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A review of the current state of research on the water, energy, and food nexus

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ABSTRACT

Study region: Asia, Europe, Oceania, North America, South America, Middle East and Africa.
Study focus: The purpose of this paper is to review and analyze the water, energy, and food nexus and regions of study, nexus keywords and stakeholders in order to understand the current state of nexus research.
New hydrological insights: Through selected 37 projects, four types of nexus research were identified including water–food, water–energy–food, water–energy, and climate related. Among them, six projects (16%) had a close linkage with water–food, 11 (30%) with water–energy–food, 12 (32%) with water–energy, and eight (22%) with climate. The regions were divided into Asia, Europe, Oceania, North America, South America, Middle East and Africa. North America and Oceania had a tendency to focus on a specific nexus type, water–energy (46%) and climate (43%), while Africa had less focus on water–energy (7%). Regarding keywords, out of 37 nexus projects, 16 projects listed keywords in their articles. There were 84 keywords in total, which were categorized by the author team depending on its relevance to water, food, energy, climate, and combination of water–food–energy–climate, and 40 out of 84 keywords were linked with water and only 4 were linked with climate. As for stakeholders, 77 out of 137 organizations were related to research and only two organizations had a role in media.

1. Background and purpose

The idea of the water–energy–food nexus was launched in earnest since at least the Bonn 2011 Nexus Conference, when the German Federal Government organized the international conference "The Water Energy and Food Security Nexus—Solutions for the Green Economy" to contribute to the United Nations Conference on Sustainable Development (Rio + 20). According to the background paper prepared by Hoff for the conference, the concept of the water–energy–food nexus emerged in the international community in response to climate change and social changes including population growth, globalization, economic growth, and urbanization (Hoff, 2011). These issues are causing increased pressure on

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water, energy and food resources, presenting communities with an increasing number of trade offs and potential conflicts among these resources which have complex interactions. For example, demands for water, energy and food are estimated to increase by 40%, 50% and 35% respectively by 2030 (US NIC (United States National Intelligence Council), 2012). Although various nexus-related conferences, research initiatives and projects have been held around the world under such circumstances, water–energy–food nexus policy has not yet been initiated in Japan.

We initiated the RIHN water–energy–food nexus project in 2013 with study sites in Japan, Canada, the U.S., Indonesia, and the Philippines. The purpose of the project is to maximize human-environmental security (minimize risk) in the Asia–Pacific region by choosing policies and management structures that optimize water–energy–food connections, including both water–energy (water for energy and energy for water) and water–food (water for food) connections including tighter cooperation with the water, energy and food sectors. We will take a regional perspective to tackle these global environmental problems around the Pacific Ocean (Taniguchi et al., 2013).

Under the RIHN nexus project, this paper attempts to understand the current status of research on the water–energy–food nexus, with the hypothesis that to date the research in this area has been somewhat fragmented. Although there were more than 53,000 hits recorded during a Google search of the phrase 'water–energy–food nexus' (as of June 2014), there is no clear definition of the term 'nexus'. Unlike biodiversity conservation or climate change research and policies led by specific United Nations Conventions, the nexus has yet to be officially facilitated, implemented, and acknowledged in a uniform way. In addition, the relationships of all three resources such as water–energy, water–food and/or water–energy–food are interrelated and interdependent, which implies that the complexity of the nexus system has not yet been clarified. Furthermore, there seems to be very few reviews on the nexus, as the concept consists of multiple disciplines, as well as interdisciplinary and transdisciplinary research results.

We narrowed the search by keeping only the research items containing: (1) the kind of nexus being conducted such as water–food nexus, water–energy nexus, or water–energy–food nexus; (2) what part of the world nexus projects were being conducted; (3) what kinds of nexus activities have been conducted; (4) who is leading the nexus projects; (5) who is involved in the nexus projects; (6) who funded the nexus projects and the budget size; (7) the purposes of the various nexus projects; (8) methodologies used for the nexus study; (9) outcomes of the projects; and (10) the project's launching year and period of study. Moreover, we examined the challenges and the outlook of future nexus studies.

