Chapter 20
An Interdisciplinary Approach for Water–Energy–Food Nexus

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Abstract This chapter summarizes the activities of the interdisciplinary study group under the RIHN Nexus project. The mission of the group was (1) to review the WEF Nexus studies as a means to understand the current state of research on the WEF, (2) to develop integrated methods to address nexus issues, and (3) to design and visualize a WEF nexus system map to understand the complexity of the WEF Nexus system. The future challenges of the interdisciplinary group are (a) to develop the concept of integration in order to understand the concept of WEF nexus, (b) to integrate each method for adopting inter- and transdisciplinary research approaches to address nexus issues, (c) to approach not only disciplines,

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but also sectors using integrated methods focusing on stakeholders to adopt a transdisciplinary approach.

Keywords Water-energy-food (WEF) Nexus · WEF Nexus methods · Interdisciplinary · Transdisciplinary · Qualitative · Quantitative · WEF Nexus system

20.1 Background to Inter- and transdisciplinary Studies of the RIHN Nexus Project

20.1.1 Primary Goals of the RIHN

The RIHN has three primary goals: (1) to promote environmental studies that elucidate the interaction between humanity and nature and critically examine the future potential of human culture, based on the accumulated body of RIHN research and the results of global environmental research in Japan and abroad; (2) to promote solution-oriented global environmental studies involving close collaborations with stakeholders, starting from the research community; and (3) to contribute to problem-solving by applying research results in support of, and participation in, on-site multi-stakeholder arrangements in society. To meet the goals of the institute, the RIHN Nexus project was initiated as a five-year project in 2013, and was requested to adopt interdisciplinary and transdisciplinary research approaches.

20.1.2 The Mission of the Interdisciplinary Study Group of the RIHN Nexus Project

Per the structure of the project explained in Chap. 1, the RIHN Nexus project was designed to fundamentally consist of five groups: (1) the water–energy nexus group, (2) the water–food nexus group, (3) the stakeholder analysis group, (4) the sociocultural group, and (5) the interdisciplinary study group. This chapter summarizes the activities of the interdisciplinary study group, consisting of experts in the fields of environmental economics, fisheries economics, computer science, water engineering and modeling, and policy studies.

The mission of the interdisciplinary study group was (1) to review the WEF Nexus studies as a means to understand the current state of research on the WEF, (2) to develop integrated methods to address nexus issues, and (3) to design and visualize a WEF nexus system map to understand the complexity of the WEF Nexus system. Interdisciplinary approaches integrate separate disciplinary data, methods, tools, concepts, and theories to create a holistic, systemic view of a complex issue (Keskinen 2010). Thus, we determined to focus on and develop methods to adopt an interdisciplinary approach following this definition of interdisciplinarity.

This chapter describes two peer-reviewed scientific articles in Sects. 20.2 (Endo et al. 2015) and 3 (Endo et al. 2017), and the results of ongoing research in Sect. 20.3.

20.2 Current State of Research on the WEF Nexus

20.2.1 Purposes and Methods

We reviewed 37 nexus case studies to understand the current state of clarification regarding the following: (1) the types of nexus being conducted, such as water–food nexus, water–energy nexus, or water–energy–food nexus; (2) the part of the world in which nexus projects have been conducted; (3) the types of nexus activity that 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) the methodologies used for nexus studies; (9) the project outcomes; and (10) the project's launching year and period of study. We also examined the challenges and outlook for future nexus studies.

We adopted a quantitative approach using secondary data included in publicly available academic publications in journals and on the web in order to: (1) select the target nexus projects; (2) review 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; and (3) conduct quadrat analysis from the perspective of nexus type (water–food nexus, water–energy nexus, water–energy–food nexus, and climate-related nexus), nexus region and type, nexus keywords, and stakeholders.

20.2.2 Results of the Review

The review demonstrated that a diverse range of water–energy–food nexus studies and projects have been conducted, based on a variety of actors' interests at different scales worldwide since the first appearance of nexus terminology in 1983, when the United Nations University (UNU) launched a Food–Energy Nexus Programme to acknowledge the important interconnectedness between the issues of food and energy.

20.2.3 Nexus Type

Among the four types of nexus project identified, the number of water–energy nexus projects was highest, including both consumption of energy for agricultural production and wastewater treatment, and consumption of water to produce energy such as hydropower. Many of the water–energy–food nexus projects focused on biofuel production consuming food and water. Another feature identified in each nexus type, i.e., social and governance activities to engage and involve the stakeholders 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.

