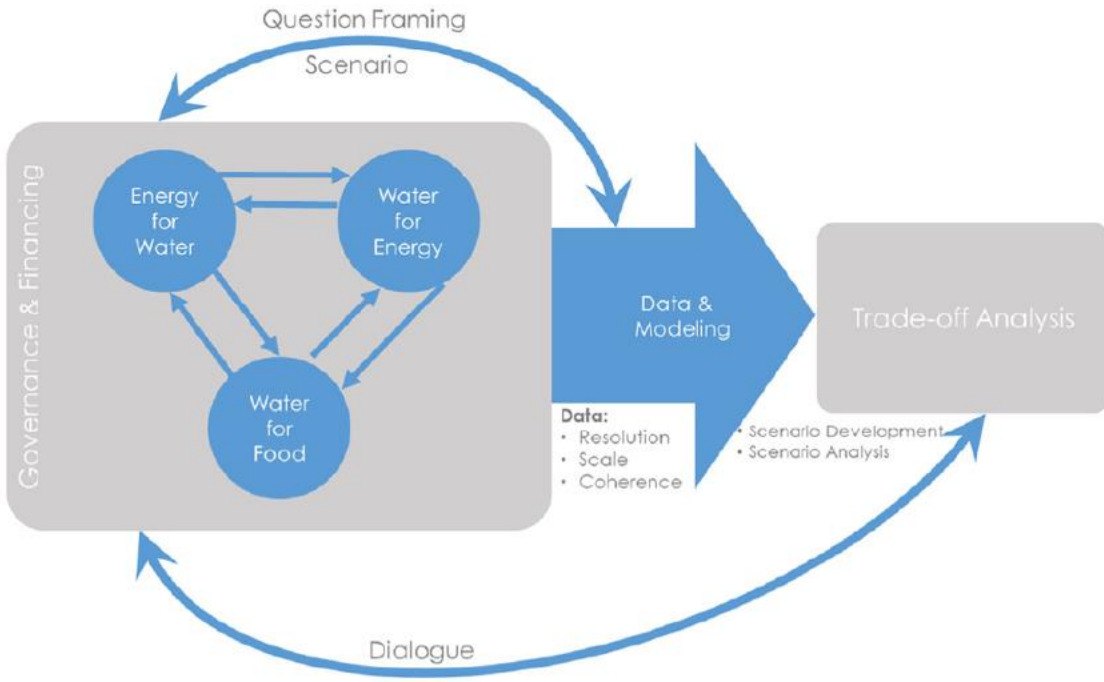

Figure 5.2: Sub-groups interdependence and interaction (Mohtar and Daher, 2019)

A summary of the ***challenges*** which faced the development of such an interdisciplinary team, and the ***transferrable lessons learned*** from it include:

Summary of Challenges:

- **Defining the boundaries of the study region.** Even though there was agreement that the San Antonio Region was the resource hotspot of interest, the subgroups defined it differently: iterations and options of boundary definition were discussed. One proposal was to focus the study on Region L, one of 16 water planning regions in the State of Texas for which the Texas Water Development Board (TWDB) issues a 5 year plan outlining its challenges and planned projects. Another proposed to use the hydrologic boundaries intersecting Region L. Other suggestions included the boundaries of the San Antonio river basin; a combination of San Antonio, Nueces, and Guadalupe basins; and a combination of Edwards & Southern Carrizo Aquifers. Additional boundary definitions included a more governance-centric focus: using the boundaries of Groundwater Management Areas (GMA's) and River Authorities (RA) intersecting with water planning region L. Due to the multiple perspectives that included modeling, governance, utilities, and other needs, it was decided that the San Antonio region definition would remain open to address these needs, and be inclusive of the major WEF stakeholders and geographical hotspots.

Figure 5.3 provides one example of the different regions: Region L includes Groundwater Management Areas (GMA) 9, 10, 13 and 15. After discussion across sub-groups, a consensus was reached that, while different sub-groups might need to focus on variations of the Region to address their respective research questions and objectives, the region of study would predominantly include water planning region L, loosely defined as the "San Antonio Region" (Figure 5.3).

- **Identifying dependency maps across sub-groups.** Figure 5.4 demonstrates an example of such a map. In order for group 1 (G1), modeling, to model scenarios, inputs were needed from G2, G3, G4, G5, and G6. G1 also provides inputs to the governance (G3) and trade-off analysis (G4). The co-identification of these needs across the six groups must be an inclusive, iterative process.