2. Methodology

We took a quantitative approach using secondary data included in publically available academic publications in journals and on the web for: (1) selecting the target nexus projects; (2) reviewing the documents of the selected projects historically, including a timeline of nexus activities, nexus concepts, and the position of the nexus project in global environmental research; (3) and conducting quadrat analysis from the perspective of the type of nexus (water–food nexus, water–energy nexus, water–energy–food nexus, and climate related nexus), nexus region and type, nexus keywords, and stakeholders. Although there is no clear definition of the term nexus so far as mentioned above, nexus is internationally interpreted as a process to link ideas and actions of different stakeholders from different sectors for achieving sustainable development. In addition, based on the fact that the water–energy–food nexus was launched in earnest since at least the Bonn 2011 Nexus Conference, we selected projects ($n = 37$) on the condition that: (i) projects highlighted the interactions of water, energy, and food; (ii) different stakeholders from different sectors were involved in the process of the projects; (iii) projects with a close linkage to the Bonn 2011 Nexus Conference were introduced at the NEXUS Resource Platform (http://www.water-energy-food.org/en/calendar.html) to screen the data and to acquire more reliable data.

3. Research outcomes

3.1. Historical review and timeline of nexus activities

3.1.1. Timeline of nexus activities

Various nexus-related conferences, research initiatives and projects have been held around the world. In 1983, the United Nations University (UNU) launched a Food–Energy Nexus Programme to acknowledge the important interconnectedness between the issues of food and energy (Sachs and Silk, 1990). In the following year, the conference on "Food, Energy, and Ecosystems", was held in Brasilia, Brazil by UNU. In 1986, the Second International Symposium on "the Food–Energy Nexus and Ecosystems" was held in New Delhi, India, again by UNU. In terms of research, the western United States focused on the interlinkages between water and electricity in the mid-1980s, and in the 1990s, the term "nexus" was used by the World Bank to link water, food, and trade (MaCalla, 1997). In the mid to late 1990s to early 2000, India's water–energy–agriculture nexus was studied by Colombia Water Center of the Earth Institute at Colombia University, and then the electricity for water nexus was applied to Mexico by Scott, C.A. (Scott, 2011). The idea of the nexus further developed under the discussion of "virtual water" and "water footprints" (Allan, 2003). With increasing international discussions such as the Kyoto World Water Forum 2003, scholars and practitioners around the globe acknowledged the need to include energy as a pillar in the nexus (Hussey and Pittock, 2012). Finally the importance of the three nexus pillars of water, energy, and food was officially announced at the Bonn Nexus Conference in 2011 in order to contribute to the Rio plus 20, which highlighted the concept of the "green economy". Following Bonn Nexus, the Water, Energy, and Food Security NEXUS Resource Platform was established by the

German Federal Government. Since then, United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES) Dresden was established for the “integrated management of environmental resources: water, waste and soil” in 2012, “The Status of the Water–Food–Energy Nexus in Asia and the Pacific” was prepared by United Nations Economic and Social Commission for Asia and the Pacific (UN-ESCAP) in 2013, “The Innovative Accounting Framework for the Food–Energy–Water Nexus: Application of the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) approach to three case studies” was prepared by the Food and Agriculture Organization (FAO), and “The Water–Energy–Food Security Nexus: Towards a practical planning and decision-support framework for landscape investment and risk management” was reported by International Institute for Sustainable Development (IISD) in 2013.

3.1.2. Nexus concepts

It is likely that the concept of nexus could vary around the world depending on the short, middle and long term goals of the region and sector (Ringler et al., 2013). FAO (United Nations Food and Agriculture Organization) (2014) defined that “water–energy–food nexus has emerged as a useful concept to describe and address the complex and interrelated nature of our global resource systems, on which we depend to achieve different social, economic and environmental goals. It is about balancing different resource user goals and interests–while maintaining the integrity of ecosystems”. Allan (2003) points out that the nexus stresses to promote the cooperation with various sectors and provides the opportunity to open up the disciplinary divides.

