Enhancing Climate Finance Readiness: A Review of Selected Investment Frameworks as Tools of Multilevel Governance

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Entangled Systems at the Energy-Water-Food Nexus:
Challenges and Opportunities

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ABSTRACT

This chapter assesses energy, water, and food resource systems based on their inter- and intra-sectoral interactions at the institutional level (including private and public activities) and how to achieve security of resource supplies. It identifies key interrelated processes, practices, and factors that underpin integrated resource management (IRM) and their attendant benefits. Applying the E4 framework of energy, economy, environment and equity to identify the main threats to these systems, the chapter evaluates their institutional, political, economic, cultural and behavioral components, and characterizes the forces that drive each of them at different governance scales. The chapter is guided by political economy, economic, and sociological theories that suggest that institutional structures affect economic factors and processes (i.e. production, distribution, and consumption processes). A case study of energy, water and food (EWF) sectors in Delaware is discussed in detail to better understand how these policy and institutional processes occur, which forms they take, and in which ways they define the quality and quantity of EWF resource systems in the State. In order to verify these parameters, E4 framework is considered to evaluate the valency and magnitude of sectoral connections, balance competing needs, and identify policy options that address various trade-offs.

Keywords: E4 framework, energy, water, food, nexus, rules and norms, integrated resource management, institutional structures

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INTRODUCTION

The energy-water-food nexus is essential for sustainable development and conceptually relevant to mitigating the risk of unintended consequences of large-scale sector-specific investments and negative trade-offs. Energy is required to produce, transport and distribute food as well as to extract, pump, lift, collect, treat, and transport water (Halstead et al., 2014). Water is required in energy generation and in the cultivation of food crops. Likewise, food is required to support the world's growing population that both generates and relies on water and energy services (Belden et al., 2008). This highlights the interlocking between water, energy and food resource systems (Figures 1 & 2).

Furthermore, policymakers and researchers in the United States, China, Spain, and Australia duly recognize the important role of a nexus approach as opposed to static experiments in deepening our understanding on "how the occurrence, valency and magnitude of sectoral connections emerge and are altered as a consequence of single sector interventions in a water–food–energy nexus" (Smajgl et al., 2016). For instance, in the United States, a proposal to create specific institutions (such as an Energy-Water Architecture Council to foster data collection, reporting, and technology innovation) to administer and research water, food, and energy ''provisioning" regulatory and planning regimes and promote optimal cross-sectoral coordination was included in the Energy and Water Research Integration Act of 2012 (GAO, 2012). However, the bill was never enacted.

REALIZING A NEW PARADIGM

The Nexus Framework

To date, water, energy, and food resource systems are still largely organized, studied, and prescribed independently. However, decisions, actions, choices, and preferences in each of the three domains fun-

Figure 1. An integrated model showing the complexities between energy, water, and food systems (Belden et al., 2008)

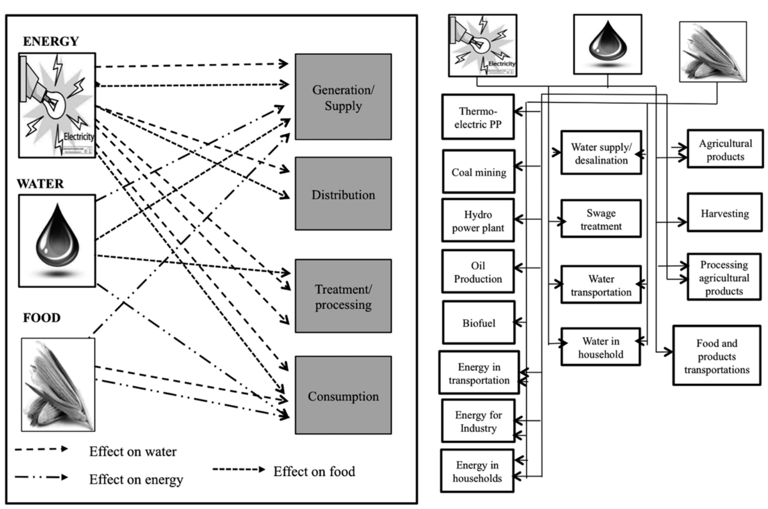
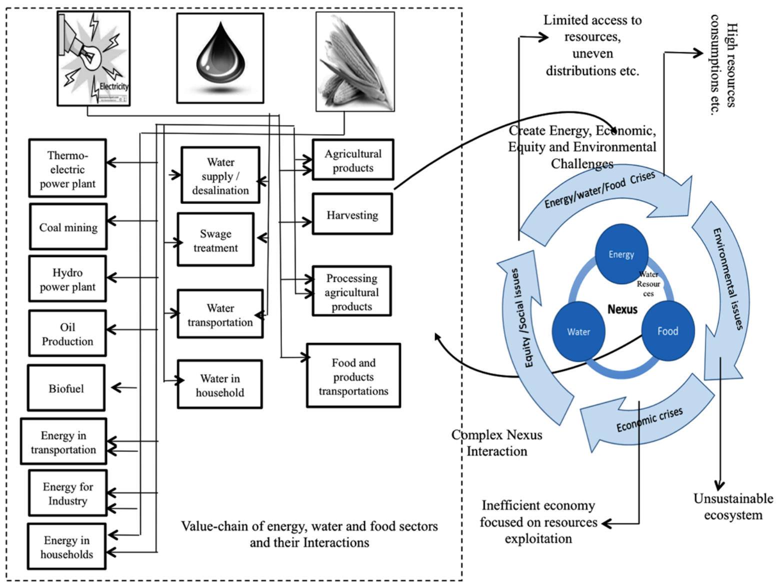


Figure 2. Value chain of water, energy and food sectors and their interactions (World Economic Forum [WEF], 2011)



damentally affect the others, often negatively (Stockholm Environmental Institute [SEI], 2011). The "Nexus approach" is required to effectively analyze these interacting resource systems. So what does a nexus approach entail? In this chapter, a nexus approach refers to multidisciplinary analysis of the relationship between water, energy, and food, in order to help ease trade-offs in production, distribution, and consumption while at the same time developing, integrating, and promoting synergies across these different sectors (Halstead et al., 2014). The synergistic and systems approach applied here is consistent with inter alia, Smajgl et al. 2016 and Foran (2015) (as cited in Smajgl et al., 2016) summarized as: "incorporating social and political context, essential for effective cross sectoral negotiations, can be achieved by reconceptualizing the Nexus as the cumulative effects of development projects coupled with an appraisal of prevailing water, food and energy "provisioning" regulatory and planning regimes" (p. 534).

