ΟΙΚΟΝΟΜΙΚΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΑΘΗΝΩΝ
ATHENS UNIVERSITY OF ECONOMICS AND BUSINESS

ΣΧΟΛΗ ΟΙΚΟΝΟΜΙΚΩΝ ΕΠΙΣΤΗΜΩΝ
SCHOOL OF ECONOMIC SCIENCES

ΤΜΗΜΑ ΔΙΕΘΝΩΝ & ΕΥΡΩΠΑΪΚΩΝ ΟΙΚΟΝΟΜΙΚΩΝ ΣΠΟΥΔΩΝ
DEPARTMENT OF INTERNATIONAL & EUROPEAN ECONOMIC STUDIES

SUSTAINABLE SYSTEMS TRANSFORMATIONS AWAY FROM THE PERMANENT MULTI-CRISIS

PHOEBE KOUNDOURI

ANGELOS ALAMANOS

IOANNIS ARAMPATZIDIS

LYDIA PAPADAKI

Working Paper Series

26-01

January 2026

Department of International and European Economic Studies

Sustainable Systems Transformations away from the Permanent Multi-Crisis

Prof. Dr. Phoebe Koundouri[1,2,3,4*], Angelos Alamanos[5], Ioannis Arampatzidis[3,4,6], Lydia Papadaki[3,4,6]

[1] School of Economics, Department IEES, and AE4RIA.ReSEES Research Laboratory, Athens University of Economics and Business, Athens, Greece

[2] Department of Earth Sciences and Peterhouse, University of Cambridge, Cambridge, UK

[3] AE4RIA.SDU ATHENA Information Technology Research Center, Athens, Greece

[4] UN Sustainable Development Solutions Network (SDSN) Global Climate Hub, Athens, Greece

[5] Independent Researcher, Berlin, Germany

[6] AE4RIA.ReSEES Research Laboratory, Athens University of Economics and Business, Athens, Greece

Abstract

The current "multi-crisis" is not a set of separate shocks but a tightly interconnected system of climate and biodiversity pressures, food–energy–water insecurity, macroeconomic fragility, widening inequalities, rapid urbanization, and geopolitical stress. While the SDGs provide an integrated blueprint for action, progress remains insufficient, pointing to a persistent gap between global ambition and operational delivery. This study argues that closing this gap requires a practical Global Commons for implementation, one that can translate policy choices and investments into measurable outcomes, account for cross-sector feedbacks, and support locally feasible pathways. We present the Global Climate Hub (GCH), an AE4RIA–SDSN anchored initiative that combines physical and socio-economic modelling with policy-relevant modelling and participatory co-design. The GCH methodology is organized in three stages: (i) continuous SDG measurement through harmonized data pipelines, spatial diagnostics, and digital twins; (ii) co-designed transformation pathways generated through living labs and coupled model chains (energy, land use, water risk, transport, health, and beyond-GDP welfare and trade outcomes) to quantify synergies, trade-offs, and distributional effects; and (iii) financing, equity, and capacity-building mechanisms that connect pathways to investable roadmaps and strengthen the skills required for sustained implementation. By integrating quantification with stakeholder ownership and open decision-support tools, the GCH positions modelling as a practical instrument for policy prototyping, learning, and course correction. The approach is directly relevant to the evidence mandate of the 2027 Global Sustainable Development Report, offering a pathway-oriented basis for accelerating SDG implementation to 2030 and informing longer-term transformation beyond it.

Keywords: Global Climate Hub, sustainable transformation, systems transformation, stakeholder engagement, sustainable pathways

[*] Acknowledgements: Funding was received from the European Research Council (ERC) under the ERC Synergy Grant Water-Futures grant agreement ID 951424

The multi-crisis state and the systems imperative

The world is at a state of multiple, tightly interconnected crises: accelerating climate change and biodiversity loss; growing insecurity across the food-energy-water nexus; inflationary pressures and persistently low growth rates; widening inequalities both between the global North and South and among socio-economic groups within countries; a rising number of countries facing or approaching sovereign default; rapid urbanization; escalating geopolitical tensions; and increasing strains on the effectiveness and legitimacy of the multilateral system. These challenges are complex, nonlinear, and spatially heterogeneous: a policy that reduces emissions today can create land-use pressures tomorrow or shift water stress across a basin; a technology that improves productivity in one region can displace livelihoods in another, while considerations like sustainable financial mechanisms and equity are often overlooked. Tackling them requires more than single-sector fixes. It demands integrated systems transformation pathways that are actionable, locally tailored, and able to reconcile short-term trade-offs with long-term goals.

The SDGs represent a brilliant and comprehensive framework for integrated systems transformation towards sustainable development. Humanity already possesses the science, the technology, the policies, and even the financial resources, both public and private, to achieve them. Yet, implementation remains strikingly low. Only 17% of SDG targets are on track worldwide, with many progressing too slowly and a significant share stalled or regressing (United Nations, 2024). Why is this the case? The answer lies in the lack of capacity and accountability within the global multilateral system, which is itself in a state of crisis. While the SDGs provide direction, there is no robust ***Global Commons*** explicitly tasked with designing and driving their implementation at scale. What we urgently need is the creation of an explicit operational structure capable of aligning global efforts, ensuring effective coordination, and delivering results on the ground. This must be supported by efficient and transparent channels for technology transfer, financial flows, and capacity building, particularly for policymakers and key stakeholders across all sectors and regions.

Data-driven modelling approaches can contribute to this capability by translating alternative policies, investments and social choices into quantified short-, medium-, and long-term outcomes across climate, food, energy, water, transport, health and economic systems. On the other hand, participatory processes and life-long training can foster shared understanding, build individual and institutional capacities, and support the co-creation of solutions that are both context-sensitive and practically implementable. The combination of these two (modelling and participatory processes), with the use of new, digital and innovative technologies, can leverage the way we perceive and apply sustainability transitions. In this context, modelling becomes an operational instrument (not an academic end) enabling decision-makers and communities to co-design, test, course-correct, own and implement actionable pathways toward the 2030 Agenda.

Global Climate Hub: What it is and how it works

The Global Climate Hub (GCH) is an **AE4RIA: Alliance of Excellence for Research and Innovation on Aephoria - United Nations Sustainable Development Solutions Network** anchored, interdisciplinary initiative that couples advanced AI-ready data infrastructure, interdisciplinary mathematical and statistical models, transdisciplinary stakeholder engagement, training and co-design methods, to produce an open access digital ***Global Commons*** that allows development of operational and implementable sustainability pathways at national to global scales. The GCH brings together nine complementary units: Digital Infrastructure & AI platforms, Atmospheric Physics & Climatology, Energy, Transport, Health, Socio-Economics & Sustainable Finance, Innovation, Participatory Co-Design, Training & Education, ensuring the co-production of techno-economic analyses and societal needs.

