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The WEF Nexus Journey

Rabi H. Mohtar [1,2,3,4]*

[1] WEF Nexus Research Group, Department of Biological and Agricultural Engineering, Texas A&M University, College Station, TX, United States, [2] Zachry Department of Civil and Environmental Engineering, Texas A&M University, College Station, TX, United States, [3] Faculty of Agricultural and Food Sciences, American University of Beirut, Beirut, Lebanon, [4] Department of Agricultural and Biological Engineering, Purdue University, West Lafayette, IN, United States

This paper describes the beginning of the WEF Nexus Journey in the classroom and shows how the Nexus emerged into the discipline that it is today. The paper offers definitions, shares some success stories from around the world, reflects on future opportunities, and provides a few concluding remarks.

Keywords: WEF Nexus, sustainability triangle, food security, Nexus tradeoffs, WEF analytics, WEF interlinkages, hotspots, stakeholder engagement

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South Africa

Correspondence:
Rabi H. Mohtar
mohtar@tamu.edu

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THE JOURNEY

In late 1990, interest in agricultural engineering was declining among students entering colleges of engineering and of agriculture. Departments across the nation changed their names to include environmental, biosystems, and other natural resource terminologies. My own department at Purdue was part of both colleges. I requested the department chair to include me in its student recruitment team for our colleges of agriculture and engineering so that, as a member of the team, I could work to recruit freshmen from both colleges into the agricultural engineering department. My recruitment strategy was focused on including non-traditional students who typically did not see agriculture as part of their future career. I introduced the department by focusing on the threatened, interconnected water, energy, and food systems; on how an agricultural engineer might contribute to this grand challenge of water, energy, and food security. My presentation introduced what I called the "sustainability triangle" (**Figure 1**). We witnessed a significant spike in interest around this grand challenge among rural and urban students of diverse ethnic backgrounds.

In 2008, as the inaugural director of Purdue's Global Engineering Program, I had the opportunity to further develop these concepts and incorporated them into the academic programs we offered. In 2009, I was invited to join the Water Security Council of the World Economic Forum and discovered that term WEF (water, energy, food) for worked well for both the Nexus and the World Economic Forum, where I further developed this systems approach to water security. The water security council included members from public and private sectors, international organizations, non-governmental organizations, and some academics. The WEF Nexus concept was adopted by the Council in January 2011 at the annual meeting of the World Economic Forum in Davos and published for the first time (Mohtar, 2011).

Thus, the Nexus took off on the global stage. What began with the water security publication of the World Economic Forum (Davos, January 2011) was followed in November with the Bonn 2011 Conference, focused on the interdependencies of water, energy, food securities and explicitly identifying the role of decision making (Hoff, 2011). In June 2012, the Rio+20 United Nations Conference on Sustainable Development recognized and highlighted the WEF linkages to nutrition, sustainable agriculture, sustainable cities, health, biodiversity, and desertification. At COP18, the United Nations Climate Change Conference of Parties in Doha, the food-water-energy nexus was presented as describing the "human face"

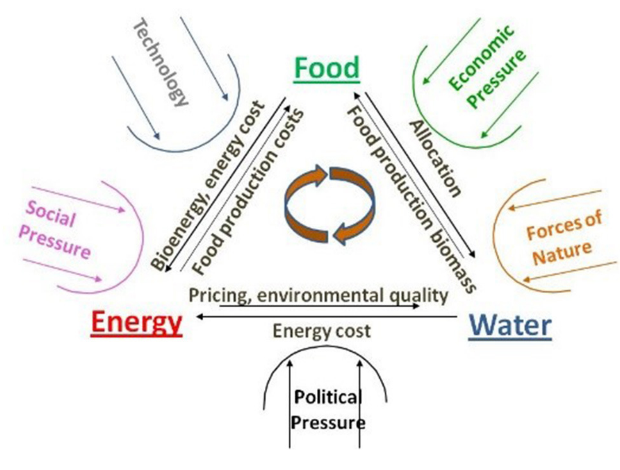

FIGURE 1 | The sustainability triangle (Mohtar, 2002).

