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Thirst for Change in Water Governance: Overcoming Challenges for Drought Resilience in Southern Europe

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Abstract

This article investigates the institutional and informational foundations of water governance in Southern Europe amid escalating climate stress. Focusing on Portugal, Spain, Italy, and Greece, it develops a multi-level analytical framework to explore how information asymmetries and governance fragmentation undermine coordinated responses to water scarcity. Integrating theories of information economics, polycentric governance, and critical institutionalism, this study applies a stylized economic model and comparative institutional analysis to assess how agents—such as farmers, utilities, regulators, and civil society—respond to varying incentives, data access, and coordination structures. Using secondary data, normalized indicators, and scenario-based simulations, the model identifies three key structural parameters—institutional friction (θ_i), information cost (β_i), and incentive strength (α_i)—as levers for governance reform. The simulations are stylized and not empirically calibrated, serving as heuristic tools rather than predictive forecasts. The results show that isolated interventions yield limited improvements, while combined reforms significantly enhance both equity and effectiveness. Climate stress simulations further reveal stark differences in institutional resilience, with Greece and Italy showing systemic fragility and Portugal emerging as comparatively robust. This study contributes a flexible, policy-relevant tool for diagnosing governance capacity and informing reform strategies while also underscoring the need for integrated, equity-oriented approaches to adaptive water governance.

Keywords: water governance; information asymmetry; climate adaptation; polycentric governance; Southern Europe; drought resilience; institutional innovation; policy transfer

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Academic Editor: Chin H Wu

Received: 9 June 2025
Revised: 10 July 2025
Accepted: 21 July 2025
Published: 22 July 2025

Citation: Santos, E. Thirst for Change in Water Governance: Overcoming Challenges for Drought Resilience in Southern Europe. *Water* **2025**, *17*, 2170. https://doi.org/10.3390/w17152170

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1. Introduction

Climate change is intensifying water scarcity across Southern Europe, making effective water governance a critical institutional and policy challenge with profound implications for equity, legitimacy, and sustainability. Countries such as Portugal, Spain, Italy, and Greece have experienced a marked increase in the frequency, duration, and severity of droughts over the past two decades. According to the European Environment Agency [1], drought-related economic losses in the region exceeded EUR 9 billion between 2000 and 2020, severely impacting both agricultural productivity and urban water security. Moreover, these four case study countries were selected because they form a recognized "Southern Europe climate hotspot"—characterized by rising mean annual temperatures, declining precipitation trends, and similarly fragmented multi-level water governance systems—making them especially suitable for structured comparative analysis (EEA [1]). These pressures have revealed persistent weaknesses in water governance systems, which are often fragmented across institutions and administrative levels. To contextualize these challenges, it is necessary to move beyond purely technical or managerial approaches and engage with critical perspectives such as water justice [2], adaptive governance [3], and the political economy of water [4]. These studies emphasize that governance is not only about efficiency but also about power, representation, and the distribution of risks and benefits. In this light, this study seeks to contribute to more equitable and democratically legitimate water governance, in addition to institutional effectiveness.

Despite reforms under the EU Water Framework Directive, governance remains highly polycentric and frequently uncoordinated, resulting in blurred roles, operational inefficiencies, and inequitable service delivery [5,6]. While prior research has addressed institutional fragmentation [7] and adaptive capacity [8], the role of information asymmetry—especially within cross-country and model-based frameworks—remains underexplored. Although studies such as [9,10] highlight data limitations in water governance, few have integrated this problem analytically with institutional fragmentation or simulated its effects formally.

This article addresses that gap by examining how informational inequalities and institutional complexity interact to shape water governance outcomes in Portugal, Spain, Italy, and Greece. Across these countries, decision-makers often lack timely, reliable, and interoperable data on water availability, demand, and use—undermining both strategic planning and regulatory implementation. This asymmetry distorts economic signals, including pricing and allocation mechanisms, and contributes to inefficiencies such as overextraction and inconsistent service delivery [11,12].

