INTEGRATIVE APPROACH FOR RISK AND DISASTER REDUCTION: THE WATER-ENERGY-FOOD-DISASTER-ECOSYSTEM NEXUS

ABORDAGEM INTEGRATIVA PARA REDUÇÃO DE RISCOS E DESASTRES: O NEXO ÁGUA-ENERGIA-ALIMENTO-DESASTRE-ECOSSISTEMA

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Introduction

Amid this Coronavirus (COVID-19) pandemic, people worldwide have seen that health is essential for well-being. In other words, well-being cannot be acquired without good health and happiness. By reading the Constitution of the World Health Organization (WHO, 2020), we can understand what exactly health means:

> ... the following principles are basic to the happiness, harmonious relations and security of all peoples:
> Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.
> The enjoyment of the highest attainable standard of health is one of the fundamental rights of every human being without distinction of race, religion, political belief, economic or social condition. (WHO, 2020)

In this passage, the point to note is "mental and social well-being." If an individual has anxiety or fear of the future, it cannot be said that they have mental and social well-being.

Today, individuals and the international community have been living with a great deal of anxiety about the present and future in many contexts (society,

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economy, and environment) and consequently are in a state far from well-being. Climate change impacts our confidence about the future, and fear of climate disasters (floods, droughts, hurricanes, etc.) can cause traumatic stress like ecoanxiety (CIANCONI; BETRO; JANIRI, 2020). In the most comprehensive United States (US) report to date, global climate change impacted socially vulnerable groups (those with low income, less formal education, minority ethnicities, and age over 65) disproportionally compared to the rest of the US population (EPA, 2021). This means that in the US and potentially worldwide, vulnerable groups shoulder unequal risk from climate change disasters including health impacts from air quality, extreme temperatures, and flooding, all of which reduce well-being and social resilience. Many organizations have been looking for solutions to reduce such anxieties and improve mental and social well-being. For example, the United Nations (UN, 2015) proposed 17 Sustainable Development Goals (SDGs), and the UN Office for Disaster Risk (UNISDR, 2015) established the Sendai Framework for Disaster Risk Reduction (DRR). The former refers to the sustainability of humankind, and the latter is aimed at disaster mitigation.

Comparing the Sendai Framework and 17 SDGs, UNISDR (2016) explained that the following targets within these SDGs have direct or indirect relations to DRR: 1.5, 2.4, 3.D, 4.A, 6.6., 9.1, 9.A, 11.5, 11.B, 13.1, 13.3, 14.2, and 15.3. UNISDR (2016) stated that all the actions to achieve the SDGs would also support the Sendai Framework. According to UNISDR (2015), the global targets of the Sendai Framework are to reduce four key impacts: (i) Mortality caused by disasters; (ii) the number of people affected; (iii) economic losses in relation to the world's Gross Domestic Product (GDP); and (iv) damage to critical infrastructure and interruption of basic services, and to increase three impacts: (v) the number of countries with national and local DRR strategies; (vi) international cooperation with developing countries; and (vii) availability of and access to early warning systems and information on DRR. With these seven targets, we will be able to achieve the principal goal of the Sendai Framework which is to reduce existing disaster risks and prevent new risks. In this Framework, the implementation of integrated and inclusive measures in the economic, structural, legal, social, health, cultural, educational, environmental, technological, political, and institutional spheres is recommended (Figure 1).

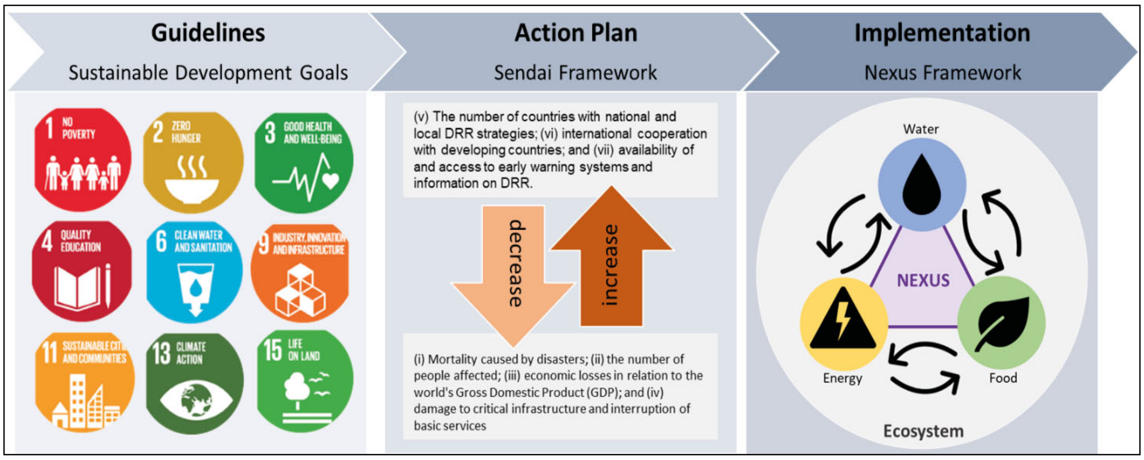
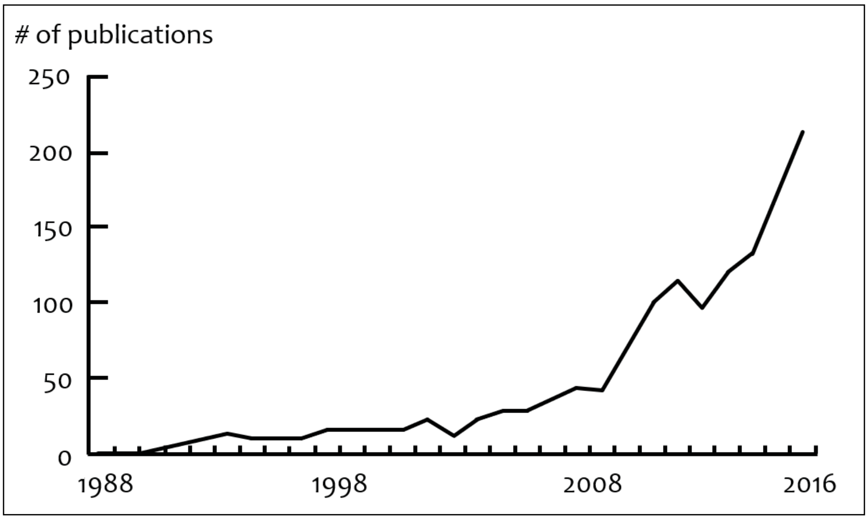


Figure 1. A conceptual process to incorporate disaster planning and guide Water, Energy, and Food (WEF) Nexus implementation.

The Water-Energy-Food (WEF), also referred to as the Food-Energy-Water System (FEWS) Nexus, is a relatively new field of study that has quickly accelerated over the past decade with support from international research initiatives and funding opportunities (Figure 2) (WHITE et al., 2017). The WEF framework started as an integrated approach to study global climate change risks, until recently, technical solutions have been the primary emphasis (NEWELL et al., 2019). In recent years, WEF studies have become much more complex providing decision-making frameworks that often incorporate aspects of sustainable development and social risks (KADDOURA; EL KHATIB, 2017). Integrating elements of the social and political context was necessary to support effective decision-making, it also increases the complexity of methods and tools to model these interconnected and embedded systems and to understand tradeoffs and synergies (ENDO et al., 2017).