of and solution to climate change. The conferences of the World Meteorological Organization (WMO) and the German Development Agency (GIZ) both focused on these issues. In 2014, the InterAction Council and the East-West Institute (EWI) presented the WEF nexus as a global security threat in their WEF risk report of 2012; EWI did the same in 2014. Also, in 2014, the G-20 Clean Energy Ministries launched its WEF workstream (World Economic Forum, 2012; EastWest Institute, 2014). In 2015 G-20 Clean Energy Ministries launched its WEF workstream (IISD 2015) and the 7th World Water Forum in South Korea and the SDGs Post 2015 Agenda were highlighted in Paris at the SDGs post 2015 Climate summit. The Nexus mushroomed again in Bonn, in North Carolina, and in a joint workshop in Washington DC through a Global Water System Project and grant from the Belmont Forum (Lawford and Mohtar, 2015). The World Bank launched its Thirsty Energy Initiative (Rodriguez et al., 2013) and the Department of Energy, in its 2017 Report to Congress, acknowledged that the dependence of energy on water is a risk to both water and energy security (US Department of Energy, 2017). Later that same year, the National Science Foundation (NSF) launched its INFEWS program: Innovations in Food Energy Water Systems.

Thus, was the progression and development of the Nexus. From its very early stages, the principles were those of a holistic, multiscale, multistakeholder nexus. First that the integrative view of water, energy, and food resources management must prevail at all levels and be based on inclusiveness for all sectors: governance, academic, civil society, and private. The second principle is to define and quantify the interconnectivity among the W-E-F resources, creating a basis for use in policy and planning. Third: to better engage the private sector for its role in supply chain management, mobilization of resources, conservation, and responsible investment, including research and development for enhanced business opportunities and technology development.

The early discussions focused on the Nexus approach as holistic and multiscale, involving multiple stakeholders, and the stated principles. Unlike other academic disciplines, the Nexus emerged from the need for better management of the primary resources of water, energy, and food. Policy makers and industry leaders endorsed the concept in high level discussions. We did not need to convince them of the importance of the new concept: *they got it*! However, after buying in, they needed guidance on implementation, demonstration, and they needed success stories.

WHAT IS THE NEXUS? HOW CAN WE DEFINE IT CLEARLY?

The Nexus offers a platform for a system of systems connecting the water-energy-food subsystems. It builds on, but does not replace, existing disciplines (Mohtar and Daher, 2012). The Nexus elements include the interlinkages, hotspots, and tradeoffs. Nexus builds on the water productivity concept familiar in agriculture, and on integrated water resources management, energy efficiency, and others. It connects government policy, society, and business supply chains (**Figure 2**; Mohtar and Daher, 2016).

The Nexus does not stop there, but continues beyond analytics to create a platform or framework that connects the science to the politics and to the political economy of the Nexus. It is the dialogue that moves the needle from conflict into cooperation. The two concentric circles in which the Nexus operates are the supply chain and the political economy, which comprise the defining factors of the resource availability and the portfolio of our resource nexus.

Building the WEF Nexus system using the food supply chain includes: (1) defining the components of the food supply chain, (2) establishing the water, energy, food resource portfolios, (3) quantifying the resource footprint (very important for modeling and existing data), (4) identifying the interventions that need to be studied (important crops, increasing self-sufficiency of other crops), (5) building the tool and doing the tradeoff analysis for various scenarios, (6) the sustainability index, and (7) the dialogue. Two types of dialogue are needed: one with the scientific community alone, and a second with the entire society: scientific, decision makers, and others involved in the resource nexus (Mohtar and Daher, 2016).

This brings us to the seven questions for setting up a nexus platform or solution (Daher et al., 2017). We must define the system, starting with the critical question to be answered and the scale at which this question is relevant. Not an easy task: the system must be defined so that anything beyond the boundary is excluded and everything within that boundary is included. Who are the stakeholders? What type of data is needed? What assessment tool can best asses the proposed interventions? How do we communicate with the stakeholders, involve them in the process, and assess their interaction with and acceptance of the process?

IMPLEMENTATION

The WEF Nexus Research Group at Texas A&M University has been active in many regional and international partnerships to assess different aspects of the Nexus. The research group