The GCH approach involves three stages:

First stage: SDG measurement – continuous monitoring and assessment. The objective is to build a rigorous evidence base that is spatially explicit, temporally consistent, and policy relevant. This is achieved by harmonizing observational and administrative data, remote sensing layers, socio-economic statistics and infrastructure inventories; perform baseline diagnostics (resource stocks, vulnerabilities, hotspot mapping); develop digital twins and quality-assured data pipelines to feed relevant models. The output is a policy-use-ready interactive baseline dashboard, hotspot maps and risk matrices that identify priority interventions and inform resource allocation, shortlisting of policy levers for immediate action (Lafortune et al., 2024).

Second stage: Science-based and stakeholder co-designed transformational pathways for SDGs implementation. We convene stakeholders in living labs to define objectives, constraints and plausible narratives (Alamanos et al., 2022; Guittard et al., 2024; Akinsete et al., 2025); run coupled modelling chains (spatial land-use, water risk, biofuel potential, marine use, energy system simulation & optimization, CGE macroeconomic assessments) with scenario ensembles (Englezos et al., 2022; Koundouri et al., 2025c); evaluate synergies, trade-offs and distributional outcomes across SDG indicators. Thus, we co-produce pathways that are technically feasible, economically realistic and socially acceptable (Koundouri et al., 2024b; Alamanos et al., 2025; Seyhan et al., 2025). The output is a portfolio of candidate transformation pathways (with short-, medium-, and long-term horizons), quantified co-benefits and trade-off matrices, ranked policy packages and investment roadmaps for decision makers (Akinsete et al., 2022; Guittard et al., 2023).

In that sense, GCH adopts a *holistic, integrated systems approach* that links sectoral models (energy system simulation and optimization; land-use dynamics and spatial downscaling; hydrological and water-risk assessments; beyond-GDP economy-wide welfare and trade outcomes via Computable General Equilibrium models; and sustainable -beyond GDP- finance at global, regional, national, micro -companies and institutions- levels). This chaining creates a dynamic feedback loop: energy and land constraints inform macroeconomic projections; macroeconomic outcomes reshape land demand and trade; water stress modifies productivity and feasible sustainable technical and financial pathways. Models are not developed in isolation. *Stakeholder engagement* through transformative living labs, and participatory workshops embed user priorities and local knowledge into alternative scenarios and assumptions. This two-way process improves legitimacy, unveils social feasibility constraints (e.g., distributional impacts), and ensures pathways' implementability. The result provides a detailed, dynamic and spatial, SDG-consistent roadmap of pathways, under different development scenarios, for achieving national, regional and international commitments to 2030 and 2050, which satisfies natural/planetary boundaries, infrastructural feasibility, economic efficiency and social acceptability.

These processes are supported by GCH's in-house built digital platforms and ***digital twins***. The GCH builds an open e-platform that harmonizes data, hosts models and results, and creates interactive scenario explorers for users. Policymakers and practitioners can select scenarios, alter parameters (e.g., dietary patterns, renewable siting constraints, carbon prices), and immediately see spatial maps, sectoral balances, welfare indicators and exposed vulnerabilities, facilitating evidence-informed decisions and rapid policy prototyping. This follows the principles of open science, as all models, key datasets, and decision-support tools are made accessible through the e-platform, accompanied by training modules and curricula to upskill local teams. This ensures reproducibility, transferability, and the long-term scaling of good practice.

Third stage: Financing, equity, and capacity building. This refers to the financing of the co-designed pathways and the fair and equitable allocation of the results. Effective transformation requires aligned fiscal instruments, blended finance and policy coherence, linking funding sources to priority measures and using compact KPIs to track progress. Yet, progress is constrained by shrinking fiscal space and an unfair, short-term-oriented global financial system that is crisis-prone and exacerbates vulnerabilities in developing countries. This multi-crisis context highlights the urgent need to reform the global financial architecture and massively scale up affordable long-term finance by aligning all flows with the SDGs.

Besides strong systems, effective collaboration, and a fair global financial system, the deeply interconnected nature of the SDGs requires skilled people in order to achieve their implementation. As such, targeted and effective capacity development is essential for the successful implementation of the SDGs to raise awareness and strengthen the abilities of individuals, institutions, and communities to actively participate in their sustainability transitions. Capacity building is seen as a multi-faceted process involving the development of skills, knowledge, and institutional frameworks necessary for achieving sustainable development. It functions as a multiplier across the SDGs by acting as a critical lever for enabling these transformations, as it enhances the skills and resources necessary for effective implementation, strengthening policy coherence, reducing negative trade-offs, and enabling the scaling of innovations. With greater institutional and systemic capacity, countries are able to design and implement integrated policies that maximize synergies across SDGs and avoid fragmented action. This highlights the importance of adopting an integrated approach that ensures that interventions maximize synergies and manage trade-offs among the various SDGs, facilitating holistic progress. Furthermore, capacity building empowers diverse stakeholders, enabling their participation in decision-making processes. This empowers inclusivity, which is vital for ensuring that solutions are context-specific and address the unique challenges faced by different communities.

