Modeling the Water-Energy-Food Nexus: A 7-Question Guideline

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Abstract

Water, energy, and food resource systems are under increasing stresses. As we prepare to move toward more sustainable resource allocation and management strategies, it is critical that we quantify and model the interconnections that exist between them. Such action will help guide decision making and planning for the future of these resources and related strategies. While there is no single cook-book method for "modeling the nexus", this chapter provides a list of seven guiding questions to help conceptualize a nexus case, model, and then assess it. The 7-Question nexus modeling guideline is demonstrated using three case studies that represent a wide spectrum of critical questions, involving stakeholders, at different scales.

Keywords: Energy security; Food security; Integrative modeling; Nexus platform; Policy making; Water security; 7-Q nexus modeling guideline.

1. Introduction

In a non-stationary world, with intertwined resource systems, uncertain externalities, and high future stakes, it is essential that we better understand the existing interconnections across different resource systems and integrate these interconnections into the decision-making process for their allocations. Doing so will play an important role in improving our ability to develop long-term, sustainable resource allocation strategies and enable us to move away from reactive, short-term tactics. Water, energy, and food securities are major constituents of a healthy economy; the ability to understand how the three resource systems interact, and the interdependencies between them, will be crucial to the development of such an economy. Different players govern and impact these resource systems, each at a different scale. To a large extent, water, energy, and food are governed and planned for from within silos: this is not synchronous with the reality of level of the interconnectedness that exists between them. Our ability to understand each of these resource systems, how they interact, and the trade-offs associated with various resource allocation pathways, offers an important tool for planning future development. Additionally, there is a need to approach ongoing and projected resource challenges through developing solutions that not only recognize the interconnectedness between resources, but also that each is multi-faceted (bio-physical and socio-economic), cross sectoral, and cross disciplinary, across different scales. Decision-makers currently lack the proper tools to assess the implications of different resource allocation strategies; this is where modeling those interactions and communicating them through proper assessment and communication tools can be a key to facilitating that process. The main goal of this chapter is to demonstrate that there is no one-size-fits-all model to address water-energy-food (WEF) related issues. While "modeling nexus issues" follows a common, guiding, holistic and cross-sectoral approach, localizing and contextualizing the issue in hand will be a key to assess trade-offs at a given scale (Mohtar et al., 2015). Thus, this chapter outlines a list of guiding questions that facilitate conceiving and modeling a "nexus issue". After that, the WEF nexus modeling platform is introduced, and then three different case studies are demonstrated. The cases studies address three critical perspectives: water security focus, energy security focus, and food security focus; and at different scales (national, state, and international levels). They highlight how building on a common platform and nexus philosophy, three different models are created to respond to different questions.

2. How do we "model the nexus"? No cook book method - A 7Q guideline

There is "no cook book" method to model a "nexus challenge": each has its own complexities at the level of resources, involved stakeholders, scale, data needs, among others. As we work toward "modeling the nexus" for the specific case in hand, several questions need to be answered (Figure 1). These questions will guide conceptualization of the needed framework, quantify existing interlinkages between resources, develop scenarios, and assess trade-offs, in order to better guide decision making. The following list summarizes seven key questions (7Q) that need to be asked; several of which need to be addressed concurrently.

- ***What is the critical question?*** It is important to identify what is driving the study; whether it is water scarcity, food insecurity, economic development or other. The central question, around which the interconnections and system of systems will be framed, is a starting point and a building block.
- ***Who are the players/stakeholders?*** Defining the critical question comes hand in hand with identifying the stakeholders, the beneficiaries of addressing those questions as well as other players connected to the systems being considered. Stakeholders need to be involved and accounted for in the process and be part of any prescribed solution. It is important that we understand the role of policy, private sector, public sector, as well as the role of civil society. These players do interact, and understanding that interaction is critical in evaluating the feasibility and effectiveness of any proposed solutions.
- ***At what scale?*** Is the critical question to be addressed at farm, city, state, national, regional, global or some other level? Identifying the scale has a major impact on how the model is created; who are the stakeholders; and what data is needed. The question also helps identify how scenarios might be assessed.
- ***How is the system of systems defined?*** It is important to define the systems based on the critical question/s identified. The more components the model includes, the more complex it will be to create and manage. Simplify the system as much as possible, without losing the key interactions of interest. Our understanding of how resource systems are interconnected may be the result of a specific methodology or approach that helps capture our understanding of more generic processes and interactions. Having said that, the level of urgency to looking at these interlinkages may vary from one country to another depending on local characteristics.
- ***What do we want to assess?*** How a scenario is assessed is an important step that allows the modeler to identify outputs that need to be quantified; and this is highly dependent on the stakeholders and the availability of data.
- ***What data is needed?*** Depending on the end use of the analysis, data resolution and complexity can be determined. If we are looking at quick assessment to better understand certain trends, a coarser level of data may be sufficient. This is particularly useful in the absence of capacity, resources, and time. If more specific interlinkages are of particular importance, more granular data may be needed.

