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Title: Water-Energy-Economics: Leveraging Market Instruments for Building Resilience

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Focal Area(s):
Energy and water systems exist in an economic context that shapes their supply and use, which in turn shapes the macroeconomics of the country. A holistic energy-water-economics view is needed that links physical resource constraints, sectoral interdependencies, policy and management practices, infrastructure investment, and creative market instruments with macroeconomic feedbacks that shape national economic outcomes.

Existing Challenge:
Water scarcity is increasingly disrupting not only agriculture, but the nation's energy infrastructure. Recent droughts have led to billions of dollars of losses in agriculture along the Colorado River and the California Central Valley (Stone et al. 2022). Recent years have seen reductions in the volume of the Ogallala aquifer, with some areas seeing wells dry up, threatening agricultural economies on the Great Plains (Rhodes et al. 2023). Texas, Alabama, and Tennessee have been forced to reduce generation at thermal plants when water for cooling was unavailable, leading to higher energy costs and reducing grid reliability (US Department of Energy 2013). These challenges are not merely the result of natural scarcity, but of management systems that allocate and price water in ways detached from the available water supply (Johansson 2002; Mansur and Olmstead 2012).

Water rights in the United States, particularly in the West are based on historical precedent. These systems often use the Prior Appropriation doctrine, under which an individual or organization that first laid claim to water rights can retain them for long periods. There is variation across states, and sometimes even within states, with how water rights are established and adjudicated (Lisk et al. 2024). This heterogeneous system can lead to inefficient water use and a limited ability to redirect water in response to changing priorities. Prior research has included empirical modeling of water use and water markets (Wheeler et al. 2014). However, there has been low implementation of water markets within the United States, and there has been little research on the economic benefits of water markets and other water management practices.

A clear understanding of the interconnections that determine water resilience, energy and industrial reliability and economic security is needed. One of these dimensions is economic resilience across different water users and the potential impacts on the greater

economy of water management or mismanagement (Garrick et al. 2020). A key research question is how water use and costs will change over time under different management practices as there is a greater need for energy-based and other industrial water usage, such as data centers. Understanding how these changes will affect broader macroeconomic outcomes such as GDP growth, labor markets, and trade, will be essential for designing policies that enhance long-term security and resilience.

These results then need to be scaled up to understand the impacts from a national perspective. The broader economic impacts, such as GDP growth, labor markets, and trade, are not consistently factored into analysis and planning. Research shows that basin-scale changes in water availability or cost affect capital, commodity, and labor markets by altering crop choices, commodity exports, industrial location decisions, and regional employment, with trickle-down effects on the country's GDP and trade. An overarching challenge is that tools integrating those dynamics on a national and global scale are either not present or lack the fidelity to inform scientific and practical insights. A comprehensive, macroeconomic perspective is essential to understand and mitigate the ripple effects hindering energy-water resilience across the national economy.

Near-Term Opportunity:
There is a current opportunity to research how different water management practices could affect industries that rely on water, and to find the practices that would yield the greatest long-term economic benefits. Modeling watersheds and streamflow, including dam and hydropower systems, could demonstrate feasible water market trades and other viable water-management practices. Data-driven empirical modeling can be done to estimate the marginal value of water to different users. These values can then be used as inputs to economic market models to simulate counterfactual outcomes of different water policies and practices. This could also include methods and processes for optimal infrastructure investment in water and energy-water-resilience, such as desalination, irrigation efficiency, etc., and anticipate how those investments could affect future freshwater supply and cost.

Research on the impact of water market implementation and usage has tended to be specific to the economics field. However, water economists have identified that the modeling of the economics of water markets needs to be combined with the latest methods for modeling hydrology and ecosystems (Garrick and Hahn 2021). Economic models lack physical system representation, such as reservoir operations, conveyance and environmental limits, groundwater-surface water coupling, return flows, and the energy requirements for pumping and water treatment. There is a current opportunity for interdisciplinary modeling in this domain that would allow for combining the technical constraints of the hydrological systems with the multi-actor dynamics of the policy makers and water users.

A further opportunity is to understand macroeconomic feedbacks from integrating water and energy into economic models. While localized economic effects of water scarcity and energy shortages are often recognized, the broader economic impacts, such as GDP

growth, labor markets, and trade, are not consistently factored into analysis and planning. Research shows that basin-scale changes in water availability or cost affect capital, commodity, and labor markets by altering crop choices, commodity exports, industrial location decisions, and regional employment, with trickle-down effects on the country's GDP and trade (Koopman et al. 2017). An overarching challenge is that tools integrating those dynamics on a national and global scale are either not present or lack the fidelity to inform scientific and practical insights. Analysis tools such as the Global Change Analysis Model (GCAM-USA) and its recent advancements in incorporating macroeconomic feedbacks (Patel et al. 2023) could be used to assess macroeconomic feedbacks of water systems, such as impacts of water infrastructure investments, public-private spending, technological advancements and sectoral labor shifts. As the U.S. faces the need to modernize its water infrastructure in the coming decades, these models can capture the co-benefits of such capital investments, quantifying not only the direct energy and agricultural effects but also the broader economic benefits, such as the stimulus from infrastructure spending and the knock-on effects on GDP, labor markets, and trade. By applying these models to future infrastructure projects, one can better understand the full economic returns of investing in water-energy resilience and prioritize investments that maximize both resource efficiency and economic growth.

Success Measure:
Better water management practices could translate into better water quality, greater resilience when droughts occur, and more reliability, stability, and long-term affordability of the water supply for agriculture, industry, and municipal needs. Dissemination of research on the economic consequences and risks at the intersection of water and energy policy could lead to increased adoption of economically efficient systems. As water demand grows and competition for limited supplies intensifies, physical limits on the available water supply can impose economic hardship on users and industries that rely on water. Leveraging market-based instruments, such as tradable water rights, reuse markets, and consumption substitution and efficiency incentives, could enable more flexible water allocations, optimized water distribution, and balance demand from agriculture, industry, and energy production. Deepening our understanding of water management practices can help design approaches that strengthen the water-energy system, promoting long-term economic health.

This work could also inform cross-sector cooperation that may increasingly be likely in the future. As water use becomes more competitive and a greater need for energy-water nexus management arises, these innovations may provide information about system design for more efficient water use. The information could also be used at a more granular level to estimate how firms and facilities may be financially affected under different policy scenarios. Changing policies and institutional structures often comes with costs to some agents. Better management practices could lead to efficiency gains and more robust economic outcomes. However, understanding who may stand to suffer economic harm from policy changes can help formulate policy to minimize harm and provide more feasible solutions with less opposition.

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