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Exploration of the Water-Energy-Food Nexus for Policy Making and Implementation

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Abstract

The research aims to evaluate the concept and policy framework of the Water-Energy-Food (WEF) Nexus in the Korean and international context for achieving water security and make suggestions for relevant policy-making and implementation. The study introduces practices of the WEF Nexus in Saudi Arabia, Ethiopia, USA and South Korea. The WEF Nexus can be defined as 'a way of thinking about the interdependencies, tensions and trade-offs between water, energy and food security in the wider context of environmental change with a focus on the impact on social systems (Houses of Parliament, 2016)'. There are three essential elements for the nexus approach, the interdependencies, trade-offs and synergies. Saudi Arabia has managed to export livestock and dairy products by consuming water produced through desalination plants. Such energy-intensive practices need to be avoided. Ethiopia has striven to achieve socio-economic development through the nexus approach which can be found from its Growth and Transformation Plan. The state of California, US, has coped with serious droughts via the introduction of brackish desalination plants. Floating solar power plants in South Korea indicates another attempt to apply the nexus approach to the existent infrastructure for efficiency and environmental conservation. Nexus-based policy-making and implementation should reflect the urgency to minimize trade-offs and optimize synergies between water, energy and food, which serves as a backbone to support the enhancement of water security. Mobilizing public and private funding will be necessary, and the socio-economic and environmental systems should be revised and adjusted to reflect nexus-based policies and frameworks.

Keywords

Water-Energy-Food Nexus, water security, interdependencies, trade-offs, nexus-based policy-making and implementation

01
Introduction

Challenges triggered by the depletion, overuse and unsustainable management of resources for human development have been compounded by population growth, industrialization, and urbanization together with adverse impacts of climate change. The Global Risk 2014 indicates that four out of the most influential and possible risks are indirectly or directly related to water and food security. In addition, energy security is increasingly becoming one of the top policy agendas in many regions, which cannot afford to be jeopardized. The security of water, energy, and food can guarantee sound economic growth and an adequate level of living standards (World Economic Forum, 2014). In this context, water security of a society or region is fundamentally in line with food and energy security for safeguarding sustainable development.

There is a growing recognition of the need to prepare an innovative and holistic approach for resolving the complexity of these challenges, and the nexus approach for tackling natural resources, i.e. water, energy and food is needed. The urgency for the nexus between water, energy, and food is imminent considering socio-economic and environmental challenges the global society is confronted with at the moment, including water shortage and stress, an upsurge of energy demand and supply constraint, and food shortage and waste.

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Such problems are often exacerbated by climate change which has led to the intensification of unpredictable natural phenomena regardless of geographical locations. The Water-Energy-Food (WEF) Nexus approach is becoming a ‘necessity’ in policy-making and implementation at the local, national, and regional levels. A lack of a good understanding of the WEF Nexus can entail unsustainable management of invaluable resources and necessities for human survival and development, and eventually spawn the downward spiral of socio-environmental conditions.

The purpose of this study is to explore the background and research trend of the WEF Nexus and conceptualize the approach for giving recommendations for policy making and implementation in the course of achieving water security. Discussions of the primary purpose of the approach are geared towards an emphasis of three significant characteristics considering an integrated approach to the three resources, such as interdependencies, trade-off and synergies. On the basis of a good understanding of the concept, the study sheds light on various cases, i.e. Saudi Arabia, Ethiopia, the state of California, USA, and South Korea.

Particular attention will also be paid to policy prerequisites for the WEF nexus approach as enabling environments, relevant policy agendas and implementation issues, and the role of national governments on how to promote the nexus approach for policy making and implementation. The discussion of these elements will pave the way for decision makers to step forward the adoption and implementation of the WEF Nexus in an integrated way and put relevant policies and programs into practice for achieving water security, eventually.

The first part of the study is to discuss the research trend of the WEF Nexus and to conceptualize the approach. In the second section, the study takes a closer look at the applicability of the theory by exploring a variety of cases not only in the Middle East and Northern Africa (MENA) but also the state of California, USA, and South Korea. The third section analyzes various policy matters, including necessary institutional arrangements for the adoption and application of the nexus approach, adequate means of policy-making and implementation, and the roles of national and local governments to promote the nexus approach.

02
Research Trend and Conceptualization

2.1. Research Trend

Previous research outcomes on the WEF Nexus have delineated how water, energy, and food sectors are interconnected and which issues are relevant. Achieving sustainable development requires an integrated and holistic approach considering a complexity of interconnectedness between various sectors, i.e. water, energy, and food sectors. Numerous theoretical and practical approaches have been suggested as platforms with which international communities can realize sustainable development, such as green growth, green economy, inclusive growth and eco-efficiency, to name a few. Nevertheless, an array of tools and theories for sustainable development have proved to be ineffective thanks to continuous silo-based approaches, inappropriate technologies, and governance structures.

The Sustainable Development Goals (SDGs) were established in 2015 on the basis of reflection of what had been done in order to overcome challenges embedded in the Millennium Development Goals (MDGs). Even though the SDGs have put more emphasis on the magnitude of invaluable resources through a setup of individual targets, i.e. water (SDG-6), energy (SDG-7), and food (SDG-2), the 2030 agendas seem to have failed to accommodate interdependencies, trade-offs and synergies via interactions in the WEF Nexus (Houses of Parliament, 2016; Mohtar, 2016; Sullivan, 2017).

Early attention to the WEF Nexus was placed on the consideration of alternatives that can help achieve sustainable development and provide practical solutions to resolve challenges caused by the rapid socio-economic development, industrialization, and technology development since the 1970s. One of the first world-wide efforts to promote the WEF Nexus was the 2011 report on water security and the WEF Nexus, which was published by the World Economic Forum (2011). Whilst discussing various elements to influence the degree of water security for society, the report points out several areas with high risk, including an imbalance of macro-economy, illegal economic behaviors and the WEF Nexus.

In particular, the WEF security can be compromised due to economic crisis, economic imbalance, and the failure of global governance. In order to overcome these barriers, a series of institutional rearrangements and new policy making are necessary, i.e. resource use planning accommodating diverse views from stakeholders, and the implementation mandate given to local authorities. In addition, governments should make the decision of prices of water, energy and food services based on market mechanisms and pursue innovation in the fields of nexus management technologies and related financing (Liu, 2017; World Economic Forum, 2011).

