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Deliverable 5.1: GOVERNANCE, POLICY AND FINANCIAL MECHANISMS FOR TAP ADOPTION AND UPSCALING

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Executive summary

This work conducts a desk literature survey, complemented with deep dive case studies involving experts and key stakeholders from 8 international basins representative of different socioeconomic and biophysical contexts, to document the barriers (and opportunities) for Transformational Adaptation Policies (TAP) adoption. We apply inductive methods to identify common candidate theories across case studies that explain the emergence and persistence of barriers for TAP adoption, while identifying enablers that may help overcome these barriers. We assess the ways in which key players in the water policy arena (including water users, regional communities, decision-makers, regulators, water works suppliers, donors) may contribute to create barriers to TAP adoption; and how this network of players and their interactions condition the relevance and strength of these barriers. Leveraging on this information, we propose a series of common principles and guidelines centered around regulations, institutions and policy, incentives, information, and debiasing, to guide the adoption of TAP that contribute to sustainable and equitable economic development and welfare growth, including under conditions of uncertainty.

Contents

1. Introduction

Water scarcity, exacerbated by climate change, is an "existential threat" to societies and nature in many parts of the world (UNDRR, 2021). Approximately 30% of freshwater ecosystems and 87% of wetlands have disappeared globally due to water overuse (UN, 2022), while water-stressed regions have seen their annual GDP growth rates (as compared to projections without water stress) decline by as much as 2.5% due to shortages—a figure that could more than double by 2050 (2030 Water Resources Group, 2019; UN, 2020). Avoiding this "misery in slow motion" (World Bank, 2017a) calls for fundamental changes in water management through Transformational Adaptation Policies (TAP), i.e., systemic (much larger scale) and/or paradigm shifts (truly new to a particular location) that integrate the adaptation of ecosystems and economic sectors to climate change with the coordinated development and management of water, land and related resources.

The adoption of TAP involves a departure from conventional supply-side policy making, which for centuries has relied on traditional grey infrastructure (e.g., canals, dams) to expand available resources and smooth out variability in supplies (Hassan, 2010). However, most water-stressed economies are facing "sharply rising incremental costs" of new supplies, which, coupled with increasing hydrologic variability due to climate change, undermines the ability of grey infrastructure to further expand available resources at affordable costs (Loch et al., 2020). Instead, water-stressed economies call for TAP that rely on demand-side (1) economic instruments and (2) water allocation systems (OECD, 2015; World Bank, 2017a); while exploiting the synergies between these two and (3) digital technologies (e.g., satellite data), (4) non-conventional water sources, and (5) nature-based solutions (OECD, 2021; UN, 2020; UNEP, 2021).

A growing body of research has undertaken the challenge of informing TAP design and implementation by providing assessments of taxonomies (Bhaduri et al., 2021), regulatory frameworks (Rouillard et al., 2022), performance (Rey et al., 2019), participatory aspects (Figureau et al., 2015; Ostrom, 2007), economic incentives (Gómez et al., 2017), institutional dynamics (Loch et al., 2018a; Rouillard and Rinaudo, 2020), politics and power relationships (Tanouti and Molle, 2013), and (mis)information (Pérez-Blanco et al., 2021), *inter alia*. All these works identify limited progress in TAP uptake, persistent barriers and gaps, unexploited opportunities, and lack of on-the-ground policy guidance. In particular, a common theme that emerges is that delays to implementation of TAP often result in reactionary responses to water scarcity – both by regulators and users – that lead to inefficient, inequitable, and unsustainable use of scarce water resources. Moreover, all these works indicate a lack of inductive research where general principles and guidelines for TAP design and implementation can be derived from the growing body of studies and observations. Accordingly, authors indicate that a key area for research is the "comparative analysis" of different TAP "within varying socioeconomic and biophysical contexts" to identify underlying common barriers and principles/guidelines that determine success (Loch et al., 2018a).

This work conducts a desk literature survey, complemented with deep dive case studies involving experts and key stakeholders from 8 international basins representative of different socioeconomic and biophysical contexts (see Figure 1), to document the barriers (and opportunities) for TAP adoption. We apply inductive methods to identify common candidate theories across case studies that explain the emergence and persistence of barriers for TAP adoption, while identifying enablers that may help overcome these barriers. Leveraging on this information, we develop generalizable principles and guidelines for transferring TAP from lab to day-to-day policy practice.

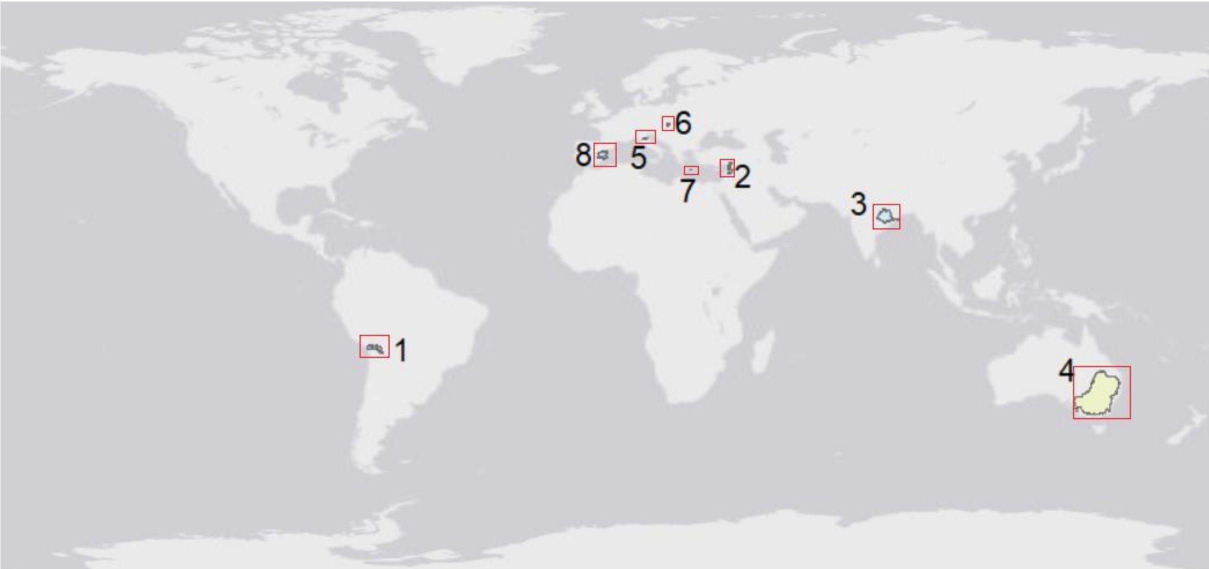

Figure 1: Deep dive case studies: Caplina-Mauri-Desaguadero Basin between Peru, Bolivia and Chile; Orontes Basin between Lebanon, Syria and Turkey; Mahanadi River Basin in the Indian states of Chhattisgarh and Odisha; Murray-Darling Basin in Australia; Reno River Basin in Italy; Nitra River Basin in Slovakia; Typmaki River Basin in Greece; and Júcar River Basin in Spain

2. Methods

To identify candidate theories that explain the emergence and persistence of barriers for TAP adoption and/or success, we first surveyed the literature on TAP, including case studies, demonstration projects, published reports and gray literature (Peters and Nagel, 2020). Our sample of studies was developed by the authors and selected experts from the 8 international basins , who identified relevant studies that assessed barriers to TAP adoption.

