Modeling and Data for WEF Nexus Analysis: A Review of Issues

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1.1 Purpose of review

To discuss challenges regarding Nexus modeling and data.

1.2 Recent findings

WEF Nexus analysis endeavors are relatively new. Modeling systems are just evolving and there are challenges that must be faced in doing high quality analysis.

1.3 Summary

Nexus modeling/data must represent, and describe complex interrelationships among WEF systems. Modeling is a necessity as the Nexus approach is about widening perspectives to unexplored levels. Nexus analysis systems must consider situations that vary from place to place. Challenges arise in representing appropriate scope and component interrelationships in a manner that supports decisions while representing uncertainty, coupling component models, economic aspects, and unexplored options both now and into the future. Data challenges arise due to proprietary interests, scale differences in model requirements, representation of unexplored possibilities, assembly cost, projecting the future and representing uncertainty.

Comprehensive innovative studies are needed addressing these challenges and showing the value of Nexus analysis.

2 Introduction

The water-energy-food (WEF) Nexus[1] deals with complex interrelationships among systems that produce, deliver, and use WEF-related factors. The purpose of considering such interrelationships is to identify and capitalize on synergies between, say, water and energy actions and the consequent impacts of coordinated actions relative to uncoordinated actions. Indeed, decisions based on Nexus wide impacts rather than individual elements are likely to produce better, if not more informed, outcomes. Yet to achieve a better understanding of the relationships among Nexus elements and capitalize on that understanding requires willingness to cooperate among traditionally more siloed actors.

Complicating matters are system elements that change over time. For example: a) growing populations alter WEF demands; b) climate change alters water supplies plus regional WEF demands; c) aquifer and fossil fuel reservoir depletion is ongoing; d) evolving technology influences WEF supplies and demands; and e) WEF infrastructure and endowments in places are depreciating or being depleted. These dynamic forces make significant Nexus management adjustments necessary both in planning for the future and adapting decisions over time.

Uncertainty is another complicating force. Weather fluctuations and climate change influence WEF production and input use. Technological evolution is uncertain as are future population increases and WEF consumption levels. Rates of aquifer and fossil fuel reservoir depletion can be estimated but have noise. The pace of climate change is uncertain. Collectively, such uncertainties raise needs for stochastic modeling and scenario analysis.

All of this raises a need for Nexus modeling systems and data that facilitate Nexus wide decision maker consideration of WEF decisions. Models and data must depict or inform on couplings, linkages, and intersections across the WEF complex, while also being dynamically capable of representing future challenges raised by population, climate change, depletion, technology and infrastructure depreciation along with other forces. Information is needed on many different items including:

- Regional economies, income distribution and jobs.
- Energy, water and food needs and prices.

[1] Many papers review and discuss Nexus dimensions and interconnectedness. We will not rather see Bazilian et al 2011, Bizikova et al 2013, Kraucunas et al 2015, Miralles-Wilhelm, 2016 and Ringler et al 2013.

- WEF production practice technology mix.
- WEF commodity conveyance and energy demands thereof.
- Emissions of greenhouse gases, particulate matter, soil erosion, nutrients and contaminated water.
- Allocation of land and water.
- Export possibilities and import needs.
- Water treatment requirements.
- Stocks of groundwater, agricultural land, oil and other fossil energy.

In considering modeling, one must also recognize that the WEF Nexus is regionally heterogeneous. Relevant elements vary between locations with, for example, some producing food or energy and some not; some having scarce water and others perhaps too much; some being food or energy self-sufficient, some exporters and some importers; some relying on local supplies of water while others rely on water flowing from distant regions. Certainly the Nexus modeling and data approach has to vary between regions and situations.

Also, one must recognize that a family of models is likely needed. Many models have evolved addressing different Nexus aspects. For example, crop models like EPIC (Wang et al, 2012) and DSSAT (Hoogenboom et al 2015), hydrologic models like SWAT (Arnold et al, 2012), regional economic crop mix and urban use models like EDSIMR (Gillig et al, 2001), agricultural sector and market models like FASOMGHG (Beach et al, 2010), energy systems models like MARKAL (Pfenninger et al, 2014), regional economic models like IMPLAN (IMPLAN, 2016), and groundwater models like MODFLOW (Langevin et al 2014). Domains of relevant models include those above plus water extraction and conveyance; crop/livestock mix; crop management possibilities; population growth; climate change effects; thermal, hydropower, fracking, and bioenergy production; and energy conveyance. Some of these models use very fine time steps with others being annual or multi-year. This introduces the complexity of simultaneously using very fine time and space disaggregated models but yet looking at the total issue regionally and over multiple years. It also raises the need for a unifying overall systems model and procedures for multi-model integration.