The integration of holistic perspectives and approaches are vital for sustainability and DRR. This integration can be described in other words like connection, connectivity, holistic, and nexus. The objective of this chapter is to explore WEF nexus issues with an emphasis on DRR and propose the Water-Energy-Food-Disaster-Ecosystem (WEFDE) Nexus. Connecting the WEF Nexus to DRR is discussed from a historical and practical point of view. Furthermore, Nexus examples in Brazil and geography's important contribution to Nexus are discussed to further justify the need for a WEFDE Nexus.



Source: Newell; Goldstein; Foster (2019).

Figure 2. Number of academic publications using the Water-Energy-Food Nexus from 1988 to 2016.

Society´s thinking about natural and environmental systems

Though there are various ways to understand the history of mankind, it can be thought that at first only nature existed on the Earth. Human beings have now developed society by altering nature. In its development, societies have built civilizations across regions of the planet and created different cultures despite resource shortages. By establishing 17 SDGs (UN, 2015), the UN is calling for sustainable development around the world to pass on a better society to future generations.

Pre-Greece era

Among the ancient Greek philosophers, the term Arche (Ancient Greek: *ἀρχή*) represented the primitive element of all things. It is said that Anaximander (610-546 BC) first used this term. At that time, several Greek philosophers sought the answer to what could be this Arche. For Thales (624-546 BC), the Arche was water, for Anaximenes (588-524 BC) air, for Xenophanes (570-475 BC) earth, and for Heraclitus (500-450 BC) fire. These philosophers each thought a different element was the most important on earth. Instead of focusing on one element, Parmenides (530-460 BC) thought that Arche was a medium between fire and earth. His thought should be appreciated because he presented a nexus of two elements.

Further advancing this nexus thinking, Empedocles (495-430 BC) considered that four classical elements “fire,” “air”, “water”, and “earth” make up the entire structure of the world. For this philosopher, the mixture of these four elements explains the generation of various new elements and phenomena and their extinction when these four classical elements are not present. If fire is translated to energy, these elements can be considered essential for ecosystems, including modern human society. It is worth mentioning that these elements are also important for food production, and this discussion will be expanded on in the present work.

Modern era

Human beings have been afraid and also worshiped natural and environmental systems; however, it is no exaggeration to say that it was based on Rio 92 Earth Summit that the environment itself became emphasized at a global scale. Rio 92 was the 1992 United Nations Conference on Environment and Development (UNCED, Rio de Janeiro, Brazil, 3–14 June 1992) which launched Agenda 21. Agenda 21 is defined as a program of participatory actions for sustainable development worldwide and unites methods of environmental protection, social justice, and economic efficiency (UNCED, 1992). Environmental issues are now considered indispensable, and together with social and economic considerations, sustainable development becomes possible. Since 1992, the UN has continued to be instrumental in improving on what was started at Rio 92. In this context, it is worth noting that two other international conferences were held during this period: Rio +10, held in Johannesburg in 2002, and Rio +20, held in Rio de Janeiro in 2012. In these events, the advances made since Rio 92 were evaluated and gaps that still existed in agreements signed during Rio 92 were analyzed.

In 2015, Agenda 2030 was adopted with sustainable development goals that address WEF resource management, climate action, as well as health, well-being, and social equality. Notably, the first target of the climate action goal is:

> strengthening resilience and adaptive capacity to climate-related hazards and natural disasters in all countries (UN, 2015).

Although holistic frameworks have begun to incorporate explicit connections between WEF resource systems and social systems, the ties that hold this Nexus together with climate change impacts like disasters that cause WEF insecurity has not been well studied in this framework.

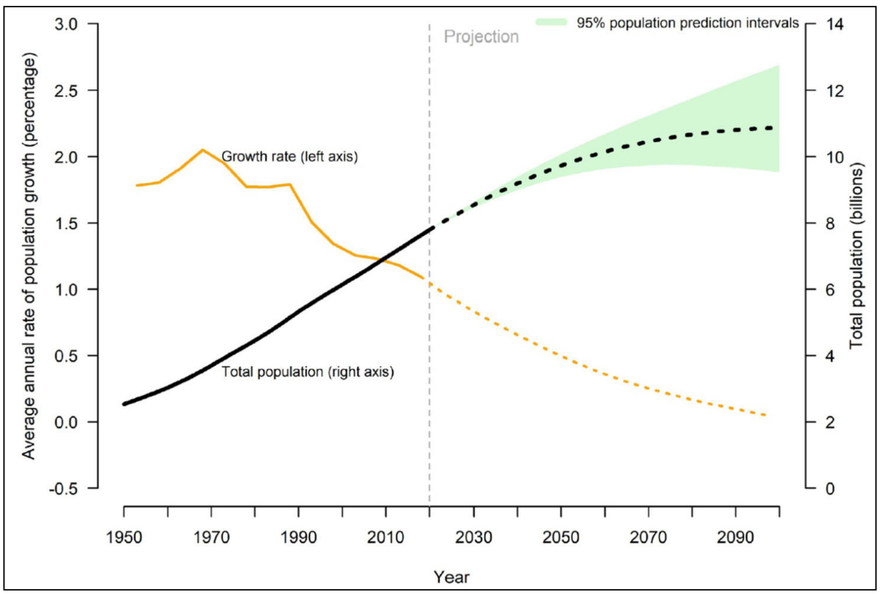
Important resource security for society

After recognizing the essential constituents of natural and the environmental systems, and understanding the relationships between human beings (or society) and the environment (nature), it becomes clear what elements are most important to human beings. As Biggs et al. (2015) and Smajgl, Ward and Pluschke (2016) assert, water, energy and food are essential, i.e., indispensable resources for all societies and human activities. In the following sections we explain how the security of each WEF resource is vital for human development and social well-being.

Water security

Gleick (1993) and Falkenmark and Rockström (2004) highlight that water availability has become more crucial to food security and human welfare under the increasing demographic pressure. Indeed, though the population growth rate is reducing, the world population is increasing and is estimated to reach 10 billion in 2100 (Figure 3).

The hydrological cycle, which naturally occurs all the time and everywhere, creates spatial and temporal variations of water resources (KOBIYAMA; MOTA; CORSEUIL, 2008). Such spatio-temporal variations generate excess and scarcity of water resources for society across regions. Water excess and scarcity are considered social, economic, and environmental problems. However, society normally uses the term "water crisis" when water scarcity occurs (GLEICK, 1993; RIJSBERMAN, 2006; BAKAS; PAPADIMITRIOU; ARGYRI, 2020). In other words, water scarcities and excesses help societies feel and recognize water crises. Here we consider qualitative or conceptual scarcity as a long and extreme shortage. In suffering from a long-term water crisis, society enacts laws to obtain water security, initiate collective actions, and manage water resources.For example, to guarantee water security worldwide across scales, UNESCO initiated the International Hydrological Programme (IHP) Phase-VIII (JIMENEZ-CISNEROS, 2015). The third thematic area of the IHP-VIII was "Addressing water scarcity and quality."



Source: United Nations, Department of Economic and Social Affairs, Population Division, 2019.

Figure 3. World demographic tendency to 2100.

Regarding health, people feel anxious when they start losing it, then they begin to seek security. Water issues can be similar to health. In brief, water scarcity makes society feel water crises, leading societies to seek water security. However, water security is related to human quality of life, which is strongly influenced also by water excess, i.e., flooding. Therefore, society should manage water resources to guarantee water security, especially during extreme hydrological events: drought and flood. Thus, water crises can include any water-related disasters (drought or flood) which are more severe than typical and usually more prolonged. Figure 4 outlines a scenario of how the hydrological cycle causes societies to implement actions to ensure water security.