Our initial set of candidate theories was further refined by a case study approach that tested the candidate theories in 8 international basins (see Figure 1) leveraging on deep dive case studies. We followed Loch et al. (2020b) and Pérez-Blanco et al. (2021) and adopted a cross-case analysis that combines the method of agreement (identification of common barriers across case studies) and method of difference (identification of the absence of barriers across case studies) to identify generalizable and widely applicable candidate theories. The deep dive case studies were implemented in two stages:

- In a *first stage*, we asked local experts to fill in a background document for each of the 8 international basins that included questions on regulations, institutions, political ecology and power relationships, stakeholders (including key behavioral drivers), and information and data gaps. This helped us to i) validate the relevance of the candidate theories identified in the literature, ii) identify new potentially relevant candidate theories that had not been accounted for in the literature review, iii) map stakeholder networks and motivations and their technological, policy, regulatory, and institutional contexts, and iv) assign each candidate theory a preliminary degree of relevance based on the assessment by local experts and authors (namely: high relevance; medium relevance; low relevance; no relevance). Annex 1 presents the background document elaborated with inputs from local experts, which served as a basis for this analysis, as well as the name of the experts and their affiliations. The background document was elaborated in the context and with support from the Horizon Europe TRANSCEND Project.

- In a *second stage*, we asked local stakeholders to assess the resultant candidate theories during a series of science-policy workshops organized in the 8 international basins under the TRANSCEND Project. This assessment allowed us to i) discard those candidate theories that were deemed not relevant by both experts and stakeholders; ii) assign a degree of relevance to the remaining candidate theories based on both the perceptions of experts and stakeholders within and across the international basins, iii) underpin and deepen our understanding of stakeholder networks and their contexts, including the identification of key players and their interconnections and how they affect the emergence and persistence of barriers to TAP adoption; and iv) collectively identify preliminary principles/guidelines that may determine success in TAP adoption. Due to the overlapping timing of this deliverable and the stakeholder workshops, this part of the assessment could be done in 2 of the 8 international basins (Nitra basin and Reno basin in Slovakia and Italy, respectively).

Building on our cross-scale analysis we assessed the ways in which key actors in the water policy arena (including water users, regional communities, decision-makers, regulators, water works suppliers, donors) may contribute to create barriers to TAP adoption; and how this network of actors and their interactions condition the relevance and strength of these barriers (Khan and VanWynsberghe, 2008). Finally, once candidate theories were identified and validated on an individual basis, and the role and relevance of players identified, we grouped barriers into 'clusters of theories' that share common theoretical foundations and/or influence each other (e.g., through player responses), which we call *main hypothesized drivers*. This approach enabled us to provide key resources for understanding the emergence of barriers, and to propose recommendations towards adopting successful TAP.

The following section presents the key findings obtained through the application of our cross-scale analysis.

3. Barriers to TAP adoption

The literature on TAP highlights a diversity of reasons and frameworks for why barriers to TAP adoption emerge and/or persist. Several theories coexist which are articulated around three explanatory levels (stakeholders, organizations and society) (Peters and Nagel, 2020):

- *Stakeholders* are groups of individuals who are directly affected or have an interest in a policy. Stakeholders can be private or public, the latter group including decision-makers, of particular relevance for the adoption of policies. Stakeholders often rely on individuals (experts) to position themselves as a group. That expertise is not entirely objective since individuals have beliefs and biases, which can lead to failure including persistent failure (Begg et al., 1992; Béland and Cox, 2011; Johnson and Seifert, 1994; Nickerson, 1998; Pande and Sivapalan, 2017; Shermer, 2011; Simon, 1955; Tversky and Kahneman, 1974). Obviously, the identification of experts by stakeholders is not necessarily unintentional and may reflect the interest of the group to support its political preferences. Stakeholders can and often will create demand for ideas that reflect their interests (Lewandowsky et al., 2012; Tanouti and Molle, 2013), some of which may have been disproven by scientific evidence (Pérez-Blanco et al., 2021).

- *Organizations* are institutionalized groups of stakeholders, which often are also committed to specific objectives and ideas. Organizations develop routines and standards to address issues relevant to their policy domain, which are often justified on their objectives and ideas. Organizations are composed of individuals who may rationalize organizational self-interests (Rawls, 1999), adopt their beliefs and further spread their policy ideas, e.g., in political confrontations with other organizations that hold different views (including other political organizations), and with decision-makers over policy design and budgets (Laffont and Tirole, 1991; Lopipero et al., 2007; Peters and Nagel, 2020; Wiarda, 1996). Through their activity, organizations can lead to policy choices upon which future choices are dependent, resulting in institutional trajectories that are difficult to change (Garrick, 2015).
- *Society* is often seen as a passive actor at the receiving end of new policies, but it plays a critical role in their persistence (Lewandowsky et al., 2012). Decision-makers often adopt policies seeking to obtain political legitimacy (Rawls, 1999), and these policies are likely to be progressively abandoned if the public is not receptive towards them (Cook et al., 2018). Interested stakeholders and organizations may respond to unfavorable changes in societal perception through strategies that promote their target policies, but without societal support these policies will eventually have little impact on actual policy (Lewandowsky et al., 2013). This has led many to stress the role of an informed society towards advancing and even catalyzing the adoption of TAP (Cook et al., 2018).

Building on the candidate theories via case studies we assess how/why different players (water users, regional communities, decision-makers, regulators, water works suppliers, donors) at each explanatory level (stakeholders, organizations and society) condition TAP adoption. By identifying and validating the individual candidate theories and understanding the role and relevance of the players involved, we can interconnect relevant candidate theories into main hypothesized drivers or “clusters of theories” that present major commonalities and/or influence each other (e.g., through player responses). This approach enables us to provide key resources for understanding, and eventually formulating guidelines for addressing, the barriers to TAP adoption. Below we discuss the relevant candidate theories identified through our cross-scale analysis, grouped in 7 main hypothesized drivers explaining the emergence and persistence of TAP barriers (namely: regulations, beliefs, path-dependence/lock-in, incentives, politics and power, information and data gaps, and limited alternatives).

Table 1: Relevant candidate theories

Source (reference)	**Level(s) of explanation**	**Main hypothesized driver**	**Player(s)**	**Description**
Constraining regulatory principles (Rey et al., 2019)	Organizations	Regulations	Decision-makers, regulators	Rigid regulatory principles may preclude the implementation of reallocation instruments that enable "systems of compensations and collections such that everyone would be better off than before" (Hotelling, 1938). For example, the regulations of several countries (including i.a. those of the EU—see OJ, 2000) follow the polluter-pays principle, which states that polluters (including those overdrafting from water sources) should face the costs of the measures adopted to prevent, control and remedy pollution. *De iure* this approach limits the adoption of (re)allocation instruments such as water markets or payments for ecosystem services (including buyback) that are based on the beneficiary-pays principle, which can offer a superior performance in several instances (e.g., because the beneficiaries are a much larger group and collecting the necessary resources from them generates lower marginal utility losses than charging the polluter, as happens with several wastewater treatment systems) (Rey et al., 2019).
Third party effects (Pigou, 1920)	Organizations	Regulations	Decision-makers, regulators	Pigou (1920) noted that resource (re)allocations could generate costs to third parties not directly involved in the (re)allocation—i.e., an externality. In the case of water, externalities are particularly severe due to an insufficient and/or incomplete regulation of return flows—i.e., the (significant) fraction of water withdrawals that is not consumed by users and goes back to the water system, thus being potentially reusable by third parties downstream (Grafton et al., 2018). Despite significant scientific evidence on the relevance of return flows for third party users, return flows are insufficiently protected: albeit *de iure* some clauses call for hydrological integrity and protection of third parties (BOE, 2001), these are rarely enforced. An objective of reallocations is to enhance economic efficiency and thus typically go from low to high value-added users, who happen to be more technically efficient also. This increases the consumed fraction of water and the value of the water traded, and reduces return flows, which benefits those directly

