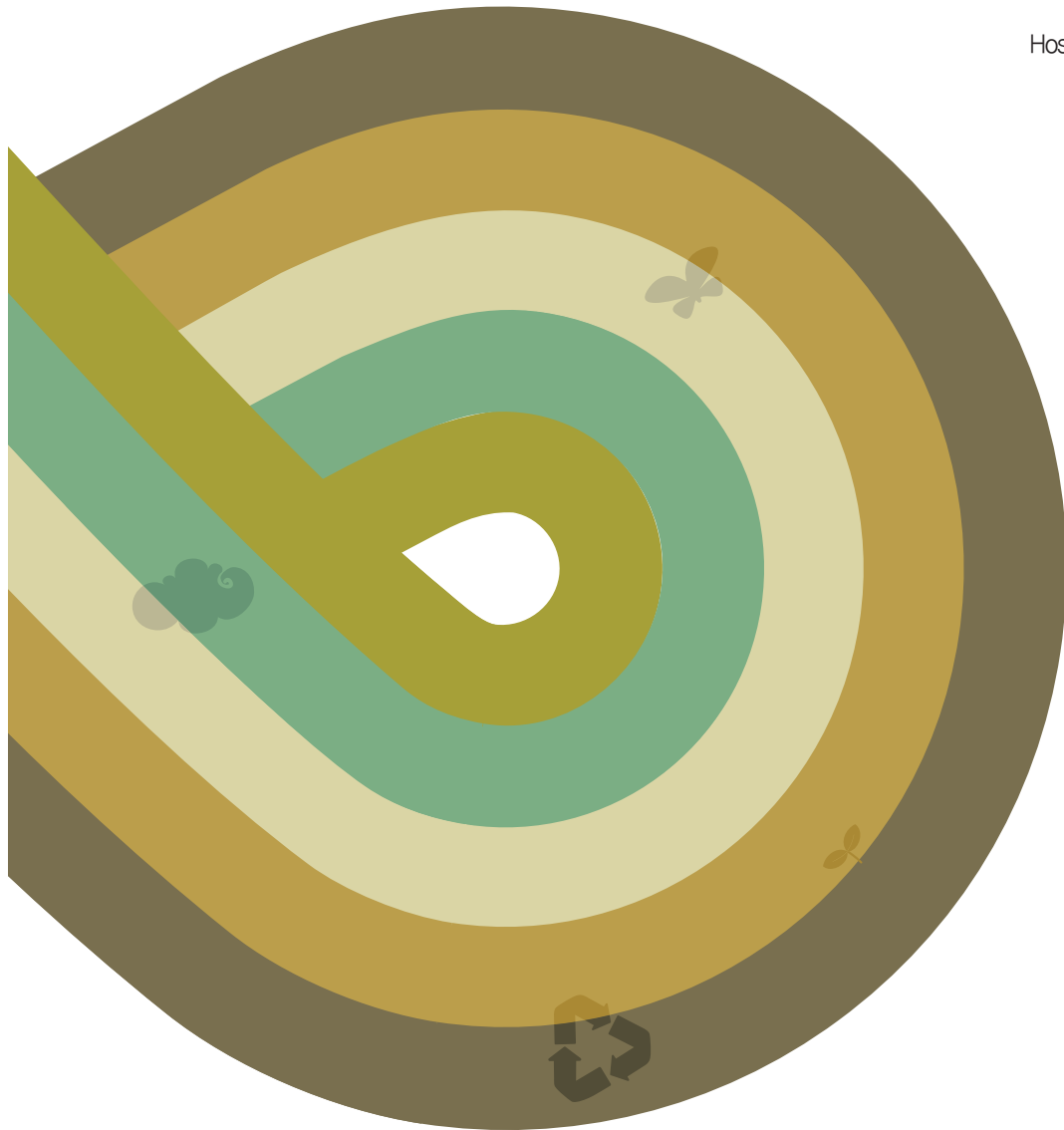


# A Study on Policy Directions for the Water-Food-Energy Nexus (I)

Water-Energy Nexus

Hoseok Kim et al.



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# FOREWORD

The UN summit held in September this year adopted the 2030 Agenda for Sustainable Development, including 17 Sustainable Development Goals (SDGs) and 169 associated targets as the new global agenda to replace the Millennium Development Goals at the end of 2015.

The 2030 Agenda commits member states to achieving the Sustainable Development Goals in a balanced and integrated manner, taking into account the inter-linkages between the three dimensions of sustainable development and their associated goals.

For the last decade, it has been increasingly recognized that co-benefits can be achieved through an integrated approach to addressing security issues related to water, energy and food, and a nexus approach is an effective way to manage the interdependences between the resources.

This study examines policy and institutional aspects of a nexus approach with a focus on the inter-dependencies between water and energy systems, which are essential elements for management and policy-making. This study will contribute to the understanding of the policy dimension of the water-energy nexus, and address the institutional arrangements for adopting more nexus-based solutions in the energy and water systems.

Kwang Kook Park,  
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# Abstract

Energy and water are vital services to be provided to all communities for their persistence. For the entire human history significant inputs and efforts has been invested to secure the services, and the size of the costs is increasing as the related resources is getting scarce.

Water and energy have been included in the development goals of most of societies in human history. In both areas, the ultimate goal is the same, which is to provide water and energy for the development of the society, but the circumstances surrounding the policy goals are different, and, therefore, the ways of policymaking vary.

The nexus perspective provides various opportunities for enhancing synergetic solutions between the systems in which the resources and activities are organized to produce final services for the community. Given the increasing understanding of the inter-connectedness between the systems, conventional perspectives dealing with the systems separately would not be seen as effective even from each system itself, as well as from the sustainability aspect of the community.

A number of recent studies have emphasized the significant roles of the energy-water nexus, but institutional and policy dimensions of the nexus have not dealt with significantly. The purpose of this study is twofold: (i) to identify the nexus interactions between water and energy system, and various nexus-based solutions that can address sectoral issues in both systems, (ii) to develop possible institutional arrangements, including public intervention, that can support the adoption of nexus approaches when they can enhance sustainability and resource security of each component systems.

Keywords: Water, Energy, Nexus, Integrated Policymaking, SDG, Sustainable Development

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## 1. Understanding the Nexus

### 1.1. Resource Security and Sustainable development

Water, food, and energy security as basic needs has been a crucial issue in human history dating back to the earliest days of civilization. But until quite recently they were not treated as a nexus, which are closely interdependent each other so that it's not possible to address an issues of one system without considering its impacts on the other systems. This seems due to that there might be no clear reason to see the systems only inter-connected.

Natural resources are basic inputs for economic development. Since the early 1970s, many studies have discussed about the role of natural resources in the economy. In 1972, *The Limits to Growth*, the famous publication of the Club of Rome, developed a set of scenarios for possible futures and predicted that continued growth of the global economy, as resource extraction increase, would result in significant resource scarcities.

*The Limits to Growth* introduced the concept that natural resource depletion will impact the ability of an economy to grow in the long-run, and this was the first occasion attracting public interest globally on the resource security as a significant threat to an economy.

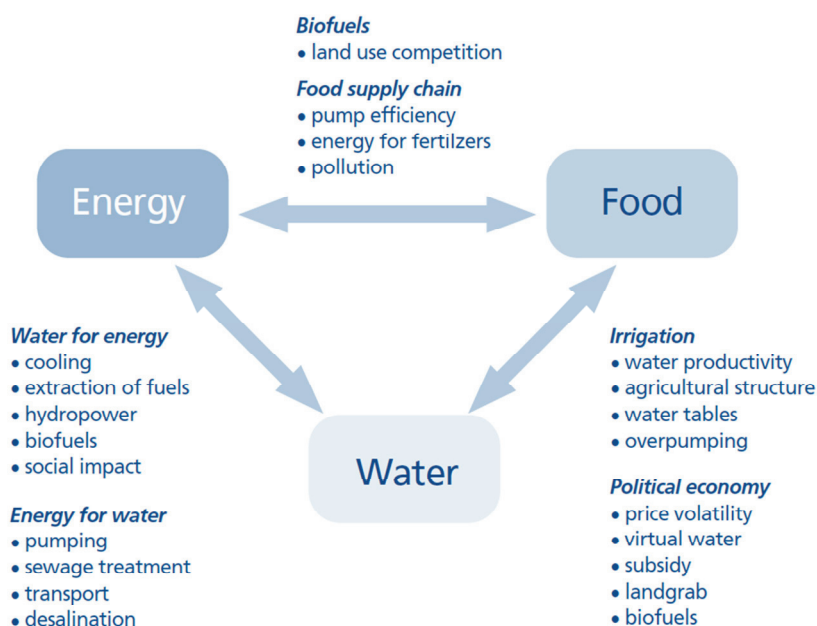
In 1987, *Our Common Future*, the report of the World Commission on Environment and Development (WCED), introduced more comprehensive concept of the interdependency between natural resource and the economy. The concept of sustainable development was based on the interlinkages between economic, environmental, and social dimensions and has been incorporated in global development agenda.

Even in the context of sustianble development, the integration of these three dimensions remains segmented. Resource security issues have been getting increased attention again in the context of the global crises in natural resources, and the nexus between resources, particularly the water-energy-food nexus, came into existence as a new approach to address water, energy, and food security issues in line with sustainable development.

The nexus perspective can be an effective way for more integrated management of natural resources and related security issues. General sectoral goals and issues, in the context of the energy-water-food nexus, which have to be incorporated in integrated approaches and policies to address the complex

relationships between energy, water, and food are as follows<sup>1</sup>:

- Energy sector
  - Stable energy supplies relative to demand at an affordable price
  - Long-term physical availability of energy supplies
- Water sector
  - Access to affordable drinking water
  - Access to safe water and sanitation
- Food sector
  - Availability of food
  - Affordability of food
  - Quality and safety of food



**Figure 1. Interdependencies between water, energy and food** <sup>2</sup>

<sup>1</sup> See Bizikova et al.(2013) for more about energy, water and food related security issues

<sup>2</sup> Figure 1 from UNESCAP (2013)

### *Historical Background*

The term “nexus”, with specific reference to natural resources, first appeared in 1983 with the Food-Energy Nexus Programme of the United Nations University (UNU), which aimed to better understand interconnected energy and food challenges in developing countries with a particular focus on technical solutions and policy. (Scott, et al., 2015) (Sacks & Silk, 1990)

Around the same time, in mid-1980s, there was some recognition that water management in the Western US would need to account for energy and environmental needs for water, as well as the prevailing agricultural and industrial needs. (Durant & Holmes, 1985)

The water-energy nexus, as it is discussed today, is known to have begun in the mid-to-late 1990s and early 2000s<sup>3</sup>. Sant and Dixit (1996) addressed energy demand for groundwater pumping in a Water-Energy Nexus project, and Scott et al. (2003) applied the electricity-for-water nexus to Jordan and extended later to Mexico with particular attention to institutional and policy dimensions.

Publications on the three-way interactions among energy, water and food, the Water, Energy and Food (WEF) Nexus, was not widely used until 2008. Hellegers et al. (2008) indicated an urgent need to assess the “entire spectrum of the water-energy-food-environment interface” so as to explore alternative strategies to address the tension between the resources and enhance the synergy benefits.

With a series of international events and initiatives on the nexus in the early 2010s, such as the Bonn 2011 Nexus Conference, the Stockholm World Water Week, and the Water, Energy & Food Security Resource Platform, the WEF Nexus began to get significant institutional support. Since then, especially after the Bonn 2011 Nexus Conference, various conceptual and analytical frameworks for the WEF Nexus have been developed by many international organizations and think tanks in reference to their concerns in sustainable development.

### *Advantages of a nexus approach*

The advantage of a nexus approach is to enable us to understand the

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<sup>3</sup> Scott et al. (2015)

complex interdependencies between the natural resources, including their uses for development purposes, so that we can manage the resources in sustainable ways allocating limited resources to optimize its contribution to sustainable development.