This study adopts an exploratory yet analytically rigorous approach, integrating a stylized economic model with a comparative institutional analysis across four Southern European countries. Drawing on systematically coded policy documents, secondary datasets, and proxy indicators, this study employs simulation-based scenario analysis to investigate the interplay between information asymmetries and institutional fragmentation. While the analysis does not rely on primary data collection, the methodology enables the generation of policy-relevant insights and the formulation of testable hypotheses. This framework contributes to the development of a theoretically grounded and operationally flexible tool for diagnosing governance bottlenecks and informing adaptive reform strategies in complex, data-scarce policy environments.

Conceptually, this study integrates information economics, polycentric governance theory, and institutional diagnostics to build a multi-level reform framework grounded in the OECD's 12 Principles on Water Governance. The approach bridges theoretical domains often examined in isolation, offering scenario-based evidence to inform both normative and practical debates on water governance.

The remainder of this article is structured as follows: Section 2 presents the theoretical foundations; Section 3 details the data and methods, including the economic model and comparative analysis; Section 4 discusses the simulation and qualitative findings; Section 5 outlines key governance recommendations; Section 6 reflects on policy implications and limitations; and Section 7 concludes this article.

2. Theoretical Framework

This paper adopts the notion of governance as an "invisible infrastructure", drawing from institutionalist traditions in political science and sociology. Mahoney and Thelen [13] and Peters et al. [14] conceptualized institutions not only as formal rules but as embedded infrastructures that condition action, enable coordination, and shape information flows and authority. Similarly, Fukuyama [15] treats governance systems as foundational infrastructures—akin to dams or treatment plants—for effective policy implementation.

Applying this lens to water governance highlights how data systems, legal mandates, and participatory norms collectively serve as the adaptive "plumbing" of resilience under stress.

2.1. Foundational Pillar I: Economics of Information Asymmetry

Originating with Akerlof [16] and expanded by Stiglitz [17], information asymmetry theory explains how unequal or distorted access to information leads to suboptimal outcomes in collective action and resource allocation. In water governance, a lack of granular, real-time data on availability, consumption, or environmental flows distorts pricing, incentives, and investment, resulting in overextraction, leakage, and infrastructure underperformance [18].

Key Parameters α_i, β_i, and θ_i:

- α_i (incentive strength): the marginal benefit an agent derives from using information effectively;
- β_i (information cost): the effort and resources required to access, process, and interpret data;
- θ_i (institutional friction): governance constraints—such as overlapping mandates or bureaucratic inertia—that impede data sharing and coordination.

These parameters translate asymmetry theory into quantifiable levers within our stylized economic model (Section 3).

2.2. Foundational Pillar II: OECD Principles on Water Governance

The OECD's 12 Principles on Water Governance (2015) offer a normative framework emphasizing the following:

- Clearly defined roles and responsibilities (Principle 2);
- Adaptive capacity and responsiveness (Principle 3);
- Transparency and open data (Principle 6);
- Inclusive stakeholder engagement (Principle 10).

While these principles guide comparative diagnostics, critics warn that their technocratic focus can obscure power asymmetries and local adaptations [19,20]. For example, Spain's basin councils are formally inclusive but often dominated by irrigation interests [18], and Portugal's ERSAR benchmarks data unevenly across regions [18].

2.3. Foundational Pillar III: Polycentric Governance Theory

Ostrom's polycentric governance theory suggests that multilayered, decentralized systems enhance resilience through redundancy, flexibility, and shared responsibility [21]. Polycentric arrangements are linked to increased legitimacy and learning, but can also generate duplication and fragmentation without harmonized data systems and coherent regulation [22].

In Italy, regional basin authorities follow incompatible data standards, undermining coordination; meanwhile, in Greece, overlapping ministerial mandates leave basin-level planning unenforced [22].

2.4. Integrative Innovation: Synergies Among Pillars

Most research addresses information systems, institutional design, and stakeholder participation as separate domains. This study introduces a novel approach by integrating all three pillars through parameters α_i, β_i, and θ_i. Specifically, reducing institutional friction (θ_i), such as by streamlining overlapping mandates, lowers the cost of accessing and using information (β_i). In turn, this increases the incentive (α_i) for actors to engage with and act on relevant data. Conversely, interventions focused on a single domain tend to deliver limited and unsustainable improvements.

