

## **A graph theory approach for Digital Twin Ocean**

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The ECOTWIN project aims to bridge the gap between mechanistic ecological models and qualitative social data by developing novel graph-theoretic methodologies for socio-ecological modelling within the European Digital Twin Ocean (EDITO). Given the complexity of marine socio-ecological systems, ECOTWIN formulates models integrating ecological, social, economic, and legal data into interoperable graph structures. These models include (i) quantitative causal graph-based models for scenario analysis. The graph-theoretic approach allows for coupling ecological and social systems through shared nodes, enabling causal inference, stability analysis, and sustainability assessments. By leveraging spectral graph properties, information theory, and Bayesian belief networks, ECOTWIN's models facilitate decision-making for marine spatial planning, ecosystem service management, and policy evaluation. This work represents a major advancement in transdisciplinary digital twin modelling, offering a scalable, data-driven framework for analyzing and managing complex marine ecosystems in response to environmental and human pressures.