Source (reference)	Level(s) of explanation	Main hypothesized driver	Player(s)	Description
				involved in the (re)allocation but reduces water availability to third parties downstream—who will oppose the reallocation as a result. Accounting and internalizing externalities in complex socio-ecological systems is far from simple and requires complex valuation and modeling exercises to inform sensible policy design.
Bundled water allocation regimes (Young, 2014)	Organizations	Regulations	Decision-makers, regulators	Water allocation systems are typically 'bundled', which creates issues in the definition and registration of water rights and their supply reliability (Bhaduri et al., 2021). In some cases, water is bundled to land, which makes water (re)allocations contingent on land (re)allocations, thus considerably reducing the liquidity of the resource (e.g., Orontes Basin). Bundling water to land also prevents volumetric water charges, a key economic instrument towards reducing water use in overallocated basins. In most cases, the amount of harvestable resources and the share of harvestable resources effectively allocated are also bundled, which creates difficulties in defining water restrictions levels of security in supply during droughts. In an unbundled scheme, environmental sustainability is achieved first by defining the total volume of harvestable resources based on an objective indicator; and next water is distributed to economic uses through a predetermined allocation mechanism (% over harvestable resources allocated to each user).
Use it or lose it clauses (Hérivaux et al., 2020)	Organizations	Regulations	Decision-makers, regulators	In most basins users cannot carry over their water right over time, and in some extreme cases, users may lose their water right if water is not effectively used during a year or several years. This prevents the implementation of intertemporal reallocation instruments such as water banks, which can increase efficiency. For example, Managed Aquifer Recharge has the potential to generate significant added value by reallocating currently available resources over time to mitigate (nonlinear) losses during drought, which typically exceed the expected benefits of water today and can create nontrivial environmental side benefits (Mastrocicco et al., 2016). Yet, these benefits cannot be realized in several basins because the right to use that water is typically lost after a year (e.g., after the irrigation campaign is finished) (Hérivaux et al., 2020).

Source (reference)	Level(s) of explanation	Main hypothesized driver	Player(s)	Description
Regulatory and institutional uncertainty (Agudo-Domínguez et al., 2022; Gómez-Limón, 2020)	Organizations	Regulations	Decision-makers, regulators	The substandard and discretionary water allocation systems currently in use prevent some reallocation mechanisms, including risk-mitigation mechanisms, to emerge. This is the case of drought insurance for irrigated agriculture: since water allocation reductions during droughts are based on a discretionary decision by the relevant water authority rather than on an objective indicator, insurers fear sharp reductions in water availability can lead to high, and potentially nonlinear economic impacts and catastrophic losses for insurers. As a result drought insurance for irrigated agriculture, albeit explored by scientists and insurance companies, is not available in the market.
Bounded rationality (Simon, 1955)	Stakeholders (individuals)	Beliefs	All	Rationality is limited by: the tractability of the problem; cognitive limitations; and time constraints. Rather than being fully rational, individuals exploit known regularities in their environment (e.g. through heuristics) to make choices.
Cognitive biases (Tversky and Kahneman, 1974)	Stakeholders (individuals)	Beliefs	All	Systematic pattern of deviation from norm or rationality in judgment, typically emerging from the use of heuristic methods, where an individual's perception of reality, instead of the factual input, guides decisions.
Disciplinary bias (Pande and Sivapalan, 2017)	Stakeholders (individuals)	Beliefs	Decision-makers, donors	Under disciplinary bias, the discipline is used to answer a wide array of problems for which it may be unsuited. For example, water policy assessments are often based on hydrologic models where human agency is ignored and treated as an exogenous factor, thus ignoring the relevant two-way feedbacks between human and water systems.
Causal belief (Béland and Cox, 2011)	Stakeholders (individuals)	Beliefs	Decision-makers, donors	Ideas are "causal beliefs", i.e. they (implicitly or explicitly) involve hypotheses of causality, which are often constructed through heuristics. Decision-makers usually make assumptions about causation in policy design (e.g. higher technical efficiency saves water—which ignores return flows and nonlinear behavioral responses by users).
Dissociation of processes in belief (Begg et al., 1992)	Stakeholders (individuals)	Beliefs	All	Repeated exposure to a belief increases its acceptance as true. Studies have shown that the stronger predictor of belief is simple repetition. Repetition can create a perception of social consensus even if this consensus does not exist.

Source (reference)	Level(s) of explanation	Main hypothesized driver	Player(s)	Description
'Patternicity' and 'agenticity' (Shermer, 2011)	Stakeholders (individuals)	Beliefs	All	The brain searches for meaning in the information that receives, which leads to the creation of beliefs (brain as "belief engine"). Once created, the brain looks for evidence that rationalizes the belief with explanations, which reinforces it, while proofing itself against information that contradicts the belief. For example, stakeholders who believe that conventional supply-side policies expand water availability will typically look for evidence over the many centuries where this policy has worked, and deny more recent evidence showing this policy is exhausted in mature water economies.
Groupthink (Janis, 1971)	Organizations, stakeholders	Beliefs	Decision-makers, donors	Individuals or small groups usually accept the beliefs within larger groups. This mechanism makes it possible to develop shared internal beliefs that can be used to justify actions and maintain cohesion.
Confirmation bias (Nickerson, 1998)	Stakeholders (individuals)	Beliefs	All	As opposed to an evenhanded evaluation of evidence to find unbiased conclusions, and then building a case to support that conclusion, confirmation bias "selectively gathers, or gives undue weight to, evidence that supports one's position while neglecting to gather, or discounting, evidence that would tell against it".
Continued influence effect (Johnson and Seifert, 1994)	Stakeholders (individuals)	Beliefs	All	Beliefs and information encoded in memory can influence judgments, even after being discredited by more recent information.
Path dependence and institutional lock-in (Garrick, 2015)	Organizations	Path dependence/lock-in	Decision-makers, donors	Over time, public incentives to specific policies (e.g., conventional water works) lock-in these policies through a process of technological and institutional co-evolution driven by path-dependent increasing returns to scale at different levels (scale economies, learning economies, adaptive expectations and network economies). A clear and alarming signal ("annealing force") may be necessary before major policy reform is achieved, as happened with the adoption of buyback programs during the Australian Millennium Drought. Moreover, unless thorough institutional reform and new incentives are implemented to drive collective action, momentum may be insufficient as shown recently with the reduction of Australia's buyback in favor of subsidies to modern irrigation technologies.