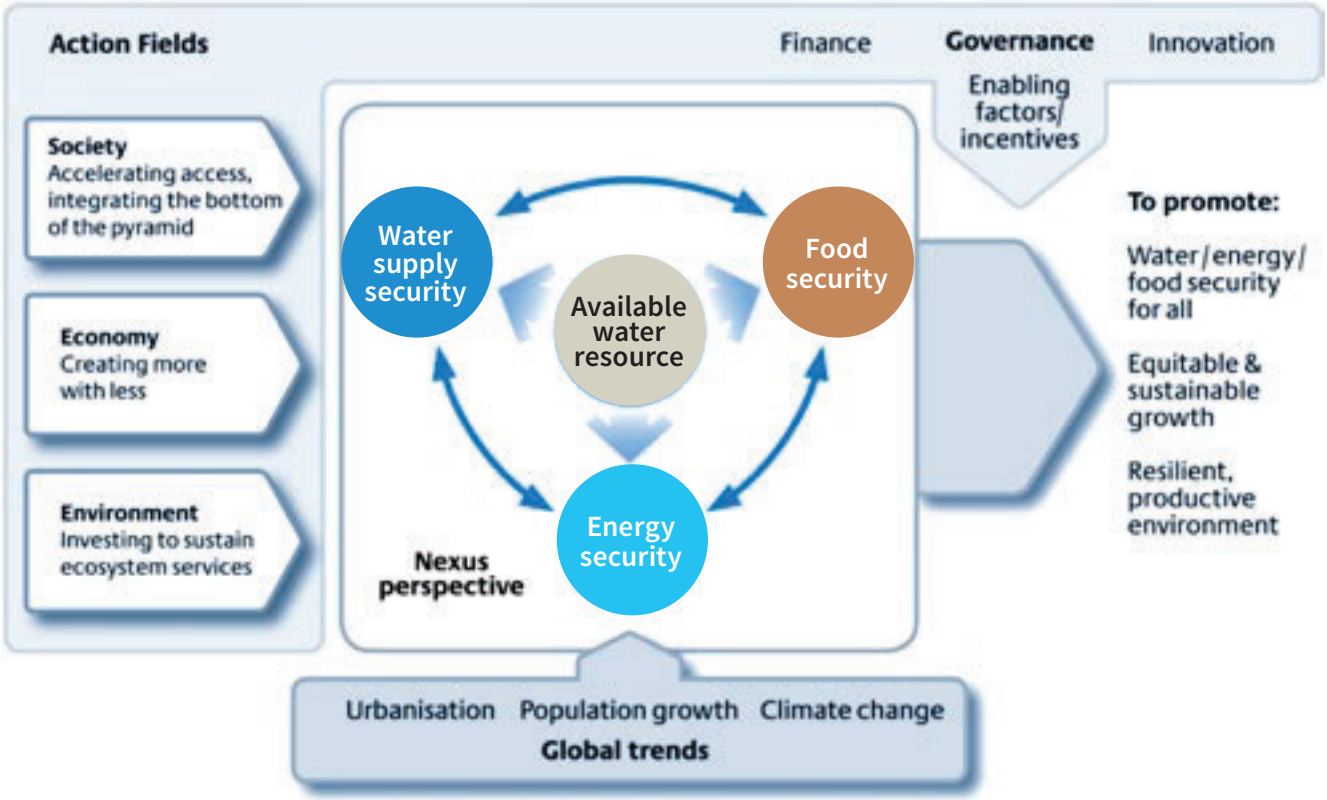

Figure 9-1 *The Water-Energy-Food (WEF) Nexus Security Framework of the Bonn Nexus Conference (Source Hoff, 2011)*

Together with the WEF report, the Water, Energy, and Food Nexus- Solutions for the Green Economy Conference in Bonn, Germany in 2011 was instrumental in terms of proliferation of the approach to the world. This conference put an emphasis on the need of decision making and interconnectedness through interactions between the sectors of water, energy and food confronted with urbanization, population growth, and climate change. More detailed suggestions included financing for water, energy and food security, an establishment of financing, economic incentives, and governance, and consistent institutions and policy making alongside the improvement of resource production and multiple uses of used resources. The conference also highlighted the magnitude of the reduction of transaction costs related to the integrated management of the three resources and suggested the urgency of policies to maximize synergistic effects of the nexus approach (Hoff, 2011; Lee, 2015; Martin-Nagle *et al.*, 2012) (See Figure 9-1).

Food challenges at the global level have been a major concern of the Food Agriculture Organization (FAO), and the organization underpins the significance of food security in the discourse of the WEF Nexus. The bottom-line principles of FAO for the WEF Nexus demonstrate its commitment to reducing trade-offs and seeking for the most efficient options to maximize synergistic effects.

More specifically, FAO takes into serious consideration the upsurge of resource development demands, population growth, the change of diet patterns, the evolving faith and behaviors of society and culture, technology development, urbanization, international trade, market, food prices, and industrialization for the implementation of nexus-based policies. In lieu of the implementation of nexus-oriented policies, it is imperative to introduce an integrated approach to considering land, capital, knowledge, and labor and call for dialogues and negotiations between diverse stakeholders from different sectors and fields. To support these initiatives, governments should be dedicated to developing and implementing a list of different scenarios and response policies based on the thorough assessment of relevant information (FAO, 2014). Figure 9-2 delineates the process of the WEF Nexus from the perspective of FAO.

A myriad of international conferences on water in recent few years has included sessions on the WEF Nexus, including the 7th World Water Forum, held in South Korea. The programs of the WEF Nexus contributed to increasing the recognition of the nexus approach for resolving not only water challenges but also its impacts on other resources (Lee *et al.*, 2015). In the 8th World Water Forum, held in Brazil, 2018, the discourse on the nexus approach continued, and it seems that the WEF Nexus will become one of the most pressing topics to be discussed and considered at the global level in the foreseeable future.

2.2. Conceptualization

The discussion of the WEF Nexus indicates the growing consensus that silo-based policy making and implementation, R&D, and operation and maintenance will not be able to help manage limited resources in an efficient and sustainable fashion. Those who are interested in research on the nexus approach strive to seek for plausible options related to

> *"The WEF Nexus is an approach to evaluate political, economic, social and environmental impacts of the exploitation of water, energy, and food with special reference to interactions between the three sectors."*

