

BRIDGING THE WATER AND FOOD GAP: THE ROLE OF THE WATER-ENERGY-FOOD NEXUS

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Bridging the Water and Food Gap: The Role of the Water-Energy-Food Nexus

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ABSTRACT

The paper introduces global resources challenges and their risks and shifts in what society defines as global securities. The paper will then introduce the water-energy-food nexus as a resource integration platform and will highlight green water as a hotspot in this nexus. Analysis will focus on the manner in which green water should be viewed as a resource base for food security. Discussions related to its regional integration into food security issues will be explored and the implications of climate change and externalities that affect water resources variability will be discussed. Nexus hotspot applications are introduced to highlight the use of the nexus as a holistic platform to address water, energy, and food resources. The paper closes with the presentation of recommendations for next steps.

1. Introduction

Food and water security are among the top global risks facing the future of our planet and our way of life. Not surprisingly, four out of the top 10 global risks highlighted in the 2014 World Economic Forum report, *The 2014 Global Risks Report*, are directly related to water and food security. The report highlights a major shift in the risks and in the manner in which the global community views these risks. The major risks are seen as economic, environmental, and societal, rather than geopolitical, and this represents a major shift in the manner in which the global community sees future risks. The report touched on enabling conditions for good resource management, i.e. governance and political and social instability. The report also highlighted the way in which global risks are interconnected and have large-scale impacts that ripple across economies and societies. Managing global risks effectively requires that we make the effort to understand, measure and foresee the evolution of the interdependencies between risks. Essentially, the report reaffirms previous calls for nexus thinking: looking not at each component in isolation, but rather, at the broader system of interactions of these components, and the refocus of our efforts into a new reality for managing their complexities.

Beginning with Bonn 2011, we will introduce the historical landmarks of the nexus scene and highlight the shift toward interdisciplinarity, understanding and identifying the role of this interconnectedness in decision making. At the same time, it must be emphasized that there is a need to create a holistic framework, one that considers the systems' existent interlinkages and offers decision makers solid grounds for debate, discussion, and action. A few of these landmarks are highlighted here.

- *Bonn conference (2011) focused on the interdependency of water, energy, and food security to be "explicitly identified in decision making".*
- *WEF "Water Security" publication in 2011, representing a major benchmark in developing the conceptual framework of the nexus.*
- *Rio+20 highlighted the linkages between water, food security, nutrition and sustainable agriculture, sustainable cities, health, biodiversity, desertification, etc.*
- *COP18, Doha, UNFCCC Executive Secretary, described the food-water-energy nexus as the "human face" and solution to climate change (WMO, 2012). The UN Secretary General highlighted the use of a Nexus Approach, urging the inclusion of environmental, social and economic dimensions (GIZ, 2012).*
- *WEF as global security issues (InterAction Council summit, Bahrain, May 2013).*
- *G-20 Clean Energy Ministries developing the WEF work stream. Korea, May 2014.*

Global Risks 2014 Report

Top 10 Global Risks of highest concern



The Big Risks: **Economic**, **environmental** and **societal** risks dominate. Although they were noted as major causes for concern, **geopolitical** and **technological** risks didn't come high on the radar.



| | | |
|-----|---|----------------|
| #1 | Fiscal crises | Blue diamond |
| #2 | Unemployment and underemployment | Blue diamond |
| #3 | Water crises | Green diamond |
| #4 | Income disparity | Red diamond |
| #5 | Climate change | Green diamond |
| #6 | Extreme weather events | Green diamond |
| #7 | Global governance failure | Orange diamond |
| #8 | Food crises | Red diamond |
| #9 | Failure of financial mechanism or institution | Blue diamond |
| #10 | Political or social instability | Red diamond |

Source: World Economic Forum Global Risks 2014 Report, Global Risks Perception Survey 2013. <http://wef.ch/grr2014>

Figure 1: Top 10 global risks of highest concern, as reported in World Economic Forum Global Risks 2014 report (Accessed online in August, 2014).

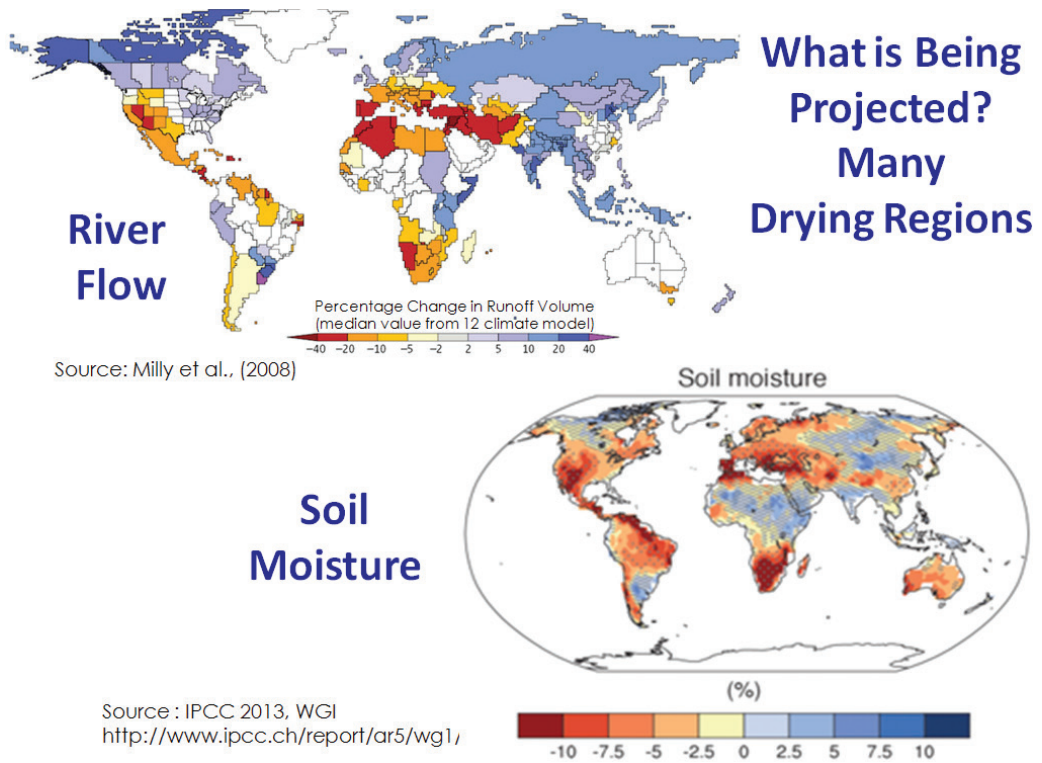


Figure 2: The projected climate change spatial variability of global shifts in river flows ("blue water") and soil moisture ("green water"). The wet regions will get wetter and the dry regions will become dryer. (Developed from Milly et al., 2008 and IPCCa, 2013)

The change in the risks, from geopolitical to economic, were also highlighted in other reports, including the InterAction council report (Axworthy and Adeel, 2014), which highlighted the Water Energy Food (WEF) nexus as a major risk for humanity, together with nuclear risks and those of terrorism. The consequences of climate change spatial variability on water and food supply are difficult to predict precisely, but, in general, the negative consequences will outweigh the positive (Godfray et al., 2010). A study of global projections based on different climate change scenarios and models, enforces the principle that wet regions will receive even more water and dry regions will become dryer; and that there will be ecological shifts due to rising temperatures, which will lead to increased risk for water and food security and their distribution (Figure 1.2). Dramatic changes are expected in the availability and spatial distribution of renewable fresh water, both 'blue water' in rivers, lakes, and ground, and 'green water' in evapotranspiration and soil moisture. Blue and green water are collectively represented by river flows and soil moisture (Milly et al., 2008; IPCCa, 2013). Figure 1.2 shows a significant and positive correlation between river flows and soil moisture.

The expected increase in drying regions is not the only manifestation in which climate change is shifting risks, as well as the potential for risk reduction through adaptation and mitigation. The temperature spatial and temporal pattern will change, and along with the change in rainfall patterns, the adaptation plan for the water-food supply will become even more challenging. Moreover, projections include more heat, decreases in subtropical intensification, longer periods between rain events, and drying of mid-continent in summer. All of these create increased risks of drought, hurricane intensities, and wind events, an increase in the number and intensity of storms, and a rise in sea level (Table 1.1). As an example, consider the potential impact of a 1.5 m sea level rise on Bangladesh (Figure 1.3): nearly 22,000 km² in coastal areas, 16% of the country's land area, will be flooded and hence no longer be arable resulting in 17 million inhabitants, or 15% of the population being impacted (UNEP/GRID, 2006).

The implications of these risks can be summarized in increased plant water needs, greater urban demand, and less fresh water supply, especially in the subtropics. There will be more pests, less grass, a general northerly crop migration, and changes in the eco-zones of crops. All of these projected risks are associated with diminishing water quality, increasing energy prices, and intensification of water-food insecurity in the most vulnerable countries in the world.

The world also faces a shift in the global grand challenges due to internal dynamics (Figure 1.4). The population is expected to grow to 9 billion inhabitants by the middle of this century; the majority of this population will live in cities in developing countries. An additional 1,669 billion cubic meters of water (40% new water) is needed, by 2030 to meet their water, food, energy and living demands (WEF, 2011). These inhabitants are expected to be wealthier and their purchasing power will enable a higher demand of processed food, meat, and dairy, causing further pressure on the food supply system (Godfray et al., 2010). At least a 50% increase in the food demand, and a 40% increase in energy demand is expected by 2030 (WEF, 2011). Such demands impose a challenging question

Table 1: Projected change in global mean surface air temperature and global mean sea level rise for the mid and late 21st century, relative to the reference period 1986-2005. (IPCC, 2013b)

Table SPM.2 | Projected change in global mean surface air temperature and global mean sea level rise for the mid- and late 21st century relative to the reference period of 1986–2005. (12.4; Table 12.2, Table 13.5)

| | | 2046–2065 | | 2081–2100 | |
|--|----------|-----------|---------------------------|-----------|---------------------------|
| | Scenario | Mean | Likely range ^c | Mean | Likely range ^c |
| Global Mean Surface Temperature Change (°C) ^a | RCP2.6 | 1.0 | 0.4 to 1.6 | 1.0 | 0.3 to 1.7 |
| | RCP4.5 | 1.4 | 0.9 to 2.0 | 1.8 | 1.1 to 2.6 |
| | RCP6.0 | 1.3 | 0.8 to 1.8 | 2.2 | 1.4 to 3.1 |
| | RCP8.5 | 2.0 | 1.4 to 2.6 | 3.7 | 2.6 to 4.8 |
| | Scenario | Mean | Likely range ^d | Mean | Likely range ^d |
| Global Mean Sea Level Rise (m) ^b | RCP2.6 | 0.24 | 0.17 to 0.32 | 0.40 | 0.26 to 0.55 |
| | RCP4.5 | 0.26 | 0.19 to 0.33 | 0.47 | 0.32 to 0.63 |
| | RCP6.0 | 0.25 | 0.18 to 0.32 | 0.48 | 0.33 to 0.63 |
| | RCP8.5 | 0.30 | 0.22 to 0.38 | 0.63 | 0.45 to 0.82 |