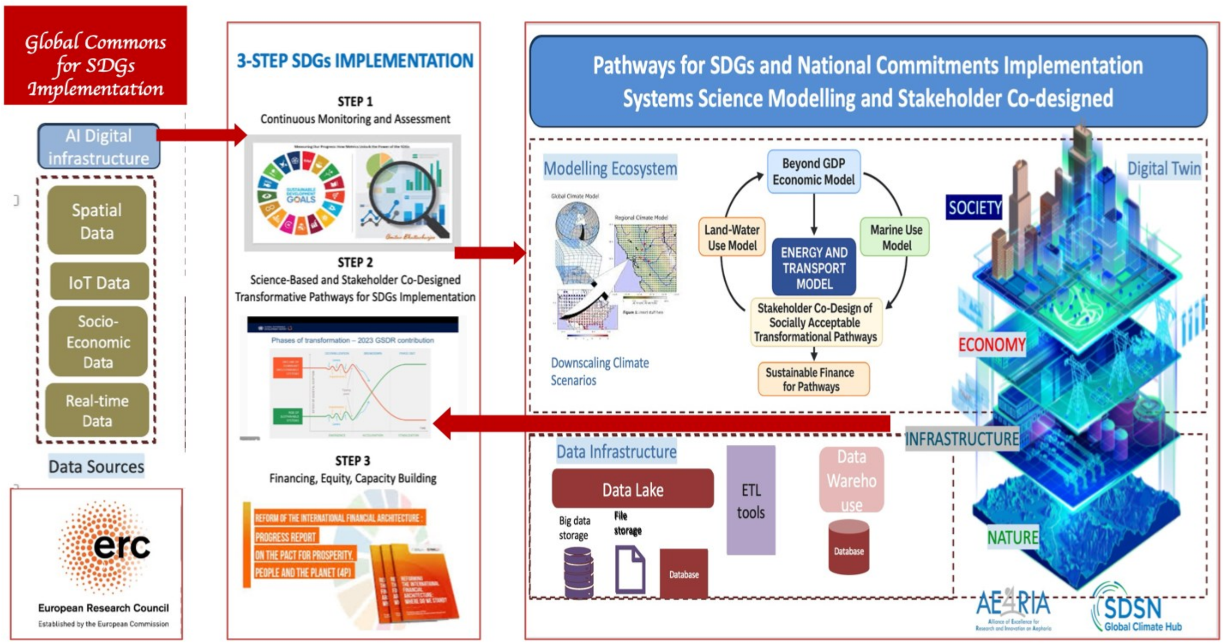

Figure 1 – AE4RIA systems transformations to SDGS implementation.

Systems transformation and stakeholder engagement

Sustainability transitions research, including the Multi-Level Perspective (MLP), Transition Management (TM), Technological Innovation Systems (TIS), Strategic Niche Management (SNM), and systemic design—provides one of the most comprehensive bodies of knowledge for understanding and steering profound socio-technical transformations. Transition frameworks offer an integrative perspective on how socio-technical systems evolve, how innovations diffuse, how institutions resist or embrace change, and how adaptive governance can steer transformations at scale. MLP provides clear analytical language for describing these dynamics. Socio-technical regimes stabilize unsustainable practices, while niches, defined as protected spaces for radical innovation, struggle to scale (see

Figure 2 - left side). According to the MLP, transitions occur when processes at niche, system, and landscape levels interact. Transition dynamics differ across domains and countries; however, typically, niche innovations acquire traction, landscape shifts impose pressure, and regime destabilization generates opportunities for diffusion and disruption (Geels, 2019). This destabilization mechanism is consistent with the theory of *creative destruction*, as articulated by the 2025 Nobel Prize in Economic Sciences laureates, who elucidated the processes underpinning innovation-driven structural change and long-run economic growth (Royal Swedish Academy of Sciences, 2025). They defined *creative destruction* as the process by which new technologies and products displace and overtake older ones, thereby fostering economic advancement.

TM builds upon this understanding by proposing governance instruments to intentionally shift systems through visioning, pathways development, experimentation, and reflexive learning (Kemp et al., 2007;

Loorbach, 2010). TM's practical cyclical methodology, named “Transition Management Cycle”, encompasses four phases, namely, strategic, tactical, operational, and reflexive phases and provides a governance framework conducive to long-term resilience (see

Figure 2 - right side). Finally, TM supports the primary objectives of systems innovation, i.e. to enable bottom-up systems change allowing for technical and social/institutional change to co-evolve (Elzen et al., 2004; Meadows, 2008). Systems innovation is defined as “the multi-dimensional, co-evolutionary transformation of technologies, infrastructures, user practices, cultural meanings, industry structures, and institutions that together constitute a socio-technical system, leading to fundamentally new ways of meeting societal needs” (Elzen & Wieczorek, 2005). This process is subsequently supported by systems design, which supplies the tools and methodologies necessary to identify challenges, prioritize opportunities, collaboratively develop pathways and visions, and facilitate engagement with innovation testing (Jones, 2014; Yasuoka et al., 2018).

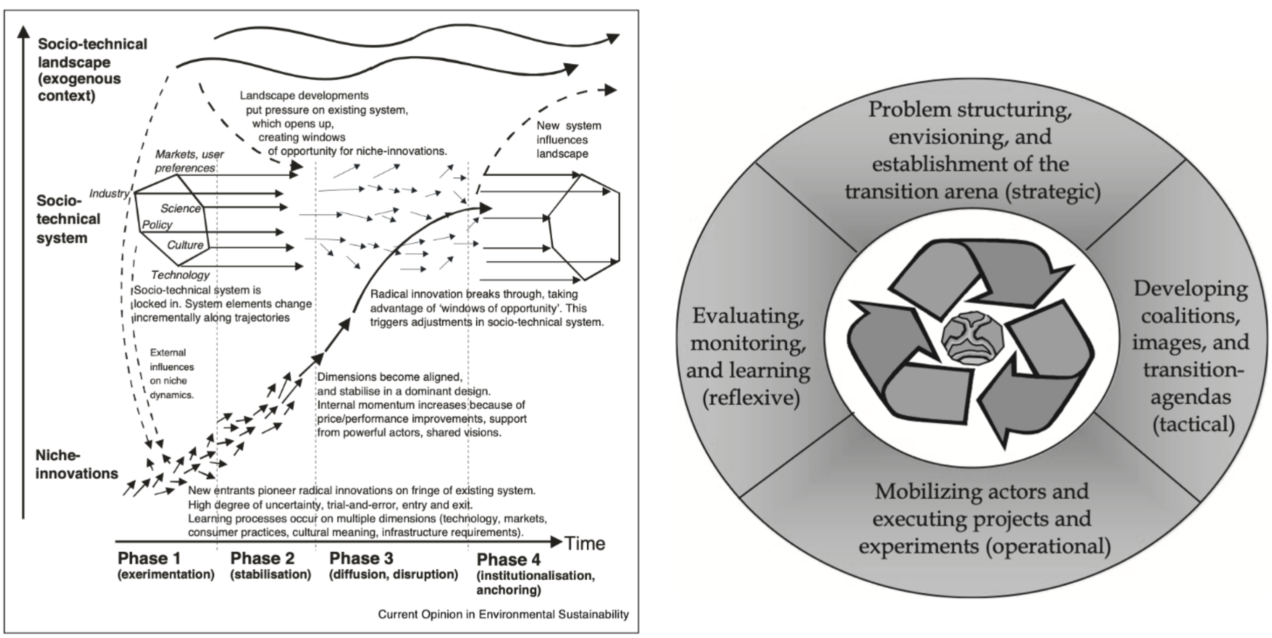

Figure 2 – On the right side: A dynamic multi-level perspective on Socio-technical Transitions (Geels, 2019); on the left side: Transition Management Cycle (Loorbach, 2010).

