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Advancing Water Policy in Europe: Addressing Challenges in the Southeast Mediterranean within the Water Futures project

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Abstract:
Water-system stress challenges driven by aridification, rapid urbanization and tourism peaks, irrigation-intensive agriculture, pollution, fiscal underinvestment and entrenched social inequities, need integrated and adaptive policy responses. We present the Global Climate Hub's interdisciplinary approach along with an application framework that was developed under the ERC-funded Water Futures project, aiming to tackle such challenges: We couple cross-sectoral modelling (physical and natural systems, water-energy systems, and economics), digital-twin forecasting and real-time monitoring, with experimental-economics, behavioural-economics and Living Labs to allow stakeholders' feedbacks and solutions' co-design. Through regulated sandboxes and randomized trials, the project tests pricing reforms, behavioural nudges and technological pilots (IoT/AI leak detection, decentralized treatment, nature-based solutions), producing robust socio-economic narratives and distributional metrics to inform investment choices. Preliminary policy guidance urges an iterative evidence loop of modelling-valuation-Living Lab validation and solution co-design, supported by open data, towards equitable tariff design, targeted subsidies, matched innovation financing and capacity building to scale proven solutions. The proposed approach translates diverse theories into operational pathways for resilient, efficient and socially just urban drinking-water systems, offering a replicable blueprint for regions facing water scarcity.

Keywords: Water Resources Management; Socio-technical transformations; Behavioural Economics; Living Labs; Global Climate Hub.

Complex and interdisciplinary water challenges

The Southeast Mediterranean region's water sector presents complex challenges due to its unique climatic and socioeconomic characteristics. Its prolonged warm to hot summers make the area arid/ semi-arid, causing high evaporation losses and scant precipitation, which stresses surface and groundwater availability (Lionello et al., 2006; Akbas et al., 2020). The region is also particularly sensitive to climate change impacts, with projections indicating increasingly hot temperature extremes and decreasing rainfall (Lelieveld et al., 2013).

However, this natural tendency toward water stress is exacerbated by anthropogenic practices and trends in development. Rapid urban expansion and seasonal tourism sharply amplify municipal demand (Al-Kalbani et al., 2015; Alamanos, 2022) while intensified, irrigation-dependent agriculture consumes the largest share of scarce supplies and degrades water quality, creating fierce competition among domestic, agricultural and industrial uses (Alamanos et al., 2019). The quality of the available water is further impaired by pollution from other sources including pesticide and fertilizer runoff from agriculture, industrial effluents and inadequately treated wastewater (Setty et al., 2020; Silva et al., 2019; Schwarzenbach et al., 2010). Chronic fiscal constraints and underinvestment leave treatment plants, meters and distribution networks outdated, and the routine absence of economic-science tools (e.g., non-market valuation, willingness-to-pay studies and rigorous cost–benefit frameworks) means policies too often ignore the true social and environmental costs of water (Koundouri et al., 2023a; 2024a). These pressures are layered over deep social injustice: low-income, peri-urban and rural groups commonly face unreliable service, higher exposure to contamination and fewer options to adapt, amplifying vulnerability and undermining equity (Prieto López et al., 2021). Moreover, water infrastructure has traditionally been managed with static frameworks that are not responsive enough to abrupt changes in consumption rates, pollution risks, or climatic disturbances. Together, these challenges, indicate the urgent need for immediate and multi-faceted engagement to tackle these issues holistically (Rasul et al., 2019). The region needs to support drinking-water systems (as the main driver of socio-economic stability) and supply chains, addressing issues of ageing infrastructure that must cope with rising baseline demand and intense touristic seasonal peaks, and to make them more efficient, interdisciplinary and resilient by exploiting new technologies (Tsiami et. al., 2025).