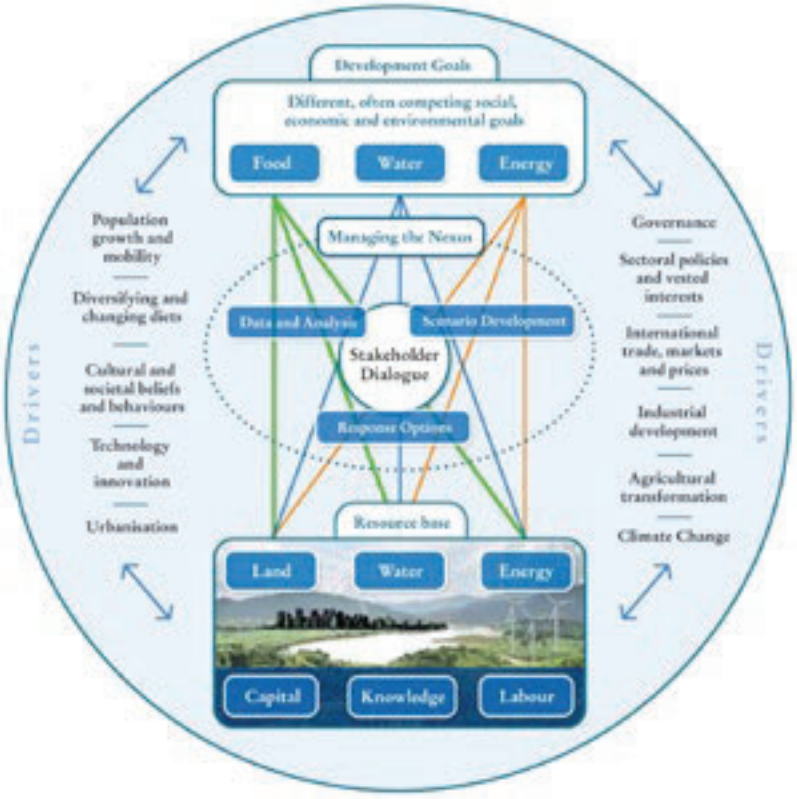

Figure 9-2 *FAO's approach to the WEF Nexus (Source FAO, 2014)*

efficient and sustainable policy making and implementation, related projects, R&D, a setup and operation of relevant governance structure.

The SDGs were established in 2015 so as to accomplish 17 goals by 2030 and can serve as a useful media that confirms the significance of the nexus approach. Although each of the SDG goals is imperative, many goals are inter-related and cross-cutting, including water (SDG 6), energy (SDG 7), and food (SDG 2). Therefore, it is necessary to take into serious account interdependencies between these goals, and the international communities will be able to witness positive outcomes based on the interconnectivity and synergistic effects between water, energy, and food towards 2030.
Weitz *et al.* (2014) visualizes the WEF nexus especially focusing on the interconnectivity between water, energy, and food as seen from Figure 9-3.

However, one of the fundamental challenges embedded in the SDGs is that the goals do not accommodate inter-connected issues such as the WEF nexus and are not committed to creating relevant targets. In order to effectively achieve the SDGs, the nexus approach should play a key role (KICT, 2017; Houses of Parliament, 2016; Mohtar, 2016; Sullivan, 2017; Weitz *et al.*, 2014).

It is useful to discuss the significance of challenges in the fields of water, energy and food prior to the exploration of the concept and definition of the nexus approach. Over 70% of the total amount of freshwater resources at the global level is exploited for food production, and the energy sector requires more than 15% of the total freshwater resources in the world for resource development and cooling water for power generation. The level of global energy demand in 2025 will be likely to increase 1.6 times than in 2005, and as a result, the water demand of the energy sector will soar to 11%.

Globally, the amount of water intake for energy generation will increase by over 20%, and the level of water consumption for this use is expected to grow by 85% until 2035.
For instance, an extreme drought in 2015 badly hit the western part of Chungnam Province in South Korea, which led to the emergency operation of a coal-based power plant due to the lack of cooling water. Power plants are becoming more efficient, cutting-edge cooling systems will be installed that require less water but demand more energy, and there will be an increase of biofuel production (Jung, 2015; Lee *et al.*, 2015; Liu, 2017; UNESCO, 2014).

More production of corn, wheat, and sugarcane for biofuel can entail a decrease of food supply, which indicates an example of trade-off between energy and food. Many developing countries in Southeast Asia, Africa, and South America lack electricity, which hampers an increase of food production. A speedy desertification, obsolete water supply systems, a dearth of sanitation facilities, and inefficient water resources management have exacerbated water availability and agricultural productivity. The population growth of the world, which is primarily led by developing countries, is expected to demand more water for the agricultural sector, which triggers more water demands by at least 19% until 2050 (Jung, 2015).

More than 3.5% of the total amount of energy consumption in the OECD countries have been attributed to food production whilst developing countries often demand 4.8% on average, and the food processing and transport sectors in rich

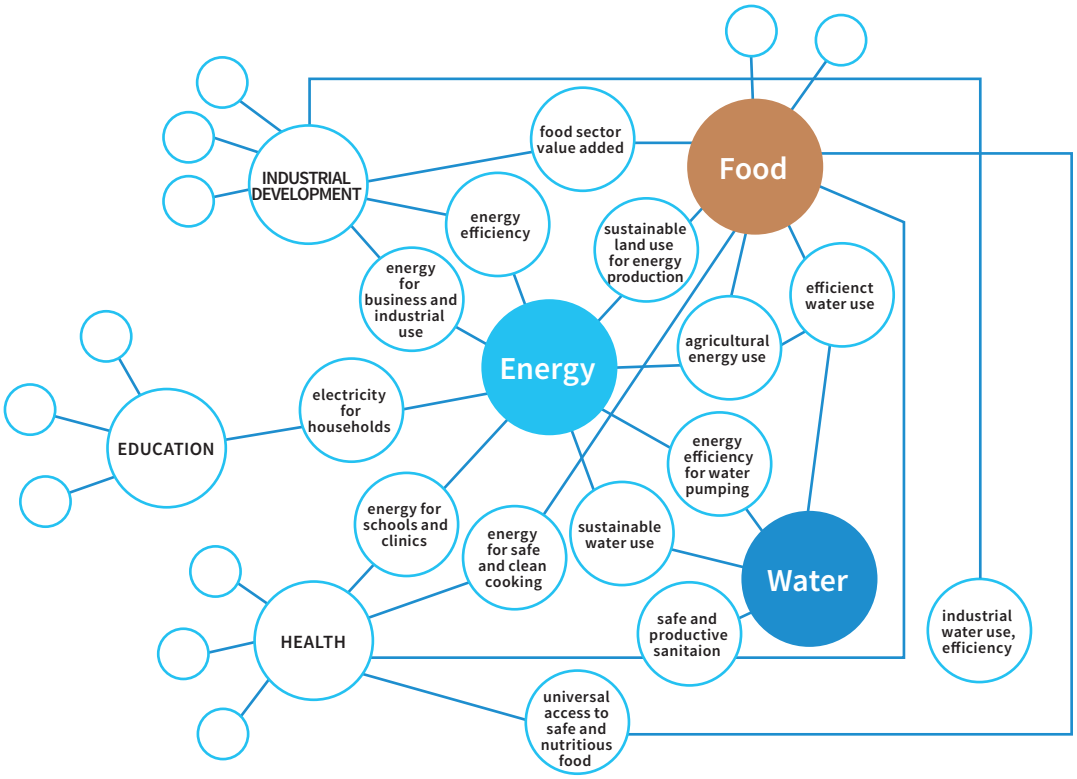

Figure 9-3 *Interactions between water (SDG 6), energy (SDG 7), and food (SDG 2) (Source Weitz et al.,2014)*

countries consume twice as much energy compared with the agricultural sector. In 2007, the food production system in USA required almost 16% of the total energy consumption at the national level, and Figure 9-4 vividly indicates the causal relationship between the food sector and the oil price indicator at the global level. The blue line shows the trajectory of food price changes and the red line the pattern of oil price changes from January 2002 to July 2015. The significance of oil supply for food production is confirmed from Figure 9-4 since the input of oil, for instance, in the fields of logistics and cooling facilities, gives influences on the production of relevant products, i.e. fertilizers (Laurentiis *et al.*, 2016).