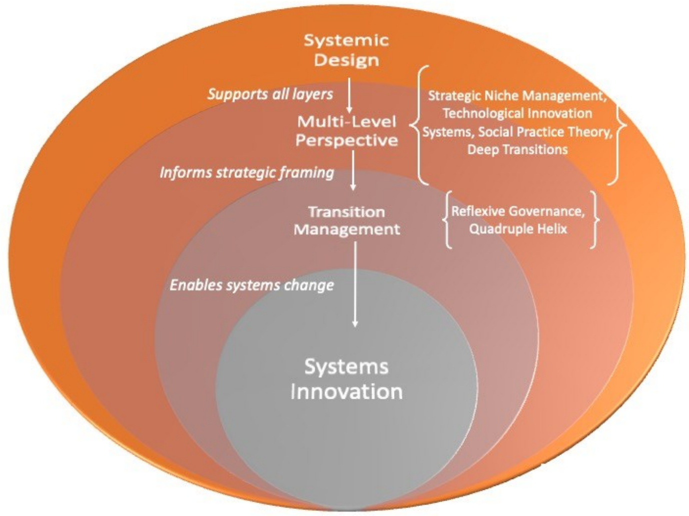

Figure 3 – Overview of Systems Innovation Theoretical Frameworks.

These interconnecting frameworks are visualized in Figure 3 and they are relevant for the GSDR mandate, which explicitly seeks to identify systemic transformations in domains such as energy, food, urban development, and digital governance. Transition frameworks offer validated conceptual and practical tools to identify system obstacles, prioritize interventions, and develop sustainable transition pathways aligned with the SDGs.

Countries are progressively seeking practical, transdisciplinary guidance rather than solely conceptual frameworks. Transition management, living laboratories, mission-oriented innovation policy, and systemic design provide methodologies for bridging the interfaces among science, policy, and society (Akinsete et al., 2025d; Alamanos et al., 2022; Mazzucato & Kattel, 2020). These methods directly support the GSDR's call for evidence that is usable, context-specific and co-produced. Furthermore, the 2023 SDSN Six Transformations framework explicitly incorporates transitions research to identify key transformations for advancing the SDGs (Sachs et al., 2019). Therefore, incorporating transitions evidence into the 2027 GSDR is not only pertinent but also essential to ensure consistency with international science-policy organizations.

IPCC AR6 emphasizes that climate mitigation and adaptation require "integrated, systemic approaches" combining technology, infrastructure, institutions, and behaviour (IPCC, 2022). SDG implementation encounters comparable interdependencies. Frameworks such as MLP and TM explicitly examine cross-level interactions—landscape pressures, regime stability, and niche emergence—enabling policymakers to comprehend how advances in one SDG are contingent upon changes in others (Koundouri et al., 2024a; Stafford-Smith et al., 2016). The GSDR's function in advancing policy coherence and integrated planning renders the focus on transitions evidence particularly pertinent.

Systems transformation and integrated modelling

Stakeholder processes are not developed and performed in isolation. Stakeholder engagement through transformative living labs, and participatory workshops embed user priorities and local knowledge into scenarios and assumptions, which are modelled explicitly to represent the way natural, social and economic systems work. This two-way process improves legitimacy, surfaces social feasibility constraints (e.g., distributional impacts), and helps ensure pathways are implementable.

The GCH links sectoral models (energy system simulation and optimization; land-use dynamics and spatial downscaling; hydrological and water-risk assessments; and economy-wide welfare and trade outcomes via Computable General Equilibrium models). This chaining creates a dynamic feedback loop: energy and land constraints inform macroeconomic projections; macroeconomic outcomes reshape land demand and trade; water stress modifies productivity and feasible pathways. The result is physically feasible, economically realistic, and policy-relevant set of results-based outputs (solution pathways) to 2050.

These processes are supported by GCH's in-house built digital platforms and digital twins. The GCH builds an open e-platform that harmonizes data, hosts models and results, and creates interactive scenario explorers for users. Policymakers and practitioners can select scenarios, alter parameters (e.g., dietary patterns, renewable siting constraints, carbon prices), and immediately see spatial maps, sectoral balances, welfare indicators and exposed vulnerabilities, facilitating evidence-informed decisions and rapid policy prototyping. This follows the principles of open science, as all models, key datasets, and decision-support tools are made accessible through the e-platform, accompanied by training modules and curricula to upskill local teams. This ensures reproducibility, transferability, and the long-term scaling of good practice.

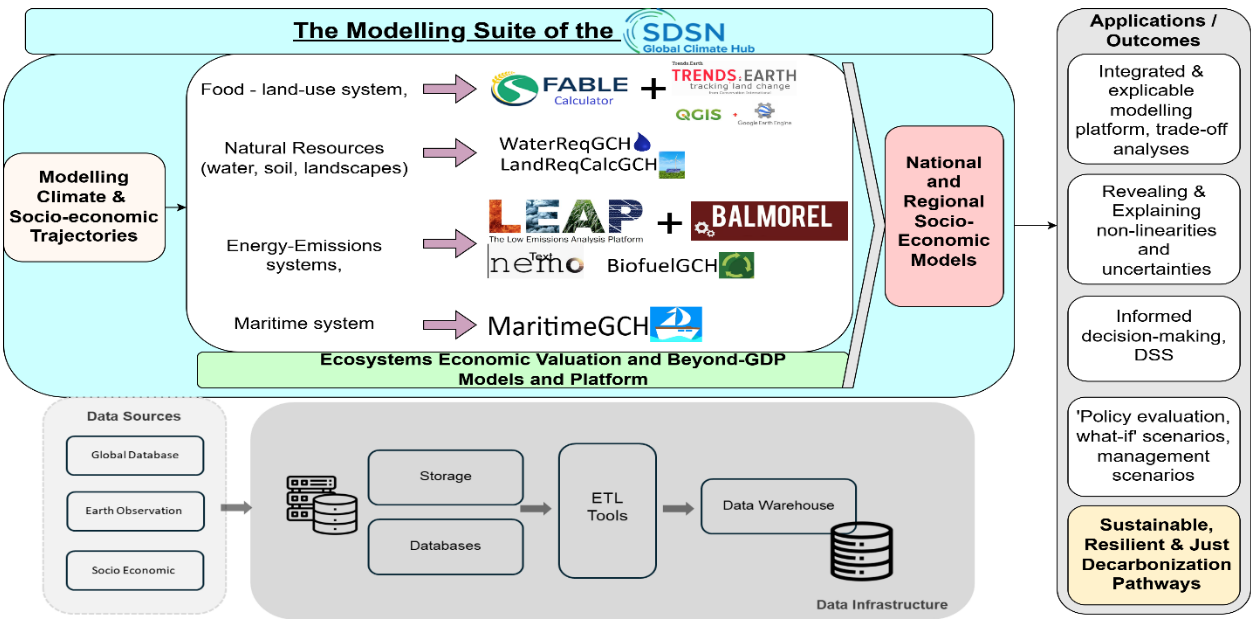

Figure 4 – An example of the GCH's modelling approach, combining multiple sectoral modules, such as the FABLE Calculator and the in-house LandGCH and WaterReqGCH models for the food-land-water systems, the LEAP, NEMO and BALMOREL models, and the in-house MaritimeGCH models for the energy and transportation systems.