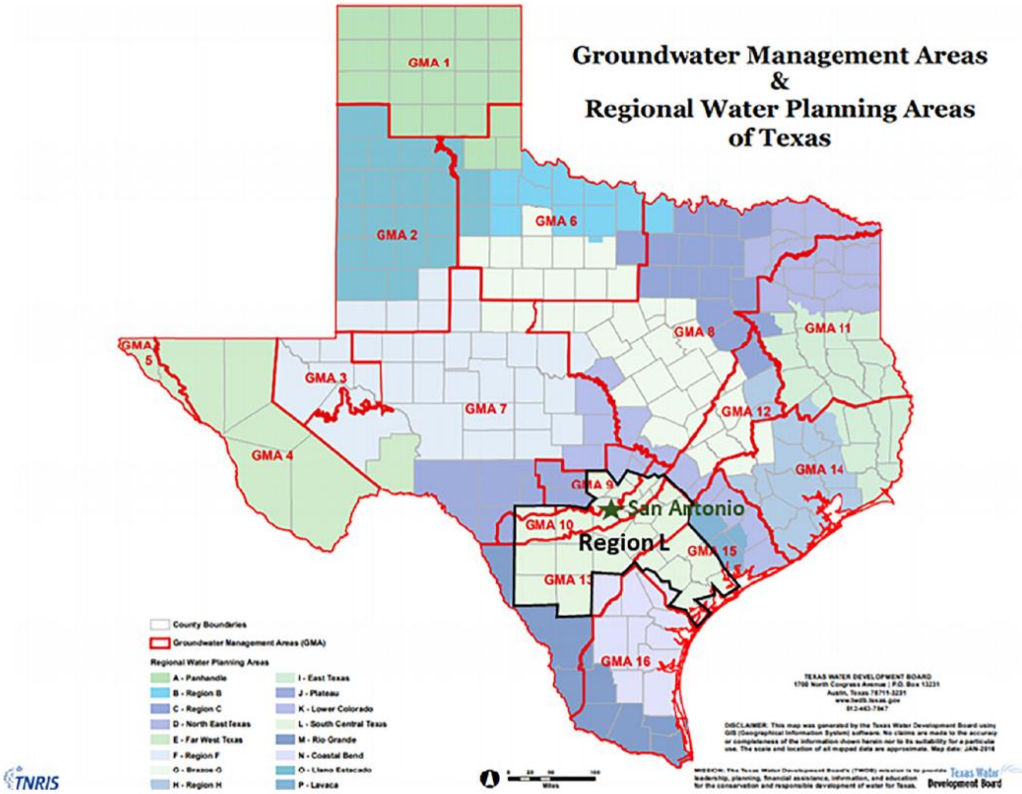

Figure 5.3: Water Planning Region L and overlapping GMA's (TWDB, 2018). From (Mohtar and Daher, 2019)

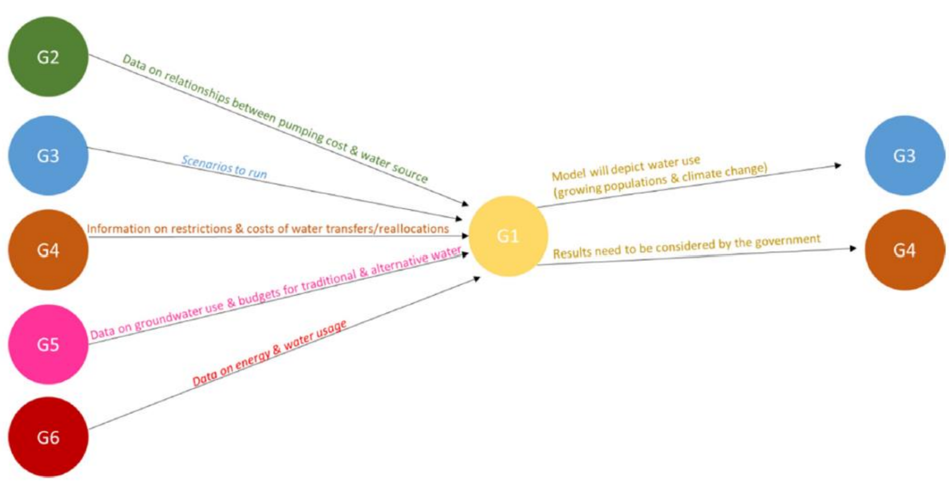

Figure 5.4: Example of dependency maps between sub-groups. (Mohtar and Daher, 2019)

- **Incompatibility of data across sub-groups.** A variety of models and tools are commonly used by sub-groups focused on given disciplinary perspectives, which are often either energy- or water- centric. The data sets required for these tools and models are distinct and provide different types of outputs and levels of resolution.
- **Variability in data availability and access across sub-groups.** It is much easier to find hydrological data than, for example, data related to energy.
- **Funding** to kick off project activities was essential to enable a team of graduate students to be hired to the various teams. The seed funding provided by Texas A&M University allowed building partnerships on campus that later successfully competed for funding from the National Science Foundation Innovations in the Food Energy Water Systems (NSF INFEWS) program. Efforts to promote the science and build a community of science and practice are critical to the long term sustainability of this work (WEFNI, 2018).

Transferable lessons learned:

- **It is an iterative processes**. Though time consuming, achieving convergence toward the project goals and objectives made it necessary to reach consensus across the sub-groups.
- **Investment of time and effort** are essential to building genuine, honest, one-on-one relations: while agreement on overarching objectives and goals is important, these must be complemented with different levels of follow up and the investment of time in order to safeguard project outcomes.

- **Differences in perspectives across disciplines exist**. A clear definition of duties and scope across subgroups is critical to the identification of synergistic goals and the understanding of the interdependencies between subgroups.
- **Outcomes and progress must be communicated** beyond disciplinary circles to include the sub-groups.
- **Acknowledge differences across disciplines while understanding the value each brings to improving the overall quality of the end result.** The final product cannot not rely solely upon disciplinary knowledge: it is an outcome of everyone participating collectively in the process.
- **The process requires time, effort, and multiple iterations**. The process includes discomfort and not fully understanding everything being developed by teams from other disciplines. No single discipline or research focus area is sufficient to address the interconnected, complex resource challenges faced today. Unless the knowledge and expertise of each discipline is brought to address the challenges, important aspects may be overlooked with resulting, unintended consequences. Working synergistically across the siloes of disciplinary work builds a deeper understanding of the issues and challenges, promoting a pathway to discovery that offers holistic solutions and will encourage long term sustainable resource allocation.