Developing efficient resource use regime and cross-sectoral policy coherence based on the nexus approach demands a clearer analytic framework to evaluate the sustainability paradigms in the energy-water-food relationship and sustainability policies articulated by Glassman et al. (2011). Glassman et al. (2011) argue that the dominant conceptualization of the relationship between resource exploitation and the attendant policies are fundamentally flawed, requiring a reframing to "balance competing needs and identify policy options that address various trade-offs." The benefit of this integrated approach emphasized by many policy makers during various international environmental governance fora, in an increasingly complex and interrelated world is the potential for a nexus-wide, ripple effects of policies in the management of resources across the sectors [European Report on Development (ERD), 2012].

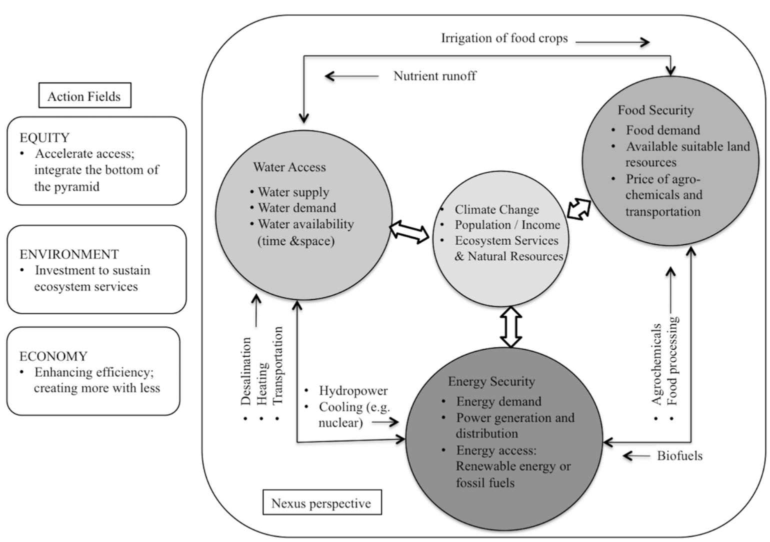
Priorities set in institutional policy design can perpetuate existing inequalities—allowing greater opportunities and access for those with certain privileges (social, class, ethnic, etc.) to access these assets thus limiting equitable participation by all the parties involved. On the other hand, adapting and repositioning existing institutional arrangements effectively could intervene to modify these distribution disparities and prevent resource collapse (Smajgl et al., 2016). However, this requires a clear understanding and use of terms such as 'institutions', 'behaviors', and 'beliefs' (Hadfield and Weingast, 2014). Embracing relational ontologies that see agencies as "distributed and emergent" and as part of unfolding action nets that emerge around issues and events (Garud et al., 2010) constitute institutional adaptation phenomenon. Viewed from this perspective, the presence of differing ontologies of the relationships between agency and structure result in confusion and constraints of time, resources and institutional adaptation needed to address the complexities of water, energy, and food resources, and who bears responsibility for the decisions. To fully characterize water, energy, and food resource systems and the nexus approach, it is imperative to further explore these interactions by examining the institutional linkages between public and private activities. The nexus core (Figure 3) consists of drivers critical for the energy-water-food linkage as it applies to the E4 framework dynamics and cross-sector feedbacks.

Benefits of Integrated Conceptualization of Energy-Water-Food Nexus

The benefit of integrating EWF resource systems on the economy, the environment, energy, and equity (E4) are fourfold. First, it promotes water, energy, and food security by advancing explicit cross-sectorial perspective and response options that supersede traditional sectorial approaches which continue to prioritize isolated investment in one specific sector (WEF, 2011). Second, it supports equitable, inclusive and sustainable growth (ERD, 2012). Third, it fosters a resilient environment (Termeer et al., 2011). And finally, it maintains ecosystem integrity (Norgaard, 2010). In this regard, conservation efforts in water and energy use improve the E4 balance, by enhancing sustainability, building synergies, reducing unintended side-effects and negative sectorial trade-offs, and improving governance across sectors to enable deliberative, legitimate change in social systems (Future Earth, 2013; Gorddard et al., 2016; SEI, 2011; Wang et al., 2006)

This highlights the need to critically assess trade-offs such as between the cost of investing in water technologies now and the potential future return on investments as well as the return on the environ-

Figure 3. Typical interactions in the water, energy and food cross-sectoral connections (Smajgl et al., 2016; SEI, 2011)