This integrative framework demonstrates that only coordinated reforms—combining digitalization, institutional consolidation, and incentive realignment—can generate systemic gains in efficiency, equity, and resilience (see Section 4).

To understand how such integration unfolds in practice, the Advocacy Coalition Framework [23] offers insight into how actors align interests and mobilize resources across institutional boundaries. In parallel, policy network theory highlights the role of dynamic, multi-actor collaboration in governance processes [24]. Finally, multi-level governance theory emphasizes the vertical and horizontal coordination required to implement coherent reforms across sectors and scales [25].

3. Data and Methods

This section compiles the empirical and conceptual inputs used across the study's three main methods: comparative policy analysis, micro-economic modeling, and integrative scenario exercises. The data are structured into three streams aligned with these methodological pillars: policy and institutional sources, physical and socio-economic inputs for model calibration, and the procedures that integrate these strands into a unified analytical framework.

3.1. Data and Sources

3.1.1. Qualitative Analysis

The qualitative analysis is based on thematic coding of water governance arrangements guided by the OECD's 12 Principles on Water Governance. It covers five core dimensions crucial for effective water management: institutional fragmentation, stakeholder participation, data transparency, technological infrastructure, and climate adaptation. Sources include policy documents, governance reports, case studies, and academic research such as Martínez-Fernández et al. [26]. A purposive sample of 85 primary documents (2010–2024) was selected based on relevance, institutional authority, public endorsement, and language accessibility (original or English). The sample spans Greece (18), Italy (16), Portugal (26), and Spain (25), including planning documents, government reports, and scholarly works. Coding was conducted using NVivo, generating an average of 27 thematic nodes per document.

3.1.2. Data Normalization

Quantitative data used for normalization and parameter estimation were sourced from national governance reports, open data platforms, institutional records, and prior academic studies. Institutional fragmentation and stakeholder participation indicators were derived from qualitative coding and cross-validated with expert input.

Normalization Procedure

All model parameters were normalized to the $[0,1]$ range using min-max scaling, calculated as follows:

$$x_i^* = \frac{x_i - \min(x)}{\max(x) - \min(x)}$$

This method was selected for its simplicity and interpretability. Normalized values reflect each actor's relative position within the empirical distribution, facilitating cross-country and cross-actor comparisons. Min-max scaling was preferred over alternatives (e.g., z-score) due to the bounded nature of the model inputs and the need to preserve ordinal relationships.

3.1.3. Data Integration

Gridded climate and hydrological datasets—including the Standardized Precipitation Evapotranspiration Index (SPEI), river discharge, and reservoir levels—were aggregated by hydrological units defined by the European Catchments and Rivers Network System (ECRINS). These physical indicators were systematically linked to governance attributes derived from legal frameworks and institutional diagnostics.

The spatial mapping process enabled a direct comparison between physical water stress (e.g., drought severity, storage deficits) and institutional variables (e.g., transparency, participation rules). Each basin was assigned to its corresponding planning or regulatory body, accounting for jurisdictional overlaps when necessary.

3.2. Economic Model

This study considers a simplified economic model in which two types of agents participate in water governance: informed agents (denoted by I) and uninformed agents (denoted by N). These agents engage in collective decision-making under conditions of asymmetric information.

The agent's propensity to use information, denoted as q_i^*, is modeled as a function of three structural parameters:

- α_i: incentive strength, reflecting the marginal benefit derived from using information;
- β_i: information cost, capturing technical and cognitive barriers to data access and processing;
- θ_i: institutional friction, representing governance constraints such as overlapping mandates, legal ambiguity, or bureaucratic rigidity.

The simplified decision model adopts the following form:

$$q_i^* = \frac{\alpha_i}{\beta_i + \theta_i} \tag{1}$$

This expression captures how an agent's willingness and capacity to act upon information depends on both its perceived value (α_i) and the total barriers posed by information costs and institutional inefficiencies ($\beta_i + \theta_i$).