2- STAKEHOLDERS: Lessons learned from studying the frequency of communication between water, energy, and food organizations in a resource hotspot

As various stakeholders make decisions affecting water, energy, and food in a given region, it is critical to have in place mechanisms that allow communication across institutions and enable potential cooperation. The lack of cooperative resource planning can, potentially, result in unintended consequences such as resource depletion that may result in future conflict and dispute. An important outcome of surveying water officials about their frequency of communication with other water, energy, and food stakeholders in San Antonio was the realization that such communication is modest: communication was higher among other water stakeholders, than with other energy and food stakeholders. This was the case even with stakeholders reported attending integrative stakeholder engagement meetings.

We investigated some of the main institutional barriers that may result in the existing low levels of communication and discovered that, even though stakeholders often realize the importance of communication and greater coordination when planning and managing future resource allocations, existing barriers inhibit or prevent such communication. These barriers vary in nature and include financial, structural, capacity related, language differences, or different interests and value systems. Addressing communication barriers will be critical to the development of a cooperative stakeholder environment that allows long term planning and resource allocation while avoiding potential unintended consequences. Additional related areas could include incorporating an element evaluating *quality of communication* and developing a better understanding of the kinds of communication that lead to cooperation. Comparative studies with other hotspots would help identify whether the barriers identified in the San Antonio Region are unique to it, or if there is a broader trend regarding communication and cooperation between cross-sectoral institutions.

Game theory (Başar and Olsder, 1999) provides a formal analytical framework with a set of mathematical tools to study the complex interactions among rational decision makers whose goals, actions, and objectives are interdependent. Social network analysis identifies major players and frequent communicators; stakeholders have different goals, interests, and values. Building on these realities, game theoretic applications could be developed to better understand and predict the dynamics of certain interactions. Game theory has had a revolutionary impact on a large number of disciplines including engineering, economics, political science, philosophy, and psychology (Başar and Olsder, 1999). Within the WEF nexus, game-theoretic tools can be used to analyze decision making among different players in response to identified levers, including technological, political and social. (Daher et al., 2017). Game-theoretic and integrated modeling tools (Bennett et al., 2013) provide a set of methods that can be used to model how resources can be efficiently allocated across the water, energy, and food resource systems. In this context, both cooperative and non-cooperative game models are applicable. Non-cooperative solutions would better model scenarios in which individual system nodes have no means of coordinating their strategies; cooperative models are suited to analyze how one might pool resources across interdependent nodes with a means to coordinate the system parameters. Different game types could be used to reflect different governance schemes that range between more centralized to decentralized decision making.

Another aspect requiring further research is *policy incoherence* across scales. Policies created to incentivize specific actions at specific scales could conflict or compete with other actions at different scales. Specifically, there is a need to develop mechanisms that quantify policy coherence through quantifying the impact of proposed policies: across different sectors, within the same scale, and across other scales. There is also need to identify the compatibility of "current institutional setup" and "cross-sectoral interaction" with the nature of physical resources and their interconnections.

3- RESEARCH-STAKEHOLDERS: Lessons learned from studying the convergence of perspectives between researchers and stakeholders in a resource hotspot

As resource challenges continue to intensify as a result of increasing pressures faced, there is a growing need for research that is able to rapidly offer solutions. This requires reducing the length of the feedback cycle between researchers and stakeholders who are making decisions, whether through introducing policy incentives, technology, and or management practices that respond to different resource challenges.

Aspects of convergence were identified between the perspectives of researchers and regional stakeholders regarding issues related to water, energy, and food in the San Antonio Region. Similar aspects of convergence were found in the perspectives of both groups toward the Texas Water Development Board strategies with most and least potential. However, both groups seemed not to converge over the direction of future regional priorities: they differed in their ranking of energy and food (second and third priority). Nevertheless both groups converged on water as a first priority. The study also indicated that both groups converge over the potential roles of “increased communication” and “sharing information between agencies” as a means to improve cooperation and address interconnected resource challenges. For those potentials to become realities, institutional mechanisms and resource allocations for such activities should be revisited.

As researchers continue to work toward a better understanding of interconnected resource challenges, and toward supporting stakeholders in addressing them, it is important to ensure a high levels of communication and engagement between both groups and at different stages of a project. This is especially useful when rapid recommendations to address timely resource challenges are needed. Based in system’s thinking, and through the quantification of interconnections between resource systems, researchers could play an important role in communicating the trade-offs associated with different scenarios. Early stakeholder involvement in the process of developing new research is particularly important to ensure convergence of perspectives and relevance of the research. Potentially, both increased communication between cross-sectoral stakeholders and increased exchange of information allow greater coherence in strategies as they manage the future of these interconnected resources. In an effort to ensure that issues are addressed early on, and to create research and solutions of greater value, the survey developed in this study allows the identification of possible areas of convergence or divergence between researchers and regional stakeholders.