A nexus approach enables us to explicitly consider the impacts (trade-offs and synergies) of a decision in one sector may have on effects on the other connected sectors. By incorporating the potential impacts on other systems in decision making, we can develop effective solutions across all sectors under considerations. Opportunities for improving resource security through a nexus-based approach are as follows<sup>4</sup>: (Hoff, 2011)

- “Increasing resource productivity”
- “Using waste as a resource in multi-use systems”
- “Stimulating development through economic incentives”
- “Governance, institutions and policy coherence”
- “Benefiting from productive ecosystems”
- “Integrated poverty alleviation and green growth”
- “Capacity development and awareness raising”

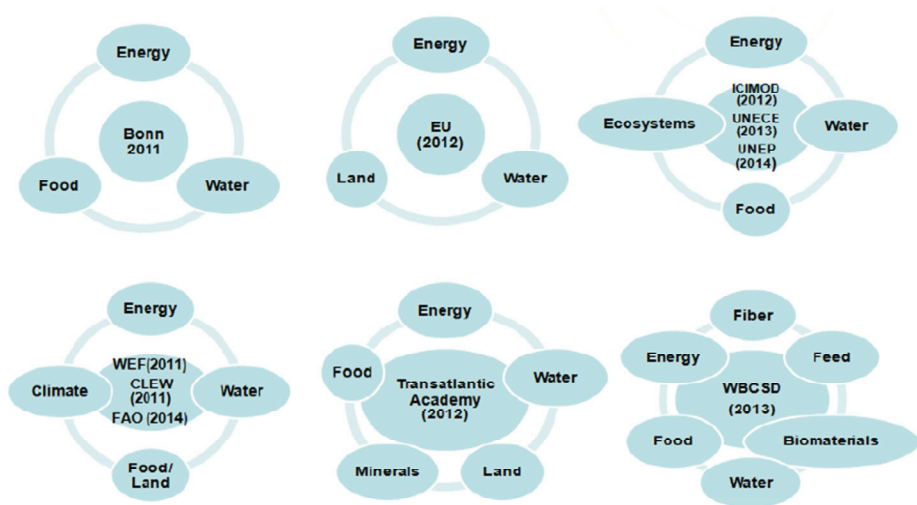
## 1.2. Various Conceptual Frameworks for the Nexus

Bizikova, et al. (2014) defined the water-energy-food nexus as “an approach to assessment, policy development and implementation that focuses on water, energy and food security simultaneously”, which offers a conceptual and methodological framework for integrated management of natural resources across different development purposes. (FAO, 2014 )

Different conceptual frameworks for the nexus vary in their scope and sectors incorporated into the nexus framework. It is quite natural for the frameworks to expand the scope of the nexus to include additional sectors of particular importance to the framework, if it is feasible to address necessary analytical issues for the nexus.

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<sup>4</sup> First 7 are from Hoff (2011)



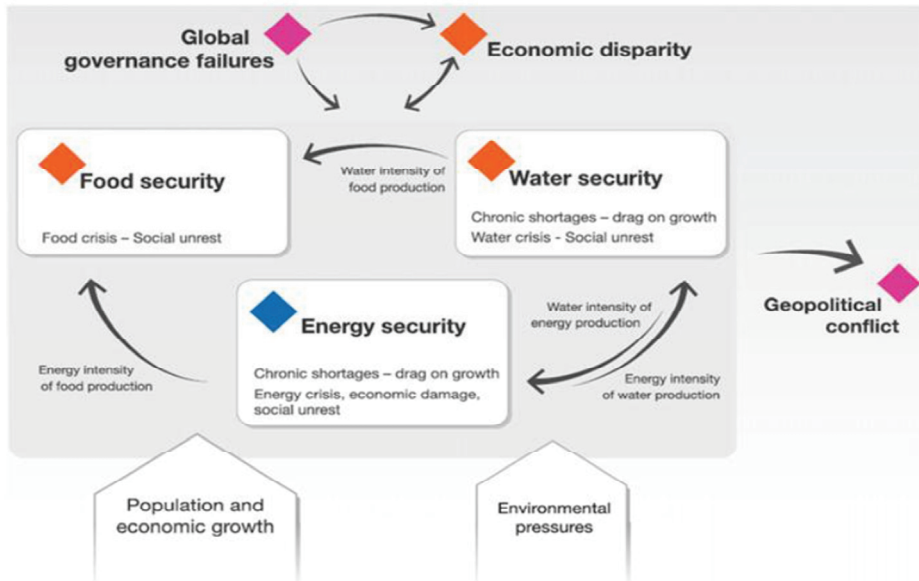
Source: UN ESCWA(2015)

**Figure 2. Some conceptual frameworks for the resource nexus**

*World Economic Forum (2011)*

WEF (2011) suggested a framework, the water-energy-food security nexus, to help decision-makers better analyze the global risk landscape so they are able to respond adequately in times of crises. The framework includes population and economic growth and environmental pressures affecting the nexus, and identifies specific important relationships among the elements of the WEF nexus, such as energy use in food production and water use in food and energy production. In the WEF nexus, water, energy and food security are linked to 'global governance failures' and 'economic disparity', and energy security is linked to economic risks in terms of energy shortages causing economic and social impacts.

The policy recommendations proposed by this framework includes "integrated and multistakeholder resource planning, market-led resource pricing, community-level empowerment and implementation, and technological and financial innovation for managing the nexus". (WEF, 2011)



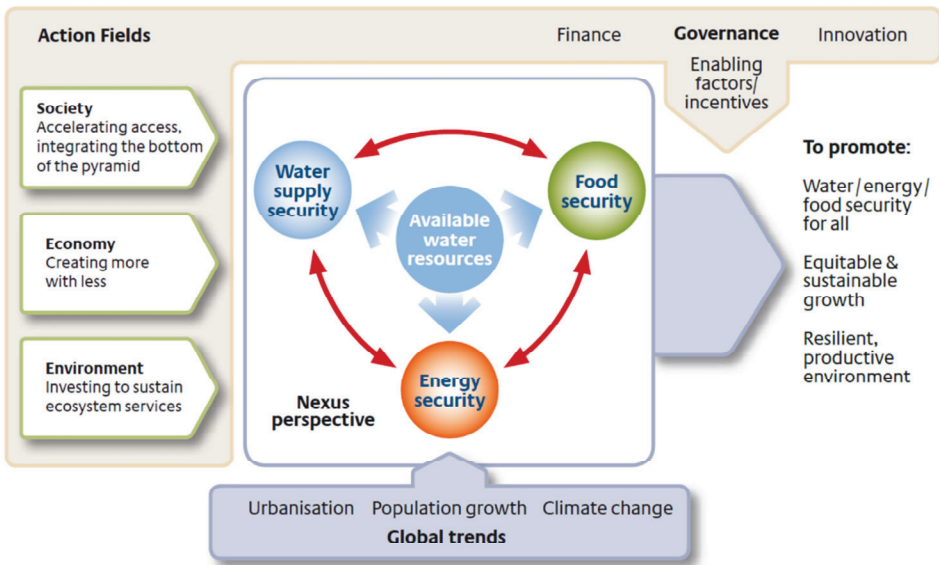
Source: WEF(2011)

**Figure 3. World Economic Forum Water-Energy-Food Nexus Framework**

### *Bonn 2011 Nexus Conference*

As its contribution to the 2012 UN Conference on Sustainable Development (or “Rio+20”), the German Federal Government hosted the international conference, “The Water, Energy, and Food Security Nexus-Solutions for the Green Economy” in 2011. The German government recognized increasing demand for energy, water, and food will result in economic, social and environmental problems as well as shortages of the resources, and emphasized a need for new approaches that address the issues interconnected within the energy, water and food security nexus.

The Bonn 2011 Nexus Conference presented a conceptual framework that aimed to support a “new, nexus-oriented approach” as a way to address “unsustainable patterns of growth and impending resource constraints and in doing so, promote security of access to basic services.”



Source: SEI(2011)

**Figure 4. Framework presented at the Bonn 2011 Nexus Conference**

The framework is centered around 'available water resources' and the elements of the nexus, such as water supply security, energy security, and food security, are inter-connected to water availability. The goal of the framework is to promote i) water, energy and food security for all, ii) equitable and sustainable growth, and iii) resilient productive environment, and the action fields to achieve the goal include;

- Society: Accelerating access, integrated the boom of the pyramid
- Economy: Creating more with less
- Environment: Investing to sustain ecosystem services

The framework specified a set of policy areas, which are important in implementing the nexus. The implementing policies are as following:

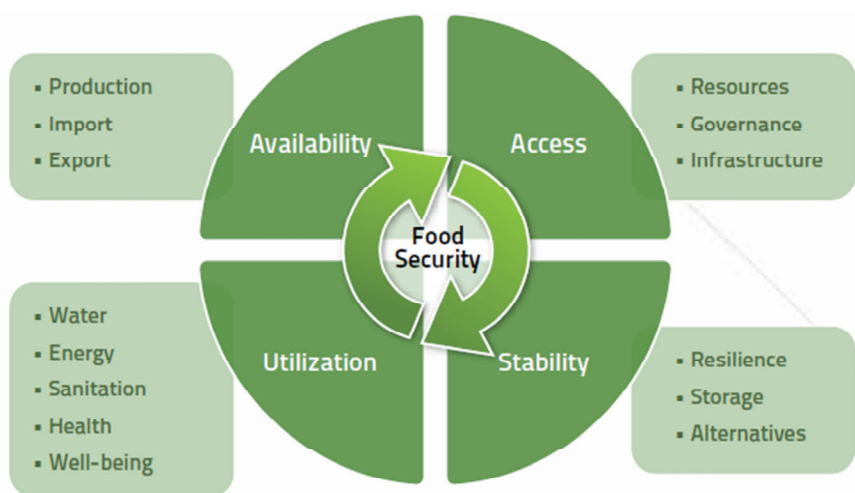
- Improving resource productivity
- Recycling waste as a resource
- Encouraging development through economic incentives
- Governance, institutions and coherent policy
- Benefiting from ecosystem services

- Integrated poverty eradication and green economy
- Capacity support and awareness

### *FAO Approach*

Poverty eradication and sustainable development rely heavily on water, energy and food. Global trends indicate that demand for these resources will increase over the next decades under the pressure of population growth and economic development. (Hoff, 2011) Agriculture is the largest use of water accounting for 70 percent of global freshwater withdrawals, and the food production and the supply chain accounts for 30 percent of total energy use globally. (FAO, 2011) As demand grows, competition for resources will grow between food and other basic needs such as water and energy, and it may result in deterioration in food security.

In this context, the Water-Energy-Food Nexus can be a useful concept to address the complex global resource systems. It, in practical terms, provides an approach to analyze the inter-connectedness between the resources and related security issues, so that a more coordinated use of natural resources across sectors is possible.



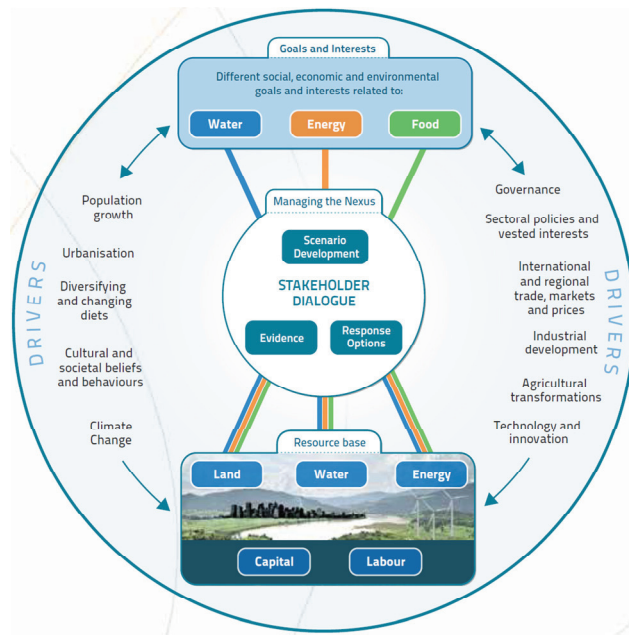
Source: FAO(2014)

**Figure 5. The Components of Food Security**



FAO defines ‘food security’, the vision of the organization, as the state in which “all people at all times have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life” (FAO, 1996). The FAO Water-Energy-Food Nexus framework is developed as part of FAO’s vision to achieve food security and sustainable management and use of natural resources and ecosystems.