According to IPCC (2022), the spatio-temporal patterns of rainfall distribution are getting more heterogeneous, intensifying water excess and scarcity in various regions and consequently enhancing the probability of flood and drought occurrences. Hence, water security will be a more serious consideration at the international level because of climate change.

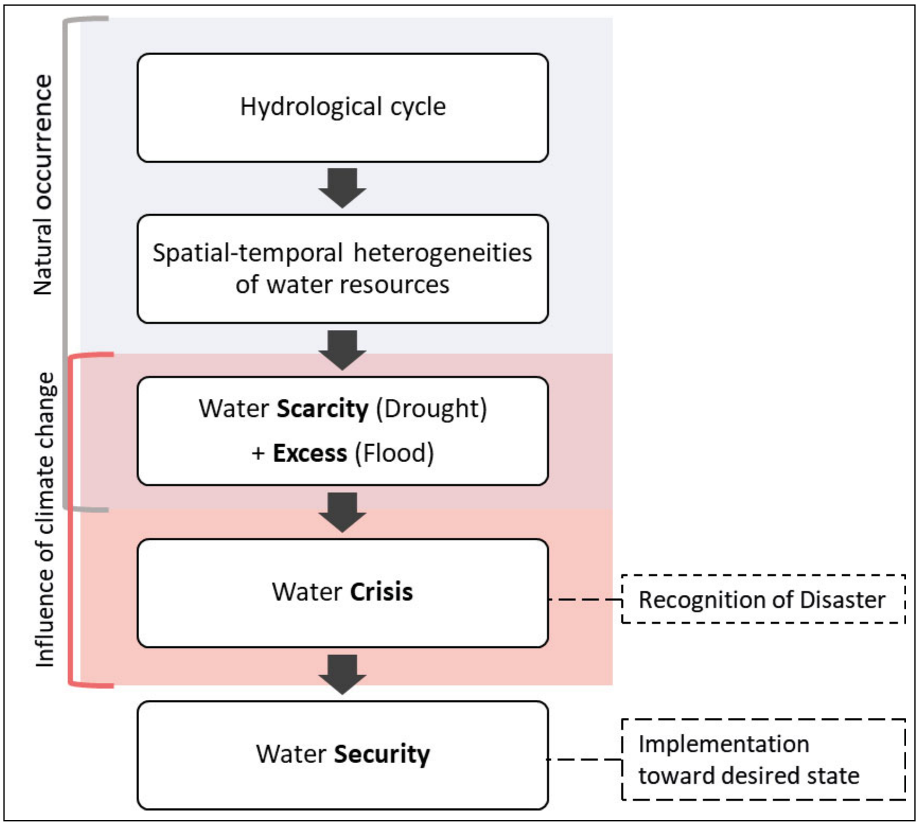


Figure 4. A water security implementation scenario.

Energy security

Electricity, gas, water, transportation, etc., which are indispensable for daily life, operate and function by directly using energy. All the products, such as agricultural products, food, clothes, etc., require significant indirect energy use from invisible production processes. It means that most human activities require energy for power production, transportation, heating, and cooling systems. Energy is physically described as the ability of a substance or system to do work. The energy can be roughly divided into mechanical energy, thermal, electric, nuclear, chemical energy, etc. These energy types can be converted into each other. Changing the form of energy in this way is called a conversion. Consumers normally use energy after conversion; for example, crude oil and uranium are converted into gasoline and electricity, respectively. Before conversion, energy is called “primary energy” (oil, coal, natural gas, nuclear power, hydraulic power, geothermal, etc.). The energy after conversion is called “secondary energy” (electricity, gasoline, city gas, etc.). The energy used by consumers is called “final energy”. The final energy may be used from the secondary energy, while the primary energy can sometimes be used directly by the final consumer.

Since 1950, the social transition to fossil fuel-based energy systems (coal, oil, gas) facilitated dramatic socio-economic changes, agricultural production, manufacturing, economic growth, urbanization, demographic growth, etc. (STEFFEN; CRUTZEN; McNEILl, 2007). In parallel, fossil fuel consumption has caused a significant impact on the Earth’s climate by increasing atmospheric CO_2 concentrations (PAGE, 2008). In the world today, energy consumption depends primarily on non-renewable (fossil fuel) sources (80%) and increases because of population and economic growth (about 2% per year). On the other hand, approximately 3 billion people do not have access to safe and reliable energy sources. D’Odorico et al. (2018) considered such energy issues as a legacy from the 20th century.

Renewable energies have recently been in the limelight to ensure energy security and support environmental and sustainability concerns. In a broad sense, renewable energies refer to all energies coming from the sun. These geophysical and biological resources are naturally replenished faster than normally used. Power generation is carried out by obtaining energy resources that are constantly (or repeatedly) replenished by natural forces such as solar power, wind power, wave power, tidal power, running water power, geothermal power, and biomass. With such renewable energies, CO_2 emissions are usually zero or low. Therefore, they certainly contribute to the diversification of energy sources. Renewable energies are environmentally friendly but generally inferior and disadvantageous to existing depleted energies in terms of cost and technology. Because of increasing energy demands and technological advances, new energy systems with shale oil, shale gas, or oil sands have been recently explored. However, Rosa et al. (2018) explain that such systems require much more water than their conventional counterparts. In addition, this type of energy source can affect not only water quantity but also quality. The extraction of oil from shale, besides using large amounts of water for its production, can contaminate surface water and underground aquifers due to leaks or incorrect disposal of effluents (VILLAR; SCHEIBE; HENNING, 2019).

According to Halder et al. (2015), energy supply is the pivotal obligation for the overall social development and quality of life improvement worldwide in this modern era. Population growth and technological development have increased local, regional, and global energy demands in many countries. Furthermore, UNDP (2000) emphasized that all human activities need energy. Therefore, the continuity of its supply is vital for socio-economic stability. From this perspective, energy security has two key aspects: reliability and supply security. The former refers to the ability of an energy system to avoid a sharp drop in energy supply to consumers; meanwhile, the latter refers to protection from events that require a reduction in energy supply over a long period of time (OLIVEIRA, 2010).

Common types of energy by country vary based on geographical conditions such as availability of natural resources, climate, topography, and economic conditions. Thus, energy scarcity, crisis, and security concerns differ among countries. However, overall, improving energy security requires similar conditions to improving water security, as shown in Figure 4. Sachs (2015) emphasized that the challenges within the world's energy system are more urgent and highly complex.

Food security

During the Rio+20 conference, the commitment of nations to improve food security and access to adequate, safe and nutritious food for present and future generations was reaffirmed (UN, 2012). Despite that, the global prevalence of moderate or severe food insecurity slowly increased between 2014 and 2019. The estimated increase in 2020 was the same as the total for the last five years. This indicates that the food insecurity is intensifying. Almost one in three people (2.37 billion) in the world did not have enough food in 2020. It increased by about 320 million in just one year (FAO et al., 2021). According to Peng and Berry (2019), food security is a very flexible concept, reflected by the many attempts to define it in research and policy. Though there are many definitions, the definition proposed by FAO (2001) is widely accepted:

> Food security [is] a situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. (FAO, 2001)

The case of food can be similar to that of water, i.e., food scarcity makes societies feel and recognize food crises, and they respond with a desire to guarantee food security. Thus, Figure 4 can be used as a food security scenario by only changing the word from water to food. To achieve food security, we first need to understand food systems. According to Ingram (2011), food systems include the various production, distribution, consumption activities that connect people to food and various social and environmental system outcomes. Therefore, the cultural, educational, and economic aspects of food consumption, agriculture, trade, food-related policies, and other institutional arrangements are factors forming the food system.