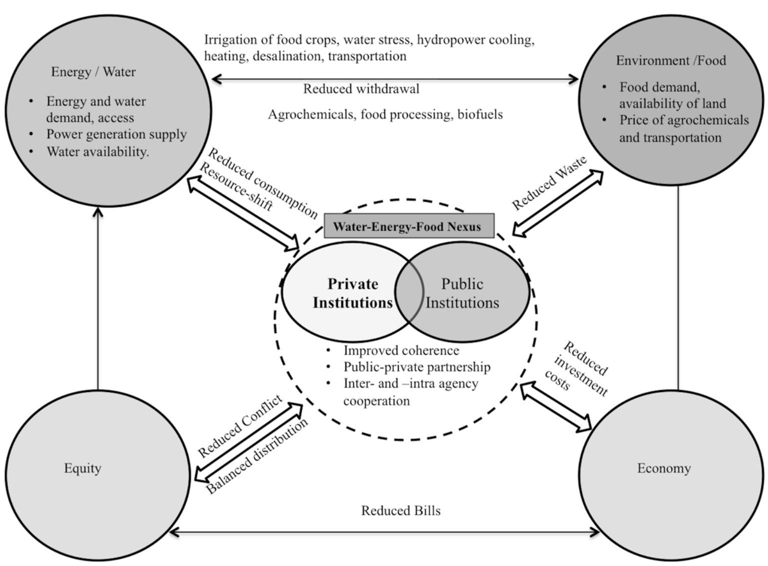


ment because these benefits depend on each other and are interlinked. The nexus approach thus provides a dynamic, integrated way of tackling these complex issues in energy and water, and soon hopefully food, globally. Moreover, to meet the growing water demands of energy and food production, historical, social, and political trajectories that give rise to contemporary energy-water-food planning and regulatory regimes should be integrated into policymaking decisions (Foran, 2015). Incorporating social and political context, necessary for effective cross-sectorial negotiations and agency cooperation between public entities, between private institutions, and between public and private institutions, therefore requires conceptualizing the energy-water-food nexus as the cumulative effects of ‘‘systems” of multiple and dynamic inter-linkages rather than ‘‘chains” of causal, linear linkages (Smajgl et al., 2016). In Figure 4 we conceptualize the additional benefits of a nexus perspective by expanding the E4 framework to include institutional linkages between public and private entities. We therefore depart from a largely conceptual, abstract domain to actual implementation by ‘transmitting’ ripple effects throughout the EWF nexus system.

1. Environment / Food

Reduced water waste and improvements in water efficiency will lower the amount of energy that is required to extract, pump, lift, collect, and transport water. This reduction in energy use will translate in reduced carbon emissions from power generation. Advances in agricultural productivity and focused management of water development through risk management instruments offer opportunities for improving water conservation and avoiding substantial breakdowns between nexus sectors (Leese & Meisch, 2015). This is largely due to the positive side-effects of safeguarding ecosystem services—provisioning, regulating, habitat or supporting, and cultural—and ecosystem functions such as nutrient cycling, bioturbation, plant growth enhancement, secondary seed dispersal, trophic regulation and pollination

Figure 4. Water, energy, and food integration benefits (Smajgl et al., 2016; Wang et al., 2006)



that support the coordinated and sustainable development of nature, economy and society (Changshun et al., 2015).

As ecosystem services and functions become scarce due to population growth, impact of human development, and effects of climate change, their demand and economic value increase resulting in changes in composition, transfer and consumption pattern of these services and functions (Nichols et al., 2008). Serious ecological and environmental problems such as ecological degradation, environmental pollution and biodiversity loss, largely associated with the destruction of natural capital such as forests, water, marine and coastal resources, as well as erosion of soils and pollution of air, threaten food production systems. For instance, water use efficiency varies depending on crop type, and bioenergy offers opportunities for new types of crop production that use water more efficiently (Organisation for Economic Co-operation and Development [OECD], 2014). Water conservation measures also have a direct benefit to the environment because of reduced rate of water extraction, enhancing ecological integrity (Andrews-Speed et al., 2015)

2. Economy

Considering the variety of characteristics common to energy, water, and food sectors, as far as national security interest is concerned, efficiency improvements in these sectors can bring long-term economic benefits, such as lowering costly investment in supply-side facilities and reducing tensions between upstream and downstream users. Reduced power and water utility bills for customers, lowered costs of modernizing or upgrading the energy-water infrastructure, and implementing adaptive institutional management and arrangements such as in fishing stock management, could help mitigate unproductive land and inefficient irrigation systems (Belden et al., 2008; Wang et al., 2006).

3. Energy / Water

In the U.S. nearly 13 gallons of water is required to produce every gallon of gasoline that fuels millions of vehicles (Story, 2014). Approximately 5 million gallons of water is required for the hydraulic fracturing of a shale gas horizontal well (this amount varies with well depths), requiring states to develop urgent strategies to reduce water usage in hydraulic fracturing and to implement cost-effective water recycling technology (Moniz et al., 2011). Studies on hydraulic fracturing in the Marcellus and Barnett shale plays showed that life cycle water for unconventional shale gas is more water intensive per unit of energy (4−10 gal/10^6 British thermal units, Btu) than conventional gas production (~3 gal/ 10^6 Btu) (Clark et al., 2013). Additionally, U.S. power plants combined withdraw nearly 200 billion gallons of water a day, with the majority of these withdrawals efficiently returned to waterways after being used for cooling (Story, 2014). According to the U.S. Department of Energy, about $4 billion is spent annually for energy costs to operate water and wastewater utilities (Ibid: 22). In this regard, reduction in energy consumption is urgently required and can be achieved at both the upstream and downstream levels:

1. Through reduction in energy use for surface and ground water withdrawal and wastewater treatment and discharge by water utilities, and
2. The use of efficient home appliances such as dishwashers, laundry machines, etc.

In the 2014 report entitled, "Water-Energy Nexus: Challenges and Opportunities," the U.S. Department of Energy outlined an integrated challenge / opportunity space around the water-energy nexus including: investment in smart water management to pioneering a smart water grid; improving pump efficiencies; developing new patented technologies to reduce electricity and added chemicals in wastewater treatment; investing in renewable energy sources; and developing new innovative solutions for water use and recycling (Department of Energy [DOE], 2014). From a technology perspective, reducing water pressure reduces leakage, which in turn translates in reduced energy consumption for collecting, treating and transporting water. Investing in water recycling also has the potential to optimize opportunity space around the water-energy nexus. Over 90% of treated wastewater in the United States is not recycled (Story, 2014). In the current era of climate change and taking into consideration the problems associated with conventional technologies of wastewater treatment, research efforts are being also accomplished towards developing innovative solutions for resource conservation with simultaneous management of wastewater (Itankar & Patil, 2015; Patil, 2012; Patil & Rao, 2015). This presents another tremendous opportunity for onsite water treatment options, wastewater reuse for non-portable applications, and development of new local and regional water treatment facilities needed to reduce the cost of energy incurred in producing and transporting the water.