Water policies in Europe have traditionally embraced the principles of sustainability and holistic management (Tsani et al., 2020), as evident in the EU Water Framework Directive, the Urban Waste Water Treatment Directive, and recently the European Water Resilience Strategy in order to strengthen water systems across Europe (European Commission, 2024). These aim to integrate environmental considerations within water management approaches, foster collective research and data sharing. However, the implementation and progress remain poor, with national and local-level obstacles persisting (Boeuf & Fritsch, 2016). Underfunding is often pointed out as an obstacle, and the use of fair and equitable pricing and tariff structures is increasingly brought up as a solution for the successful implementation of water policy - both on the part of consumers, as a behavioural tool to drive economically motivated efficiency in water use, as well as on the part of the suppliers as a means to achieve full cost recovery for water services (Martínez-Dalmau et al., 2023). These tariffs should be complemented by subsidies for low-income households as well as investments in metering systems aimed at fair and accurate billing. However, trade-offs in the design of pricing mechanisms would have to bring about the trade-off between economic efficiency and social equity. Promising practices on water pricing in Europe include the volumetric pricing in Denmark and progressive water pricing in France (Pizzol et al.,2020; Rinaudo et al., 2012). The adoption of such mechanisms in the Southeast Mediterranean countries would require strong regulatory frameworks, accurate metering, and, more importantly, acceptance by the public. This calls for making these processes as transparent and inclusive as possible; working closely with the various stakeholders involved, and undertaking sufficient socio-economic analysis to ensure that the frameworks underpinning the water pricing policies are fair and effective.

The approach of the Global Climate Hub (GCH)

Addressing holistically the issues mentioned requires a detailed understanding of the underlying natural and socio-economic systems that support the sustainable management of water resources, through the application of novel and interdisciplinary methodologies, to provide a robust scientific and publicly-acceptable basis for decision-making.

The Global Climate Hub (GCH) is an SDSN (Sustainable Development Solutions Network) research led initiative aiming to solve holistically such interdisciplinary challenges, including water management (Alamanos et al., 2025). The institutions involved in the GCH are:

- **Hosting Institutions**: Athens University of Economics and Business (AUEB) and the "Athena" Research and Innovation Center in Information, Communication and Knowledge Technologies (ATHENA RC), both of which are part of the Alliance of Excellence for Research and Innovation on Aephoria (AE4RIA), an initiative for collaboration between research institutions, innovation accelerators, and science-technology-policy interface networks focused on sustainable development.
- **Co-founding institutions:** the Academy of Athens and the Technical University of Denmark.
- **Chair:** Prof. Phoebe Koundouri, who also is the founder and director of AE4RIA.

To achieve its mission, the GCH mobilizes nine interdisciplinary research units to apply integrated cross-sectoral modelling of the physical, economic and social systems, deep stakeholder engagement and transformational processes. These units cover AI-supported data platforms, climatology, integrated models of physical systems, energy-emissions models, socio-economic models, human health, innovation and acceleration for the application of the solutions, education and training.

Co-designing with key stakeholders holistic, implementable pathways for resilience and sustainable development, based on integrated, cutting-edge modelling, and financial solutions is a key angle in the GCH's approach (Koundouri et al., 2024b). Practically, it bridges physical (e.g. water, for our case) models with participatory living-labs, ensuring science- and tech-driven solutions in a socially grounded, equitable and policy-ready way.

The GCH is supported by participating institutions through competitive grants. Such an example is the prestigious European Research Council (ERC) Synergy Grant for the project “Water Futures”. The holistic approach of the GCH is applied to bridge the science-policy gap for drinking water systems, addressing the aforementioned challenges through new theoretical frameworks and empirical approaches tailored to water infrastructure planning and management, ensuring resilience, robustness and adaptability of long-term solutions.

Water Futures

The Water Futures project aims to develop an innovative and interdisciplinary methodology for designing and managing future urban drinking water systems. The core of the project is to recognize the deep uncertainties that arise in the urban water infrastructure development and make sure that these systems are flexible, sustainable, and resilient to handle future challenges (Vaquet et al., 2024a). This goal is inspired by the knowledge that conventional water infrastructure planning methods have been reactive and have failed to account for the complex interrelations between factors such as urban development, climatic change, economic constraints, and social justice (Chatzistamoulou and Koundouri, 2024; Koundouri et. al., 2024a). The ERC Water Futures project’s practical applications are designed to be tested and validated in different urban water systems representing different degrees of development (Netherlands, Germany, Greece, Cyprus), to ensure transferability in different socio-economic and environmental settings. At this stage, it is worth specifying the approach for a Southeast Mediterranean case study, considering the urban water system in Athens, one of the largest in Europe, serving 4.4 million people.