To avoid implausible corner cases (i.e., $\alpha_i = 0$), which would imply that certain actors derive no benefit from information—contradicting empirical evidence—a minimum threshold was imposed such that $\alpha_i^{\min} \geq 0.05$. This ensures that even marginalized actors (such as NGOs or smallholders) retain some incentive for information use, especially under stress scenarios.

All parameters were normalized to the $[0, 1]$ interval using min-max scaling based on empirical institutional diagnostics (see Appendix B). This enables meaningful cross-country and cross-actor comparisons.

3.2.1. Equilibrium Analysis and Suboptimality

Given Equation (1), each agent's equilibrium level of information use is determined by the ratio of marginal benefit to total cost—comprising both informational and institutional components.

Under current governance constraints, these q_i^* values remain significantly below what would be expected in a socially optimal configuration in which barriers are minimal and incentives are maximized (i.e., $\alpha_i \to 1$, $\beta_i + \theta_i \to 0$).

The decentralized equilibrium is suboptimal in two ways:

- Agents facing high $\beta_i + \theta_i$ operate with limited information use, even when incentives exist;
- System-wide utility is not maximized due to uncoordinated decisions and unaddressed externalities.

Although the model does not formally solve for a Pareto optimum, it enables diagnostic comparison between current governance outcomes and a benchmark scenario with reduced friction and improved incentive alignment. As shown in Section 4, simulated reforms targeting β_i and θ_i—alongside moderate increases in α_i—can significantly elevate q_i^* across agents, particularly those initially disengaged.

3.2.2. Assumptions and Limitations

The model assumes that agents are risk-neutral within a single season and do not consider intertemporal effects such as groundwater dynamics across years. Information is public and perfectly observable; private signals are independent. The regulator commits ex ante to an allocation rule, and climate uncertainty is treated as an exogenous shock to total water availability. Interactions among agents are non-cooperative, with no side payments.

While conceptually useful, the model omits several dynamics, such as the following:

- Intertemporal strategies (e.g., water storage over drought cycles);
- Cross-sectoral trade-offs (e.g., irrigation vs. hydropower);
- Behavioral responses (e.g., status quo bias, institutional distrust).

These simplifications provide analytical clarity but limit predictive applicability. Therefore, the model should be interpreted as a heuristic tool for exploring governance structure and reform potential. Future research may extend this framework through empirical calibration, behavioral heterogeneity, and multi-seasonal dynamics.

3.3. Data Integration Procedure

To ensure hydrological dynamics could be compared with institutional structures, climate indicators (SPEI, river discharge, storage anomalies) were interpolated to basin centroids and aggregated via area-weighted averages. Governance units were matched through a two-step process involving legal mandate review and spatial jurisdiction analysis. Overlapping governance structures (e.g., in Italy) were handled via proportional disaggregation. This spatial–institutional linkage enabled simulations grounded in observed environmental and administrative conditions.

3.4. Sensitivity and Robustness Checks

To assess model robustness, a sensitivity analysis was conducted by perturbing each parameter (α_i, β_i, θ_i) by ±10% and ±20%. The resulting changes in q_i^* values were typically within ±0.15, indicating moderate sensitivity. However, some contexts (e.g., NGOs in Greece) exhibited greater volatility, suggesting lower robustness under high friction. Future improvements could include Monte Carlo simulations or bootstrapping to generate confidence intervals and support uncertainty quantification.

4. Results

4.1. Results from Comparative Institutional Analysis

This section presents a qualitative comparison of water governance across Portugal, Spain, Italy, and Greece, using thematic coding aligned with the OECD's 12 Principles on Water Governance. The analysis focuses on five dimensions: institutional fragmentation, stakeholder participation, data transparency, technological infrastructure, and climate adaptation.

Table 1 summarizes governance challenges by country and reveals important differences. Portugal shows moderate institutional coherence through agencies like ERSAR and INAG but faces regional disparities. Spain suffers from high fragmentation between national bodies and autonomous communities, although basin agencies such as those in the Ebro basin offer strong coordination. Italy presents a complex landscape involving multiple overlapping mandates among ATOs, municipalities, and regions, creating challenges for clear governance. Greece exhibits severe fragmentation with unclear basin-level authority and limited institutional coordination, reflected in a high fragmentation score of 0.85 (see Table A2 in the Appendix A).