Source (reference)	**Level(s) of explanation**	**Main hypothesized driver**	**Player(s)**	**Description**
Institutional transaction costs (Garrick, 2015)	Organizations	Path dependence/lock-in	Decision-makers, donors	Escaping institutional lock-in will involve non-trivial transaction costs, namely the resources used to change institutions and organizations towards the adoption of alternative policy instruments that effectively address the problem at hand.
Informal institutions (Hernández-Mora and De Stefano, 2013)	Organizations	Path dependence/lock-in	Decision-makers, users	When formal institutions fail to deploy flexible water reallocation arrangements, informal institutions may arise. While informal institutions can offer flexibility and result in profits for those directly involved in reallocations, they typically worsen the negative issues that prevented the development of formal institutions in the first place (such as externalities). This is for example the case of informal water markets in both developing countries such as China, India and Pakistan (Hadjigeorgalis, 2009) or developed countries such as Spain (Hernández-Mora and De Stefano, 2013), which do not require a formal change of ownership and thus remove much of the bureaucratic costs of trading, but do not account for reductions in return flows that negatively affect third party users downstream. This may increase opposition to formal reallocation policies, since downstream farmers negatively affected by upstream illegal trading may oppose rather than facilitate a formal water market, even if this accounts for return flows, due to their negative perception of this policy.
Limited enforceability (Adam Loch et al., 2020a)	Organizations	Path dependence/lock-in	Decision-makers	The development of institutions capable of legally prosecuting and convicting illegal water users involves nontrivial transaction costs. Accordingly, in several regions worldwide the rates of prosecution and conviction are often low or very low. Moreover, even when sanctions are applied, these may be insufficient either because the fine is below the expected benefits, or because the time-lag between the illegal use and the sanction reduces the net present cost of water theft. This is illustrated by the case of illegal water use in the agricultural areas surrounding the Doñana Park in Spain: albeit the NGO WWF has been systematically documenting illegal abstractions, out of 2,000 reported cases of water theft only 28 guilty verdicts have been issued (2.2% ratio), and sanctions can take 5+ years to be effectively implemented since the date of the illegal abstraction. Moreover,

Source (reference)	Level(s) of explanation	Main hypothesized driver	Player(s)	Description
				since several of these users operate in publicly owned land, the sanction is often paid by the administration rather than offenders.
Utility maximization (Pérez-Blanco et al., 2020)	Stakeholders (individuals)	Incentives	All, particularly users	Utility and profit maximization state that economic agents aim to optimize the satisfaction ("utility") they can obtain from their choices, within a given domain. Utility maximization is constrained by bounded rationality and information gaps, which explain lack of optimality in real life choices.
Liquidity (UNEP, 2021)	Stakeholders (individuals)	Incentives	Users	Some services, particularly environmental services, can be difficult to monetize, which may reduce their perceived value and difficult the attribution of costs and benefits among potential users. This is the case for example of Nature-based Solutions that provide nontrivial regulatory services to multiple uses. For example, retention ponds can mitigate the costs of floods by reallocating water across space and thus benefit individuals potentially affected by the flood, insurers, reinsurers and the general public. There is growing scientific consensus that these Nature-based Solutions can be cost-effective as compared to alternative engineering approaches, and on top of that, typically offer significant ecological and socioeconomic benefits. However, they face significant challenges related to culture, acceptance, and financial aspects, including low liquidity and challenging monetization that leads to incorrect perception of their value, often driven by lack of business innovation.
Free riding (Baumol, 1952)	Stakeholders (individuals)	Incentives	Users	Free riding is observed where some agents do not to contribute their corresponding share to the costs of a shared infrastructure that delivers a valuable service to them. Their failure to contribute may make the infrastructure and service economically infeasible to produce.
Private transaction costs (Loch et al., 2018b)	Stakeholders (individuals)	Incentives	Users	Private transaction costs are the expenses incurred when conducting an economic transaction, and include search and information, bargaining and enforcement. While they do not directly preclude the deployment of TAP, they can limit their penetration rate by reducing the expected returns of the reallocation.
Second-round effects (Parrado et al., 2020)	Society	Incentives	Regional communities	Users' responses to policies have an impact beyond the economic sector where these responses developed, and spread throughout the economy through forward and backward linkages among economic sectors. For example, higher charges will

Source (reference)	Level(s) of explanation	Main hypothesized driver	Player(s)	Description
				conserve water and reduce farmers income; but also constrain the supply of agricultural commodities, increase their prices, and reduce employment and income generation in the food industry. Moreover, beyond the redistribution of income and water, water reallocations can generate nontrivial asymmetric impacts on strategic services such as food security, food supply independence, habitat and landscape protection, soil conservation, carbon dioxide sequestration, and biodiversity conservation (TEEB, 2015).
Diffusion of innovation (Balmann, 1997)	Stakeholders	Incentives	Users	Research on the diffusion of innovations and technologies seeks to explain how, why, and at what rate new ideas and technology spread. Attempts to model this theory in the water resources domain have been conducted in the field of Multi-Agent Cellular Automata (MACA). MACA combine utility theory and the explicit representation of spatial and environmental interactions to model replication (e.g., through technology adoption), for which constraints are introduced in form of network-threshold values that reflect the cumulative effects of individual experience and observation of peers' experiences.
Political legitimacy (Rawls, 1999)	Organizations	Incentives	Decision-makers	Political legitimacy arises from the attitudes and beliefs of citizens as well as the social and political context in which they have saliency. Interventions which are perceived capable of limiting or reducing negative outcomes (e.g., profit losses, environmental deterioration) can greatly appeal to citizens and strengthen political legitimacy. Accordingly, it is only natural for those in authority to align policy choices and investments (financial, natural, human, political and built) with widespread beliefs and attitudes that strengthen their political legitimacy.
Budgetary constraints (UNEP, 2021)	Stakeholders (individuals), society	Incentives	Decision-makers	The recurrent financial crises and policy interventions (including bailouts) have put public budgets under stress, thus increasing the opportunity cost of implementing costly TAP such as nature-based solutions or unconventional resources (desalination, wastewater treatment). Budgetary constraints can also spur the use of implicit subsidization as a means to alleviate water management issues, often through loose environmental constraints or low cost recovery levels. This compensates the lack of financial capital with natural capital and can lead to environmental deterioration.

Source (reference)	Level(s) of explanation	Main hypothesized driver	Player(s)	Description
Rent-seeking (Tullock, 1967)	Stakeholders	Politics and power	Users, water works suppliers	Rent-seeking exists when an individual increases his share of wealth without creating new wealth. It reduces economic efficiency, wealth-creation and public revenue, and increases inequality. Profitable rent-seeking requires that the cost of rent-seeking is below the value of the new acquired wealth, which is typically attempted by co-opting decision-makers. Notably, utility-maximizing agents with political leverage may attempt to modify the domain constraining choices to their advantage (e.g., by promoting policies that favor their interests, such as dam construction in the case of water works suppliers).
Regulatory capture (Laffont and Tirole, 1991)	Organizations	Politics and power	Users, water works suppliers	Regulatory capture is often the result of rent-seeking and occurs when a public political or regulatory entity is co-opted to serve the interests of a minor constituency, such as a stakeholder group. The effects of regulatory capture are visible in the (sometimes significant) divergence between *de iure* aspects of water resources management and the water *realpolitik*. For example, while the political discourse in water resources management revolves around the development of policies that achieve the good ecological status of water bodies, actual policy making is primarily focused on delivering the necessary resources to address existing demands (UN, 2022).
Political ecology and power (Tanouti and Molle, 2013)	Stakeholders	Politics and power	Decision-makers, donors, users, water works suppliers	The relationships between environmental development, power structures, and the narratives used to justify choices mean that, most often, water policies are discussed among, and benefit, the financially or politically dominant players; while those negatively affected are excluded from the negotiations, either because they are unaware of the negative consequences of the intervention or due to their limited political power (e.g., public consultation processes of river basin plans in Europe often engage or are directly designed by consultancies owned by water works suppliers).
Lobbying (Lopipero et al., 2007)	Organizations	Politics and powers	Users, water works suppliers	Lobbying is the act of lawfully attempting to influence public policy through the actions of decision-makers. Lobbying can involve conflict of interests, manipulation, and sometimes outright deception, and is often seen as one of the causes of a democratic deficit.

Source (reference)	**Level(s) of explanation**	**<u>Main hypothesized driver</u>**	**Player(s)**	**Description**
Corporatism (Wiarda, 1996)	Organizations	Politics and power	Users, water works suppliers	In corporatist systems, elites (privileged stakeholder groups) can gain access to decision-makers (legislators and regulators), becoming part of the "extended state".
Misinformation (Lewandowsky et al., 2012)	Stakeholders, organizations	Politics and power	Users, water works suppliers (drivers); all affected	Attempts to sow misinformation and deny scientific consensus, so to spread skepticism. We can identify three types of skeptics: trends, attribution and impact skeptics. Trend skeptics are doubtful that water scarcity is growing. Attribution skeptics may accept that there is a water crisis but attribute the cause to factors other than extant policies, which they believe are correct (e.g., insufficient investments on water supply policies). Attribution skeptics are arguably the most important group. Impact skeptics may concede that extant policies are not delivering what they promise but believe their impact on the water crisis is not relevant (e.g., attributing the crisis to climate change rather but not to poor governance).
Oversell (Peters and Nagel, 2020)	Organizations	Politics and power	Decision-makers, donors	Since extant policies are legitimated by legislatures, there is an incentive to "oversell" them: instead of admitting the uncertainty and risk inherent to any policy choice, decision-makers overselling will argue that the policy implemented is the best solution to the problem, which creates a "high bar for success". Oversell is a key driver of widespread preference towards water panaceas.
Incomplete performance assessments (or lack thereof) (Asian Development Bank, 2017; World Bank, 2017b)	Organizations	Information and data gaps	Decision-makers, donors	The ex-post evaluation is the last element of the governance cycle. Yet, decision-makers and donor organizations supervising and funding water reallocations, be it through demand or supply projects, have not been vigilant in shaping this practice 'on the ground', and as a result ex-post assessments are limited. Moreover, the lack of standardized practices means that, where available, those assessments typically do not provide comparable efforts that inform on the relative performance of the reallocation.
Risk-aversion (Kosovac and Davidson, 2020)	Stakeholders, organizations, society	Information and data gaps	Decision-makers, donors, users	Complex socio-ecological systems can be highly unpredictable, and the effects of resource (re)allocations highly uncertain (Anderies et al., 2006). This can motivate a "fear of the unknown": since decision-makers (similarly to other economic

Source (reference)	Level(s) of explanation	Main hypothesized driver	Player(s)	Description
				agents) are risk-averse, they will prefer a lottery with a more foreseeable but possibly lower payoff, to a lottery with an unforeseeable but possibly higher payoff, and thus may end up penalizing TAP as compared to already tested conventional instruments (Kosovac and Davidson, 2020). “Fear of the unknown” has important ramifications in decision making. Cost-Effectiveness Analysis (CEA) and Cost Benefit Analysis (CBA) are the two main types of decision analysis methods used to inform the performance of water (re)allocations. CEA compares a monetary estimate of the costs of water (re)allocations to an estimate of the effect expressed in units other than monetary, e.g., the ecological status of a water body. CBA, on the other hand, compares the benefits against the cost of a (re)allocation, and thus requires assigning a monetary value to all (re)allocation outcomes, including i.a. the environmental or health benefits, which is costly, technically challenging, and adds further uncertainty to the assessment. When uncertainty is considered to be excessive, caution may be emphasized through the precautionary principle, which aims at identifying policies that ensure some safe minimum standards are met. For example, in the EU context the main objective of water policy is to achieve the good ecological status of water bodies at the least cost, irrespective of the benefits. Critically, by ignoring the benefits of a (re)allocation CEA may preclude the design and deployment of a system of “compensations and collections” à-là-Hotelling (1938), and thus may reject superior (re)allocations that leave everyone better off than before.
Filtering information (Peters and Nagel, 2020)	Organizations, Stakeholders	Information and data gaps	Decision-makers, donors	Decision-makers face complex choices, much information and numerous ideas. Thus, it is only natural for decision-makers to filter the information they receive to “reduce the negative effects of the blooming, buzzing confusion of the world”. Yet, while bounded rationality and the associated filtering devices are crucial for minimizing decision-making costs, this can also lead to the exclusion of transformational ideas including TAP, and the persistence of conventional supply side approaches.

Source (reference)	Level(s) of explanation	Main hypothesized driver	Player(s)	Description
Gaps in the monitoring (Foster et al., 2021, 2020)	Organizations, Stakeholders	Information and data gaps	Decision-makers, users	There are persistent gaps in monitoring of water demand and availability. This can be the result of technical (lack of implantation of key technologies such as meters or remote sensing), budgetary (inability to pay for key data gathering technologies), noncompliance (illegal users circumventing legal channels to receive water rights), regulatory (official water registers may by their design ignore certain categories of water users, e.g. due to their implicit desire to not regulate low-income users), and reporting aspects (in some parts of the world the overwhelming majority of water meter data – especially for rural agricultural uses – is self-reported by users, which creates opportunities for deliberate or accidental false reporting).
Gaps in modeling	Stakeholders, organizations, society	Information and data gaps	All	Ensemble experiments, exploratory analysis and other techniques have been developed and used to quantify uncertainty and support the identification of robust (re)allocations that show a satisfactory performance under most plausible futures (Marchau et al., 2019). However, major limitations persist, particularly in human system modeling: while water system models have been developed to a large extent in SES research, human system models are still treated in an incipient form, with major problems persisting (Konar et al., 2019). Uncertainty in human and water systems modeling has significant ramifications in decision making processes, and can condition the choice of the performance assessment method—and thus also of the water policy adopted.
Absence of alternative mental models (Lewandowsky et al., 2012)	Stakeholders	Limited alternatives	All	People often prefer an incorrect framework/model to an incomplete framework/model, and may return to conventional supply policies in the absence of a perceived better alternative.
Lack of policy alternatives (Peters and Nagel, 2020)	Organizations	Limited alternatives	Decision-makers	Conventional policies can persist simply because there is no alternative available. The public sector often lacks the organizational, intellectual, physical or financial capacity to implement alternative ideas effectively. This works in favor of the persistence of known policy options, which are often regarded as more predictable.

4. Guidelines and principles for successful TAP adoption

Building on our assessment of TAP barriers, we propose below a series of common principles and guidelines centered around regulations, institutions and policy, incentives, information, and debiasing, to guide the adoption of TAP that contribute to sustainable and equitable economic development and welfare growth, including under conditions of uncertainty.

Regulations

Water regulations worldwide are "Byzantine and substandard" (Santato et al., 2016), having roots in "century old traditions" that are often seen as immutable (Meinzen-Dick, 2014). Growing pressures in water-stressed economies have led a limited set of countries to revise their water right system (e.g., UK, Spain, Australia, Chile), with mixed outcomes (Wheeler, 2021). These reforms reflect a growing need to adapt water regulations that were designed in times of relative abundance to a new context marked by inelastic and increasingly variable supplies (Young, 2014). Building on our assessment of the literature and case studies, we propose that water allocation regulations are revised based on the following principles:

- *Standard accounting practices*. The regulatory framework must require periodic reporting of water use based on standardized accounting principles, and centralize this information in a publicly accessible register. The accounting framework adopted should build on best practices and provide information on water use, but also effective consumption and return flows, distinguishing between usable and reusable return flows (Willardson et al., 1994). The register should include data on formal water allocations as well as on effective water use, building on data reported by users but also on active monitoring through satellite data, smart meters, or citizen science (e.g., involving citizens in water-use monitoring, for example by reporting illegal wells).
- *Hydrological integrity*. To address externalities that reduce water availability to third parties not involved in TAP adoption (e.g., environmental water use decreases due to higher consumption by economic users and reduced return flows), water allocations should pay attention to the amount of water withdrawn *and* consumed. This calls for clauses that establish the periodic revision of the amount of water that can be withdrawn where policies and autonomous adaptation responses by users increase the consumed fraction of water (Rouillard et al., 2022). For example, in parts of the US there are adjustment factors applied to water trades or sales where the use transfers from higher to lower (or vice versa) levels of consumptive use. Alternatively, some have called for water allocations based on the right to consume rather than the right to withdraw, which may be technically and legally challenging to implement, nonetheless (Rouillard et al., 2022). Moreover, managing water resources solely based on consumptive use is problematic where the main challenge is short term acute scarcity (e.g., shortfalls in a drought, streamflow depletion, etc.): since return flows are not instantaneous and can take months or even years to become available again, mismanaging withdrawals can exacerbate short term scarcity.
- *Unbundling*. Water stressed basins should specify a maximum threshold for withdrawals and/or consumption, while individual allotments should be defined as a fraction/share of this threshold. Where shortages occur, the maximum threshold should be reduced accordingly to ensure hydrological integrity (Young, 2014).

- *Legal security* should be provided to users, and these regulations actively enforced. This is particularly relevant for environmental users, which is the use that typically suffers the most from overallocation and has the handicap of lacking legal personhood (with a few exceptions, as happens in some Indian rivers and the Mar Menor lagoon in Spain). The absence of legal personhood means that the environment i) lacks legal standing (it cannot sue or be sued), ii) cannot enter and enforce legal contracts, and iii) cannot own property (O'Donnell and Talbot-Jones, 2018). As a result, addressing externalities that negatively affect the environment relies entirely on the response provided by the public sector, who also represents other interests and may be subject to lobbyism or regulatory capture by the economic uses generating the externality. This can be addressed by giving legal personhood to the environment (Eckstein et al., 2019) and creating an institution that embodies that legal personhood; or by fully translating the impacts of externalities to other economic uses (rather than the environment), e.g., by creating and actively enforcing higher priority in use for the environment. The economic users negatively affected as a result, who can be in the same use category as the originator of the externality (e.g., farmers downstream are affected by upstream water trading from low to high technically efficient farmers), are more likely to exert effective pressure to address the externality due to the private pecuniary losses involved, which are more visible and involve lower uncertainty than the valuation of environmental impacts.
- *Policy auditing and accountability*. Ex-post policy performance assessments should be required by law. Moreover, those in charge of taking water (re)allocation decisions should be made accountable for their choices by imposing a cost on decision-makers that fail to act in the public interest (e.g., by limiting access to donors' funding).

Institutions and policy

Water research and policy tends to over-emphasize the relevance of specific instruments such as markets or water charges in addressing water management challenges, sometimes portraying them as silver bullets, cure-for-all solutions, or *panaceas* (Ostrdom, 2007). The narrative for panaceas has been cemented by the historic dichotomy between regulatory and economic instruments, which have been portrayed as alternative rather than complementary instruments (Gunningham, 2009); and by "ivory tower theorizing", i.e., the scientific bias that focuses the analysis of (re)allocation instruments on their intrinsic properties, rather than their capacity to effectively contribute to a societal objective (Hahn, 1989). Yet, more often than not water panaceas have failed to live up to their expectations (Meinzen-Dick, 2007), as exemplified by water markets and water charges.

In the case of water markets, although they have been typically presented as a tool to maximize allocative efficiency and economic value (Mendelsohn, 2016), the unique characteristics of water (fugitive but bulky, private and public at the same time and variable along space and time) have created market failures and externalities that have typically led to the depletion of water bodies (e.g., reallocations towards more productive and technically efficient irrigators that eliminate the return flows on which third parties depend, including the environment). Regarding charges, as per Art. 9 of the Water Framework Directive (OJ, 2000) water charges in the EU should aim at achieving the good ecological status of water bodies through full cost recovery, including environmental and resource costs, but in practice are only designed and implemented as a revenue raising tool to recover the financial costs of water supply infrastructures.

The evidence with water panaceas around the world shows that their contribution to the multiple targets they pursue is typically imbalanced, and for some targets, counterproductive. This is in line with the Tinbergen principle, formulated by the first Nobel Price on Economics (Tinbergen, 1952), which states that a number of targets requires an equal number of instruments to be achieved. Building on our assessment of the literature and case studies, we propose that institutions fundamentally revise their policy-making principles to include the following:

- *Tinbergen Principle*. Water policy pursues multiple targets (sustainability, growth, equity, robustness, and resilience, *inter alia*), and therefore should be made of multiple parts, each of which addresses a specific target (Tinbergen, 1952).
- *Assignement Principle*. Each water policy should be applied to achieve the target to which it is suited better, and avoid using this policy to pursue other target(s) (Mundell, 1962). In other words, the Tinbergen and Assignment Principle caution us against water panaceas, calling instead for a comprehensive policy mix. This turns the attention from the design of a single optimal policy to the *coordination* of multiple policies, notably through the analysis of sequencing and synergies.
- *Sequencing***.** Sequencing refers to the order of policy implementation, and has received growing attention as a critical aspect of water reallocations (Young, 2014). For example, from a budgetary perspective, public reacquisitions of water rights are better implemented before water markets are enacted, since the latter will reveal the market value of water for users and increase the cost of water reallocations for the public sector. Similarly, a recognition of water use limits (hydrological integrity) and the definition of water rights that are consistent with these limits (unbundling) is a prerequisite for the design of sustainable water markets.
- *Synergies*. Perhaps one of the greatest challenges in water policy design is the possibility that an intervention will generate interactions and feedbacks between different components of the social, economic, and biophysical systems that may lead to unexpected consequences. Thus, the policy mix has to be designed to enhance positive and reduce negative feedbacks and achieve stated policy objectives in an efficient way.
- *Robustness*. Feedbacks among systems can lead to multiple plausible futures with varying impacts on the multiple targets of water policy. Where these plausible futures can be attributed a probability, optimality is warranted. However, this is unlikely to happen in water resources management, particularly in the case of TAP where very limited evidence of their performance exists. This makes optimality unsuitable for informing policy design. Instead, priority should be given to robustness, through the identification of policies that show a satisfactory performance under most plausible futures (Marchau et al., 2019).
- *Adaptive governance*. Some futures cannot be anticipated and modeled, and a few of these may result in catastrophic and extreme outcomes—i.e., *black swans*. This calls for institutions that are flexible and adaptable, to adjust or change extant policies where necessary—i.e., adaptively efficient (Arthur, 1994). There is no clearly defined set of principles for the design of adaptively efficient institutions (Adam Loch et al., 2020b). However, the literature points out that adaptively efficient institutions are likely to show decreasing transaction costs over time. Accordingly, gathering data on transaction costs over space and time from the beginning of policy reforms can provide valuable information on what drivers are more likely to i) overcome institutional lock-in/path dependence (the so-called "annealing forces") (Unruh, 2002) and ii) change institutional trajectory towards adaptive efficiency. This data can inform the development of reforms elsewhere that effectively achieve adaptive efficiency.
- *Annealing forces*. Increasingly often, water shortages create disproportionate losses for those who cannot ensure sufficient water supply, and this nonlinear change has become a major driver of TAP adoption. This is the case of the deployment of water markets worldwide, which

has followed a pattern of gradual and sluggish progress interspersed with periods of major development that coincided with extreme droughts. For example, attempts to develop water trading in Australia started in the 1980s but took off during the Millennium Drought of 1997-2010. In California, water markets were first envisioned in the 1970s as a means to enhance efficiency in water allocations but took off during major drought events in the 1980s and early 1990s. In Spain water trading must undergo a Byzantine bureaucratic process to be authorized, and has been under scrutiny due to its failure to comply with the precautionary principle, but these regulatory barriers are waived during extreme droughts where most water exchanges have taken place (as illustrated by the trading of 40 million m^3 from Seville to Almería irrigators during the 2023 drought). This has led some to suggest that extreme drought periods put in place favorable economic incentives towards TAP adoption, which should be exploited to implement policy reforms ("never waste a good crisis") (Wheeler et al., 2017). Since these periods will become more frequent in the future, we can expect more windows of opportunity for integrating TAP into water policy. While exploiting these windows of opportunity may be sensible, actively seeking them is dangerous and potentially counterproductive. Much evidence has shown that delaying policy action can lead to extreme and irreversible costs via nonlinearities (e.g., disinvestments such as the loss of permanent crops). In line with the precautionary principle, decision makers should anticipate and avoid potential nonlinear events where possible (Bishop, 1978). A less costly annealing force may be the **judiciary**. Until recently, knowledge gaps (e.g., about the impact of return flows on third parties) and conflicting interpretations on the affection of water resources management on the interests of the public (e.g., who creates the affection in the first place) have often prevented univocal interventions from the judiciary, as manifested by diverging interpretations of the cost recovery principle in the EU (Jääskinen, 2014). However, as scientific consensus grows on some key issues such as third-party impacts of water (re)allocations, some consistent ruling from the judiciary has been issued. For example, the U.S. Supreme Court recently ruled against the State of Wyoming for allowing "pre-1950 water appropriators to increase their net water consumption by improving the efficiency of their irrigation systems," which reduced water availability for downstream farmers in the State of Montana, and awarded pecuniary compensations to the latter (Barton, 2018). Continued enforcement can become, in those countries where regulations are in place, a relevant annealing force driving TAP.

- *Institutional certainty*. Users should be given as much certainty as possible with regards to reallocations. For example, the methods used to define the maximum threshold for withdrawals and/or consumption should be clearly established, so that when shortages occur users can plan in advance and adapt. Institutional certainty is a prerequisite for TAP such as drought insurance for irrigated agriculture, where the volume of losses and compensations is conditional on the institutional decision to allocate water to users during shortages.

Incentives

Water reallocations via TAP can enhance economic efficiency and welfare in two ways: through Pareto efficiency improvements that increase the wellbeing of at least one agent without leaving no other agent worse-off; or through Kaldor-Hicks efficiency improvements where winners win more than losers lose. It follows that while Pareto improvements are desirable or indifferent to all agents involved in the reallocation, Kaldor-Hicks efficiency improvements are undesirable for those who lose from the reallocation—who can organize themselves to actively oppose reform through, e.g., lobbyism.

Accounting and addressing these negative impacts is relevant to water overallocated economies, where it is "extremely challenging" that Pareto improvement opportunities can naturally emerge (Gómez et al., 2017). In fact, in nowadays market economies it is very challenging to reallocate water or other environmental resource without making at least one agent involved in the reallocation worse off—usually the agent relinquishing the right. As a result, reallocations will typically create winners and losers, with incentives to favor/oppose the reform.

Critically, the winners of a Kaldor-Hicks improvement could hypothetically compensate losers and leave everyone better-off—e.g., by granting part of the proceeds from the reallocation to those negatively affected. This is well illustrated by research on water markets worldwide (Wheeler, 2021), but not only. Coordination improvements via economic incentives can also help address current inefficiencies due to poorly designed subsidies, use it or lose it property rights, open access arrangements, and/or poor enforcement programs, *inter alia*, and enhance welfare—both private and public. For example, research on water charges has found that the benefits from enhanced environmental supplies often exceed the costs experienced by economic users since water use is relinquished in marginal lands with low added value (Sapino et al., 2020).

As a result, achieving efficiency improvements and enhancing societal welfare requires active intervention to develop systems of economic incentives that enable "compensations and collections such that everyone would be better off than before" (Hotelling, 1938). Based on our literature review and deep dive case studies, we suggest that the following principles should be followed to achieve this end:

- *Appropriate rationales for participation and incentive compatibility*. In mature water economies where supplies are fully allocated, creating adequate economic incentives that achieve efficiency improvements and enhance societal welfare necessitates that two basic conditions are met: appropriate rationales for participation, and incentive compatibility (Fudenberg and Tirole, 1991). Appropriate rationales for participation indicates that water users will engage in TAP if they expect to achieve private benefit. Incentive compatibility stipulates that actions from water users should be aligned or made compatible with collective public objectives. Hence, opportunities to use economic incentives to drive higher welfare exist in situations where: (i) there are welfare-improving opportunities that can be transformed into private benefits for water-users (e.g., compensations for transferring water to environmental uses); and (ii) collective gains then arise in terms of achieving public water policy objectives—or at least these objectives are left unaffected (e.g., reallocations among water users that lead to private benefits only). Where only collective gains exist, this may offer welfare enhancing opportunities, but an application of economic incentives may not be the most appropriate instrument (this situation may favor the use of, e.g., regulations). Much evidence has shown that the growingly inelastic water demand function resulting from recent land use reallocations towards high value-added crops is increasing the opportunities for Kaldor-Hicks improvements among users. Notably, the literature on water pricing has shown that water overallocated basins typically show an inelastic demand for water, meaning that users are able and willing to pay a high amount of money for water due to the high return it provides. In theory, irrigators respond to water restrictions by phasing out first irrigated crops in marginal land, and only after these crops shift to rainfed agriculture, by phasing out high value-added crops. However, due to the high value of water in overallocated catchments, the surface of crops irrigated in marginal land is very limited. This means that the quantity demanded of water is relatively static when its price changes. On the one hand, this renders charging ineffective in reducing demand until a high and potentially unacceptable charge is set. On the other hand, this offers significant welfare-enhancing opportunities through reallocations among users and revenue raising tools that fund policies that lead to collective gains (e.g., buyback). Importantly, this inelastic response can be significantly smoothened where intensive margin adaptation (deficit and supplementary irrigation) and training that expands the range of actions/domain are consideredre.

- *Market structure.* The distribution of the revenues from welfare-enhancing opportunities between private and collective gains depends on the market structure in place, where high market power can be used to direct a larger fraction of revenues for private or public agents. Notably, in most countries the power to enact a water market lies on the public sector (Wheeler, 2021), meaning that the public sector can discretionary decide who buys and sells, and can institute itself as the sole buyer (and subsequently the sole water allocator and potential seller) in the market. This gives the public sector the opportunity to exploit its monopolistic-monopsonistic position to buy water at low monopsonistic prices and sell water at high monopolistic prices, thus raising significant revenue that can be used e.g., to pay for the reacquisition/buyback of water rights (Gómez-Limón et al., 2020). Moreover, the public sector can exploit its monopolistic-monopsonistic position to apply first-degree price discrimination and pay to each willing buyer/seller their reserve price, thus fully transforming the market surplus into public revenues and further amplifying the resources available to reacquire water rights or implement other water (re)allocation policies (Pérez-Blanco et al., 2023). Under first-degree price discrimination, the water bank pays/asks a different price for every unit of water sold/bought, which matches the maximum/minimum price that every buyer/seller in the market is willing to pay/accept (reserve price). Thus, both the consumer and producer surpluses are wholly transformed into public revenues, which reduces the budgetary burden of the environmental restoration without negatively impacting economic efficiency where the quantity of water not sold is used to restore natural assets (it should be noted that the transaction costs of managing such a system may be relevant and require larger bureaucratic infrastructures that are also costly.
- *Business innovation.* Putting in place adequate sets of incentives demands business innovation to correctly allocate costs and benefits among those agents affected by TAP, so as to make sure that those who gain/lose from TAP adoption pay/are compensated. For example, insurers who benefit from the provision of regulatory services through Nature-based Solutions should pay for their adoption (UNEP, 2021). Business innovation that puts in place adequate sets of incentives can reduce free riding and strategic behavior. There are also opportunities for business innovation and welfare gains through Public–private partnerships (PPPs). PPPs are lasting collaborations between the private and public sector to exploit their complementary strengths in providing a service (Mysiak and Pérez-Blanco, 2016). Several examples of PPPs that led to Kaldor-Hicks improvement can be found in the literature on voluntary agreements (Maziotis and Lago, 2015), such as the one brokered between the river basin authority of the Ebro River and the private hydropower operator of the Mequinenza-Ribarroja-Flix Dam System to release pulse flows twice a year to improve the quantitative and qualitative status of water bodies, which also contributed to cleanse the outlets of the dams at a competitive cost (as compared to mechanical removal) and to the social corporate strategy of the private operator (Gómez et al., 2014).

