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Present and future of the water-energy-food nexus and the role of the community of practice

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Abstract The paper discusses an integrated approach to the management of three primary resources: water, energy, and food (WEF), as these increasingly represent the greatest global risks because they are expected to be highly impacted by climate change, demographics, aging infrastructure, and other challenges in the twenty-first century. As background, the WEF nexus is defined; significant historical developments of nexus thinking noted; and important connections to systems-science theory presented. An interdisciplinary WEF nexus platform is defined and proposed to support scholarship and to be a bridge between science, policy, and the general community of stakeholders. The interdisciplinary nexus platform is then differentiated from more common discipline-specific approaches. A review of the WEF nexus history, important benchmarks, and the foundation in system-science theory are presented. The paper concludes with a call for a WEF nexus community of practice (NCoP) to promote and enable an integrative approach to develop and employ tools with the purpose of strengthening sustainable food security, increasing energy production, and bridging water supply gaps that have arisen in demands for both food and energy. The transdisciplinary platform created by the NCoP will carry strong societal impact while addressing the scarcity and sustainable management of these primary resources.

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Human and environmental change, resource scarcity, and global risk

Population growth is a major external stress on three primary resources: water, energy, and food (WEF). By the year 2100, the United Nations projects that global population could pass 10 billion, with this growth occurring primarily in urban environments, which are projected to contain up to 60 % of the earth's inhabitants by 2030 (UN-DESA 2011). This growing population alongside clustering in urban areas negatively impacts the security of these resources, leading to increasing stress on water supply and decreased water quality, particularly in regions such as the Middle East-North Africa (MENA), Asia, and Central America which are already experiencing water stress (UN-DESA 2011). Additionally, 795 million people currently lack sufficient food to lead a healthy life, with the majority living in developing countries, where nearly 13 % of the population is undernourished (WFP 2015). Many of the same geographic regions, including sub-Saharan Africa, MENA, Asia, and Central America, also exhibit poor energy security and access (EAPI 2013). As productive land is taken over by urban sprawl, both agricultural production and the transportation of food from producer to consumer are stilted.

Climate change also impacts the availability of WEF resources by impacting crop productivity, water supply, and demands for cooling and heating. With subtropical regions already experiencing both the greatest population growth and the highest stress on WEF resources, the effects of climate change will likely reduce rainfall further, thus making surface water less available and further depleting stored soil moisture

(Milly et al. 2008; IPCC 2013). Much of the food we consume is produced through rain-fed agriculture, which is very vulnerable to decreased precipitation and carries serious implications: as rainfall decreases, less water available for food and energy production. At the same time, storm intensities and periods between rain events are both expected to increase and this will impact both agricultural production and soil quality. Longer dry spells and less precipitation will lead to increased water needs and decreased water quality and freshwater availability. However, more intense individual storms will lead to greater property damage as well as probable increased exposure to pests and disease.

Climate change is likely to have a ripple effect in which stress on one primary resource provokes wider consequences because of the interconnectedness of the WEF nexus, leading to greater competition when supply decreases. Examples of this interrelatedness include the fact that nearly 55 % of the operating costs of water utilities go to energy, while food production consumes between 70 and 90 % of total water used for human activities (IRENA 2015; FAO 2011). Consequently, with less water available to support energy production, access to energy-dependent activities such as cooling, lighting, and travel is likely to decrease.

Global shift in risk identification

While geopolitical and technological risks are more commonly considered to be worrisome, WEF resource security is consistently ranked by the World Economic Forum as among the highest concerns for the global economy (2015), leading to a global shift in the way societies look at risk and security. WEF insecurity is determined to have the greatest potential impact: their inherent interconnectedness, together with global population and climate shifts, not only speak of a dynamic world of climate and societal change but further make it essential to pursue a more integrative, holistic approach to the assessment and management of tradeoffs regarding the consumption of primary resources. This illustrates the need for a platform that engages all stakeholders and enables them to better manage WEF resources by understanding the issues and consequences of decisions. Such a platform would facilitate the mapping of relevant data (water resources, climate, land use, etc.); track actions and developments; and permit informed, science-based decision-making that allocates resources sustainability for maximum benefit (Mohtar and Daher 2012; Daher and Mohtar 2015).