Table 1. Governance challenges by country.

Challenge/ Country	Greece	Italy	Portugal	Spain
Institutional fragmentation	Severe fragmentation across ministries; unclear authority at basin level	Highly complex, involving ATOs, municipalities, regions; frequent overlap of mandates	Moderate coherence through ERSAR and INAG; some regional disparities	High fragmentation between national bodies and autonomous communities; strong basin agencies
Stakeholder inclusion	Minimal participatory infrastructure; top–down planning prevails	River contracts in the north; weak national-level inclusion	Frameworks in place (e.g., river basin forums), but engagement is shallow in rural areas	Dominance of irrigation consortia; limited NGO voice in planning
Data transparency	Sparse data access; gaps in real-time monitoring	No unified national database; local systems disconnected	Partial open data platforms; regional variability	Basin-level data exist, but lack standardization
Digitalization	Very limited; digital infrastructure underfunded	Urban pilots (e.g., Milan); rural areas lack smart metering	Pilots in Algarve/Alentejo; scale-up pending	Strong in Ebro basin; weak in southern regions
Financing	Chronic underfunding; low EU fund absorption	Poor cost recovery; stalled CAPEX projects	Centralized tariffs; uneven capital investment	Decentralized tariffs; EU funds fill gaps
Climate change adaptation	Plans on paper; limited execution capacity	Fragmented plans; weak cross-sector alignment	National strategy exists; uneven implementation	High drought exposure; weak regional integration

In addition to horizontal fragmentation across agencies and sectors, vertical conflicts between governance levels are highly relevant, especially in decentralized contexts. For example, in Spain, basin agencies frequently face institutional tensions with autonomous communities over jurisdiction and budgetary control [19]. In Italy, competing responsibilities between national regulators and regional governments hinder coherent planning and policy alignment. These inter-scalar tensions—typical of multi-level governance arrangements [25]—increase institutional friction (θ_i) and reduce the effectiveness of top–down reforms unless explicitly addressed.

Regarding stakeholder inclusion, Portugal maintains frameworks such as river basin forums; however, engagement remains shallow in rural areas (e.g., Algarve pilot projects). Spain's governance is dominated by irrigation consortia with limited NGO participation in planning processes, as documented in the Guadalquivir basin [26]. Italy's river contracts are mostly confined to northern regions, with weak national-level inclusion, while Greece exhibits minimal participatory infrastructure, relying largely on top–down planning [27].

Beyond horizontal fragmentation, vertical coordination failures are a central driver of institutional friction (θ_i), particularly in decentralized systems. In Spain, regional governments often resist basin-level authority—as seen in the Ebro and Tajo basins—where disputes over water transfers and tariff harmonization have led to institutional standoffs [26,28]. In Italy, legal ambiguities between national agencies such as the ARERA and regional ATOs produce overlapping mandates, stalling infrastructure investments and data standardization efforts [20,27]. Greece faces similar challenges, with the Special Secretariat for Water nominally responsible for national coordination but lacking enforcement capacity over municipal and regional utilities [28]. These inter-scalar misalignments diminish policy coherence, increase transaction costs, and amplify actor disengagement—factors formally captured by elevated θ_i values in simulation results. Recognizing these vertical governance pathologies is essential to understanding why isolated reforms often fail to mobilize key actors.

Data transparency varies: Portugal shows partial open data platforms with regional disparities; Spain maintains basin-level datasets but lacks standardization; Italy's local systems remain disconnected, preventing unified national data access; and Greece suffers from sparse data availability with significant gaps in real-time monitoring. Digitalization efforts also vary widely: Portugal pilots digital irrigation dashboards in Algarve and Alentejo; Spain's Ebro basin leads digital adoption, while southern regions lag; Italy conducts urban pilots like Milan but rural areas lack smart metering; Greece remains largely underfunded in digital infrastructure.

Concrete examples include Portugal's smart irrigation dashboards aimed at improving data-driven agricultural planning, while Spain's Ebro basin agencies coordinate water management through interoperable platforms and legally empowered governance bodies. These initiatives illustrate how targeted digital investments and institutional authority can reduce costs of information use (β_i) and institutional friction (θ_i), respectively.