Notes:

- ^a Based on the CMIP5 ensemble; anomalies calculated with respect to 1986–2005. Using HadCRUT4 and its uncertainty estimate (5–95% confidence interval), the observed warming to the reference period 1986–2005 is 0.61 [0.55 to 0.67] °C from 1850–1900, and 0.11 [0.09 to 0.13] °C from 1980–1999, the reference period for projections used in AR4. *Likely* ranges have not been assessed here with respect to earlier reference periods because methods are not generally available in the literature for combining the uncertainties in models and observations. Adding projected and observed changes does not account for potential effects of model biases compared to observations, and for natural internal variability during the observational reference period (2.4; 11.2; Tables 12.2 and 12.3)
- ^b Based on 21 CMIP5 models; anomalies calculated with respect to 1986–2005. Where CMIP5 results were not available for a particular AOGCM and scenario, they were estimated as explained in Chapter 13, Table 13.5. The contributions from ice sheet rapid dynamical change and anthropogenic land water storage are treated as having uniform probability distributions, and as largely independent of scenario. This treatment does not imply that the contributions concerned will not depend on the scenario followed, only that the current state of knowledge does not permit a quantitative assessment of the dependence. Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the *likely* range during the 21st century. There is *medium confidence* that this additional contribution would not exceed several tenths of a meter of sea level rise during the 21st century.
- ^c Calculated from projections as 5–95% model ranges. These ranges are then assessed to be *likely* ranges after accounting for additional uncertainties or different levels of confidence in models. For projections of global mean surface temperature change in 2046–2065 *confidence* is *medium*, because the relative importance of natural internal variability, and uncertainty in non-greenhouse gas forcing and response, are larger than for 2081–2100. The *likely* ranges for 2046–2065 do not take into account the possible influence of factors that lead to the assessed range for near-term (2016–2035) global mean surface temperature change that is lower than the 5–95% model range, because the influence of these factors on longer term projections has not been quantified due to insufficient scientific understanding. (11.3)
- ^d Calculated from projections as 5–95% model ranges. These ranges are then assessed to be *likely* ranges after accounting for additional uncertainties or different levels of confidence in models. For projections of global mean sea level rise *confidence* is *medium* for both time horizons.

about the adequacies of water, land, energy resources and infrastructures to meet the needs of the increased number of inhabitants. The question is not only about availability but also about equitable distribution and accessibility to these resources all over the world. For instance, the decrease in precipitation in most subtropical regions is associated with decreased food production. In addition to these uncertainties and challenges, the most critical challenge, from the science and policy perspective, is that they are non-stationary: the past will no longer be a reliable predictor of the future, and this reality plays an important role in the ability to predict and plan for adequate water, food, energy infrastructures under uncertain and changing climate conditions (Milley et al., 2008). In the end, we must develop adaptation plans for water, food and energy supply systems. These plans must maximize resilience to the dynamic internal and external stresses that are occurring in our world.

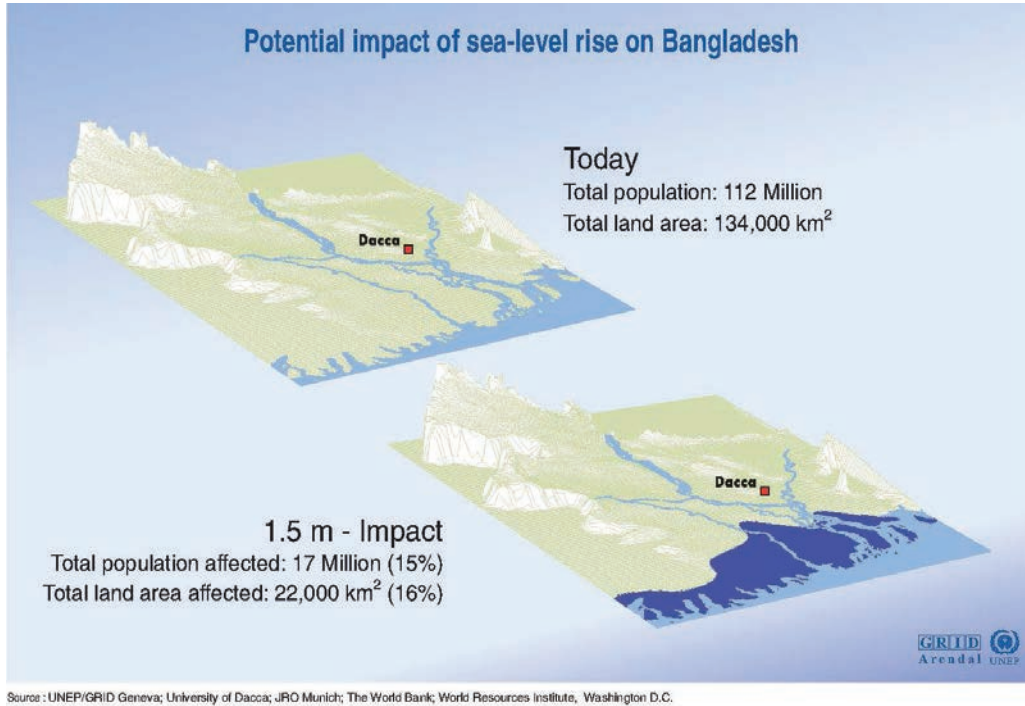


Figure 3: The potential impact of 1.5 m sea-level rise on Bangladesh (UNEP/GRID, 2006)

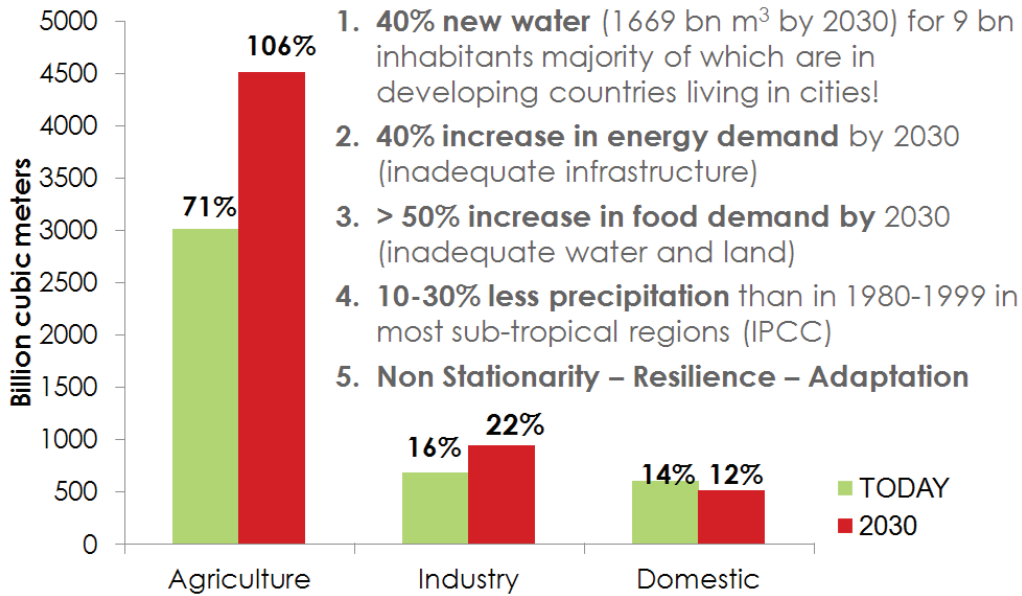
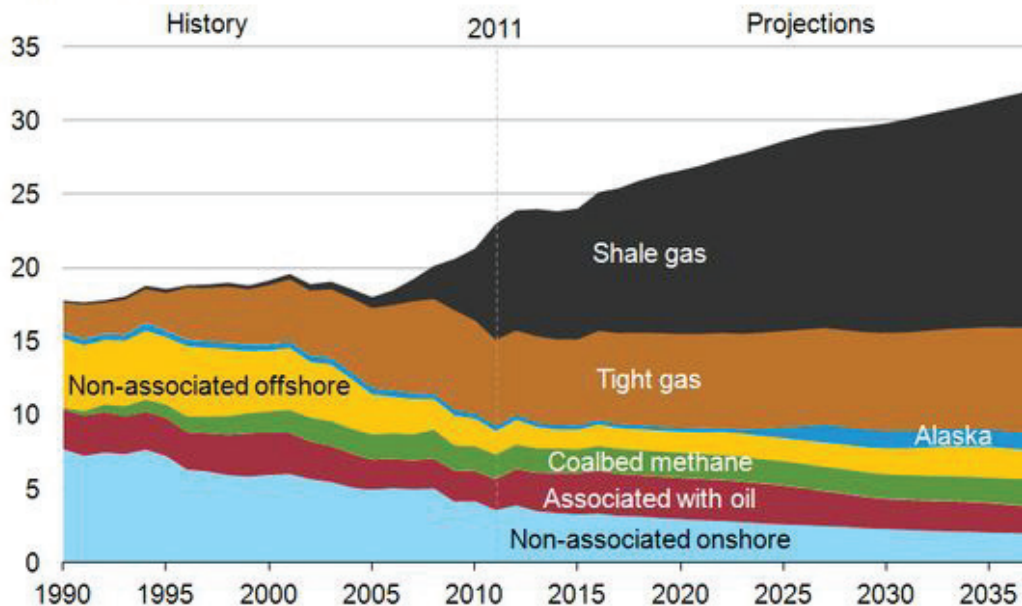


Figure 4: A summary for the global view of the grand challenges. (Data from WEF, 2011)

The high demand for energy is a driving force to find more resources. Despite the positive socio-economic implications, some of these resources add additional pressure on the quantity and quality of water resources. As a result of fracking, for example, the United States now is ranked first in shale gas production. Figure 1.5, below, shows a projection, from the U.S. perspective, of fracking and its potential contribution to gas production. However, this production imposes several environmental concerns or threats, including: water use in parched areas, creating waste water, the triggering of small earthquakes, contaminating groundwater, and reducing the demand for carbon-free renewable energy sources such as solar and wind, due to the low cost of natural gas.

The high interconnectivity of water, food and energy supply-demand management requires a holistic, multi-scale, multi-stakeholder approach. It requires a Nexus platform to determine the interlinkages and trade-offs for resources management and allocation and to look into hotspot interventions where nexus solutions can be entered.

**U.S. dry natural gas production
trillion cubic feet**



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2013 Early Release*

Figure 5: Projection from U.S. perspective of fracking and its potential contribution to gas production (EIA, 2013)

2. Situational Analysis of the Global Water-Food Demand and Supply Challenges

The biggest debate nowadays in tackling water and food security is: *whether the water-food crisis is due to the insufficiency of natural resources or due to a poor understanding and improper management of these resources*. As discussed in the introduction, the answer for such a question is geographically dependent, but we do believe that, overall, it is the poor understanding and improper management of the natural resources. For example, Godfray et al. (2010) concluded that "the world can produce more food and can ensure that it is used more efficiently and equitably". Still, 1-2 billion people are suffering from lack of access to sufficient dietary energy and/or micronutrients (Barrett, 2010). This means that more than 13% of the world's population lacks access to food or are chronically malnourished (FAO, 2009a; Godfray et al., 2010, Keating et al., 2014). Similarly, Oki and Kanae (2006) showed that the current global water withdrawal is far below the upper limit of global renewable fresh water. They questioned our concerns about water security, knowing that globally we are using only 10% and 30% of the blue and green water resources, respectively. However, there are still more than 1 billion people who lack access to safe drinking water (Gleick, 2003), and at least twice that number live in water-stressed areas due to the uneven distribution of the water resources.