By showing that the food issues are closely related to environmental problems, raw materials problems, and poverty political and social problems, Goncharova and Merzlyakova (2021) emphasized that we should not try to solve the food problem in isolation but should solve it together with other problems facing humankind. D'Odorico et al. (2018) reported that climate change reduced food production in recent decades. In this case, food security should be treated together with climate change. It is worth remembering that D'Odorico et al. (2018) advocated for nutritious food to be at the center of food security instead of food in general. To guarantee the true health of human society, not only food quantity but also food quality (nutrition) must be considered. Food access is another important element of food security. Although food is vital to human well-being, WEF Nexus research has not effectively included important issues of access (allocation and affordability) that are essential to building well-being for all through social equity and justice (NEWELL; RAMASWAMI, 2020).

Water-Energy-Food Nexus

Though water security, energy security, and food security can be examined individually, it is more realistic to treat them simultaneously or to manage them in an integrated way because they are components of the Earth system. Thus, nexus thinking has become important to societies and scientific communities worldwide. The challenges of simultaneously managing these three resources are urgent and must meet multiple potentially conflicting objectives without compromising the resource base of any sector. Leck et al. (2015) defined the nexus as one or more connections linking two or more things. Hence the nexus might be considered an integration, connection, chain, continuum, and holistic approach. The essential consideration is that the systems are part of a whole. As Kahil et al. (2019) pointed out, many researchers believe that water scarcity has highlighted the importance of nexus thinking, shifting from maximizing individual production to overall efficiency across the sector. In this case, it can be said that the WEF Nexus has held a water-centric mindset. Although all three resources have the same weight in society, some nexus research still focuses on just one system (water, energy, or food). However, we think that it is unnecessary to center one resource system in the WEF Nexus.

Many researchers (e.g., ALBRECHT; CROOTOF; SCOTT, 2018; SIMPSON; JEWITT, 2019; PURWANTO et al., 2021) consider WEF (2011) and Hoff (2011) the principal forces in the development of WEF Nexus thinking worldwide. After these two articles, the water, energy, and food (WEF) Nexus has become a major academic, policy, and societal topic (PURWANTO et al., 2021). To explain how the nexus approach became popular globally, Bazilian et al. (2011) described the urgent necessity to maintain WEF security despite competition among components of these systems at all the levels, originating the use of WEF Nexus as a concept.

There are similarities between the WEF Nexus and the integrated water resources management (IWRM). The IWRM is defined by GWP (2000) as:

> A process which promotes the coordinated development and management of water, land and related resources, to maximize the resultant economic and social welfare equitably without compromising the sustainability of vital ecosystems. (GWP, 2000)

Thus, water is a starting point in the IWRM approach. On the other hand, the WEF nexus ideally looks at WEF as a whole system, which is a distinct purpose of the nexus approach.

The relationship between two resources is evaluated to simplify analyses; the first is the Water-Energy Nexus. With a hydropower plant construction, water can generate electric energy. Furthermore, water indirectly plays an important role in energy generation. D'Odorico et al. (2018) explained that nuclear power has the highest water consumption among thermoelectric technologies due to a necessity to cool the exhaust steam and control the temperature during the uranium fission process. Additionally, uranium mining and processing require substantial amounts of water. Biofuel production also requires large amounts of water. On the other hand, ensuring water security requires much more energy to treat water, wastewater, and saline water and transport and distribute them. IEA (2016) estimated that the global energy use in the water sector is projected to more than double during the period from 2014 to 2040, increasing more rapidly than water withdrawal. Hence, water and energy are strong determinant factors.

Second, the Water-Food Nexus incorporates food produced through plant and animal growth that depends on water availability. Thus, water availability is a determinant factor for food production (FALKENMARK; ROCKSTRÖM, 2006). On the other hand, food production influences the water system's quantity and quality. Since the major food-producing sector is agriculture, agriculture itself changes land use and consequently the hydrological cycle. According to WWAP (2003), agriculture is responsible, on average, for 70% of water withdrawals from springs in the world. In addition, agriculture is a major cause of water quality issues in the Water-Food Nexus, primarily due to the increased use and diffusion of nitrogen and phosphorus (MATEO-SAGASTA; ZADEH; TURRAL, 2017; SHEN et al., 2020).

Third, in the Energy-Food Nexus Ingram (2011) described that energy is used for various food-system activities such as machinery operation, packaging, transporting, cooling, and food processing. Biofuel production (e.g., sugar cane) is one of the most prominent examples of the link between energy and the food market (D'ODORICO et al., 2018). In this case, it raises concerns about diverting resources from one product (food) to the production of another (biofuel). In addition, there can be disputes over land use for food and energy production.

Pulling together the three systems, D'Odorico et al. (2018) reported that competition in water use for energy and food security is the core of an emerging debate about the WEF Nexus. The recent reviews on the WEF Nexus are detailed in Leck et al. (2015), Scanlon et al. (2017), D'Odorico et al. (2018), Simpson and Jewill (2019), Torres et al. (2019), Abdi, Shahbazitabar and Mohammadi-Ivatloo (2020), and Purwanto et al. (2021) and briefly described here. The first-generation biofuels that are mostly produced utilizing crops that could also be used as food (or flex crops) are a clear issue in the WEF Nexus (D'ODORICO et al., 2018). A typical example in Brazil is sugar cane, whose demand has been causing forest loss and land-use changes. Agriculture intensification for energy and food production normally achieves one principal goal, i.e., food and biofuel production. However, it causes energy consumption, water use, water quality degradation. The plan to increase biofuel production will surely achieve a goal to generate energy, but naturally causes land-use changes, water consumption, food quantity reduction, etc. (FOLEY et al., 2011).

Another typical issue in the WEF Nexus is dam construction, which aims to create reservoirs reducing temporal heterogeneity of water resources in a determined locality. Water stored in reservoirs is used for hydropower production, irrigation, drinking water supply, fishery (POFF et al., 2016), recreation, and so on. Because of the many functions of reservoirs, researchers have investigated criteria for multiple-objective reservoir management for a long period (CHOONG; EL-SHAFIE, 2015, GIULIANI et al., 2021). Though dam construction certainly increases WEF security for some regions, it changes fluvial regimes, which causes a potential reduction in WEF security for other regions, especially downstream areas. Therefore, dam construction in WEF Nexus requires knowledge on basin management and the river continuum concept proposed by Vannote et al. (1980).

Even though the Nexus approach seems relatively easy at first, it is not easy to do in practice. Semertzidis, Spataru and Bleischwitz (2018) explained this reason: the WEF Nexus needs to be observed from many different scales and perspectives, from biophysical to political. Furthermore, Bof et al. (2021) commented that the Nexus' importance is easily recognized but still poorly documented in a way that supports conflict resolution and decision-making about water allocation. These two articles indicate that managers trying to implement WEF Nexus need interdisciplinary knowledge and holistic skillsets.