With a focus on water, Allan also mentioned that the concept, potential, and controversies of the “water, food, and trade nexus” are more or less similar to that of “virtual water”. The term is a useful metaphor to describe the supply and demand trading dynamics of not only water itself but also water that is used for producing agricultural commodities. The concept is now valued and quantified into monetary forms by economists and politicians. On the other hand, Velazquez et al. (2011) argue that the concept of “virtual water” and “water footprint” contains different perspectives to analyze economic processes. The former focuses on the production side while the latter focuses on the consumption side. The author emphasizes that these differences are often neglected when they are applied in practice. Moreover, Ringler et al. (2013) highlight that the concept of nexus is linked with the concept of integrated water resource management (IWRM). However, while IWRM is water sector oriented and narrows the contact with other sectors, nexus is opened to more sectors that could facilitate collaboration with other sectors by encouraging resource use efficiency. Based on our review of the literature, “virtual water” deals with production, “water footprint” deals with consumption, “IWRM” deals with entire life cycle of water, and “nexus” deals with life cycle of water and other related processes including energy, land and food.

Overall, there is no fixed concept of nexus, and the nexus is internationally interpreted as a process to link ideas and actions of different stakeholders under different sectors and levels for achieving sustainable development.

3.1.3. Position of nexus in a global environmental research

Since the first Global Change Open Science Conference in 2001, international global environmental research has been promoted through the Earth System Science Partnership (ESSP) based on four programs on global environmental change including (1) the International Geosphere–Biosphere Programme (IGBP), (2) the International Human Dimension Programme on Global Environmental Change (IHDP), (3) the International Programme on Biodiversity Science (DIVERSITAS), (4) the World Climate Research Programme (WCRP) (EESP (Earth System Science Partnership), 2015). In 2013, Future Earth was initiated as the global research platform supported by the Science and Technology Alliance for Global Sustainability comprised of International Council for Science (ICSU), the International Social Science Council (ISSC), the Belmont Forum, Sustainable Development Solutions Network (SDSN), the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Environmental Programme (UNEP), UNU and World Meteorological Organization.

Future Earth promotes interdisciplinary research between different disciplines such as natural science, social science, engineering, humanities and law, including co-design and co-productions with stakeholders such as research, the science-policy interface, funders, governments, development organizations, business and industry, civil society and media, which encompasses the so-called transdisciplinary approach.

The Future Earth 2025 Vision (Future Earth, 2014) was published and three research themes, including Dynamic Planet, Global Development, and Transformations towards Sustainability, were categorized and eight key focal challenges were prioritized. The water–energy–food nexus is one of the challenges and the vision says “Deliver water, energy, and food for all, and manage the synergies and trade-offs among them, by understanding how these interactions are shaped by environmental, economic, social and political changes”. Under the framework of Future Earth, the international conference on “Sustainability in the Water–Energy–Food Nexus. Synergies and Tradeoffs: Governance and Tools at various Scales” was held in 2014 in Bonn, Germany.

3.2. Analyzing the current state of research on the nexus

3.2.1. Nexus type

Through selected projects ($n = 37$), four types of nexus research were identified: water–food ($n = 6$), water–energy ($n = 12$), water–energy–food ($n = 11$), and climate related ($n = 8$). Using an ordinal scale, the number of water–energy projects was the

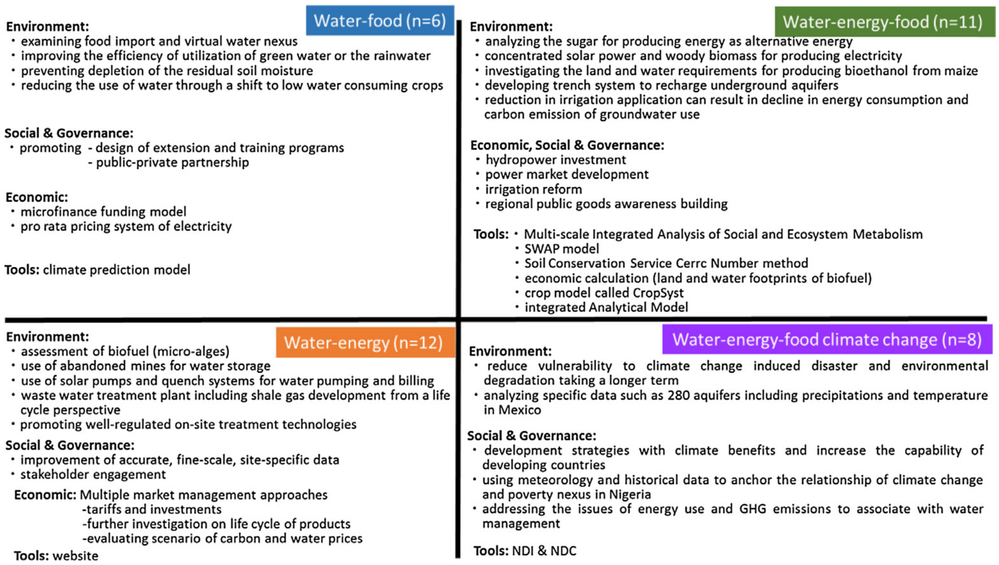

Fig. 1. Types of nexus.

highest, contributing 32%, followed by water–energy–food accounting for 30%, climate related with 22%, and water–food with 16% (Fig. 1). Details of the nexus types are described in the following section.