4. Equity

Investing in a balanced EWF nexus paradigm, resource conservation, and efficiency improvements help in optimizing their allocation between competing users during times of scarcity such as climate change-induced energy supply disruptions, especially droughts, food shortages, and electricity blackouts and brownouts (Gorddard et al. 2016; Wang et al, 2006). Moreover, climate change produces new concerns about procedural fairness and equity such the rules and expectations regarding compensation for damage, highlighting the need for inclusive, deliberative process-oriented approaches in the decision processes, particularly ethical and equity propositions (Abel et al., 2011). In this regard, reformulating decision contexts in order to optimize resource allocation could help to reduce conflicts over riparian rights, food scarcity, and energy consumption. The implication of resource induced conflict is profound because of its potential to change social relationships and perceptions of mutual rights and responsibilities between individuals, social groups and the state as well as the possibility to alter the perceived legitimacy of institutions and their obligations over resources (Belden et al., 2008)

THE MAIN THREATS TO ENERGY, WATER AND FOOD SUPPLIES IN DELAWARE: THE E4 ANALYTICAL PERSPECTIVE

Institutional Arrangements in Water and Food Sectors

To examine the main threats to the quality and quantity of EWF supplies in Delaware, as well as the occurrence, valency, and magnitude of sectoral connections in the energy–water–food nexus, it is vital to analyze how these resource systems are managed, commodified, traded and consumed in the state as a common-pool resource (Ostrom, 2010) The paradigms, processes, and practicalities that define the quality and quantity of these resources emerge at different scales, from the individual scale (private) to the state and national scales (public) (Halstead et al., 2014) Within the Delaware state government, increased confidence in the role of institutions charged with managing water and food supplies may stimulate a movement toward deregulation of these resources. Consequently, the emerging institutional arrangements managing these resources can either be a centralized system, or a decentralized one or a combination of both—i.e. regulated or deregulated. In this regard, policy and management decisions on energy, water and food related issues could come from different state departments and elected officers responsible for planning decisions (e.g. agriculture, health, water, etc.), or be the exclusive purview of a single department of energy and water. Furthermore, the emerging organizational structure can either be a top-down, or a bottom-up principally led by local governance and administration (DOE, 2014).

However, the complexity of energy-water-food resource systems precludes top-down management and policy panaceas, thus requires 'polycentric' structures of actions (Byrne et al., 2015). The Paris Agreement, which has ushered in a new policy commitment to ramp-up climate mitigation and adaptation worldwide by containing global temperatures to "well below 2°C above pre-industrial levels" focused on applying "polycentric strategies" based on efforts outlined in the national pledges on climate action called ("intended nationally determined contributions" or INDCs) (Taminiau & Byrne, 2015). The Agreement is fundamentally a revolution in the Conference of the Parties (COP) process. It commits all nations—developed and developing—to curb emissions and tracks their performance over time. To realize just and sustainable climate actions, and in accordance with Decisions 1/CP.19 and 1/CP.20, Parties to the United Nations Framework Convention on Climate Change (UNFCCC) submitted their climate plans based on their national circumstances, rather than focusing on dividing up that responsibility among nations. Additionally, while procedural aspects of the agreement (e.g. communication of nationally determined contributions which is to be housed in a public registry and maintained by the Secretariat) are legally binding, substantive elements (e.g. their content and targets) are not.

Because INDCs are bottom up, countries determine their targets, which they communicate to the UNFCCC Secretariat. As a result, the Agreement promises a flexible, balanced and hybrid approach between a bottom-up system of national pledges-and-review (mandated through a set of transparency measures every five years after 2023) and a top-down, rules-based system for compliance and transparency framework. The polycentric approach lets the process of setting emissions cuts play out within each country. The model "can be considered 'ecological' seeking to enhance institutional 'fit' with the complexity of Earth's social-ecological systems" (Taminiau & Byrne, 2015). The agreement thus could be summed up as an outcome and a push in that direction. It replaces a "non-linear, uncertain, and unpredictable character of environmental degradation" with this "pledge and review" strategy organized through "polycentric networks of creative innovation and leadership" (Taminiau, 2015).

Institutional change demands effective coordination by officers responsible for planning decisions at different levels. Polycentric strategies can be "considered 'ecological', seeking to enhance institutional 'fit' with the complexity of Earth's social-ecological systems" (Taminiau & Byrne, 2015). The agreement thus could be summed up as an outcome and a push in that direction. It replaces a "non-linear, uncertain, and unpredictable character of environmental degradation" with this "pledge and review" strategy organized through "polycentric networks of creative innovation and leadership" (Taminiau, 2015). Equally, realizing a new investment paradigm (i.e. decentralized and community driven solutions) in the energy, water, and food sectors requires mobilizing 'polycentric financing strategies' by engaging the private sector, capital markets, cities, and transnational and subnational authorities. Against this backdrop, Table 1 provides a brief overview of some institutions in the water, energy, and food sectors in the Delaware State.