- ***How do we communicate it? Where do we involve the decision-maker in the process?*** The point at which a decision-maker becomes involved is critical. The model should be presented so that unnecessary complexities are eliminated: such complexities should be addressed within the model, but appear 'transparent' to the stakeholder. The model should not take over the decision-maker's authority or make decisions on their behalf, rather, it should be able to assess possible scenarios and highlight the trade-offs associated with each. These trade-offs would then be presented to the decision-maker who would prioritize them and make choices based on simplified results.

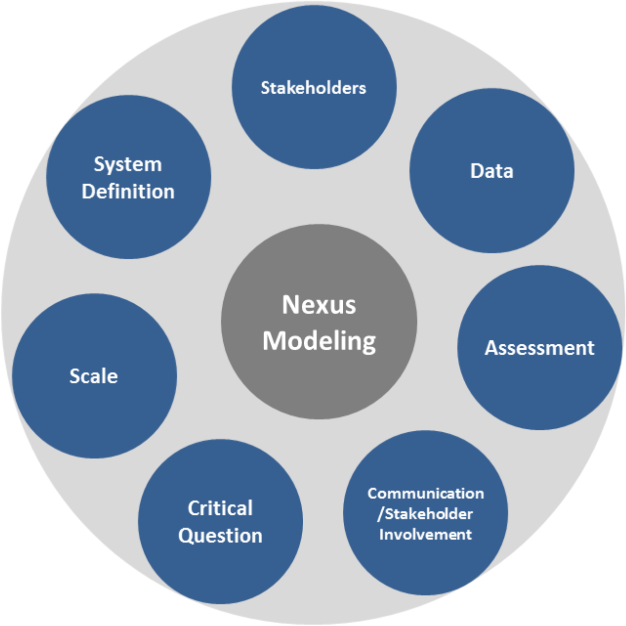

Figure 1: 7-Question guideline for modeling nexus issues

3. Modeling the WEF Nexus

3.1 WEF Nexus Platform

Many available models cover different aspects of the nexus. Some focus on answering water specific questions; others take a more energy-centric approach; while some seek to answer food security related questions. A review of existing models, the areas they cover, and the types of inputs required and outputs delivered can be found in Daher and Mohtar (2015), IRENA (2015), and FAO (2014). Following the guiding questions introduced in Figure 1, it is possible to frame the pieces that constitute the desired model. A model is both an assessment tool and a communication tool: it should help produce the required analytics to capture the consequences of different trends or practices that feed into a larger platform.