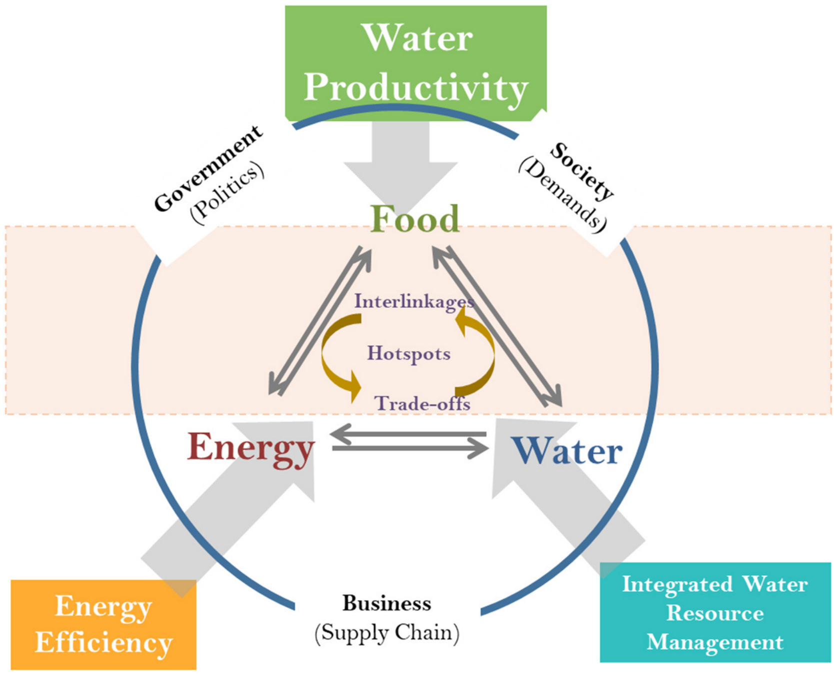

FIGURE 2 | Connectivity of the nexus elements (Mohtar and Daher, 2012).

looked at thematic and geographic applications, beginning with the launch of Qatar's National Food Security Program in 2011. When *Qatar* was struggling to find a solution to its food security challenges, our application allowed an analytical platform that considered the implications of achieving food security in Qatar (Mohtar and Daher, 2014).

In *Abu Dhabi*, the group worked with the International Renewable Energy Agency (IRENA) to help produce a comprehensive study on the steps needed for promoting renewable energy as part of the energy portfolio mix and how it interfaces with other energy sources, conditions, and limitations to this energy (International Renewable Energy Agency, 2015).

There are additional examples of energy deployment, including the sustainable energy portfolio of *Texas,* where the group worked on the projected water gap, critical when hydraulic fracturing was at its peak and the water needed for this process was taken from other sectors, mainly domestic and agriculture (Daher et al., 2019). This work focused on the tradeoffs between energy, water, and transportation. The transportation lifeline for water used in the hydraulic fracturing process are the roads, which also provide the transportation lifeline for communities and impact traffic and the safety of transport (Mohtar et al., 2019). As addressed more specifically below, the research group also considered the WEF Nexus in the San Antonio region (Mohtar, 2019), and a specific issue in Matagorda County, which neighbors Houston and has a large nuclear power plant whose need for cooling water competes with water needs of other sectors (Kulat et al., 2019).

A comprehensive study conducted in the *Gediz Basin* of Turkey looked at the tradeoffs between planting food for export, which competes for local resources in the region (Degirmencioglu et al., 2019). In Lebanon, we took a health centered approach that places health at the center of the Nexus (Bachour et al., 2020).

Morocco's phosphate industry posed a special challenge in water-scarce Morocco: phosphate production has a high-water footprint. We looked at the tradeoffs between the water used by the industry vs. the water used by other sectors, such as agriculture (Lee et al., 2020). In Morocco, we also looked at the tradeoffs between Nexus and the different sustainable development goals (SDGs) for water, energy, and food as part of the national plans for resource management (Daher and Mohtar, 2021).

In two unpublished studies, one in the Mekong Basin and the second in Nigeria, we looked at the Nexus tradeoffs between the hydropower industry (hydraulic energy), agricultural irrigation, community livelihood, and food security. Each of these case studies shares a common element of quantification of the interlinkages and the tradeoffs that exist in the analysis and validates the conclusion that the Nexus systems approach can offer economic benefits to multiple sectors.

A WEB BASED WEF NEXUS TOOL

The tool developed for implementing these concepts was first released in Qatar (Mohtar and Daher, 2012) and provided a user interface that allows entering the portfolios and questions about scenario components (food self-sufficiency, water sources and quantities, energy sources) and impact (import countries and the relative risks of importing commodities from that country). An administrative interface and a science component provide a "behind the scenes" look at local data characteristics. The Tool's output is the entire footprint of water, energy, land, carbon emission, financial constraints, and other elements. Combined, the policy and the science allowed us to produce a sustainability index, which, in turn, allowed comparison and ranking of various scenarios. Further development of the tool was later completed and published (Daher and Mohtar, 2015).