Water–food nexus. Regarding the water–food nexus, activities on reducing water consumption for producing food and increasing efficiency of water resources for producing food were identified. Environmental activities of the water–food nexus included examining food imports and the virtual water nexus (Qadir et al., 2007), improving the efficiency of utilization of green water (the rainwater held in the soil profile), preventing depletion of residual soil moisture in the field after crop harvest by reducing the fallow period, and reducing the use of water through a shift to low water consuming crops (Kumar et al., 2012). Along with environmental activities, social, economic and governance approaches were observed such as promoting the design of extension and training programs by stakeholders (Akangbe et al., 2011), microfinance funding model (CWC, 2015a), public–private partnership (CWC, 2015b), pro rata pricing system of electricity in the farm sector (Kumar et al., 2012). Data intensive methods such as climate prediction models for agriculture (CWC, 2015c) were developed to combine other projects and activities.

Water–energy nexus. Projects on water–energy nexus ranged from energy for water to water for energy. Examples of consuming water for producing energy include hydropower generation and biofuel using water. Energy consumption examples included pumping water for food and treating wastewater using electricity. For example, agricultural irrigation in the Spanish water sector showed large growth in its energy requirement (Hardy et al., 2012).

An assessment of bioenergy such as microalgae (Murphy and Allen, 2011), use of abandoned mines for water storage, and use of solar pumps and quench systems for water pumping and billing (CWC, 2015d) were identified as environmental activities. Multiple market management approaches including tariffs and investments (Malik, 2002), investigation on waste water treatment plant including shale gas development from a life cycle perspective (Mo and Zhang, 2013), promoting well-regulated on-site treatment technologies (Rahm et al., 2013), evaluating scenarios of carbon and water prices (Ackerman and Fisher, 2013) were also identified. From a social and governance perspective, projects were developed to improve accurate, fine-scale, site-specific data (Stillwell et al., 2011) for quantitative assessment of the water–energy nexus and stakeholder engagement (CWC, 2015e). Information dissemination through websites is another method for the enhancement of the water–energy nexus (Energy Saving Trust, 2014).

Water-energy-food nexus. Activities of the water–energy–food nexus were promoted through integrated water resource management (IWRM) (Bogardi et al., 2012). Several activities relating to biofuel were also found including analyzing sugar for producing alternative energy in Mauritius (LIPHE4, 2013a), concentrated solar power and woody biomass for producing electricity in South Africa (LIPHE4, 2013b), and investigating the land and water requirements for producing bioethanol from maize in China (Yang et al., 2009).

Regarding groundwater, a project to develop a trench system to recharge aquifers for agriculture production along with five micro dams was conducted in Ethiopia (CWC, 2015f), and in Iran, a project showed that reduction in irrigation application can result energy consumption and carbon emission decline of groundwater use (Karimi et al., 2012). Regional integrative management approaches on hydropower investment, power market development, irrigation reform, and regional public goods awareness building were studied in Central Asia from multiple perspectives (Granit et al., 2012).