Such a survey could be considered a '*spot check'* in the life time of a project; one that would allow evaluating the research progress as well as the level of stakeholders engagement and the level of convergence between them. This would help identify potential gaps in communication or perceptions towards the different issues facing a resource stressed region. While this study examines convergence between stakeholders and researchers in the context of the San Antonio resource hotspot, a similar methodology could be used to address hotspots elsewhere. Building on the methods used in the study to understand the level of convergence between researchers and water, energy, and food stakeholders in San Antonio, future work could include contexts in which consensus-building among the different stakeholders is a goal. For example, situations in which competition over common resource pools exist, such as transboundary water conflict settings.

As nations work toward achieving the 2030 Sustainable Development Goals, particular attention must be given to the level of interdependence between these goals. This applies to the water, energy, and food goals, as well as all the others. Failure to do so risks advancing the development of one goal at the expense of another. In order to sustainably arrive at year 2030, we need to develop research that better understands and quantifies the interconnections between the goals, and to develop coherent, consistent policies strengthened by the research understanding of the challenges and their interdependencies. This could be accomplished by creating the necessary environments to allow development of the necessary research, cross-sectoral cooperation in planning for the future of resource allocation, and appropriate levels of engagement and exchange of information between researchers and related stakeholders. While the 2030 Agenda is global, localization of its goals, indicators, critical questions, solutions, and involved stakeholders must be contextualized. This is essential to the potential success of any plan, at any scale, to achieve the goals.

This dissertation offers lessons learned from a case study of the resource hotspot of San Antonio, TX. The overall approach, methodologies, and lessons learned from this study could be customized and contextualized to better understand and address other resource stressed regions globally.

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APPENDIX A

SURVEY 1: LIST OF WATER, ENERGY, FOOD AND CROSS-CUTTING STAKEHOLDERS

Water stakeholders (57)

Edwards Aquifer Authority	Bandera County River Authority & Groundwater Conservation District
Any Irrigation District	Barton Springs/Edwards Aquifer & Groundwater Conservation District
A TCEQ Office in Austin	Blanco-Pedernales Groundwater Conservation District
Any TCEQ Freshwater Supply District	Comal Trinity Groundwater Conservation District
Texas Water Development Board in Austin	Cow Creek Groundwater Conservation District
Texas Water Development Board Region K Office	Evergreen Groundwater Conservation District
Texas Water Development Board Region L Office	Gonzales County Underground Water Conservation District
San Antonio Water System (SAWS)	Hays Trinity Groundwater Conservation District
Live Oak Municipal Utility	Headwaters Groundwater Conservation District
Canyon Regional Water Authority	Kinney County Groundwater Conservation District
Any Storm water Management or Control District	McMullen Groundwater Conservation District
Texas Water Resources Institute in College Station	Medina County Groundwater Conservation District
Texas State Public Utility Commission	Pecan Valley Groundwater Conservation District
Texas General Land Office	Plum Creek Groundwater Conservation District
Texas State Soil and Water Conservation Board, Region 2 Office	Post Oak Savannah Groundwater Conservation District

South Texas Watermaster	Uvalde County Underground Water Conservation District
Edwards Aquifer Association	Alamo Soil & Water Conservation District #330
Texas Alliance of Groundwater Districts	Comal-Guadalupe Soil & Water Conservation District #306
Any Drainage District	Wilson County Soil & Water Conservation District #301
Bexar County Heritage & Parks Department	Trinity River Authority
Brazos River Authority	Trinity River Vision Authority
Central Colorado River Authority	San Antonio River Authority
Guadalupe-Blanco River Authority	Upper Colorado River Authority
Lavaca-Navidad River Authority	Upper Guadalupe River Authority
Lower Colorado River Authority	Groundwater Management Area #9 Office
Nueces River Authority	Groundwater Management Area #10 Office
Hill Country Priority Area Office	Ozarka Spring Water Company
Trinity Aquifer Priority Area Office	Any Professional Hydrologist or Geologist

Energy stakeholders

ExxonMobil	EOG Resources
Shell Oil	Blue Wing Solar, Inc.
Valero	Texas Public Utility Commission
City Public Service (CPS) Energy	GE Power and Water
Duke Energy	Halliburton
Marathon Oil	Association for Electric Companies of Texas
Pioneer Natural Resources/Reliance Joint Venture	Texas Comptroller, Office of Energy Conservation

Food stakeholders

San Antonio Food Policy Council	Sysco Central Texas, Inc.
San Antonio Food Bank	Labatt Food Services
H.E.B.	Del Norte Foods, Inc.
Kroger	Cargill Food Distributors
NatureSweet Company	Texas Farm Bureau

Cross-cutting stakeholders

Office of Texas House Speaker Joe Strauss	Texas Railroad Commission
Joint Base San Antonio	San Antonio Mayor's Office
Office of State Representative Lyle Larson	San Antonio City Manager's Office
Office of Texas State Senator Carlos Uresti	Bexar County Commissioners or County Manager
San Antonio City Office of Sustainability	San Antonio Metro Health District
San Antonio Parks & Recreation Department	San Antonio Greenspace Alliance

APPENDIX B

SURVEY1: WATER MANAGEMENT IN THE SAN ANTONIO REGION

Q9. Over the last year, as part of your job, how often have you communicated with any of these organizations, or decision makers from these organizations, **about water issues affecting the San Antonio Region**?