Table 1. Major institutions in the water, energy and food sectors

Institution	Function	Sector
The Delaware Public Service Commission (DPSC)	Sets rates on water and wastewater services to cover the cost of water collection, treatment, testing, and delivery.	Water
The Delaware Department of Natural Resources and Environmental Control (DNREC)	● DNREC Division of water oversees pollution regulation for both surface water and groundwater discharges. ● The U.S. Environmental Protection Agency has delegated authority to DNREC to administer permits under the National Pollutant Discharge Elimination System (NPDES) pursuant to Section 402 of the Clean Water Act. ● DNREC also monitors water quality in the state. DNREC Division of Energy and Climate administers programs to avoid the adverse impacts of energy use on environment, health, and economy.	Water and energy
Public Service Commission (PSC)	Regulates the distribution of electricity in the state.	Energy
Delaware River Basin Commission (DRBC)	Manages water quality protection, supply allocation, permitting, conservation, planning, drought management, flood control, and recreation in four basin states (Delaware, New Jersey, Pennsylvania, and New York).	Water, energy, food.
Delaware Agricultural Lands Preservation Program	● Landowners who place their lands into Agricultural Preservation Districts agree to not develop their lands for at least 10 years, devoting the land only to agriculture and related uses. ● The owners receive tax benefits, right-to-farm protection, and an opportunity to sell an easement to the state that keeps the land free from development permanently.	Food
Delaware Agricultural Forestland Preservation Program	● The Program protects forest lands through perpetual conservation easements. ● The program currently receives a $1 million appropriation annually.	Food
Delaware Office of Food Protection	● Ensures the regulatory foundation of programs in retail food protection and safety includes which current, science-based requirements. ● Ensures that complaints and outbreaks associated with the food consumption are appropriately investigated. ● Ensures that effective compliance and enforcement procedures for food establishments, production and processing are promulgated and are used appropriately to reduce the risk of foodborne illness.	Food
The United States Department of Agriculture Farm Service Agency (FSA)	● Oversees a number of voluntary conservation-related programs which address farming and ranching related conservation issues including: o Drinking water protection o Reducing soil erosion o Wildlife habitat preservation o Preservation and restoration of forests and wetlands.	Food
Federal agencies	Federal Energy Regulatory Commission (FERC) for regulating prices and even licensing hydropower plants; USDA Natural Resources Conservation Service, USDA (Farm Services Agency, Forest Service), Environmental Protection Agency (EPA) with water conservation programs.	Water/ Energy/ Food
Delaware's Sustainable Energy Utility (SEU)	A unique non-profit organization offering a one-stop resource through its Energize Delaware initiative to help residents and businesses save money through clean energy and efficiency.	Energy
Delaware's Renewable Portfolio Standard (RPS).	Eligible renewable energy technologies include: geothermal electric, solar thermal electric, solar photovoltaics, fuel cells using non-renewable fuels, landfill gas, wind, anaerobic digestion, fuel cells using renewable fuels, biomass, hydroelectric, tidal, wave, ocean thermal. RPS is set at 25% by compliance year 2025-2026 (Delaware State Senate, 2016).	Energy

Exogenous Factors

The success of these institutions in achieving their missions depends on a number of considerations: the availability of the energy, water, and food resources; the occurrence of external shocks; and the synchronicity with other trends or events occurring within the system (Graedel et al., 2014) Therefore, understanding the interactions between these exogenous variables, which shape either the quality or quantity of the three resources in the Delaware state, or a combination of the two is fundamental to the nexus approach. The following development strategies were identified for this book chapter: Energy (e.g. hydropower, concentrated solar thermal and concentrated solar power (CSP) systems, energy crops); water (e.g. water diversion); and food (e.g. irrigation projects, fisheries management, and corn production).

These interactions are shaped and influenced by a trifecta of variables, including: (i) resource and/or biophysical conditions, (ii) rules and norms, and (iii) community attributes that influence consumption patterns of the respective resources (Ostrom, 2005). Resource or biophysical conditions including: the size of the resource (actual); the magnitude of the resource (potential); and its location (Macknick et al., 2011) explain the pattern and rate of consumption and whether the resource is evenly distributed or geographically dispersed within the state.

Within the state, rules and norms that determine the quality and quantity of the resources (i.e. energy, water and food supplies), include government regulations (i.e., water and food policies at the City, County and State levels); established precepts, moral behavior, values or norms that guide behavior on use of water and food resources (e.g., decisions such as use of hydraulic fracturing and its potential impact in contaminating underground water resources); state instructions (i.e., existing strategies on improving and sustaining quality and quantity of water and food supplies); and principles that guide these sectors (e.g., water and food resources are location specific) (Hanlon et al., 2013). Finally, community attributes include culture and values that define different energy-water-food choices on what is perceived to meet the set standards of quality and the quantity consumed thereof; the State's homogeneity and preferences for certain foods and/or brands of treated water over the other; the level of commonality in water-food options, the composition and size of the community using different resources; and the equity and ethical implications that exist in accessing these resources in the state. Figure 5 displays the interactions of these exogenous variables at the institutional level in the E4 framework.

The three variables—resource conditions, community attributes and rules and norms—as illustrated in figure 4, taken together present a coherent longitudinal orientation of the constraints on water, energy, and food resources, with conceptual integration and dialectical rationality as their cornerstones (FAO, 2011; Halstead et al., 2014; Ostrom, 2005; SEI, 2011). For instance, rules and norms shape and define community attributes, and in turn define resource conditions and consumption patterns. Figure 6 provides a summarized schematic framework of such interactions at the institutional scale.

Key tenets of this interaction, driven by self-organizing emergent processes embodied by the E4 framework towards long-term sustainable energy-water-and-food system, energy resiliency, long-term sustainable economic growth, and equitable distribution of the resources, however, have rested on essentially narrow models of society. Consequently, conceptual frameworks and theoretical positioning of the linkages between lifestyle choices and the resultant macro-behavior have yielded inadequate sustainable resource insights even as demand for these resources has grown. As a result, Delaware State faces constant threats to maintain sustainable quality and quantity of energy, water, and food supplies.