We target the development of smart, real-time monitoring systems that utilize explainable machine learning (ML) models to enhance dynamic decision-making (Vaquet et al., 2024b; Artelt et al., 2024). These technologies enable urban water networks to learn continuously, improve performance, and optimize the use of resources so that water services are always guaranteed even in unanticipated situations (Vaquet et al., 2024a). Simultaneously, we disrupt the conventional water management paradigm by incorporating economic, ethical, and social values in its decision-making framework (Koundouri et al., 2023b; 2024b). Thus, we treat urban water systems not just as engineering artifacts but as integral assets to the broader well-being of society. Ultimately, we envision modern, cutting-edge and real-time learning drinking water networks operating and under principles of rational decision-making as well as ‘eudaimonia’, or the concept of human flourishing (Pittis et. al., 2021). This innovative approach of coupling physical-technical-engineering and socio-economic aspects, using cutting-edge methods is the core philosophy of the GCH, and is applicable to several similar problems.

Here, a unique and particularly interesting angle, is how we can effectively achieve such an ‘eudaimonia’ state: We take a novel approach combining an Experimental Economics-Living Lab loop, to co-create pricing strategies that are rooted in a scientific understanding of consumer-decision making and fine-tuned to the local context: From the one hand, the use of economic experiments in the form of stated preference methods facilitates public consultation and stakeholder engagement, provides insight into what the broader public is willing and able to pay for water services improvements, and informs policy and decision-makers on the distribution of disproportionate costs (Brouwer, 2008). On the other hand, Living Labs (LLs) are defined as open innovation ecosystems in real-life environments based on a systematic user co-creation approach that integrates research and innovation activities in communities and/or multi-stakeholder environments, placing citizens and/or end-users at the centre of the innovation process (Akinsete et. al., 2022; Alamanos et. al., 2022; Guittard et. al., 2024).

With this novel approach, we examine the influence of a variety of economic incentives on the behaviour of the local community, while co-developing and validating new technologies or even assess the efficacy of social and environmental policies. This process takes place in the structured environment of the LLs, where:

- AI-powered digital twins are incorporated, simulating water demand and supply scenarios under various climate and policy conditions, thereby assisting decision-makers in refining predictive models (Zanutto et. al., 2024).
- Participants, together with researchers and inventors, can identify and employ emerging technologies, e.g., for Internet-of-Things-based leak detection, AI-driven water forecasting, and precision irrigation, and use the LLs as a testing ground. This approach ensures that these innovations are practicable and scalable before the adoption of policy or new investments.
- Behavioural transformation takes place, with pricing policies starting to consider loss aversion. Pricing policies start seeing excessive water use as a financial loss rather than a conservation incentive. A crucial feedback is the public perception and preference for new investments in conventional and non-conventional climate resilient water management practices, as measured through choice experiments. For instance, we are measuring the public Willingness-To-Pay for new investments in green water infrastructure (watershed reforestation), to close the loop between water supply and wastewater treatment (water recovery from wastewater) and grey water infrastructure (rainwater harvesting, desalination).
- We can measure the effectiveness of different policies based on their acceptability by the public, which can be estimated by means of behavioural experiments and non-market valuation techniques (Brouwer et al., 2015).

Typically, such a LL combines physical pilots and a cloud-native digital backbone to run an iterative policy-testing loop. Physically, utilities deploy smart meters, IoT leak sensors, pilot decentralized treatment and nature-based sites; these feed telemetry to a secure data platform. Digitally, an AI-powered digital-twin ingests meteorological, demand, hydraulic and socio-economic data, and runs (combinative) scenarios. The results of those simulations are critical information and material for discussion within the LLs, while they support the capacity-building process for researchers, policymakers and community representatives. Operationally, the workshops run randomized trials and choice experiments (WTP, loss-aversion nudges), and deliver real-time feedback on the participants' preferences. Results (behavioural uptake, system performance, distributional impacts) iteratively recalibrate models and tariffs or investment choices within a regulatory sandbox (co-design process), while impact metrics, clear communication and procurement roadmaps enable validated pilots to scale. Thus, we have created a feedback loop (within the LLs) where we can directly evaluate the outputs of the economic experiments and the impact of various economic incentives on water use behaviour (e.g., smart meters with real-time consumption data, water waste reduction, aquifer recharge and precipitation harvesting, dynamic pricing and tariffs, etc.). Therefore, such LLs serve as regulatory sandboxes that enable policymakers to evaluate novel strategies, including incentive-based conservation programs or decentralised water governance models, prior to their full-scale implementation.

