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Review

# Adaptation opportunities and constraints in coupled systems: Evidence from the U.S. energy-water nexus

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ABSTRACT

Over the past decade, adaptation has emerged as an important risk management strategy to address climate change and avoid adverse consequences. These endeavors overwhelmingly focus on actions within sectors and thus fail to account for coupled effects across systems. This paper focuses on adaptation constraints that arise from the interdependencies of coupled systems, and the opportunities that emerge when adaptation strategies integrate such interdependencies. Three general constraints to adaptation in coupled systems are identified and detailed using evidence from the United States energy-water nexus: insufficient data and information, path dependence, and institutional fragmentation and disorganization. Adaptation constraints within the energy-water nexus are especially difficult to avoid or overcome at local and regional scales owing to complex, and poorly integrated, governance structures. This indicates that some degree of national coordination is an important enabling condition to overcome constraints and enable adaptation throughout the energy-water nexus.


## 1. Introduction

Over the past decade, adaptation has emerged as an important risk management strategy to address climate change and avoid adverse consequences (Mimura et al., 2014). This was highlighted in the 2015 Paris Climate Change Agreement, which acknowledges adaptation as an essential response to climate change to protect people and ecosystems (United Nations Framework Convention on Climate Change, 2015). While adaptation efforts have increased recently, they generally remain focused on discrete sector-specific actions (Mimura et al., 2014). For example, numerous climate change publications including the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR) and the United States (U.S.) National Climate Assessment organize adaptation by sector (IPCC, 2014; Melillo et al., 2014), as do various adaptation plans (Hughes, 2015; Woodruff and Stults, 2016).

Inherent limitations to applying a sector-specific approach in the pursuit of adaptation exist (Adger et al., 2005). The concept of a sector is a convenient heuristic for organizing adaptation efforts and aligning information and actions to stakeholder groups, economic indicators, or jurisdictional elements. In practice, however, sectors represent complex systems of physical, social, political, and economic processes. These systems are often coupled – they interact, overlap and have effects on the inputs, constraints, and outcomes of each other. For example, the coupling of energy and agriculture systems is evident in the environmental, economic, and social consequences that stemmed from the implementation of U.S. federal incentives for bioenergy (Preston et al., 2015a). These incentives exacerbated competition for corn which led to rapid increases in ethanol-related corn production, particularly compared to food-related corn production, and contributed to decade-level high prices for corn and ethanol during the 2012 U.S. drought (Preston et al., 2015a).

This paper focuses on adaptation constraints that arise from the interdependencies of coupled systems, and opportunities that emerge when adaptation strategies integrate such interdependencies. This paper argues that such interdependencies are the norm, not the exception, and thus the dominant framing of adaptation responses as sector-specific is a “failure of understanding” that must be addressed in the development of robust adaptation responses (Preston and Kay, 2009 based on Clark, 2002, p. 115). In

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contrast, reorienting framing toward *holistic adaptation,* or adaptation concerned with complete systems, has the potential to identify mutually beneficial adaptive responses to climate change and to produce more effective outcomes than adaptation focused on a single system.

This paper proceeds with a theoretical review of consequences that arise when adaptation planning does not consider coupled systems. This is followed by a review of the foundational literature on adaptation constraints to establish context for subsequent discussion. The practical implications of coupled systems for adaptation are then explored by using evidence from the U.S. energy-water nexus (EWN). The paper concludes with a discussion of pathways to overcome constraints and pursue opportunities related to adaptation implementation within the U.S.-EWN and lessons that can be applied to adaptation more broadly.

## 2. Adaptation within coupled systems

Despite the need for a holistic framing of adaptation, there is little academic literature and few practical examples detailing adaptation approaches within coupled systems (Moser, 2009). Moser (2009) notes widespread acknowledgement that cross-sector adaptation is necessary but that most entities have postponed this challenge. Examples of adaptation efforts show the narrow focus of adaptation implementation: Norwegian municipalities used the past to guide adaptation efforts (Amundsen et al., 2010); U.S. federal lands pursued adaptation within units without integration (Jantarasami et al., 2010); and Swedish municipality efforts lacked sectoral coordination (Storbjörk, 2010). Failure to consider coupled systems in adaptation efforts can result in four consequences: unrecognized tradeoffs, maladaptation, ineffective outcomes, and missed ancillary or co-benefits of strategies.