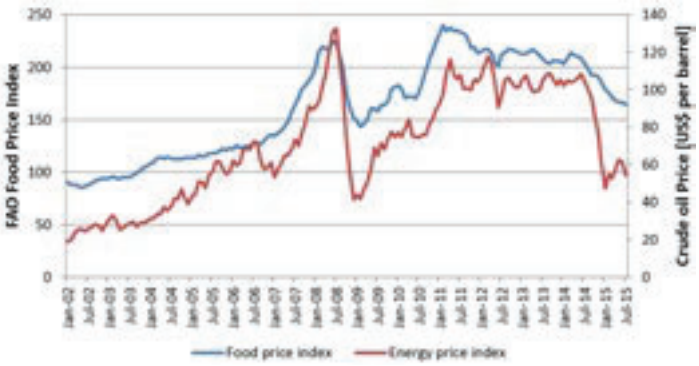

Figure 9-4 *Food and oil price changes from January 2002 to July 2015 in the world (Source Laurentiis et al., 2016)*

One of the essential steps on the study of the Water-Energy-Food (WEF) nexus is to explore the definition of the nexus approach. Simply speaking, the WEF nexus approach explores water, energy and food systems that interact with each other and the environment as a whole. For instance, food crops need energy for fertilizers and pesticides, water for irrigation, and depend upon environmental processes for cycling of nutrients and pollinating crops (Houses of Parliament, 2016).

Discussions on the nexus between these elements are not totally new, and the term, 'nexus' has been used for analyzing the interactions between water, energy and food since the 1980s. It was the Food-Energy Nexus Programme of the United Nations University that first began to adopt the concept on the relationship between food and energy. The programme focused on the introduction of technical solutions and relevant policies for the interconnectivity between food and energy for developing countries (Kim *et al.*, 2015).

The WEF Nexus is an approach to evaluate political, economic, social and environmental impacts of the exploitation of water, energy, and food with special reference to interactions between the three sectors. The nexus accommodates a myriad of principles, such as universal access of all the people including the poor and the weak in society to water, energy and food in development, an increase of resource efficiency, and safeguarding sustainability for sustaining productive ecosystems (Weitz *et al.*, 2014).

In a similar vein, according to the Economic and Social Research Council (ESRC) in the UK, the definition of the WEF Nexus is referred to as 'a way of thinking about the interdependencies, tensions and trade-offs between food, water, and energy security in the wider context of environmental change with a focus on the impact on social systems' (Houses of Parliament, 2016). It is important to note that there are three important interactions in the nexus circle: 1) interdependencies; 2) constraints; and 3) synergies.

The first interaction is neatly explained related to fossil fuel electricity generation which requires water abstraction. Also, energy is needed to extract, treat and distribute drinking water. Constraints in the nexus occur related to trade-offs between systems. If an abstraction of water is increased for irrigating more food crops, water availability for other uses should be reduced, i.e. drinking water consumption, and hydropower, thermal power or nuclear power generation. Synergistic effects can be found in the nexus. Nexus-aware policy-making and implementation can reduce pressure on whole WEF systems, which leads to achievement of sustainable development in the long term (Houses of Parliament, 2016) (See Figure 9-5).

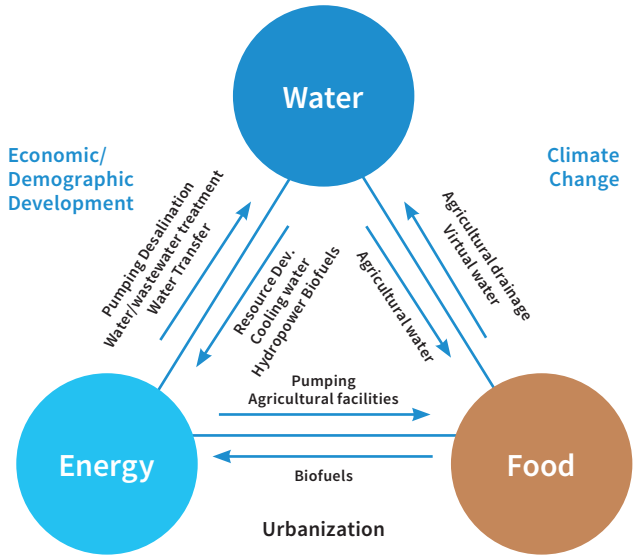

Figure 9-5 *Interaction between water, energy, and food in the WEF Nexus (Source Author)*

On the basis of the discussions above, the WEF nexus is also regarded as a policy platform with which public authorities are able to develop an assessment system, a development mechanism, and implementation measures for implementing policies, programs and projects for the sectors of water, energy, and food in an integrated fashion. Policy approaches related to the nexus play a pivotal role in consolidating water, energy, and food security. In a broader sense, the nexus framework can advocate harmonious management and use of natural resources regardless of scales (Liu, 2017).

03
Case Studies

3.1. Saudi Arabia and Ethiopia

The MENA countries are energy rich (fossil and solar energy), water scarce, food deficit and economically and environmentally vulnerable to climate change and constitute the primary case study areas in which the complexity of impacts derived from WEF interactions has already been prevalent (Mohtar, 2016). Although the Gulf Cooperation Council (GCC) states are referred to as the main cases, the countries endowed with less oil and natural-gas are worth looking into.[1] The study highlights the period since the new millennium (about 15 years) in order to closely scrutinize the changes and influences of WEF interactions in the region.