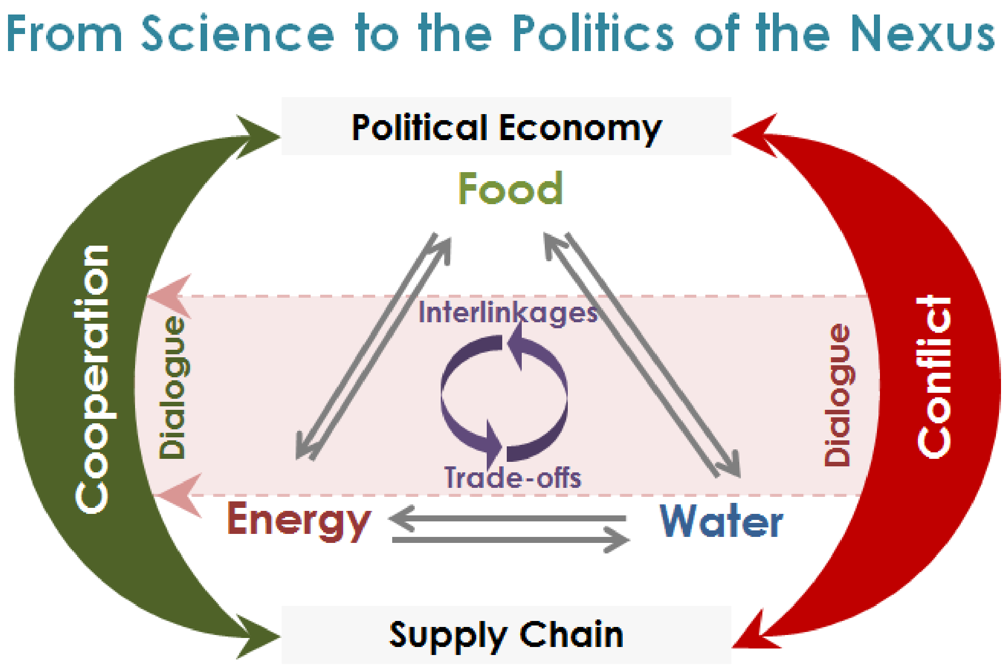

Figure 2: Water-Energy-Food Nexus Platform – Analytics and Stakeholder Dialogue **(**Mohtar and Daher, 2016)

Two main pieces constitute the platform (Figure 2) as presented by Mohtar and Daher (2016). One is the "nexus analytics" where interlinkages among resource systems are quantified and trade-offs assessed for an identified hotspot. These analytics are needed to facilitate a dialogue among stakeholders. The platform does not make decisions for the stakeholders: it allows them to have the necessary data, trends, and challenge that enables them to understand potential outcomes of possible resource allocation decisions.

3.2 Model Structure: Exploring the WEF Nexus Tool 2.0

The conceptual generic structure for the WEF assessment tool was conceived through the development of the WEF Nexus Tool 2.0 (Daher and Mohtar, 2015), which outlines main elements and stages of a nexus assessment. This tool is not rigid, but is inspired by a strong nexus philosophy that considers the interconnectedness of systems, the need for holistic assessment, and stakeholder involvement. The tool is fluid in the sense that it takes different shapes and sizes depending on the specifics of the study at hand; this will be further demonstrated in the following case studies.