According to Barrett (2010), food security is based on three inherently hierarchical pillars: availability, accessibility, and utilization. The factors affecting each of these pillars varies across the globe. There is high variation in the availability of natural resources, water, land, and energy, even across regions of the same climate. This is in addition to the socio-economic, cultural, natural, financial, and political constraints that also affect access and utilization of these resources. Together, these factors form a major challenge to successfully addressing the water and food crisis. The availability of sufficient natural resources to produce food is vital for water-food security. However, in many cases it is not the only reason for the global water and food crisis. The main reason for the suffering of more than one seventh of the world's population is access to food due to poverty and spikes in food prices (Foley et al., 2011; FAO, 2009b). It is expected that these spikes in food prices will become more frequent with the increase in competition for natural resources, mainly due to the bio-fuel production but also due to climate change. Thus, with the projected food prices shown in Figure 2.1, new political and economic dimensions will be added to the poverty and social dimensions already mentioned as factors essential to the effective understanding of the food crisis (Godfray, 2013). It should also be noted that the two major historical food prices spikes were primarily due to the challenges of the energy issue. In the 1970s, the oil crisis caused a spike in global food prices, and one of the major reasons for the 2008 spike was bio-fuels production.

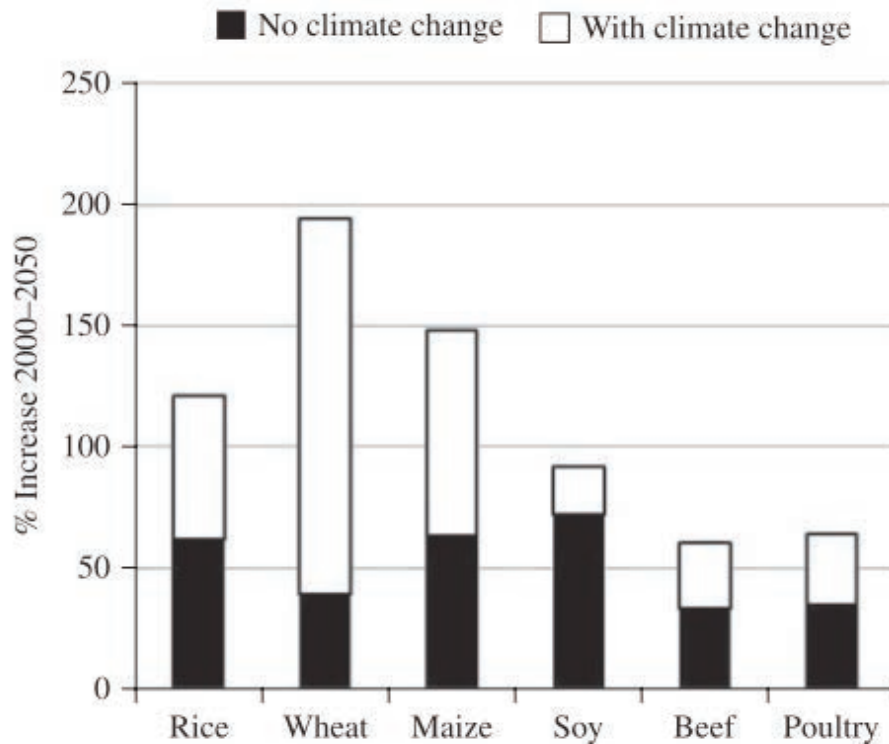


Fig. 2. Projected increases in the price of selected food categories between 2000 and 2050 with and without climate change. Source: Nelson *et al.* (2009).

Figure 6: Projected increases in the price of selected food categories between 2000 and 2050 with and without climate change. (Nelson *et al.*, 2009)

The third pillar, utilization, is also important. It highlights the societal values, attitudes and awareness about conserving valuable resources. In fact, utilization is a measure of the good use of the water and food accessible to human beings. Figure 2.2 shows the water footprint for the food supply chain. Nearly 50% of the food produced in the USA is lost or wasted at home, and the situation in UK is not much different, whereas the majority of the food loss in developing countries occurs on the farm, in transportation, and in processes due to other technical and financial reasons. Utilization is another dimension that concerns the use of safe, nutritionally balanced and essential food. These dimensions shed light on the need to change agricultural consumption patterns: considered to be a strategic necessity for facing food security challenges.

Agricultural intensification is one of the proposed solutions for facing the projected need for a 60-100% increase in food production by 2050 (FAO, 2006; Foley *et al.*, 2011; Alexandratos and Bruinsma, 2012) and to successfully meet the water-food crisis. The basis of this concept is to maximize food production while still using the same amount of water and land. To be sustainable, the impact on the

environment must be minimized. This represents a major challenge for many reasons, among them: (1) the area of productive land is decreasing due to human factors such as urbanization, and human-climate change factors (desertification, salinization, and soil erosion); (2) even though it seems more reasonable to carry out land reclamation in order to increase the productive use of land in some parts of the world, humans need to be conscious about the nature of this land. For instance, converting forests and wetlands to productive, agricultural land will increase greenhouse gases, thus quickening climate change; (3) the way in which food is produced also significantly impacts water resources, in terms of both quality and quantity. It further impacts the surrounding environment with respect to greenhouse emissions and biodiversity, as well as soil structure and health, both of which, in turn, affect the functionality of the productive land to continue to produce food in the future.

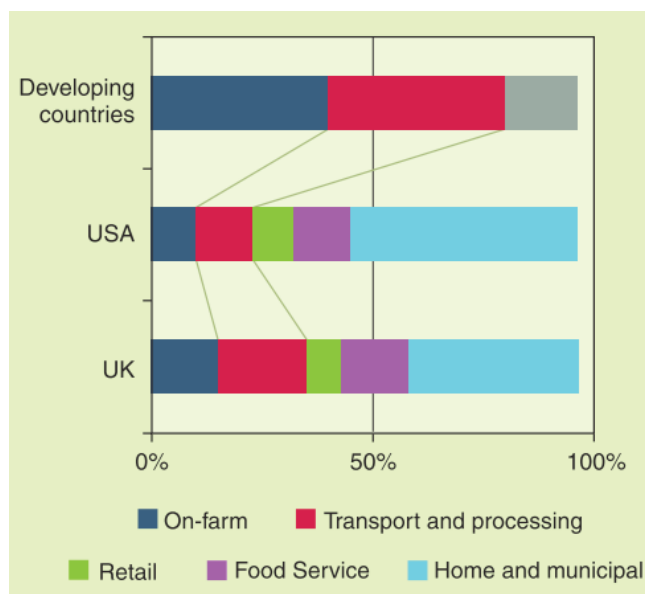


Figure 7: Makeup of total food waste in developed and developing countries. Retail, food services, and home and municipal categories are lumped together for developing countries (Godfray et al., 2010)

Considering the constraints mentioned above, agricultural intensification is a two-fold challenge. The first is about bridging the yield gap through minimizing the difference between current productivity and best potential productivity (Godfray, 2010; Foley, 2011). The second is about increasing the efficiency of usage, and thus the productivity of agriculture's natural resources: soil, water, and energy. In both cases, there is a need for access to better varieties of crop species, sufficient nutrients, safe water-supply, improved technologies, and management frameworks that optimize and maximize food production while minimizing its environmental side-effects. Foley et al. (2011) showed that bringing the yield for 16 staple crops (barley, cassava, ground nut, maize, millet, potato, oil palm, rapeseed, rice, rye, sorghum, soybean, sugar beet, sugarcane, sunflower and

wheat) to 95% of their best potential production will increase their current supply to the world food market by 58% (2.3 billion tons $\sim 5 \times 10^{15}$ kilocalories). While the spatial variability of such improvement is very high, as shown in Figure 2.3, the ability to bridge the yield gap is exceedingly constrained by the availability of soil, water, and energy resources.

Global food supply can also be increased by reducing food waste and altering the diet. Globally, 30-50% of the food produced on the farm is never consumed (Gustavsson et al., 2011; Lundqvist et al., 2008). As shown in Figure 2.2., the reasons behind such enormous losses vary and have a high relation to the type of countries, whether 'developed' or 'developing'. Foley et al., (2011) studied the potential increase in food supply as a result of altering the diet to use the same 16 staple crops (Figure 2.4). The motivation behind such an idea is the fact that more than 75% of the world's agricultural land is used to feed animals, and about 35% of the total mass of global crop production is used to feed these animals. They found that shifting these 16 staple crops' production to feed human beings, rather than animals, will add 1 billion tons (a 28% increase) to the food supply market. Such a shift is controversial and, in any case, very few countries are able to contribute toward it (as shown in Figure 2.4).

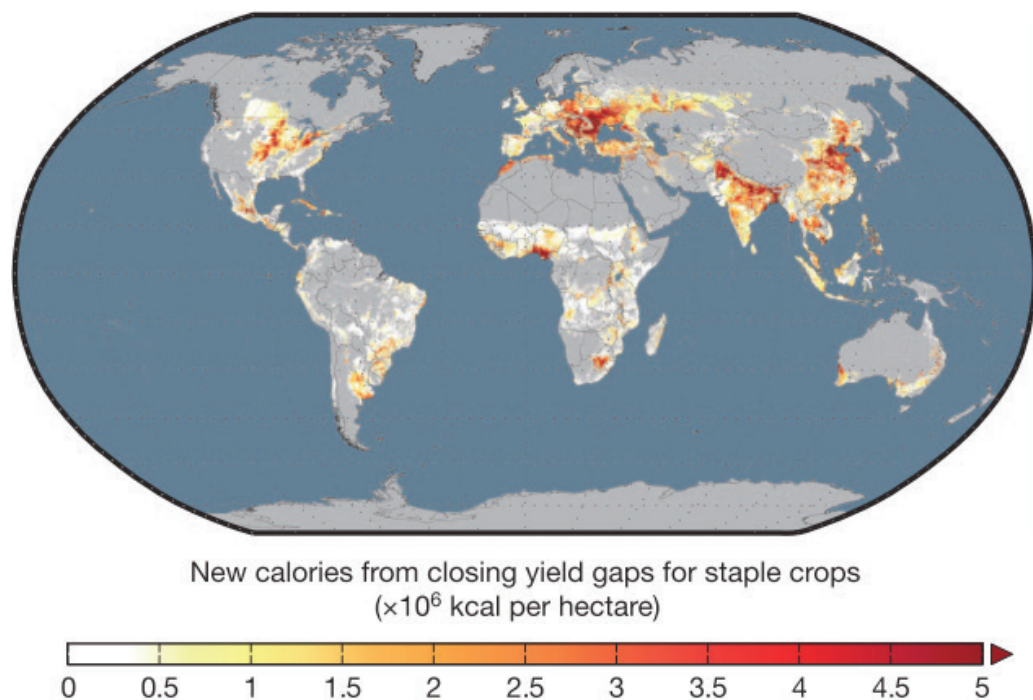


Figure 8: Spatial distribution of the potential new calories that can be added to the world food supply by bringing the world's yields to within 95% of the best potential yield for staple crops. The distribution and availability of the natural resources of soil, water, and energy have a clear footprint on the ability to bridge the yield gap (Foley et al., 2011).