The WEF nexus in review

A nexus is a connection or link—often causal—between a group or series of objects, ideas, or, in our case, the water, energy, and food sectors that comprise the WEF nexus. The Food and Agriculture Organization of the United Nations (FAO) describes the nexus as "a new approach in support of food security and sustainable agriculture" and as a means to understand and manage "the complex interactions between water, energy, and food" (FAO 2014a, b). This nexus serves to balance the different goals and interests of the parties using WEF resources, while maintaining the ecosystem integrity through integrated management.

The idea of a framework or a platform for the integrated management of WEF resources is not, in itself, new. The Integrated Water Resource Management Association (IWRA) was formed in 1971 to "improve and expand the understanding of water issues through education, research and information exchange among countries and across disciplines." Alcamo (2015) identified the use of systems thinking to investigate the common principles and models used to describe the WEF nexus and the use of systems theory to establish its scientific basis (Alcamo 2015). He identified four areas where the WEF nexus can use systems thinking: (1) mapping the nexus and its linkages, (2) finding critical linkages, (3) using models for nexus problems, and (4) realizing the rebound effect in a systems setting (Alcamo 2015). Alcamo (2015) also has also identified lessons from systems theory that are helpful in moving the WEF nexus forward: (1) realizing the "rebound" effect from spatial resolution by reducing basin-wide scarcity, rather than in individual areas; (2) realizing the "rebound" effect from neglecting critical linkages of the system, including human behavior; and (3) realizing a system-level solution, rather than solutions for individual components.

In 2011, more than 550 people gathered in Germany at the conference *The Water, Energy and Food Security Nexus—Solutions for the Green Economy*, which called for new approaches to address the WEF security nexus by developing a framework to define it and enabling integrated solutions to address the challenges it posed (Bonn Nexus Conference 2011). In the same year, the World Economic Forum Water Initiative published *Water Security: The Water-Food-Energy-Climate Nexus*, (World Economic Forum 2012) then followed by the Rio+20 Conference on Sustainable Development (United Nations 2012). These conferences, discussions, and publications identified trends in resource scarcity and impacts on global security and inspired geopolitical think tanks to begin focusing on these concepts as a foundation from which to address these issues. The InterAction Council of Former Heads of State and Government and the East West Institute, among other geopolitical think tanks, began to include the WEF nexus as a top global risk, even above risks such as bridging the religious divide and nuclear non-proliferation.

In June 2013, the World Bank released *Thirsty Energy*, identifying the impacts of the energy sector on water resources (Rodriguez et al. 2013). The WEF nexus and WEF sustainability came together again in Bonn in 2014 at the conference

Sustainability in the Water-Energy-Food Nexus, which explored an agenda for related research and recognized the need for an internal policy consultation process to inform, influence, and catalyze action by key players—including policymakers, non-governmental organizations, the private sector, educators, and researchers, leading to a special issue of Water International (Bhaduri et al. 2015). In the same year, the US Department of Energy released a Water-Energy Nexus report highlighting options for reducing the resource footprints of energy production and water treatment, while other meetings like *Nexus 2014*: *Water*, *Food*, *Climate and Energy Conference* and *Earth Observations and the Water-Energy-Food Security Nexus* took place in the USA and in Italy.

In August 2014, Future Earth, supported by the National Science Foundation (NSF), launched "eight initiatives to accelerate global sustainable development," including one aimed to increase sustainability through the application of integrated information and improved governance, intended to "kick-start integrated activities and strengthen interdisciplinary collaboration." In February 2015, NSF released a "Dear Colleague Letter" outlining the importance of "understanding the interconnected and interdependent systems involving food, energy, and water and aiming to accelerate fundamental understanding and stimulate basic research on systems that… include couplings to energy and food… investing in a systems-based approach to understanding, predicting, and reacting to stress upon and changes in the linked natural, social, and built environments surrounding food, energy and water" (NSF 2015). NSF then funded a series of workshops to promote the interdisciplinary WEF theme and, in December 2015, released its first call for Innovations at the Nexus of Food, Energy, and Water Systems (INFEWS) (NSF 2015).