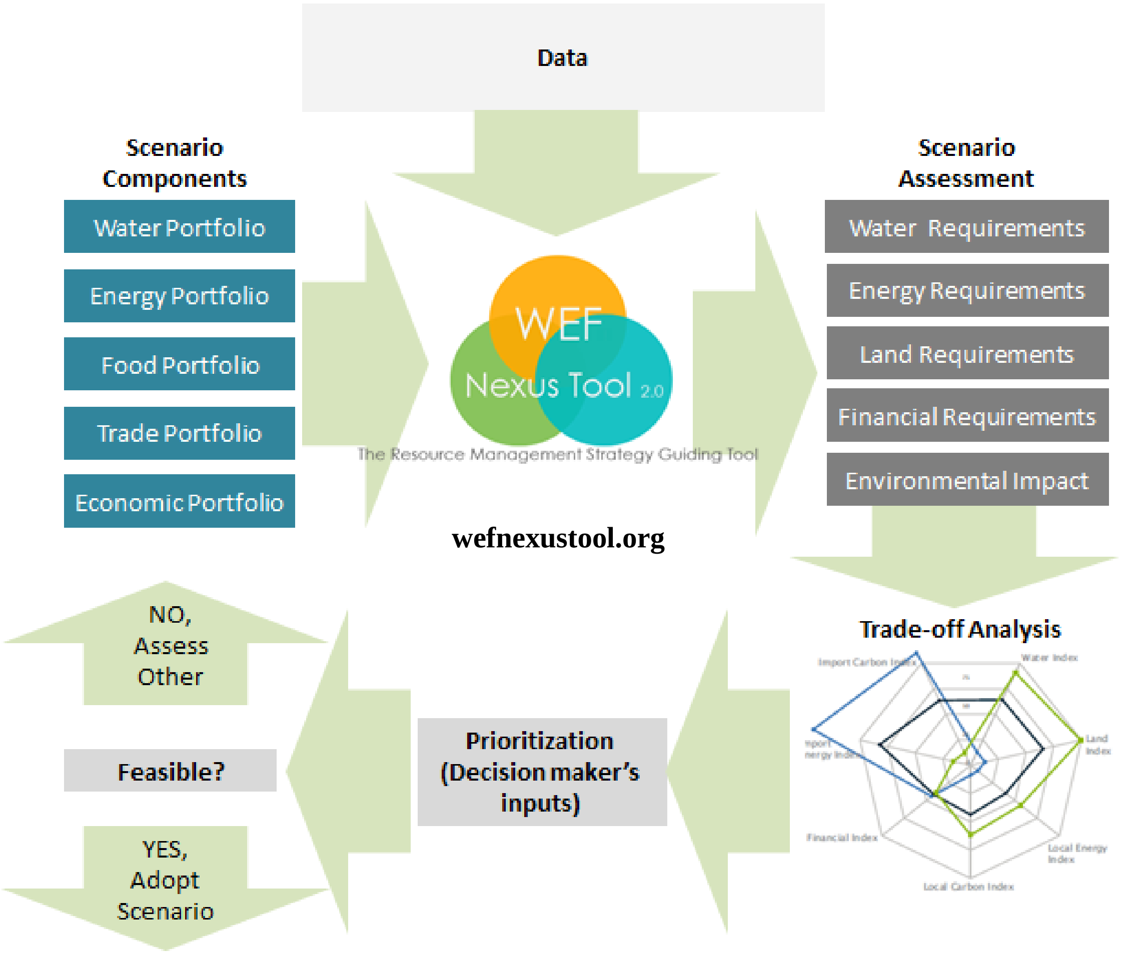

Figure 3: Overall Generic Modelling Approach

Data need to be collected for quantifying the interlinkages among the different resource systems. The data depends on the scale in which scenarios will be created, and the way by which the modeler decides to construct and assess the scenario itself. Defining the scenario components will reflect the degrees of freedom that the designed model provides to a user. Do we want to change different water sources or energy sources? Do we want to make agriculture related decisions? Which question should be asked first? Are those questions independent, or does one feed into another? After addressing these questions, the scenario assessment components must be identified. How do we plan to assess a scenario? Are certain outputs more important than others? Do we want to know what water requirement is associated with a given scenario? Is it something the decision-maker needs to be alarmed to? After deciding that and holistically assessing different scenarios through a list of identified, quantifiable outputs, the feasibility and trade-offs among different scenarios need to be highlighted. In what format should the trade-offs be presented to the decision-makers? What information needs to be included and what is of less significance? The presented WEF Nexus Tool does not decide which assessed scenario is the best for adoption; rather it provides an overview of the list of resource requirements associated with a developed resource allocation scenario. It highlights areas in which a given scenario might fall short of being feasible due to local resource availability or externalities. The decision-maker's input is then captured through a prioritization process, which reflects the relative importance of reducing each of the resource requirements needed for a scenario. Only after a combination of holistic assessments regarding localized resource needs, and with a mechanism to capture the priorities of the decision-makers, the WEF Nexus Tool will be able to identify feasibility of the given scenario. If deemed satisfactory, the scenario could be further studied and discussed among different stakeholders; otherwise, a different variation of the scenario could be assessed through the same process. More information on the platform and WEF Nexus Tool can be found on www.wefnexustool.org.

4. Case Studies: Analyzing WEF Nexus Trade-offs

In this section, three case studies will be demonstrated in the context of the presented water-energy-food nexus platform and 7-Q modeling guideline. The case studies were chosen to cover a wide spectrum of scales, stakeholders, and critical questions.

4.1 Case Study I: Food Security in the Gulf State of Qatar

The State of Qatar, an arid country known for its abundance of natural gas, water scarcity, and harsh environmental conditions, imports more than 90% of the food it consumes. In the past few years, driven by national security concerns, the country began developing a food security master plan, which brought to light that while there are risks associated with high reliance on imported food, other challenges arise when considering the resources needed for increasing local food production. According to the 7-Q modelling guideline, the following questions are addressed.

- **What is the critical question?**

  In response to the new food security master plan, what is an appropriate level of local food production in Qatar?

- **Who are the players/stakeholders?**

The Qatar National Food Security Programme is the entity given the responsibility of putting together the food security master plan, and hence, the primary stakeholder/beneficiary of the tool. The program which has been transformed to an interministerial committee does not exist anymore in its former capacity in the past years. This also gives an idea of the dynamic nature of involved stakeholders in some cases, and the need to evolve with the needed framing and analysis accordingly. Furthermore, other players who also have a role that must be reflected in developing the strategy and scenarios would include the ministries of environment, finance, water and energy.

- **At what scale?**

  This case study covers the entire state of Qatar and looks at improving the level of food security and associated costs from a national perspective.