The case of Saudi Arabia explicitly shows how imperative the WEF Nexus approach is. A large number of dairy farms and cattle farms in the country have been developed coupled with a good degree of export industry of food for the region, which is possible thanks to subsidized water. This water has been 'produced' based on desalination plants, subsidized land, subsidized labor, and in a tax-free environment.
Not to mention, the country's oil export revenues have played a key role. Around 70% of the country's total water use have stemmed from desalinated water, which means that Saudi Arabia is the world's largest producer of desalinated water. Desalination plants in the country need over half of domestic oil production, which implies that a stable and reliable supply of oil can only guarantee water security for the country (Rambo *et al.*, 2017; Sullivan, 2016).

What if there would be a revolutionary change of global energy market, and the primary energy source for transport and Saudi Arabia would be green options, not oil or natural gas? The country would face real economic difficulties and political uncertainties. The World Bank (2012) predicts that Saudi Arabia could burn 8 million barrels a day to produce freshwater by 2040 whilst they are already consuming about 1.5 million barrels a day to desalinate. Possible ramifications of burning 8 million barrels a day for desalination could be tremendous to the global oil market.

These encompass a rapid depletion of precious fossil fuel sources such as oil, a destruction of the ozone layer because of the increase of greenhouse gases, an acceleration of climate change, and an increase of occurrence and scale of damage caused by water-related disasters.
Nexus-considered policies, programs and projects can help reduce anthropogenic and human-induced disasters and establish society with a good degree of sustainable development. Similar pictures could be applied to Kuwait and other oil export countries in the GCC (Sullivan, 2017).

Mohtar and Daher (2016) suggest a WEF Nexus 'hotspot' in which a vulnerable sector, country or region is confronted with stresses in one or more of its resource systems triggered from the interconnectedness of water, energy, and food resources. Such hotspots are often found in the MENA region where some countries like Saudi Arabia, Qatar, and Kuwait are endowed with large amounts of fossil fuels (oil and natural gas). Many countries in the region face water scarcity, and massive amounts of food should be imported to the region. In addition, climate change-induced socio-economic and environmental risks are particularly high in the region.

A good practice of the application of the nexus approach to policies is found in Ethiopia, Africa. The Growth and Transformation Plan (GTP) I (2010–2015) of Ethiopia, which envisaged the socio-economic development in next five years, stressed the urgency to accelerate the development of the agricultural and energy sectors for export. The GTP embraced the plan to scale up the agricultural productivity by 30%, the amount of energy production at 300%, sugar production by 600%, and meat production by 1,000%. In addition, the plan aims to boost food production, advocate energy generation through biofuels, and increase the amount of hydroelectricity via the Grand Ethiopian Renaissance Dam which is under construction on the Blue Nile (International Rivers, 2014; Weitz *et al.*, 2014).

Close attention is paid to individual targets included in detailed development plans of Ethiopia, which are directly associated with food production, bioenergy generation, hydropower development and irrigation projects.
An evaluation of inter-connected challenges between the Blue Nile and Tana Lake indicates that the commercialization and scale-up of the agricultural sector can result in an increase of agricultural productivity but may spawn negative influences on aquaculture downstream and livelihoods near the Tana Lake. Whereas policies for invigorating the agricultural sector can produce positive results in the short term, such policies might hinder food security in the region.

By analogy, the increase of biofuel production can lead to an increase of profits through an export of biofuels to other countries, a decrease of greenhouse gas emission by replacing them with fossil fuel sources, and universal access to energy supply. However, a rise of biofuel production can also require large amounts of water resources for irrigation and vast areas of plots of land. Consequently, these procedures can engender fierce competitions between food production and ecosystem services (Weitz *et al.*, 2014).

3.2. California, USA

The State of California boasts the largest population in the USA and produces vast amounts of vegetables, fruits, and nut products, which accounts for almost half of the total production of these items. Therefore, water security is one of the most urgent and imperative agendas for the state government. Most of the agricultural products in California

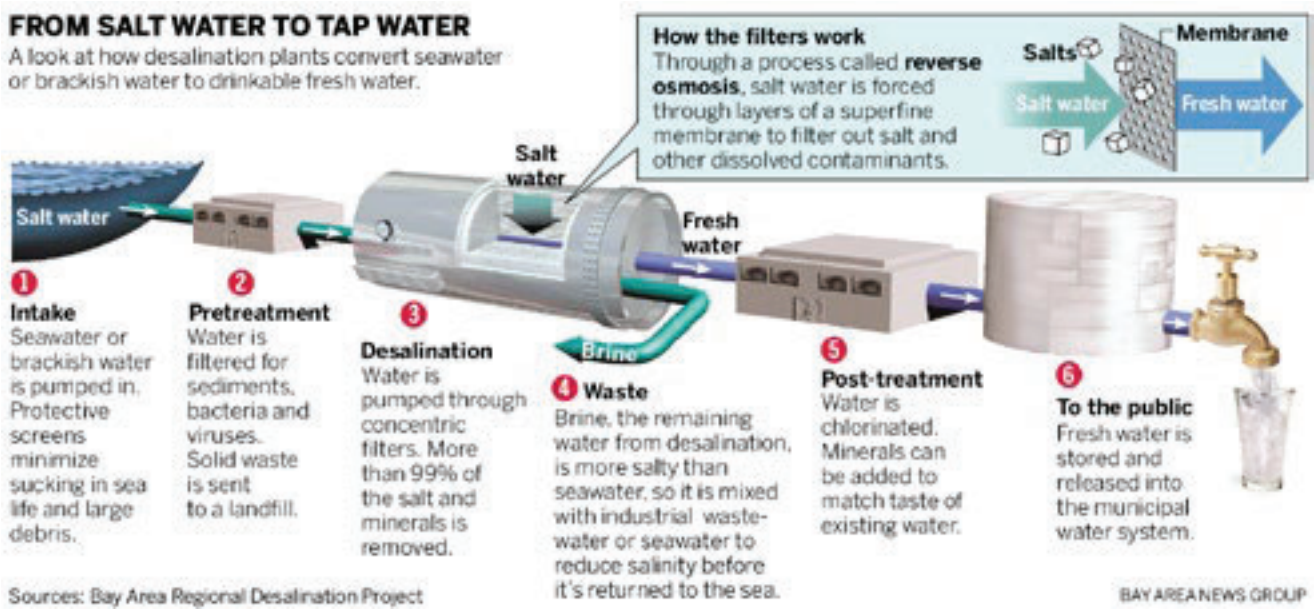

Figure 9-6 Desalination process in desalinization plants of Southern California (Source Rogers, 2018)Remarks: MPD indicates multipurpose dam, and HGD hydropower generation dam. Modified based on the Han River Flood Control Office Website http://www.hrfco.go.kr/eng/service.do (accessed 15 June 2018)

are grown based on irrigation projects that require heavy amounts of water resources, and apart from Northern California where water is relatively abundant, the other areas of the state, especially agricultural fields, receive water through large-scale and long-distance aqueducts.

