IN.CYCLE

Closing the loop: an innovative treatment train for load-adaptive wastewater valorization and reuse in industries with highly polluted effluents

Water4All
Water security for the planet

Coordinated by Early Career Researcher

Abstract

Industrial wastewater treatment must evolve to meet future environmental, regulatory, and resource management challenges. Wastewater treatment plants (WWTPs) are increasingly recognized not only as pollution control facilities but also as resource recovery hubs, in line with the European Green Deal and the UN Sustainable Development Goals.

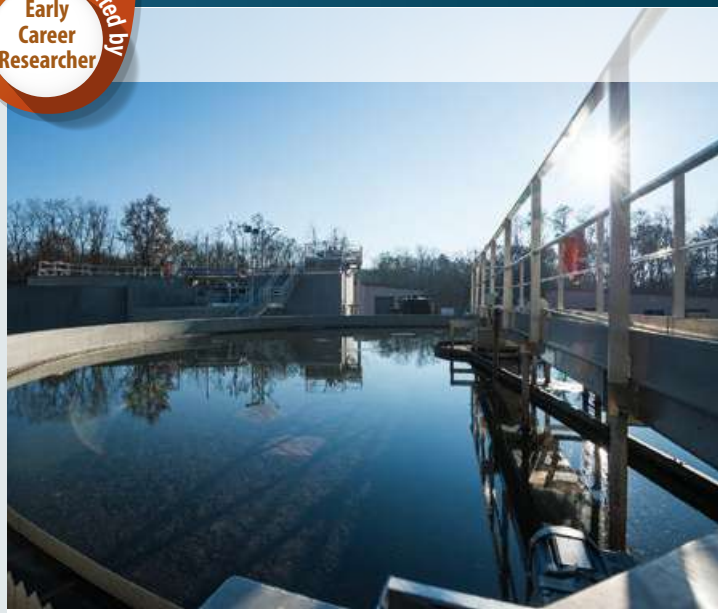
Industrial effluents, particularly those rich in salts and organic matter, offer significant yet underexploited opportunities for water, energy, and material recovery. However, conventional treatment technologies severely limit valorization due to salinity impacts on biological processes and the presence of hazardous micropollutants that threaten compliance with the revised Urban Wastewater Treatment Directive (UWWTD) and the Water Framework Directive (WFD).

IN.CYCLE addresses these challenges by developing an innovative, modular treatment train combined with a digital twin (DT) framework for adaptive wastewater valorization. The project pursues four interconnected objectives:

- (1) electrochemical desalination to enable resource recovery and protect downstream biological treatment,
- (2) high-rate anaerobic treatment for enhanced energy recovery via methane production,
- (3) hybrid membrane and advanced oxidation processes for micropollutant removal to meet reuse standards, and
- (4) real-time, scenario-driven decision support through a predictive DT integrating process monitoring, modelling, and life cycle assessment.

The novel treatment technologies will be developed and validated in laboratory-scale experiments using wastewater from the Joint Water Treatment Plant GKW. Following optimization, pilot-scale units will be implemented and demonstrated under real operating conditions at GKW, treating complex industrial and municipal effluents. Real-time sensors, smart monitoring tools, and a modular DT architecture will support dynamic process management, predictive maintenance, and environmental performance evaluation.

Through the integration of advanced technologies with adaptive digital decision support, IN.CYCLE will significantly enhance resource efficiency, energy recovery, and industrial water reuse, contributing to sustainable water management and circular economy transitions in Europe.



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Project partners

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- GEMEINSCHAFTSKLÄRWERK BITTERFELD-WOLFEN GMBH - GERMANY
- SWEDISH ENVIRONMENTAL RESEARCH INSTITUTE - SWEDEN

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