- **How are we defining our system of systems?**

  In this case study, the framework was food-centric. The first building block for a scenario constituted a new level and choice of local food production. After that, different sources of water for growing the food were included, each with its specific financial, energy and carbon footprint tag; likewise, different sources of energy, each with a different carbon tag were also included. Energy is an input necessary for securing water (pumping, treating, desalinating), and in different food production processes (tillage, harvesting, fertilizer production, and local transport).

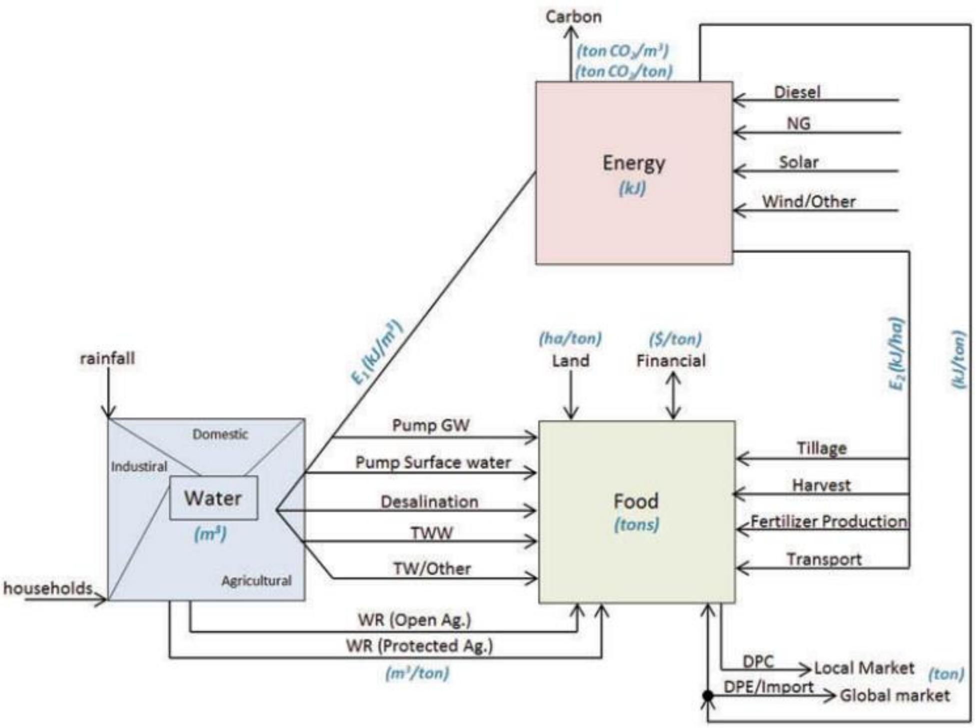

Figure 4: Diagram demonstrating the water–energy–food nexus framework (Daher and Mohtar, 2015)

- **What do we want to assess?**

  A scenario consisted of choosing:

  1. Food: type, amount of food to be produced
  2. Ag. Practice: type of ag. practice per product (open field vs. green house)
  3. Water: sources of water
  4. Energy: sources of energy
  5. Trade: countries of import and export

  The tool in turn assessed the following for each scenario:

  1. Water requirement (m3)
  2. Local energy requirement (kJ)
  3. Local carbon emission (ton CO2)
  4. Land requirement (ha)
  5. Financial requirement (QAR)
  6. Energy consumption through import (kJ)
  7. Carbon emissions through import (ton CO2)

- **What kind of data is needed?** Among the data needed was: yield per food product (ton/ha); water requirement per food product (m^3/ton); annual rainfall (mm); energy requirement for water (kJ/m^3); energy requirement for agricultural production (kJ/ha); carbon footprint (ton CO_2/kJ); market price ($/ton)

- **How do we communicate it? Where do we involve the decision-maker in the process?**

In 2012, scenarios of 50, 80, and 100% self-sufficiency of 8 chosen locally produced food products were explored and assessed. Even though aware of how resource demanding such levels of self-sufficiency could be, the interest to investigate higher levels of locally produced foods branches from a national security perspective. A preliminary assessment by WEF Nexus Tool 2.0 framework showed that a 10% increase in self-sufficiency of a few food products grown locally helped highlight the water, energy, carbon, financial costs and risks associated with local food production (Figure 5). That information, when shared with local stakeholders, contributed to a shift in the overall narrative of what can be done and what are the trade-offs. The complete case study could be found in Daher and Mohtar (2015).