	Once a week or more (1)	Monthly (2)	Once every 3 months (3)	Once a year (4)	Not at all (5)	This is my own organization (6)
a. Edwards Aquifer Authority	○	○	○	○	○	○
b. Any Irrigation District	○	○	○	○	○	○
c. A TCEQ Office in Austin	○	○	○	○	○	○
d. Any TCEQ Freshwater Supply District	○	○	○	○	○	○
e. Texas Water Development Board in Austin	○	○	○	○	○	○
f. Texas Water Development Board Region K Office	○	○	○	○	○	○
g. Texas Water Development Board Region L Office	○	○	○	○	○	○
h. San Antonio Water System (SAWS)	○	○	○	○	○	○
i. Live Oak Municipal Utility	○	○	○	○	○	○
j. Canyon Regional Water Authority	○	○	○	○	○	○
k. Any Stormwater Management or Control District	○	○	○	○	○	○

l. Texas Water Resources Institute in College Station	○	○	○	○	○	○
m. Texas State Public Utility Commission	○	○	○	○	○	○
n. Texas General Land Office	○	○	○	○	○	○
o. Texas State Soil and Water Conservation Board, Region 2 Office	○	○	○	○	○	○
p. South Texas Watermaster	○	○	○	○	○	○
q. Edwards Aquifer Association	○	○	○	○	○	○
r. Texas Alliance of Groundwater Districts	○	○	○	○	○	○
s. Any Drainage District	○	○	○	○	○	○
t. Bexar County Heritage & Parks Department	○	○	○	○	○	○

Q10. Over the last year, as part of your job, how often have you communicated with any of these specific organizations, or decision makers from these organizations, **about water issues affecting the San Antonio Region**?

	Once a week or more (1)	Monthly (2)	Once every 3 months (3)	Once a year (4)	Not at all (5)	This is my own organization (6)
a. Bandera County River Authority & Groundwater Conservation District	○	○	○	○	○	○
b. Barton Springs/Edwards Aquifer & Groundwater Conservation District	○	○	○	○	○	○
c. Blanco-Pedernales	○	○	○	○	○	○

Groundwater Conservation District						
d. Comal Trinity Groundwater Conservation District	○	○	○	○	○	○
e. Cow Creek Groundwater Conservation District	○	○	○	○	○	○
f. Evergreen Groundwater Conservation District	○	○	○	○	○	○
g. Gonzales County Underground Water Conservation District	○	○	○	○	○	○
h. Hays Trinity Groundwater Conservation District	○	○	○	○	○	○
i. Headwaters Groundwater Conservation District	○	○	○	○	○	○
j. Kinney County Groundwater Conservation District	○	○	○	○	○	○
k. McMullen Groundwater Conservation District	○	○	○	○	○	○
l. Medina County Groundwater Conservation District	○	○	○	○	○	○

m. Pecan Valley Groundwater Conservation District	○	○	○	○	○	○
n. Plum Creek Groundwater Conservation District	○	○	○	○	○	○
o. Post Oak Savannah Groundwater Conservation District	○	○	○	○	○	○
p. Uvalde County Underground Water Conservation District	○	○	○	○	○	○
q. Alamo Soil & Water Conservation District #330	○	○	○	○	○	○
r. Comal-Guadalupe Soil & Water Conservation District #306	○	○	○	○	○	○
s. Wilson County Soil & Water Conservation District #301	○	○	○	○	○	○

Q11. Over the last year, as part of your job, how often have you communicated with any of these specific organizations, or decision makers from these organizations, **about water issues affecting the San Antonio Region**?

	Once a week or more (1)	Monthly (2)	Once every 3 months (3)	Once a year (4)	Not at all (5)	This is my own organization (6)
a. Brazos River Authority	◯	◯	◯	◯	◯	◯
b. Central Colorado River Authority	◯	◯	◯	◯	◯	◯
c. Guadalupe-Blanco River Authority	◯	◯	◯	◯	◯	◯
d. Lavaca-Navidad River Authority	◯	◯	◯	◯	◯	◯
e. Lower Colorado River Authority	◯	◯	◯	◯	◯	◯
f. Nueces River Authority	◯	◯	◯	◯	◯	◯
g. Trinity River Authority	◯	◯	◯	◯	◯	◯
h. Trinity River Vision Authority	◯	◯	◯	◯	◯	◯
i. San Antonio River Authority	◯	◯	◯	◯	◯	◯
j. Upper Colorado River Authority	◯	◯	◯	◯	◯	◯

k. Upper Guadalupe River Authority	○	○	○	○	○	○
l. Groundwater Management Area #9 Office	○	○	○	○	○	○
m. Groundwater Management Area #10 Office	○	○	○	○	○	○
n. Hill Country Priority Area Office	○	○	○	○	○	○
o. Trinity Aquifer Priority Area Office	○	○	○	○	○	○
p. Ozarka Spring Water Company	○	○	○	○	○	○
q. ExxonMobil	○	○	○	○	○	○
r. Shell Oil	○	○	○	○	○	○
s. Office of Texas House Speaker Joe Strauss	○	○	○	○	○	○
t. Joint Base San Antonio	○	○	○	○	○	○
u. Valero	○	○	○	○	○	○
v. Any Professional Hydrologist or Geologist	○	○	○	○	○	○
w. Office of State Representative Lyle Larson	○	○	○	○	○	○
x. Office of Texas State Senator Carlos Uresti	○	○	○	○	○	○

Q12. Over the last year, as part of your job, have you personally participated in any kind of **stakeholder forum or cooperative planning effort** with organizations or agencies other than your own?