3 Key Challenges/Research Questions

The complexity and scope of the Nexus raises a number of challenges for model and data development and use as discussed below.

3.1 Modeling Related Challenges

While there are a large number of modeling issues associated with Nexus analysis, a few of the more prominent and challenging ones are covered below.

3.1.1 Scope of Nexus Issue

A fundamental challenge involves properly establishing system scope. First, decisions as to the geographic scope of the analysis must be determined with the understanding that actions in one geographic region often influence, and are influenced by, actions in another geographic region via markets or natural linkages (e.g., river systems). For instance, water withdrawals in the upper reaches of the Colorado or Indus rivers likely impact the availability of agricultural and hydropower water downstream. Alternatively, sectoral and resource scope are also important if not challenging. For example, in an ongoing Texas case study, there are significant dimensions of ground and surface water; electrical energy production reliant on cooling water; little hydropower; hydraulic fracturing; rapid aquifer recharge; significant irrigated agricultural acreage; rapid regional population growth; dire climate change projections; alternative brackish and wastewater treatment plant water sources; and the possibility for interbasin water transfers. In an Egyptian analysis, there are upstream water flows that need to be considered along with world markets for fruits and basic grains. In a US bioenergy production setting, one needs to consider how alterations in US agricultural commodities affect prices and in turn production elsewhere in the world.

3.1.2 Considering Full Complexity

Another challenge is appropriate selection, development and integration of diverse component models plus development of unifying models for study of trade-offs. In the Nexus context, this could involve a need for models of ground and surface water hydrology, regional economics and environment, energy production, agricultural cropping and land use, urban growth and WEF commodity usage. Some of these can be tuned off the shelf models, while others will require development of regionally specific data based relations. The models need to interact with more detailed models per providing parameters to more aggregate models and the more aggregate models feeding back prices, demands, water allocations, etc.

3.1.3 Rendering Modeling Useful for Decision Support and Dialogue

The more interactive and visually-friendly models and their outputs are, the more useful such models are to decision makers. Useful interactive models require continual dialogue between those that build the models and decision makers, both to facilitate ease-of-use as well as ensure the appropriate policy and management options are considered. Strong stakeholder involvement will also improve model conceptualization, provide a more accurate array of management possibilities, and allow for timely model validation. It also requires strong visualization capabilities to rapidly and effectively communicate model results and strategy choices in turn stimulating dialogue.

Finally, modelers must recognize that their models are generally not numerical answers but rather providers of insights regarding implications of novel alternatives and testbeds for strategies. They also need to recognize that models are generally better at comparing alternatives, predicting direction of change direction rather than creating absolute predictions. Models also serve as a point of stimulus for dialogue among decision makers and as a means of identification of data gaps and critical points. This means that sample analyses need to demonstrate capabilities for providing insights as the project evolves.

3.1.4 Uncertainty Characterization

As mentioned above, the characterization of uncertainty is critical. Uncertainty may be represented by year-to-year variations in water supplies and commodity prices caused by drought plus potential longer run levels of population growth, energy and commodity prices or climate change incidence. Such uncertainties may either be present permanently in the model and/or the subject of alternative scenarios. In the south-central Texas EDSIMR (Gillig et al 2001), for example, shorter run uncertainty was addressed by a model which contained nine different water availability, drought impacted groundwater recharge and crop yield conditions. For longer run uncertainty, the model was run under alternative scenarios involving population futures.

3.1.5 Model Coupling

A major challenge is developing an automated model interface that permits rapid scenario analysis. This involves establishing a multidisciplinary dialogue so as to facilitate proper information flows. It also may imply model modification to represent potentially more radical ideas such as interbasin transfers, desalination, increased water reuse, movement of more heat tolerant crops into the region, and agricultural use of saline waters.

3.1.6 Representing Technological Alternatives

Another major challenge is representation of new technological and WEF resource development alternatives that have not previously been adopted in the region. Such developments include new strategies for water and/or energy conservation, and different land use choices and new crop and livestock enterprises or use of saline waters. Appropriate possibilities need to be identified either through stakeholder dialogue, literature searches, examination strategies used in similar regions elsewhere, and/or scientific discussions.

3.1.7 Bringing in the Future

A major challenge is to represent the future in terms of:

- Climate change effects on water and energy consumption along with water supplies, and food production levels plus usages of cooling water;
- Population implications for WEF demands;
- Altered technology;
- Altered out of region trading possibilities for WEF goods.