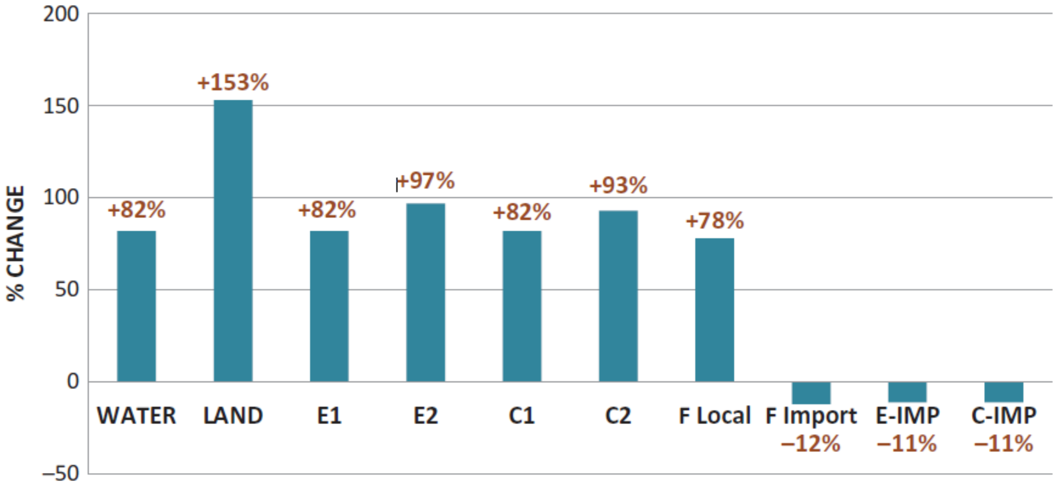

Figure 5: Resource requirement for a 2010 scenario (input data from the Qatar National Food Security Programme – QNFSP) and percentage change in the resource requirements as a result of a 10% increment in self-sufficiency (Daher & Mohtar, 2015).

4.2 Case Study II: Renewable Energy Deployment

The world has decided to move forward with phasing out fossil fuels; most recently that commitment was relayed through the historic Paris Climate Agreement in December, 2015. Changes within the energy system, will affect other, interconnected, resource systems. As different countries explore possible renewable energy options, it is important to understand the implications associated with each and the extent one has upon the other systems.

- **What is the critical question?** How can we assess different renewable energy deployment options through quantification of the impact of different national energy mix possibilities?
- **Who are the players/stakeholders?** Ministries of Energy, Ministries of Environment, International Energy Agencies, and International Climate Change Agencies that are interested in understanding the implications of shifts in the energy mix.
- **At what scale?** The scale at which the scenario assessment is made is national. Yet, there is also interest in the aggregate collective global picture as a result of shifts across different national boundaries.
- **How are we defining our system of systems?**

  Using the same framework and understanding of resource interactions, the building block is no longer food as the previous case study, but rather energy. The central piece of the framework is the well-known IEA energy balance sheet. Such sheets have been consistently reported by the IEA for different countries over the years. The sheet provides a summary of production, import, export, and consumption, for different types of energy sources. The model developed in this case allows a user to make changes to a base year energy mix, and then assess the implications of those changes. Parallel sheets were conceptually developed (IRENA, 2015) to allow us to make these assessments. Those included a table for “water for energy”, “land for energy”, “emissions for energy”, and “cost of energy”.