○ Yes ○ No ○ Not sure

Q13. Overall, how concerned are you about **future water availability** in the San Antonio Region?

0 Not Concerned at all	1	2	3	4	5	6	7	8	9	10 Extremely Concerned
○	○	○	○	○	○	○	○	○	○	○

Q15. Over the last year, as part of your job, about how often have you communicated with organizations, or decision makers from these organizations, **about any issues affecting the San Antonio Region**?

	Once a week or more (1)	Monthly (2)	Once every 3 months (3)	Once a year (4)	Not at all (5)
a. City Public Service (CPS) Energy	○	○	○	○	○
b. Duke Energy	○	○	○	○	○
c. Marathon Oil	○	○	○	○	○
d. Pioneer Natural Resources/Reliance Joint Venture	○	○	○	○	○
e. EOG Resources	○	○	○	○	○
f. San Antonio City Office of Sustainability	○	○	○	○	○
g. Texas Railroad Commission	○	○	○	○	○
h. Texas Comptroller, Office of Energy Conservation	○	○	○	○	○
i. Texas Public Utility Commission	○	○	○	○	○
j. Texas Farm Bureau	○	○	○	○	○
k. San Antonio Mayor's Office	○	○	○	○	○

l. San Antonio City Manager's Office	◯	◯	◯	◯	◯
m. Bexar County Commissioners or County Manager	◯	◯	◯	◯	◯
n. San Antonio Metro Health District	◯	◯	◯	◯	◯
o. San Antonio Parks & Recreation Department	◯	◯	◯	◯	◯
p. San Antonio Food Policy Council	◯	◯	◯	◯	◯
q. San Antonio Food Bank	◯	◯	◯	◯	◯
r. H.E.B.	◯	◯	◯	◯	◯
s. Kroger	◯	◯	◯	◯	◯
t. NatureSweet Company	◯	◯	◯	◯	◯
u. Sysco Central Texas, Inc.	◯	◯	◯	◯	◯
v. Labatt Food Services	◯	◯	◯	◯	◯
w. Del Norte Foods, Inc.	◯	◯	◯	◯	◯
x. Cargill Food Distributors	◯	◯	◯	◯	◯
y. Blue Wing Solar, Inc.	◯	◯	◯	◯	◯
z. San Antonio Greenspace Alliance	◯	◯	◯	◯	◯
aa. GE Power and Water	◯	◯	◯	◯	◯
bb. Halliburton	◯	◯	◯	◯	◯
cc. Association for Electric Companies of Texas	◯	◯	◯	◯	◯

Again, thanks for taking the time to answer these questions. When completed, please return this questionnaire in the self-addressed stamped envelope and return the postcard separately to:

Prof. Kent Portney, Director
Institute for Science, Technology and Public Policy
Texas A&M University
TAMU 4350
College Station, Texas 77843-4350

APPENDIX C

SURVEY RESPONSE RATE CALCULATIONS AND POTENTIAL RESPONSE BIAS

SURVEY 1 – Chapter 3

Response Rate Calculations

For Survey 1 in Chapter 3, 101 completed questionnaires were received. Since 289 initial questionnaires were mailed, the raw or nominal response rate would be calculated as 101/289 = 35.0%. However, the denominator for this calculations does not accurately reflect the size of the actual population of people surveyed. As a result of the mailings, it was determined that some people on the original list were not available or eligible to be included for one reason or another. For example, 21 questionnaires were returned by the U.S. Postal Service as "undeliverable." Additionally, 4 people had left their respective positions, and 3 people were on long-term leave from their positions. We also discovered that one of the private water service providers had lost its certification, and all 4 of the people there who had been sent questionnaires were not eligible to participate in the survey. Based on these results, an adjusted response rate is calculated as 101 / (289 – 21 – 4 – 3 -- 4) = 101 / 257 = 39.3%.

A more accurate estimated response rate needs to take into consideration that some of the people (and organizations) included in the survey probably should not have been surveyed because their water governance decisions truly don't have any connection to the San Antonio Region, as described above. In those situations where 1) there was a priori reason to believe an organization probably did not have any connection to the San Antonio Region, and 2) respondents reported that they indeed have no connection to the San

Antonio Region, those respondents were considered to be not part of the eligible survey population. By our count, a total of 25 people meeting these criteria were mailed questionnaires and should not have been. Thus, a third adjusted response rate would be calculated as 101 / (257 – 25) = 101 / 232 = 43.5%.

Potential Response Bias

In the absence of full (100%) response, there is the possibility of some type of response bias being reflected among the third of people who did respond. While analysis of the potential for response bias will continue, an initial effort was made to determine whether some types of organizations were over or under represented in the final sample based on the initially targeted population of 289 potential respondents. Here we examined several categories of types of organizations whose people were surveyed. We provide an assessment of the number of people who were surveyed, what proportion of the total they represent, and how the sample respondents compared.