Figure 5. An illustration of how exogenous variables influence quality and quantity of energy-water-food supplies at public and private institutional levels in Delaware State (Ostrom, 2005)

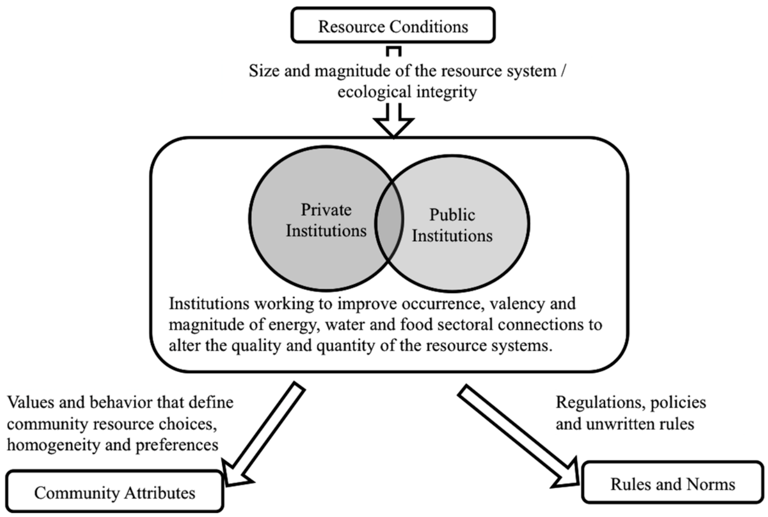


Figure 6. A simple framework for institutional analysis (Ostrom, 2005)

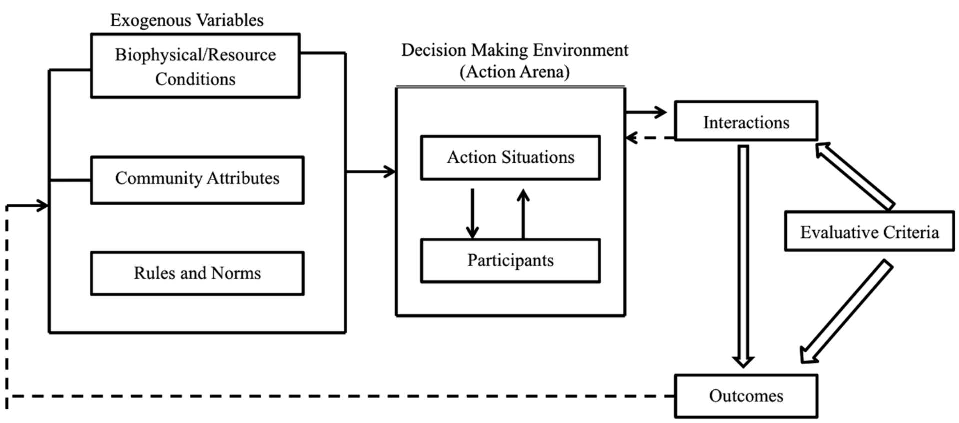


Table 2 provides a summary of different categories of threats with respect to these resources.

Investments in the EWF systems in Delaware remain inadequate sub-optimal by individual sectors. Statewide connectivity implies that investment factors (or drivers) interact between nexus sectors, transmitting the effects of magnitude and valency of these interactions and feedbacks from one part of the State to another and to other sectors. According to the Nature Conservancy (2014), "94 percent of the State's [Delaware] creeks and rivers fail to meet fish and wildlife needs under the Clean Water Act, 86 percent are unfit for swimming and 30 rivers carry warnings against eating fish caught in them" (p. 4). In March 2014, Delaware Governor Jack Markell proposed an increase of $800 million in water sector investment to clean Delaware's waterways, curb stormwater runoff and flooding, and protect drinking water supplies (Montgomery & Murray, 2014) Although the cost of the program was to be met through a statewide tax that would cost homeowners $45 a year, once implemented the governor's proposals

Table 2. Threats to quality and quantity of energy, water and food supplies in Delaware

Categories of Threats	Threats
Political and Institutional risks	Lack of coordination and skilled personnel to develop, design, finance, build, operate, and maintain water and food related projects and programs.
	Reliance on non-renewable energy sources to collect, treat and transport water and food supplies.
	Uncoordinated research and development (R&D) in water and food sectors.
Economic and Financial risks	Unclear signals sent to potential investors in water and food sectors which may lead to high risk perception by investors and heightened uncertainty.
	High upfront cost of constructing water infrastructure projects and lack of structured investment options and innovative financial mechanisms in the water and/or food sectors.
	Lack of one-stop investment repository of water and food resources in the state.
	Lack of up-to-date best practices in investment decision making in water and food sectors.
Regulatory risks	Existing regulatory structures that favor large scale commercial food companies and not small food producers and processors.
	Lack of a centralized database (for all county, city and state focused) of water and food related regulations and stages in their implementation.
	Lack of a strong targeted regulatory presence that focuses on both policy and administration of water and food organizations.
	Conflicting research findings on genetically modified organisms (GMOs) food crops; biotechnology and balanced intellectual property rights thus creating uncertainty on food security in the state; concerns and implications of hydraulic fracturing on underground water resources.
Technical risks	Preference for pipeline extensions and centralized water treatment facilities by water utilities.
	Connectivity, perishability, availability, and quantity concerns related to food distribution and transportation.
	Lack of clear quality standards for home water purification and related accessories.
Socio-cultural risks	Little involvement and participation of consumers in influencing water and food related decisions and related services.
	Decision making precludes local participation.
	Poor information diffusion on the use and benefits of quality water and food to producers and consumers.

would have improved the State's capacity to secure its fresh waters, improve its coastal resilience, and broaden the constituency for water conservation (Jerome, 2016). However, this proposal was rescinded as other sectors were prioritized for State financial investments. "Everyone wants a cleaner environment, but no one wants to pay for it," the governor observed (Bittle, 2016).

Like most states, financing water infrastructure through debt securitization is still very expensive. The high cost of debt directly affects investments in water utilities and related sectors including food and food processing companies that depend on availability of uninterrupted water supplies.