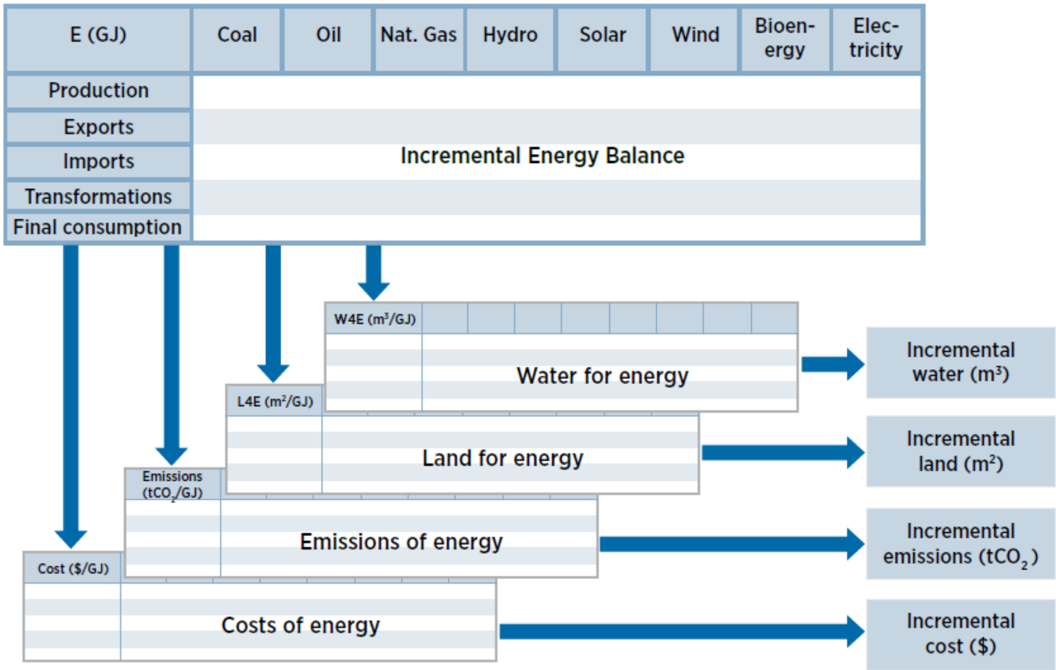

Figure 6: Estimation of the water, land, emissions and cost implications of the assessed energy policy (IRENA, 2015)

- **What do we want to assess?** As stakeholders aim to investigate the implications of different shifts in energy mixes, this model allows them to assess the water needs, land needs, emissions, and costs associated with possible changes. Being able to provide such a holistic overview of resource needs provides a foundation for a trade-offs discussion and dialogue among involved stakeholders.

- **What kind of data is needed?**
  Among the list of needed data are the IEA reporting data on national energy mixes; water requirements for different energy options; land requirements for different energy options; emission associated with each energy source; the cost of implementing each of the new energy sources.

- **How do we communicate it? Where do we involve the decision maker in the process?**
  Similar to the first case study, the holistic assessment of the various shift scnearios needs to be provided; afterwhich, local or national resource constraints and strategies could be incorporated to filter out unfeasible scenarios.

4.3 Case Study III: Water Scarcity in Texas

The State of Texas expects to face a 40 % gap in water availability by the year 2060 to satisfy growing demands (TDWB, 2012). It is planned to cover 60% of the gap by conventional water sources, 24% from conservation, and 16% from non-conventional water supply-reuse and desalination (Arroyo, 2011). The state of Texas has the fastest growing cities in the United States, accompanied by the boom in shale gas production through hydraulic fracturing, and the growth in agricultural activities in different regions of the state. Understanding the growth of these burgeoning water thirsty sectors, the trade-offs associated with limiting one in favor of the other, and the implications for social, economic, and environmental indicators will be of particular importance to plan.

- **What is the critical question?** How could we better allocate water resources to help bridge the projected 40% water gap in the State of Texas by year 2060?
- **Who are the players/stakeholders?** A main stakeholder is the Texas Development Water Board. According to their 5 year plan report, planning groups for each of the 16 planning zones across the state consist of representatives of the general public, county, municipalities, industry, agriculture, environment, small businesses, electric-generating utilities, river authorities, water districts, and water utilities (TWDB, 2016). All these stakeholders are voting members and have a say in the development of the state water plan.
- **At what scale?** State. The threat of water scarcity is a state issue, yet addressing it might take different forms, depending upon each region and its characteristics (practices and resources). Texas is a large state that includes great variability in resource distribution and resource demand hotspots.
- **How are we defining our system of systems?**
  Different hotspot areas, in which projected resource demands and resource availability are in conflict, must be identified. In this case study, particular importance should be given to identifying the spatial and temporal distribution of demand and availability. Thus, the building block of this model is a map representing the distribution of resource supplies and the demands on them.

