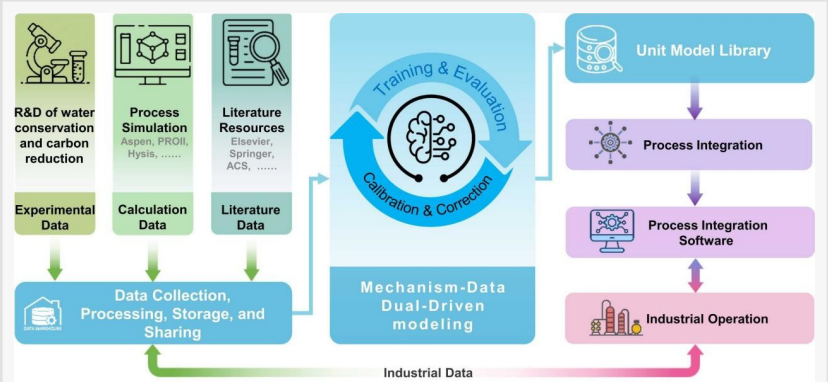
Mechanism-data Dual-driven Research Framework for Water Conservation and Carbon Emission Reduction

GA, UNITED STATES, November 26, 2025 /EINPresswire.com/ -- This study proposes a mechanism-data dual-driven framework to address the challenge of balancing water conservation, carbon emission reduction, and aquatic ecosystem preservation in China's industrial sector at minimal cost. It involves developing hybrid models for water-use and treatment processes and establishing a superstructure optimization model. This model identifies the optimal pathway for simultaneous water saving and carbon mitigation, supporting cost-effective decisions for industrial park water network optimization. Case studies confirm the framework's effectiveness in balancing economic and environmental benefits.



Research framework for dual-driven whole-process water conservation and carbon emission reduction.

The Chinese industrial sector is facing the challenge of achieving an optimal balance among water conservation, carbon emission reduction, and aquatic ecosystem preservation at a manageable or minimal cost. To that end, Yuehong Zhao and Hongbin Cao from Institute of Process Engineering of Chinese Academy of Sciences proposed a mechanism-data dual-driven framework. The framework involves developing hybrid models to characterize water-use and treatment processes along with their associated carbon emissions, as well as constructing a superstructure optimization model to solve water-carbon-economy nexus problem.

“By solving the obtained optimization model, the optimal technical pathway for simultaneous water conservation and carbon emission reduction at a minimum water-use cost can be identified,” explains Zhao, who is the lead author of the study(doi: https://doi.org/10.1016/j.wateco.2025.100003) published in Water & Ecology. “It provides valuable information to support the decision-making about water network optimization within industrial parks.”

Based on a deep understanding of the mechanisms underlying typical water-use, wastewater

treatment and reuse processes within industrial parks, the hybrid modeling approach within the framework, integrates mechanistic understanding with data-driven techniques, enhancing model interpretability and generalization even with limited training datasets. “This represents an effective approach to promoting the application of machine learning/AI technologies in the industrial sector,” says Cao. “However, a systematic theory and methodology for hybrid modeling remain underdeveloped. The key to challenges includes how to select the appropriate mechanism and its expression for integration with machine learning.”

A superstructure optimization model was then constructed on the basis of unit models and domain knowledge, encompassing feasible unit technologies, their interconnections, and relevant constraints to identify optimal solutions. “Deterministic optimization algorithms were applied to achieve global optimum solutions with minimal water-use cost,” shares Zhao. “In a case study, a multi-scale optimization methodology for water conservation in industrial parks was established, leading to the development of a practical software tool successfully applied in steel companies.”

“The framework can provide a solution which balances local and overall benefits, as well as economic benefits and environmental impacts,” adds Cao.

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