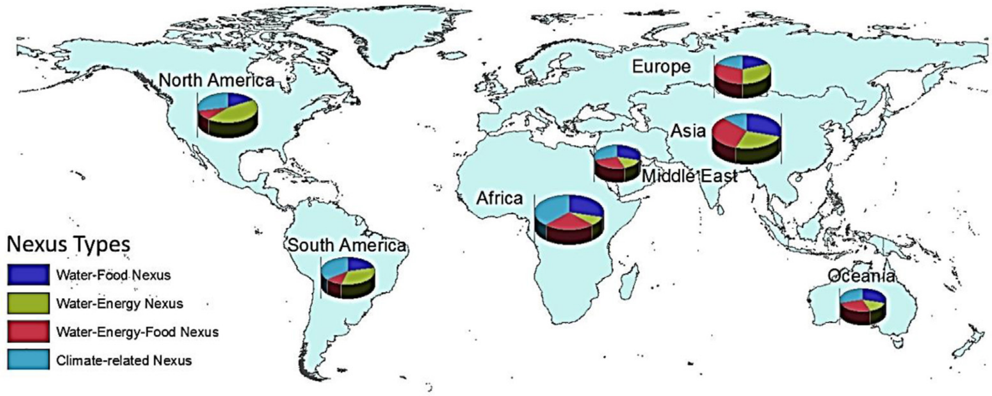

Fig. 2. A graphical presentation of nexus types in different regions.

It became clear that nexus projects can utilize tools such as the Multi-scale Integrated Analysis of Social and Ecosystem Metabolism (MuSIASEM), SWAP models (Karimi et al., 2012), the Soil Conservation Service Curve Number method (CWC, 2015g) and other economic calculations (Mustaq et al., 2009) including land and water footprints of biofuel (Yang et al., 2009), a crop model called CropSyst (Marta et al., 2011) and the Integrated Analytical Model (Bazilian et al., 2011; Hoff 2011; WEF (World Economic Forum), 2011).

Climate related nexus. Many climate related nexus activities were conducted to reduce vulnerability to climate change induced disaster and environmental degradation in the long term. Davidson et al. (2003) notes that development strategies with climate benefits and capacity improvements in developing countries should be focused on poverty alleviation and economic development.

Multiple approaches were used for climate related nexus projects including analyzing specific data such as 280 aquifers including precipitation and temperature in Mexico (Scott, 2011), using meteorology and historical data to anchor the relationship of the climate change and poverty nexus in Nigeria (Agbola, 2011), addressing the issues of energy use and GHG emissions in water management (Rothausen and Conway, 2011), developing two risk metrics including Normalized Deficit Index (NDI) and Normalized Deficit Cumulated (NDC) as a method to estimate potential water risk (CWC (Columbia Water Center), 2013).

The climate related nexus was also explored in urban areas. A system dynamics tool was applied in Australia to address with the Australian National Electricity Market's severe water shortage in 2007 (Newell et al., 2011). Hybrid energy such as methane and hydrogen-based energy is developed to produce additional energy in urban areas (Novotny, 2013). In Africa, transformation of the urban governance system was facilitated to improve urban resilience and sustainability with human health (Smit and Parnell, 2012).

3.2.2. Nexus regions

In Fig. 2, we can observe how the different nexus projects are distributed in different regions. The regions were divided into Asia, Europe, Oceania, North America, South America, Middle East and Africa. In this classification, the Middle East is considered a region separate from Asia due to a significant number of on-going nexus projects. If a nexus project is implemented internationally, it was counted as a project that occurs in all regions. In this analysis, we observed that six projects were implemented internationally: two projects for water–food, one project each for water–energy and water–energy and food, and two for climate-related. North America and Oceania had a tendency to focus on a specific nexus type, water–energy (46%) and climate related (43%), while Africa had less focus on water–energy (7%). The other regions had relatively balanced interest in each nexus type (Fig. 2).

3.2.3. Nexus keywords

Out of 37 nexus projects, 16 projects listed keywords in their articles. There were 84 keywords in total and among them, 13 words were duplicated. Keywords were categorized by the author team depending on its relevance to water (e.g., water scarcity, groundwater), food (e.g., food security), energy (e.g., shale gas, electricity planning, on-site energy production), climate (e.g., climate change), combination of water–food (e.g., irrigation scheduling, water footprint, per capita arable land), combination of water–energy (e.g., waste water treatment, water transportation, seawater desalination), and combination of energy–food (e.g., agroforestry) or others (e.g., training needs, skill gap, policy, resilience). As shown in Fig. 3, the number of keywords linked with water was highest ($n = 40$) followed by energy related keywords ($n = 29$), and the lowest number was keywords linked with climate ($n = 4$).