It is obvious that there is no single general solution to the water and food crisis. The variation in the availability of natural resources, together with socio-economic, political and financial variability around the globe, make it more feasible to localize the water-food management system. Considering water utilization as a major global challenge, Gleick (2003) urged a soft path to localize the water supply system as a means of increasing the sustainability of these systems and the resilience of the communities depending upon those supplies. We agree with Gleick on the need to localize water-food supply systems and propose a new paradigm that enables quantification of the interaction and processes between the major natural components of climate, soil, and water: this paradigm will be discussed in section 3. At the same time, we suggest that the food-water system contains a third element and that the nexus of all three must be considered in a holistic approach that includes energy. We propose a framework to reduce the water-food crisis by localizing the food-water systems *and* globalizing the consequences through a water-food-energy Nexus Approach.

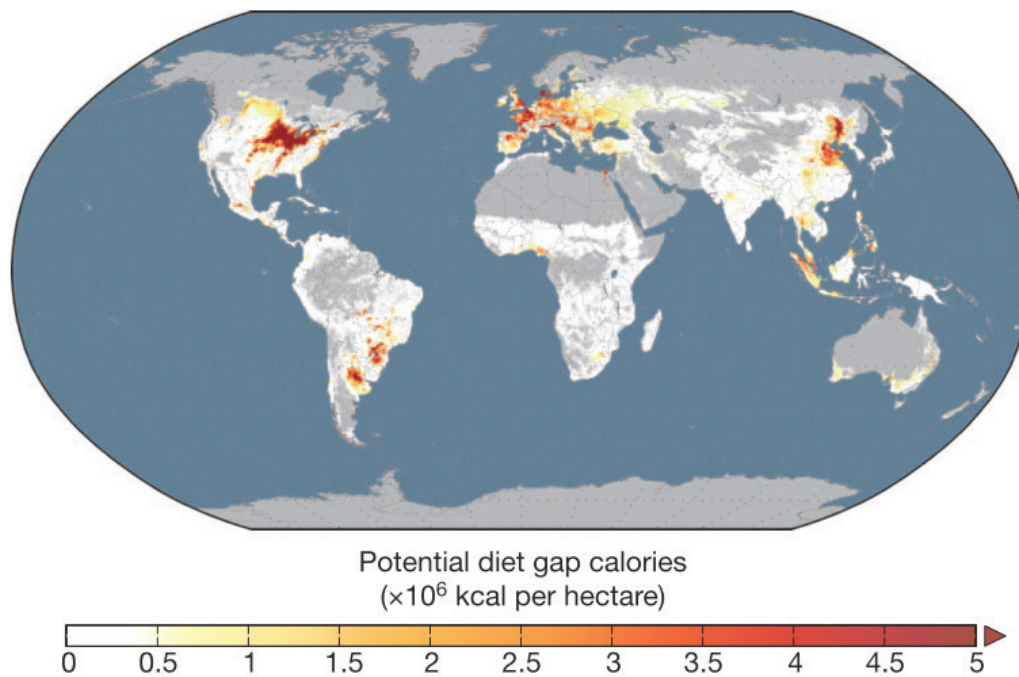


Figure 9: Spatial distribution of the potential new calories that can be added to the world food supply by devoting 100% of the 16 staple crops for human consumption. The distribution and availability of the natural resources "soil, water, energy" has a clear footprint on the ability to contribute for such a shift (Foley et al, 2011).

3. The Systemic Approach Applied to Quantify the Water-Food Nexus

The most promising, sustainable solutions for addressing the water-food crisis rest upon the assumption that there will be no additional land allocated for agricultural production. Thus, limited land resources requires our most effective and efficient use of water resources, the best seed varieties, and a minimum impact on the environment and soil health. This section will address two of these assumptions: (1) the effective use of water resources, namely, quantification and accounting for green water, and (2) the understanding, quantification and proper management of the impact of human agro-environmental practices on soil structure: a major contributor to the soil health. Such a task requires a new paradigm to consider the natural organization of the soil medium, and to physically quantify its interaction with water and with the surrounding environment. As mentioned before, water and environment, climate, and climate change, play pivotal roles in food security.

3.1 Water-Food Nexus

The question remains: how do we bridge the water-food gap that exists today, as well as the projected increase in this gap in the coming 10-15 years? Without doubt, trade, investment, and virtual water have been, and will continue to be, considered a significant element of the water-food security portfolio (Fig. 3.1). Many countries in dry and semiarid regions of the world will be incapable locally of producing sufficient food to satisfy their own needs. Another necessary element of the portfolio will be conservation: improved crop genetics, improved efficiency and appropriate policies. All of these components must be included as part of the food and water security portfolio for these and all nations. Nevertheless, this section will not highlight these important, and crucial elements but will focus on: better utilization of underappreciated and ill-defined sources of water, namely (1) green water, generally defined as the portion of rainwater that is stored in the soil and used by plants for evapotranspiration and consumptive use; and (2) NEW water (greywater, wastewater, and produced water from oil and gas operations), by quantifying and understanding the impact of such use on soil health, quality and productivity.

Based on the above description, an improved accounting mechanism and a better definition of green water (GW) must be established. This accounting mechanism will form the basis of geospatial mapping, allowing us to geospatially map green water resources, including regional integration of concepts for managing this resource. While defining these concepts, we must look at a larger scale of water use efficiency: that which goes beyond the farm gate and allows for a regional view of water use efficiency, and water and cropping allocation. Such mapping is not possible without scalable hydrological modeling that allows for the transfer of information from one scale to the other and across scales.

Similarly, NEW water (NW), consisting of grey, produced, brackish, and waste water, are resources that should constitute a significant part of bridging the water and food gap portfolio. However, three research and development gaps must be addressed for

Water-Food Nexus

1. Green Water

- ✓ Better accounting
- ✓ Mapping/Management
- ✓ Multi-scale Modeling

2. NEW Water

Grey, waste, and produced water, etc. :

- ✓ Potential use
- ✓ Impact on soil quality and health

3. Trade and foreign investment (Virtual water)

4. Conservation, efficiency policy, genetics

How to Bridge the Water Gap by 2030?

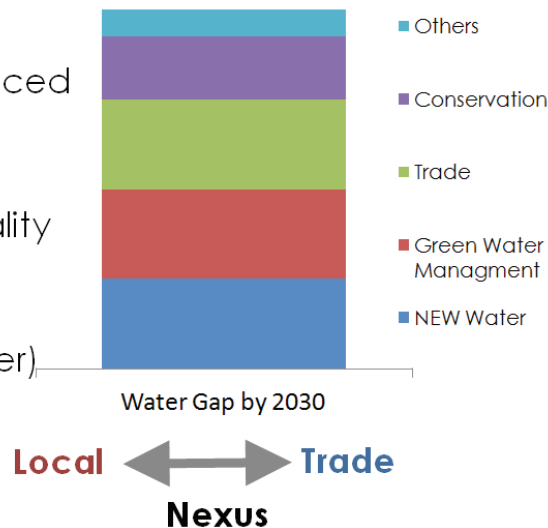


Figure 10: The nexus between local water resources and trade ("virtual water") and the question that scientists and policy makers alike will need to answer is: how much water can be derived from each resource to use for a specific location or scenario? The gap can be met with green water and the creation of water reuse scenarios that can fulfill some of the gap.

this to happen: (1) the need to establish the potential reuse of NEW water, in terms of quantification, proximity and use, and water quality regulations, (2) the need to establish the quantifiable impact of using these chemically enriched waters on soil quality and human health, and (3) an economic optimization of where and how technology for cleaning and remediating these NEW waters can be used, while keeping the end goal in mind in terms of the quality of the water and the cost of its use. Current waste water treatment methodologies are too costly and are not customized for specific effluent characteristics and the costs associated with selective treatment. For a long-term, more resilient water and food security system, the use of these two water supply pillars, green and new (grey) waters (GW and NW), must first be optimized for a specific community. Only then will we be able to look into trade and virtual water solutions.

3.2 Issues Surrounding the Green Water Concept

The sustainable use of the three pillars of the natural system, namely soil, water, and atmosphere, is key to addressing the water and food crisis of today and the future. However, managing these resources requires a quantifiable, physical characterization and modeling of the hydro-functioning of the soil-plant-atmosphere system. The lack of such a framework makes it difficult, if not impossible, for the scientific community to agree on a unified definition for green water. GW is that portion of rainwater naturally

available for crop production, and most importantly, for the functioning of all biotic and abiotic processes taking place within the soil. The global soil moisture (GW) represents only 5% of the global fresh water; however, four very important facts greatly increase its value: (a) 60% of global food production is produced by GW (Cosgrove and Rijsberman, 2000), (b) 87% of the water used in global crop production in the year 2000 was GW (Liu and Yang, 2010), (c) 58% of the world's cereal production is cultivated in areas that use only GW, and (d) we utilize only 30% of the renewable green water globally. In their study of modeling blue and green water availability in Africa (Schuol et al., 2008), and as shown in Figure 3.2, Schuol et al. concluded that there is double green water storage in the soil water profile as blue water availability in Algeria and Morocco. Even though the numbers in Figure 3.2 are preliminary and require additional precision in terms of accounting for the various water pools, these numbers substantiate the fact that, by itself, GW is a resource that must be better utilized and that while most dryland regions focus on blue water resources, special focus on green water is a worthwhile and perhaps, more productive effort (Kauffman et al., 2014).