These conceptual discussions and acknowledgments of the changing global landscape highlight the importance of the WEF nexus in the resource sustainability agenda and demonstrate the necessity of a holistic framework as a means to simultaneously manage each of the resources without infringing on the other two. Now let us consider how to move from *concept* to *analytics* and then from *analytics* to *action*: what are the policy changes, technology shifts, and public and consumer behaviors that must be addressed? How do we assess and evaluate the interdependencies of the systems involved?

Developing a WEF nexus platform: the role of systems theory

Transitioning an integrated WEF nexus program from concept to action requires a WEF nexus platform. In turn, such a platform can only succeed if it builds on studies of the WEF nexus and is deeply embedded in the lessons of systems theory for data management, modeling, and analytics. Systems theory contributes to a framework for addressing this complex issue in terms of the state of the variables and the description, scale, scope, and representation of the WEF system itself (Braudeau and Mohtar 2009, 2014). The elements of the emerging WEF nexus system can be initially summarized as follows:

1. Interlinkages between the individual elements at the proper scale and scope: the conceptual platform must take into account how each of the portfolios is individually quantified.
2. The multi-scale nature of the issue: the need to assess local, regional, and national perspectives.
3. The scope of the issue: various sectors of society, *vertically* in terms of governance (government in some cases) and *horizontally* in terms of the academy, technology providers, civil society, and the private sector.
4. The complexity of the issue points out the need to consider holistic, integrative approaches and the need for evidence-based approaches to understand and manage these primary resources.

The WEF nexus platform: building upon the existing disciplinary pillars

The nexus will not, nor should it, *replace* existing disciplinary strengths: the proposed platform must complement disciplinary conservation and efficiency by building upon the existing, very strong, and interconnected WEF disciplinary pillars and integrating these without infringing upon them or optimizing any one over another. A long-standing challenge for water management is the lack of integration between the sectors interacting with water across geographical areas and within large, often transboundary, basins through integrated water resource management (IWRM). In an effort to foster IWRM in 1996, the Global Water Partnership (GWP) was founded by the World Bank, the United Nations Development Programme (UNDP), and the Swedish International Development Cooperation Agency (SIDA) to promote the "coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP 2012).

The key difference between the nexus approach and that of IWRM is that the latter begins with water when considering WEF interrelationships, whereas the WEF nexus approach ideally begins with an interrelated system and then notes the two-way relationships between water, food, or energy and the other resources. The United Nations Secretary-Generals' Advisory Board on Water & Sanitation (UNSGAB) sees the two approaches as complementary (UN-DESA 2011) and states that both approaches facilitate sustainable growth and

protect essential environmental services, as summarized in the following table (UNSGAB 2012):

	IWRM	Nexus
Allows sustainable development pathways	✓	✓
Promotes efficiencies in the resource development and allocation	✓	✓
Calls for greater co-ordination between inter-linked resource producing/consuming sectors	✓	✓
Clearly recognizes the consequences of decisions made in one sector for the other sectors	✓	✓
Emphasizes the need to change the way policy and decision-making occurs in order to improve human welfare and social equity	✓	✓

However, in reality, nexus thinking also normally starts from one of the WEF perspectives, making the concept appear more relevant to that specific sector than would the IWRM approach of water-first. Consequently, the nexus approach could make integration more palatable to some nations in transboundary basins heretofore reluctant to embrace IWRM because of the emphasis on bringing all activities in line with *water* management.