20.2.4 Nexus Regions

The regions were divided into Asia, Europe, Oceania, North America, South America, the Middle East, and Africa. We found that North America had a tendency to focus on the water–energy and climate-related nexus types, while Africa mainly focused on climate-related types. The other regions had a relatively balanced interest in each nexus type.

20.2.5 Nexus Keywords

Eighty-four keywords were identified in 37 nexus projects, including the four identified nexus types of water–food (n = 6), water–energy (n = 12), water–energy–food (n = 11), and climate-related (n = 8). The 37 projects were all related to water, and many of the selected keywords (40 out of 84) were also linked with water, mostly focusing on fresh water including river water, rain water, reservoir, groundwater, and seawater and mainly related to terrestrial activities for agriculture production and wastewater treatment.

20.2.6 Nexus Stakeholders

A wide variety of stakeholders were involved in nexus activities such as the United Nations 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). We re-categorized the 137 organizations into 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). The stakeholders with the highest number were research (n = 77) followed by governments (n = 47); the lowest was media (n = 2).

20.2.7 Challenges of WEF Nexus Research

We next identified the challenges of nexus studies, namely: (1) understanding the interrelationships between resources and the subsequent complexity of nexus systems is limited, especially since projects involve the linkage of two resources, e.g., water–food or water–energy; (2) the nexus is likely to be recognized at the research level, but is not fully acknowledged on the ground; (3) the ways to connect local nexus issues within a community to broader national and global environmental issues and themes were often missing from site-specific case studies; (4) the differences and/or changes in tradeoff relationships between different spatial and/or temporal scales were poorly analyzed; (5) the definition of synergy effects in nexus case studies remains unclear; and (6) the academic concept of “WEF nexus” has not been clearly defined due to the above five reasons.

20.3 Methods of the Water–Energy–Food Nexus

The second mission of the interdisciplinary study group was to develop WEF Nexus methods to reduce the tradeoff relationships and produce synergistic effects. We determined the methods, developed existing methods, and/or created new discipline-free methods, based on synthesizing and harmonizing team-based production, collected from individual scientists in different disciplines from each group for interdisciplinary research approaches. We also faced the further challenge of developing these approaches to incorporate non-scientific/non-disciplinary views in the analysis for the transdisciplinary research approach.

We then classified the integrated methods as qualitative or quantitative to contribute to both interdisciplinary and transdisciplinary research studies. The methods for interdisciplinary research can be used to unify a collection of related variables, visualize the research problem, evaluate the issue, and simulate the system of interest. The qualitative methods that we analyzed consisted of questionnaire surveys, ontology engineering (Kumazawa et al. 2017), and integrated mapping. The quantitative methods included physical models, benefit-cost analysis (Burnett et al. 2017, Wada et al. 2016), integrated indices (Orencio et al. 2015), and optimization management models (Burnett et al. 2017).

20.3.1 Pros and Cons of each Method to Address Nexus Issues: Qualitative Methods

As a result of our analyses, we identified the pros and cons of each method along with accompanying case studies from research sites in Japan and the Philippines. Although the case studies are specific to the project research sites, we see these methods as applicable to other areas with appropriate calibration. All methods discussed here are transdisciplinary in that they begin by engaging stakeholders as a means to identify the appropriate research question. They are then used to design the scientific approach to collect appropriate data in order to parameterize and develop models. In turn, this allows researchers to answer the policy or management question of interest.

Regarding the three qualitative methods, we used questionnaire surveys in the case of Laguna de Bay to contribute to a nexus assessment that aimed to address the question of how the population's security is affected when various natural and social hazards disrupt the linkages among the three systems. The questionnaire survey was especially useful in incorporating the local people's general outlook on their level of economic, food, and livelihood security when various shifts occur in terms of the quality and quantity of the water–food nexus. Consequently, this provides the information necessary to make decisions and thus optimally manage local nexus resources. However, we must acknowledge that the quality of the survey instrument always affects the data resulting from this approach.

Ontology Engineering is one of the base technologies in semantic web technology, where the internet is used to create a knowledge base that computers can deal with directly by means of adding metadata (Mizoguchi 2005, 2012). An ontology consists of concepts and relationships that are used to describe the target world. It provides common terms, concepts, and semantics by which users can represent the contents with minimum ambiguity and interpersonal variation of expression. The construction of a well-designed ontology presents an explicit understanding of the system. We used Ontology Engineering in Obama City and Beppu City to display a conceptual map focusing on water. Ontology engineering could be used for (1) designing the project to build a list of common conceptual terms; the linkages of each term among stakeholders included researchers and practitioners, (2) assessing whether the policy/plan would cover all disciplines including natural sciences, social sciences and the humanities, and sectors such as WEF.