The concept of green water was first introduced by Falkenmark (1995) as a potential option for increasing agricultural production. He defined green water as the fraction of rainfall that infiltrates into the root zone and is used for biomass production or evapotranspiration. In fact, not all the water that infiltrates into the root zone stays there. Some of it percolates or flows to groundwater and rivers, becoming blue water. Later (Rockström, 1999) redefined green water by considering evaporation from surface and intercepted water as a non-

Average Available and Renewable Water in North Africa (km³/yr)

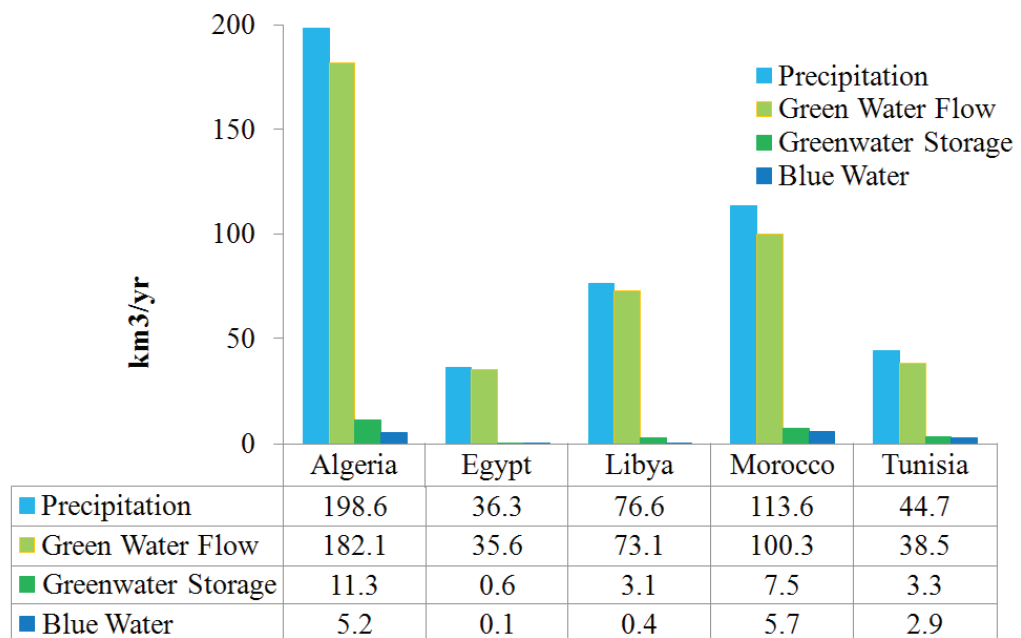


Figure 11: The green and blue water portions of total precipitation. (Data obtained from Schuol et al., 2008)

productive fraction of green water. This definition brought additional confusion regarding the identity of GW by considering evaporation as green water. Finally, both Falkenmark and Rockström (2006) concluded that GW consists of two parts: (a) green water resource (storage) which equals the soil moisture; and (b) green water flow, which equals the sum of the actual evaporation and actual transpiration. However, Gerten et al. (2005) had a different definition of GW: it is the precipitation water stored in the soil and eventually transpired by natural and agricultural vegetation. Gerten thus excludes the accounting of evaporation in GW, thereby contradicting the definition by Falkenmark and Rockström (2006).

3.3 Pedostructure -SREV Concept: A Quantification Tool of Soil-Water-Atmosphere Interactions

Part of the confusion surrounding the definition of green water as an important resource that must be better utilized is related to how we consider the soil-water medium. Here we will explore three research gaps in soil-water physics and modeling that limits our ability to precisely define and quantify green water.

Gap 1: *The lack of recognition and characterization of soil as the organized physical medium, providing the physical conditions for life and development of the numerous biotic and abiotic processes inside the soil medium.*

We will show here that we must adopt a new paradigm for characterizing and modeling the physics of the water cycle in the soil and the interaction of water with the natural environmental medium consisting of soil and air. Only then will we be able to quantify and manage the green water. To model these natural interactions, we distinguish between what is called 'free' or 'blue' water, whose principle driving force is gravity, and what we will now refer to as 'thermodynamic water' or green water, which is linked in dynamic equilibrium with other basic components of the local environment: namely solid particles and air or atmosphere. In fact, in contrast to blue water, which is well known and modeled by hydrologists, the thermodynamic aspect of water is poorly known, especially within the soil medium. The problem is that the water in soil is mainly thermodynamic but cannot be neglected due to its direct link to the climatic conditions for life in the soil and in the air above the soil.

The soil medium is differentiated into horizontal layers, called soil horizons. These soil horizons have different structures, each of which is characterized by its own hydro-structural properties. These horizons and their characteristic structures (pedostructure) result from the pedo-climate regime which is the direct product of both water cycles: the blue water cycle, starting with rainfall on the soil surface and going down or laterally through gravity, and the green or thermodynamic water cycle, which is linked to the medium and goes up through the soil-plant-atmosphere continuum. See Figure 3.3.

Today, the problem lies in characterizing the organization of the soil medium and its functionality with water, as illustrated in Figure 3.4 (Lin et al., 2006). Both graphs represent the three axes of description for any organized object, in this case the soil. Axis 1 represents the evolution of soil over time, axis 2 represents the nature and morphology of soil (soil genesis and organization, or pedostructure). Together, axes 1 and 2 represent the solid plane, where the soil properties are a function of the morphology and evolution as these are impacted by soil management. This plane offers substantial descriptive or qualitative

Physics of soil and water interactions in the critical zone

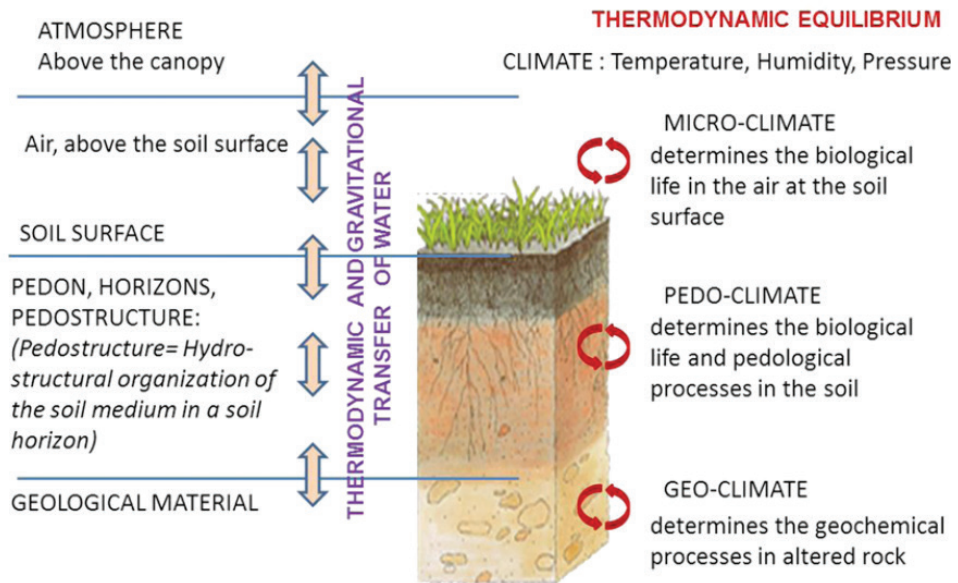


Figure 12: Modeling the soil-plant-atmosphere as an organized system in thermodynamic equilibrium dependent upon the local water content. (Braudeau and Mohtar, 2014)

information that is used to prepare the helpful soil maps available today. The third axis represents the hydraulic functionality of this soil-water system. The difference between Figures 3.4 (a) and (b) lies in the connectivity or linkage with this fundamental plane. Existing soil-water modeling, as shown in Figure 3.4(a), uses the widespread concept of the Representative Elementary Volume (REV) principle. The REV concept overlooks or ignores the soil structure. Assuming the soil medium to be a mixture of solids, liquids, and gases, and that the base volume changes dynamically with the swelling and shrinkage properties of a given soil, this representation leads to a disconnect between the hydro-functional axis and the other two axes, which describe the morphology and evolution of the multi-scaled soil organization. Thus, there is a need to move away from the disconnected models and toward a model connected with soil structure.

This connection was identified by Braudeau and Mohtar (2009) and defines a new paradigm in the soil science pedostructure-SREV concept. The pedostructure concept defined as the soil medium organization as an assembly of primary aggregates; where the Structure Representative Elementary Volume (SREV) concept comes to define soil mass rather than the varying soil volume as the basis of soil water relationship. Pedostructure defines two types of thermodynamic water in the soil medium organization: micro-poral water or the internal water of primary peds, and macro-poral water or that which is external to primary peds within the pedostructure. At equilibrium state, water potential is equal in both poral spaces. The SREV concept governs the discretization of the soil medium and allows for the transformation of the soil medium organization into closed thermodynamic systems that are closed on the solid particles of the structure (Figure 3.4(b)).

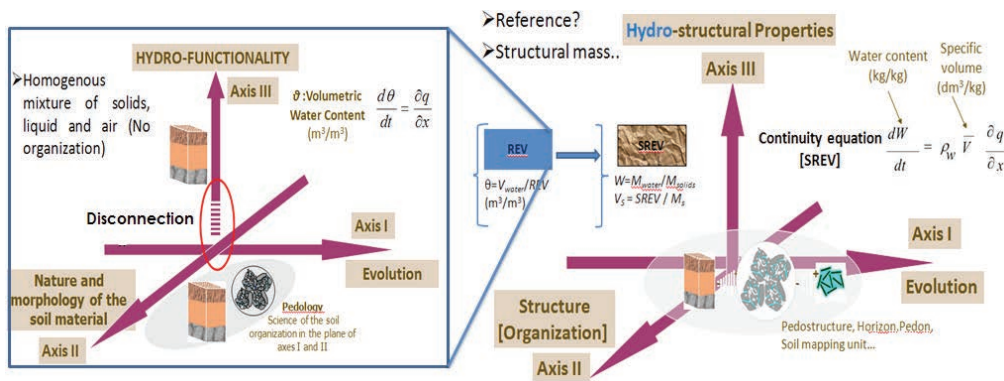


Figure 13: Modeling the soil-water system within the soil-plant-atmosphere continuum. Overcoming the disconnect with the soil structure by shifting the paradigm from the Representative Elementary Volume Concept (REV Concept) (a) into the Structural Representative Elementary Volume Concept (Pedostructure-SREV Concept) (b). (Modified from Braudeau and Mohtar, 2009)

In the new paradigm, one can physically differentiate and quantify two water cycles in the natural environment, the blue water cycle and the green water cycle (referred to here as a thermodynamic water cycle) within the pedostructure. This will eliminate a large amount of confusion about the definition and quantification of green water as a valuable source for the functionality of the soil-water system and provide the pedo-climate for the occurrence of biotic and abiotic processes vital for food security (Braudeau and Mohtar, 2013).

Gap 2: *Quantification of the soil natural organization or structure with measurable (physical) parameters that describe the interactions within the soil-water system.*

One of the most challenging issues for the soil water research community is to quantify and characterize the impact of agro-environmental practices on soil structure, which is of course, a good indicator of soil health. Soil structure evolves over time and human intervention can affect its evolution, and thus its hydraulic functionality. Using the pedostructure-SREV concept and with the continuous measurement of three state variables of the soil-water system, namely soil water content, the corresponding volume, and the potential of this soil-water system, Assi et al. (2014) were able to identify a set of measurable parameters, each of which identify a specific physical characteristic within the measured soil-water medium (Figure 3.5). The implication of such a characterization is the ability to quantify soil structure and its evolution over time. This externality could be presented by changes in soil management (tilling practices) as well as by the use of chemically enriched water for irrigation. These are now much more critical than in the past: dwindling water resources will cause the community to look at alternative resources to satisfy their demand. The limitation has always been our lack of understanding of the long-term impact of these factors on soil quality. This paradigm means that soil quality can be quantified as well as the long-term impact of the externalities.