Building such policies on this science-stakeholder basis we developed, make them as holistic as possible. Considerations that often are hidden in only modelling or only workshop studies, can now be reflected. In particular, future thoughts on urban development, climate change, economic constraints and social justice can be each a testable policy variable, either in the modelling (e.g. climatic, population, affordability scenarios) or in the LLs (perceptions on development, water scarcity, social justice): Urban growth and tourism are represented in the digital-twin and physical pilots (peri-urban meters, peak-demand trials), so planning and zoning choices are evaluated against real system stress. Climate change enters as ensemble scenario shocks (drought, extreme rainfall, impacts on groundwater availability) used to stress-test supply, recharge and nature-based options. Economic constraints are handled through trialled pricing, subsidy and financing instruments (WTP experiments, targeted lifelines, outcome-based contracts) that reveal cost-effective, distributive trade-offs. Social justice is central, as the whole co-design process, with the sampling and distributional metrics quantifying impacts on vulnerable groups and ensuring compensation or exemptions where needed. Together, the loop converts modelled hypotheses into socially legitimate, fiscally realistic and climatically robust interventions before full deployment.

Policy Recommendations

Although the project is still ongoing, there can be some preliminary policy recommendations, that can work complementarily, summarized below (in a random order):

- *Incorporate more holistic approaches in water policy:* Policymaking should treat integrated modelling, economic valuation and LLs evidence as a single, iterative evidence loop: models generate scenarios, economic tools assign social and distributional value, and LLs test feasibility and public acceptability in real settings. Thus, water-related decisions must therefore be made on robustness and equity criteria (ensemble model outcomes plus welfare/distributional metrics) rather than single-point forecasts.
- *Strengthening governance and institutionalizing LLs:* Clear channels of collaboration between regional, national, and local organizations should be put in place. Institutionalizing LLs can bring behavioural parameters and technology pilots to

continuously update models and recalibrate pricing or investment choices. The significance of behavioural economics in a ‘living’ water/ socio-technical system management should be acknowledged.

- *Openness for scalable solutions:* Require open-data protocols, transparent socio-economic narratives, and mandated model–economics–lab validation before major infrastructure or tariff reforms to ensure policies are evidence-based, legitimate and scalable.
- *Establish transparent, equitable pricing frameworks* that reflect full financial and environmental costs while protecting vulnerable households through targeted subsidies and lifeline tiers; link tariffs to modelled scarcity and distributional metrics so prices are defensible and adaptive.
- *Scale innovation pipelines coupling accelerators with utility pilots*: fast-track real-time/AI monitoring, leak detection, decentralized treatment and nature-based solutions through matched funding, outcome-based contracting and open evaluation criteria.
- *Invest in human and institutional capacity/ technical upskilling, integrated water management units, and regional knowledge-sharing platforms*. to translate pilot evidence into replicable investment and operation plans (including desalination and irrigation upgrades where appropriate).

So far, we believe that these can be valuable suggestions to make pricing, technology, governance and social protection mutually reinforcing, turning Water Futures’ integrated evidence loop into durable, scalable policy.

Outlook and Conclusion

Water Futures exemplifies the Global Climate Hub’s (GCH) holistic, interdisciplinary approach by using integrated modelling (of water supply and demand, with explainable ML, digital-twin forecasting, and real-time monitoring), powerful AI/data infrastructure, socio-economic narratives and deep stakeholder engagement. Its Experimental Economics–Living Lab loop operationalizes the GCH’s “transformative & participatory” approach (research unit). By embedding choice experiments, randomized trials and stakeholder co-creation, the project builds the socio-economic narratives and public buy-in necessary for implementable policy pathways. Simultaneously, Water Futures advances the GCH’s “innovation & acceleration” unit by validating technological solutions such as leak detection, precision irrigation, water recycling etc., and scaling them in different urban contexts. The result is expected to be a concrete, operational programme for resilient urban water systems. In sum, Water Futures is a prototypical GCH application: a data-driven, model-linked, participatory and policy-focused process that integrates technology, economics, governance and ethics to design flexible, just and resilient urban water futures.

Our broader take-away from this process and overall experience is the need to apply this philosophy as a way of working/addressing complex problems: Theoretical, procedural, technical and fiscal innovations (such as those being developed by the Water Futures – and in line with the GCH’s approach) have a key role to play in advancing the development and effective implementation of sustainable policies and systems (not just water management), while bridging historically persistent gaps in the water science-policy nexus.

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