The WEF nexus platform could provide the analytical basis necessary for identifying and quantifying the interlinkages between water, energy, and food resources; helping define hotspots; and enabling quantitative assessment of tradeoffs to be considered in decision-making. This platform will enable translation from science into political discourse while maintaining the structural integrity of relevant concepts to enable informed, and thus effective, decision-making. Nexus analytics become the foundation on which informed dialogue is made possible. Furthermore, focusing only on the analytics—one aspect of the nexus—restricts our ability to induce change, whether in policy, technology, or consumer behavior. Lastly, dialogue must occur within and between three critical circles: the politico-economic, the supply chain, and the consumer. Only thus can it help to move society from a mode of conflict into one of cooperation through improved utilization of primary resources for a more sustainable world.

Stakeholders and applications

The nexus dialogue relies upon an approach that is vertical in scale and horizontal in audience, involving a multiplicity of stakeholders. The public sector should address ownership and governance by exploring the use of incentives, procedures, and policies that should be promoted, particularly in relation to sustainable food, water, and energy policies that can be mutually supportive of and do not infringe upon the other two resources. The private sector should seek to optimize operations and minimize costs (or maximize profits), whether the stakeholder provides water, energy, or technology. Civil society should seek to improve quality of life by safeguarding health and reducing risk; it values information, citizenship, and access to data that informs decisions regarding changing resource allocation behaviors.

Data and modeling challenges

Delineation, scaling, and developing an appropriate system are challenges inherent to developing such a platform. It is critical to define the stakeholders, whether private, public, or from the science sector, and understand at what scale each is represented, whether local, regional, national, or global. This knowledge will dictate the scope of the modeling platform to be used. Modeling should be kept simple: WEF systems are already complex, so adding unnecessary externalities will make the analytics excessively complicated, while the scale and scope of modeling must be tailored to the needs. Processes modeling or tradeoff analyses must be considered: the choices made will vary depending upon for whom the specific platform is designed. Defining interlinkages between variables will stem from existing disciplinary data that helps identify the interconnectedness between the resources. The resolution, aggregation, disaggregation, quality of, and access to data must also be considered.

Identifying hotspots, applications, and impact: two examples

Several WEF nexus tools are becoming available with different analytical approaches, depending on the inputs required, the desired outputs, and the scale of the issue at hand. Some of the basic tools have a limited scope but have proved to be very useful in bridging the gap between a disciplinary approach and a more comprehensive nexus assessment. Examples of nexus tools include the following: Climate, Land-use, Energy, and Water (CLEW) (Alfstad 2013), The Water, Energy, Food Nexus Tool 2.0 (Mohtar and Daher 2012; Daher and Mohtar 2015), MARKAL/TIMES (Loulou et al. 2005), WEAP-LEAP (SEI 2013), FAO's nexus assessment methodology (FAO 2014a, b), and MuSIASEM—The Flow-Fund Model (FAO 2013).

Fischer et al. (2013) introduced a new paradigm for interdisciplinary resource assessments, emphasizing that as resources become increasingly scarce, integrated assessments across sectors are needed to both maximize potential synergies through joint strategies and ensure that developments in one sector do not result in greater costs to other sectors than the benefits provided. They also highlighted that integrated assessments and planning are rarely done at a national level, but are needed to ensure that strategies in all sectors are

consistent with national priorities, with each other, and across scales. As an example, they applied this protocol for the country of Mauritius, combining existing, proven models of energy, water, and land use, including IIASA's Agro-ecological Zones (AEZ) modeling framework.

The nexus platform can help identify hotspots or locations or challenges where specific policy, technology, and/or consumer behavioral changes can be assessed and evaluated. We will offer two examples from different locations and contexts: food security in Qatar, which reflects interactions between demands for water, energy, and land, and shale gas production or hydraulic fracturing in Texas, which reflects interactions between demands for water, energy, and transportation.

In Qatar, the implications of increasing food security (independence from imports) from 10 to 20 % was analyzed by quantifying the increased food production, considering the costs of energy, carbon, and water footprints. The study determined that a 10 % increase in food production would require more than 150 % additional land, which was simply not available (Mohtar and Daher 2014). Secondly, the water-energy-transportation nexus in Texas is analyzed using a scenario-based approach by examining sustainability indices to create an economic-environmental-social index because the sustainability of energy production in the state is of high priority. The approach has implications for policy, regulation, subsidy, the development and transfer of new technology and changing behaviors regarding how these issues are approached (WEF Nexus Research Group 2015).