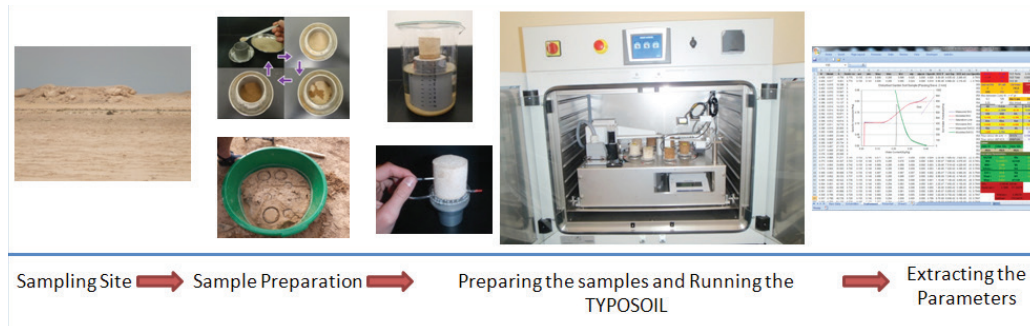


Figure 14: Extracting the hydro-structural parameters, where each parameter quantifies a specific physical characteristic of the soil-water medium.

Gap 3: *The Natural Multi-scale Organization*

The third gap is related to scaling and the transfer of knowledge across scales, whether from policy to practice or from practice to larger scale. Because of the current challenges in the modeling paradigm discussed above, current modeling frameworks are incapable of translating from a larger or smaller scale to the opposite. Delineation of hydro-structural mapping units must be established using the existing soil units as a basis (Salahat et al., 2012). These soil units still lack quantifiable elements for characterization. The characterization protocol mentioned above can enhance the qualities of these maps by including data such as hydrostructural parameters. Once updated with quantitative attributes, they can and should be used as a basis for mapping data rather than guessing. With such a protocol, verified with soil samples and extracted relevant hydrostructural parameters using continuous and simultaneous measurements of soil shrinkage/swelling curves and water potential, these maps or models can be scaled to allow the transfer of information across the scale.

In this section, we highlight the major gaps that limit our vital exploitation of maximizing the use of underutilized water resources, whether due to the lack of a framework to quantify its availability and map its spatial distribution, as in the case of green (thermodynamic) water; or to the lack of a reliable tool to quantify its impact on soil health and productivity, as in the case of NEW water. With such an integrated framework, we will not only save water, but will also be able to observe and quantitatively evaluate the degradation of our limited productive land, both of which are vital for reduction of the risks posed to water-food securities.

4. Water-Energy-Food Nexus Approach

Section 3.1 highlights the importance of better accounting of water sources and the need for a deeper understanding of the potentials of each source. Such understanding and accounting will enable better utilization of locally available resources and contribute to bridging the food gap locally. At the same time, this will ensure an increased level of resilience, bringing with it a combination of robust trade strategies and foreign investment, conservation, and increased efficiencies. However, food

production is not the only consumer of water. Second only to agriculture, energy production consumes 15% of global freshwater withdrawals annually (IEA, 2012). Moreover, even with expected changes in the global energy mix, the quantity of water withdrawn and consumed by the energy sector is expected to rise.

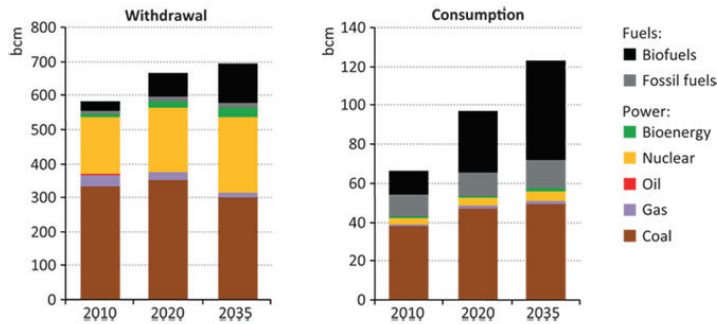


Figure 15: Global water use for energy production by fuel and power generation type for different future policy scenarios (World Energy Outlook-2012).

Water, energy, and food are highly interconnected. In order to assess the local-trade nexus presented earlier, a holistic, system-level platform for resource nexus solution assessment is necessary. Such a platform will help to identify and quantify the interlinkages between water, energy, and food systems. Moreover, it will provide quantifiable trade-offs for various solutions and ensure that a given solution that meets the goals of a single pillar does not infringe on the other two pillars. Further, it will enable consideration and evaluation of informed 'hotspot interventions' where appropriate nexus solutions can be adopted. These quantifications, analyses, and evaluations constitute 'nexus analytics'.

The relevant analyses are often lead by the scientific community, creating space and informed guidelines for policy, technological, and stakeholder dialogues. The dialogues must be based on the inclusion of all sectors of the economy: governance, academia, civil society, private sector. They should enable and induce changes in attitude, practices, and behavior that are based on knowledge. Such knowledge-based dialogue can and will change the dynamic of conflict into one of cooperation by highlighting the need for and understanding of the trade-offs involved. The elements of the nexus platform must include an integrative view of water, food, and energy resource management; a view that needs to prevail at all levels. Last but not least, we must better engage the private sector and exploit its role in supply chain management through the mobilization of resources, the promotion of conservative, responsible investment and R&D for enhanced business opportunities, and the development of appropriate technologies.

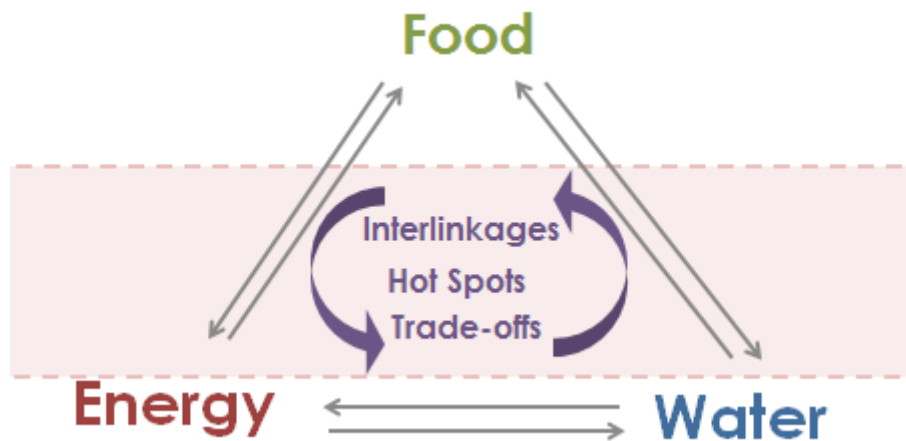


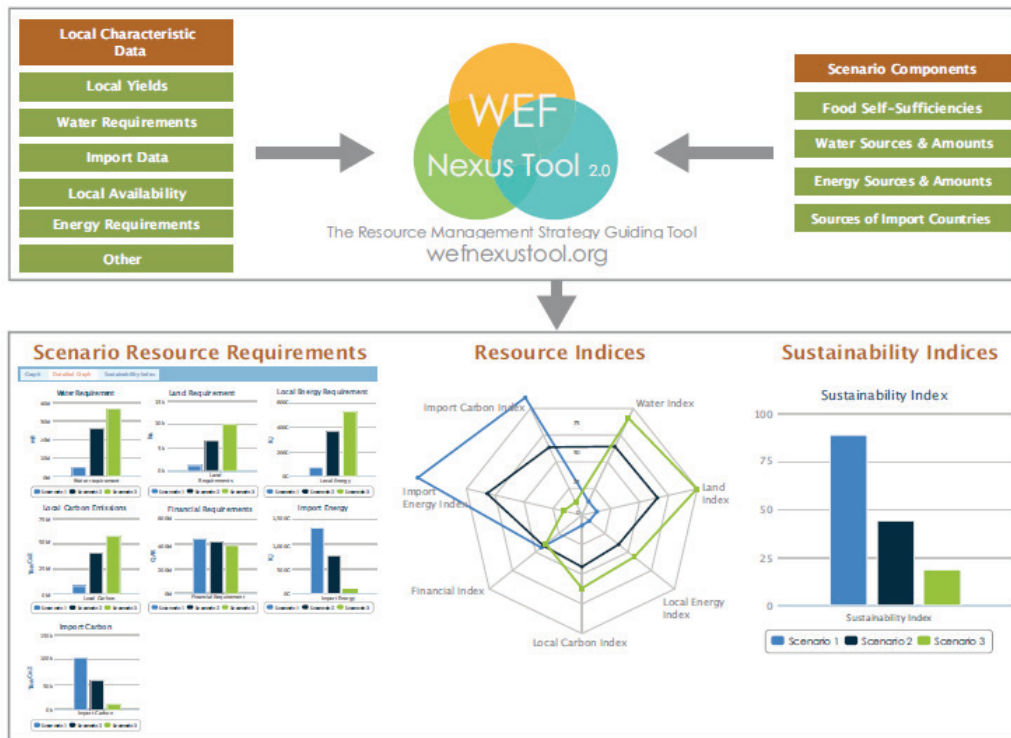
Figure 16: Water-Energy-Food Nexus Analytics.

4.1 Water-Food-Energy Nexus Tool: A Platform for Trade-off Analysis

In an effort to facilitate the nexus analytics, our Nexus Research group developed the WEF Nexus Tool, which provides a platform for scenario development and trade-off analyses. The tool captures inputs from both technical and scientific circles, as well as incorporates inputs from decision making circles. It reflects specific strategies, costs and trade-offs. The tool enables the development of scenarios by defining the food, water and energy, and trade portfolios of a chosen area. The WEF Nexus Tool output provides more than mere financial costs for a given scenario. It quantifies the elements of the scenario and includes:

- Water requirements
- Local energy requirements
- Local carbon emissions
- Land requirements
- Financial requirements
- Energy consumption through import
- Carbon emissions through import

The user is able to calculate and visualize the amount of resources consumed by different proposed scenarios. The user is then able to make an informed decision regarding the relative importance of reducing each of the 'costs' (water, local energy, local carbon, land, financial, imported energy and imported carbon), on a scale of 0-1 (0 for a cost that is least important to reduce, and 1 for a cost that is most important to reduce). Based on the relative importance of reducing any of these costs or resource requirements, the tool user is able to calculate the sustainability index for each scenario and then decide on the one that is most favorable for adoption.



Source: Daher and Mohjar, 2013, wefnexusool.org.

Figure 17: WEF Nexus Tool Structure. (Mohtar and Daher, 2014)

The underlying framework representing the quantitative relations and interconnections among the three systems, water, energy, and food, is generic. In order to create a scenario using the tool, site specific data such as local yields, rainfall, water resource availability, etc., must be identified. The tool's framework is under continuous development and can be used to answer specific questions for various applications and across different eco-zones and scales.

4.2 Hotspots and Nexus Applications

Following the introduction of nexus analytics and the WEF Nexus Tool above, this section will explore case studies that represent different hotspots and reflect several critical questions to be addressed while making use of the nexus interlinkages and trade-offs.