<u>Beyond-GDP Valuation: Integrating Ecosystem Services into Transformation Pathways</u>

A core element of the Global Climate Hub's socio-economic modelling capability is the integration of ecosystem-services, externalities valuation into macroeconomic, and general equilibria modelling and assessments. Measuring ecosystem services in monetary terms is essential for internalizing environmental and social externalities, enabling policymakers and businesses to reflect the true costs and benefits of natural and social capital within decision-making processes. When such values are incorporated into fiscal instruments, investment frameworks, or blended-finance schemes, they lay the groundwork for bankable instruments/projects that reward conservation, restoration, and sustainable resource use. Building on extensive work in environmental and resource economics, this approach provides a systematic, transparent, and operational methodology for monetizing ecosystem services and embedding these values directly into economy-wide modelling frameworks. Drawing from global databases of empirical valuation studies and robust econometric methods, the **Valuation Platform of Ecosystem Services** led by Professor Koundouri and collaborators employs meta-analytic value-transfer functions and biophysical–economic modelling to generate context-specific welfare estimates, including in data-scarce environments. This methodological foundation is reinforced by advances in the valuation of ocean and marine ecosystem services (Koundouri et al., 2023a; Koundouri et al., 2023b; Remoundou et al., 2009), as well as recent work on individuals' willingness-to-pay for urban ecosystem-service improvements, such as enhanced air quality, urban cooling, and reduced flood risk (Halkos et al., 2024), all of which demonstrate how rigorous non-market valuation can inform SDG-aligned policy design and strengthen evidence-based decision-making.

Within the GCH architecture, this valuation approach connects directly to the socio-economic modelling unit, which employs dynamic equilibrium and Computable General Equilibrium (CGE) frameworks—including tools such as GTAP—to analyze global trade, welfare effects, and distributional outcomes. By translating ecological changes, from ecosystem degradation, restoration, fisheries recovery and changes in water quality to coastal protection, into quantifiable welfare shocks and sectoral adjustments, the modelling chain enables a transition from narrow GDP-based assessments to comprehensive, welfare-oriented evaluations of sustainability pathways. These welfare assessments are further strengthened by the economic rationale for declining discount rates in long-run policy evaluation (Gollier et al., 2008), which underscores the need to give proportionally greater weight to future ecosystem services, climate benefits, and intergenerational equity considerations. Incorporating these principles allows policy and investment strategies to more accurately reflect the long-term economic contribution of natural capital, reveal distributional and equity implications, and identify where ecosystem-service investments generate co-benefits across climate, biodiversity, trade, and socio-economic objectives. In turn, this enhances the GCH's capacity to evaluate synergies, trade-offs, and long-term system dynamics across the SDGs in a holistic and spatially explicit manner.

This approach also aligns with the **ESG–SDG Toolkit for Businesses** developed by Koundouri et al. (2024a), which supports firms in measuring their environmental and social impacts, integrating non-market values into corporate reporting, and designing sustainability strategies that align with global goals. By enabling companies to quantify ecosystem benefits and externalities, the toolkit helps translate impacts into financially relevant metrics, facilitating the development of green bonds, sustainability-linked loans, adaptation and resilience finance products, and other bankable instruments that mobilize private capital toward sustainable development.

The AE4RIA Metrix Framework: Financial Intelligence for Sustainable Development

The SDGs provide a universal framework for transformation, but progress remains starkly insufficient, with fewer than 20% of targets on track globally. This implementation failure is not only a macro-economic or geopolitical issue, but also the result of granular financial behaviours that collectively determine real-economy outcomes: what companies invest in, how they manage risks, how investors allocate capital, how value chains are structured, and how markets reward or penalize sustainability performance. In the absence of robust accountability mechanisms, these micro-level decisions are often shaped by short-term incentives, partial data, inconsistent metrics, greenwashing, and fragmented disclosure requirements.

Crucially, micro-level finance must be embedded within a wider ecosystem of integrated modelling, monitoring, and stakeholder engagement. This is where the GCH becomes essential. Within GCH's architecture, micro-level sustainable finance operates as a critical enabling layer, informing the financial feasibility, risk assessment, and investment prioritization of transformation pathways. The AE4RIA Metrix system becomes the financial analytics engine within this broader GCH ecosystem translating corporate behaviour into measurable sustainability value and aligning firm-level decisions with system-wide SDG trajectories.

The AE4RIA Metrix system represents a comprehensive suite of analytical tools designed to quantify micro-level sustainability performance and link it directly to financial outcomes. Integrating more than 600 ESG KPIs, machine-learning algorithms, econometric models, global asset-pricing datasets, and corporate-level SDG impact metrics, AE4RIA Metrix offers a coherent and integrated methodology through which companies, investors, and regulators can evaluate sustainability in a robust, comparable, and decision-relevant manner. At the foundation of the system lies a set of tools for mapping corporate activities and value-chain impacts. These tools allow firms to conduct detailed analyses of their operational structures, identifying competitive advantages, inefficiencies, and the primary and secondary activities that generate emissions or other externalities. Emissions measurement tools then quantify direct (Scope 1), indirect (Scope 2), and value-chain (Scope 3) emissions, enabling firms to identify hotspots, set science-based targets, and chart credible decarbonization pathways.

Beyond technical performance, AE4RIA Metrix embeds methods for assessing stakeholders and double materiality, which are central components of contemporary sustainable finance regulation. Stakeholder mapping identifies the actors who influence or are influenced by a firm's activities, while double materiality assessment quantifies both how sustainability risks affect financial outcomes and how the firm's operations impact society and ecosystems. This dual lens directly supports compliance with EU CSRD and ESRS standards and fosters a more holistic understanding of long-term value creation and responsibility. To translate these diagnostics into standardized practice, the AE4RIA Metrix dashboard harmonizes firm-level KPIs with global ESG standards, supporting the development of short-, medium-, and long-term sustainability targets. These targets can be grounded in scientific benchmarks, policy requirements, peer comparisons, or financial optimization. Such harmonization strengthens the integrity and comparability of corporate sustainability disclosures—a prerequisite for effective oversight and capital allocation.