3.1.8 Addressing Numerous Economic Issues

Demonstration of economic benefit or low economic cost is generally essential in supporting decision-making as is representation of income distribution. Here we list economic considerations for WEF Nexus modeling drawing on McCarl (2015).

3.1.8.1 Incorporation of Market Reactions and Prices

Changes in WEF use/production or allocation may lead to market price alterations. For example, corn ethanol production raised prices and that in turn diverted land to corn resulting in altered water use in many regions and more rapid depletion of groundwater stocks. Additionally, large scale production of biodiesel resulted in market saturation in the glycerol market, a by-product. Consequently, prices dropped severely. Consideration of the direct effects of both of these outcomes on the prices of WEF production and products is warranted.

3.1.8.2 Behavior Changes

Nexus type analyses are conducted frequently under the assumption of continued current practices. Thus, for example, when improving water delivery, one can assume that the same crop mix will be employed. But it is possible that farmers may switch to crops that use more water per acre or expand into previously unirrigated lands (Pfeiffer and Lin, 2014 found this occurred in Kansas). The basic issue here is how can we anticipate or model such behavioral modifications.

3.1.8.3 Income Distribution and Third Party Effects

Nexus actions will not make all parties better off. Actions such as more efficient irrigation water use or alterations in water source will probably raise farmer costs or lower profits but may release water for more valuable uses by others. It is important to estimate the incidence of benefits and costs across different parties. Such information potentially can be used to design incentive and project finance systems. There are also third-party externalities to consider. For example, enhanced graywater reuse reduces inflows into rivers and, potentially, water supply availability for downstream interests. Environmental externalities may also appear, including altered water quality due to changes in agricultural erosion and chemical runoff or discharge of produced fracking water. Such effects need to be estimated and provided to decision-makers although this is frequently not done using economic metrics (due to difficulties with nonmarket valuation).

3.1.8.4 Value of Water in Alternative Uses

It is important to develop information on the value of water in alternative uses, such as irrigation, ecological support, downstream urban, pollution dilution, hydro-electric use, cooling, and fracking (both now and in a future time period). Such information gives insight for decision-makers to possible water reallocation needs and groundwater extraction rates.

3.1.8.5 Adding Consideration of Limits

One needs to examine and quantify the limits to strategy adoption. Such limits will be imposed by knowledge of new practices, or limited resources plus scarce financial and human capital. Limits may be alleviated through educational programs, extension programs, loan programs, grants and other actions.

3.1.8.6 Benefits Transfer

Frequently, results from other studies are transferred into Nexus like analyses. For example, estimates of the value of water elsewhere could be used in the focus region. Such "transfers" need to be done with caution as there are often locational specific influences. This raises the economic concern surrounding benefits transfer. Discussion of the issue can be found in Brouwer (2000) who argues that most transfers appear to result in substantial transfer errors.

3.1.8.7 Designing Incentives

Nexus strategy implementation may require incentives to stimulate some to adopt costly practices in the interest of promoting gains to others. Incentives can be implemented by establishing markets, regulations, technology standards, subsidies or taxes. For example, one can introduce a water marketing mechanism to allow water transfer that provides incentives for low value water users to sell to higher value water users. One can also subsidize equipment for energy and water conserving practices. Model based analysis of incentive designs is often a valuable input into decision processes.

3.2 Data/Knowledge Gaps

Challenges also arise in data availability, use and assembly. Generally data needs for Nexus modeling and analysis almost always exceeds initial data availability and requires compromises for several reasons which will be discussed below.

3.2.1 Proprietary Data

Many parties to Nexus issues are companies with proprietary interests. For example, companies who have developed innovative water and energy conserving practices may not wish to reveal data on water and energy use. Additionally, government agencies that collect data often suppress data releases at low levels of aggregation due to confidentiality agreements rather than reporting these data only at larger geographic aggregates. For example, county level data on large confined animal operations is rare given that there may only be one or two operations in a county. This limited data availability often requires assumption based data creation or creative inferential approaches.

3.2.2 Granularity, Consistency, and Regional Heterogeneity

Models with different focus typically utilize data at different scales. Hydrology models work on small watersheds, crop models on individual plants or fields, and economic models on counties or crop reporting districts. Often some of the needed data like that on land use and soil type data are available at very fine resolutions. However, economic data like crop budgets are frequently available only at a multicounty, crop reporting district level. Downscaling and upscaling procedures are often needed to meet data requirements when specifying models and passing the results between models and data visualization schemes.

Additionally data availability varies greatly globally so presents great challenges in Nexus analysis and modeling in many countries and settings.