Category of organization	Number of people surveyed	Percentage of the total surveyed	Number of respondents	Percentage of the total respondents	% Under or over represented
Groundwater conservation districts	81	28.0%	26	25.7%	- 2.3
River authorities	46	16.0%	22	21.8%	+ 5.8
State agencies (including regional offices)	26	9.0%	10	9.9%	+ 0.9
Private municipal water service providers	30	10.4%	6	5.9%	- 4.5
All others	106	36.6%	37	36.6%	0.0
Totals	289	100.0%	101	100.0%	-----

These results do not factor in the number of people surveyed who were later deemed to be ineligible. Even so, these results suggest that there is only one category of organization whose respondents appear to be over-represented in the sample – river authorities. These included the Nueces River Authority, San Antonio River Authority, Guadalupe-Blanco River Authority, Lavaca-Navidad River Authority, Upper Colorado River Authority, Brazos River Authority, Upper Guadalupe River Authority, Bandero River Authority, and Trinity River Vision Authority. River authorities made up 16% of the population, and 21.8% of the final sample. Among state agencies, there is only very slightly over-representation. These agencies include the Texas Commission on Environmental Quality (TCEQ), the Texas Water Development Board (TWDB) and people from its regional offices, and the Texas Water Resources Institute (TWRI). Although people from these organizations make up a relatively small portion of the people surveyed (9.0% of the total) and of the people who responded (9.9%), clearly they are slightly over-represented. Private water service providers, which made up about 10% of the population of respondents, were under-represented in the final sample by about four people, with only 5.9% of the respondents from this group. And groundwater conservation districts were slightly under-represented, composing 28% of the population and 25.7% of the sample.

SURVEY 2 – Chapter 4

Response Rate Calculations

For Survey 2 in Chapter 4, 71 responses were received. 370 questionnaires were emailed to water, energy, and food stakeholders from governmental, non-profit, business, and research organizations from the San Antonio Region. The raw or nominal response rate is

71/370 = 19.2%. The same list of the 370 stakeholders was invited to the Stakeholder Engagement Meeting in January 2018 in San Antonio. 88 invitees attended the meeting. The attendance rate at the meeting is 88/370= 24%.

Based on the response rate for this survey, there is the possibility of some type of response bias being reflected among the third of people who did respond. While analysis of the potential for response bias will continue, an initial effort was made to determine whether some types of organizations were over or under represented in the final sample based on the initially targeted population of 370 potential respondents.

Potential Response Bias

		Water	Energy	Food	Cross-cutting	Total
SURVEY RESPONDENTS	Governmental (G)	9	0	1	4	**14**
	Non Profit (N)	1	1	0	9	**11**
	Business (B)	4	1	2	7	**14**
	RESEARCHERS	7	2	2	21	**32**
					Total	**71/370 (19.2%)**
WORKSHOP ATTENDED BY		**Water**	**Energy**	**Food**	**Cross-cutting**	**Total**
	Governmental (G)	13	0	1	5	**19**
	Non Profit (N)	4	0	5	4	**13**
	Business (B)	4	2	1	8	**15**
	RESEARCHERS	12	4	6	19	**41**
					Total	**88/370 (24%)**

The table above provides an overview of the categories of types of organizations and the sectors of those who responded, and those who attended the workshop. We notice that higher numbers of respondents who identified having a water focus, compared to energy and food. We also notice comparable numbers of "cross-cutting" respondents. Energy and Food respondent levels were lower than both water and cross cutting. According to the table, we notice the absence of any responses from Energy-Governmental and Food-Non-Profit.

Our analysis mainly took place at a more aggregate level, with researchers in one hand, and regional stakeholders in another. Even though the analysis done in this study did not investigate relations and interactions at the granular level depicted in the table, it is believed by the authors that the more diverse repetition across sectors and types or organizations, the more insight we would be able to gain from the responses. Having a higher number of respondents who identify as “cross-cutting” could be considered to capture some of these gaps.

APPENDIX D

SURVEY 2: TOWARDS CREATING AN ENVIRONMENT FOR INCREASED COOPERATION BETWEEN WATER-ENERGY-FOOD PLAYERS IN SAN ANTONIO

Q1-a. To what extent do you think water, energy, and food resources are connected to each other?

Very Low	Low	Moderate	High	Very High
○	○	○	○	○

Q1-b. In general, to what extent do you think that agencies and organizations should collaborate, coordinate, or cooperate across issues of water, energy, and food?
Agencies should coordinate, cooperate, or collaborate:

A great deal	A little	Not much	Not sure
○	○	○	●

Q1-c-i. What do you see as the current relative priorities of water, food, and energy in the San Antonio region:

- Water resources
- Food and agricultural resources
- Energy resources

Q1-c-ii. What do you think the relative priorities of water, food, and energy should be for the San Antonio region in the future?

- Water resources
- Food and agricultural resources
- Energy resources

Q1d.i- Overall, how concerned are you about future water availability in the San Antonio Region?

0 Not concerned at all	1	2	3	4	5	6	7	8	9	10 Extremely concerned
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Q1d.ii- Overall, how concerned are you about energy security in the San Antonio Region?

0 Not concerned at all	1	2	3	4	5	6	7	8	9	10 Extremely concerned
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Q1d-iii- Overall, how concerned are you about food security in the San Antonio Region?

0 Not concerned at all	1	2	3	4	5	6	7	8	9	10 Extremely concerned
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Q1e. How familiar are you with the Texas Water Development Board’s water supply strategies for the San Antonio Region in the 2017 State Water Plan?