Implementation of the SDGs

The Tool allows us to look at the tradeoffs of implementing a series of interventions. The interconnected SDGs 2, 6, and 7 (zero hunger, clean water and sanitation, affordable and clean energy) represent our first attempt to create a consortium promoting the use of Nexus within the SDG community. Texas A&M led the effort in collaboration with World Wildlife Fund (WWF), International Union for Conservation of Nature (IUCN), Swedish Environmental Institute (SEI), The World Bank, International Food Policy Research Institute (IFPRI), Global Water Partnership (GWP), Deloitte, Asian Development Bank (ADB), International Water Management Institute (IWMI), and the OCP Policy Center. The take-away lessons showed that improving access to electricity can negatively impact ambient water quality, water availability, and ecosystem health. Ensuring universal access to affordable, reliable, modern energy services means substantially increasing the share of renewable energy in the global energy mix, doubling the global rate of improvement in energy efficiency, enhancing international cooperation to facilitate access to clean energy research and technology (including renewable energy, energy efficiency, and advanced, cleaner fossil-fuel technology, and promoting investment in energy infrastructure and clean energy technology). This would be done by expanding infrastructure and upgrading the technology to supply modern, sustainable energy services for all those living in developing countries, particularly the least developed countries, in accordance with their respective programs of support.

First in Morocco, we looked at the analytics of how water, energy, and food are interconnected in the national plan and then identified the associated tradeoffs. Morocco's green water plan sets targets for introducing income such as increasing production of olive, citrus, fruits, and vegetables. The effort to generate income resulted in reducing cereals production by 20% and moves from a self-sufficiency model into an economic model for agriculture. Morocco's 2030 water strategy includes desalination and treated wastewater (TWW); its energy strategy includes increasing renewable energy by up to 42%. After quantifying the interlinkages, we realized that these three plans compete for the same resources, mainly those needed for capital resources. Thus, if one looks at food, the tradeoff involves increasing the water-land-energy factor at the expense of food security. Regarding energy: reduced emissions come at the expense of finance, land, and water. Increasing the quantity of renewable energy means changing the allocation of land and water from agricultural production into energy production. Additionally, while water security is improved with added water and TWW, so are both energy demand and the financial burden. In conclusion, the tradeoffs that we identified and quantified must be considered before making the appropriate decisions presented in these national plans. The Nexus framework and Tool allow identification of these issues and is essential for such analysis to be accomplished.

The second version of the Tool, released to assess food security in Qatar (Mohtar and Daher, 2012, 2014; Daher and Mohtar, 2015), allows users to create scenarios for a given location by defining the inputs of the water, the food, and the energy portfolios. Users create scenarios and the Tool generates the sustainability index for each and quantifies the tradeoffs. This index is a measure of how sustainable the scenario is based on water, energy, land, environmental footprint and considering user preferences. For example, Qatar does not have sufficient land to independently ensure complete food security, so solutions requiring extensive land resources will not rank high on the sustainability index. The WET Tool (water-energy-transportation) used scenarios related to oil price, natural gas, and lateral drill length. We quantified tradeoff analysis for the scenarios and determined which is most site-specific and appropriate scenarios (Daher et al., 2019).

The San Antonio case studies focused on Region L of the Texas Water Plan (Mohtar, 2019) and used a system of systems approach. Thematic teams (Energy for Water, Water for Food, and Water for Energy) worked with stakeholders to collect data for modeling, governance, financing, and tradeoff analysis. A circular approach that circled some data back to stakeholders improved decision making. The goal was to better understand the Texas water gap projected over the next 20 years. By focusing on three subregions, each representing a distinct hotspot, we used a holistic systems approach to identify ways to bridge the projected 40% water gap for Texas.

We discovered that solutions are different for each zone or hotspot. In the Lubbock area, which has a declining water table due to over pumping by farmland, we encouraged dryland farming: different sources of water and fresh investment in the sector were needed for agriculture. In San Antonio, a growing area with high demand for municipal water, solutions included implementation of low impact development solutions, which requires investment and could carry potential for both ground water recharge and urban agriculture. The Eagle Ford shale region produces a lot of energy and developing shale production increases ground water consumption. One unique aspect of shale gas production is its very intense consumption of water, in both space and time. The wells are very localized and require a lot of water at certain peaks, which presents a particular challenge that must be addressed in terms of total quantity of water needed and in terms of the spatial location and time so as not to coincide with other peak demand times for water, whether for agriculture or municipal.

IMPACT OF WEF NEXUS SOLUTIONS

Three tools can highlight the impact of WEF Nexus solutions. The Water-Energy-Transportation (WET) Tool, designed to quantify the relations and tradeoffs between the water, energy, and transportation sectors for different scenarios, using factors like increased oil and gas production, market prices, lateral lengths of wells, and input amounts of water. The tool allows us to look at the scenarios and promote the best options as we move forward (Daher et al., 2019; Mohtar et al., 2019).