Ecosystem Considerations

Even before Rio 92, environmentalism was a worldwide social movement. For example, the United Nations World Commission on Environment and Development (UNWCED, 1987) reassessed critical issues like poverty, inequality, environmental degradation and formulated an extensive list of practical suggestions for solving them. Understanding environmental and development issues consequently raised global commitment to environmentalism. Furthermore, this report proposed an agenda advocating economic growth based on policies that do not harm the environment and may even enhance it. For UNWCED (1987), economy and ecology must coexist in harmony. Otherwise, the resources necessary for future generations will be scarce. It is thus reasonable to include ecosystems in the nexus approach. In other words, any human actions should consider natural ecosystems, environments and ecologies.

Water-Energy-Food-Ecosystem Nexus

Healthy ecosystems are essential for sustainability; the SDGs also regard ecosystems explicitly and implicitly in various goals and targets, for example, Target 6.6 (water-related ecosystems); Target 14.2 (marine and coastal ecosystems); Goal 15 (terrestrial ecosystems). Rio 92 asserted that no sustainable development exists without ecosystem consideration. Likewise, no sustainable security of WEF can be achieved without a healthy ecosystem. WEF resources should be considered in the context of ecosystems. In this sense, the WEF Nexus naturally incorporated the term ecosystem and became Water-Energy-Food-Ecosystem (WEFE) Nexus; for example, Carmo-Moreno et al. (2021) defined WEFE Nexus as follows:

> The water–energy–food–ecosystems (WEFE) Nexus is an approach that moves away from the traditional focus on separate entities but rather integrates management and governance across the multiple sectors of food, energy, water, and ecosystems as being complex and inextricably entwine. (CARMO-MORENO et al., 2021)

As WEF resources all have economic aspects (or values), the ecosystem also needs to be evaluated with economical aspects. In this case, the ecosystem services concept can be useful. According to Millennium Ecosystem Assessment (2005), ecosystem services are defined as the benefits people obtain from ecosystems. Hassan, Scholes, and Ash (2005) classified them into four types with detailed explanation: (i) provisioning services (food; fiber; genetic resources; biochemicals, natural medicines, and pharmaceuticals; and freshwater); (ii) regulating services (air quality regulation; climate regulation; water regulation; erosion regulation; water purification and waste treatment; disease regulation; pest regulation; pollination; and natural hazard regulation); (iii) cultural services (cultural diversity; spiritual and religious values; knowledge systems; educational values; inspiration; aesthetic values; social relations; sense of place; cultural heritage values; and recreation and ecotourism); and (iv) supporting services (soil formation; photosynthesis; primary production; nutrient cycling; and water cycling) (Figure 5).

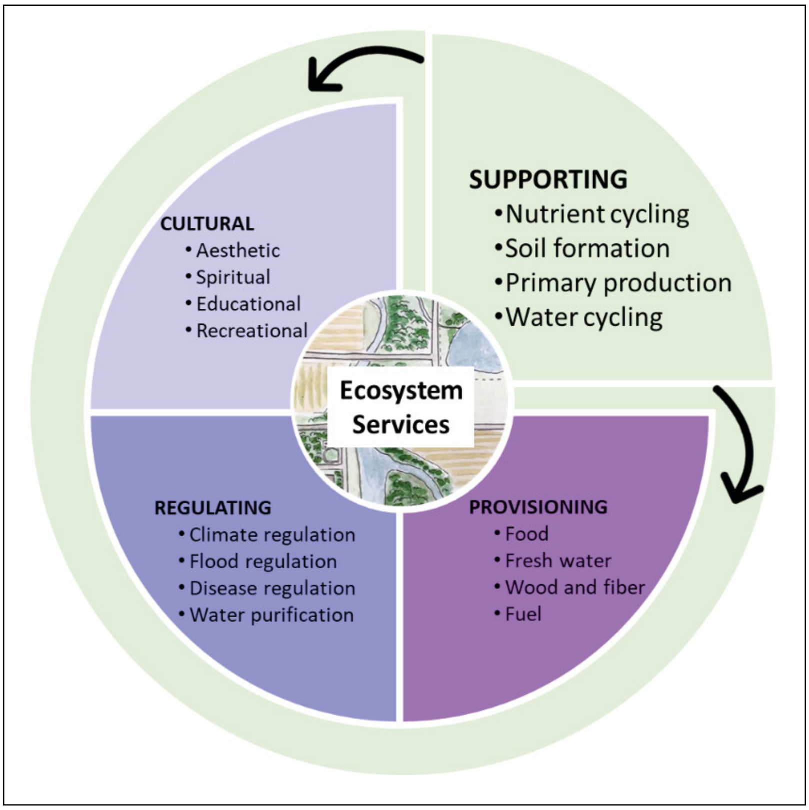


Figure 5. Categories of ecosystem services in relation to human well-being.

As many ecosystem services are issues within the scope of the WEF Nexus, ecosystems should be included as a central part of this Nexus. Bekchanov, Ringler and Mueller (2015) also explained how ecosystem services are essential for the livelihoods of many poor people, especially in developing countries, and these services are also important for regional public welfare.

Naturvårdsverket (2018) presented why the ecosystem services should be economically evaluated: (i) To investigate conflicting objectives and to facilitate trade-offs between different objectives; (ii) to determine if a project leads to socio-economic profitability and to prioritize different measures or alternatives; (iii) to serve as a basis for decisions on land use; (iv) to form the basis for decision-making about a company's strategic direction; and so on. Since several services are not easy to measure and estimate, it is a scientific challenge to properly establish methodologies for valuing ecosystem services. These challenges and difficulties result from the wide diversity of services. Indeed, societies have used ecosystem services to solve several resource problems. Jax (2019) reported that in British Columbia, Canada, the ecosystem services of salmon in rivers not only provide food, but also maintain the local culture. This makes valuing ecosystem services more complicated. Furthermore, in the context of water and food security, Sonneveld et al. (2019) proposed nature-based solutions, even though this work did not specifically mention the term nexus.

Eco-DRR (Ecosystem-Disaster Nexus)

As Hassan, Scholes, and Ash (2005) presented natural hazard regulation as one of the regulating services of an ecosystem, the use of ecosystem services has been increasingly utilized in the context of disaster risk management. In the past, actions in the risk and disaster management cycle were, in principle, just response and reconstruction rather than prevention. Today, engineering should focus on planning and using the natural landscape features to reduce disasters. As an example, the Centers for Natural Resource and Development and the Partnership for Disaster Risk Reduction (CNRD-PEDRR, 2013) emphasized this approach: Ecosystem-based disaster risk reduction (Eco-DRR), in which disaster risk management incorporates ecosystem management tools. According to Estrella and Saalismaa (2013), Eco-DRR is defined as the sustainable management, conservation, and restoration of ecosystems to reduce disasters risk and achieve sustainable and resilient development.

Even though degraded ecosystems can still play a protective role, they perform to a lesser extent than fully functional ones; it is recommended to keep ecosystems healthy. Healthy ecosystems reduce socioeconomic vulnerability by sustaining human livelihoods and providing essential goods such as food, fiber, medicines, and building materials (CNRD-PEDRR, 2013). Ecosystems can reduce physical exposure to common natural hazards such as landslides, floods, avalanches, storms, forest fires, and droughts by serving as natural infrastructure, protective barriers, or buffers (RENAUD; SUDMEIER-RINEUX; ESTRELLA, 2013).

Risk and disaster management must be integrated with environmental management as exposure is related to the environment (or ecosystems). Thus, Potschin et al. (2016), Monty, Murti and Furuta (2016), and Moos et al. (2018) claimed a major advantage of Eco-DRR, i.e., it has the potential to simultaneously reduce natural hazards and provide ecosystem services. In this sense, the Eco-DRR can be called an Ecosystem-Disaster Nexus. According to Moos et al. (2018), the most prominent example of Eco-DRR in mountainous regions are forests that protect people, settlements, and infrastructure against natural hazards such as mass movement and flash floods. Monty, Murti and Furuta (2016) commented that forest maintenance would certainly increase biodiversity and reduce natural hazards.