An integrated map is an overlay of various single maps, and can be used as a method to support the implementation of synthesized policies between land and sea. In contrast to sectoral management and monodisciplinary research approaches (which often focus on a single ecological system), an integrated map informs policies capable of restoring and maintaining the interdependence between land and sea. The creation of an integrated map brings many benefits. First, it can be used to incorporate individual research results into maps as integrated methods for an interdisciplinary research approach to enhance mutual understanding between members. Second, it can be used to unify the data, information, and knowledge on maps to visualize and disseminate the current status of environment and utilization in river basins and coasts to stakeholders. Third, an integrated map can facilitate the identification of key nexus issues, such as the impact that nutrient flows have on coastal ecosystems. Finally, integrated maps can be used as a transdisciplinary method, engaging stakeholders and policy-makers to discuss through an integrated map how to implement integrated management of land and coastal areas. An example of an integrated map is that created for Beppu Bay. It is possible to create a site-specific integrated map at the local level to visualize the current conditions of water, energy, and food resources, as well as resource users. However, it would be challenging to create an integrated map at the national or global levels. In addition, an integrated map shows a static condition, not future scenarios, which limits the map's ability to demonstrate inter-scale, inter-generational, and inter-area circumstances.

20.3.2 Pros and Cons of each Method to Address Nexus Issues: Quantitative Methods

While we presented the specific per-site results in several forms, the quantitative methods normalized these forms to allow for direct comparison with other results at different project locations in the Asia-Pacific region. This makes it possible to decide on optimal policies regarding the sustainable management of water, energy, and food, not only for project members, but also for stakeholders.

With regard to the integrated physical model, we calibrated the model using data from Obama City. The models (such as those that measure water balance), and hydrological parameters (such as water exchange between rivers and groundwater, and groundwater discharge into the ocean) are useful methods for hydrologists. Material transport (including the transport of nutrients from land to ocean by rivers and groundwater) is important for fisheries. Hydrology, fisheries, and geochemical and biochemical information can be applied to this integrated physical model in an interdisciplinary way.

Integrated physical models can simulate the balance between water, energy, and food production; therefore, simulations based on potential future scenarios can be useful for decision makers. However, the results of integrated model simulation without social and local knowledge may lead people to misconstrue the model's results if the numbers from simulations are unrealistic for political, economic, or other reasons.

Benefit-cost analysis (BCA) entails using benefit-cost models (BCMs), which assess the desirability of a proposed policy or project, either independently or ranked according to highest net benefit if selecting from a range of alternatives. BCMs can be used in the context of evaluating WEF nexus projects to clearly consider the trade-offs in a particular region where one or more of the WEF elements will be utilized. We developed a BCM to analyze the construction of a new dike between the Pacific Ocean and Otsuchi's coastline. The WEF Nexus is inherently about trade-offs. BCA enables researchers to provide decision-makers with information regarding the consequences of these trade-offs and to explicitly examine the net benefits of decisions in order to allocate scarce resources (such as water) toward food or energy. In addition, to improve understanding of the trade-offs, BCA makes the costs and benefits accrued over individual time periods transparent.

The optimization management model provides one possible method with which to examine optimal resource allocation. We used the Optimization Management

Model to study the groundwater allocation problem in Obama City. The model allows researchers to explicitly represent the interaction of natural resources, which is key to understanding the trade-offs inherent in the WEF nexus. Decisions to draw down one resource often affect other resources, as well as the social welfare of the community of interest. For example, the decision to use groundwater for fisheries rather than agriculture depends on the production costs of both fish and agriculture, including energy. Economic optimization allows the researcher to determine how to allocate scarce resources over time, when doing so has consequences for the surrounding ecosystem and society.