Externalities lead to unrecognized tradeoffs when adaptation efforts are not holistic. The IPCC-AR5-Working Group 2 reported examples of potential tradeoffs that may occur when adaptation planning does not consider multisystem interactions (Table 1). For example, while increased pesticide use may adapt crops to new conditions, it also creates externalities in related systems including increased costs for farmers, pollutants to the environment, human exposure to pollutants, and greenhouse gas (GHG) emissions (Klein et al., 2014). The distribution and severity of unrecognized tradeoffs displaced onto related systems may be unequal and unjust which will exacerbate existing inequalities or create new ones.

A second consequence of sector-specific adaptation is maladaptation, which is defined as adaptive actions that adversely impact or increase vulnerability in other systems or groups (Barnett and O'Neill, 2010, p. 211). Barnett and O'Neill (2010) use the construction of the Wonthaggi desalination plant for Melbourne, Australia to detail five types of maladaptation: 1) the energy-intensive desalination process increases GHG emissions; 2) the contested Aboriginal-owned location of the plant and increased utility costs overburden vulnerable populations; 3) the aforementioned social costs and environmental costs such as reduced flows of the Murray river create opportunity costs; 4) the use of seawater for desalination masks freshwater availability and undermines conservation efforts; and 5) the scale and permanence of the project creates path dependence. In Melbourne, the sole pursuit of ensuring water availability was achieved at the expense of related systems that must then manage the resultant maladaptation. When multiple, related systems pursue adaptation singularly, maladaptations transfer onto other systems thereby increasing vulnerability and not effectively reducing climate risk across systems. Additionally, when adaptive actions that generate maladaptation are coupled, effects on related systems become even more pronounced.

The case of the Wonthaggi desalination plant also details ineffective outcomes of adaptation focused on a single system. For one, the plant has never been used–the first water order was announced in March 2016 amid calls that it was unnecessary, and as of December 2016, the plant has not initiated the month long process to begin operation (Willingham, 2016). Despite never operating, plant owners are paid 1.8 million dollars per day to ensure operability (Willingham, 2016). While the plant is often referred to as a water "insurance policy" (Willingham, 2016), other measures that consider coupled systems like pursuing treated wastewater, captured rainwater, and conservation could enable more effective water savings and ensure water availability for less cost (Barnett and O'Neill, 2010) even when shortages are not dire.

In addition to negative consequences of single-system adaptation, ancillary or co-beneficial adaptation opportunities are often missed. For one, low-regrets and demand-management actions are frequently overlooked in favor of supply-management and infrastructure-based actions (Pittock, 2011). Emphasizing the latter neglects opportunities to lessen system and resource demand through conservation or efficiency measures. For example, pursuing energy efficient retrofitting in U.S. homes could reduce household energy demand by as much as 40% (Council on Environmental Quality, 2009). These efforts have multiple co-benefits including: reduced GHG emissions "by up to 160 million metric tons annually"; potential annual cost savings of 21 billion dollars on household energy bills (Council on Environmental Quality, 2009, p. 1); more jobs (U.S. building energy efficiency investments could create "3.3 million cumulative job years of employment", Fulton, 2012, p. 3); avoided energy supply expansions; and lessened water demand for electricity generation. Second, considering coupled systems in adaptation helps identify opportunities for synergistic technologies like utilizing waste heat "for desalination and combined heat and power", using water systems "for energy storage or electricity demand management", and capturing "energy generation in man-made water conduits" (U.S. D.O.E., 2014, p. x, 129). While holistic adaptation could help avoid negative consequences and realize multisystem benefits, it will also experience constraints.

## 3. Current discourse on adaptation constraints

The concept of adaptation constraints has emerged within the climate change adaptation literature to describe "*factors that make*

**Table 1**
Potential adaptation tradeoffs: selected examples from Table 16-2 in Chapter 16 of the IPCC-AR5 (Klein et al., 2014, p. 918).

| Sector | Adaptation Objective | Adaptation Option | Real/Perceived tradeoff |
|---|---|---|---|
| Agriculture | Maintain yields; suppress pests/invasives | Increase chemical fertilizers/pesticides | Adverse impacts of pesticide use on non-target species; increased: GHG emissions; human exposure to pollutants; discharge of nutrients/chemical pollution |
| Biodiversity | Enhance regulations for at-risk species | Protect critical habitat | Addresses secondary not primary pressures; property rights concerns; regulatory barriers to development |
| Coasts | Protect assets from inundation/erosion | Sea walls | High direct/opportunity costs; equity concerns; coastal wetland ecological impacts |