Different social, economic and environmental goals and interests related to water, energy and food depend on ‘the resource base’ including natural and economic resources. In the framework, interactions between the goals and interests and the resource base take place in the context of relevant drivers, such as population growth, urbanization, diversifying and changing diets, cultural and societal beliefs and behaviors, climate change, governance, sectoral policies and vested interests, international and regional trade, markets and prices, industrial development, agricultural transformations, and technology and innovation.

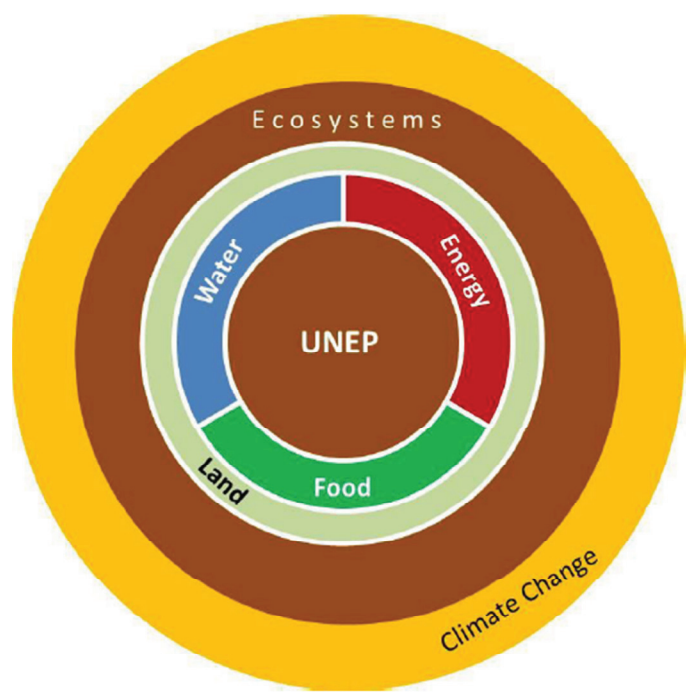


Source: FAO(2014)

**Figure 6. The FAO Approach to the Water-Energy-Food Nexus**

*UNEP Approach*

The UNEP framework emphasized the role of ecosystems in the nexus related to its function providing goods and services that are vital for energy, water and food security. In the conceptual framework, ecosystems are the source of water, energy and food (“inside”), as well as the “surrounding” component of the nexus regulating the interactions between the resources.



Source: Boelee & Hoa(2014)

**Figure 7. UNEP’s Ecosystem Approach to the Nexus**

2. Energy-Water Interdependency

Energy and water are critical to human well-being and sustainable development and its importance in achieving the SDGs is increasingly recognized. Due to growth of population and expansion of economic activities over the coming decades, demand for energy and water will continue to increase, and this will increase pressures on water and energy resources and related ecosystem services.

The inter-connectedness between water and energy has growing attention in recent years. Water is essential to produce and transport all forms of energy, and energy is required for the process of extraction, distribution, and treatment of water. Energy and water systems have changed as technological advancements have been made over the past century. In the current state of technological development, in most countries, the system for water supplies heavily relies on energy, and energy production is one of the major factors driving the demand for water. As a consequence of technological advancement, energy and water needs each other increasingly, which make both systems more dependent on one another, and the importance of the interdependence between energy and water is increasing as demand for both resources increases.

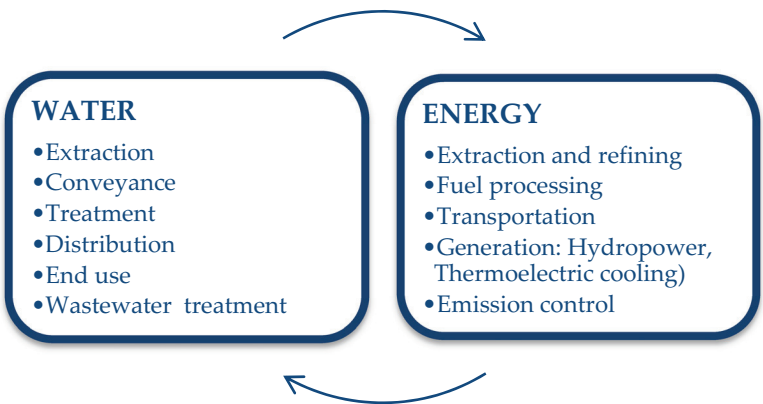


Figure 8. Water-Energy Interdependencies

2.1. Water for Energy

Globally, about 20% of water is used by industry (including energy production and power generation, and this is the second largest demand for water after agriculture of 70%. Energy production heavily relies on water. Water is necessary for resource extraction, refining and processing, generating electricity, and cooling thermal power plant.

*Energy production*

Water is necessary in most of energy production processes. In the primary energy production, water is used for research extraction, refining and processing. Biofuels are much more water intensive than conventional sources of fossil resources, such as coal, oil and gas. It requires about 10,000-100,000 liters of water to produce 1 GJ of energy compare to 1-10 liters for oil and gas. (WEF, 2011)

Table 1. Key uses of water for energy (OECD/IEA, 2012)

Primary energy production	
Oil and gas	Drilling, well completion and hydraulic fracturing.
	Injection into the reservoir in secondary and enhanced oil recovery.
	Oil sands mining and in-situ recovery.
	Upgrading and refining into products.
Coal	Cutting and dust suppression in mining and hauling.
	Washing to improve coal quality.
	Re-vegetation of surface mines.
	Long-distance transport via coal slurry.
Biofuels	Irrigation for feedstock crop growth.
	Wet milling, washing and cooling in the fuel conversion process.
Power generation	
Thermal (fossil fuel, nuclear and bioenergy)	Boiler feed, i.e. the water used to generate steam or hot water.
	Cooling for steam-condensing.
	Pollutant scrubbing using emissions-control equipment.
Concentrating	System fluids or boiler feed, i.e. the water used to generate

<b>solar power and geothermal</b>	steam or hot water.
<b>Hydropower</b>	Cooling for steam-condensing.
	Electricity generation.
	Storage in a reservoir (for operating hydro-electric dams or energy storage).

Note: Adapted from (OECD/IEA, 2012)

Water uses in the process of primary energy production, from the extraction to its use, vary significantly between fuels. Generally, conventional gas is less water-intensive than other fossil fuels as well as biofuels. Most of the water used in coal production is required for mining activities, such as coal cutting and cleaning. Coal washing is to remove impurities in the rock to increase its quality, but it requires additional water. For instance, in China washing accounts for 18% of total national water use for coal production. (OECD/IEA, 2012)

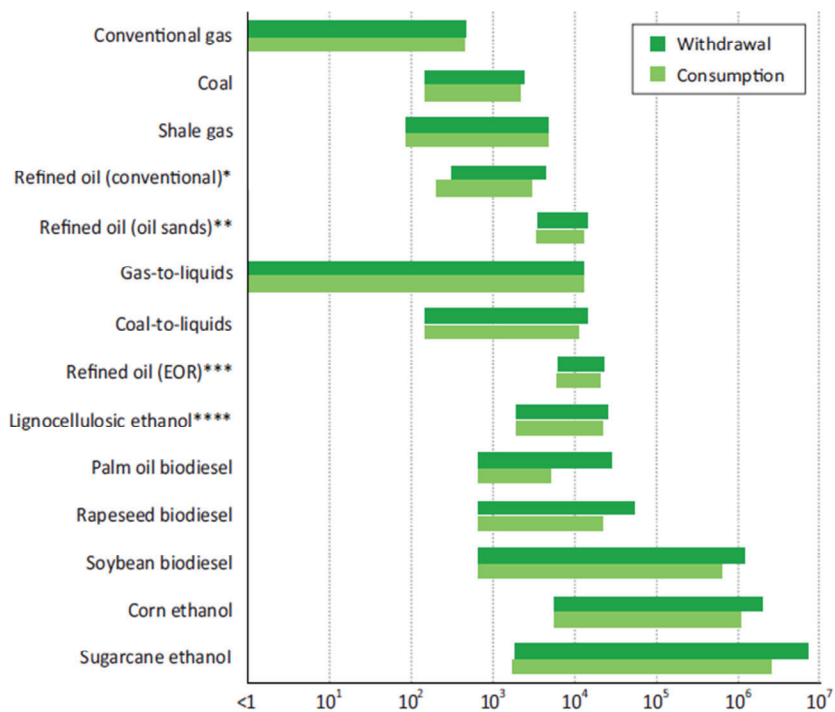


Figure 9. Water Use for Primary Energy Production (L/toe) (OECD/IEA, 2012)

### *Electricity generation*

Thermal power plants and nuclear power plant are the largest users of water in the energy system.

Electricity generation, including fossil fuel-based thermal power plants (coal, oil, and gas), nuclear plants, and renewables (such as biomass, wind and solar), is a large use of water sources. In case of thermal plants, water is heated up by burning fuel to produce steam and turn turbines. The volumes of water used in a thermal power plant quite differ depending on the type of plant, fuel, and cooling system. (UNESCAP, 2013)

The type of cooling system is a factor that determines water requirements for any given types of power plant. There are two types of cooling system commonly used in thermoelectric generation: 'once-through' and 'closed-loop'. (OECD/IEA, 2012)

Once-through (or open-loop) systems pass water through a steam condenser and return higher temperature water to the environment, and a small fraction of water are evaporated. Compared to other cooling systems, the capital costs of the systems are lowest, but they require higher water withdrawals and the large discharge downstream at higher temperatures, which can cause environmental impacts and, thereby, lead to the systems gradually phased out.

Wet closed-loop systems pass freshwater through a steam condenser, and the heated water is cooled in a wet tower. Water is returned to the system for reuse, and not consumed by evaporation. Water consumption is much lower than once-through systems, reducing risks posed by constrained water stock as well as environmental impacts. Trade-offs compared to once-through systems include higher water use and greater land requirements. The cost for installing the systems is about 40% higher than for once-through systems in the US case. (US DOE/NETL, 2008).

In dry cooling systems, air flow is used to condense steam. As their water use are very small compared with other alternative systems, they are better systems under dry climates. But the cost for the systems is more than three times higher than for wet tower systems. Dry cooling system can reduce

average generation by about 2-7% depending on the type of plant (US EPA, 2009).

**Table 2. Types of power plant cooling systems<sup>5</sup>**

	Advantages	Disadvantages
<b>Once-through</b>	Low water consumption	High water withdrawals
	Mature technology	Impact on ecosystem
	Lower capital cost	Exposure to thermal discharge limits
<b>Closed-loop (or Wet tower)</b>	Significantly lower water withdrawal than once-through	Higher water consumption than once-through
	Mature technology	Lower power plant efficiency Higher capital cost than once-through
<b>Dry</b>	Zero or minimal water withdrawal and consumption	Higher capital cost relative to once-through and wet tower
		Lower plant efficiency, particularly when ambient temperatures are high
		Large land area requirements.
<b>Hybrid</b>	Lower capital cost than dry cooling	Higher capital cost than wet tower
	Reduced water consumption compared with wet tower	Limited technology experience.
	No efficiency penalty on hot days	
	Operational flexibility.	