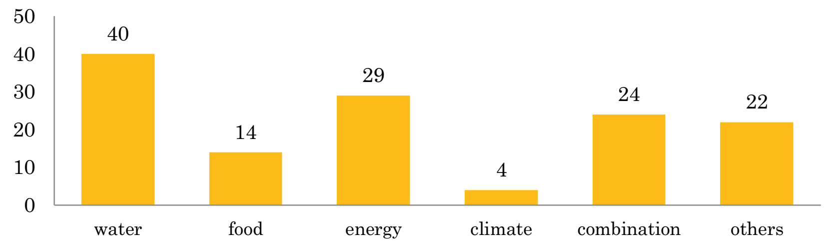

Fig. 3. Number of keywords in each nexus related category.

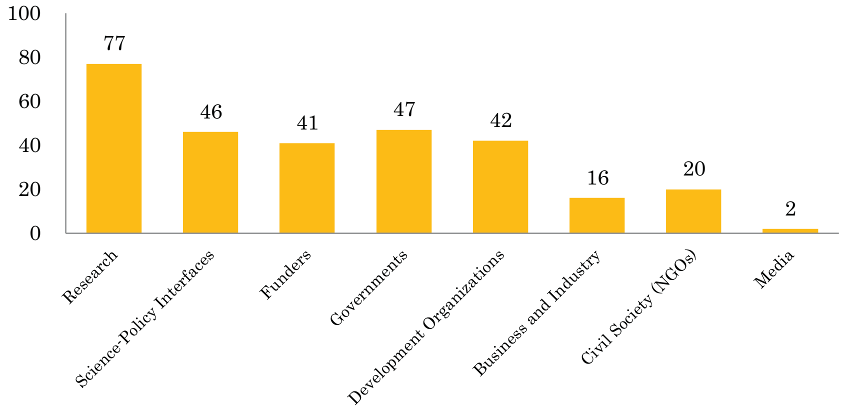

Fig. 4. Number of organizations in each stakeholder category.

3.2.4. Stakeholders

A wide variety of stakeholders were involved in nexus activities such as United Nation Agency ($n = 16$), international groups, institutes and NGOs ($n = 28$), private companies ($n = 7$), national governments and agencies, institutes and universities in Europe ($n = 19$), in North America and Latin America ($n = 28$), in Asia ($n = 28$), in Oceania ($n = 7$) and in Africa ($n = 4$). They were identified from the 37 projects as well as the NEXUS Resource Platform (out of 137 identified organizations, 43 organizations were identified from 37 projects) (Table 1).

As shown in Fig. 4, each organization was categorized by the author team according to the eight categories listed by Future Earth, namely research, science-policy interfaces, funders, governments, development organizations, business and industry, civil society (NGOs), and media (Future Earth, 2013). Some organizations had more than double roles among the eight categories (e.g., World Bank and FAO had roles in science-policy interfaces, funders, and development organizations). The stakeholders with the highest number were research ($n = 77$) followed by governments ($n = 47$); the lowest was media ($n = 2$).

4. Discussion

By reviewing nexus projects historically and analyzing them from the point of views of the nexus types, nexus regions and keywords, it became clear that diverse projects have been implemented by numerous stakeholders around the world. Budget size, the project's launching year and the period of the projects were not clearly identified due to limited information. The projects were conducted based on a different actor's interest, the four identified types of nexus were all related to water, and many of the selected keywords were linked with water (40 out of 84 keywords) mostly focusing on fresh water including river water, rain water, reservoir, groundwater, and seawater mainly relating to terrestrial activities for agriculture productions, and wastewater treatment. The number of water–energy nexus projects was highest among the 4 types including both consumption of energy for producing agricultural productions and for wastewater treatment, and consumption of water for producing energy such as hydropower. Many of water–energy–food nexus projects focused on biofuel production consuming food and water.

Explanations of the interrelationships are limited because one of the most significant characteristics of the nexus is the inextricable link between three essential resources. Another feature identified in each nexus type, social and governance activities for engaging and involving stakeholders who would be affected by the research results and/or policy decisions through the activities of capacity building and policy planning, was combined with environmental and economic research activities. Developing methods such as integrated indices, models and economic assessment methods to integrate interdisciplinary, multi-sectors, and multi-dimensional research results is essential to analyze and understand interrelationships and tradeoffs among these three resources.

Table 1
Identified nexus stakeholders.