The most renowned water transfer project is called, 'the State Water Project – SWP', which purposes to supply sufficient amounts of water to 75 million locals and 3,000 km^2 irrigated fields in Northern California, the San Francisco Bay area, the San Joaquin Valley, the Central Coast, and Southern California. This gigantic water transfer scheme had effectively been in operation, however, in January 2014, severe droughts in successive years brought about the first suspension of water supply in 54 years owing to a critically low level of water storage in reservoirs within the scheme. More than 25 million residents were affected, and as large as 750,000 acres of farmland had to rely on some other water resources instead (Pickert, 2014).

Aware of adverse impacts of climate change, the California state government has paid close attention to the linkage between climate change and water resources, which displays that the speed of water consumption has been faster than that of water recharge through the hydrological cycle. Large amounts of surface water in California stem from winter rainfall and glacier melting, and over the last three decades, the Californian winter has become warmer, which results in reducing the amount of melted snow and altering the time of snow melting. Such phenomena have consequently caused much less water available for California.

One of the coping strategies considered in Southern California is to introduce ocean desalination plants along the seashores and brackish desalination plants for enhancing water security.[2] In January 2018, the California state government gave a green light for the construction of eight desalination plants with a budget of US$ 34.4 million, and six of them are for brackish desalination. The reason why more brackish desalination plants are preferred is that the plants are less costly compared with ocean desalination plants. Ocean water is often three time saltier and more expensive to be converted into freshwater (Rogers, 2018) (See Figure 9-6).

A major concern about this option is that desalination plants require vast amounts of electricity. The water sector claims approximately 19% of the total amount of electricity supply in California, which are required for water pumping, water transfer, water treatment and the allocation and operation of water for domestic, agricultural, and industrial purposes. If desalination plants were introduced and in operation, the level of electricity consumption for water services would soar up. The option of desalination plants in California would contribute to a reduction of water import from other states, which was estimated at 3 million m^3 per annum on average. But a different side of the coin for this option is that California would need additionally tremendous amounts of electricity at around 3 TWh (Weitz *et al.*, 2014).

3.3. South Korea

Attention is placed on the amount of electricity consumption by the water sector in South Korea. Approximately 7% of the total amount of electricity consumption in the country is allocated for operating and maintaining tap water supply facilities, which demonstrates low degrees of trade-off impacts between water and energy. More specifically, the total amount of annual electricity consumption of water intake points reach 1.35 billion kWh, water treatment plants 1.18 billion kWh, industrial water treatment plants, 32 million

kWh, and wastewater treatment plants 2.53 billion kWh (Lee *et al.*, 2015).

Desalination plants of the country are much smaller than those of the MENA in terms of capacity, of which size ranges from 10 m^3/day to 1,000 m^3/day. In 2014, there were 109 desalination plants with the total capacity of 8,333 m^3/day. These plants are situated in small islands and do not consume large amounts of energy (Ministry of Land, Infrastructure and Transport, 2016). In addition, South Korea does not produce much in terms of agricultural products, such as sugarcane, corn, and wheat, for biofuel production, and therefore, there is a weak connectivity between energy and food.

The agricultural sector in South Korea has been the largest water user and claimed around 49% of the total amount of water resources as of 2011. Systematic maintenance works and the continuous construction of agricultural reservoirs have paved the way for farmers to have good access to sufficient amounts of agricultural water although sequential droughts pose a serious threat to water security. 39% of water resources are allocated for domestic uses and 12% for industrial uses. Among the industrial uses, the level of water consumption of fossil-fuel power plants for cooling is 167 m^3, and the amount of ocean water accounts for 166 m^3 (Kim, 2016; Jung, 2015).

Large-scale infrastructure projects or national-level programs related to the WEF nexus are not necessarily common at the national and global levels but South Korea has witnessed a myriad of new attempts to apply the WEF nexus approach to practical cases through several pilot projects. The first case is linked to the Integrated Operation and Management of Dams in a river basin reflecting the nexus between water and energy. This project aims to increase the efficiency of operation and management of existent hydropower and multi-purpose dams. In particular, the government plans to upgrade single-purpose dams (hydropower generation) which are taken care of by Korea Hydro and Nuclear Power into multi-purpose ones that are operated by K-water, which can result in securing an additional flood control capacity of 240 million m^3 and an additional water supply capacity of 540~880 million m^3. Consequently, the new scheme will not only optimize the operation and management of hydropower dams but also utilize extra amounts of water for hydropower generation (Lee & Choi, 2018) (See Figure 9-7).

Figure 9-7 *Dams along the Han River (Source Lee, 2018) Remarks: MPD indicates multipurpose dam, and HGD hydropower generation dam Modified based on the Han River Flood Control Office Website http://www.hrfco.go.kr/eng/service.do (accessed 15 June 2018)*

Figure 9-8 *Floating solar power plant on the surface of the reservoir at Chungju Dam (Source Jecheon City Hall, January 2018)*

The second case demonstrates an innovative approach to the generation of electricity through photovoltaic plants installed on the surface of freshwater, often dubbed as 'floating solar power plants'. A floating solar power plant embraces several advantages compared with the one installed on land. First, relevant facilities are installed on the surface of freshwater lakes or reservoirs, which eventually requires less land areas and gives less strain on land-short countries or regions. Second, installed facilities on the surface serve as a canopy to prevent heavy sunlight, which results in ameliorating a phenomenon of green algae and providing favorable conditions for fish spawning. Third, floating solar power plants can produce more electricity than the plants installed on land, since the water of lakes or reservoirs cools the panels of the plant that has a better efficiency of electricity generation at 10% compared with land-based solar power plants (Lee & Choi, 2018).

In recent few years, floating solar power plants have become popular in South Korea, particularly both in agricultural and multipurpose dam reservoirs. For instance, K-water has installed floating solar power plants in the Habcheon Dam, 2012 with a generating capacity of 500 kW, the Boryung Dam with a capacity of 2MW, 2016, and the Chungju Dam with a capacity of 3MW, 2017 (See Figure 9-8). In addition, the Korea Rural Community Corporation has spearheaded a boom of floating solar power plants in agricultural reservoirs and plans to build three large-scale floating solar plants in Dangjin (100 MW) and Daeho Lake (100 MW) in the Chungnam Province and in Goheung Lake (80MW), the Jeonnam Province until 2020 (Lee, 2017; Shim, 2017).