3.2.3 What Has Been Done versus What Could Be

Data obtained through surveys, interviews or census means are typically reflections of what has been done in the past and not what could have been done. In particular, the set of production possibilities that are used are those that are best given historical prices and resource availability. However, Nexus actions can alter prices or resource allocations. Forces such as climate change can alter crop and livestock suitability. Consequently, previously unattractive production technologies may now become desirable. This raises the challenge of assembling data on prospective technologies. Sometimes experimentation can be used, yet more commonly one may need to use data from other regions raising the challenges discussed above under benefits transfer.

3.2.4 Cost of Data Collection versus Accuracy of Data Engineering

The data requirements of many models often exceed data availability due to granularity and/or proprietary interests among other forces. This then raises the possibilities of collecting primary observational data, developing data through experimental means and/or performing some data engineering where estimates are developed deductively. Challenges exist in terms of the cost and time acquired to generate observational data versus the accuracy of manufactured data along with the time to develop experimental data.

3.2.5 Difference between Production, Withdrawal, and Consumption

Description of water and energy flows raises substantial issues regarding net production and consumption. Flood irrigation is famous for using water with about 50% efficiency where there is a substantial difference between diversions and net water removed from a river after return flows are considered. Bioenergy production is another example where there may be substantial fuel used in bioenergy production and there is a consequent difference between total production and net production available. Intermediate use of WEF commodities along with return flows, their timing and locations need to be reflected in the data.

3.2.6 Describing Possible New Major Strategies

Nexus analyses are often performed in regions where there has been substantial water and energy planning producing a number of suggested strategies. See for example the Texas Region L plan (Texas Water Development Board, 2016) which identifies 51 different types of strategies to cope with future water demands. Therein data on cost and water yield are presented although not under a range of water supply conditions including drought. Nexus analyses will need to identify and possibly augment such information. Also data on energy capacity construction and operating costs may be difficult to obtain locally since construction of such major facilities involves regionally specific considerations. A major data challenge will be both identifying transformational strategies systematically and developing estimates on their fixed and operating costs and water/energy use; the consequences for production and consumption of FEW commodities under uncertainty is also a challenge. Regional stakeholder input will likely be required.

3.2.7 Projections on Climate, and Population

Regionally increasing population and climate change requires localized future projections. Population projections and their variations based on differing assumptions (e.g., alternative levels of immigration) can often be obtained from state demographers. When climate change projections are available by grid cell, downscaling is needed. Projections of highly relevant phenomena such as incidence of drought, freezes, dry intervals, and extreme storms may not be reliably available. Incorporating data to represent these factors in the analysis will be a challenge.

3.2.8 Characterizing Uncertainty

For uncertain parameters, point estimates must be displayed alongside their uncertainties, which often requires min-max identification or confidence bounds. Furthermore, care is also required in the consideration and representation of joint rather than individual probabilities. For example, there is a joint distribution between crop yields, precipitation, temperature, extreme events and river flow. Characterizing and incorporating such joint distributions in the analysis presents challenges.

3.3 Potential Transformative Solutions Needing More Research

Analyses of WEF Nexus issues are relatively new and, consequently, most of the challenges above require more research. The biggest transformative action currently in short supply, if not entirely absent, is demonstration of the gains to Nexus related decision-making versus individual area decision-making. Additionally, there is a substantial need to better understand how to achieve broader acceptance and participation in overall Nexus solutions from decision-makers in the separate domains. Consideration of both alternative institutional design and incentive structures are likely required to enhance Nexus collaboration.

There is also substantial need for research on model integration and the potential to incorporate visualization tools into the overall structure.

3.4 Impact on Science and Society

There are many papers that deal with the overall importance and structure of Nexus decision making and we will not repeat that coverage. Here we focus exclusively on model and data development issues. Consequently, Nexus related efforts provide two distinct contributions to society and science. First, the data and models we develop can be used to inform stakeholders and policymakers on an actual Nexus issue specific to particular regions improving regional welfare and resource usage efficiency. Second, by disseminating information on innovative Nexus modeling and data efforts that others can employ elsewhere, we improve Nexus analysis and management in other regions.

4 Conclusions

The information generated by analyses supported by Nexus models and related data can help stakeholders and policymakers better understand the cross-sector implications of actions within the water, energy, or food sectors and develop more efficient, equitable, and sustainable policies. In addition to moving beyond siloed models and analyses, Nexus models must pay particularly close attention to incorporating uncertainty. Finally, while Nexus models can be extremely useful for their ability and flexibility in evaluating the implications of a variety of possible policy instruments on current and future WEF outcomes and time profiles, care must be taken to acknowledge the sensitivity of particular outcomes to assumptions regarding economic behavior, demand, population growth, technological change, and climate change along with possible feedback effects.

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