◯ Not at all familiar ◯ Slightly familiar ◯ Moderately familiar

◯ Very familiar ◯ Extremely familiar

Q1f. Please indicate **how much potential** you think each listed strategy has for managing water to help the San Antonio Region meet its water needs over the next ten years?

	Very low potential	Low potential	Moderate potential	High potential	Very high potential
Conservation of Irrigation Water	○	○	○	○	○
Build a New Reservoir	○	○	○	○	○
Municipal Water Conservation	○	○	○	○	○
Indirect Water Reuse	○	○	○	○	○
Direct Water Reuse	○	○	○	○	○
Drought Management	○	○	○	○	○
Aquifer Storage & Recovery	○	○	○	○	○
Seawater Desalination	○	○	○	○	○
Groundwater Desalination	○	○	○	○	○
Direct Potable Water Reuse	○	○	○	○	○

Q2. Over the last year, about **how often have you communicated** with any of these organizations, or decision makers from these organizations, on issues related to water, energy, and food/agriculture planning in the San Antonio region?

Daily (1)	Weekly (2)	Monthly (3)	Once every 3 months (4)	Once a year (5)	Not at all (6)	This is my own organization (7)

Q3. Do you currently work for an agency or department that deals with water, energy, or food issues in the San Antonio region?

◯ Yes ◯ No ◯ Not in the San Antonio Region ◯ Not sure

Q4. If you answered "Yes" above, about what percentage of your time in a typical week do you currently spend working on water issues of any sort?

◯ 0-10% ◯ 11-20% ◯ 21-30% ◯ 31-50% ◯ 51-75% ◯ 76-100%

Q5. What agency or department do you work for?

Q6. About how many years have you worked in any **[water][energy][food]-**related field?

◯ Less than a year ◯ 1-2 years ◯ 3-4 years ◯ 5 years or more

*** Q7. What type of organization are you primarily a part of?**

◯ Academic

◯ Government

◯ Business/ Private sector (including consulting)
Nonprofit business trade organization

◉ Nonprofit / NGO

Other (please specify) ▭

Q8. Is the organization you primarily work for most associated with water, food/agriculture, energy, or a combination of these?

- Water
- Energy
- Food/Agriculture
- Water AND energy
- Water AND food/agriculture
- Energy AND food/agriculture
- Water, energy, AND food/agriculture
- My organization is not primarily associated with the above options.

Q9. What position do you currently hold in this department or agency?

Q10. Is your work full-time, part-time, or is it purely voluntary?

◯ Full-time ◯ Part-time ◯ Voluntary

APPENDIX E

SURVEY 2: WEF STAKEHOLDERS IN THE SAN ANTONIO REGION

Ground Conservation Districts (GCDs)	Texas Public Utility Commission
Underground management areas	Texas General Land Office
River Authorities	San Antonio Office of Sustainability
TCEQ	Texas Railroad Commission
Regional Planning Areas	Texas Farm Bureau
Texas State Public Utility	Guadalupe County Farm Bureau
Texas General Land Office	USDA
Edwards Aquifer Authority	Texas Department for Agriculture
Texas Irrigation Districts	San Antonio Parks and Recreation
Texas Groundwater Protection Committee	RSAH2O, LLC
Texas Alliance Groundwater Districts	Accelerate H20
San Antonio Water System (SAWS)	Xylem Inc
Drainage Districts	El Paso Water Utilities
Texas Water Resources Institute (TWRI)	Blue Tech Research
Water Conservation Districts	Texas Alliance of Groundwater Districts
Texas Water Development Board (TWDB)	Water Reuse Research Foundation
US Army Corps of Engineers	H20 Midstream, LLC
Texas Floodplain Management Association	Alan Plummer Associates, Inc.
San Antonio Office of Sustainability	Carollo Engineers
Texas Railroad Commission	RWL Water
Texas Comptroller, Office of Energy Conservation	
CDM Smith	San Antonio Food Policy Council
Layne	San Antonio Food Bank
Ozarka Spring Water Company	H.E.B.
ExxonMobil	Kroger
Shell Oil	NatureSweet Company
Valero	Sysco Central Texas, Inc.
Blue Wing Solar, Inc.	Labatt Food Services
GE Power and Water	Del Norte Foods, Inc.
Haliburton	Cargill Food Distributors
Association for Electric Companies of Texas	Ranches
City Public Service (CPS) Energy	Texas Water Foundation

Duke Energy	Texas Rural Water Association
Marathon Oil	Association of Water Board Directors
Pioneer Natural Resources/Reliance Joint Venture	Mission Verde Alliance, SA Clean Tech
EOG Resources, Inc.	Texas A&M University-Global Petroleum Re Inst
NOV-National Oilwell Varco	Association of Electric Companies of Texas
Exelon Corporation	The Nature Conservancy
Anadarko Petroleum	Sustainable SA
Schlumberger	Youth and Food Program
STAR Park	Berkeley Research Group
Aramco Services Company	Texas Parks and Wildlife
Hunt Oil Co.	USDA-Natural Resources Conservation Service
The Texas Sustainable Energy Research Institute at UTSA	Hahn Public
Schertz-Seguin Local Government Corporation	City of San Antonio (OOS)
Forbes Environmental	Texas Center for Applied Technology
Green Spaces Alliance	South Texas Program Office Chief, San Antonio
HMM Risk Group	Bexar County, Environmental Engineer
Southwest Research Institute	Environmental Defense Fund