AE4RIA Metrix also includes a sophisticated modelling architecture for ESG performance. Econometric and statistical models aggregate KPIs into comprehensive ESG ratings, benchmark firms against sectoral peers, and simulate future performance trajectories under alternative strategies and policy conditions. This helps companies understand how operational and governance decisions translate into sustainability outcomes and financial risks over time.

A central innovation of the framework lies in its SDG alignment capabilities. The SDG footprint model uses cosine-similarity machine-learning algorithms to map ESG KPIs to the 232 SDG indicators, generating a quantifiable bridge between corporate actions and global development objectives. Econometric models then estimate sensitivities between KPIs and SDG indicators across two decades of data, offering insights into firms' direct and indirect contributions to the SDGs. By transforming the SDGs from high-level aspirations into performance-linked metrics, AE4RIA Metrix embeds global priorities into financial decision-making.

Value Chain Level 1	SDG / Value Chain Level 2	1	2	3	4	5	6	7	8	9	10	12	13	15	16	17
1. Sourcing	1.1 Inbound Logistics	4	4	4	2	3		4	3	2	4	2	4		4	4
	1.2 Milk Zone	4	4	4	2	3		4	3	2	4	2	4		4	4
	1.3 Raw Materials WH	4	4	4	2	3		4	3	2	4	2	4		4	4
2. Production	2.1 Processing	4	4	4	4	3	2	3	4	3	4	4	3	3	4	4
3. Logistics	3.1 Intercompany	4	4	4	2	1			3	2	2	2	4		4	4
	3.2 Outbound Logistics	4	4	4	2	1			3	2	2	2	4		4	4
4. Sale and end of cycle	4.1 Retail	4	4	4	3			4	3	2	2	2	4		4	4
	4.2 Disposal / recycling	4	4	4	3			4	3	2	2	2	4		4	4

Figure 5 – An overview of the AE4RIA Metrix Framework.

The sustainability-adjusted asset pricing component extends this integration into capital markets. By incorporating ESG momentum (the change in ESG score over 24 months) into a Fama-French style framework, AE4RIA Metrix demonstrates that firms with improving sustainability profiles systematically outperform their peers, while those facing escalating controversies underperform. SDG-specific pricing factors quantify how alignment or misalignment with global goals influences expected returns. These innovations translate sustainability into measurable financial value and empower investors to hedge SDG-related risks, construct aligned portfolios, and reward firms demonstrating resilience and transparency.

Scalable success stories and operational evidence

The GCH approach is already operationalized in place-based studies that demonstrate its practicability and policy relevance. The work and methodological approaches of the GCH are currently being further developed within the context of the ERC-funded Water Futures project, which aims to develop the next generation of smart urban water systems (Savic et al., 2024; Zanutto et al., 2024). In addition, the GCH approach is currently being implemented within the context of the UNFCCC Global Innovation Hub (GIH), where through a Systemic Innovation Process both the GCH and the GIH attempt to address core challenges such as urban resilience and sustainable water resource management in different regions of the world, from Seoul to West Africa.

Greece: An integrated, multi-model assessment combined food-land, water, maritime and energy system analyses under business-as-usual and National Commitment scenarios (2020–2050) (Koundouri et al., 2025a). The exercise exposed critical interdependencies, e.g., how renewable land-use expansion competes with agriculture, or how shipping decarbonization affect domestic fuel demand, and does not exploit the biofuels production potential. It also produced a decision support tool that ranks policy packages using fuzzy multi-criteria analysis. The outcome is a tailored SDSN scenario that achieves faster, lower-cost decarbonization than the single-focused energy national plan, while flagging governance and infrastructure gaps that must be addressed for implementation.

Europe: Applying the framework across 35 diverse national plans revealed continent-wide patterns and pressures (e.g. irrigation, water-energy trade-offs, slower transportation electrification at parts, major economies remaining net importers of biofuels, renewable land-use expansion feasibility concerns), and need for coordinated cross-border electricity and hydrogen trade (Koundouri et al., 2025b). The study yielded policy recommendations spanning alignment and integration of different policies, cross-border grid investments, and equity-oriented finance mechanisms.

Digital Twins of the Ocean: Utilizing state of the art dynamic virtual models in the form of Digital Twins allows for the combination of real-time data, predictive modelling, and visualizations to mirror and simulate physical systems, such as the Oceans. This not only allows for better monitoring of ocean environments but provides a deeper understanding of the challenges and the development of more effective solutions (Falk et al., 2024). In the marine context, these Digital Twins effectively integrate satellite observations, sensor data, modelling outputs, and human expertise to represent the ocean’s physical, chemical, biological, and economic processes (European Commission, 2025; UNESCO, 2025). The effective incorporation of socio-economic data and scenarios within Digital Twins still remains a scientific challenge due to the vast local disparity and as such requires a detailed modular approach towards seamless integration. Within the Black Sea, a Blue Economy Observatory for the Black Sea[†] has been developed as the socio-economic component of the Black Sea Digital Twin demonstrator providing an overview of the current status and future perspectives of the Blue Economy, including findings from the BRIDGE-BS project (Koundouri et al., 2023a; Koundouri et al., 2023b) It is a user-friendly online platform that collects and visualizes data on Black Sea maritime sectors and describes the development of maritime sectors in each Black Sea country, future scenarios, business roadmaps, and sustainable pathways that use innovative solutions. The Observatory provides insights on the state of the Blue Economy for policymakers, researchers, and businesses. It integrates common environmental, economic, and social metrics for monitoring the sustainable development of Blue Economy sectors, thereby identifying trends to inform policies and highlight the current deficiencies in terms of sustainability in the region, and data gaps and access issues. By providing reliable and harmonized data, the observatory enhances collaboration between policymakers, businesses, and researchers, enabling evidence-based decision-making for the sustainable use of marine resources. The longevity of the Blue Economy Observatory depends on continued user engagement, data provision and long-term financial and human resources. In

[†] https://blackseabeo.eu/

addition, more work is needed on strategies to integrate socio-economic data from the Blue Economy Observatory into the Black Sea Digital Twin demonstrator.