In the US, water withdrawal for cooling in thermoelectric power plants exceed any other uses. Thermoelectric production uses an almost equal amount of freshwater withdrawals to that of irrigated agriculture. Although most of the water withdrawn for thermoelectric power plants can be returned

<sup>5</sup> Table 2 from Mielke et al. (2010)

to the environment or reused for other ends, but the water quality may be degraded in the cooling process. About 98% of water withdrawn for thermoelectric production is returned, whereas only about 40% of withdrawals for irrigated agriculture. Nuclear power plants use more water than any other power plants. The water intensity of nuclear plants, in the US, is about 2.5 times greater than gas and 25% than coal. (Faeth, 54)

**Table 3. Average water intensities of thermoelectric plants (gal/kWh)<sup>6</sup>**

	Withdrawal	Consumption
<b>Steam turbine (coal, gas, biomass)</b>	Once-through 34.98	Once-through 0.25
	Closed-loop 0.64	Closed-loop 0.56
	Dry 0.01	Dry 0.01
<b>Stream turbine (nuclear)</b>	Once-through 41.97	Once-through 0.31
	Closed-loop 1.25	Closed-loop 0.86
	Dry 0.03	Dry 0.02
<b>Combined-cycle gas turbine</b>	Once-through 11.86	Once-through 0.08
	Closed-loop 0.24	Closed-loop 0.20
	Dry 0.01	Dry 0.01
<b>Integrated gasification combined cycle (coal)</b>	Closed-loop 0.39	Closed-loop 0.32
<b>Geothermal Steam</b>	Closed-loop 1.95	Closed-loop 1.70
<b>Solar trough</b>	Closed-loop 0.88	Closed-loop 0.92
<b>Solar tower</b>	Closed-loop 0.78	Closed-loop 0.78

**Box 1. Water requirement of Renewable Energy: Solar (OECD/IEA, 2012)**

Concentrating solar power (CSP) is the most effective in areas with long hours of strong sunlight, but these areas tend to be drier and are more likely to face water scarcity challenges. CSP presently generates a near negligible share of global electricity output, but in the New Policies Scenario it grows quickly (23% per year on average), reaching 1% of global electricity generation in 2035. Most capacity additions are in the United States, China, India and South Africa, all of which

<sup>6</sup> From Water in the West (2013)

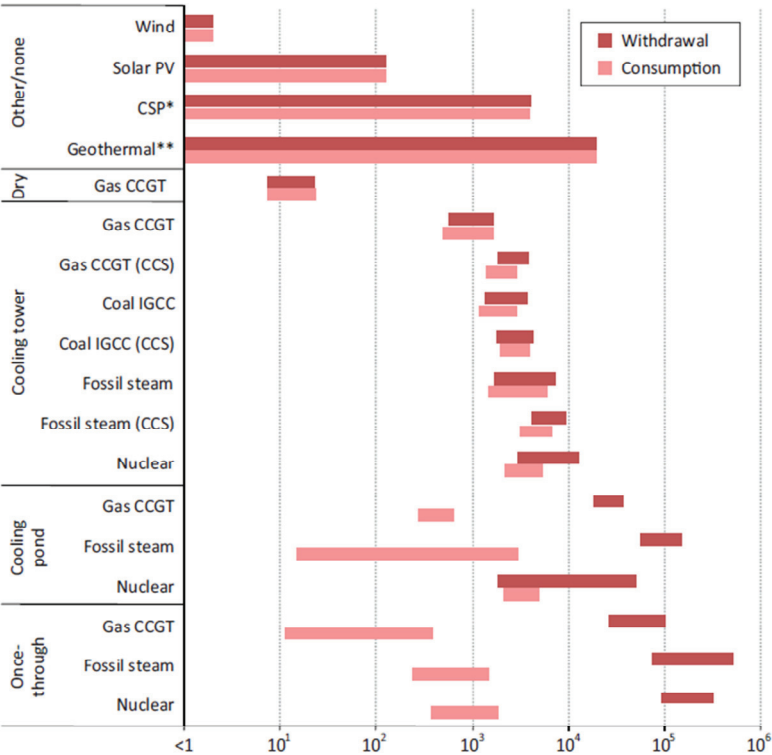


contain regions of water scarcity.

The choice of technology and cooling system determines the level of water requirements for CSP. Using wet tower cooling, CSP based on parabolic trough, solar tower and Fresnel technologies can have water needs comparable to fossil fuel-based and nuclear power plants using the same cooling system. Some projects being built in the Mojave Desert in California and in semi-arid areas of Shaanxi province in China, for example, are employing dry cooling to mitigate water constraints. However, dry cooling can appreciably lower plant efficiency and raise costs: in hot climates, CSP trough plants using dry cooling can see annual electricity production fall by 7% and electricity generating costs rise by about 10%. Solar tower technology has a higher conversion efficiency and therefore incurs a lower penalty when employing dry cooling.

CSP based on parabolic dish (Stirling engine) technology is cooled by air and requires no water for operation. Its land requirements are lower and conversion efficiency is higher than other CSP technologies. However, its small capacity (less than 1 MW per dish) means that many of dishes are needed for utility-scale generation.

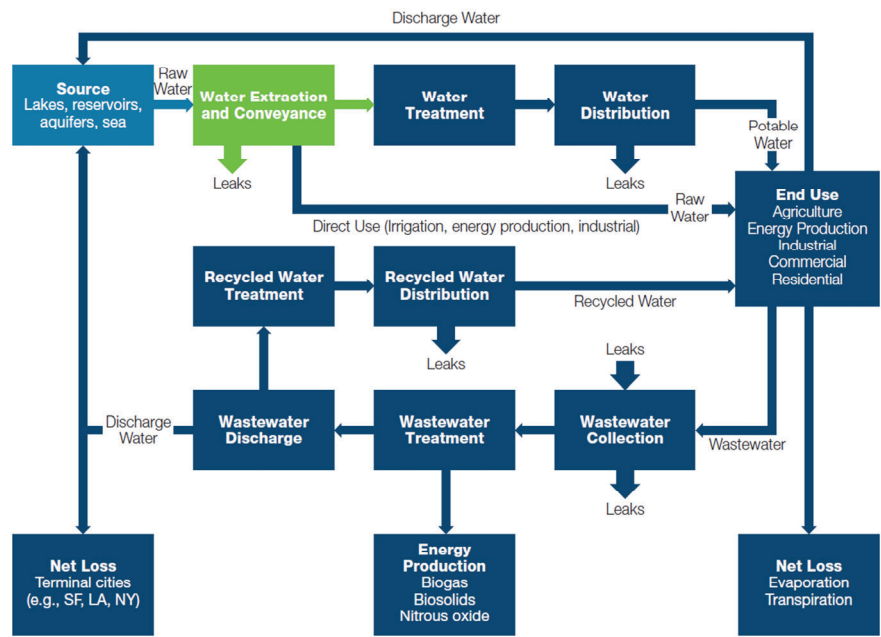
*Source: OECD/IEA(2012)*



**Figure 10. Water use for electricity generation by cooling technology (L/MWh) (OECD/IEA, 2012)**

2.2. Energy for Water

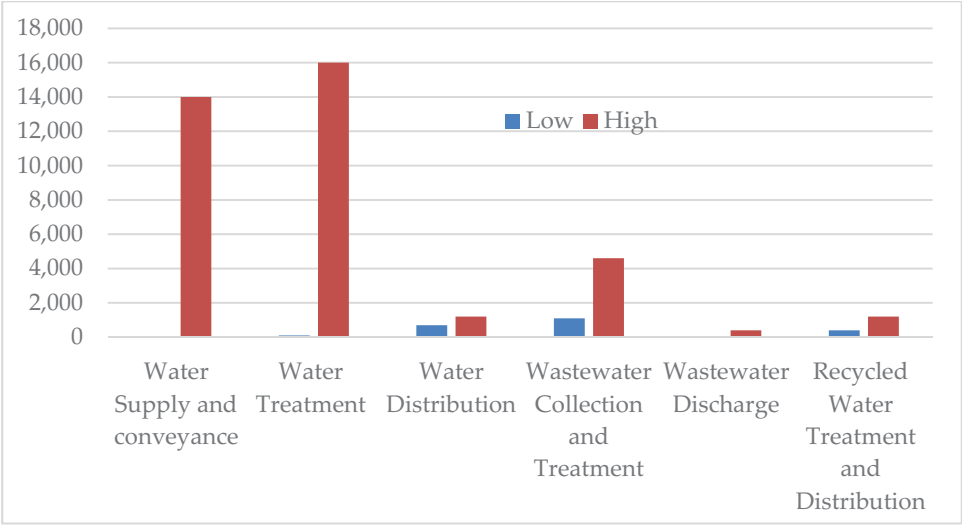
The water system consists of several stages of the water supply life-cycle including collection, conveyance, treatment, distribution, end-use preparation, wastewater collection and treatment, and wastewater discharge. First, water is extracted from a source, then conveyed to water treatment facilities, and finally distributed to end uses. After used by end users, wastewater, especially from urban uses, is collected and discharged back to the water body.



Source: Water in the West(2013)

Figure 11. Water Flow Chart

At all stage of the water use cycle, including end-uses, energy is used as a basic input, but it is not easy to measure energy use by the water sector since energy is not measured separately for water-related uses. Depending on its technical characteristics, each stage of water use cycle has differential levels of energy intensity. Figure 12 illustrates the unique values of energy intensities for the stages of the cycle.



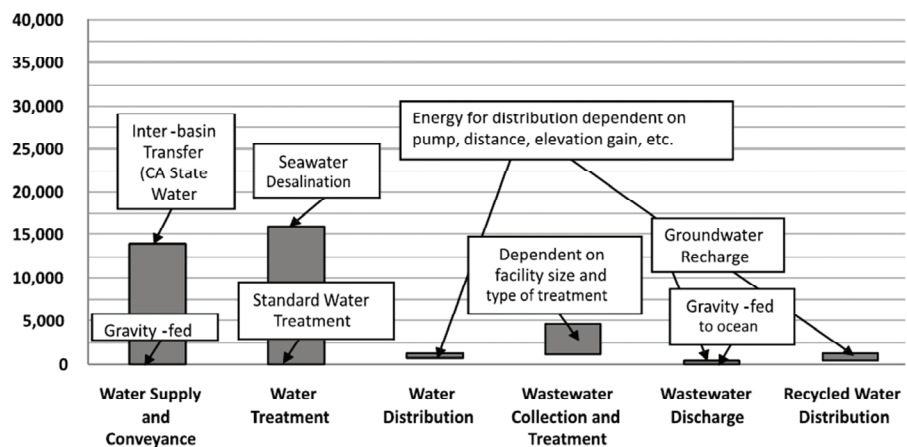
Source: California Energy Commission(2005)  
**Figure 12. Range of Energy Intensities for Water Use Cycle Segments (kWh/MG)**

Figure 13 shows a range of energy intensities for each stage of the public water supply life-cycle of California water utilities which are useful for understanding the general features of energy needs of the water sector.

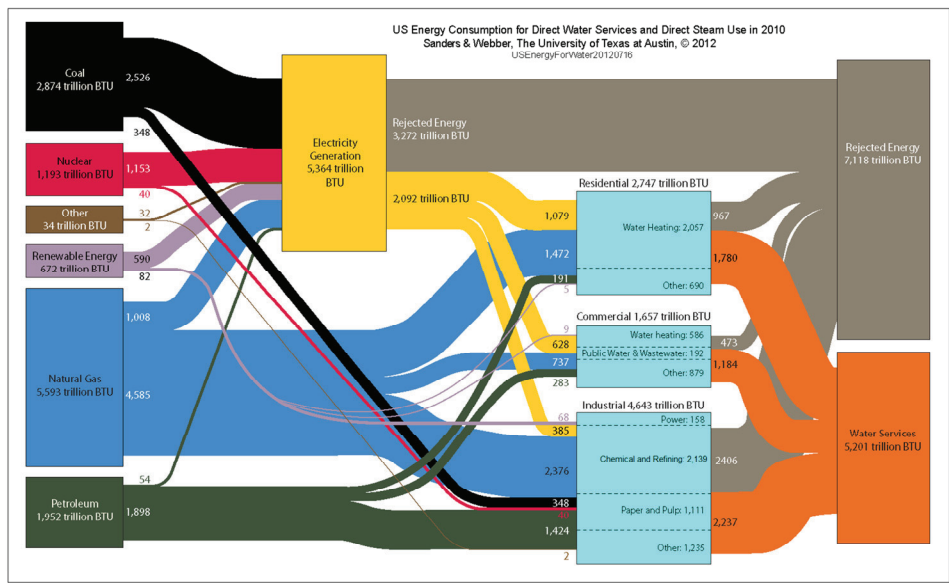
Sanders & Webber (2012) indicated that the energy embedded in the US water system was about 12.6% (12.3 quadrillion BTUs) of total primary energy consumption in 2010. Among this 66.7% (8.2 quads) was used for the direct water services and 32.5% (4.1 quads) was consumed for the direct steam use categories.

This study also estimated that 5.4 quads, accounting for 43.9% of direct-related energy consumption, was used to generate electricity for pumping, treating, heating, cooling and pressurizing water, which is about 25% greater than the amount of energy used in the Residential and Commercial sectors for lighting.