> *"The government should appraise the interconnectivity between water, energy and food and consider appropriate measures to ensure water, energy and food security alongside least trade-offs."*

The Water-Food Nexus has long been recognized for rural communities in Korea, and relevant cases are found in irrigation projects of the country. In order to save water and increase the efficiency of water use, farmers and government authorities have taken into serious consideration various methods on how to improve food productivity with less water and better output. An attempt is the introduction of the System of Rice Intensification (SRI) for paddy rice fields. The SRI technique can help reduce the amount of water for the growth of paddy rice through the introduction of drip irrigation which allows water to be directly supplied to roots and stems of paddy rice. As a consequence, less water is required for rice production by 44%, rice yield is increased per hectare at 52%, and a net income per hectare increases at around 128% based on the SRI technique. These explicitly show synergistic effects of the water-food nexus as well as the case of sustainable agricultural production (Lee & Choi, 2018; Selvaraju, 2013).

04
Water-Energy-Food Nexus Policy

4.1. Enabling Environments

Policy making and implementation of the WEF Nexus approach encompasses several features that are unique and distinguishable from sectoral approaches. Relevant policies are balanced considering the interconnectivity between the three sectors and can be implemented based on appropriate legal settings and systematic governance structures for the achievement of sustainable development. The approach facilitates an increase of resource use and a conservation of resources for future generations, which should be reflected in policy making and implementation with the recognition of interconnectedness between the three sectors. These efforts will culminate in accelerating synergistic effects (Lee *et al.*, 2015).

There are policy actions for the WEF Nexus policy making and implementation. First, it is necessary to set up macro-scale and comprehensive planning for the WEF Nexus that should be spearheaded by governments and embrace integrate systems to accommodate diverse demands and requests from the three sectors. In the long-term, governments are committed to achieving resource-independent policies on the basis of the WEF Nexus approach. Attention should be paid to the reduction of trade-offs in the course of ensuring water, energy and food security. In addition, flexible measures are taken into account faced with mega trends at the global level, including climate change, population growth, land use change, urbanization and industrialization.

Second, strategies for the management of resource consumption and supply are necessary in order to evaluate the evolving patterns of resource consumption due to the change of industrial structure and living patterns of ordinary people and to respond to these changes. In particular, it is critical to consider brand-new policies and cutting-edge technologies such as a smart water grid in order to cope with an unstable water supply, an increase of water-related disasters and deteriorating circumstances of water quality compounded by climate change (Lee *et al.*, 2015).

Third, it is imperative to establish a forum where unique and special features related to the WEF nexus approach are freely discussed and explored through diverse dialogues and discussions between different stakeholders. This forum can be called as 'the Water-Energy-Food Nexus Committee', and should invite various kinds of stakeholders in a society, such as the central and local governments, private companies, social associations/NGOs, and expert groups. Such a governance-based structure will be able to guarantee the soundness of policies and least trade-offs.

Fourth, a maximization of resource use efficiency between the three resources is one of the most significant purposes in the WEF nexus policy making and implementation. The government has to adequately appraise the interconnectivity between water, energy and food and take into consideration appropriate measures to ensure water, energy and food security together with least trade-offs. In the course of that, the government should focus on the principle of sustainability, which echoes with the principles of eco-efficiency and green growth, 'more value with less impact' (Lee *et al.*, 2015; Min *et al.*, 2013). Table 9-1 summarizes detailed measures for maximizing the efficiency between two resources, water-energy, energy-food, and food-water.

Pairing Resources	Measures for Maximizing Efficiency
Water-Energy	• Reduction of the significance of water for power generation • Technology development in bioenergy • Improvement of water use for power generation • Measures for the enhancement of stable water supply • Efficient use of multipurpose dams • Energy recycle in the course of desalination
Energy-Food	• Separate policy making for the agriculture products, i.e. wheat, sugarcane, and corn, for food production and biofuels • Reduction of unnecessary energy loss after the harvesting period • Adoption and proliferation of green agricultural technologies
Food-Energy	• Amelioration of water shortage between nations and regions through the promotion of virtual water trade • Ensuring water supply for food production • Reduction of the amount of garbage in the fields of food production and consumption

Table 9-1 Measures for maximizing the efficiency between water, energy, and food (Source Modified based on Lee et al., 2015)

Severe droughts in consecutive years often occur in many parts of the world, and coping with this kind of water-related disaster would be a formidable challenge to international communities. Policies of the WEF nexus approach will be instrumental for ameliorating and resolving challenges brought by droughts. Amongst various kinds of droughts, the study highlights agricultural droughts. Agricultural droughts are directly linked to the nexus between water and food and gives indirect impacts on the energy sector. Once an agricultural drought takes place, the first fatal impact will be given on the agricultural water supply sector, which results in reducing water availability and the decrease of food production. As a chain effect, the prices of different food items will surge, and the food import from other areas will increase. More water can increasingly be allocated for the agricultural sector, which means less water available for domestic use,

> *"It is necessary to establish comprehensive planning for the WEF Nexus that should embrace integrated systems to accommodate diverse demands from the three sectors."*

environmental flow, cooling for power generation or hydropower generation. The nexus approach paves the way for authorities to assess possible trade-offs between overall water supply policies and drought-driven emergency water supply policies for the agricultural sector, which eventually leads to efficient and sustainable policy decisions.

Agricultural droughts are closely connected to the water sector and deeply associated with the energy sector. The occurrence of agricultural droughts engenders a rising demand of water not only for agricultural reservoirs but also for other water sources. For instance, more pumps can be required for fetching water from underground, and water for hydropower generation can be reallocated to the agricultural. As droughts become severer, a rapid increase of energy consumption can be followed. Nexus-based policies can serve as a new policy framework to tackle such complicated challenges caused by agricultural droughts (Lee, 2015) (See Figure 9-9).

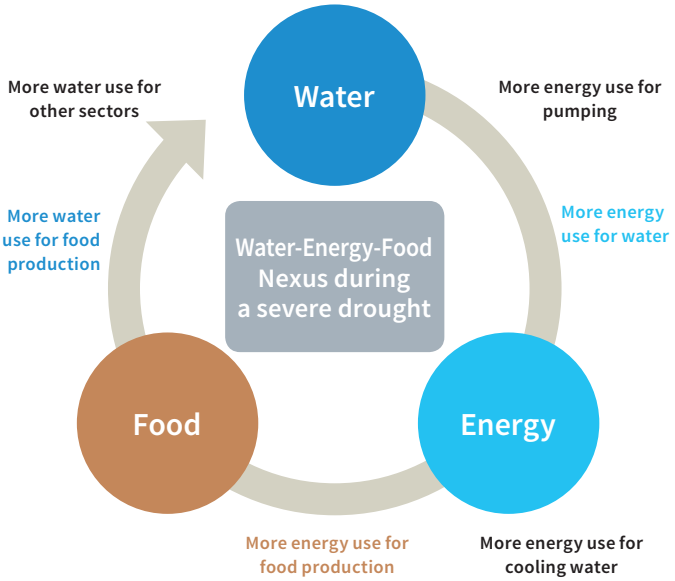

Figure 9-9 *WEF Nexus-based responses to agricultural droughts (Source odified based on Lee, 2015)*

4.2. Role of Government

The roles of governments for the WEF Nexus approach are significant because the water, energy, and food sectors are often the sole responsibility of the public sector although private sector participation has been increasing in the sectors in recent few decades. To begin with, the role of the government should be linked to its encouragement of investment and commitment of relevant bureaus and private players from small-scale technology advancement to a large-scale and national-level establishment of an integrated system for the nexus approach.