SOLUTIONS AND RECOMMENDATIONS FOR DELAWARE

The application of the E4 framework to study the main threats to the quality and quantity of energy, water and food resources in Delaware represent one aspect of this analysis. However, it is imperative to note that these threats do not operate in a vacuum. Economic, institutional, political, regulatory, and sociotechnical innovations that nurture sustainable trajectories in order to respond effectively to the threats identified above also provide insightful synergistic perspectives. Therefore, employing a robust integrated framework that clearly outlines the interactions between exogenous variables (i.e. resource conditions, rules and norms, and community attributes) and their influence on water and food resource systems in Delaware is a prudent strategic response. Major gaps and needs between the desired resource quality and quantity, and public and private institutional interactions, however, remain wanting and in need of policy and institutional reorientation.

Policy Options

Achieving massive reforms that are associated with huge investments in the EWF sectors undoubtedly require socioeconomic restructuring and additional monetary and fiscal resources to stimulate sustainability transformation. This requires a strong State government policymaking regime (i.e. political will) as well as multi-stakeholder participation especially in the public and private sectors to prioritize implementation of policy options that incentivize promising sociotechnical innovations. Leaving management of water, energy, and food resource systems completely to the whims of market factors often do not effectively support inclusive and sustainable transformation (OECD, 2014). Thus, policy options that translate nonmarket concerns such as sustainable watershed funding, water, and food pollution control, water quality assessment and treatment, avoidance of population migration peaks due to change in access to the resources, and identifying the ensemble of EWF system criticalities and understanding them as intervention points instead of a singular focus on one sector are primary strategies. However, government policies alone are not adequate. In this regard, rather than relying completely on government policies in order to effectively address current and future threats, effective solutions to energy-water-food resource challenges should be bold and integrative and should not be constrained by economic and political undertones (as a means to embody the E4 framework (SEI, 2011).

Second, given that both federal and state water resource appropriations have been on the decline, Delaware must identify other sources of revenue to fund its huge capital-intensive water pollution control program in the Delaware Basin. For instance, potential sources of revenue include the user/polluter pays principle by addressing the negative externalities from upstream water pollution that can impair downstream consumers. Successful user/polluter pays approaches have been implemented by New York City (to protect its Catskill/Delaware water estuaries in upstate New York), San Francisco, and Boston to promote cost-effectiveness of resource use, innovation, and alignment of financial benefits with pollution reduction (Hanak, 2011). Other funding sources include the use of water quality trading by deploying successful pollution control principles as successfully demonstrated by the Clean Air Act to reduce the threat of SO_2 and acid rain from atmospheric emissions (DOE, 2014).

Third, there is need to re-evaluate the value of water because water prices charged currently do not reflect the full opportunity cost of utilizing the resource. Non-pricing tools such as landscaping ordinances and restrictions (e.g., limits on the planting of lawns and use of outdoor watering), public education, plumbing and appliance standards, tiered rate structures, and rebates to encourage new technology adoption can encourage conservation (Hanak, 2011). The current water cost structure whereby consumers pay for water at its average cost when the resource is abundant and not based on its overall scarcity value has contributed to undervaluing water resources. As a result, investments in the water sector have remained small as federal, state, and local governments continue to underinvest in water resources and water pollution control programs. In addition, solutions to the financial challenges confronting interrelated sectors such as the food sector may lie in effectively implementing river basin management strategies whereby beneficiaries and users of the river resources bear some of the costs of the restoration.

Fourth, with regards to the three domain sectors, local level planning should be prioritized because it incorporates community attributes—their choices and their preferences about the kinds of changes in food supply, distribution, processing and transportation they want implemented. Further, three policy perspectives that legitimize the role of local institutions in the three domain sectors in Delaware have been offered:

- Analytical-operative, which considers the local scale the best means to establish diversified and effective regulatory policies, and in obtaining contextual knowledge of food, water, energy, environmental, and public health issues.
- Policy perspective, which requires bottom-up endogenous development of decentralized energy, water and food management strategies in which the local dimension is prioritized through avenues such as Farmers Markets, Farm to Table, etc. This perspective favors inclusive decentralized knowledge at the local level as the most suitable scale at which to introduce the nexus perspective as it is effective in closing the cycles of material flows and improving food production system efficiency, thereby improving resource conditions (Bagliani et al., 2010)
- Finally, the third policy perspective supports the local dimension approach due to its potential to drive variants of small signal transformations by 'transmitting' ripple effects statewide throughout the nexus system, through better articulation of the regulated energy, water, and food functions; improved coherence and understanding of sectoral linkages; and enhanced investment readiness in the domain sectors.

However, like the water and energy sectors, management of food resource systems in Delaware State can hardly be described as bottom-up driven. Its history has been heavily top-down and the complexity of this high conceptualization has tended to be ineffective.

INSTITUTIONAL MEASURES AND STAKEHOLDER ENGAGEMENT

As discussed in the E4 framework, successful realization of an integrated policy regime in energy, water and food resource systems requires commitment by all stakeholders to help deliver broad economic, equity, energy security and environmental benefits. In Delaware, it is evident that various stakeholders including the federal and state governments, private firms and non-profits all support opportunities that seek to mitigate policy, finance, regulatory, and institutional threats to these resources. However, as revealed in Table 1, multiple, interlocking missions often hinder progress towards an integrated energy-water-food perspective rather than segregated series of liability. Overcoming these threats thus requires multiple, mutually reinforcing actions that are often beyond the scope of the current institutional capacity.