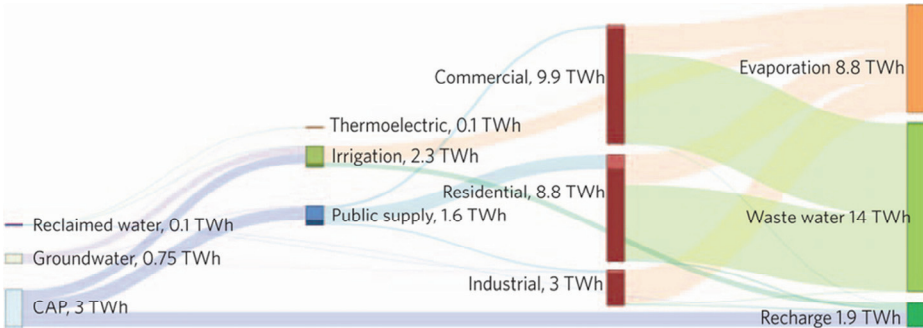
Despite of its significance in the electricity consumption, as also indicated in the study for the US, advanced technologies for improving energy intensity of the water sector has been receiving far less policy attention than energy-efficient lighting technologies.



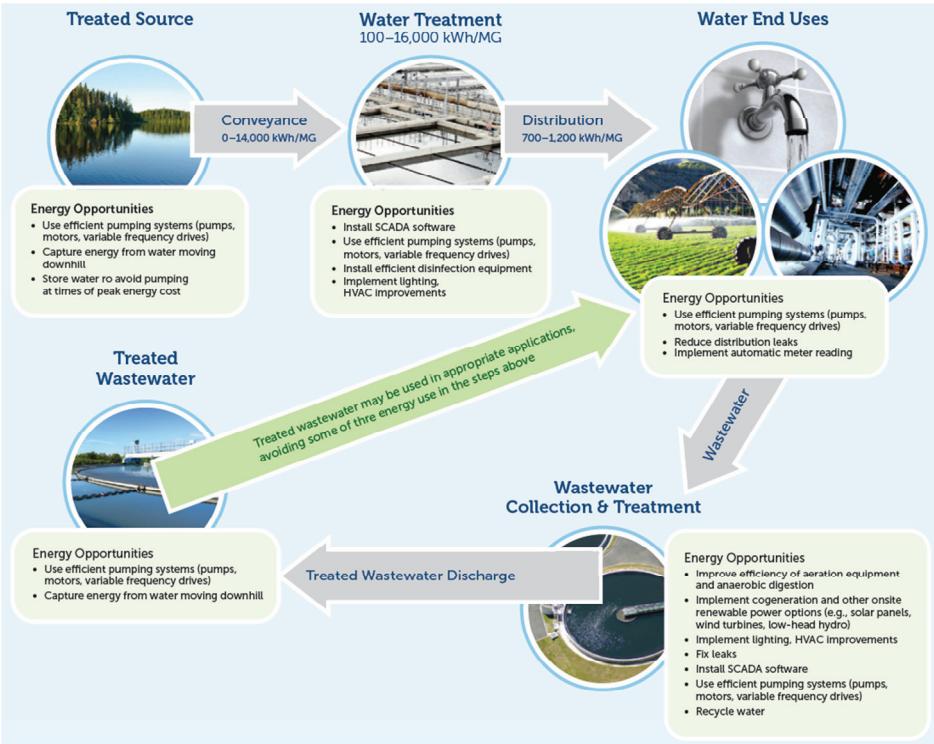
Source: Sanders & Webber(2012)  
**Figure 13. The energy intensity of each stage of the public water life-cycle in California (kWh/MG)**



Source: Sanders & Webber(2012)  
**Figure 14. Illustrative example of energy consumption for water services**



**Figure 15. Example: The embodied energy in the water-cycle components in Arizona, USA in 2008**



Source: US EPA(2013)

**Figure 16. Energy intensity of each stage in the water use cycle**

#### *Water conveyance*

Energy use for this stage of the cycle is primarily determined by the volume of water and the distance.

#### *Water treatment*

The factor that determines the volume of water for the water treatment stage is the extent of treatment to be done, which is determined by the sources of water and the intended end use. Some sources of water require little treatment, but some other sources may require additional treatment, which result in high energy intensity.

#### *Water distribution*

Water distribution systems requiring some pumping will use more water than gravity-fed water distribution system.

#### *Wastewater collection*

Wastewater collection systems requiring lifting and transferring the wastewater use more water than the system using gravity to collect the wastewater

#### *Wastewater treatment*

It may differ in the level of treatment required and the technologies used in the treatment system, however all wastewater treatment systems rely on energy.

#### *Wastewater discharge*

Wastewater discharge systems requiring lifting and transferring the wastewater use more water than the system using gravity to discharge the wastewater to the water body.

### 3. Water-Energy Nexus: Opportunities and Case Studies

#### 3.1. Global Sustainable Development and Nexus Thinking

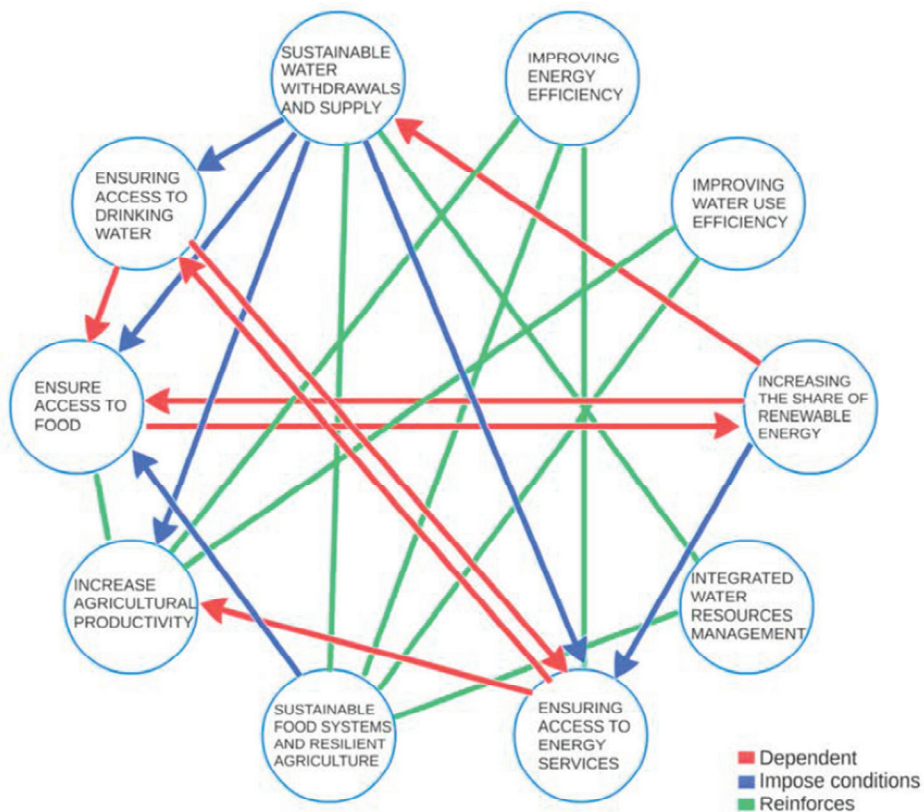
The concept of the interlinkages between different aspects of sustainable development and the necessity of integrated solutions to address them is clearly highlighted in the new global sustainable development agenda, *Transforming Our World: the 2030 Agenda for Sustainable Development*, adopted by UN member states in September 2016.

“Nexus thinking increasingly features in a number of processes launched by the UN General Assembly in their preparations for the post-2015 development agenda and during deliberations on the sustainable development goals....Furthermore, by identifying and quantifying trade-offs and synergies, a nexus approach has important implications in terms of investment requirements and policies, and influences the financing of sustainable development objectives at the local and international levels” (UN ESCWA, 2015)

The interpretation of sustainable development in terms of interactions between the three pillars of sustainability and the importance of harmonization of economic, environmental and social policies are now widely regarded as vital. The Rio+20 outcome document set out a mandate to establish an Open Working Group (OWG) to develop a set of sustainable development goals consistent with the UN development agenda beyond 2015. In 2014, UN Member State proposed a set of SDGs and they were adopted as reference goals for the global community in September 2015. The 17 goals can be seen as a network of various aspects of sustainable development, which have to be taken into account in all policy making to achieve the goals.

"The interlinkages and integrated nature of the Sustainable Development Goals are of crucial importance in ensuring that the purpose of the new Agenda is realized. If we realize our ambitions across the full extent of the Agenda, the lives of all will be profoundly improved and our world will be transformed for the better." (United Nations, 2015)





**Figure 17. Mapping targets at the Nexus between SDG areas<sup>7</sup>**

As cross-sectoral interactions had been integrated in the design of the SDGs, a nexus approach can be instrumental in achieving SDGs by identifying trade-offs and synergies from priority areas, such as water, energy and food. Blandi et al. (2013) offer three requirements necessary to achieve any proposed list of SDG as follows:<sup>8</sup>

- “Balancing the social, economic and environmental dimension: the goals should integrate and balance social, economic and environmental dimensions of sustainability to promote synergies and avoid tradeoffs among them.

<sup>7</sup> Figure 17 from Weitz et al. (2014)

<sup>8</sup> First 4 are from Blandi, Richerzhagen, & Stepping (2013).

- “Achieving coherence across goals: the goals should be coherent with other (sustainable) development goals of the post-2015 agenda and take into account an integrated perspective with a view to the water-energy-land nexus.
- “Agreeing on universal goals: the goals should apply to all countries”

Weitz et al. (2014) show how to identify interactions among goals through examples from the energy-water-food nexus, and propose “nexus goals as entry points for developing an integrated framework,”<sup>9</sup> which aims to provide decision makers with the information.

The study adopted a three-step approach for illustrating how interactions between goals can be identified. First, the targets under the goals of the nexus, the water-energy-food/agricultural nexus in this case, are reviewed to identify possible inter-linkages between the targets. Second, the nature of interactions between targets (e.g. potential trade-offs or synergies) is examined. Third, Possible “nexus targets” are established between the goals of component systems of the nexus.

The advantage of integrated approaches is to provide decision makers with the information and analysis needed to achieve the goals and targets in a balanced and integrated manner in all three dimensions of sustainable development.

The water-energy nexus is also being increasingly accepted as a new framework to implement global initiatives, such as the United Nations Sustainable Energy for All (SE4All). In the initiative, the energy systems which is strongly interdependent with other global systems is placed at the center of the global development agenda to address other development challenges including access to water and sanitation, poverty and hunger, and gender and education.<sup>10</sup>

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<sup>9</sup> Weitz, Nilsson and Davis (2014)

<sup>10</sup> See, for example, Yillia & Yumkella (2014)

**Table 4. Interlinked areas of focus SD areas<sup>11</sup>**

<b>Focus areas</b>	<b>Interlinked areas</b>
<b>Poverty eradication</b>	Action in all other focus areas.
<b>Sustainable agriculture, food security and nutrition</b>	Poverty eradication, health and population dynamics, gender equality and women's empowerment, water and sanitation, energy, climate, conservation and sustainable use of marine resources, oceans and seas, and ecosystems and biodiversity
<b>Health and population dynamics</b>	Sustainable agriculture, food security and nutrition, gender equality and women's empowerment, water and sanitation, economic growth, promote equality, promote sustainable consumption and production, and climate
<b>Education</b>	Poverty eradication, Sustainable agriculture, food security and nutrition, health and population dynamics, gender equality and women's empowerment, economic growth, employment and decent work for all, and promote sustainable consumption and production
<b>Gender equality and women's empowerment</b>	Poverty eradication, sustainable agriculture, food security and nutrition, health and population dynamics, education, water and sanitation, energy, economic growth, employment and decent work for all, and peaceful and non-violent societies, rule of law and capable institutions
<b>Water and sanitation</b>	Poverty eradication, sustainable agriculture, food security and nutrition, health and population dynamics, education, energy, economic growth, industrialization, sustainable cities and human settlements, and ecosystems and biodiversity
<b>Energy</b>	Poverty eradication, sustainable agriculture, food security and nutrition, health and population dynamics, education, gender equality and women's empowerment, water and sanitation, economic growth, promote sustainable consumption and production, and climate

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<sup>11</sup> Table 4 from UN (2014)