4.2.1 Qatar Food Security

Qatar currently enjoys a period of growth and development catalyzed by an abundance of oil and gas resources. Yet Qatar also faces severe challenges of water scarcity, aridity, and harsh environmental conditions: Qatar imports more than 90% of the food it consumes. While there are risks associated with such a high reliance on food imports to supply the local market, a decision to increase local production requires a comprehensive understanding of the interconnected water-food-energy systems and of the trade-offs between them. Integrative

planning is essential to ensure sustainable growth and eliminate unintended, negative consequences. Qatar aims to meet 40% of its food demand with local supply in the coming decade (Gulf Times, 2014). Achieving this goal will require the use of major resources, including water, energy, land, and financial resources. We conducted a sensitivity analysis for these resources and concluded that the land requirement is the one most sensitive to increases in food production (Daher and Mohtar, 2014), and this is primarily the result of low local yield due to environmental conditions that are hostile to efficient agricultural production: land would be a major bottleneck for food production. While this could be partially bridged with technology, doing so comes at a high cost: Qatar receives an average of 80 mm/year of rainfall and water withdrawals were recorded at 455% of actual, total renewable water resources in 2005 (Aquastat, 2014). Therefore, tapping the ground water to implement the food security plan is not an option.

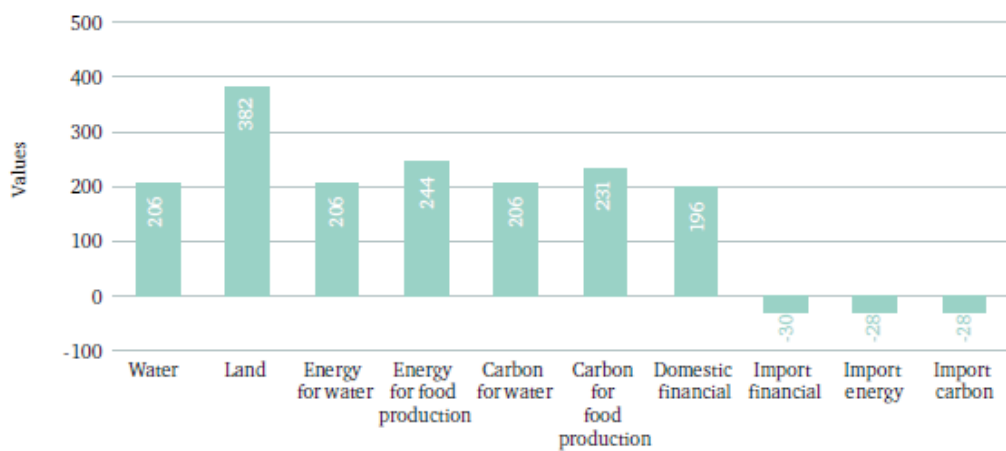


Figure 18: Percentage change in resource needs for a 25 per cent increase in the self-sufficiency of eight food products. (Mohtar R.H. & Daher B., 2014)

Part of Qatar’s food security plan involves the use of solar-desalination to provide water for agriculture. A preliminary assessment conducted by Daher and Mohtar using the WEF Nexus Tool showed the need for 206% more water to enable an increment of 25% in food self-sufficiency for eight selected food products (Mohtar R.H. and Daher B., 2014). Even though solar desalination is considered to be the way forward in providing the needed water, aggressive infrastructural investments would be needed to increase current desalination capacities to achieve the set goal of food production. Alternatively, “new” water, or unconventional water (Treated Water), which is treated to the tertiary level, and sometimes to the quaternary level, is a valuable resource that should not be overlooked. Table 4.1 shows the energy required to deliver one cubic meter of clean water using different sources of water (Cramwinckel, J. F., 2011). This water is a valuable resource and comes at a lower cost when compared to more expensive desalinated water. It would contribute to bridging the water gap, while minimizing costs and reducing the need for infrastructural upgrades in terms of desalination capacity.

Table 2: Energy required to deliver 1 m³ of clean water from different sources.

| Source | Energy required (kW-h/m ³) |
|----------------------|--|
| Lake or River | 0.37 |
| Groundwater | 0.48 |
| Wastewater Treatment | 1-2.50 |
| Wastewater Reuse | 0.62-0.87 |
| Seawater | 2.58-8.50 |

4.2.2 Texas Water Scarcity and Implications

According to the Texas Water Plan of 2012, the state expects a 40% water gap and a supply-demand deficit of 8.24 billion m³ by the year 2060. It is planned that 60% of the gap will be covered by conventional water sources, 24% from conservation, and 16% from non-conventional water supply - reuse and desalination (Arroyo, 2011). Arroyo also expected that 2.24 billion m³ of water would be needed to generate electricity in 2060.

How will this gap be bridged throughout the state? Due to high variability in ecology, climate, population, and the types of activities in different regions of the state, the plan divides the state into 16 regional water planning zones. The report notes that each zone is characterized by distinct populations, water demands and existing water supplies. Even though the expected water gap is statewide, it will affect the various areas differently. The way to bridge that gap will also vary with the region and depend upon resource availability versus need, and the type of water consumption activities happening in each region. Returning to Arroyo’s prediction of 60% of the gap being covered by conventional water, we introduce the following questions: can we do more?; can we better utilize green water to reduce stresses?; how could we better use New water in energy and agriculture?; what would work where? Even though the problem is the same, solutions will need to be different for each specific scenario, giving rise to the need for a holistic assessment with localized solutions.

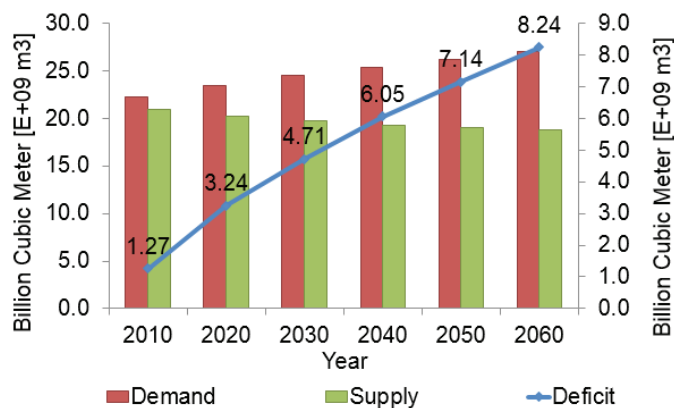


Figure 19: Projected water deficit in Texas (Texas Water Development Board, 2012).

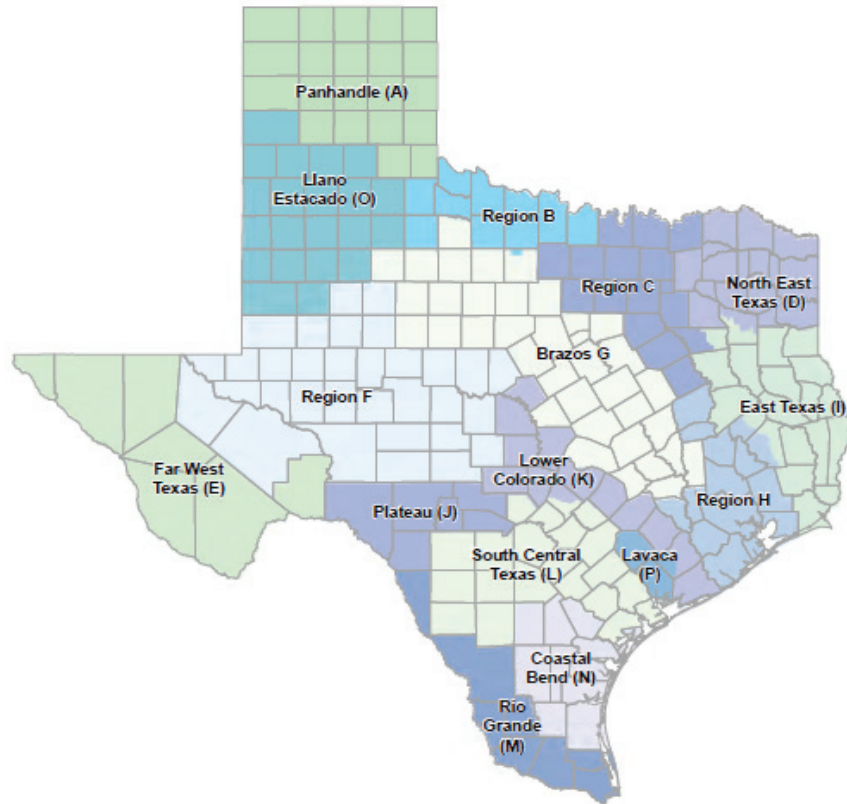


Figure 20: Regional Water Planning Areas (Texas Water Development Board, 2012).

4.2.3 Water-Fracking-Transport Nexus

Fracking has expanded rapidly across the United States, with more than 82,000 new wells reported between 2005 and 2013 (Environment America, 2013). The fracking industry has brought a higher level of energy security at the national level as well as economic benefits to individual states and local communities. In Texas, more than 4,890 drilling permits were issued in the last 5 years in the Eagle Ford Shale formation alone (Rail Road Commission of Texas, 2014), causing energy production from shale to greatly increase.

Fracking, as an industry, is not independent from other resource systems, nor is it isolated from surrounding local communities and their environments. Therefore, there is a need to understand the interlinkages fracking has with these different, yet interconnected, systems. There is also a need to quantify the impact that each of these systems has on the others so that, as fracking activity expands, unintended negative consequences are minimized. Three primary interlinkages will be explored in this framework.

Fracking-Transport interlinkages: Transport is an important element present at multiple stages in the lifetime of a fracking site. Whether at the site set-up stage, drilling stage, or production phase, trucks are needed. The transport of produced oil and gas, solid waste, and other operational activities, requires the movement of

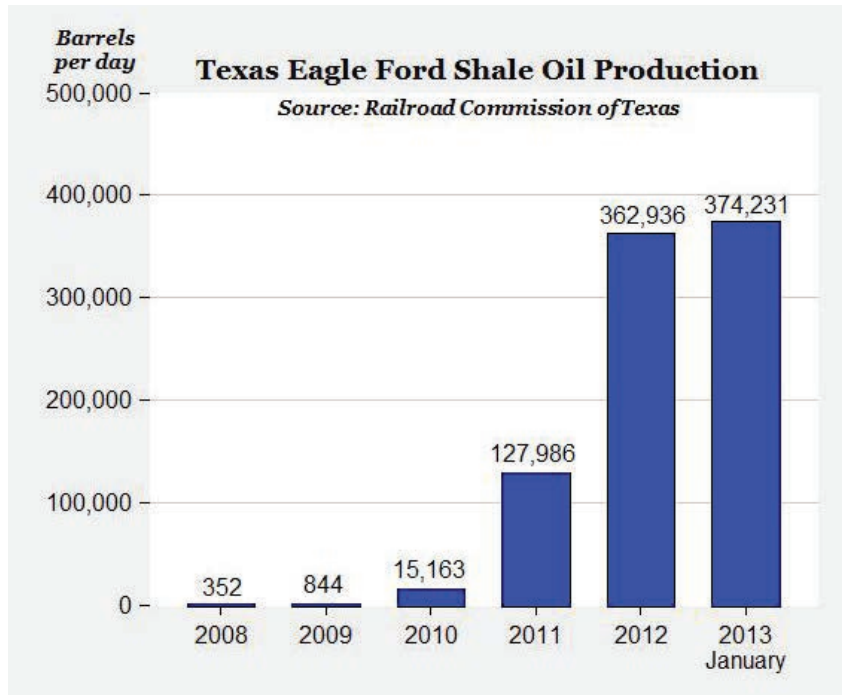


Figure 21: Texas Eagle Ford Shale Oil Production from 2008-2013. (Green, 2013)

trucks from site to delivery or disposal locations. With the growing number of fracking sites, and ultimately the number of trucks required to service them, road infrastructure deteriorates at a faster rate. This also impacts the level of service provided by the roads due to congestion. A better understanding of the relation between increased fracking activity and transportation is crucial to determining future plans for road rehabilitation and expansion. It will also help to determine better circulation patterns for trucks in order to minimize negative consequences on existing and projected traffic.