The WEF nexus platform offers a very useful means of providing a holistic perspective that is both spatially and temporally relevant to assist in resolving the multiple challenges facing us in a non-stationary world where resources are limited and vulnerable. It can be further used to bridge the water gap without infringing on energy and food production by offering an integrated means of analysis to inform decision-making, and the information it offers can then be extrapolated from a given hotspot to be applied in a broader relevance. For example, the state of Texas has a variety of eco-zones, so the solutions that are effective in one region will not work in others; however, because the WEF nexus platform is holistic, it can effectively assess which solutions will work under which conditions or with which tradeoffs.

The WEF nexus community of practice concept

The concept of a community of practice has been used in the social sciences, private and public organizations, governments, education, and international development for decades, while recent, rapid growth in digital communications and social media has made the concept more feasible. A "community of practice" (CoP) refers to a group of people who share a craft or profession; it signifies a way of knowing and learning and focuses on people engaged in sharing knowledge and practices regarding a specific set of issues. Wenger (2011) defined the CoP as a group of people who share concern or passion for what they do and who learn how to do it better through regular interaction. Its members share a common domain of interest, and the CoP renews itself by generating new knowledge (Wenger and Snyder 2000). Successful CoPs are involved in many activities, such as solving problems through brainstorming; seeking or sharing information, experiences, coordination, and synergies; providing feedback to ideas; and mapping knowledge and knowledge gaps (Wenger 2011). Li et al. (2009) highlight the importance of building a balance between satisfying individual member's needs for personal growth and empowerment with the larger goals of the community; this balance should guide the evolution of the WEF NCoP concept.

The WEF NCoP can help develop a global science-policy platform for sharing data, knowledge, and best practices. The WEF platform would define data gaps and develop a common accounting framework for the nexus, while the CoP could help monitor the effectiveness of nexus governance by offering good governance models.

Example: Group on Earth Observations (GEO) Integrated Global Water Cycle Observations (IGWCO) community of practice

The CoP concept was used successfully by the Group on Earth Observations (GEO), which includes 100 member nations and 80 international participating organizations and has used the CoP dialogue for over a decade to recruit and engage experts who volunteer their time toward the development of the GEO System of Systems (GEOSS) in different disciplines, moving forward a number of activities related to the GEOSS Water Strategy. The objectives of this GEO Integrated Global Water Cycle Observations (GEO-IGWCO) community of practice include the following:

1. Providing a framework to guide decisions regarding priorities and strategies for the maintenance and enhancement of water cycle observations
2. Promoting strategies to facilitate the acquisition, processing, and distribution of data products needed for management of the world's water resources
3. Coordinating and facilitating the inputs of the global water community into GEOSS plans and reports
4. Fostering the development of tools, applications, and systems that facilitate the inclusion of water cycle information in decision-making

In most cases, the GEO CoPs were launched by assembling a group of experts in a given subject area to review issues in their domain. Generally, each CoP develops terms of reference which are submitted to GEO for review, while in some cases

the community develops a subject-related document that provides direction for their work and for the broader community. During the early stages, a small executive that involves key stakeholders proves helpful in defining and motivating specific studies and initiatives. This executive is designed to be a facilitative and advisory mechanism rather than fulfilling a management role. Based on this example within the GEO framework, the elements of success for the CoP appear to include the following:

- A significant role for the community within the management structure of a larger body (in this case, GEO)
- Services provided by the community to its members through regular communication and engagement
- A chairperson with the vision and experience to lead the group and the freedom to allocate significant time to the effort

Given the regional nature of WEF issues, there would be value in developing a few of these communities at the national level as well as one at the global level.