Water-Energy-Food-Disaster-Ecosystem Nexus

In the disaster management cycle consisting of three interlinked steps (pre-event, event, and post-event) (KOBIYAMA et al., 2006; VANELLI; KOBIYAMA, 2021), the "event" step, which corresponds to warning and response stages, is the moment at which people most need the WEF resources. Due to life disruption and deterioration of life quality, victims require water, energy, and food during the warning and response stages much more than during the pre-event and post-event steps. It means that Nexus thinking should be enhanced in the disaster management cycle, especially during the event stage.

Ecosystem issues should be included to improve the WEF Nexus, creating the WEFE Nexus. The Nexus should be enhanced for risk and disaster management, especially at the "event" stage. Recently, ecosystem-based disaster risk reduction has been required worldwide. Considering these three interconnected systems, we propose the Water-Energy-Food-Disaster-Ecosystem (WEFDE) Nexus. Sustainability concerns and climate change both point toward the explicit incorporation of ecosystems in the WEFDE Nexus. Here we define the WEFDE Nexus as a holistic thinking approach and practice that performs risk and disaster management to maintain water, energy, and food security based on ecosystem services. Hence, its main goal is to increase the quantity and quality of the WEF resources and reduce the magnitude and frequency of disasters by using ecosystem services and keeping ecosystems healthy.

As Montanari et al. (2013) reported, the current Scientific Decade (2013–2022) in the International Association of Hydrological Sciences (IAHS), the main theme of this Scientific Decade is "*Panta Rhei* — Everything Flows." Based on this concept, we see that ecosystems, society, and WEF resources are all dynamic. It means that they all are changing at any time and place on the planet. Normally we observe their dynamic equilibrium in a system (planet). However, when disequilibrium between society and another factor or within the society takes place, disaster occurs. Figure 6 shows the idea of the WEFDE Nexus. Since the Sendai Framework recommends implementing integrated and inclusive measures in various spheres, the WEFDE Nexus can be more appropriate. Moreover, this Nexus supports many SDGs.

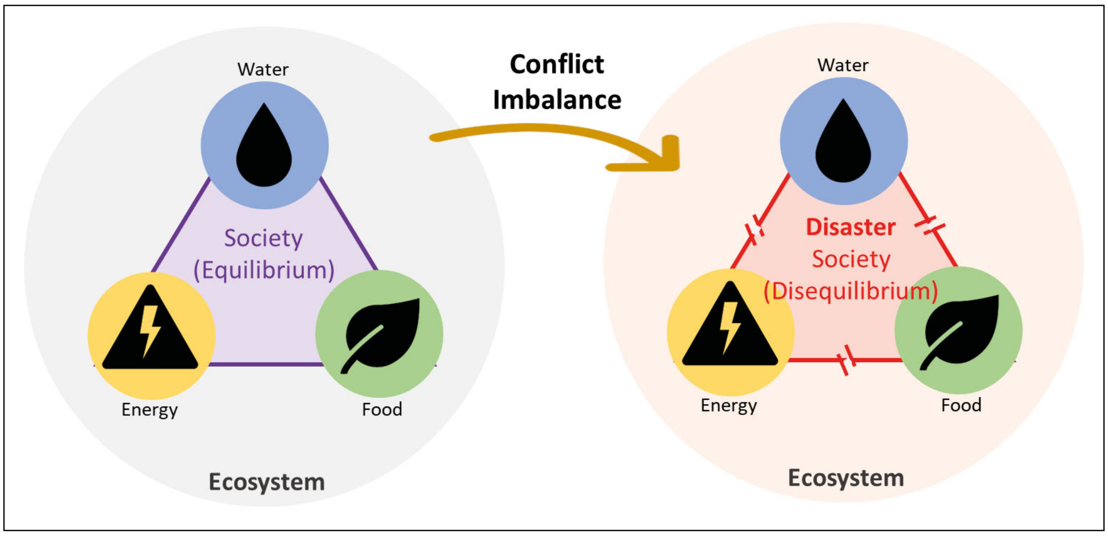


Figure 6. A visual description of the Water-Energy-Food-Disaster-Ecosystem (WEFDE) Nexus. In this framework, WEF resources are situated within an ecosystem and disasters create disequilibrium among WEF resources.

Nexus extension and geography

Nexus diversity

Observing sectors sharing natural resources that have interdependent and interconnected systems, Torres et al. (2019) performed a literature review and identified Nexus elements as follows: Water, energy, food, ecosystem, environment, land, agriculture, climate, carbon, economic, health, nutrition, and waste. The authors reported that water was the most common element, existing in all the WEF Nexus studies, which could mean that water is essential in the Nexus even if all the elemental constituents of the Nexus should carry the same weight. The second most frequently used term after water was energy, followed by food. They did not encounter papers that explicitly used the term disasters within the Nexus. Purwanto et al. (2021) found that most frameworks consider external factors such as climate change, population, and socio-economic development in managing WEF resources.

Climate change poses a global threat. This global phenomenon is normally explained by air and seawater temperatures and rainfall. Within the Climate change context, the spatio-temporal distributions of water become strongly heterogeneous, threatening water, energy, and food security. Therefore, it is natural and necessary to study the water-energy-food-climate Nexus, for example, WEF (2011), Dodds and Bartram (2016), Matthew (2016), and Adebiyi et al. (2021). Leck et al. (2015) considered the WEF Nexus as a potentially effective approach for considering the interdependencies between WEF security and climate change at various scales. When climate change is discussed, the chemical element carbon is also a subject of debate. For example, Meng et al. (2019) examined carbon production and emission within the Water-Energy Nexus for urban contexts. The emission of CO_2 into the atmosphere intensifies climate change and the acidity of rainfall. Acid rain accelerates chemical weathering of surface materials. By investigating the water chemistry in the Yangtze River Basin (China), Guo et al. (2015) reported that anthropogenic acidification had enhanced the chemical weathering by 40% during the past three decades.

Biggs et al. (2015) discussed the livelihoods–water–energy–food Nexus with consideration on environmental livelihood security (ELS) which refers to the challenges of maintaining global food security and universal access to fresh water and energy to sustain livelihoods while sustaining key environmental systems functionality, particularly under variable climatic regimes. In this discussion, the authors considered natural hazards as external influencing factors on the Nexus. When assessing well-being, security is often a central concern. In this sense, the disaster issues may be substituted for livelihood or well-being in the Nexus approach (Figure 7).