Small-scale technology development and relevant policies and programs of the nexus approach appear to have given little impacts on the overall policies and industries of water, energy and food so far. The gradual effects will come into being, which brings about substantial synergies between the three sectors and spawns good benefits to society.
The benefits thanks to the nexus policies will encompass better quality compared with the ones created by each sector, separately. Furthermore, these benefits will have a positive impact on society from socio-economic and environmental perspectives.

It will be difficult to create an independent bureau or agency dealing with the nexus issues, because the complexity of vested interests and heterogeneous problems from the water, energy and food sectors is virtually impossible to be tackled by a single agency. An entity in charge of the WEF Nexus policies should play a coordinating role in accommodating various views, opinions, and problems from the three sectors and therefore, a council or committee should be established in which all the concerned stakeholders are invited and discuss related issues on the basis of good governance.
The temporarily named, 'Water-Energy-Food Nexus Council', will serve as a medium where potential benefits thanks to the nexus policies are adequately distributed and shared between different stakeholders.

Prior to detailed policies and projects for the WEF Nexus approach, it is critical to identify and eliminate pervert subsidies and institutional bottlenecks that hamper nexus-friendly and integrated approaches to water, energy, and food. Socio-economic effects can be optimized through WEF Nexus technologies that facilitate synergistic outcomes on the basis of such enabling environments.

Detailed tasks for institutional frameworks of the WEF Nexus approach are as follows. First, the government should provide opportunities for the public and private sectors to maximize water use efficiency in the process of production and consumption of energy. Second, energy efficiency should be scaled up in the process of water resources management, water treatment, and water allocation. Third, the water and energy system should be enhanced based on principles and mechanisms of eco-resilience. Fourth, non-traditional ways of securing water resources should be promoted, including water reuse and recycle, and rainwater harvesting.
Fifth, a tailored management of energy is necessary for coping with challenges caused by water shortage, water pollution, ecosystem damage, droughts, floods and earthquakes.
Sixth, various measures and methods should be considered in order to create productive and synergistic effects between the water, energy and food sectors (Kim *et al.*, 2015).

4.3. Steps for Policy Making

Policy making regarding the WEF Nexus encompasses specific stages. At the first step, the government has to undertake thorough studies and research on the current circumstances of the nexus approach. This assessment exercise will unveil the interconnectivity between water, energy and food security and various elements that have an impact on the current and future scenarios of the nexus approach. In the course of this exercise, the interconnectedness of water, energy and food with other sectors have to be simultaneously considered and discussed, such as land ownership and land use, and an array of institutional instruments can be explored, including incentives and penalties.

Second, it is useful to envisage WEF nexus scenarios for the future. At this stage, a myriad of distinguishable and creative ideas should be introduced for promoting the WEF nexus approach in policy making and implementation. Future scenarios include policy implementation measures for providing solid foundations for nexus policies, diverse incentives for attracting investors, and relevant institutional settings.

At the third stage, investment for the WEF nexus should be promoted. Investment strategies are proposed for countries or regions, and the most efficient strategies for the nexus approach are geared towards the benefits of the people living in a country or region and should accommodate their opinions and perspectives.

Fourth, the entire systems for water, energy and food need to be transformed for the nexus approach. Major stakeholders are given the mandate to implement the strategies that have been proposed. One of the prerequisites for the successful implementation of relevant policies will be clear institutional instruments and frameworks. In addition, the process of policy implementation should be transparent so that stakeholders can double-check the soundness of progress and give feedback on the whole process. It is necessary to have the process of double-checking and giving feedback for an adequate level of risk management and effective implementation of policies
(Bizikova *et al.*, 2014; Kim *et al.*, 2016).

An adequate regime of water, energy, and food pricing should be imperative for resource use efficiency under the transformation of sectoral policies into nexus-based policies. For example, pervert subsidies that have distorted the level of prices for water and food have to be removed, which have been created and kept in status quo due to political considerations. An introduction of carbon taxes can be an option to be considered as well for the two sectors. Also, the government can rectify the market failure in the water and energy sectors through the introduction of integrated management of water and energy resources and create a new regime of property ownership for water and energy (Kim *et al.*, 2016; UNESCAP, 2013).

05
Conclusion

The study has examined the concept and definition of the WEF Nexus with reference to several case studies, including Saudi Arabia, Ethiopia, USA, and South Korea. In-depth analyses have been made in order to explore how to introduce nexus friendly policies, programs and project by having a closer look at enabling environments, roles of government, and various steps to reach the stage where plausible conditions for nexus policies are available. Whereas an equilibrium between water, energy, and food security is necessary, guaranteeing water security is a basic foundation for the nexus-related policies and projects to be established and implemented as discussed in the case studies.

Numerous research institutes and national government agencies seem to have been busy promoting the significance of the WEF nexus approach for enhancing resource use efficiency, achieving sustainable resource consumption and saving limited amounts of invaluable resources in the world. Nevertheless, as the study has indicated, a plethora of research papers and reports only focuses on a 'possible' application of the nexus approach to policy making and implementation in practice. As potential is much explored, tangible outcomes are not necessarily visible related to the nexus approach. The case studies of Saudi Arabia, Ethiopia, USA and South Korea sketch large potential of how this approach can be developed at least on a small scale but it would be plausible to argue that the nexus approach is critical in achieving the SDGs by 2030.

An array of institutional and political barriers needs to be dismantled for giving more impetus on the viability of the WEF nexus approach for policy making and implementation. Silo-based approaches should be de-emphasized and integrated approaches are advocated for reflecting uniqueness of each sector and seeking for best options that accommodate a variety of benefits and challenges from the water, energy, and food sectors.

> *"Silo-based approaches should be demolished and integrated approaches are advocated with the best options that accommodate benefits and challenges from the water, energy, and food sectors."*

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Notes

1. The Gulf Cooperation Council (GCC) states are Bahrain, Kuwait, Oman, Saudi Arabia and the United Arab Emirates.
2. Brackish desalination plants filter salty water not from ocean but from a river, bay or underground aquifer for drinking water, and this option is often regarded as energy efficient and ocean life friendly (Rogers, 2018).