20.3.3 WEF Nexus Methods for the Transdisciplinary Approach

To adopt the approach of co-design and co-production through the project process, each method should be developed as a science-policy interface method, despite each method having different uses at various stages. Ontology Engineering would be the most useful method for project design during the initiation stage to build a list of common concepts and terms; the linkages between terms among stakeholders included researchers and practitioners. In addition, Ontology Engineering could be used at the policy planning stage to assess whether the policy/plan would cover all disciplines, including natural sciences, social sciences, and humanities, and sectors such as water, energy, and food (in order to address the key issues that were originally identified during the initiation stage). Questionnaire Surveys would be more useful for collecting information to analyze WEF interlinkages when little data exist; their use would then help to identify the key issues during the initiation stage. Integrated Maps can provide an opportunity to share knowledge showing actual conditions at a spatial scale among stakeholders during the policy planning stage. BCA and an Optimization Management Model would play important roles in clarifying trade-offs during the initiation stage, creating and providing policy options during the policy planning stage. Physical models could be quite essential to understand WEF nexus systems; if it were developed to clarify interlinkages between the physical conditions of water, energy, and food, as well as human activities by working with social scientists, then it could be used to address the key issues more holistically during the policy planning stage. Using an Integrated Index can be a discipline-free method that incorporates and integrates each result with different disciplines, then evaluates trade-offs during the policy planning stage. Simultaneously, interdisciplinary team members could themselves act as interpreters or coordinators for the science-policy interface, using those approaches when they have a commitment to both science and society from the initiating stage.

20.3.4 Challenges of WEF Nexus Methods

From the perspective of spatial and temporal scales, despite covering spatial, physical, and economic dimensions, our approach is somewhat limited in terms of vertical and horizontal elements, as well as on a temporal scale to address the WEF nexus. To address these challenges, it is possible to use global data such as a global model to set our site-specific case studies within a global context on a vertical spatial scale (Guillaume et al. 2015). In addition, the creation of future scenarios that further integrate each integrated method mentioned in this paper remains a challenge; however, doing so will allow the WEF nexus to be analyzed based on a temporal scale (Keskinen et al. 2015). To address the issue of temporal scale, we determined if we could use each method to address the nexus problems during the initial stage, developing stage, and policy planning stage to design future scenarios.

20.4 Design and Visualization of the Water–Energy–Food Nexus System

After reviewing the current condition of nexus research, developing nexus methods to address nexus issues, and identifying the challenges of nexus research and methods, we determined to design and visualize the WEF Nexus system to identify the interrelationships between WEF resources and to understand the subsequent complexity of WEF nexus systems systemically, adopting an interdisciplinary approach.

Object-oriented concepts and ontology engineering methods were applied according to the hypothesis that the chains of changes in linkages between water, energy, and food resources holistically affect the water–energy–food nexus system, including natural and social systems, both temporally and spatially. The water–energy–food nexus system that is developed is significant because it allows us to: (1) visualize linkages between water, energy, and food resources in social and natural systems; (2) identify tradeoffs between these resources; (3) find a way of using resources efficiently or enhancing the synergy between the utilization of different resources; and (4) aid scenario planning using economic tools.

20.4.1 Challenges of Designing a WEF Nexus System

The challenges of designing and visualizing a WEF nexus system include clarifying the linkages between events, identifying: (1) how changes in linkages between water, energy, and food resources affect the WEF nexus system holistically and systemically; (2) what the driving force is; and (3) whether there are hidden or unexpected factors that would impact the WEF nexus system. The second challenge is to identify the tradeoffs between resources, for example, tradeoffs in the use of land resources between energy and food production. The third challenge is to find a way of using resources efficiently or enhancing the synergy between the utilization of different resources, for example, to streamline, recycle, or cascade resources and/or to add higher value to resources. Finally, a fourth challenge is to contribute to scenario planning.

Forecasting scenario planning includes four steps, namely: (1) problem setting; (2) constructing causal networks to represent the targeted system; (3) describing scenario storylines; and (4) describing details, including parameterization and quantification. On the other hand, backcasting scenario planning consists of six steps: (1) determining the purpose of scenario building; (2) specifying goals, constraints, and targets; (3) describing the present system; (4) specifying exogenous valuables; (5) undertaking scenario analysis, including developing scenarios; and (6) undertaking impact analysis, including comparison of scenario results with predetermined goals (Robinson 1990). Both scenarios require designing the target system in the course of scenario planning.

20.5 Future Challenges

We reviewed 37 nexus projects based on academic papers and identified the current situation and challenges of nexus studies. In addition, to address nexus issues, we identified and determined the integrated methods, when and how we could use those methods, and the pros and cons of each. Furthermore, we are now developing a nexus system map.

The future challenges of the interdisciplinary group are (1) to develop the concept of integration in order to understand the concept of WEF nexus, (2) to integrate each method for adopting inter- and transdisciplinary research approaches to address nexus issues, (3) to approach not only disciplines, but also non-academic sectors using integrated methods focusing on stakeholders to adopt a transdisciplinary approach.

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