Region	Name of the institutions
UN Agencies	United Nations General Assembly
	World Bank (WB)
	United Nations Development Programme (UNDP)
	United Nations Environment Programme (UNEP)
	United Nations Food and Agriculture Organization (FAO)
	United Nations Industrial Development Organization (UNIDO)
	United Nations Human Settlements Programme (UN-HABITAT)
	United Nations Educational, Scientific and Cultural Organization (UNESCO) International Hydrology Programme (UNESCO-IHP)
	United Nations University (UNU)
	United Nations World Water Assessment Programme (WWAP)
	UN-Water
	United Nations Economic and Social Commission for Asia and the Pacific (UN-ESCAP)
	World Meteorological Organization (WMO)
	Global Environment Facility (GEF)
	Intergovernmental Panel on Climate Change (IPCC)
	United Nations Convention to Combat Desertification (UNCCD)
International groups, institutes, & NGOs	World Resources Institute (WRI)
	Water Partnership Program (WPP)
	Global Water Partnership (GWP)
	International Association of Hydrogeologists (IAH)
	International Water Association (IWA)
	International Food Policy Research Institute (IFPRI)
	World Vegetable Center (AVRDC)
	International Association for Energy Economics (IAEE)
	International Renewable Energy Agency (IRENA)
	International Geosphere–Biosphere Programme (IGBP)
	World Federation of Engineering Organizations (WFEO)
	Organisation for Economic Co-operation and Development (OECD)
	World Business Council for Sustainable Development (WBCSD)
	World Economic Forum (WEF)
	International Finance Corporation (IFC)
	World Wide Fund For Nature (WWF)
	International Union for Conservation of Nature (IUCN)
	International Institute for Sustainable Development (IISD)
	Christian Aid
	World Vision
	ICLEI—Local Governments for Sustainability
	Ellen MacArthur Foundation
	International Renewable Energy Agency (IRENA)
	International Water Management Institute (IWMI)
	International Renewable Energy Agency (IRENA)
	Energy Foundation
	Dubai Initiative
	The Ceil and Michael E. Pulitzer Foundation
Private Company	McKinsey & Co.
	Philips
	Shell
	Nestlé
	The Guardian
	Pepsi
	VEOLIA Water

Europe	European Commission (EC)
	European Union (EU)
	European Investment Bank (EIB)
	Government of Germany
	Federal Ministry for Economic Cooperation and Development (BMZ), Germany
	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ), Germany
	University of Lüneberg, Germany
	Potsdam Institute for Climate Impact Research (PIK), Germany
	UK Environment Agency, UK Department for Environment, Food and Rural Affairs
	Natural Environment Research Council, The Royal Society, UK
	Imperial College London, UK
	Stockholm Environment Institute (SEI)
	Stockholm Resilience Institute (SRI)
	Stockholm International Water Institute (SIWI)
	Ministry of Foreign Affairs, Norway
	University of Life Sciences, Norway
	Erasmus University of Rotterdam, Netherlands
	Ente Cassa di Risparmio di Firenze Consorzio LAMMA—Laboratory of Monitoring and Environmental Modelling
	Ministry of the Environment, Estonia
North America & Latin America	U.S. Agency for International Development (USAID)
	U.S. Department of Agriculture
	U.S. Government Accountability Office
	U.S. Department of Energy
	U.S Environmental Protection Agency
	U.S. Air Force Air Force Research Laboratory
	U.S National Oceanic and Atmospheric Administration (NOAA)
	National Science Foundation
	U.S. Geological Survey
	National Hydropower Association, USA
	Great Lakes Commission, USA
	Texas State Energy Conservation Office
	Water Resources Research Center at the University of Arizona
	Arizona Water Institute
	Morris K. Udall and Stewart L. Udall Foundation
	Illinois Institute of Technology
	Argonne National Laboratory
	American Association for the Advancement of Science (AAAS)
	Columbia Water Center, Columbia University, USA
	School of Global Public Health, University of North Carolina, USA
	Harvard University
	Massachusetts Institute of Technology
	Universal Technology Corporation
	University of British Columbia (Canada)
	Canadian Hydropower Association
	Ministry of Science, Technology and Innovation, Brazil
	Under-Secretariat of Territorial Development and Decentralisation, El Salvador
	Inter-American Institute for Global Change Research (IAI)

Table 1 (*Continued*)

