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Moving from theory to practice in the water–energy–food nexus: An evaluation of existing models and frameworks

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ABSTRACT

The recognition of the interlinked nature of water, energy and food (WEF) resources has resulted in growing momentum to change the approaches for managing these interlinked resources. Initially, models were developed as a mean of integrated methodology for watershed management. Several frameworks and models have been proposed to help policymakers understand the complexity of the nexus and to assist with planning and regulating these resources. Most countries and governments manage these natural resources with different institutions that have their own mission and objectives, and with their own staff, data, measures and tools. This has mostly led to huge variations in terms of methodological approach to design these models, type of data used and eventually results interpretations and policies design.

We conducted a review of current literature on the water–energy–food nexus to understand what's known and what's missing and identify key opportunities and challenges facing WEF design and modeling. Our analysis also identified the followings:

- Our review reveals that there are a limited number of models and frameworks that address all WEF together and there are even fewer models and frameworks that has diverse methods and transdisciplinary approaches in analyzing the nexus. It's essential as we design out modeling tools to analyze the nexus to incorporate several dimensions beyond the WEF sectors such as political, social and economic in order to reach nexus thinking and therefore address complexity of the multi-sectoral resources.
- Agricultural sectors require significant amounts of energy as an input to production, yet few water–energy–food resource planning approaches have incorporated spatial cropping patterns and land use by combining energy and water requirements.
- Policymakers are provided with an effective way to analyze the nexus on an aggregate level using macro-drivers, but these often omit the complexity of managing the resources at a smaller scale where other factors such as climate and geography have tremendous influence on supply and demand.
- There are knowledge gaps pertaining the incorporation of spatial–temporal drivers as well as the spatial–temporal dynamics of resource availability or accessibility. This is a significant component in the WEF framework design as natural resources are subject to dramatic changes over space and time.
- There are a considerable number of WEF framework and models that demonstrate promising tools to analyze the nexus but some of these models fall short of capturing interactions among nexus components due to lack of data sharing and availability.

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The increased regional and global variation in natural resources distribution over time and space creates a need to develop more sophisticated models that incorporate these drivers to support the planning and regulatory policy process. These models should also be flexible enough to be applied at varying geographic levels to support resource management at the national, regional, watershed and project levels. Integrating spatial–temporal drivers would result in more comprehensive models that can deliver better policies for sustainable development, increase synergies between institutions and improve social welfare.

Contents

Introduction

Water, energy, and food are vital natural resources needed to resolve critical global issues of hunger, improving health and building a sustainable and desirable economy. These resources are complex aggregates formed and influenced by the collection of elements and managing them relies on several factors such as technology choices, fuel choices, resource availability and market factors, which can all be affected by national resource policies. In addition to their own individual complexity, these resources are also interlinked:

- Water is needed to produce energy,
- Energy is needed to extract, distribute and treat water and
- Food production requires both water and energy

The interdependence of these resources is commonly referred to as the water–energy–food (WEF) nexus. Recognizing this, the policies that govern these resources are also interrelated. In many policy dialogs, managing these interlinked resources is handled by separate institutions to facilitate decision-making, which overlook the interdependences and interconnectivity of the resources. There has been some progress in the last decade to emphasize the nexus and to increase policymakers' awareness of these issues. Several models and frameworks have been proposed in theory and application. Most of these models contribute in many ways of properly integrating the nexus into natural resource policy.

The methodology of most of these models and frameworks is based on identifying the problems, describing the interlinkages and eventually promoting transition to sustainability. As this considers a major step forward in enhancing the integrating modeling approach, some knowledge gap remains. For instance, the dynamic of the nexus over space and time and how optimizing a certain objective function for one resource in the nexus would affect the other resources remains a main challenge. One explanation of this shortcoming in available modeling tools is due to the high interlinkage between the resources and/or due to lack of data.

Optimizing one objective function usually results in shifting the problem from one sector to another or delaying resolutions from the short-term to long-term where it could be more challenging and costly to fix. Therefore, it is vital to uncover the consequences of optimizing the use of one resource on the surrounding environment and other resources primarily due to the dynamic nature of natural resources, and supply and demand. Consider this example of a national resource policy that optimizes food production without considering the knock-on effects on water, energy and land, and how these dynamic input components change over time and space. In north-western India, poorly planned natural resource policies led farmers to deplete the region's natural resources using increased agricultural inputs (fertilizers and excessive amount of ground-water for irrigation) to support national food security (Aggarwal et al., 2004). The impact of this policy was an ecosystem with depleted resources that did not achieve the desired policy outcome of higher levels of food security.

The water–energy–food nexus is also a policymaking challenge due to the complex interlink of these resources. Although models and frameworks have been proposed to improve resource policy planning, more sophisticated models are needed to identify practical methods to manage natural resources in an integrated way. In other words, there is an urgent need for integrated planning and system thinking rather than optimizing the use of one resources over another.

The main goal of this paper is to conduct a review of the current literature on the water–energy–food nexus to understand what's known, what's missing and identify key opportunities and challenges facing WEF design and modeling. In doing this, we have three objectives: