TRANSCEND

Deliverable 5.2: White Paper on Financing Mechanisms

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Executive summary

The TRANSCEND project aims to explore transformative pathways towards water resilience through locally tailored analyses and co-creation exercises conducted in seven pilot laboratories. This report supports the co-development of these pathways by digesting insights and lessons learned on financial mechanisms for sustainable water resources management. It explores equitable and sustainable financing mechanisms to facilitate the transition to sustainable water pricing policies and cost recovery strategies aligned with environmental sustainability and resilience objectives.

Throughout the report, we confront the notion of water as an economic good, as suggested by the 1977 Mar del Plata Action Plan, with the concept of the human right to water and sanitation recognized in the 2010 UN General Assembly Resolution. We argue that it is essential to value water in its multiple dimensions—social, cultural, economic, and environmental—and integrate these values into policy and governance frameworks.

The review of economic and financial mechanisms includes pricing instruments (tariffs and taxes), tradable instruments, and risk transfer mechanisms. We explore the economic rationale behind water pricing and the need for full cost recovery to ensure financial sustainability and efficient resource allocation. We also discuss how environmental costs should be internalized in water pricing to address market failures and present experiences and lessons learned from water trading. Risk financing is explored, including insurance and other risk management instruments, such as catastrophe bonds and resilience bonds, which provide financial protection and incentivize risk reduction. These tools are crucial for managing residual risks and ensuring rapid recovery from water-related disasters. Innovative approaches, like insuring ecosystem services, provide financial incentives for the conservation and restoration of natural ecosystems, enhancing resilience and sustainability.

In conclusion, the report underscores the necessity of integrating economic, social, cultural, and environmental values in water management. It advocates for a combination of compatible instruments tailored to regional contexts to address water management challenges. The private sector's involvement, alongside public administration, is crucial for fostering change and ensuring the long-term viability of water services and risk management. By providing a comprehensive analysis, this report aims to inform the design of transformative adaptation pathways, serving as a foundational document for developing locally tailored solutions and advancing sustainable water management practices.

Contents

1. Introduction

Few environmental resources are as universally important as water. Beyond sustaining life, well-being, and a healthy environment, water holds deep social and cultural significance (Jackson, 2021; Paerregaard, 2018). In essence, it is essential for agriculture, industry, transportation, energy generation, waste disposal, recreation, human consumption, and sanitation services. Socially, water fosters community cohesion through shared irrigation practices and local governance. Culturally, it is revered in traditions and rituals, symbolizing purification, renewal, and spiritual cleansing, and is celebrated in art, music, and literature. This complex interplay of roles and uses makes water uniquely significant on both global and local scales, shaping policies, practices, and preservation efforts.

The lack of safe, equitable, and affordable access to water resources is known by various terms, each with its own and often diverging meanings, such as **water stress, water deficit/shortage, water insecurity, water bankruptcy, and water crisis** (Naik, 2017). Water scarcity, equated to inadequate access to sufficient and safe water supplies or the inability to meet both human and ecological demands, is influenced by multiple biophysical and socioeconomic factors that determine the marginal value of a unit of water (Jaeger et al., 2013). It can be physical (actual availability of water), economic (lack of infrastructures or financial resources to access water) or induced by pollution and degradation of water quality (Jain & Singh, 2010). Water stress, on the other hand, is often seen as a manifestation of scarcity or, alternatively, a broader term that encompasses water scarcity but goes beyond it (Schulte, 2004). While water scarcity is an intrinsically anthropocentric concept, it is distinct from water deficit, which refers to an insufficient quantity of water for specific biophysical processes. Whether a water deficit constitutes conditions of water scarcity depends on the societal value placed on those biophysical processes (Jaeger et al., 2013). This means that water deficit may not imply water scarcity.

More often than not, a water crisis[1] is a policy-induced crisis (Trottier, 2008), stemming from **governance failure** (Gupta et al., 2013) rather than a genuine physical shortage of clean, usable water. Water crises profoundly impact not only human life but also the environment. A lack of clean, usable water exacerbates health crises by increasing the prevalence of waterborne diseases. In 2020, 2 billion people lacked safely managed drinking water services, and 3.6 billion lacked safely managed sanitation services (World Health Organization (WHO) & United Nations Children's Fund (UNICEF), 2021). Water scarcity and poor management threaten food security by limiting agricultural productivity and food supply, exacerbate social inequalities and hinder social development (Nature 613, 2023).

Economic stability is also at risk, as water scarcity affects agriculture, industry, and energy production, leading to high economic losses in regions excessively reliant on these water bodies for irrigation and industrial activities (Nature 613, 2023; Nature 615, 2023). In the energy sector, which relies heavily on water for cooling and other processes, scarcity leads to operational challenges and contributes to broader energy crises.

[1] https://water.org/our-impact/water-crisis/

Water crises are caused or exacerbated by, and intricately interwoven with, climate and biodiversity crises, forming a vicious cycle where insufficient efforts to address one amplify the negative effects on the others. Climate change influences the hydrological cycle, altering precipitation patterns, increasing the frequency and intensity of extreme weather events, and causing sea level rise (Caretta et al., 2022). These changes disrupt freshwater-dependent ecosystems, threaten aquatic habitats and biodiversity (Vollmer & Harrison, 2021).

Ecosystems such as wetlands, forests, and grasslands contribute to water purification, flood regulation, and groundwater recharge. Ecosystem health is compromised as water bodies deteriorate in quality and quantity. Pollution, eutrophication, and habitat destruction disrupt aquatic ecosystems, affecting biodiversity and the services these ecosystems provide. Basically, biodiversity plays a vital role in maintaining the water cycle. Loss of biodiversity driven by habitat destruction, pollution, or climate change can impair or compromise these functions, thereby intensifying conditions of water scarcity. Therefore, addressing water crises requires integrated approaches that also tackle climate change and biodiversity loss (Pörtner et al., 2023).

Integrated approaches that consider the interdependencies between water, climate, and biodiversity are essential for sustainable management and conservation efforts (Reid et al., 2019). Addressing these interconnected issues requires transformative policies and actions that recognize the central role and value of water. This includes water pricing policies designed to incentivize efficient water use, while ensuring equity, and reflecting the true cost of water services. Protecting and restoring natural ecosystems can enhance water security and resilience, while providing multiple co-benefits for biodiversity and communities. Nature-based solutions, such as reforestation, wetland restoration, and sustainable water management, offer promising strategies to the above triple crises (Van Rees et al., 2023).

Transformative adaptation policies embrace systemic changes in response to water, biodiversity, and climate risks, recognizing that detrimental global environmental change was not merely a side effect, but a characterizing trait of modern societal development (Raworth, 2017). Transformative change involves changes in social structures and power relations (Pelling et al., 2015), as well as norms and institutions that shape behaviour of people and organizations (Sachs et al., 2019), and structural reforms that reduce people's and system's exposure to shocks (T. D. Gibson et al., 2016), while addressing the root causes of vulnerability. These changes are concerned with "deliberate" action and processes initiated purposefully (Nalau & Handmer, 2015). Transformative adaptation encompasses innovation, reorganization, expansion, and reorientation (Few et al., 2017; Warner & Kuzdas, 2017). The role of political economy is crucial in framing and enabling transformative adaptation, and challenging the pre-existing power dynamics that contribute to vulnerability (Warner & Kuzdas, 2017). Transformative policies involves changes in existing practices, governance, and market structures, for which social learning, community engagement, and deep understanding of socio-ecological impacts is a prerequisite (Käyhkö et al., 2020). Implementing transformative adaptation faces challenges, such as institutional inertia, resource constraints, and socio-political resistance. However, it also presents opportunities for co-benefits like improved social equity, resilience, and environmental sustainability (Warner & Kuzdas, 2017). Apart from these generic insights and propositions, practical guidance on how to induce, design, and implement transformative adaptation is rare. Sachs et al. (2019) formulated six macro-transformations as modular building blocks for achieving the Sustainable Development Goals (SDGs): (i) Education, gender, and inequality; (ii) Health, well-being, and demography; (iii) Energy decarbonization and sustainable industry; (iv) Sustainable food, land, water, and oceans; (v) Sustainable cities and communities; and (vi) Digital revolution for sustainable development. Additionally, (European Commission. Directorate General for Research and Innovation., 2020) proposed a framework for local transformative adaptation committed to:

– Resilience of environmental systems, with a commitment to long-term sustainability and the regeneration of critical community systems (which includes water security) most affected by climate risks,
– Resilience of social and economic systems, with a commitment to equity, social and gender justice, engaging children and youth, and leaving no one behind.
– Resilience of political systems, with a commitment to inclusiveness, deliberation, shared values, solidarity, and respect for diversity.

Main objective of the TRANSCEND project. The TRANSCEND project has a similar scope of exploring transformative pathways towards water resilience through locally tailored analyses and co-creation exercises conducted in seven pilot laboratories (WP2). These pilot labs, established within local partnerships, follow a scenathons approach to facilitate comprehensive policy discussions and provide innovative strategies to address water management challenges effectively (WP1). Each pilot lab is designed to address specific local challenges and contexts, ensuring that the solutions developed are relevant and applicable. By convening stakeholders from different sectors and backgrounds in a series of structured discussions, the project aims to generate a shared vision for water resilience and identify actionable steps to achieve it, ensuring that these steps are scientifically sound, socially acceptable, and politically feasible. The locally tailored assessments and co-creation exercises are informed by complementary reviews of knowledge and insights from international literature. This knowledge synthesis (WP5) explores barriers to transformation and potential solutions, combining insights from various fields such as governance and economics, to create a holistic understanding of the issues and develop robust strategies for overcoming them.

Purpose and structure of this report. This report (Deliverable D5.2: White Paper on Financing Mechanisms) supports the co-development of transformative pathways (Task T2.2) by summarizing insights and identifying financial mechanisms for transformative adaptation pathways analysis. It explores equitable and sustainable financing mechanisms to facilitate the transition to sustainable water pricing policies and cost recovery strategies that align economic incentives with environmental sustainability and resilience objectives. Based on a targeted desk literature survey, the report aims to deliver a 'primer' on economic instruments (tariffs, taxes, trade, and risk transfer) for sustainable water management, serving as a sourcebook to inspire the development of locally tailored solutions in the seven project pilots. It sets the stage for developing lab-specific policy briefs to inform the next round of local workshops. This document is intended to be understood as an evolving "living" document, extended with intermediary outcomes from pilot labs and new knowledge from similar initiatives (WP7), which may be relevant for the evolving discourses in the pilots.

There is a substantial body of literature addressing various aspects of economic and financial instruments for water management (Expósito & Berbel, 2024; Gómez Gómez et al., 2018; Graveline, 2020; Kraemer et al., 2003; Olmstead, 2010; Olmstead et al., 2007; Olmstead & Stavins, 2009; Ong et al., 2023; Stavins, 2003), and the authors of this report, along with other members of the TRANSCEND consortium, have significantly contributed to building this knowledge base. Previously, they participated in a comprehensive assessment of Economic Policy Instruments (EPIs) for achieving water policy goals as part of the EU FP7 project EPI-WATER: Evaluating Economic Policy Instruments for Sustainable Water Resource Management in Europe (2011-2013, Grant agreement 265213), resulting in an extensive compendium (Lago et al., 2015). They also contributed to numerous review and analytical papers summarizing the advantages and disadvantages of various financial mechanisms, which this report partly relies on (Bhaduri et al., 2021; Mysiak et al., 2017; Palomo-Hierro et al., 2022; Pérez-Blanco, 2022; Rey et al., 2019). The report also builds upon the not-yet-published outcomes of other initiatives such as PIISA[2], INBESTSOIL[3], INVEST4NATURE[4], and NATURANCE[5]. Given the extensive body of knowledge in the referenced papers, this report does not aim to provide an in-depth literature assessment. Instead, it offers a high-level introduction designed to stimulate creativity for those involved in designing transformative pathways in the project pilots.

The document is structured as follows: **Section 2** introduces international discourses on valuing water and treating it as an economic good, including examples and lessons learned from large-scale water policy reforms in Europe and elsewhere, with a focus on innovative economic principles, equity and justice considerations, and technical challenges. **Section 3** explains the economic rationale behind water economics and delves into various categories of financial mechanisms, including pricing (tariffs and taxes), trade, and risk transfer instruments. **Section 4** provides an overview of major funding sources, both within the European Union and internationally, serving as an entry point for those seeking investments. The section outlines various financial instruments and funding mechanisms available to address water security, sustainable management, and infrastructure development challenges. **Section 5** summarizes the challenges and recommendations in applying these principles.

2. Examples of policy reforms

2.1. International coalitions

International recognition of looming water crises and connected challenges emerged early on, prompting the organization of dedicated **UN water conferences** and related UN development and environmental conferences. One of the earliest such conferences was held in 1977 in Mar del Plata, Argentina (Biswas & Tortajada, 2023). The UN conferences aimed to address the growing concerns over

[2] Piloting Innovative Insurance Solutions for Adaptation (HE, 2023-2026, GA 101112841)

[3] Monetary valuation of soil ecosystem services and creation of initiatives to invest in soil health: setting a framework for the inclusion of soil health in business and in the policy making process (HE, 2023-2026, GA 101091099)

[4] Promoting investments in NBS and accelerating market uptake by gaining a better understanding of the economic performance of NBS, considering climate mitigation and risk reduction (HE, 2022-2026, GA 101061083)

[5] Nature for insurance, and insurance for nature (HE, 2022-2026, GA 101060464)

water scarcity, sustainable water management, and their implications for global development and environmental health. They have been pivotal in raising awareness, fostering international cooperation, and setting the framework for sustainable water resource management worldwide. The 1992 **Dublin Conference on Water and the Environment** (Keulertz & Riddell, 2022; Priscoli, 2019) established four key principles for managing freshwater resources, known as the Dublin Principles. The conference underscored that water is a limited and vulnerable resource critical for sustaining life, development, and the environment. It called for water management to be inclusive, engaging users, planners, and policymakers at all levels. The central role of women in providing, managing, and safeguarding water was highlighted, along with the recognition that **water holds economic value** in all its competing uses and should be treated as an economic good (United Nations, 2013).

Mar del Plata Action Plan (Biswas, 1988; Falkenmark, 1977) was a significant milestone in recognizing the **universal right to access drinking water** of sufficient quantity and quality to meet basic needs. This agenda was furthered by the United Nations Committee on Economic, Social and Cultural Rights, which affirmed water as a human right in 2002 (UN Committee on Economic, Social and Cultural Rights, 2003). Eventually, the United Nations General Assembly adopted Resolution 64/292 on July 28, 2010 (United Nations General Assembly, 2010), which officially recognized the human right to safe and clean drinking water and sanitation as essential for the full enjoyment of life and all other human rights. The resolution calls on states and international organizations to provide financial resources, capacity-building, and technology transfer to assist countries, especially developing nations, in providing safe, clean, accessible, and affordable drinking water and sanitation for all. It emphasizes the importance of sustainable management and development of water resources to meet the needs of present and future generations.

The United Nations has designated several **Decades for Action on water**, each with specific objectives to address global water challenges. The International Drinking Water Supply and Sanitation Decade (1981-1990) aimed to provide safe drinking water and sanitation to all by 1990, focusing on public health and development. The International Decade for Action, "Water for Life" (2005-2015), sought to fulfill international commitments of the Millennium Development Goals (MDGs) related to water, improve access to safe drinking water, promote integrated water resources management, and enhance sanitation services. Building on these efforts, the International Decade for Action, "Water for Sustainable Development" (2018-2028), focuses on improving water quality, increasing water-use efficiency, implementing integrated water resources management, and fostering international cooperation.

The United Nations' SDGs include several targets directly related to water, reflecting its critical importance for sustainable development. In this regard, SDG 6, "**Clean Water and Sanitation**," aims to ensure availability and sustainable management of water and sanitation for all by 2030. This goal includes targets for achieving universal access to safe, affordable drinking water, improve water quality by reducing pollution and hazardous chemical release, and increase water-use efficiency. It emphasizes integrated water resources management, including transboundary cooperation, and the protection and restoration of water-related ecosystems, like rivers, wetlands, and lakes. Water is fundamental to other SDGs, including SDG3 (Good Health and Well-being), SDG11 (Sustainable Cities and Communities), and SDG13 (Climate Action), while affecting performance of most other SDGs.

The 2023 UN Water Conference, held from March 22-24 in New York, marked a historic effort to address global water challenges. The conference featured over 6,500 participants, resulting in approximately 700 commitments to improve water management. Key outcomes included the establishment of a **UN Special Envoy for Water**, highlighting the importance of water as a **global common good**, and promoting integrated water resources management and innovative financing for water-related initiatives.

The "**An Agenda for Water Action**" (United Nations, 2018) of the UN High-Level Panel on Water (HLPW) provided leadership and guidance on addressing the global water crisis and to accelerate progress towards ensuring sustainable water and sanitation management. The Panel, established in 2015, was composed of 11 (at that time) sitting Heads of State or Government and a Special Advisor. The HLPW Agenda is structured into three key stages. The first stage, **Foundation for Action**, emphasizes the importance of understanding the value of water in its social, cultural, economic, and environmental dimensions. This requires investing in data and strengthening water governance mechanisms to manage water resources effectively. The second stage, **Leading an Integrated Agenda Locally and Regionally**, focuses on an integrated approach to water management that transcends political and sectoral boundaries. This includes ensuring sustainable and universal access to safe water and sanitation, building resilient societies and economies, investing in water-related infrastructure, addressing environmental issues, and creating sustainable cities and human settlements. The third stage, **Catalyzing Change and Building Global Partnerships**, highlights the need to foster innovation, promote partnerships, increase financing, and strengthen institutional support for water management at the global level. Enhancing international cooperation and leveraging the Water Action Decade are the key to driving impactful action on a global scale.

The Agenda placed an emphasis on the **importance of valuing water** to ensure its sustainable, efficient, and inclusive use. Key principles for valuing water, designed to foster better water management, prevent conflicts over water resources, and support sustainable service delivery, include:

- Recognize and embrace **water's multiple values**: Understand and account for the diverse values of water to different groups and interests in all water-related decisions.
- **Reconcile values** and build trust: Conduct inclusive, transparent, and equitable processes to reconcile different water values, sharing benefits among all affected parties.
- **Protect the sources**: Value, manage, and protect all sources of water, including watersheds, rivers, aquifers, and ecosystems, for both current and future generations.
- **Educate to empower**: Promote public awareness and education about the intrinsic value of water and its critical role in all aspects of life to encourage sustainable practices.
- **Invest and Innovate**: Ensure adequate investment in water infrastructure, institutions, information, and innovation to derive multiple benefits from water and reduce associated risks.

The HLPW Agenda underscores the need of integrating these principles into political and business decisions, pricing water services appropriately, and involving all stakeholders, particularly marginalized groups, in the valuation process. The **Valuing Water Initiative** (VWI)[6] was launched to implement the aforementioned principles and integrate the diverse values of water into decision-making to ensure sustainable management. By promoting better governance, and encouraging investments in water projects, the initiative seeks to inspire systemic changes in how water is valued and managed globally.

Among other international initiatives, it is worth mentioning the comprehensive programme on water developed by the Organisation for Economic Co-operation and Development (OECD). It focuses on enhancing sustainable water management through improved governance, sustainable financing, and effective risk management. The programme aims to facilitate increased investment in water security by promoting the use of economic and financial instruments. Key initiatives include the Roundtable on Financing Water, which brings together public and private stakeholders to address financing challenges, and the use of blended finance to mobilize additional resources for water-related projects. Economic instruments such as water pricing, pollution charges, and tariffs are also emphasized to reflect the true cost of water services and incentivize sustainable practices (OECD, 2019, 2020, 2022). These efforts are part of the OECD's broader agenda to ensure water security and promote sustainable development globally.

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[6] **Valuing Water Initiative** (VWI) : https://valuingwaterinitiative.org

2.2. European experience

In late 2000, the European Union (EU) adopted the Water Framework Directive (WFD), a cornerstone of comprehensive water legislation aimed at promoting sustainable water resources management and improving and protecting the quality of water resources across Europe. The WFD establishes a framework for the protection of inland surface waters, transitional waters, coastal waters, and groundwater, emphasizing the need for integrated river basin management, public participation, and coordinated efforts across member states. This directive seeks to achieve good qualitative and quantitative status of all water bodies by setting clear objectives, deadlines, and measures to address pollution, over-extraction, and habitat degradation. Key principles include managing water resources at the river basin level, achieving good ecological status through systematic planning, implementing full cost recovery in pricing mechanisms, and ensuring public participation in developing and updating river basin management plans. The WFD operates in 6-year cycles, with the first cycle spanning from 2009 to 2015, the second from 2016 to 2021, and the third from 2022 to 2027. Complementary daughter directives address specific issues more in depth: the quality and quantity of groundwater (2006/118/EC) and the quality of surface water (Directive 2008/105/EC). A regulatory fitness check in 2019 recognized the WFD as a **global model for water governance**. It acknowledged progress in prioritizing water quality, improving transboundary cooperation, and enhancing international networks. Additionally, the directive fostered hydrological skills among non-water competent authorities and generated valuable knowledge that would not have been acquired otherwise.

The WFD emphasizes the importance of considering pollution and environmental degradation, as well as resource depletion and opportunity costs in water pricing to achieve sustainable water management, following the so-called **full cost recovery principle**. It mandates that these costs, along with maintenance and operational costs of water services' provision are included in water pricing to incentivize water conservation, reduce waste, and promote sustainable use of water (European Environment Agency., 2013). While the WFD offers **a global model** for integrated water resources management and economic policy instruments, it faces significant challenges. There is considerable variability in how EU Member States implement cost recovery principles. This includes differences in the definitions of water services, methods of calculating costs, and levels of cost recovery achieved. Achieving full cost recovery is difficult due to political, societal, and technical obstacles, particularly in agriculture. Currently, only about 70% of financial costs are recovered through tariffs and public funds, with the recovery of environmental and resource costs being even more challenging (Farnault, & Leflaive, 2024). Demographic trends, climate change, and progressive environmental policies are contributing to an increasing financing gap, with substantial additional expenditures required to meet the WFD compliance by 2030.

2.3. Other national experiences

This section summarizes experiences and lessons learned from large-scale water reforms worldwide, focusing on innovative economic principles, equity and justice considerations, and technical challenges. The examples show how countries have tailored their reforms to address regional challenges, incorporating sustainability, equity, and integrated water resources management principles.

Australia. The water reform in the Murray–Darling Basin (MDB), initiated under the 2007 Water Act, aimed to address water insecurity through comprehensive water management and governance. The reform's scope included the reduction of irrigation water extractions, the acquisition of water entitlements for environmental purposes, and the implementation of the 2012 Basin Plan which set sustainable diversion limits (SDLs) for both surface and groundwater. Key strategies involved direct buybacks of water entitlements and substantial subsidies for irrigation infrastructure to improve efficiency and reallocate water to the environment. Despite its ambitious goals, the reform faced significant challenges. Political and socio-economic pressures led to compromises in the SDLs, reducing the intended environmental benefits. Amendments in 2018 allowed for increased irrigation extractions, further straining the Basin's water resources. Additionally, the effectiveness of infrastructure subsidies was questioned due to high costs and minimal environmental gains. The reform's implementation was also hindered by issues, such as inadequate water accounting, regulatory capture, and governance failures, resulting in insufficient progress towards achieving the environmental objectives of the Water Act. These challenges underscore the complexity of balancing water use between agricultural needs and ecological sustainability (Grafton, 2019).

South Africa. The South African National Water Act (NWA) of 1998 aimed to address racial inequities in water allocation and establish a comprehensive water management system. Key goals included creating catchment management agencies (CMAs), transforming irrigation boards, and ensuring equitable water access. Implementation has faced significant challenges. Only two out of nine proposed CMAs have been established, and many irrigation boards remain unchanged. Efforts to ensure equity in water access have been limited, with most water still allocated to white commercial farmers. The water use licensing process is delayed, and the water use registration system is outdated, complicating billing and compliance. Protecting aquatic ecosystems has been difficult due to technical and operational barriers. Challenges stem from leadership instability, capacity constraints, and socio-political dynamics. Frequent turnover of ministers and directors-general, internal departmental tensions, and high staff turnover have undermined policy consistency. Rapid and extensive changes required by the NWA overwhelmed departmental resources and capacity, leading to staff attrition and increased reliance on consultants. Ideological and political divisions, resistance from established power blocs, and practical issues, such as enforcing scientific flow regimes and inadequate monitoring systems, have further impeded progress. The NWA's implementation underscores the need for aligning technical capabilities with legislative ambitions, focusing on foundational water management elements, and fostering inclusive partnerships for sustainable water governance (Schreiner, 2013).

China. China has implemented a series of reforms to improve water management, address pollution, and ensure sustainable water usage.

- The 2015 **Water Pollution Prevention and Control Action Plan**, known as the Water Ten Plan[7], aimed at reducing key pollutants, improving water quality in major rivers and lakes, and eliminating black odor water in urban areas through comprehensive measures including pollution source control, enhanced wastewater treatment, promotion of water-saving technologies, and

[7] https://chinawaterrisk.org/notices/new-water-ten-plan-to-safeguard-chinas-waters/

stringent monitoring and enforcement. The plan has led to significant improvements in water quality, particularly in urban areas, though challenges remain in balancing economic growth with environmental protection (Tang et al., 2022; Zhou et al., 2021).

- The **River Chief System** (RCS) in China is an institutional innovation designed to address water pollution and ecological issues within river basins. Implemented nationwide in 2016, the RCS assigns government officials at various administrative levels as "river chiefs," responsible for the protection and management of designated water bodies. These officials oversee pollution control, water conservation, and ecological restoration efforts, enhancing accountability and coordination among government departments. The system promotes local responsibility and collaborative efforts to achieve water quality targets. The RCS has shown notable success in improving water quality, particularly in regions like the Taihu Lake Basin, where significant reductions in pollutant levels have been observed. However, challenges such as high implementation costs, information asymmetry, and limited public participation persist (B. Wang et al., 2021).
- The **South-to-North Water Diversion Project** (SNWDP) is the largest interbasin water-transfer scheme globally, designed to address water scarcity in northern China by diverting water from the more abundant southern regions. This large-scale infrastructure project has three main routes: the Eastern, Middle, and Western routes, with the Eastern and Middle routes already operational. The SNWDP plays a crucial role in alleviating water shortages, supporting agricultural, industrial, and domestic water needs, and enhancing environmental sustainability in the northern regions (Kattel et al., 2019). Despites the economic development benefits, concerns persist over environmental impacts, such as biodiversity loss, changes in hydrological regimes, water quality deterioration in donor regions, ecological impacts on aquatic habitats, and risks of biological invasions along the diversion routes (Yan et al., 2023).

New Zealand. The Three Waters[8] reforms in New Zealand aim to centralize the management of drinking water, wastewater, and stormwater services to address aging infrastructure, regulatory failures, and regional disparities. These reforms address several critical issues, including aging infrastructure, regulatory failures, and regional disparities in service quality. The 2016 Havelock North water contamination incident, which resulted in widespread illness and deaths, promoted a comprehensive reform. Key components of the reforms include the establishment of several publicly owned regional entities that will take over responsibilities from the 67 local councils. These entities will be tasked with delivering drinking water, wastewater, and stormwater services. Each entity will have a board of directors, including representatives from local government and iwi (Māori tribal) groups, ensuring a balanced and inclusive approach to governance. These entities will be held accountable to both local communities and the central government through regulatory frameworks and performance monitoring. To oversee drinking water safety and monitor the performance of the water service entities, the government established Taumata Arowai, a new water services regulator. Additionally, the Environmental Protection Authority (EPA) and regional councils will continue to regulate the environmental impacts related to wastewater and stormwater. The water service entities are expected

[8] https://www.dia.govt.nz/Water-services-reform-about-the-reform-programme

to finance ongoing and future investments through service charges and borrowing, leveraging their larger scale to access more favorable financing terms than individual councils could achieve. Despite the potential benefits, the reforms have faced significant controversy and challenges[9]. Local governments are concerned about losing control over water assets, and there is public opposition due to fears of increased costs and reduced local influence. Ensuring meaningful iwi/Māori participation and managing the complex transition from local to regional management also pose significant challenges.

Mexico. In 1992, Mexico implemented a significant water sector reform through the National Water Law, aiming to decentralize water management and introduce private participation. This reform transferred responsibility for water utilities from the federal government to municipalities, encouraging the creation of autonomous water utilities to manage their own budgets and resources. The National Water Commission (CONAGUA) was established to oversee and support these efforts, promoting technical, financial, and managerial autonomy. Key features included decentralization, allowing local governments to take control of water supply and sanitation services; private participation, enabling private companies to manage water utilities through concession contracts while ownership remained public; and the formation of autonomous utilities to improve efficiency, financial sustainability, and service quality. The reform emphasized revenue collection, including the ability to cut services to non-paying customers. The performance assessment showed mixed results. Private management demonstrated higher efficiency due to better revenue collection and less political interference, but autonomous public utilities did not significantly outperform non-autonomous ones. Many municipalities lacked the technical and financial capacity to manage utilities effectively, and inter-municipal coordination posed challenges. While revenue collection improved, many utilities remained financially dependent on federal or state support, particularly those managed by public entities. Enhanced regulatory frameworks and technical capacity at the local level were found critical for achieving the reform's goals (Salazar-Adams, 2021).

3. Economic and Financial instruments

3.1. Economic rationale

The Dublin Principles, adopted in 1992, embrace a neoliberal approach to water resources management by suggesting that water, having economic value in all its competing uses, should be treated as an **economic good**. Implicit in this is the recognition that economic incentives can stimulate water conservation and reduce waste, while market mechanisms can effectively allocate water resources. Water uses that generate the highest economic value should be prioritized across sectors, such as agriculture, industry, and domestic consumption, thereby benefiting society by maximizing the aggregate social value obtained from water use. If the price of water reflects the true cost—including extraction, treatment, distribution, scarcity, and environmental costs—then users will consume water

[9] https://theconversation.com/with-the-three-waters-reforms-under-fire-lets-not-forget-that-safe-and-affordable-water-is-a-human-right-192933

only up to the point where the marginal value of its use equals its price. Ensuring the full costs of water services recovered from users through tariffs, taxes, and transfers (3Ts) contributes not only to the financial sustainability of water service provision but also to the optimal allocation and efficient use of resources. This does not mean that social equity is neglected. Policies should ensure that essential water services remain accessible and affordable to all, particularly to poor and vulnerable social groups. By recognizing water as an economic good, the Dublin Principles promote more efficient, equitable, and sustainable water management practices, balancing economic, social, and environmental needs.

Environmental costs associated with water use deserve closer attention because the true cost of water use is higher than the private cost reflected in its market price. Water pollution from industrial discharge, agricultural runoff, and untreated sewage can severely degrade aquatic ecosystems, compromise the services these ecosystems provide, and increase the costs of providing water for other users, such as through higher water treatment expenses. Neglecting these externalities results in market failure, because the true social cost of producing or consuming a good is higher than the private cost reflected in the market price, leading to overproduction or overconsumption of these goods (Kanakoudis & Tsitsifli, 2016). This can lead to overuse and misallocation of water resources, referred to as the "tragedy of the commons" (Chappells & Medd, 2008), where individuals, acting in their self-interest, deplete shared resources, leading to long-term negative consequences for the entire community. Full cost recovery ensures that negative impacts on the environment are factored into the price paid for water, thereby generating revenues for remediation. This is consistent with the 'polluter pays principle' (Verbruggen, 2023) which imposes liability on the person who pollutes the environment and compensate for the ensuing damage. By incorporating environmental costs into water pricing, users are charged for the true cost of their water consumption, which includes the costs associated with environmental degradation and resource depletion. This approach promotes the efficient use of water and provides the necessary funds to address and mitigate environmental damages.

Pigovian taxes (Pigou et al., 2013) are designed to correct market failures by imposing costs on activities that generate negative externalities, thereby aligning private costs with social costs. Basically, these taxes incentivize producers and consumers to reduce harmful activities by increasing the pollution cost. This is equivalent to a carbon tax on fossil fuels as it aims at cutting greenhouse gas emissions by encouraging the adoption of cleaner energy alternatives (Barraqué & Montginoul, 2015). In addition to Pigovian taxes, governments can implement regulations to limit or control activities causing negative externalities, such as setting emission standards or banning harmful substances. Cap-and-trade systems, which cap the total level of pollution allowed and issue permits for emissions (Massarutto, 2020), also provide economic incentives to reduce pollution. Applying the concept of full cost recovery in water pricing operates in a similar manner to Pigovian taxes. Addressing negative environmental externalities through these measures helps align private incentives with social well-being, fostering a more sustainable and efficient use of resources. Economic instruments, like water pricing, subsidies, and tradable water rights, encourages conservation and efficient use, reducing overuse and ensuring sustainable management.

Adopting market-based mechanisms to achieve more efficient allocation and use of water resources does not necessarily imply support for the privatization or commodification of water services. While privatization can, in some cases, enhance efficiency, attract investment, and spur innovation in water services by introducing market competition, it is not a one-size-fits-all solution. Private entities may indeed improve service quality and reduce costs, but there are also instances where privatization has led to negative outcomes[10]. Consequently, some municipalities have opted to revert to public provision of water services after experiencing issues, such as higher costs and reduced access for vulnerable populations (Lobina et al., 2014). Similarly, ensuring affordability of water services for low-income households while achieving cost recovery remains a significant challenge. Balancing social equity with the need for full cost recovery requires careful consideration and design of pricing mechanisms.

A similar trend has been observed in the biodiversity and ecosystem restoration literature. It has been suggested that ecosystem services hold significant economic value, even when no direct price is paid for them. By making this value explicit, ecosystem restoration can gain a greater prominence on policy and political agendas. Ecosystems constitute components of the natural and semi-natural environment, and they are a source of vital services, benefits, and goods to mankind. Ecosystems can provide means to mitigate natural hazard risks and boost societal resilience, locally or regionally. Restoration of ecosystems and their services, where they have been degraded or otherwise altered, provides solutions to societal challenges, such as the climate and biodiversity crises. These are commonly referred to as nature-based solutions (NbS) (Calliari et al., 2019). NbS can provide means to mitigating climate risks - through mass stabilisation, water flow regulation, wind dissipation, and temperature regulation - remove particle pollution and improve air quality, protect soil and biodiversity, and enhance climate resilience. It provides over one-third of the cost-effective climate mitigation (Griscom et al., 2017) required to stabilise warming to below 2°C. Research on the global value of ecosystem services, which began in the late 1990s (Costanza et al., 2014, 2014; Jiang et al., 2021) and has continuously expanded since, underscores the immense economic value provided by natural ecosystems. The aggregate valuation framework was criticized for focusing on total rather than marginal value, which reflects incremental changes in ecosystem services. Critics argue that it can lead to misguided policy decisions, as understanding marginal value is crucial for assessing the impact of resource allocation changes on welfare and efficiency (Farley, 2012; Pearce, 1998). A 2022 report (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2022) of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) explored diverse values and valuation frameworks of nature, producing a comprehensive typology. Broad values, such as freedom, justice, and harmony with nature, are moral principles informed by worldviews and embedded in societal norms. They underpin specific nature values, which include instrumental values (nature as a means to an end), intrinsic values (nature's inherent worth), and relational values (meaningful human-nature interactions).

[10] https://www.iwapublishing.com/news/impact-privatisation-sustainability-water-resources, https://www.theguardian.com/commentisfree/article/2024/jun/12/the-guardian-view-on-water-privatisation-end-an-experiment-that-has-failed

3.2. Water pricing

Incentive water pricing instruments include various mechanisms designed to promote efficient water use and conservation: tariffs and charges, environmental taxes, and subsidies and payments for desired behaviors (e.g., payment for ecosystem services). These instruments set a price on the use of natural resources or the emission of pollutants. While the cost to the user (e.g., per unit of pollution) is known and fixed, making it clear for businesses and consumers how much they will pay and allowing for predictable budgeting, the overall environmental impact is uncertain. The actual reduction in use or pollution depends on how responsive businesses and consumers are to the price signal. If the price is too low, it may not lead to significant changes in behavior or substantial reductions in emissions.

- **Tariffs** for water supply and sanitation (WSS) are pricing systems applied for domestic and industrial provision of clean water and wastewater management to recover the costs associated with the extraction, treatment, distribution, and maintenance of water supply infrastructure, as well as the collection, treatment, and disposal of wastewater. Agricultural tariffs are pricing systems for the provision of irrigation water. Water tariffs have different forms: (i) *flat rate* tariffs, which charge a fixed amount regardless of usage; (ii) *volumetric* tariffs, which are based on the actual volume consumed; (iii) *increasing/decreasing block* tariffs, where the unit price rises/declines with higher consumption levels; (iv) *seasonal* tariffs, which apply different rates depending on the time of year, with higher prices during dry seasons to reflect water scarcity; and (v) *two-part* tariffs, which combine a fixed charge with a variable charge based on the water usage. In agriculture, additional tariffs systems, i.e., *area-based* tariffs, which is based on the size of the irrigated area rather than the volume of water used, may be applied.
- **Charges** and fees are a broader mechanism for managing water resources and protecting water quality. Charges for *wastewater treatment* are a part of the above water tariffs. *Abstraction* charges are levied for extracting water from water bodies. Occasionally applied *usage* charges are fees based on the volume of water consumed. *Pollution* charges are payments based on the measured or estimated quantity and quality of pollutants discharged into natural water bodies, implementing the polluter-pays principle, even when their calculation does not directly reflect damage costs.
- **Environmental taxes** are compulsory, unrequited payments (OECD, 2001) imposed on activities or products that have a detrimental impact on the environment, aiming to internalize environmental costs and promote sustainable practices. These taxes are levied on a tax base defined as "a physical unit (or a proxy of it) of something that has a proven specific negative effect on the environment," (European Commission. Statistical Office of the European Union., 2024) and have been integrated into international environmental accounting frameworks. Types of environmental taxes include *emissions and effluent* taxes, which directly tax pollutants released into the environment; *product* taxes, which tax goods likely to cause environmental harm during their lifecycle; and *natural resource* taxes, which place a price on the use of scarce natural resources. Designing optimal pollution taxes that balance damage costs and control costs requires comprehensive data on environmental impacts and economic conditions. Calculating these taxes requires precise information on the quantity and quality of pollutants, which can be challenging to obtain.

Distinguishing between taxes and other levies can be challenging, complicating the classification and implementation of these financial instruments.

- **Payment for Ecosystem Services** (PES) is an instrument that compensates land stewards for ecosystem conservation and restoration. The PES programs can take various forms, such as *biodiversity offsets*, *watershed protection* payments, *community-based conservation*, or *carbon farming*. They create financial incentives for maintaining or enhancing ecosystem services by providing payments to those who manage the land in ways that deliver these services. The effectiveness of the PES programs depends on their design, implementation, and the socio-economic context in which they operate. Challenges associated with PES include ensuring accurate measurement and valuation of ecosystem services, addressing potential inequities, and managing transaction costs (Farley & Costanza, 2010; Kinzig et al., 2011; Milder et al., 2010). Although PES are subsidies, unlike other subsidies, tax reliefs, and rebates for water-saving technologies and practices, they are performance-based and conditional on the provision of specific ecosystem services to receive the payment.

Pricing instruments, especially those based on volumetric or performance-based approaches and tiered pricing with higher rates for increased water consumption, incentivize conservation by making users directly responsible for the cost of their water usage. These mechanisms encourage consumers to use water more efficiently, as higher consumption leads to higher costs, thereby providing a financial incentive for conservation. However, the effectiveness of these pricing instruments relies on several key assumptions.

One critical assumption is the **price elasticity of demand for water**. If the demand for water is inelastic, meaning that consumers' water usage does not significantly decrease in response to price increases, higher prices will primarily generate additional revenue without substantially reducing water consumption. The demand for piped water in households is generally inelastic, with price elasticity usually falling between -0.5 and -0.3 (Wheeler et al., 2023), both in developed and developing countries, respectively. However, this elasticity can fluctuate depending on different factors, such as geographical location, seasonal variations, and household income levels. Price elasticity of agricultural water in the US ranges from -0.1 to -1.12, depending on water sources, price measurements, and agricultural contexts across reported studies (Bruno & Jessoe, 2021). Other factors including consumer awareness, income levels, and the availability of water-saving technologies also play significant roles in the success of these pricing strategies. For instance, if consumers are not aware of the pricing structure or lack access to efficient water-saving devices, the intended conservation effects may not materialize. Understanding and accurately estimating the price elasticity of demand is essential for designing effective water pricing instruments that achieve both revenue generation and conservation objectives. Moreover, as water conservation efforts succeed and water is used more efficiently, the volume of water delivered decreases, but the fixed costs of water infrastructure remain unchanged, leading to higher per-unit costs of water (Moffitt & Danilenko, 2014). Consequently, to maintain financial solvency, water utilities may need to increase rates to cover fixed costs (Spang et al., 2015). Reduced wastewater flows can also affect the operation and efficiency of treatment plants, increasing treatment costs.

The second assumption relates to the actual reduction of water consumption with increasing efficiency of the water use. Empirical evidence suggests that this may not always hold true, as demonstrated by the **Jevons paradox** or rebound effect (Y. Wang et al., 2020). For example, farmers who adopt more efficient irrigation technologies such as drip or sprinkler systems often end up expanding their irrigated area or growing more water-intensive crops. This can lead to an overall increase in water consumption despite the improved efficiency of the irrigation systems. Therefore, while efficiency measures are crucial, they must be complemented by effective pricing strategies and regulatory measures to ensure real reductions in water consumption.

The third assumption, or rather a limiting factor, is the universal character of pricing instruments, which can **disadvantage socially-vulnerable and low-income users**. Pricing instruments for water, such as tariffs, charges, and environmental taxes, set a fixed cost for water usage or pollution emissions that can represent a significant portion of income of socially-vulnerable and low-income users. While the intention of pricing instruments is to signal users to conserve water, low-income households often have less flexibility to reduce their consumption. These households may already use water efficiently out of necessity, and thus have limited capacity to further cut back without compromising their basic needs, which could have serious implications for health, hygiene, and overall well-being. Moreover, the financial strain from increased water prices might prompt these households to reduce other essential expenses, exacerbating their financial hardship. As water is an essential resource and a human right, it is crucial to design pricing policies that consider the economic constraints of low-income households not only to avoid placing undue burdens on them but also to ensure equitable access to this vital resource. Such considerations might include tiered pricing structures with lower rates for basic water needs, subsidies, or targeted assistance programs to support vulnerable populations.

3.3. Water trading

Water trading involves the voluntary exchange of rights or entitlements to use water. It operates under the governance constraints that are set by water authorities and convert water use into tradable property rights. These constraints ensure an overall cap on water use rights, within which users can trade. This system enables water to be allocated to higher-value uses without exceeding sustainable limits. Similarly, cap-and-trade systems set a total limit (cap) on the amount of a particular resource that can be used or the amount of a pollutant that can be emitted. Permits or allowances are distributed or auctioned, and entities can trade these permits in the market. Cap-and-trade systems ensure that the total level of resource use or emissions stays within the set cap, providing certainty about the environmental outcome, as the cap directly limits the amount of resource that can be abstracted or pollution that can be released into the environment. However, the price of permits is determined by the market and can fluctuate based on supply and demand. If demand for permits is high, prices will increase; Otherwise, prices will decrease. This creates uncertainty for businesses regarding the cost of compliance, as they do not know in advance how much they will need to spend to acquire permits.

Water trading can take several forms, each with distinct features and benefits. Spot markets facilitate short-term trades of water rights within a single basin. These trades can be informal or formal, occurring immediately or in the near future. Spot markets are particularly useful for addressing temporary water shortages and reallocating water quickly to where it is most needed. Water banks act as central institutions that manage water rights transactions. They collect information on the supply and demand of water rights and facilitate trades, often adding a markup to cover operational costs. Water banks help standardize and streamline the trading process, making it easier for users to buy and sell water rights. Bulletin boards function similarly to water banks but without a central pricing authority. Instead, buyers and sellers post bids and offers on a platform managed by an entity like an irrigation district authority. Prices are determined through negotiations between parties, reflecting real-time market conditions. Auctions are used to allocate water rights among multiple users who compete for the same resource. They can be structured as single-bid or double-auction markets, where sealed bids are submitted and the highest bids secure water rights. Auctions ensure transparent and competitive allocation, often resulting in efficient pricing. Derivative markets involve long-term agreements for water rights, such as options and forward contracts. For instance, in option markets, parties agree on future water deliveries, with both sides obligated to fulfill the contract. On the other hand, forward contracts allow buyers to forego purchases before expiration, with sellers compensated for any breach. Environmental leasing and purchase programs aim to enhance environmental flows by leasing or purchasing water rights for conservation purposes. Governments or environmental trusts may buy water rights from users to ensure sufficient flow in rivers and lakes, supporting ecosystem health.

While water trading offers significant benefits, it also faces several challenges. Ensuring that water trades do not harm the environment is crucial. Trading schemes must account for potential negative impacts on ecosystems, such as reduced river flows or groundwater depletion. Proper safeguards and environmental assessments are required to maintain ecological balance. Trades can affect third parties who are not directly involved in the transaction. For example, downstream users may experience reduced water availability if upstream users sell their rights. Effective regulatory frameworks must address these externalities to prevent unintended consequences. Defining and enforcing water rights is complex, particularly when integrating surface and groundwater resources. Water rights must be clearly defined, tradable, and aligned with sustainable use limits to avoid over-allocation and legal disputes. Transferring water over long distances involves significant costs and potential losses from evaporation and infiltration. These factors must be considered when evaluating the feasibility and efficiency of trades, particularly for inter-basin transfers. Successful water trading requires robust institutional support, including legal reforms, monitoring systems, and enforcement mechanisms. Institutions must be capable of managing water rights, ensuring compliance, and addressing disputes.

Despite these challenges, water trading presents numerous opportunities for improving water governance and resilience. By reallocating water to higher-value uses, trading can enhance the economic productivity of water resources. This is particularly beneficial during droughts or periods of scarcity, where efficient allocation becomes critical. Market mechanisms incentivize innovation and investment in water-saving technologies and practices. Users seeking to maximize their returns will adopt more efficient methods, contributing to overall water conservation. Water trading provides flexibility, allowing users to adapt to changing conditions and demands. This adaptability enhances the resilience of water systems to climate variability and other stressors. By optimizing existing water resources through trading, there is less need for costly infrastructure projects, like dams and pipelines. This approach promotes sustainable water management without significant capital expenditure.

Experience from various regions underscores the potential and challenges of water trading. For instance, the Murray-Darling Basin in Australia has a complex water market that has faced issues, like over-allocation and environmental degradation. Efforts to address these challenges include regulatory reforms and financial instruments to buy back water for environmental purposes. In the Tagus River Basin in Spain, voluntary trading agreements have optimized water use without extensive infrastructure investments. These agreements highlight the importance of stakeholder involvement and compensation for third-party effects. In Chile, water markets have been used to reallocate water in semi-arid regions, but challenges like downstream conflicts and environmental impacts persist. Reforms are ongoing to address these issues and improve market functioning.

Water trading, when carefully designed and implemented, can significantly enhance water resources management by promoting efficient allocation, fostering innovation, and increasing resilience. However, it is essential to address environmental and social impacts, ensure robust institutional support, and involve all stakeholders to realize the full potential of water markets. The experiences from different regions provide valuable lessons for developing sustainable and equitable water trading schemes that balance economic benefits with environmental and social considerations.

3.4. Risk financing

Insurance and other risk management instruments, such as contingency credit and insurance-linked securities (ILS), play a vital role in managing the financial impact of water-related disasters, including flood and drought, particularly under a changing climate. Apart from providing financial protection, they incentivize risk reduction and support sustainable water management practices, ultimately contributing to greater water security and resilience against water-related risks. Risk financing addresses residual risks that regulatory or economic instruments cannot efficiently mitigate. Comprehensive strategies ensure capacity to manage and mitigate the costs of water-related disasters, enabling rapid recovery (OECD, 2015).

- **Insurance**, the most common form of financial protection against contingent losses, involves policyholders transferring the cost of potential loss to insurers in exchange for premiums. By absorbing, pooling, and diversifying individual risks, insurers make these risks assessable and manageable. However, not all risks are insurable (Mysiak et al., 2017). Risks that are quantifiable in terms of both the probability of occurrence and the extent of losses incurred are more likely to be insured. Climate change introduces challenges to the insurability of water-related risks, since it increases the uncertainty connected to both their occurrence and magnitude (Grossi et al., 2005; Lamond & Penning-Rowsell, 2014). This can be particularly problematic for droughts, agriculture and grassland production (Vroege & Finger, 2020). Additional limits to insurability are introduced by the spatial correlation of water-related risks and the connected losses, as well as the presence of significant information asymmetries (Kron et al., 2019; Kunreuther & Michel-Kerjant, 2007a). As a result, certain risks or areas can be considered outright uninsurable (Schäfer et al., 2019), and the others might be charged higher premiums which reduce their attractiveness to potential policyholders (Lamond & Penning-Rowsell, 2014). Nevertheless, large climate-related disasters display weak correlation across countries and time (EIOPA, 2023), and moral hazard does not seem to be too much of an issue (at least for flooding) (Hanger et al., 2018; Hudson & Berghäuser, 2023; Shao et al., 2019). So, it is expected that climate risks will remain insurable in the next decades (Hoeppe, 2016). While flood insurance relate is all sectors (households, businesses, agriculture, public, etc.), drought insurance is mostly used in the agricultural sector. There are two main types of insurance contracts. Indemnity-based products link compensation to actual losses. More sophisticated schemes may include comprehensive income/revenue insurance packages, covering production and market risks, though most policies focus on direct losses (e.g., yield variability risk (Kunreuther & Michel-Kerjant, 2007b)). In parametric (index-based) products compensation is triggered by the verification of certain physical/climatic conditions, and there is no direct link with the losses suffered. Index-based insurance is becoming increasingly popular, and it is frequently used to cover against water scarcity and droughts (Bucheli et al., 2021; Gómez-Limón & Granado-Díaz, 2023; Guzmán et al., 2020; Vroege et al., 2021). Designing efficient indices, which reduce the wedge between actual losses and compensation (the so-called basis risk) is crucial. Recent research has shown that tailored indices (for specific clients or events) (Bucheli et al., 2021; Gómez-Limón & Granado-Díaz, 2023), satellite data (Schwarze & Sushchenko, 2022; Vroege et al., 2021) and digital tools (such as artificial intelligence, machine learning, and so on) (Bucheli et al., 2021; Schwarze &

Sushchenko, 2022) are promising avenues in this regard. Index design is relevant also for other risk financing instruments, such as ILS and catastrophe bonds, which are commonly based on such parameterization. Insurance schemes to protect against water-related risks differ across countries, but often involve the public sector, either through premium subsidies, participation in reinsurance systems or public-private partnerships (PPPs), where the public sector supports the market to ensure coverage and financial stability. Indeed, not only are the better-performing markets those with an established involvement of the public sector (Hudson et al., 2020), but absent some form of subsidization there would be little to no demand for insurance coverage (Gómez-Limón & Granado-Díaz, 2023; Hill et al., 2019; Liu et al., 2023). This is especially the case for agricultural insurance and in less developed economies. The European Union, for instance, supports farm risk management through rural development programs, promoting insurance uptake and risk management practices (Mysiak et al., 2017), with subsidies up to 70% of annual premiums (European Commission, 2023a). Likewise, in developing countries, (index-based) agricultural insurance is almost subsidized through public or donor funds (Jensen & Barrett, 2017). An important aspect of any insurance scheme, particularly given the frequent use of subsidies for policies covering water-related risks, is the issue of justice. Oftentimes those most vulnerable to climate hazards also present the highest socioeconomic vulnerability (both within and across countries) (IPCC, 2023), who, without subsidization, might have to forego insurance coverage and rely on their (limited) resources to cope with climate hazards (Schäfer et al., 2019). However, this remains largely an unsolved issue, as common view on what constitutes a just insurance scheme is lacking (Lehtonen & Liukko, 2011; O'Neill & O'Neill, 2012; Penning-Rowsell, 2015). What there seems to be agreement on is the belief that current insurance schemes do not perform well on the justice scale. Public-private partnerships that include numerous stakeholders and spread risk across multiple layers is advocated as a promising approach to ensure that coverage is offered through a market-based system without cross-subsidization, while simultaneously including tools to make it affordable to more vulnerable groups (EIOPA, 2023; Kousky & Kunreuther, 2017).

- **Insuring ecosystem services** is an innovative risk financing approach which provides financial protection and incentives for the conservation and restoration of natural ecosystems. This concept involves creating insurance products that cover ecosystem services, such as water purification, flood protection, and biodiversity conservation, against the risk of loss or degradation due to disasters or anthropogenic pressures. By placing a monetary value on these services, insurance schemes encourage investments in natural infrastructure, promoting resilience and long-term sustainability. While ecosystem services can be restored and protected through various instruments, like pricing and trade, few practical applications of these concepts have been tested extensively. Notable examples include coral reef and forest insurance. Commercial examples of coral reef insurance schemes have been developed (in Mexico and Hawaii) to provide rapid funding for reef restoration after hurricanes and other damaging events, thereby helping to maintain the ecological and economic benefits these reefs provide (*Insuring Nature to Ensure a Resilient Future*, n.d.; Woodhead et al., 2019). These are parametric schemes that trigger compensation, up to $4mln, when wind speed exceeds predetermined thresholds. Analogous products could be developed in the future for, among others, mangrove forests, salt marshes, kelp forests, since they also contribute to alleviating storm surge and flooding risk. Another, more well-established, type of ecosystem insurance is represented by forest insurance schemes. These are designed to protect forest ecosystems against losses from wildfires and other disasters, ensuring the continued provision of ecosystem services, such as carbon sequestration, biodiversity conservation, and water regulation (*Linking Forest Treatment to Insurance Benefits by Reducing Wildfire Risk*, n.d.). To this date, however, such policies are used primarily to cover the value of timber lost, but not the cost of reforestation, despite it being technically and economically feasible (Kousky & Light, 2019).

– **Catastrophe bonds** (cat bonds) are financial instruments that transfer the risk of catastrophic events from insurers to investors. Originating in the early 1990s due to disasters like Hurricane Andrew, cat bonds are issued by a special purpose vehicle (SPV) to isolate the bond issuer from the sponsor's financial risks. Investors purchase these bonds, and the funds are held in a collateral account managed by the SPV. If a predefined catastrophic event occurs within the bond's term, the bond's principal covers the sponsor's insurance claims. If no event occurs, investors receive their principal back at maturity, along with higher-than-average interest payments to compensate for the risk(Motlagh et al., 2024). Such products offer an alternative to commercial reinsurance, increasing the capacity to handle catastrophic risk (Michel-Kerjan & Morlaye, 2008). This is particularly the case with parametric solutions (Polacek, 2018), which outperform commercial reinsurance in cases of high reinsurer default risk, low basis risk and in high-risk layers (Götze & Gürtler, 2022). **Resilience bonds** use a similar architecture as cat bonds but monetize avoided losses through a rebate structure. Unlike cat bonds, resilience bonds do not finance ex post recovery and reconstruction after an event, but projects and initiative aimed at enhancing ex ante resilience. The difference in expected losses under business-as-usual scenarios with those including protective measures is captured as a resilience rebate, funding the resilience project. This approach provides financial protection and incentivizes risk-reducing investments, enhancing community resilience (Vaijhala & Rhodes, 2018). Other types of bonds, such as green and environmental impact bonds, have been developed and used to build resilience and reduce environmental impacts, even though they function more as credit instruments than risk financing instruments (Motlagh et al., 2024). The D.C. Water Bond, for example, funded green stormwater infrastructure in Washington D.C. to reduce stormwater flow into the combined sewer system. This reduction decreases sewer overflows into the Potomac River and Chesapeake Bay. Cost savings from less stormwater flow repay the bond (Brand et al., 2021).

Integrating risk financing with water management frameworks through innovative financial instruments enhances resilience and promotes investments in risk reduction and sustainable water use. Tools like insurance, catastrophe bonds, and resilience bonds secure funding for critical measures that mitigate water-related risks and ensure sustainable water management. These instruments provide immediate financial relief after disasters and incentivize long-term investments in infrastructure, ecosystem restoration, and practices that enhance water security, aligning economic incentives with environmental sustainability and resilience objectives and fostering a proactive stance on water management.

4. Funding of investments in water security

In the previous sections, we reviewed economic and financial instruments that contribute to the cost recovery of water services and other purposes. Nevertheless, to meet the United Nations' SDGs and ensure access to clean water and sanitation, significant additional investments are required (Borgomeo et al., 2023). A recent analysis estimated the annual spending gap for water supply and sanitation services between 2017 and 2030. It was estimated to range from USD 131.4 billion to USD 140.8 billion, respectively, with a middle estimate of USD 138.0 billion, representing 0.45-0.48% of the GDP of 113 reviewed countries. To bridge this gap, countries need to increase the annual spending by 2.7 to 3.0 times the current level. Sub-Saharan Africa has the largest annual spending gap, demanding an increase of 9.5 to 17.0 times the current spending level. South Asia and the Middle East and North Africa also face significant gaps, needing increases of 8.5 to 8.8 times the current spending levels (Joseph et al., 2024). The irrigation subsector faces a significant spending gap. Analysis of 41 countries shows that they are not spending enough to meet low-cost targets by 2030, with an annual shortfall of USD 3.5 billion between 2015 and 2030, representing about 0.07% of their 2017 GDP (Joseph et al., 2024). Without adequate financing, many communities, especially in developing regions, will continue to encounter water insecurity and related health and economic challenges (McCoy & Schwartz, 2023).

EU Member States have access to various funding sources for water security, including the Recovery and Resilience Facility (RRF), the LIFE Programme, Horizon Europe, and the EU Cohesion Policy (Climate Adapt, 2024). These instruments help address sustainable water management and infrastructure development challenges.

- **Recovery and Resilience Facility** (RRF) is the centrepiece of Europe's recovery plan, NextGenerationEU, designed to mitigate the economic and social impact of the COVID-19 crisis and enhance the sustainability and resilience of European economies and societies. The RRF provides significant financial resources to EU member states to support investments and reforms, particularly in green and digital transitions. Each member state is required to develop a National Recovery and Resilience Plan outlining the reforms and public investment projects to access this funding (Bokhorst & Corti, 2023). European Parliamentary Research Service (EPRS) assessed to what extent the RRF has been used to promote sustainable water management within the EU (D'Alfonso, 2024). Fifteen Member States have dedicated at least €12.92 billion towards sustainable water management, doubling the EU cohesion funding for water-related projects up to 2027. Spain and Italy have the largest allocations, focusing on water management, conservation, and infrastructure improvement. These plans integrate investment and reform measures to address challenges, such as infrastructure deficits, water scarcity, and quality improvement. Reforms often accompany investments to enhance governance and impact.
- **LIFE Programme** is the EU's funding instrument for environment and climate action. Its Climate Change Mitigation and Adaptation sub-programme supports the transition to a sustainable, energy-efficient, renewable energy-based, climate-neutral, and resilient economy. By financing projects that contribute to sustainable development, the LIFE Programme address the environmental challenges posed by climate change. The programme has been instrumental in funding innovative projects that demonstrate new methods and technologies for addressing

environmental issues. For the 2021-2027 period, the European Commission has increased LIFE Programme funding by almost 60%, up to €5.4 billion (LIFE - European Commission, 2024).

- **EU Cohesion Policy** is the main investment policy aimed at supporting sustainable development and improving citizens' quality of life. It is implemented through various funds, including the European Regional Development Fund (ERDF), which focuses on strengthening economic, social, and territorial cohesion by correcting regional imbalances. The Cohesion Fund targets the reduction of economic and social disparities, particularly through environmental and transport infrastructure investments. These funds support projects that enhance resilience to climate change, promote sustainable urban development, and improve infrastructure connectivity. An estimated 16.4 million people will be reached by the Cohesion investments into Clean water and improved wastewater infrastructure (European Commission, 2023b).
- **European Agricultural Fund for Rural Development** (EAFRD) provides funding for rural development programmes, co-financed by national budgets. These programmes promote resource efficiency, support the shift towards a low-carbon and climate-resilient economy, and enhance the sustainability of agriculture, food, and forestry sectors. A significant portion of the EAFRD funding is dedicated to environmental and climate-related measures (World Water Council, 2024).
- **Horizon Europe** is the EU's key funding programme for research and innovation, tackling climate change, achieving the UN's Sustainable Development Goals, and boosting the EU's competitiveness and growth. The programme supports cutting-edge research and innovation across various sectors, including climate resilience and adaptation. In 2021, the EU launched several science-policy innovation Missions, including the Mission on Adaptation to Climate Change and Mission Restore our Ocean and Waters (European Commission, 2024a, 2024b). The Mission Adaptation focuses on supporting regions and communities to build resilience against the impacts of climate change through innovative solutions and sustainable practices. Concurrently, the Mission Ocean emphasizes the restoration of aquatic ecosystems, pollution reduction, and sustainable management of marine resources. Research into water security is a critical component of these missions. Efforts are directed towards improving water quality, enhancing water use efficiency, and developing technologies for water purification and conservation.
- **European Investment Bank** (EIB) is a major investor in climate action and environmental sustainability globally. The EIB supports projects that increase climate resilience, including investments in cities, infrastructure networks, coastal areas, and ecosystems vulnerable to climate change. Through initiatives like the Climate Adaptation Investment Advisory Platform (ADAPT) and Natural Capital Financing Facility (NCFF), the EIB provides technical and financial expertise to accelerate the financing of climate adaptation and biodiversity projects (European Investment Bank, 2023a, 2023b). A variety of debt and equity instruments are exploited to finance water security. These instruments provide the necessary capital for projects, often blending different types of financing to meet specific project needs and risk profiles. Equity investments are particularly suited for start-up or high-growth phase companies, while debt instruments are often employed for more established projects requiring predictable repayments (European Investment Bank, 2023a; C. W. Gibson, 2022):

- **Debt instruments**, such as municipal bonds and bank loans, are commonly used by public-private partnerships to finance large-scale water infrastructure projects. These instruments allow for the upfront capital needed for construction and maintenance, while the debt is repaid over time through various revenue streams, such as water tariffs and taxes. Concessional loans are offered at reduced interest rates to projects with significant biodiversity or climate impact potential. Guarantees involve third-party agreements to cover a borrower's financial obligations, reducing risk exposure for lenders and enabling access to loans.
- **Equity financing**, including private equity and public equity markets, provides an alternative funding mechanism by selling ownership stakes in water projects or companies. This form of financing can be particularly effective in reducing the debt burden and sharing risks associated with water infrastructure investments. Equity instruments include common stock, which grants shareholders co-ownership and voting rights, and preferred stock, which has priority claims on assets and earnings.

International adaptation finance refers to funding aimed at helping countries, especially developing ones, manage the impacts of climate change. This includes investments in infrastructure, technology, and practices to enhance resilience and reduce vulnerability to climate-related hazards, like floods, droughts, and sea-level rise. Under Paris Agreement, developed countries committed to mobilize USD 100 billion per year by 2020 to support climate action in developing countries, striking a balance between mitigation and adaptation finance. This commitment extends to 2025, with a plan to set a new, higher goal before then.

There is a significant gap between available adaptation finance and actual needs, estimated to be 10–18 times the available public funding. Bridging this gap requires enhanced international cooperation, increased public and private sector investments, and innovative financing mechanisms. The most recent Adaptation Gap Report (United Nations Environment Programme, 2023) estimates adaptation costs for developing countries at USD 215–387 billion per year this decade, which is a significant increase from previous editions and a level expected to be reached only by 2030. Modelling suggests costs could be USD 215 billion annually, rising towards 2050, while analysis of national plans estimates USD 387 billion needed annually for 2021-2030. In 2021, international public adaptation finance to developing countries was USD 21 billion, a 15% decrease from 2020. Only 66% of bilateral finance commitments were disbursed compared to 98% for all development finance, highlighting barriers to adaptation (United Nations Environment Programme, 2023).

Climate Policy Initiative (CPI) annually publishes an overview of public and private climate finance flows for both mitigation and adaptation (Buchner et al., 2023). It analyses the status, trends, and future needs. In 2021/2022, adaptation finance reached an all-time high of USD 63 billion, a 29% increase from 2019/2020. Despite this growth, the funding still falls significantly short of the estimated USD 212 billion needed annually by 2030 for developing countries alone. Most of the adaptation finance is provided by public actors, with development finance institutions (DFIs) contributing 86% of the total. National DFIs were the largest source, followed by multilateral DFIs. Adaptation funding primarily targets sectors, e.g., water and wastewater, which received almost half of the tracked finance. This focus highlights the importance of infrastructure to build resilience against climate-related risks, such as floods and droughts. However, other critical sectors, such as agriculture, forestry, and land use (AFOLU), received much less funding, underscoring the need for a more balanced allocation of resources (Buchner et al., 2023).

Climate finance for adaptation to climate change involves various funding sources and instruments aimed at enhancing resilience and reducing vulnerabilities. Key funding instruments include grants, concessional loans, and bonds, such as green bonds and resilience bonds, which provide capital for climate-resilient infrastructure and projects. Additionally, public-private partnerships and insurance mechanisms, like catastrophe bonds, offer financial protection against climate-related losses. Major sources include international funds, such as the Green Climate Fund (GCF), the Adaptation Fund, and the Global Environment Facility (GEF). Bilateral and multilateral development banks, including the World Bank and regional banks, like the Asian Development Bank, also play significant roles.

- **Green Climate Fund** (GCF)[11] is a financial mechanism established to support developing countries in their efforts to mitigate and adapt to climate change. It provides funding for projects and programs that aim to reduce greenhouse gas emissions and enhance climate resilience.
- **Global Environment Facility** (GEF)[12] is a multilateral environmental fund that provides grants and blended finance for projects, among others, related to transition to low-emission and climate-resilient development pathways. It was established in October 1991 and serves as a financial mechanism for other UN Conventions, in addition to UNFCCC, such as the Convention on Biological Diversity (CBD) and United Nations Convention to Combat Desertification (UNCCD).
- **Special Climate Change Fund** (SCCF)[13] was established under the UNFCCC in 2001 to finance projects related to climate change adaptation and mitigation, technology transfer, and capacity building in developing countries. It is managed by GEF and addresses specific needs not covered by the GEF.
- **Least Developed Countries Fund** (LDCF)[14] is dedicated to addressing the special needs of the Least Developed Countries (LDCs) under the UNFCCC. It supports the preparation and implementation of National Adaptation Programs of Action (NAPAs) to help LDCs adapt to climate change impacts. Together with SCCF, it is managed by GEF.
- **Adaptation Fund** (AF)[15] established in 2001, finances concrete adaptation projects and programs in developing countries vulnerable to climate change. Initially funded by a 2% share of certified emission reductions (CERs) from the Clean Development Mechanism (CDM) of the Kyoto Protocol, and other sources, the Fund now serves the Paris Agreement as of January 1, 2019.

[11] **Green Climate Fund** (GCF): https://www.greenclimate.fund

[12] **Global Environment Facility** (GEF): https://www.thegef.org

[13] **Special Climate Change Fund** (SCCF): https://unfccc.int/topics/climate-finance/resources/reports-of-the-special-climate-change-fund

[14] **Least Developed Countries Fund** (LDCF): https://www.thegef.org/what-we-do/topics/least-developed-countries-fund-ldcf

[15] **Adaptation Fund** (AF): https://www.adaptation-fund.org/

- **Loss and Damage Fund**[16] is a new mechanism under the UNFCCC aimed at addressing the loss and damage associated with the impacts of climate change, particularly in vulnerable developing countries. It is intended to provide financial support to help these countries respond to both economic and non-economic losses and damages resulting from the adverse effects of climate change, including extreme weather events and slow onset events.

[16] **Loss and Damage Fund**: https://unfccc.int/loss-and-damage-fund-joint-interim-secretariat

5. Conclusions

The UN High-Level Panel on Water emphasized that what cannot be measured, cannot be managed. Accurate data on water quantity, quality, distribution, access, use, and the multiple risks associated with inadequate access to water and water services is essential for effective decision-making. **But in a world of ever-increasing supply chain, trade, and financial interdependencies, understanding the value of water means unravelling the wider systemic impacts of water scarcity**, not just the effects on immediate uses and users. Impact chains (Zebisch et al., 2021) trace the cascading effects of water scarcity through different sectors, and risk storylines (Van Den Hurk et al., 2023) provide context and narrative to these impacts. The European Drought Risk Atlas (European Commission. Joint Research Centre., 2023) uses impact chains to map the sequence of events contributing to water scarcity impacts, helping to identify key risk drivers and understand the systemic nature of water-related risks. This visual representation helps to identify critical intervention points. Building on this, the European Climate Risk Assessment employed storylines to trace dynamic interdependencies and feedback loops among risk drivers, and their propagation through risk pathways. Storytelling of climate risks considers how climate hazards may compound, cascade, or spill over across geographic or functional boundaries, and how the interplay of risk drivers unfolds in specific situations (European Environment Agency., 2024). Water scarcity, pollution, and freshwater supply shortage can cause significant financial losses and operational disruptions in water-intensive industries, like agriculture, energy, and manufacturing, threatening investments, affecting market value and credit ratings of businesses, insurance premiums required for financial protection, and asset valuations. Recognizing water risks as financially material underscores the need for comprehensive risk assessment and management strategies (Davies, & Martini, 2023). Therefore, investors are increasingly considering water risks in their assessments, influencing investment decisions and company valuations.

Reconciling the principles of economic efficiency, environmental protection, and social equity in water management is challenging and often involves complex trade-offs. However, it is not impossible (Yates & Harris, 2018), and the Dublin economic principle and the right to water approach are only apparently irreconcilable. A neoliberal approach to water management can effectively allocate resources among multiple and conflicting uses, but it must operate within a framework where societal development goals and priority values—social, environmental, and cultural—are well spelled out and attended to. Both the lack of effective regulation and oversight by governments and the shortcomings of market mechanisms in internalizing environmental and social costs have contributed to the emerging patterns of water and biodiversity crises. As Stieglitz put it, the invisible hand of the markets - the idea that markets lead to efficiency – "is invisible because it is not there" (Stiglitz, 2002). Many agree that market failures cannot be solved by the same means that caused them. Policies that recognize the need for water to preserve the integrity of ecosystems and social dignity can balance efficiency with equity and sustainability.

The water cycle – within the envelope of a stable climate – is a public good and a condition to which societies have adapted. Locally and regionally, water regulating services of glaciers and snowpacks, forests, and wetlands have contributed to water provisions during less rainy seasons, which would otherwise fail to meet human demand for water. Climate change threatens these established equilibria and forces communities to adapt, but it also provides momentum to cut through the gridlock of pre-existing and deeply ingrained inefficiencies and inequalities in water allocation and use. It drives the need for innovative solutions that address both environmental and social dimensions, promoting resilient and equitable water management practices and fostering cross-sector collaboration for sustainable outcomes.

There is no one-size-fits-all solution for addressing water-related challenges; the suitability of various policy mixes depends on path dependencies and specific economic, regulatory, cultural, and other contextual factors in each of the project pilot studies (Pahl-Wostl et al., 2010). Rather, a combination of mutually compatible instruments is needed, each targeting a specific goal. Effective water management strategies must be tailored to the unique circumstances and histories of each location, incorporating a blend of approaches that address the specific needs and constraints of the region: *Financial recovery* of costs is crucial for sustainable water service provision, addressing challenges, such as establishing infrastructure in underserved areas, upgrading aging systems, accommodating growing urban populations, combating water pollution, and adapting to climate-induced changes in water availability. *Pricing instruments* internalize environmental externalities by combating pollution and encouraging less harmful practices. *Tradable mechanisms* prioritize phasing out overexploitation and pollution, enabling those who can make low-cost substitutions to act first, thereby buying time for others to find solutions without major economic shocks. *Risk financing instruments* are crucial for managing residual risks and addressing low-probability, high-impact events, providing necessary resources for recovery and rebuilding, and ensuring resilience against unexpected environmental disruptions.

Designing a policy mix must begin with societal consensus on high-level water allocation priorities, delegating specifics to appropriate instruments. This consensus aligns policy goals and supports tailored approaches for regional needs. Effective governance and innovation-enabling conditions are essential for these instruments to function well. Restoring ecosystem services and implementing nature-based solutions can replace lost services and build water security, driving innovative, proactive measures that address environmental and social dimensions, promote resilient and equitable water management, and foster cross-sector collaboration for sustainable outcomes. Exploiting the ever-increasing spatial and temporal resolutions of climate predictions and projections, along with a better understanding of current and past climates, opens the door to a range of climate and resilience services. These services offer actionable risk assessments designed to improve business operations and preparedness, including for the public. The private sector's involvement is crucial for fostering change and contributing to sustainable water management and manageable water-related risks. Water utilities and insurers can encourage water conservation and more efficient water use, even if it may seem in contradiction with their traditional business models or original purposes. In fact, their long-term viability depends on their success in this role. Without proactive measures, insurance may become unaffordable or the risk unquantifiable, while issues with water availability and quality could render the provision of safe drinking water unfeasible.

Throughout this report we have trace the notion of water as an economic good, but also a cultural, environmental and social one, rather than a mere economic commodity. This is consistent with the water evaluation principles of the Agenda for Water Action (United Nations, 2018) of the UN High-

Level Panel on Water: Recognize water's diverse values, reconcile differences through inclusive processes, protect all water sources, educate the public, and invest in infrastructure and innovation to ensure sustainable water management. These principles not only represent general guidelines but also form an agenda for designing transformational water adaptation.

6. References

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