The IGWCO community of practice is chaired by an expert with an assistant who also serves as the secretariat for the activity. Functionally, this lead tracks all activities related to GEO water and submits biannual reports. The chair continuously scans the programmatic landscape for and then communicates information that would be beneficial to members, in addition to representing the community at meetings, giving feedback on relevant issues, leading in the development of strategy documents, and providing ongoing advice and administrative support. An expert from the GEO secretariat also provides a link to the overall program. Within GEO, the IGWCO CoP was strengthened by its role as a coordinating mechanism, including keeping informed of the community's water-related activities, ensuring that activities were fully explained in GEO's planning documentation, and addressing roadblocks encountered in the implementation of specific projects or actions by CoP members. These defined roles meant that the group functioned well beyond simple self-interest. Moreover, the development of the GEOSS water strategy carried out by the IGWCO CoP resulted in a number of recommendations that provided a stronger focus and renewed interest in many of the community's discussions and actions.

Regarding size, it would appear that there is an optimum size for the community of practice: if too small, there are insufficient active members to cover the range of issues to be discussed; if too large, people lose interest as activities may become less relevant to their interests. Currently, the IGWCO community of practice is considering subdivision, either on the basis of geography to support new initiatives developing in the USA or by function to better address the GEO focus on user engagement.

The WEF nexus community of practice platform

The strong dynamic relationships between water, energy, and food systems compound the stresses exerted on each individual system by changes in human societies and the global climate. The relationships between these systems lead directly the water-energy-food (WEF) nexus as a platform for the sustainable management of these primary resources. Recent developments of nexus tools and applications point to be potentially significant benefits of a facilitated nexus community of practice to share best practices and knowledge for advancing future nexus implementation.

The NCoP and its sub-communities would be instrumental in creating a platform to empower local communities: they would consider site-specific information and enable data transfer, adaptation, and application in multiple contexts to encourage holistic approaches. The communities would facilitate monitoring and understanding environmental conditions and needs and would promote and address the significant knowledge gaps that exist in science, education, and governance. The NCoPs would enable integrated research efforts, capacity building, outreach, and education, as well as empower local work related to global problems. Nexus solutions would be applied locally, yet transcend regional and national borders; they would promote interdisciplinary cooperation and inclusive, transparent approaches among stakeholders, which must complement the Sustainable Development Goals (SDGs) and encourage scientifically enabled policy, monitoring, assessments, and cooperation. The NCoP has the potential to engage with global nexus efforts and to share experiences, data, and tools, thus distributing best practices and helping learn to avoid pitfalls that often arise in the implementation of integrated holistic approaches.

The WEF nexus framework can be built on joint management across the nexus sectors and supported by technologies, observations, science, and good governance as well as the formation of a nexus community of practice that could play an important role in supporting the nexus platform as it moves from planning to implementation (Lawford and Mohtar 2015).

Successful achievement of any single SDG would require global efforts and holistic, multidisciplinary approaches, representing an opportunity for coordination through nexus means. For example, the nexus platform, provided by the WEF NCoP, could help by answering questions related to achieving the water goal without sacrificing food security,

given that food security is inherently dependent upon water availability. The post-2015 agenda and its implementation will have huge implications for the WEF nexus.

Summary

As described, the nexus approach offers an effective method for achieving sustainability through interdisciplinary cooperation at local, national, and global scales—it offers inclusive, transparent, intergovernmental approaches for all stakeholders, and it supports the UN SDGs as well as encourages the use of scientifically enabled policy, monitoring, assessment, and cooperation. While a nascent version of such a community is a natural outcome of the WEF activities described in this paper, it is essential to formalize the mechanism: the WEF NCoP would have an instrumental role in creating a platform to empower local communities; would consider site-specific information and data that can be transferred, adapted, and applied in multiple contexts to encourage holistic approaches; and would facilitate the use of monitoring and understanding ecosystem conditions and needs. Moreover, the WEF NCoP would take the lead in identifying and addressing the significant knowledge gaps that exist in science, education, and governance of the nexus. Furthermore, the community would enable integrated research efforts, capacity building, outreach, and education to address local efforts related to global challenges. Just as nexus solutions applied locally will transcend regional and national borders, so should they promote interdisciplinary cooperation and inclusive, transparent approaches among all stakeholders?

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