The Matagorda County Tool shows that annual income could increase by as much as $32 million dollars above the current "business as usual" scenario, mainly in the agriculture sector that is currently suffering from a lack of water (Kulat et al., 2019). The Energy Portfolio Assessment Tool (EPAT) allows options for the energy portfolio and shows that some energy policies can mitigate carbon emissions, even after capacity increase, by decreasing water withdrawal volume by almost 10% and, that CPP technology policy increases water consumption by 5%, land use by 143%, and cost by 18% (Mroue et al., 2019).

Tradeoffs of Wastewater Reuse in Agriculture

The benefits of wastewater reuse in agriculture are clearly translated into economic growth, coastal and riparian protection, reduction of climate variability and risk, and food security (Dare et al., 2013, 2017). Trade-offs carry some negative aspects: farmer and consumer perceptions, carbon emissions, treatment and conveyance costs, public, and environmental health risks. The tradeoffs need to be facilitated through supportive public policy, good governance, and viable economic models. The potential of water reuse for agriculture must consider all the principles identified in a water-energy-food nexus approach and then simulate these to begin assessing the different scenarios and their tradeoffs.

AUB Success Stories

In Lebanon, The American University of Beirut (AUB) launched The Water-Energy-Food-Health Nexus Renewable Resources Initiative (WEFRAH) in 2018. The WEFRAH community is one of the largest in the region working on the interconnectedness of resources. WEFRAH encompasses over 100 members and 60 researchers spread over 9 research clusters. Community members represent policy, business, agriculture, health care, technology, physical sciences, engineering, social sciences, natural sciences, arts and design, nutrition, public health, nature, ecosystems, and more. The goals of the WEFRAH community include understanding system complexities, reducing interdependencies of primary resources, increasing community resilience, and promoting ecosystem and human health and wellbeing. Adding the health component into the Nexus places additional complexity in the system. Nine projects are being developed, which impacts include: a digital framework for detection of plant pests, an optimized air distribution system for poultry houses, anaerobic digestion to head poultry houses, data on uptake of antibiotics by plants, technology based on the movement of antibiotics in water, a prototype to identify and promote healthy sustainable diets, prototypical solutions in humanitarian engineering, and circular aquaponics systems. We are looking into various venues to publish the work.

FUTURE OPPORTUNITIES

Future opportunities begin with a sustainable business model for agricultural systems: the current food and agriculture system is not sustainable. While food production has provided real success stories in terms of producing enough food globally for the world's population, some questions have been ignored such as nutritional value relative to water and energy use, as well as air quality and impact on soil health. In the future, we will not have the same quantity of water allocated to agriculture, thus, we need a different model. One that allows the use of multiple and different sources of water; one that considers the human and ecosystem values of this water. Here is where the Nexus can contribute.

A second future opportunity lies in the circular food and agriculture system. Inputs to such a system include renewable water, renewable energy, and nutrients. A circular system would have reduced carbon emissions, reduced chemical and biological pollutants, and reduced food wastes and loss. If we look at the tradeoffs in the outcomes of such a model, keeping in mind the human and ecosystem resource nexus, the choices for a circular food and agriculture system changes and are site specific. Making such a transition requires appropriate technologies and policies but more importantly behavioral changes.

Another future opportunity is the water-food-health nexus, where "one health" is promoted through the interconnections of water and human health. Drinking water, sewage, seas, and rivers are considered with their interconnections among water, animals, and food. This includes irrigation water, farm aquaculture, food poisoning, and especially antibiotics and antibiotic resistance. All these lead to a "one-health" system that allows real focus on the human ecosystem and animals in the food supply chain, i.e., the food system as a single unit.

CONCLUSION

We must take a step back and look beyond the tradeoffs and zero-sum resources allocation model. Today we are at a place where the projected requirements for primary resources have gaps in providing the water, energy, and food needed. We have low resilience to climate change, as is manifested through wildfires, record temperatures, and reduced agricultural productivity in many parts of the world. We have inequity and variability in distribution. We have tradeoffs among possible interventions. Looking at the tools that allow work with technologies, social, political, and economic levers and into the platform created to bring in the private sector, the public sector, and civil society, it is possible to make a leap into the future. A leap that increases the resource base by creating synergies, reducing interdependencies, improving equity and distribution, to achieve the sustainable development goals (SDGs) and improve overall resilience.

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RM is the sole author of this manuscript and wholly accountable for its contents.

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