Integrating an IRIO hydro-economic model with a physically-based hydrological model to characterize water scarcity in sub-basins of Tuscany, Italy.

Topic: Special session: From Basins to Planet: Unraveling Water-economy Interactions across Scales with MRIO Models

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Traditional input-output models that link economic activity with water resources often rely on economic units of analysis, overlooking the geographical and hydrological relevance of river basins. However, river basins serve as the fundamental units for evaluating water ecosystems and their interactions with the productive system. This study examines the balance between water supply and demand across five local labor systems (LLS) in the upper Arno River basin, Tuscany, Italy.
Water supply is modeled using the Soil and Water Assessment Tool (SWAT), which simulates key hydrological components such as precipitation, evaporation, surface runoff, and groundwater recharge. On the demand side, the study distinguishes between blue water (withdrawn from surface and groundwater sources), green water (soil moisture available for plant uptake), and gray water (used for pollutant dilution). Demand estimation is conducted using a multiregional input-output hydro-economic model (MRIO), which is fully integrated with SWAT and a water quality mixing model. This integration provides a comprehensive assessment of water flows and their economic implications.
One of the studyâ€™s critical innovations is its spatial harmonization approach, which aligns sub-basins with their corresponding LLS. This ensures that hydrological and economic analyses are not conducted in isolation but rather within a coherent spatial framework, leading to a more precise assessment of water dynamics.
The integrated modeling framework identifies two key endogenous effects that significantly influence water dynamics:
1. Adjustments in agricultural water withdrawals based on green water availability, reflecting the ability of crops to rely on soil moisture rather than irrigation.
2. Changes in industrial gray water requirements due to variations in runoff and groundwater recharge, impacting water availability for pollutant dilution and industrial processes.
By simulating these effects over a 13-year period, the model captures the interannual variability of hydrological components, providing insights into long-term water use trends.
Unlike traditional economic models that lack physical hydrological integration, this approach provides a more accurate representation of green water supply. This, in turn, enables a more precise assessment of agricultural water demand dynamics, as it accounts for seasonal variations and climate-induced fluctuations. A key advantage of this integration is that it allows for a better understanding of the variability in blue water demand, particularly for the agricultural sector, which is highly sensitive to hydrological conditions.
To quantify water scarcity at the LLS level, the study synthesizes results into multiple indicators, incorporating different demand and supply perspectives. These includes:
â€¢ Demand-based approaches: total withdrawals, net demand, and extended demand.
â€¢ Supply-based perspectives: natural ecological supply and feasible supply.
By analyzing multiple hydrological years, the study assesses the variability of these indicators, allowing for an evaluation of the risk of exceeding various thresholds suggested in the literature. This long-term perspective is crucial for understanding the resilience of local labor systems to water scarcity risks and for designing adaptive water management strategies.
Beyond water scarcity assessments, the model offers a powerful tool for evaluating the economic impacts of local and regional decision-making on water resources and labor systems. Given its integrated hydro-economic framework, it can inform policy interventions, helping decision-makers assess the trade-offs between economic development and water sustainability.

The results highlight the importance of integrating physical and economic models to develop more effective policies for managing water resources sustainably. In an era of increasing climate variability and water stress, this approach offers a robust framework for ensuring the long-term viability of water-dependent economic activities, while minimizing the risks associated with water scarcity and pollution.

By bridging the gap between hydrology and economics, this study provides a comprehensive approach to water resource management, demonstrating the value of spatially-explicit, physically-grounded economic models in addressing water sustainability challenges.