<b>Economic growth</b>	Poverty eradication, health and population dynamics, education, industrialization, infrastructure, employment and decent work for all, promote sustainable consumption and production, and peaceful and non-violent societies, rule of law and capable institutions.
<b>Industrialization</b>	Poverty eradication, education, energy, economic growth, infrastructure, employment and decent work for all, and promote sustainable consumption and production
<b>Infrastructure</b>	Poverty eradication, sustainable agriculture, food security and nutrition, health and population dynamics, water and sanitation, energy, economic growth, industrialization, sustainable cities and human settlements, promote sustainable consumption and production, and climate
<b>Employment and decent work for all</b>	Poverty eradication, sustainable agriculture, food security and nutrition, health and population dynamics, education, economic growth, industrialization, promote sustainable consumption and production, and conservation and sustainable use of marine resources, oceans and seas
<b>Promote equality</b>	Some areas that could be considered in furtherance of greater equality within and among countries through high and sustained growth in developing countries include progress in education, energy, industrialization, infrastructure, and peaceful and non-violent societies, rule of law and capable institutions
<b>Sustainable cities and human settlements</b>	Poverty eradication, sustainable agriculture, food security and nutrition, gender equality and women's empowerment, economic growth, infrastructure, promote sustainable consumption and production, climate, and peaceful and non-violent societies, rule of law and capable institutions
<b>Promote Sustainable Consumption and Production</b>	Sustainable agriculture, food security and nutrition, health and population dynamics, education, energy, economic growth, industrialization, infrastructure,

	sustainable cities and human settlements, climate, conservation and sustainable use of marine resources, oceans and seas, ecosystems and biodiversity
<b>Climate</b>	Sustainable agriculture, food security and nutrition, health and population dynamics, education, gender equality and women's empowerment, water and sanitation, energy, promote sustainable consumption and production, sustainable cities and human settlements, conservation and sustainable use of marine resources, oceans and seas, ecosystems and biodiversity
<b>Conservation and sustainable use of marine resources, oceans and seas</b>	Sustainable agriculture, food security and nutrition, water and sanitation, economic growth, employment and decent work for all, climate, ecosystems and biodiversity, and peaceful and non-violent societies, rule of law and capable institutions
<b>Ecosystems and biodiversity</b>	Poverty eradication, sustainable agriculture, food security and nutrition, health and population dynamics, water and sanitation, employment and decent work for all, promote sustainable consumption and production, climate, and peaceful and non-violent societies, rule of law and capable institutions
<b>Means of implementation/Global partnership for sustainable development</b>	the means of implementation/Global partnership for sustainable development cut across and contribute to the attainment of all goals
<b>Peaceful and non-violent societies, rule of law and capable institutions</b>	Poverty eradication, gender equality and women's empowerment, economic growth, promote equality, sustainable cities and human settlements, conservation and sustainable use of marine resources, oceans and seas, ecosystems and biodiversity

### 3.2. Regional water resources and energy in Central Asia<sup>12</sup>

Central Asia, the largest closed drainage basin with an area of more than 5 million square kilometers, is a region facing significant challenges in water management. The challenges are mainly rooted in impact of climate change and environmental degradation, as well as socioeconomic transition after the collapse of the Soviet Union, beginning in the late 1980s.

In the period of the USSR, there was a complex scheme in water and energy transaction among the countries in the region. It was developed to irrigate cotton production, and the expansion of irrigation caused environmental degradation, including the disappearance of parts of the Aral Sea, which was one of the world's largest lake.

In the region, as there is a need to balance national and regional interests, a complicated nexus was emerged among water, energy and food security, and the region confronted with conflicts between upstream hydropower generation and downstream irrigation interests. For example, there was tension between Kyrgyzstan that needs to release water in the winter season for electricity and Uzbekistan and South Kazakhstan that need water in the summer season for irrigation.

“While irrigation was practiced for over 2000 years in the river basin, it was only in the period of Soviet rule, water was diverted from the river on a large scale through an extensive irrigation infrastructure such as diversion dams, storage dams, canals, distributaries and pumping stations to enable the irrigated cultivation of cotton, fodder, wheat, fruits and vegetables. In these arid areas of the Central Asia, cultivation of such crops is possible only with irrigation. Most of the crops grow during the warmer period from April to September, often referred to as the vegetation season. The only exception is winter wheat, which is usually sown in October or November and harvested, in the second quarter of the year. The period from October to March is cold and is referred to as the non-vegetation season. For purposes of convenience, these two seasons are referred to in this report as summer and winter seasons.”

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<sup>12</sup> This regional case was adapted from UNESCAP(2013)

(World Bank, 2004)

This challenge was discussed in several studies, including World Bank (2004) and UNESCAP (2013), in the context of the water-energy nexus. With particular focus on water, UNESCAP (2013) offered a nexus approach with following elements:

- “Cooperation with international donor community, particularly in raising the Aral Sea as a global issue”
- “New widows of opportunities for new financial facility, capacity building and knowledge networks”
- “Opportunities to learn from the experience of other transitional river basins using the nexus approach”

World Bank (2004) offered a “revised approach” with a set of key elements that need to be considered to address the issue through the regional cooperation.

- “To eliminate the present barter arrangement of fossil fuel supply for electricity imports, and artificial tinkering of prices to include an implicit and indirect payment for annual and multi-year water storage services;”
- “To recognize explicitly the principle that the upstream country needs to be compensated in cash for the water storage service, which it is obliged to provide at considerable cost to its economy;”
- “To explicitly provide in the agreements for the amounts to be paid in cash for such water storage services;”
- “To de-link the energy trade (summer exports of electricity from and compensatory fossil fuel supplies in winter to the Kyrgyz Republic) from the water services trade, and allow it to be carried on in the normal way using normally negotiated market prices without any distortion;”
- “To ensure a true multi-year approach to the management of the multi-year storage reservoir and to maximize the net benefits to the basin as a whole.”

### *Institutional Framework*

Due to competing demands by the independent states after the collapse of the Soviet Union, water resources from Kyrgyzstan basin and Tajikistan basin became an issue in the region. The current institutional arrangement for regional cooperation to address the issue includes (UNESCAP, 2013):

- In 1992, Central Asian head of states established the Interstate Commission for Water Coordination (ICWC) of Central Asia as an agreement on cooperation in management of international water resource protection. ICWC is a technical authority supervising the allocation of water resources and infrastructure.
- The agreement on Joint Activities for Addressing the Crisis of the Aral Sea and the Zone around the Sea, Improving the Environment and Ensuring the Social and Economic Development of the Aral Sea Region (entered into force 1993) instituted the Interstate Council for the Aral Sea (a policy organization), and the International Fund for Saving the Aral Sea (an executive organization) in 1993. The two organizations were united into a newly defined IFAS as the supreme policy organization on water resource management in the region. IFAS is the political authority guiding the work of the ICWC based on principles and policies agreed among the member states. ICWC and its executive bodies were annexed to the IFAS in 2004 and were converted into an international organization. Central Asian countries established other regional bodies including the Basin Water Associations, the Scientific-Information Centre, the Training Centre and the Coordination Metrological Centre.



### 3.3. The Water-Energy Nexus in the US

Considering the nature of water issues in relation to energy, there are some states that have acted upon the potential impact of water shortages on energy use. The case of Texas provides a lesson on the emergency response to droughts at the state level, and the case of Arizona provides a lesson on the local-regional tradeoffs in the production and consumption of water resources.

Texas is the largest generator and consumer of electricity and eastern half of the state is water-rich, while the western half experiences extreme variability (Hussey and Pittock 2012). When droughts occur, demand for water increases because of additional need for air conditioning and thus an increased electricity generation, which requires water for cooling. Moreover, supply of electricity also decreases due to droughts; increased use of power plants relies on water discharges, which may not be met well (Scanlon et al. 2013).

Consequently, the governor of Texas declared a drought proclamation (section 418.016 of the Texas Government Code), which suspended all rules and regulations that may inhibit or prevent prompt response to the threat of drought for the duration of a “state of disaster”. Considering the need for water for electricity generation, the government granted temporary water permits to some power plants during the 2011 drought (Lake Bastrop, Cedar Creek Reservoir, Martin Lake, Trinidad Lake). The reasoning behind this grant derives from the Prior Appropriation Doctrine of the U.S. water rights system, which depends on first come first serve basis. The priority date of a water right establishes water rights, not land ownership (Texas Commission on Environmental Quality).

In 2012, the state government announced the Texas State Water Plan, which outlined that additional infrastructure will be built to transport surface water to points of use. Moreover, Groundwater Conservation Districts are to be established.

Not only governments but power plants have taken measures to reduce vulnerability to potential risks of droughts. Instead of once-through cooling, power plants can use wet cooling towers. The plant can also operate only the gas combustion turbine, which requires no cooling water, and not the steam turbine part of the Morgan Creek Power Plant in west Texas. Another option

is to use natural gas combustion turbines, which uses cooling towers not once-through systems. Researchers suggest that retrofitting power plants with new cooling technologies will not be cost-effective in Texas. Another technology to consider is to promote alternative or 'non-traditional' water sources – municipal wastewater (reclaimed water), brackish water, and seawater.

Located in the west of Texas, Arizona is a state of water scarcity with less than 1% reliance on nonrenewable energy use and representative of the semi-arid feature of the southwestern U.S (Scott et al. 2011). Due to increases in water demands for traditional methods of electricity generation, the Arizona Corporation Commission denied permits for conventional and solar power plants. Water demands of the state are met by pulling water and energy resources from distant locations around the state agency called the Central Arizona Project (CAP). Since CAP uses both energy and water resources across multiple scales, it is a boundary organization to link its consumers (water utilities) and commercial partners (electrical utilities).

## 4. Policy Dimensions of the Water-Energy Nexus

### 4.1. Institutional issues

Compare to the increasing numbers of studies on the technical aspects, relatively fewer literatures have been dealt with institutional aspects of the nexus. Scott et al. (2015) suggested three ways to examine institutional issues of the nexus.

- “Institutional structure”: The first perspective starts with institutional structure or institutional ‘levels’ of analysis ranging from the household level to sub-national, national and multinational levels. Each level may have a different institutional process for resource management, and this have to be considered in the analysis to determine the relevant level of analysis.
- “Institutional functions”: The roles of government for resource management include the range of state functions, such as supporting social consensus, improving economic production, and administrating legal and regulations frameworks. Insofar as these government activities promote economic production, they converge with the functions of private institutions; while insofar as they promote social integration, they converge with the functions of non-governmental institutions”.
- “Human needs and wants”: These are often related with sectoral needs assessments and development of solutions, for which existing institutions are generally ineffective.

Scott et al.(2015) identified three broad questions to be address by an institutional perspective on the nexus.

- “Intersectionality: what are the critical mass factors at the intersection of material fluxes, public financing and changes in institutional and biophysical environments that can define the scope and relevance of the nexus approach to environmental management?”
- “Inter-actionality: how can feedback loops be structured to capture both vertical and horizontal linkages among (i) legal and policy reform, (ii) structural changes in economy and society and (iii) variability in the biophysical environment?”

- “Hybridity: what role can trans-disciplinary approaches play in building capacity through support for innovative planning instruments and monitoring and assessment methods, advances in pedagogic and didactic techniques, formative and summative assessments and accreditation and certification of blended learning curricula that support the achievement of nexus competency?”<sup>13</sup>

Bazilian et al. (2011) identified a set of the descriptive elements of the Water-Energy-Food nexus that provides useful implications in establishing an institutional framework for the nexus:

- All three areas have billions of people without access in terms of quantity or quality or both
- All three resources have growing global demand
- All systems have resource constraints
- All three resources involve trade and have global implications
- All three resources have different regional availability and variations in demand
- All three systems have strong interdependencies with climate change.
- All three resources are fundamental to the functioning of society and have deep security issues
- All three systems operate in highly regulated markets.
- All three resources require the explicit identification of risks.