The central aim, here, is to provide institutional measures and deliberative stakeholder engagements that hasten cross-sectoral coordination in areas where progressed has slowed or even regressed by:

- Creating a conducive environment to private investment in renewable energy technology deployment, water and food security;

- Developing adequate infrastructure options for adaption needed to scale up and deploy sustainable energy-water-food solutions with the least resource intensive options;
- Ensuring stricter requirements for more efficient energy use, and water and food conservation by government agencies;
- Implementing utility reforms to enhance electricity grid reliability and sustainable service delivery, values-based water management strategies, and rules-based changes in food administration including legislative reform; and
- Strengthening local financial institutions by positioning their product rollout and investment in the energy, water, and food services towards a nexus paradigm.

A water-centric analysis of the institutional challenges to the quality and quantity of supplies sustained by the Delaware River Basin reveals that management and administration of water resources in the State is confronted by complex institutional and governance concerns that require explicit cross-sectoral perspective and urgent response options (Cody & Carter, 2009). As a result, this can put the various state governments managing the basin in dispute with their upstream or downstream neighbors leading to interstate conflicts. To respond to these institutional and governance challenges, the state should implement a sectorally balanced, dynamic nexus approach, such as:

- Moderating competing water uses for energy generation and agricultural food production between upstream and downstream stakeholders;
- Balancing and adapting institutional arrangements at the federal, state, city, and local levels, for example for fishing, hydropower development and irrigation;
- Promoting dynamic processes that reveal a set of decision-making elements that are important in 'transmitting' ripple effects throughout the energy-water-food nexus system to advance multidisciplinary knowledge networks in the fields of science and policy in these domains.
- Developing mechanisms to develop cost effective solutions, pricing structures, and rate designs of energy, water and food resources; and
- Finally, implementing market-based instruments to control nonpoint sources of water pollution—the runoff from agricultural fields, mining, urban streets, timber harvesting, gardens, and construction sites.

Kneese and Bower (1984) raised three fundamental questions on the state of Delaware Rivers, which we still have not answered: "Do we want good water quality 90%, 95%, or 98% of the time? How can we achieve a desired level of good water quality at least cost? What are the best institutional arrangements for managing water quality in [the Delaware] river basins? These questions underscore why water-centric policy approaches have yielded relatively minor additional dividends. Hence, the need for a variant of integrated approach in designing and assessing investment across multiple sectors and scales. Identifying policy, finance and market interventions such as energy, water, and food conservation campaigns for monetary incentives to change consumptive behavior and habits as well as undertaking better assessment of the impacts of energy choices on water availability for agricultural purposes. Furthermore, state governments must undertake regular complementary analysis of their freshwater withdrawal for agriculture and quality assessment by energy type (e.g., breakdowns by technology including aggregate data and details by industry sector such as energy, agriculture, manufacturing, and domestic use).

FUTURE RESEARCH DIRECTIONS

Rules and norms, social structures, and values, which are internalized by institutions in order to sustain existing social arrangements at different governance scales, could perpetuate distribution disparities in energy, water, and food resources (Gorddard et al. 2016). Understanding institutional structures and operational and implementation mechanisms through which these structures perpetuate or create exclusion is thus the first and foremost step in achieving a comprehensive energy-water-food nexus perspective. The chapter examined the EWF resource systems in Delaware at the institution level given underlying factors implicit therein at private and public levels. However, further research is required to explore how complexity of socio–ecological systems, economic preferences, and EWF resource distributions in turn influence institutional structures, the occurrence, valency, and magnitude of sectoral connections that alter the quality and quantity of the resource systems.

CONCLUSION

Given the complexity of modern energy, water, and food planning and management as common-pool systems, cross-sectoral coordination and investment strategies in these sectors based on the nexus architecture remain a protracted process. There is neither no guaranteed proven system for successful management nor established paradigms with guaranteed end results, and any proven policy interventions and institutional strategies will require regular reviews and adjustments to make them relevant to the prevailing market, as the change and impacts of climate change on water resources information becomes evident and population grows. In this regard, formulation of desirable goals for these sectors may seem a hopeless endeavor in a fast changing and unpredictable modern society, where serendipitous political and economic changes have become ubiquitous. However, the nexus paradigm for energy, water, and food sectors examined in these asset-intensive sectors can happen very fast, as has happened in the telecoms sector in other parts of the world especially Africa, Asia, and Latin America. Yet in the water, food, and energy sectors, adding a 'wicked' problem such as climate change to this mix further complicates management of policy, investments and market criticalities needed to produce more sustainable outcomes. For example, uncoordinated management of these three domains, can make the sustainable transition process takes much longer because of the time required to transform sociotechnical systems and realize the return on investments. But one thing is clear. Through innovative financing mechanisms such as user/polluter pays and energy/water trading schemes ("cap and trade" systems), unlocked by market competition and fair pricing, integrated and coordinated management of these vital resources while meeting social and ecological needs and promoting economic development, significant incentives and opportunities can be optimized, hastened and realized in the energy-water-food nexus approach.

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KEY TERMS AND DEFINITIONS

Community Attributes: These include influence of culture and values that define how choices in resource use are made i.e. cultural values and behavior that define different energy, water, and food resource choices, homogeneity, and preferences for a given resource over the other.

Complexity of Socio-Ecological Systems: These include occurrence, valency and magnitude of sectoral connections in the water–food–energy nexus.

E4 Framework: Conceptualizes the benefits of integration from economic, energy, equity and environmental perspectives.

Rules and Norms: Determine the quality and quantity of the resource (e.g. water and food supplies) and include *inter alia*: regulations, established precepts or moral behavior, values, and principles that guide the resource sectors.

APPENDIX

Hybrid Sankey Diagram of Interconnected Water and Energy Flows

Energy and water are interconnected through various sectors of the U.S. economy. Large quantities of water are used for cooling energy systems, while significant quantities of energy are required to pump and heat water. Water is also used in small but important ways in fuels production. Figure 7 displays a hybrid Sankey diagram of energy flow for the U.S. produced by Lawrence Livermore National Laboratory for 2014.

Figure 7. Hybrid Sankey diagram of energy flow in U.S. (National Academy of Sciences, 2014)