EcoTwin - Advancing Interoperable Digital Twins for Marine Socio-Ecological Systems

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The EcoTwin project (Emulating complex causal socio-ecological models in digital twins of ocean), a Horizon Europe Research and Innovation Action funded under the call HORIZON-MISS-2023-OCEAN-01-08, will develop four distinct classes of novel SE models and analysis tools, EcoTwin aims to facilitate their seamless integration into the European Digital Twin Ocean (EDITO) and local DTOs. **https://ecotwinproject.eu**

EcoTwin Project Overview: Emulating Complex Socio-Ecological Systems:

EcoTwin's central ambition is to explore the potential of the European DTO by providing the necessary models, tools, and methods to understand and assess the intricate interplay of social, economic, and ecological factors in marine and coastal domains. The project employs a multi-actor approach, actively engaging policymakers, local communities, and marine industries to co-develop solutions that address the challenges of modelling marine Socio-Economic (SE) systems and their integration into the emerging European DTO framework. EcoTwin is developing four innovative classes of SE models:

- **Class I: Quantitative Causal Graph Theoretic Models:** These models utilise mathematical graph theory to represent causal relationships between ecological and socio-economic variables, allowing for quantitative analysis of their interactions.
- **Class II: Qualitative Causal Graph Theoretic Models:** Similar to Class I, but focused on qualitative assessments of connectivity and the direction and strength of interactions using ordinal scales, enabling analysis of system properties like stability and sustainability.
- **Class III: Network Models with Participatory Feedback:** These models explicitly incorporate dynamic feedback from stakeholders, gathered through workshops and participatory engagement, to refine the representation of SE interactions and ensure their relevance for decision-making.
- **Class IV: Parallel Generative AI Models:** These models utilise generative artificial intelligence trained on diverse datasets from EDITO and other sources to extract causal relationships, enhance accessibility to DTO outputs through natural language interfaces, and provide rapid, data-driven insights.

These modelling innovations are underpinned by methodological protocols designed to ensure seamless integration with DTOs, with a strong emphasis on the interoperability, accessibility, reliability, and sustainability of transdisciplinary data. The project will validate these models and tools through four distinct use cases located in the North Sea, Celtic Sea, Thracian Sea, and Waterford Harbour, addressing pressing challenges related to marine spatial planning, renewable energy development, fisheries management, and ecosystem health.

EcoTwin's development efforts are generating technical services and solutions directly relevant to the advancement of thematic and local DTOs, particularly in enhancing their capabilities for socio-ecological analysis:

- **Novel Socio-Ecological Modelling Frameworks:** EcoTwin will provide open-access methodologies and frameworks for developing and implementing the four classes of SE models. These frameworks will be adaptable for various thematic and local DTO applications, enabling users to represent and analyse complex SE interactions.
- **Causal Graph Theoretic Analysis Tools:** The project will deliver specific software tools and algorithms for constructing, analysing, and visualising both quantitative and qualitative causal graph theoretic models. These tools will allow DTO users to uncover cause-and-effect relationships within their systems, identify key drivers of change, and assess the potential impacts of various interventions.
- **Participatory Feedback Integration Methodologies:** EcoTwin will establish protocols and best practices for incorporating stakeholder knowledge and feedback directly into SE models. These methodologies will enable local and thematic DTOs to build more robust and socially relevant representations of their systems.
- **Generative AI-Powered Insight Generation:** The foundation AI models and associated tools developed by EcoTwin will offer a novel technical service for enhancing the accessibility and interpretability of DTO data and model outputs. By using natural language processing and other AI techniques, these tools will facilitate interaction with complex information for a broader range of users.
- **Socio-Ecological Performance Indicators:** EcoTwin will develop SE performance indicators, derived from the various model classes, to assess system connectivity, stability, sustainability, and the impacts of different scenarios. These indicators will provide valuable metrics for evaluating the state and trajectory of thematic and local DTOs, supporting policy assessment and management effectiveness.
- **Methodological Protocols for DTO Integration:** A key technical service provided by EcoTwin will be the development of clear and actionable protocols for integrating transdisciplinary data and models into existing and emerging DTO infrastructures. These protocols will address critical aspects of interoperability, data standards, and the seamless exchange of information between different DTO components and platforms, contributing to the federation of ocean knowledge.

Integration with EDITO and Local DTO Ecosystems:

EcoTwin's design explicitly prioritises the integration of its outputs into the wider DTO ecosystem. The developed socio-ecological models, algorithms, and decision support tools will be integrated into EDITO-Infra. Moreover, the socio-ecological model outputs from all use cases will be transferred and presented through the EDITO-Model Lab, contributing to the evolving digital ecosystem of operational DTOs.

At the workshop, an overview of the project and models will be presented