#### *Some examples*

Scott et al. (2011) demonstrated the importance of institutional setting and decision-making in the energy-water nexus, and highlighted four aspects of institutional dimensions of the energy-water nexus: First, the energy-water nexus is more than just the analysis of input-output relations between resources, such as energy and water, it should explicitly consider institutional aspects to implement the nexus. Second, due to its relevance to climate change issues, energy policy offers more scope for global and national issues, and water policy offers more scope for local and regional issues despite of the

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<sup>13</sup> First 3 are from Scott et al. (2015)

growing recognition of its importance from global perspectives. Third, the nexus approach can be a way to address negative impacts of energy development on water, environment, and society by bringing energy and water policy into a common institutional framework. Finally, it is inevitable that the nexus-based decision-making may not eliminate the tradeoff between energy and water uses completely, but it can address such tensions to an extent by maximizing the potential synergy that comes from the integrated policymaking.

**Table 5. Multi-tiered institutional arrangements<sup>14</sup>**

	Southwestern – electricity – water nexus	Eastern – coal – water quality nexus	Northeastern and Central – shale natural gas – water quality nexus	National – energy – water tradeoff scenarios
<i>Energy–water resource coupling</i>				
Energy and water sources and demands	Local sources, regional demands	Local sources, national demands	Local sources, regional and national demands	Domestic and global sources, national demand
Local environmental and social impacts	Water scarcity, emissions, air quality, continued growth	Land and water quality, social and economic marginalization	Water quality, local interest group rivalry	Localized impacts diminished in national perspective
Global change implications	Electricity central to climate adaptation, current generation hinders climate change mitigation	Continued coal dependence has emissions and local impacts	Natural gas preferred energy source that has local impacts comparatively lower than for coal	Energy portfolio diversification, water resource implications offset by regional generation, electricity transmission
<i>Multi-tiered institutions</i>				
Institutional coordination	Sole water source reliance leading toward localized innovation	Asymmetry between local jurisdictions and national commercial interests	Interest group politics leading to provisional state regulation	Stakeholder consultation and scenario modeling, nascent federal energy–water policy
Policy to reconcile local impacts with national demand, adapting to global change	Enhanced solar (photovoltaic) to minimize water demand; long-term mitigation through energy diversification and renewable water	Regulation of local impacts; increased total (not just commercial) cost of coal; waste product water for beneficial energy generation	Social conflict mediation; embed cost of waste remediation in price of delivered gas	Portfolio scenarios to enhance low local-impact renewable energy and water sources; manage tradeoffs across scales

Eichelberger (2010) examined the connection between energy and water insecurity in Alaska’s Northwest Arctic Borough. In rural villages of the regions, domestic water access was significantly affected by “high energy costs and the need for fuel-based transportation”<sup>15</sup>, and increases in energy costs have decreased domestic water access and resulted in negative impacts on household hygiene.

<sup>14</sup> Table 5 from Scott et al. (2011)

<sup>15</sup> Text taken from Eichelberger (2010)

## 4.2. Stakeholders<sup>16</sup>

### *National agencies and negotiators*

- To ensure that WEF security is a key consideration of investment decisions and operationalization.
- To ensure that WEF-relevant data and information relating to both management practices and development obligations are assembled for the negotiations.
- To ensure that regionally appropriate WEF strategies are incorporated into national policies, programs and decision-making as well as investment allocation.
- To clarify the role of domestic regulations, law and strategies in relation to the planning investments.
- To create a negotiating team to bring together strong negotiating capacity and relevant expertise on the range of issues that will arise in the negotiation.

### *Regional and local government authorities*

- To provide guidance and inputs on specific sub-national future policies and measures relevant for WEF.
- To translate national-level policy and programs into locally appropriate WEF-outcomes such as poverty reduction, community development, etc.
- To provide regional and local data and information collected at this level for the negotiators and to guide the investment monitoring.
- To help identify and convene other stakeholders relevant to WEF for the region.
- To understand necessary institutional, policy and market changes necessary for WEF security and implement these changes as appropriate with other stakeholders.

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<sup>16</sup> Types of potential stakeholders to engage in the WEF initiative (Bizikova, et al., 2014)

*Research institutions and academia*

- To help inform integrated/systems approaches in the region correlating water-energy-food information.
- To help quantify and interpret data on WEF security.
- To develop a quantitative model of relevant areas of WEF security to assess trade-offs and synergies between investment choices and WEF.
- To develop monitoring procedures and help interpret data.

*Private stakeholders*

- To inform key components of WEF security- access, availability and utilization of water, energy and food in the region.
- To understand and incorporate the notion of multiple benefits and trade-offs in day-to-day decisions and processes.

*Sector-specific and market stakeholders*

- To represent key sectors such as industry, agriculture, livelihoods and other key components of WEF at the local level.
- To inform and test discussions on trade-offs and synergies.
- To understand necessary institutional, policy and market changes necessary for WEF security and lobby for these changes.

*Community groups and nongovernmental organizations*

- To identify key WEF contributions, including property and resource rights.
- To express needs and preferred future areas of WEF security and related poverty reduction, employment and other environmental and social goals.
- To participate in monitoring and review of the impacts of investments on WEF.
- To communicate and gather insights on key issues from community members.
- To understand necessary institutional, policy and market changes necessary for WEF security and lobby for these changes.

*Development and international agencies and banks*

- To share best practices from other places and help replicate successes from regional initiatives to other regions.
- To provide guidance on investments obligations, monitoring and feasibility and impacts of investments based on their experiences with other jurisdictions.
- To share lessons with the international community and development peers.
- To act as moderators, facilitators, or simply as “observers.”



### 4.3. Potential Roles of Government

The understanding on the water-energy nexus and various possible nexus-based solutions give an economy more flexibility to address water and energy issues in environmentally sustainable and economically efficient ways, and there would be no questions that nexus approaches are far more effective than conventional approaches in achieving sustainable water and energy systems.

Nexus approaches are possible at various levels of scale from small technological solutions to systems or country-wide integrated policy approaches. Incremental benefits of a nexus approach come from increasing synergies or reducing tradeoffs between water and energy. The benefits are the net gain of nexus-based approaches compared to conventional segmented approaches. In terms of decision-making, the incidence of benefits would have a significant effect in the adoption of nexus approaches.

In many cases, decision-making on adopting nexus-based approaches may not be made by a single authority. The nexus benefits, not only in the form of private benefits but also external or social benefits, would be (not necessarily equally) shared by water and energy systems separately unless two systems are fully integrated in terms of decision-making. Depending on the size of shared benefits, each system would have different incentives for adopting the nexus-based approach, and this asymmetry could be the cause of preventing the deployment of socially beneficial nexus-based solutions and technologies.

The role of government in the nexus would be to address various mismatched incentives and institutional bottlenecks hindering the adoption of nexus-based solutions so that the economy can enjoy the potential benefits of advanced technologies and techniques of the nexus.

In addition to these institutional issues, there are general nexus challenges that need to be addressed and incorporated in the process of developing institutional arrangements<sup>17</sup>:

- Optimize the freshwater efficiency of energy production, electricity generation, and end use systems
- Optimize the energy efficiency of water management, treatment,

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<sup>17</sup> From US DOE (2014 )

distribution, and end use system

- Enhance the reliability and resilience of energy and water systems
- Increase safe and productive use of nontraditional water resources
- Promote responsible energy operations with respect to water quality, ecosystem, and seismic impacts
- Exploit productive synergies among water and energy systems

In terms of its role as the regulatory authority, the most important thing governments should do about the water-energy nexus is to strengthen price signal to ensure efficient use of water and energy resources. Basically, this can be done by removing inefficient subsidies, changing taxation policies, and remedying market failures, so that correct prices would stimulate private investment in advanced energy-water nexus technologies.

Governments also could promote the adoption of nexus approaches by removing other barriers that cannot be overcome by correcting the price distortions in the markets. Incomplete information, including lack of relevant data and mismatched incentive structures are the more prevalent barriers among them.<sup>18</sup>

#### *Key Elements of Policy Framework*

Environmental governance, especially in developing countries, suffers from fragmented approaches to development planning and environmental and resource policy implementation. Fragmented approaches can arise from competition among local governments for fiscal transfers from central government, overlapping legal and regulatory boundaries and inadequate coordination among ministries.

In many cases, fragmented approaches are supported by an unclear evidence based on the environmental outcomes of infrastructure construction. For example, absence of disaggregate and reliable information makes it difficult to anticipate the environmental consequences of constructing infrastructure. Institutional fragmentation is supported by weak interactions

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<sup>18</sup> See, for example, UNESCO (2014)

between legal and policy development, variation in physical environment and socio-economic change within communities of resource users. As a result, decision-makers cannot plan project interventions with precision, therefore may not be able to respond effectively to consumers' feedback on changes in service delivery parameters. (Scott, et al., 2015)

Understanding the nexus requires addressing the complex and dynamic interactions between the component systems. In providing the resources to the society, water, energy and food are interconnected connected through infrastructures, and this feature creates a dimension of integrated or coordinated solutions to nexus challenges.

The goal of all nexus-based approaches is to identify, realize, and maximize synergies in the nexus between resources, and this is possible when the interactions, which are conventionally separated, are integrated into decision-making. An integrate approach is required to integrate nexus interactions into decision-making, and it should include a process of identifying nexus challenges, stakeholders, opportunities, and strategies.

International Institute for Sustainable Development (IISD) developed a framework for empowering decision makers to incorporate the nexus. In the study, four key stages were recognized for the implementation of the framework as follows:<sup>19</sup>

- Assessing the WEF Security System: This stage focuses on assessing current status of water, energy and food security. It requires understanding interlinkages among water, energy and food to identify relationships and the most influential drivers affecting the component systems in the present and under future scenarios. This helps identify potential future elements such as land ownership and relationships among different policies and incentives.”
- Envisioning Future Landscape Scenarios: The goal of this stage is to develop scenarios of the future. These future scenarios help to develop a list of actions that are robust, and will help identify development obligations for investors, as well as policies to support these obligations.”
- Investing in a WEF-Secure Future: In this stage, participants develop

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<sup>19</sup> Quotes from Bizikova et al.(2014)

an investment strategy for the region. An effective strategy will be representative of the aspirations of people of the region as a whole. This stage brings together outcomes of the previous steps and involves interactions with stakeholders to develop an investment strategy.

- **Transforming the System:** This stage focuses on implementing the identified strategy by ensuring that key stakeholders are ready to take action. One of the most important mechanisms for successful implementation is clear identification of institutional arrangements that will be accountable for implementing the strategy. Also, it is important to ensure a formal monitoring and reporting through which stakeholders learn from the process. Monitoring and adaptation are also required to ensure effective implementation with suitable risk management.

In order to re-orienting government policy framework for the nexus, governments need to strengthen price signal to encourage efficient use of resources. For example, governments can enhance economic efficiency in water and energy markets by removing energy and water subsidies, or introducing carbon taxes, which also encourage both sectors behave efficiently. Governments also can correct market failures, which may enable redesigning of property right regimes to encourage co-management of resources. (UNESCAP, 2013)

**Box 2. FAO's approach to assess the WEF nexus (FAO, 2015)**

FAO is currently developing an approach to assess and manage the water-energy-food nexus. As part of this, FAO developed a methodology to assess the context status and the impact of specific interventions from a nexus perspective. The Nexus Approach intends to inform decision-making processes and to guide the development of "Nexus-sensitive" policies, supporting countries in designing and implementing them in a participatory manner. It also provides a basis for decision-makers to weigh trade-offs and benefits of possible interventions across sectors and scales.

The Nexus Assessment (including the Nexus Rapid Appraisal) consists of an easily applicable methodology, which relies on indicators that are readily available based on different country typologies, allowing a quick assessment of possible interventions against overarching development goals such as food security, and the sustainability of energy and water supply, use and management.

The methodology is outlined in the report, *Walking the Nexus Talk: Assessing the Water-Energy-Food Nexus in the Context of the Sustainable Energy for All Initiative* (FAO, 2014).

Source: FAO(2015)

#### 4.4. Policy Challenges

##### *Economic value of water*

One of the key principles discussed the 1992 International Conference on Water and Environment was that water has an economic value, which means that although one energy source is cheaper than another, the relative prices could change dramatically depending on competition for water.

As many countries try to moves closer to enumerating true economic value of water, long-term planning and policy for energy will need to take the change of water costs into consideration when performing economic analysis for new projects.

##### *Efficient technologies*

Governments should encourage the development of efficient technologies and practices through its policy activities in the energy and water sector. Improved water and energy data will help in identifying energy and water applications that represent innovation opportunities and help to encourage innovation. Barriers to adoption of new technologies are various. Improved dissemination of existing knowledge can increase confidence in adopting more efficient energy and water technologies and practices.