Information

There is a fundamental policy need to better understand the interconnected dynamics and co-evolution of complex socio-ecological systems, and their cascading uncertainties, and to represent them in actionable modeling tools that inform the adoption of robust TAP by stakeholders. Moreover, while socio-ecological and ensemble modeling can guide design of TAP, implementation of policies in the real-world requires knowledge and tools that enable stakeholders to monitor performance, enforce rules related to water use and allocation, and trigger corrective action where outcomes deviate from expectations. Yet, in almost all water-scarce regions globally, water managers lack reliable or complete information to effectively monitor and review policies post-implementation, weakening ability to effectively manage current and future water scarcity and conflict. To address data and modeling gaps, we propose the following:

- *Better and more integrated models*: science should focus on producing interdisciplinary approaches that "explicitly account for the two-way feedbacks between human and water systems" (Sivapalan et al., 2012). Although significant advances have been produced over the last decade in integrating human aspects into water resources modeling, major gaps still persist that should be addressed in order to better inform demand-driven TAP (Konar et al., 2019).
- *Better data*: Future efforts should aim at developing data-driven monitoring and accounting tools that enable stakeholders to track critical user-defined indicators of water availability, water use (differentiating between beneficial/non-beneficial consumption and return flows), and socio-economic impacts of TAP over space and time, while also providing critical baseline and historical data to parameterize, calibrate and validate socio-ecological models used for ex-ante TAP design and assessment. These tools should build on data resources and monitoring systems already used by stakeholders (e.g., in-situ metering, flow gauging, etc.), integrating these data with new sources of information such as earth observation (e.g. satellite-based ET and land cover products such as SEN-ET or WaPOR) and citizen science to provide a comprehensive scientifically-grounded solution to existing gaps in monitoring of water policies. Digital technologies for data storing such as blockchain can also contribute to reduce information asymmetry and private transaction costs by storing information in an immutable fashion (which reduces policing and enforcement), "tokenizing" the economy (i.e., the creation of a digital representation of the water asset) to facilitate trading (which reduces bargaining costs), and creating "smart" contracts to execute automated functions when certain conditions are met (Bhaduri et al., 2021).
- *Uncertainty awareness.* Uncertainty quantification in water resources modeling is far from thorough, with point predictions still playing a major role in informing water policies (Gain et al., 2021). Point predictions oversell model accuracy and may convey a false sense of security to decision makers on the ability of the model to anticipate policy performance. Reflecting recent advances in socio-ecological modeling, future applications should thoroughly reflect input, parameter, structural and contextual uncertainties in modeling, notably through ensemble experiments that couple multiple systems, models and scenarios (CMIP6, 2023; ISIMIP, 2023).
- *Engaging science.* Major recent advances in modeling (including ensemble experiments) and data monitoring have not permeated yet to policy makers and the Decision Support Systems (DSS) used in river basin planning and management, which rarely account for socio-ecological feedbacks, typically disregard the new generation of datasets (notably remote sensing), and ignore or insufficiently address uncertainties within and across systems. A major scientific effort should be targeted towards mainstreaming cutting edge advances in modeling and data monitoring into the DSS used by decision makers.

- *Transparent data*: While asymmetric information can allow asymmetric profits, including "supernormal profits", in markets (Knight, 1921), the public release of reallocation data can prevent information asymmetries and supernormal profits, and enhance allocative efficiency and policy performance (Loch et al., 2014). Moreover, big and transparent data can significantly reduce the private transaction costs of (re)allocations, thus increasing the penetration rate of TAP.

Debiasing

In facilitating a transition from conventional supply-side policies to TAP, cognitive biases and misinformation must be reduced through debiasing (Lewandowsky et al., 2012). Debiasing is a process to reduce the influence of cognitive biases caused by misinformed processes in belief on decision making, and thus help agents (mainly decision makers) take better informed and more rational choices. Several types of debiasing frameworks exist that can be applied to facilitate TAP adoption in water resources management (Cook et al., 2018; Lewandowsky et al., 2013; Pérez-Blanco et al., 2021). Building on our revision of the literature and deep dive studies, we formulate the following principles to facilitate successful debiasing:

- *Group learning*. Debiasing interventions in which agents can observe each other (*observational learning*) increase the effectiveness of debiasing efforts (Yoon et al., 2021).
- *Repetition***.** Repeating debiasing interventions in successive interventions is often necessary to ensure successful debiasing (Lewandowsky et al., 2012).
- *Expose vested interests*. Cognitive biases are often the result of the misinformation sowed by groups with vested interests. Exposing the vested interests of these groups so that the agents affected by misinformation can clearly link misinformation with a gain by some group(s) has been shown to enhance the performance of debiasing (Cook et al., 2018).
- *Evidence-based communication***.** Defusing cognitive biases calls for clear and concise communication that is tailored to the audience's worldview. Agents performing debiasing exercises should avoid the overt negation of the belief acquired by the target group to avoid backfire effects. Instead, examples and empirical observations should be used (Lewandowsky et al., 2012).
- *Scientific consensus*. Scientific consensus is a major driver of policy change. On the contrary, where there is disagreement among scientists, misinformation can more easily permeate and prevent decisive action (Lewandowsky et al., 2013).
- *Alternative framework*. People often prefer an incorrect framework/model to an incomplete framework/model, and may return to conventional supply policies in the absence of a perceived better alternative. Once debiasing has been successfully implemented, it is important to fill in the vacuum with the concepts listed above to ensure that agents, particularly decision makers, do not return to the previous framework.
- *Preventive debiasing*. In an analogy to biological inoculation, research has shown that preemptively exposing people to a "weakened" version of major reasoning errors or misinformations can confer cognitive resistance to them, thus reducing their likelihood and spread and the need for the treatment above (Cook et al., 2018)

5. Conclusions

In this document we identify candidate theories for the emergence of barriers to TAP adoption, and assess the relationships and role of key players in the emergence and persistence of these barriers, while also identifying opportunities for overcoming these barriers. We conclude that successful TAP adoption needs to build on a series of key guidelines and principles articulated around regulations, institutions and policy, incentives, information, and debiasing. Following these guidelines and principles will allow the organized adoption of TAP that contribute to sustainable and equitable economic development and welfare growth, including under conditions of uncertainty.

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Annex I

The Background document elaborated by experts from the 8 case study sites is available at the Digital Library of the TRANSCEND Project Website.