Fracking-Water interlinkages: Fracking is a thirsty source of energy. Water is required for all phases of the process. Depending on the technology used, different amounts and qualities of water are required. Water could be pumped onsite or transported from a different location. It is important to understand the relation between the amount of water required for fracking and the trade-offs associated with allocating more water to this industry as opposed to other, competing businesses, industries, or sectors in the area of interest. Fracking produces large quantities of contaminated water which must be treated and then properly disposed of. Depending on the level of treatment, choice of disposal site and technology, different resource requirements and risks must be accounted for.

Transport-Water interlinkages: The water required to complete the various stages of fracking can be transported through pipelines from neighboring sources, pumped onsite from existing aquifers, or transported by trucks onto the site. It is important to understand the water required and its sources for a given site; likewise, it is important to study the number of trucks that would be introduced onto the roads, thereby causing

congestion and infrastructure deterioration. Produced water is also transported out of the fracking site for treatment or disposal. Truck volumes must be considered in order to correctly capture and assess their effect on the road infrastructure.

The whole nexus between the three systems is effected by multiple factors, each plays a role in affecting the relations between them. These factors include economy, technology, policy, environment, and community engagement. For this application, it is imperative to use a holistic platform for the nexus to quantify and assess different growth scenarios associated with specific trade-offs, and then to adopt a holistic approach that looks primarily at the interrelations within the transport and infrastructural system. Those scenarios will be assessed by a list of identified economic, social, and environmental indicators.

4.2.4 US-China Agricultural Trade

The Food and Agriculture Organization of the United Nations (FAO) estimates that, to achieve global food security, 70% more crop production will be required by 2050 (FAO, 2013). Much of this future demand will come from Asia, where the future economic centers are located. While this is often described as a driver of future food demand, very few studies analyze the impacts that future demand for food commodities will have.

China is projected to be the most likely environmental and economic hotspot of the twenty-first century. China will not be able to feed itself with the water resources directly available to it. Without external inputs, water will be the limiting factor in achieving economic growth and providing the emerging affluent middle classes with food products sufficient to meet increased demands (USDA, 2014). This is already understood in policy circles in Asia and the United States.

China's heavy dependence on limited, water-thirsty, fossil and renewable fuels will limit significant expansion of domestic food production. As a result, the government has begun to invest in agricultural trading houses to access food from other parts of the world. US decision makers from the public and private sectors view US-Chinese ag-trade as a pivotal strategic issue in global trade. The private sector has understood these new circumstances. For example, Bunge has invested 300 million USD in building the first export food commodity terminal in over 25 years in Longview, Washington. It will serve Asian markets more efficiently and rapidly. At the same time, EU trade with China is growing by similar numbers (Bunge, 2014). In addition, China has begun to actively externalize environmental costs as a result of recognizing the increasing competition between water, energy and food in China. There are also serious concerns about water quality.

One of the most bullish supply chains is the dairy supply chain. Over the past 15 years, China has become the largest dairy importer worldwide, with China's dairy imports increasing by approximately 10 per cent annually since 2000 and expected to grow further in the coming years (USDA, 2014). While this will allow the US to benefit economically from increased trade, it will also add further pressures on water, energy and food systems, parts of which will be increasingly affected by climate change, for example the South-Western and Western regions of the United States that produce not only dairy but also animal feed.

A proposed approach to this nexus will evaluate the extent to which existing market governance is fit for purpose by mapping and modeling the future resilience of US food systems with respect to the availability of water, energy and food resources in the wake of increasing demand from China. The study will fill a gap in understanding the environmental consequences of increased trade between US and China.

The framework should aim to quantify the use of water and energy at the state level using state data on dairy production to provide a natural resources perspective on resources use in dairy. In addition, data on dairy exports will be incorporated in the analysis to provide an understanding of questions such as: how much water and energy is exported in dairy to China; to what extent is the US dairy system sufficiently resilient to sustain future trade growth with China; how will increased agricultural production for export affect interconnected water and energy systems?

5. Conclusions and Recommendations

We have explored the grand challenges surrounding resource scarcity and the need for a holistic platform to quantify these interlinkages and analysis trade-offs. We introduced a platform that can help with analyzing scenarios and provided examples of hotspots where holistic thinking can be applied in the form of a nexus. In conclusion to this paper, four points need to be made:

1. There is a need for a holistic platform to determine interlinkages and trade-offs for resource management and allocation. Such a platform will offer a systems view of the solution for each of the pillars, without infringing on the other pillars.
2. There need is a need for site-specific accounting to determine the feasibility of alternative water for bridging the water food gap. Such feasibility must be accompanied by long-term impact studies on soil quality and human health.
3. Green water is a precious resource that must be better defined, accounted for, and represented in thermodynamic modeling and hydrologic scaling. Such a multi-scale hydrologic platform will enable quantification and mapping for managing system resources at a regional scale, where local information of the soil thermodynamics can easily be scaled up to the policy level, and vice versa.
4. There needs to be a research focus in the understanding and characterization of the soil water medium to enable better quantitative understanding of soil-water behavior under different externalities.

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ABOUT UNU-FLORES

MISSION

“Advancing the Nexus Approach to the sustainable management of environmental resources”

In line with the general mission of UNU to foster sustainable development, UNU-FLORES aims to contribute to the resolution of pressing challenges to the sustainable use and integrated management of environmental resources, such as water, soil and waste. UNU-FLORES strives to advance the development of integrated management strategies that take into consideration the impact of global change on the sustainable use of the environmental resources. To this end, the Institute engages in research, teaching, advanced training, capacity development and dissemination of knowledge.

VISION

UNU-FLORES acts at the forefront of initiatives promoting a Nexus Approach to the sustainable management of water, soil and waste. The Institute supports the overall mission of UNU as a think tank for the United Nations and its member states, in particular addressing the needs of developing countries and emerging economies. In this role, UNU-FLORES aspires to become an internationally recognized hub and intellectual focal point promoting integrated management strategies.

Additionally, UNU-FLORES engages in policy-relevant research, postgraduate education and capacity development in a broad sense. The Institute attracts high-calibre students for postgraduate study and research programmes in cooperation with other research institutions. Furthermore, UNU-FLORES builds the capacity of future leaders in the area of environmental resources management and develops innovative concepts for target- and region-specific knowledge transfer.

ORGANIZATIONAL STRUCTURE

In developing its functional structure, UNU-FLORES has positioned itself well to consolidate the scientific foundation of the Nexus Approach. The institutional arrangement is a direct response to critical knowledge gaps relating to integrated management of the environmental resources water, soil and waste. The organization of UNU-FLORES into five academic units – three core scientific units (Water Resources Management (WRM), Waste Management (WM) and Soil and Land Use Management (SLM)) supported by two cross-cutting units (System Flux Analysis Considering Global Change Assessment (SFA) and Capacity Development and Governance (CDG)) – supports the think tank function of the Institute. All scientific units are supported by the operational support units, which consist of the Office of the Director, Finance and Administration, Communications and Advocacy, and Computing and ICT.

OUR DEFINITION OF THE NEXUS APPROACH TO ENVIRONMENTAL RESOURCE MANAGEMENT

“The Nexus Approach to environmental resources’ management examines the inter-relatedness and interdependencies of environmental resources and their transitions and fluxes across spatial scales and between compartments. Instead of just looking at individual components, the functioning, productivity and management of a complex system is taken into consideration.”

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ABOUT THE DRESDEN NEXUS CONFERENCE

As a hub for initiatives on the Nexus Approach, UNU-FLORES is not only committed to strengthening its own network but also to providing an international platform to foster cooperation and networking amongst all actors working on or with the Nexus Approach to managing environmental resources. That platform is the **Dresden Nexus Conference (DNC)**.

Every two years UNU-FLORES will organize a DNC, welcoming scholars, politicians, and practitioners from all regions of the world to meet and discuss the most recent and innovative initiatives on a Nexus Approach to the management of environmental resources.

DNC2015: GLOBAL CHANGE, SUSTAINABLE DEVELOPMENT GOALS AND NEXUS APPROACH

Building on the outcomes of the 2013 “International Kick-Off Workshop on Advancing a Nexus Approach to the Sustainable Management of Water, Soil and Waste”, UNU-FLORES organized the inaugural Dresden Nexus Conference (DNC). From 25 to 27 March 2015 representatives from academia, politics and civil society assembled in Dresden under the theme “Global Change, Sustainable Development Goals and Nexus Approach”. Working together with co-organizers, TU Dresden and IOER, in 2014 UNU-FLORES solicited applications from numerous renowned academic institutions from around the world. Categorized under three key themes – climate change, urbanization and population growth – 18 sessions were selected for the first DNC. Comprising a comprehensive selection of the diverse initiatives on the Nexus Approach, sessions will be convened by UN entities, international research organizations, universities and non-governmental organizations. Besides these 18 sessions, the organizers have arranged for six keynote speeches and concluding talks by renowned scholars as well as panel discussions with senior officials from UN Member States. During the entire conference academic initiatives will be on display in the poster and exhibition halls.

In parallel to the organizational activities of the DNC2015, UNU-FLORES arranged for the drafting and distribution of nine position papers to help build and consolidate the background knowledge of the three topics covered during the conference: climate change, urbanization and population growth and the increasing demand for environmental resources. This working paper has emerged from one of those position papers.



www.dresden-nexus-conference.org

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The United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES) was established in Dresden, Germany in 2012 with the support of the Federal Ministry of Education and Research (BMBF) and the Ministry for Higher Education, Research and the Arts (SMWK) of the Free State of Saxony, Germany. As part of the United Nations University (UNU), the Institute helps build a bridge between the academic world and the United Nations. UNU encompasses 13 research and training institutes and programmes located in 12 countries around the world. UNU as a whole aims to develop sustainable solutions for pressing global problems of human survival and development.

UNU-FLORES develops strategies to resolve pressing challenges in the area of sustainable use and integrated management of environmental resources such as soil, water and waste. Focusing on the needs of the UN and its member states, particularly developing countries and emerging economies, the Institute engages in research, capacity development, advanced teaching and training as well as dissemination of knowledge. In all activities, UNU-FLORES advances a nexus approach to the sustainable management of environmental resources.

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ADVANCING A NEXUS APPROACH TO THE SUSTAINABLE
MANAGEMENT OF ENVIRONMENTAL RESOURCES

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