Finally, evidence emerging from AE4RIA Metrix demonstrates that micro-level sustainable finance is already generating meaningful and scalable impacts across global markets. The first and most compelling body of evidence comes from ESG momentum analysis (Koundouri and Landis, 2023). Across more than 11,400 companies, firms with steadily improving ESG profiles systematically outperform those with declining performance. A second layer of insight emerges from ESG controversies, which serve as counter-signals capable of detecting hidden risks and exposing inconsistencies in corporate sustainability claims. Controversy momentum exhibits even stronger predictive power than traditional ESG scores. Portfolios that favour firms reducing their controversies outperform the market by more than 120% in several cases (Koundouri and Landis, 2023). Finally, the SDG pricing factor methodology offers a unique mechanism for linking firm-level behaviour to global development goals (Koundouri and Landis, 2023). By weighting ESG KPIs according to their alignment with SDG indicators and integrating these weights into asset pricing models, AE4RIA Metrix enables investors and policymakers to quantify SDG-related financial risks and opportunities. This provides a missing bridge between sustainability science and financial economics, allowing capital markets to internalize global goals into their valuation frameworks.

These cases show that transformation pathways can be operationalized in holistic, tangible, locally tailored and policy-ready for implementation ways. Building on these foundations, GCH is developing an even more sophisticated global case study that scales the approach to multi-region interactions and systemic tipping points, further proving the approach's modelling and operational nature. Moreover, the GCH e-platform is central to scalability: by hosting harmonized data, model interfaces, and visualization tools, it democratizes access to complex analyses, supports regional replication, and enables continuous updating as new data and policy choices emerge.

Significance for the 2027 GSDR

In the context of providing actionable evidence for the final stretch to 2030, it is crucial to have solid guidance for the provision of integrated transformation pathways. The provision of a comprehensive modelling-technological-stakeholder approach for implementable strategies that account for resource limits and local realities is directly relevant, and can inform immediate policy decisions (e.g., renewables expansion requirements, phasing out fossil fuel subsidies, how to align energy, agri-land and water instruments), taking into account equity considerations, while highlighting medium-term investment needs and distributional consequences.

By design, integrated pathways influence all SDGs simultaneously, but to different degrees. Evidence from cross-sector modelling and correspondence of the solutions to specific funds to ensure their implementation, enables policy packages that maximize co-benefits and minimize displacement of progress across goals.

Beyond 2030

There is still ground to be covered for the achievement of the 2030 Agenda. But now we have the science, the technology, the fiscal and financial resources, in blended mode, to create Global Commons dedicated to implementing the SDGs—an **operational framework capable of aligning global efforts, ensuring effective coordination, and delivering results on the ground,** supported by efficient and transparent channels for **technology transfer, financial flows, and capacity building**, particularly for policymakers and key stakeholders across all sectors and regions.

References

Akinsete, E., Stergiopoulou, L., El Said, N., Koundouri, P. (2022). Multi-actor working groups as fora for WEF nexus innovation and resilience. Environmental Sciences Proceedings 15(1), 69. https://doi.org/10.3390/environsciproc2022015069

Akinsete, E., Velias, A., Papadaki, L., Chatzilazarou, L.A., Koundouri, P. (2025). Blending experimental economics and living laboratories in water resource management. Annual Review of Resource Economics 17 (1), 149-165. https://doi.org/10.1146/annurev-resource-013024-033007

Alamanos, A., Koundouri, P., Papadaki, L., Pliakou, T., Toli, E. (2022). Water For Tomorrow: A living lab on the creation of the science-policy-stakeholder interface. Water 14(18), 2879. https://doi.org/10.3390/w14182879

Alamanos, A., Xenarios, S., Assubayeva, A., Landis, C., Dellis, K., Koundouri, P. (2025). Systems-thinking innovations for water security. Frontiers in Water 2024, 6. https://doi.org/10.3389/frwa.2024.1492698

Elzen, B., & Wieczorek, A. (2005). Transitions towards sustainability through system innovation. Technological Forecasting and Social Change, 72(6), 651–661. https://doi.org/10.1016/J.TECHFORE.2005.04.002

Englezos, N., Kartala, X., Koundouri, P., Tsionas, M., Alamanos, A. (2022). A novel hydroeconomic – econometric approach for integrated transboundary water management under uncertainty. Environmental and Resource Economics Journal. https://doi.org/10.1007/s10640-022-00744-4

European Commission (2025). European Digital Twin of the Ocean (European DTO). [Online], Available: https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/restore-our-ocean-and-waters/european-digital-twin-ocean-european-dto_en (Accessed: 20/11/25)

Falk, J., et. al., (2024). Emerging threats from climate change on our oceans demand proactive action. [Online], Available: https://www.stsforum.org/racc2024/pdf/statement.pdf (Accessed: 20/11/25)

Geels, F. W. (2019). Socio-technical transitions to sustainability: a review of criticisms and elaborations of the Multi-Level Perspective. *Current Opinion in Environmental Sustainability*, *39*, 187–201. https://doi.org/10.1016/J.COSUST.2019.06.009

Gollier, C., Koundouri, P., & Pantelidis, T. (2008). Declining discount rates: Economic justifications and implications for long-run policy. Economic Policy, 23(56), 758-795. https://doi.org/10.1111/j.1468-0327.2008.00211.x

Guittard, A., Akinsete, E., Demian, E., Koundouri, P., Papadaki, L., Tombrou, X. (2023). Tackling single-use-plastic in small touristic islands to reduce marine litter: Co-identifying the best mix of policy interventions. Frontiers in Environmental Economics, 2. https://doi.org/10.3389/frevc.2023.1145640

Guittard, A., Kastanidi, E., Akinsete, E., Berg, H., Carter, C., Maneas, G., Martínez-López, J., Martínez-Fernandez, J., Papadatos, D., de Vente, J., Vernier, F., Tiller, R., Karageorgis, A. P., Koundouri, P. (2024). Using multi-actor labs as a tool to drive sustainability transitions in coastal-rural territories: Application in three European regions. GAIA – Ecological Perspectives for Science and Society 33(1), 57-63. https://doi.org/10.14512/gaia.33.s1.9

Halkos, G., Aslanidis, P. S., Landis, C., Papadaki, L., & Koundouri, P. (2024). A review of primary and cascading hazards by exploring individuals' willingness-to-pay for urban sustainability policies. City and Environment Interactions, 100178. https://doi.org/10.1016/j.cacint.2024.100178

IPCC. (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. https://www.ipcc.ch/report/ar6/wg2/

Jones, P. H. (2014). Systemic Design Principles for Complex Social Systems. 91–128. https://doi.org/10.1007/978-4-431-54478-4_4

Kemp, R., Loorbach, D., & Rotmans, J. (2007). Transition management as a model for managing processes of co-evolution towards sustainable development. International Journal of Sustainable Development and World Ecology, 14(1), 78–91. https://doi.org/10.1080/13504500709469709;CTYPE:STRING:JOURNAL