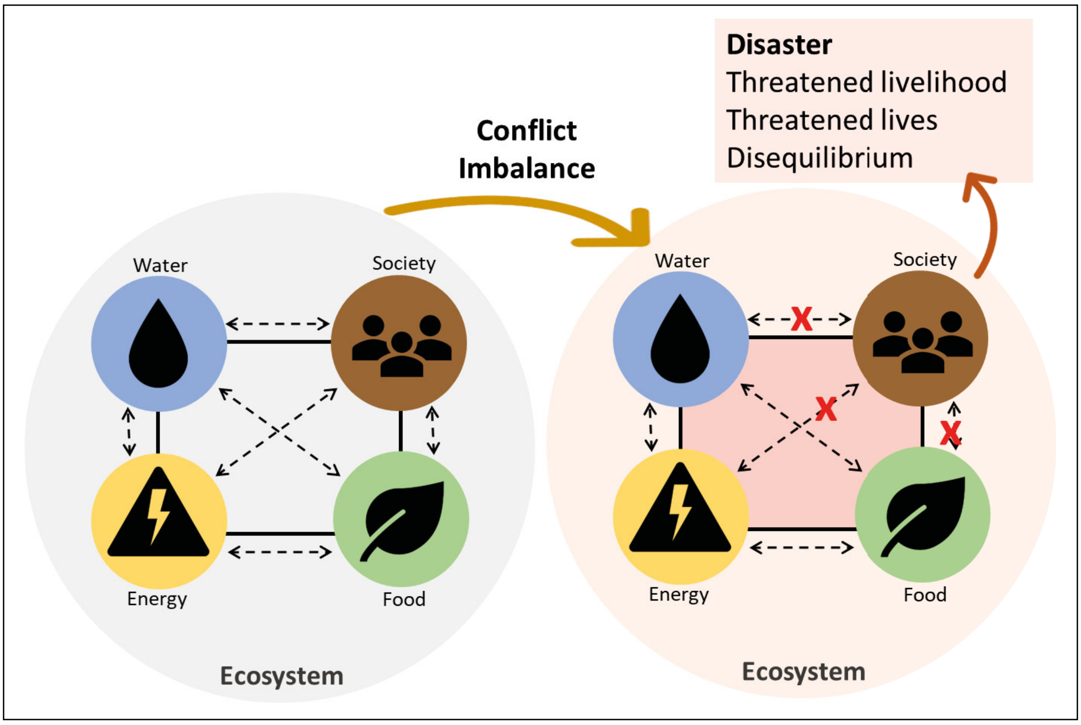


Figure 7. A visual description of the Water-Energy-Food-Disaster-Ecosystem Nexus with society added gas a resource within the Nexus.

Several types of human indices can characterize issues like well-being and disasters. When Nexus modeling needs metrics for factors under investigation, socio-economic metrics are usually more complicated than environmental ones like water consumption and energy production. Semertzidis, Spataru and Bleischwitz (2018) proposed using GDP (Gross Domestic Product), Human Development Index (HDI), Happy Planet Index (HPI), and Better Life Index (BLI). Yet, it is difficult to measure different types of factors within the same index. Imagine incorporating both infrastructure costs and social inequities into the same index, how would you decide what to measure and which of these factors are more important, this complexity makes Nexus modeling very complicated.

Contribution of geography

Geography is the traditional science that emerged in the work of Aristotle in ancient Greece as an extensive study of the natural processes on and near the Earth's surface. Therefore, it is a popular expression that geography is the mother of sciences (PATTISON, 1964). Though there are a lot of definitions of geography, we use here one described by National Geographic (2022):

> Geography is the study of places and the relationships between people and their environments. Geographers explore the physical properties of Earth's surface and the human societies spread across it. They also examine how human culture interacts with the natural environment, and the way that locations and places can have an impact on people. Geography seeks to understand where things are found, why they are there, and how they develop and change over time. (NATIONAL GEOGRAPHIC, 2022)

Geography is generally divided into two groups: human and physical. Human geography is a social science dedicated to the study and description of interactions between society and space. It helps people understand the geographic space where they live. Human geography can be divided into the sub-areas such as economic geography, political geography, cultural geography, urban geography, rural geography, and social geography. On the other hand, physical geography is the study of the natural features of the Earth's surface. Its purpose is to understand the lithosphere, hydrosphere, atmosphere, pedosphere, biosphere and their interactions. Subdivisions of physical geography include pedology, geomorphology, climatology, hydrology, biogeography, oceanography, and glaciology. Geography is a Nexus science, combining many social and physical sciences. Just as nexus thinking embraces both the social and natural sciences (LECK et al., 2015). Therefore, geography is a science suitable for studying all kinds of Nexus types such as WEF, WEFE, and WEFDE.

Leck et al. (2015) reported that disciplinary 'boundary crossing' has long been encouraged in academic and policy circles, especially within geography, which has a constant concern about crossing the boundary between physical and human geography, and that it has proven difficult to achieve. Investigating just the Gulf region, Abulibdeha and Zaidan (2020) proposed a holistic and comprehensive systemic framework to optimize WEF resources management at different integrated geographical scales (the national, regional, and international levels). Focusing on household fats–oils–grease, Foden et al. (2019) introduced the Nexus at the household scale as a starting point for exploring the WEF Nexus. These two articles show there are various geographical or spatial scales at which Nexus studies can be conducted. It also indicates the importance of geographical approaches.

Based on a literature review, Purwanto et al. (2021) described three criticisms against the WEF Nexus: (i) its concept is still expanding, relatively immature, not useful in application, and without a common definition; (ii) its application requires much more time and frequently does not work due to lack of data sharing; and (iii) too high expectations.

To improve the WEF Nexus, Purwanto et al. (2021) proposed four principal actions: (i) to make the nexus more understandable, (ii) to ensure reliable and valid data, (iii) to make the nexus adaptable to many diverse situations, and (iv) to make the nexus applicable across scales. It will be difficult to perform actions (ii), (III), and (iv) without geographical methods.

An overview of the current state of geographical research on resources reveals that geographic research on energy has been widespread. Thinking energy can connect different geographic concepts and debates is an important area of future research. Calvert (2016) and Baka and Vaishnava (2020) reviewed geographical studies about energy and demonstrated the important contributions of energy geographies to scientific, social, economic, and political demands. Based on their suggestions obtained from the literature analyses, we need to emphasize socio-technical knowledge and perspective, establishment of socio-environmental system, geopolitical and ecological approaches, and spatial decision support. These issues are all addressed by performing geographical studies.

Thus, various case studies demonstrate the importance of geography for energy concerns. For example, Fingerman et al. (2010) and Gerbens-Leenes et al. (2014) reported that the water used for biofuels strongly varied with crop type, geographic location, climate, and soil. Performing a case study in the UK, Bridge et al. (2013) demonstrated how the low-carbon energy transition is essentially a geographical process that involves reconstructing current spatial patterns of economic and social activity and provided a set of basic concepts for mapping the geographies of a low-carbon energy system. This set consisted of six geographical items: location, landscape, territoriality, spatial differentiation, scaling, and spatial embeddedness. For energy geography in Brazil, where hydroelectric production accounts for more than 70% of the country's electricity supply matrix (SEMERTZIDIS; SPATARU; BLEISCHWITZ, 2018), basin geography should be still very relevant in Brazil. Hence the hydrographical approach is required.

Similar to energy geography, there are several studies on food geography, for example, Shanahan (2002), Mandelblatt (2015), and Kneafsey et al. (2021). However, food geography is not as well developed as energy geographies, and no studies of water geography were encountered. This reason might be that hydrology can be considered water geography and that hydrologists present hydrological studies without writing the term "water geography." Regardless of the resources that the Nexus considers, it is impossible to manage them without monitoring. The data obtained from the monitoring network and their analyses are essential to a better understanding of the WEF Nexus (SCANLON et al., 2017). Both monitoring and modeling activities are powerful parts of geography. As the number of Nexus subjects increases, for example, WE to WEF, WEF to WEFE, and WEFE to WEFDE, the importance of interdisciplinary research increases significantly, as does the necessity to apply geography (holistic and integrated science).