Region	Name of the institutions
Asia	Drinking Water & Sanitation Department (DWSD) of the Government of Jharkhand
	WASH Institute
	The Energy and Resources Institute (TERI)
	University of Engineering and Technology Lahore
	Government of Nepal
	Government of Korea
	Ministry of Water Resources, Government of India
	Royal Thai Government
	Office of the National Water and Flood Management Policy, Thailand
	Japan International Cooperation Agency (JICA)
	University of Tokyo, Japan
	Government of China
	China Scholarship Council
	National Basic Research Program of China
	Nonprofit Industry Research Special Fund of China
	National Natural Science Foundation of China
	State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering
	Chinese Academy of Sciences
	Liaoning Social Science Foundation of China
	Punjab Agricultural University (PAU)
	Committee of Geology and Subsoil Use, Kazakhstan
	Thailand Environment Institute (TEI)
	Universiti Teknologi, Malaysia
	Network of Asian River Basin Organizations
	Mekong River Commission (MRC)
	International Centre for Integrated Mountain Development (ICIMOD)
	Cities Development Initiative for Asia (CDIA)
	Asian Development Bank (ADB)
Oceania	University of South Australia (UniSA)
	Australian Centre for Sustainable Catchments
	University of Southern Queensland
	Australian National University
	Hilda John Water Endowment Fund
	University of Technology, Sydney
	Australian National Climate Change Adaptation Research Facility
Africa	Nairobi City Water and Sewerage Company, Kenya
	Water Research Commission (WRC), South Africa
	African Centre of Meteorological Applications for Development (ACMAD)
	African Union (AU)

By observing the identified stakeholders, it also became clear that the nexus is likely to be recognized at the research level (77 out of 137 organizations) but are not fully acknowledged on the ground (out of 137 organizations, only 16 were from business and industry and only 20 were from civil society). There is also a need for more publicity (only two were from media) to make sure that the nexus projects are facilitated by private sectors on the ground under the co-design and co-production concept of the Future Earth framework.

For further discussion, from a spatial scale perspective, there were local site-specific projects such as at the community level in Miiha (CWC, 2015h) and a country-level quantitative assessment of the water–energy nexus in the Middle East and North Africa (MENA) region (Siddiqi and Anadon, 2011). More precisely, the Miiha project was planned to scale up to other areas horizontally. On the other hand, from a vertical spatial perspective, the MuSIASEM project was conducted in Punjab, India using three district perspective such as the household, the interface Punjab/India, and the interface India/international market (LIPHE4, 2013c). In addition, a set of performance indicators was selected to characterize water and energy relationships at three management levels: basin, irrigation district, and farm (Soto-Garcia et al., 2013).

However, ways to connect local nexus issues within a community to broader national and global nexus issues and themes (the vertical dimension) were often missing from site-specific case studies. For example, we need to consider how the developed indicators to solve specific issues at the local level can be used in other areas or at the national, regional and global level. At the same time, it is important to understand how an event related to water–energy–food resources in one case study area would affect other case study areas (the horizontal dimension). Finally, we should also consider how current events are likely to impact future water–energy–food resources on a temporal scale (Endo et al., 2015).

5. Future directions for nexus research

After reviewing and analyzing the current status of research on the water–energy–food nexus, we found it essential to develop a unifying framework of nexus research to share solution-oriented common goals. This framework should be shared not only among projects members, but also among stakeholders in society, to develop integrated methods to integrate monodisciplinary research results and to understand the complexities of water–energy–food systems in order to contribute to reducing tradeoffs and increasing synergies of three resources uses. The framework can also be used within interdisciplinary and transdisciplinary approaches under the Future Earth framework, and to encourage local-to-global connected nexus systems.

Another opportunity for advancements in the RIHN nexus research would be developing more explicit linkages between terrestrial and marine systems since fisheries activities are quite essential for providing animal protein to the populace in Japan and other Asian countries. A primary challenge of the RIHN nexus project is to analyze the interlinkages between groundwater and fisheries production, regarding the hypothesis that the flow of nutrients from land to ocean affects the coastal ecosystem. This suggests that water use for producing and/or consuming food and/or energy on land might affect fisheries production in coastal areas. RIHN's focus on fisheries and marine related activity are unique among the international nexus projects (RIHN (Research Institute for Humanity and Nature), 2015).

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