Reducing the costs of adoption and furthering understanding of the expected benefits are central to establishing sustainable energy and water sectors. Additionally, stakeholders have to be encouraged to invest in future RD&D, because, after all, it is in every stakeholder's decision to optimize the use of energy and water resources, and, by doing so, to reduce overall costs.

Synergies among different stakeholders' interests should be identified and collaborative work supported. The government positioned to facilitate RD&D activities from industry and government, to leverage each other's expertise for common goals.

##### *Energy planning*

Long-term energy planning should take into account various non-energy issues that can affect energy demand and supply, such as droughts, increasing temperatures and rising sea level. Energy policy-makers and producers should be wary of indirect effects of water constraints on energy production.

Many countries are reflecting life-cycle costs, carbon emissions and the costs of climate change in energy planning. Water use and the associated costs also need to be considered in energy planning if we are to avoid unexpected consequences and costs caused by water stress resulting in disruptions that lower energy security.

#### *Public-Private Partnerships*

Several industries are actively engaged in energy-water nexus issues, but there has been little clear public leadership in the energy and water sectors.

Public-private partnerships can promote collaboration and increase research and information. The government should encourage an effort aimed at reducing barriers to adoption of more efficient water and energy technologies and practices.

#### *Data Gaps*

It is very important to get reliable and comprehensive data on energy use for water and water use for energy by all stakeholders. More reliable data can support informed decision making and help prioritize investments in energy and water related infrastructure, and lead to energy and water use practices.

#### *Policy coherence*

Policy coherence can be increased by ensuring that synergies and trade-offs between water and energy are identified in development and implementation of policies and investments, and also by incentivizing coordination for mutually beneficial nexus-based approaches.

#### 4.5. Case: The US Institutional Framework for the Energy-Water Nexus

##### *Energy vs water needs*

The energy-water nexus has received more attention with increasing demand for water and energy resources in the U.S (Sanders and Webber 2012). To meet energy needs, water is required in large quantities for mining, fuel production, hydropower, and power plant cooling (Copeland 2014). Energy is needed for water supply as well for pumping, treatment, and distribution of water and for collection, treatment, and discharge of wastewater. There are also energy-intensive technologies to increase water resources: desalination plants and inter basin water pipelines (Sanders and Webber 2012).

Energy consumption of regional water systems varies by geographic location, climate, season, and local water quality standards (Sanders and Webber 2012). There are four major differences between water and electricity systems (Scanlon et al. 2013). Electricity can be created and/or generated, but water generally cannot. Moreover, there are substitutes for water but many different sources of electricity. Water is stored in oceans, surface reservoirs, aquifers; meanwhile bulk storage of electricity is technologically infeasible. Electricity can readily be transported through the grid, with relatively low transmission losses but transport of water through pipelines is limited.

##### *Water needed for energy production*

Consequence of growing water needs of the U.S. electric utility industry (Sovacool 2009). Most conventional power plants (coal, oil, natural gas, and nuclear facilities) use one of three types of cooling cycles for electricity generation. Three major water withdrawal states for thermoelectric generators are Texas, Illinois, and Tennessee. Once-through cooling systems withdraw water from a source, circulate water, and return water to the surface body; 91% of the U.S. water resources used for power plants is for this purpose. Re-circulating or closed-loop systems withdraw water and recycle within the power system; this option withdraws less water but consume more by recycling. Dry cooling system use air instead of water to cool power stations. The power sector is not only vulnerable to variability in water quantities and



but also potential climatic changes (Macknick et al. 2012).

**Table 6. Six Mechanisms to avoid future water shortages (Sovacool 2009)**

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|---|
| <ol style="list-style-type: none"> <li>1. Increase R&amp;D funding for alternative power plant cooling cycles.             <ul style="list-style-type: none"> <li>• Using reclaimed water (brackish, gray, nonpotable) to cool power plants</li> </ul> </li> <li>2. Place a moratorium on thermoelectric power generation.             <ul style="list-style-type: none"> <li>• Improve energy efficiency, wind and solar energy use to meet increases in electricity demand</li> </ul> </li> <li>3. Strongly promote energy efficiency and demand-side management.             <ul style="list-style-type: none"> <li>• Demand-side management would be profitable for all utilities.</li> <li>• Generating peak electricity is extremely expensive.</li> <li>• Energy efficiency improvement could save up to 3,32 MW of peak demand within two years, according to research by Natural Resources Defense Council and Pace University Law School Energy Center.</li> </ul> </li> <li>4. Rapidly deploy wind turbines and solar photovoltaic panels.             <ul style="list-style-type: none"> <li>• Wind, which does not require water for cooling, has become cheaper than before.</li> </ul> </li> <li>5. Change electricity prices and give electricity customers more feedback and information             <ul style="list-style-type: none"> <li>• More accurate electricity pricing, altered electricity billing practices, utility-wide information program to educate consumers.</li> </ul> </li> <li>6. Ask the federal government to designate select regions of “Electricity-Water Crisis Areas.”             <ul style="list-style-type: none"> <li>• Few benefits over state-level action.</li> <li>• Interstate organization to monitor and manage electricity-water resources.</li> </ul> </li> </ol> |
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At the U.S. federal level, the Energy and Water Research Integration Act formulated but not enacted into law before the closing of the 111<sup>th</sup> Congress in 2010 (Scott et al. 2011). This Act represents the national level determination for energy-water policy coupling to ensure water intensity in energy projects conducted by the Department of Energy (DoE). Moreover, DoE plans to develop programs to guarantee “efficient, reliable, and sustainable delivery of energy and water resources”. In 2012, the Department of Energy formed the

Department-wide Water-Energy Tech Team to increase cohesion within DoE and strengthen the partnership with other agencies and external stakeholders.

**Table 7. Six Areas of Focus by the Department of Energy**

<div><div>1. Optimize the freshwater efficiency of energy production, electricity generation, and end use systems.</div><div><div>To reduce water intensity of the energy system.</div><div>While carbon capture may increase the water intensity, wind and PV can lower water intensity.</div></div></div>
<div><div>2. Optimize the energy efficiency of water management, treatment, distribution and end use systems.</div><div><div>This will also reduce water intensity of the energy system.</div></div></div>
<div><div>3. Enhance the reliability and resilience of energy and water systems.</div><div><div>Old infrastructure can increase vulnerability and risk, in addition to those of climate change.</div></div></div>
<div><div>4. Increase safe and productive use of nontraditional water sources.</div><div><div>Produced water from oil and gas production, municipal wastes, seawater and brackish water may be useful.</div></div></div>
<div><div>5. Promote responsible energy operations with respect to water quality, ecosystem, and seismic impacts.</div><div><div>This agenda will find the linkages between energy operations and risks to water quality.</div></div></div>
<div><div>6. Exploit productive synergies among water and energy systems.</div><div><div>Synergies can exist across inputs of the systems or across policies.</div><div>Currently, policy decision landscape for energy-water nexus is highly fragmented.</div><div>Loan guarantee program: financing of the first project for energy technologies with positive water implications.</div></div></div>

In addition to the recent Act, there are numerous other laws on water at the federal level: the Water Resources Development Acts, the Clean Water Act, the Safe Drinking Water Act, the Reclamation Act, the Federal Power Act, the National Environmental Policy Act, and the Endangered Species Act (DoE 2014).

Federal government is the appropriate level of government to impose energy policy, but may not be the best level to determine water savings, since water supply influenced by local and regional conditions (Mann 2011). In addition, energy resources are more transportable, compared to water resources. Consequently, adaptation strategies of energy-water nexus may be easier from the energy policy perspective than water policy perspective. For resource management decision-making, multi-tiered institutional arrangements are needed. In the case of energy-water management, resource linkages do not match the scale of institutions, so oversight is needed.

Energy-development at the federal or state agencies means local authorities may not be involved for local resource management. Currently, water supply management through rights and permit allocation, not the state's responsibility in the U.S. (Copeland 2014). For example, corn needs no irrigation in Minnesota, but must be irrigated in California. Therefore, Minnesota should encourage ethanol use but not in California. Moreover, the state government can make the decision whether the project is appropriate and also take charge of monitoring and distribute federal funds in the form of tax savings (e.g. the low-income housing credit).

For actual water resource management, there are two main views. One group supports that regional analyses are useful for initial assessments, but water issues are local and evaluation of water shortages for power plants needs to be conducted at the local scale (Scanlon et al. 2013). Another view is that policies for energy-water nexus should not be focused on the operational point of use at the power plant but more at regional levels of natural resource stocks and changing human demands for energy and water required (Scott et al. 2011).

#### *Using tax credit*

Putting a price on water is more difficult than pricing carbon, because the

full economic costs of transport, treatment, storage and opportunity costs of water are difficult to quantify. Rather than pricing water, policy makers can pick technology winners that reduce both GHG emissions and save water. A key market strategy to influence producers is to use taxes or subsidies. U.S. taxpayers have three options: production tax credit (PTC), investment tax credit (ITC), and grant instead of credit. Tax credits are available in the U.S. for clean coal facilities and refined coal production facilities. The current tax system does not differentiate between energy sources that require much water.

Investment Tax Credit (ITC) is a tax credit of 10 or 30% of the project cost for “energy property”. An energy property is one that generates electricity by solar, wind, closed-loop biomass, open-loop biomass, geothermal, land-fill gas, trash, hydropower, marine and hydrokinetic renewable energy. All of the tax benefits of the ITC are valid as soon as the project is in service, so that the credit can be used to pay for the fixed cost. However if the project is sold, ITC must be recaptured (taxable income increases by the ITC amount). Cash grants are economically equivalent to ITC.

Production Tax Credit (PTC) reduces tax liability over the 10-year period after the project begins to produce electricity and based on the amount of the electricity produced, not the cost of property. New solar electric projects are no longer eligible for PTC.

Whether to use PTC or ITC depends on two project-specific factors: installed project costs and the expected capacity factor (production). PTC is preferred if the capacity factor is high and installation costs are low. If the goal of the public policy is to increase supply of renewable energy, PTC is better than ITC. First of all, the former provides incentives to produce renewable energy, rather than to invest capital in a renewable project. Moreover, it is more cost-effective because it subsidizes output of a broad range of technologies that displace fossil fuel without biasing one energy solution or altering relative prices of capital and labor in production. In terms of water used, wind should receive more subsidies per unit of energy. Unintentionally, \$6.15 per million metric BTUs is given to wind and geothermal energy by the U.S. government, compared to \$2.93 given to open-loop biomass energy.

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## 국문요약

### 지속가능한 물-식량-에너지 넥서스를 위한 정책방향 연구(1):

#### 물-에너지 넥서스 정책방향

1970년대부터 관심이 높아지기 시작한 자원의 희소성 문제는 경제성장은 물론 지속가능발전에 있어서도 중요한 주제로 다루어져 왔다. 자원 간 상호의존성에 대한 이해와 그러한 관계성을 고려하지 않으면 해당 자원들과 관련된 희소성 이슈를 근본적으로 해결할 수 없다는 인식에 기반하여 등장한 것이 최근 점차 관심이 높아지고 있는 ‘넥서스 접근’이다.

넥서스 접근은 넥서스의 구성 시스템(대표적으로는 물-에너지-식량) 간의 연관성을 기초로 한 다양한 기술적 혹은 운영적 기법을 통해 해당 자원의 희소성 및 여타 지속가능성을 제고하는 접근을 의미한다. 일반적으로 넥서스를 구성하는 시스템들은 동일한 사업 주체나 의사결정체계 하에 있지 않다. 따라서 다양한 장점에도 불구하고 넥서스 접근의 실제 적용 가능성은 그것이 가능하도록 하는 일련의 조정, 특히 관련 관련된 제도적, 정책적 지원 여부에 따라 크게 달라진다.

본 연구에서는 물-에너지 넥서스를 중심으로 두 자원 간의 상호의존성과 이에 기초한 다양한 넥서스 접근 가능성을 개발하는 한편, 이를 실제 적용하기 위해 필요한 다양한 정책 방향을 모색하였다.

주제어: 지속가능발전, 넥서스, 물, 에너지, 통합 정책, SDG