Koundouri, P., Halkos, G., Landis, C., Alamanos A., (2023a). Ecosystem services valuation for supporting sustainable life below water. Sustainable Earth 6(1), 19. https://doi.org/10.1186/s42055-023-00068-1

Koundouri, P., Halkos, G., Landis, C., Dellis, K., Stratopoulou, A., Plataniotis, A., Chioatto, E., (2023b). Valuation of marine ecosystems and Sustainable Development Goals. Frontiers in Environmental Economics 2:1160118. https://doi.org/10.3389/frevc.2023.1160118

Koundouri, P., and Landis, C.F.M. (2023). ESG momentum in international equity returns and the SDG content of financial asset portfolios. In Transforming our world: Interdisciplinary insights on the Sustainable Development Goals. SDSN Europe. https://egd-report-2023.unsdsn.org/esg-momentum-in-international-equity-returns-and-the-sdg-content-of-financial-asset-portfolios/

Koundouri, P., Landis, C., Dellis, K. & Plataniotis, A. (2024a). "Integrating SDGs in ESGs and the Sustainability Transformation of the EU Business Sector," DEOS Working Papers 2401, Athens University of Economics and Business. https://ideas.repec.org/p/aue/wpaper/2401.html?utm_source=chatgpt.com

Koundouri, P., Alamanos, A., Devves, S., Landis, C., Dellis, K. (2024b). Innovations for Holistic and Sustainable Transitions. Energies 2024, 17(20): 5184. https://doi.org/10.3390/en17205184

Koundouri, P., Alamanos, A., Arampatzidis, I., Devves, S., Dellis, K., Deranian, C., Nisiforou, O. (2025a). Climate Neutrality Pathways for Greece: Integrated Assessment and Decision Support Tool. Report, UN SDSN Global Climate Hub. June 2025, Athens, Greece. https://unsdsn.globalclimatehub.org/wp-content/uploads/2025/06/REPORT_GCHmodels_SDSNscenario_Greece__2.pdf

Koundouri, P., Alamanos, A., Arampatzidis, I., Devves, S., Deranian, C., Pliakou, T. (2025b). An integrated assessment of the European National Commitments for climate neutrality. Report, UN SDSN Global Climate Hub. June 2025, Athens, Greece. https://unsdsn.globalclimatehub.org/wp-content/uploads/2025/08/GCHmodels_EU_a4_cover_web-3.pdf

Koundouri, P., Alamanos, A., Deranian, C., Garcia, J.A., Nisiforou, O. (2025c). Too hard to decarbonize: Insights from a decision support tool for the Greek maritime operations. Environmental Research Letters. https://doi.org/10.1088/1748-9326/ae114e

Lafortune, G., Fuller, G., Kloke-Lesch, A., Koundouri, P., Riccaboni, A. (2024). European Elections, Europe's Future and the SDGs: Europe Sustainable Development Report 2023/24. Paris: SDSN and SDSN Europe and Dublin: Dublin University Press. https://doi.org/10.25546/104407

Loorbach, D. (2010). Transition management for sustainable development: A prescriptive, complexity-based governance framework. Governance, 23(1), 161–183. https://doi.org/10.1111/J.1468-0491.2009.01471.X

Mazzucato, M., & Kattel, R. (2020). COVID-19 and public-sector capacity. https://doi.org/10.1093/oxrep/graa031

Meadows, D. H. (2008). Thinking in Systems: A Primer. Chelsea Green Publishing Company, 133(37), 14840. https://books.google.com/books/about/Thinking_in_Systems.html?hl=el&id=CpbLAgAAQBAJ

Remoundou, K., Koundouri, P., Kontogianni, A., Nunes, P. A. L. D., & Skourtos, M. (2009). Valuation of natural marine ecosystems: an economic perspective. Environmental Science & Policy, 12(7), 1040–1051. https://doi.org/10.1016/J.ENVSCI.2009.06.006

Royal Swedish Academy of Sciences, T. (2025). The Prize in Economic Sciences 2025 – Press Release.

Sachs, J. D., Schmidt-Traub, G., Mazzucato, M., Messner, D., Nakicenovic, N., & Rockström, J. (2019). Six Transformations to achieve the Sustainable Development Goals. Nature Sustainability 2019 2:9, 2(9), 805–814. https://doi.org/10.1038/s41893-019-0352-9

Savic, D., Hammer, B., Koundouri, P., Polycarpou, M. (2024). Long-Term Transitioning of Water Distribution Systems: ERC Water-Futures Project. Editorial Universitat Politècnica de València. https://doi.org/10.4995/WDSA-CCWI2022.2022.14441

Seyhan, K., Dürrani, Ö., Papadaki, L., Akinsete, E., Atasaral, Ş., Özşeker, K., Akpınar, H., Kurtuluş, E., Mazlum, R.E., Koundouri, P., Stanica, A. (2025). Bridging the gaps for a thriving Black Sea Blue Economy: Insights from a multi-sectoral forum of Turkish stakeholders. Frontiers in Marine Science 12, 1491983. https://doi.org/10.3389/fmars.2025.1491983

Stafford-Smith, M., Griggs, D., Gaffney, O., Ullah, F., Reyers, B., Kanie, N., Stigson, B., Shrivastava, P., Leach, M., & O'Connell, D. (2016). Integration: the key to implementing the Sustainable Development Goals. Sustainability Science 2016 12:6, 12(6), 911–919. https://doi.org/10.1007/S11625-016-0383-3

UNESCO (2025). The Global Ocean Observing System (GOOS). [Online], Available: https://www.ioc.unesco.org/en/global-ocean-observing-system (Accessed: 20/11/25).

United Nations. (2024). The Sustainable Development Goals Report 2024. United Nations, New York. https://doi.org/10.18356/9789213589755

Yasuoka, M., Akasaka, F., Kimura, A., & Ihara, M. (2018). LIVING LABS AS A METHODOLOGY FOR SERVICE DESIGN - AN ANALYSIS BASED ON CASES AND DISCUSSIONS FROM A SYSTEMS APPROACH VIEWPOINT. DS 92: Proceedings of the DESIGN 2018 15th International Design Conference, 1, 127–136. https://doi.org/10.21278/IDC.2018.0350

Zanutto, D., Michalopoulos, C., Chatzistefanou, G.A., Vamvakeridou-Lyroudia, L., Tsiami, L., Glynis, K., Samartzis, P., Hermes, L., Hinder, F., Vaquet, J., et al. (2024). A Water Futures Approach on Water Demand Forecasting with Online Ensemble Learning. Engineering Proceedings 69, 60. https://doi.org/10.3390/engproc2024069060