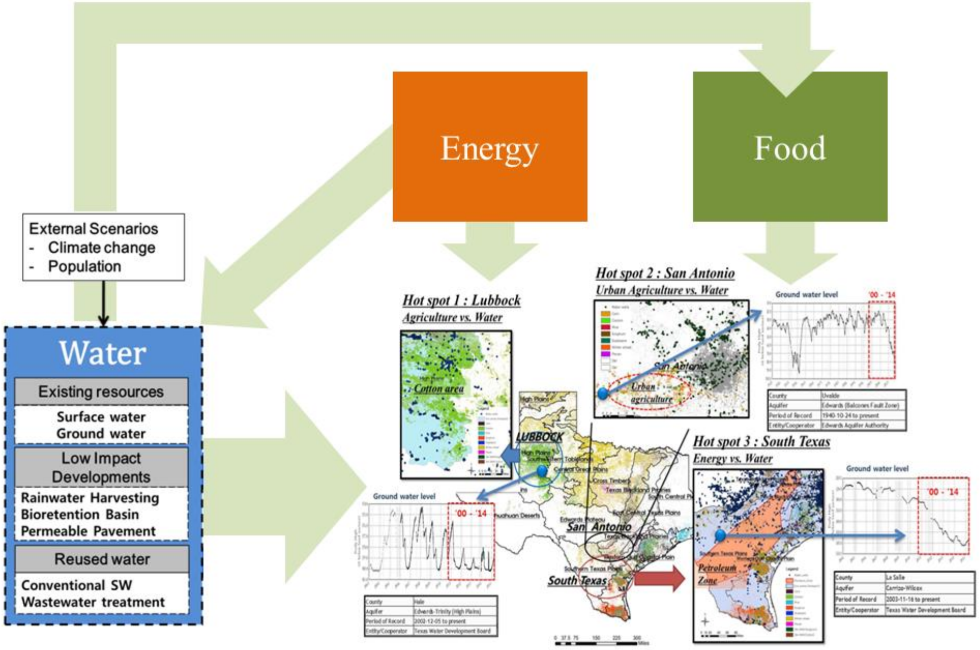

Figure 7: Water-Energy-Food Nexus based on water management in various hot spots

Each hotspot would be treated as a separate resource allocation case study in which the competition over different sources of water could be analysed. Different water sources require different amounts of energy. Energy, in turn, could come from different sources (oil or gas or other renewable energy sources) which are also water consumers. Different environmental impacts are also attributed to the use of different sources of energy (emissions, soils and water degradation). In areas where irrigated agriculture is growing, more water will be needed: the ability to assess the different costs associated with the use of different sources is of great importance.

- **What do we want to assess?**

Based on the characteristics of the hotspot and of the involved stakeholders, different outputs could be of particular interest. For example, the San Antonio Region is a hotspot: the city is projected to grow in the coming decade, as is the hydraulic fracturing industry and cotton production. The assessment must include scenarios of growth in these different areas and over different times of the year, for each of the three water demanding activities. The scenario outputs will include a list of social, economic and environmental indicators that will need to be compared.

- **What kind of data is needed?**

  Among the data that needs to be collected for this case study include water resources (type, quantity, spatio-temporal distributions); energy sources; agricultural activities; emissions data; economic and social indicators over time, among others.

- **How do we communicate it? Where do we involve the decision maker in the process?**

  The effect on different sustainability indictors could be shared, with different strategies for the growth of conflicting sectors in a given hotspot. A decision maker would be able to understand the impact of a specific strategy on different resource systems and indicators. The WEF Nexus perspective can help bridge the overall water gap in Texas, doing so requires holistic but localized, system level solutions that take into account impacts on energy, food, economics, carbon, and social indicators. In addition, the nexus variables might depend on spatial and temporal characteristics of individual hot spots given by location, temporal resource availability and demand, and climate change. Therefore, spatio-temporal water management of each hot spot is required to solve the water scarcity problem in Texas.

5. Summary, Conclusions and Future Potential of the Nexus Modeling

“WEF Nexus” is not a magical term; it is a philosophy that guides the navigation of a holistic resource modeling platform that enables decision-makers to build their integrative resource plans on the basis of specific, identified needs and interests. Those decision makers vary in scope and capacity: they could be making decisions at small association, local, regional, national or international levels. So do their interests and the complexity of their critical questions differ. The challenge of the WEF nexus modeling philosophy is providing those interested decision-makers with clear, simple, yet comprehensive answers. Consequently, it is unrealistic to expect a single modeling approach to fit all interests, at different scales. Instead, modeling approaches of WEF nexus issues should be built case by case, but guided by the same philosophy. In this paper, the authors introduced their WEF nexus modeling philosophy through a 7-Question approach. These questions serve as a guideline to help develop customized models that produce the needed analytics to facilitate dialogue among involved stakeholders. The strength of the proposed framework lies in its dynamic and easily modifiable structure, while considering inputs from scientific spheres and decision makers. Some challenges remain in the availability and compatibility of data sets. The different tools that are useful within the context of this WEF platform require continuous development so that they continue to capture needed interconnections and trade-offs. In addition to accounting for physical resource interactions, it is also important to capture the interactions among the different players and stakeholders governing those resources.

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