To ensure the well-being of society, WEFDE security is indispensable. Therefore, we proposed the Water-Energy-Food-Disaster-Ecosystem Nexus where the number of variables, characteristics, and involved disciplines will be greatly increased. In this case, we must remember that there is more than one way to study the WEFDE Nexus. Because geographical conditions (climate, landform, society, etc.) vary from region to region, it is very important to be aware of geographic realities at the beginning of Nexus implementation.

Nexus in Brazil

For an exploratory and statistical investigation of the WEF Nexus works carried out in Brazil during the period 2000-2013, Caixeta (2019) analyzed the access to potable water; access to electricity, and average protein supply, and the demonstrated strong correlation among these three factors. The author confirmed that Nexus-based management can contribute to sustainability processes in Brazil.

Brazil has a vast territory (8,515,767 km^2) and is characterized by a regional bias in natural resources (water, energy, etc.). These geographical heterogeneities of resources do not coincide with the demographical one, which requires more tradeoffs between various societal sectors. Thus, the Nexus approach should be more applied to Brazilian realities. Nexus thinking was born out of the guarantee of WEF securities, and urgent action on water security was initially due to water scarcity. Therefore, it is naturally understood that further research and practice of the Nexus approaches are needed especially in northeastern Brazil or the semi-arid region which has historically suffered from severe drought.

One of the most famous problems related to the Nexus is the São Francisco River Basin (639,219 km^2), whose major part is in the semi-arid region. In this basin, there are longstanding and strong conflicts between irrigation and hydropower projects (IORIS, 2001), social issues have likewise been a concern (NOBREGA, 2011; TALLMAN; BENEDICTO, 2018). Hence the São Francisco River Basin is a typical example where social concerns are central to resources issues. Alternatively, by changing our perspective, we might view society as human or social resources and pursue social resilience as well as WEF security.

Applying a hydro-economic model with a stochastic dual dynamic programming approach, developed by Tilmant, Arjoon and Marques (2014), to the São Marcos River Basin (12,140 km^2) inside the Paraná River Basin, Bof et al. (2021) discussed the WEF Nexus tradeoffs. The authors demonstrated that, since the agricultural benefits outweigh the potential energy losses in the modeled system, the best action is to find an economically compensated reallocation strategy, based on negotiation among users, rather than imposing water supply cutbacks to the agriculture sector. This conclusion differed from Pereira-Cardenal et al. (2016), which carried out a similar study with a stochastic dual dynamic programming approach. Bof et al. (2021) added that tradeoff information between water uses is not always evident, and specific assessment is necessary to acquire this kind of information.

Their comment certainly implies the importance of case studies because every place has its own geographical conditions and consequently has its own unique set of Nexus conditions. The securities scenarios vary from region to region. Rather than building the basic principles of the Nexus for the whole country, it must be encouraged to find the most suitable method for each region by a case-by-case method.

Reporting a serious drought that various regions in Brazil were suffering from in 2021, Getirana, Libonati and Cataldi (2021) proposed, as a national security priority for avoiding crop failures and soaring power costs, urgent actions like sources diversification, soil moisture monitoring, local-hydroclimate dynamics modeling and treat water. According to Hunt et al. (2022), this water scarcity has continued since the drought in 2014 and 2015, and a large potential for hydropower has not been well explored because of the low water level in most of reservoirs in Brazil. This shows that reservoir levels of the hydropower plants have a significant impact on the river flow. Hunt et al. (2022) commented that Brazil needs to generate thermoelectricity, solar and wind power, while conserving energy to allow the reservoirs to rise. Then, these authors demonstrated that Brazil can generate more hydropower with existing dams, reduce its electricity costs and reduce CO_2 emissions from thermal electricity sources. Considering the serious concerns in Brazil's disaster risk reduction strategy and the current and future effects of climate change in Brazil, our proposal of WEFDE Nexus is also appropriate for Brazil.

Final remarks

Considering that the WEF Nexus is central to the discussion about SDGs achievement, Biggs et al. (2015) integrated livelihood dynamics into the Nexus and proposed a novel framework. From different points of view, livelihood security and DRR can be quite similar issues. Besides, this new framework of Biggs et al. (2015) focused on environmental concerns. Therefore, even though Biggs et al. (2015) adopted the term WEF Nexus in their work, their new framework was similar to our proposal, i.e., Water-Energy-Food-Disaster-Ecosystem Nexus. Indeed, in the literature, Biggs et al. (2015), has dealt with the WEF resources and various types of natural disasters in parallel based on ecosystem types. Since studies like this developed the WEFDE Nexus appropriately without the term, some would say there is no need to define the WEFDE framework.

Nevertheless, we dare to recommend the use of the WEFDE Nexus. Adding the term "disaster" into the Nexus incites people to think of the Nexus and Sendai Framework in parallel. Biggs et al. (2015) linked the Nexus to SDGs, and we believe the WEFDE Nexus is also central to the Sendai Framework. Droughts, which result in water scarcity, cause a climatological disaster. Urban power outages caused by weak hydropower and services to high electricity demand, such as the use of air conditioners, during the drought (SEMERTZIDIS; SPATARU; BLEISCHWITZ, 2018) are also a type of disaster. Natural disasters like landslides, debris flows, flash floods, earthquakes, and tsunamis frequently damage infrastructures, including electric power plants, water supply systems, and irrigation systems, consequently reducing WEF security. Even so, people do not associate WEF security with disaster management. Even as disaster concerns are necessary for Nexus practice, the educational effect of explicitly including the term "disaster" is also beneficial for the general public, we conclude that the "Water-Energy-Food-Disaster-Ecosystem Nexus" is appropriate for the current situation in Brazil and many places around the world.

To achieve the SDGs, support the Sendai Framework, and improve individual and social well-being, a place-based WEFDE Nexus Ruralization proposed by Kobiyama, Campagnolo and Fagundes (2021) can be useful in the Nexus for urban environments.

> [Ruralization is] actions to coexists with vegetation, soil and rainwater and also to carry out processes that go against modern urbanization. The philosophical components of ruralization include: “Small is Beautiful,” “Slow is Beautiful,” “Simple is Beautiful,” “Soil is Beautiful,” and “Science is Beautiful.” (KOBIYAMA; CAMPAGNOLO; FAGUNDES, 2021)

Since ruralization practices incorporate many ecosystem services, they are considered ecosystem-based practices. Therefore, they can be all be included in the Nexus.

According to D’Odorico et al. (2018), the WEF Nexus approaches rely on (i) the enhancement of resources production with new and adequate technology; (ii) reduction of resources’ consumption through more sustainable diets, (iii) efficient use of resources, and (iv) waste reduction. For achieving approaches (iii) and (iv), the authors recommended including in the WEF Nexus the concept of Circular Economy, described by UNIDO (2017). As Stahel (2016) emphasized: “reuse what you can, recycle what you cannot reuse, repair what is broken, remanufacture what cannot be repaired.” As water circulates (the hydrological cycle), the dynamics of many resources should have circular features. Consumption and waste reduction and reuse depend upon residents’ actions based on their education and values and knowledge of the geography of the region in which they live. However, these individual actions are not possible without systems and infrastructure that support circular economies.

Finally, we would like to send this message: Water-Energy-Food-Disaster-Ecosystem Nexus thinking, training and environmental education for residents and geographical investigation for database construction should be enhanced. Geography education in and outside of schools not only help residents understand local environmental ecosystems and social form and function, it also gives them interdisciplinary and holistic ways of thinking and decision-making. Therefore, each community must strengthen its geography education with the Nexus in mind.

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