Financing structures differ: Portugal relies on centralized tariffs but experiences uneven capital investments; Spain uses decentralized tariffs supplemented by EU funds; Italy struggles with poor cost recovery and stalled capital expenditure; and Greece confronts chronic underfunding and low EU fund absorption. Climate adaptation strategies are national but unevenly implemented in Portugal; Spain suffers high drought exposure with weak regional coordination; Italy has fragmented plans lacking cross-sector alignment; and Greece's strategies often remain unexecuted.

4.2. Results from the Economic Model

4.2.1. Baseline Scenario: Suboptimal Information Use and Strategic Relevance

The economic modeling indicates that actors across all four countries—Spain, Greece, Italy, and Portugal—operate below the socially optimal level of information utilization in water governance. This suboptimal equilibrium arises despite varying national contexts, suggesting systemic underperformance linked to institutional, economic, and cognitive constraints. The corrected indicator of strategic relevance, calculated via normalized dimensions of influence, capacity, and legitimacy, reveals striking disparities. Small farmers in Portugal and Spain attain relatively high scores, signaling their stronger role in decision-making structures. Conversely, Greek actors consistently display corrected values near or at zero, highlighting institutional disengagement or marginalization. This finding suggests that governance processes in Greece lack the strategic alignment or capacity needed for participatory, data-driven water management.

For modeling purposes, actors were grouped into functional categories consistent with the classification provided in Appendix B and the categories presented in the tables. These include regulators (e.g., national authorities such as ministries and central agencies), water utilities (public or private service providers), small farmers (such as irrigation consortia and agricultural producers), and NGOs and civil society organizations (including user committees and environmental groups).

4.2.2. Simulated Propensity for Information Use

The simulation of information adoption behaviors (represented by the variable q_i^*) under baseline governance constraints reveals marked differences in agent readiness across the four countries. These values were derived using the model's core formula:

$$q_i^* = \frac{\alpha_i}{\beta_i + \theta_i}$$

This formula is based on the normalized parameters outlined in Table A5. To ensure plausibility and avoid implausible extremes, damping factors were applied, as explained in Appendix B.2.

Portugal consistently shows high q_i^* values across all actor categories, indicating a supportive institutional environment for information-based governance. Spain displays moderate values, suggesting room for policy enhancement. In contrast, Italy and Greece exhibit very low or zero q_i^* values for several actor types—particularly NGOs and regulators—signaling severe institutional constraints that undermine the potential benefits of data use.

These findings underscore the role of structural governance barriers—especially institutional friction and information cost—in determining whether actors engage meaningfully with data. Even when economic incentives exist, weak institutional coordination or lack of access can prevent information from being transformed into action.

4.2.3. Governance Reform Simulations

Three key reform scenarios were modeled: digitalization (enhanced data availability), institutional streamlining (reduced bureaucratic complexity), and incentive alignment (cost reductions and improved regulation). These interventions were simulated both independently and in combination.

Digitalization alone yielded modest but consistent gains, particularly among actors with baseline familiarity or engagement with information systems. Institutional reforms were more effective in unlocking participation from previously disengaged agents, particularly in Greece and Italy. Incentive alignment produced strategic improvements among actors on the margins, such as utilities and small farmers.

When all reforms were applied simultaneously, synergistic effects emerged: actors with initially low q_i^* values demonstrated significant increases in information uptake, transforming from passive to actively engaged stakeholders. This underscores the importance of integrated reform approaches, especially in fragmented systems.

The simulation results highlight the synergistic effects of combined reforms—particularly those enhancing data transparency, stakeholder inclusion, and institutional coordination. A particularly notable case is that of small farmers in Greece, whose optimized contribution to governance processes (q_i* value) increases markedly from 0.06 to 0.83 under the integrated reform scenario (see Table A6 in Appendix B). This outcome illustrates a transition from near-total marginalization to active strategic engagement, driven by concurrent improvements in access to information, participatory mechanisms, and institutional coherence.

4.2.4. Climate Stress and Institutional Resilience

A climate stress scenario was simulated to assess systemic resilience, operationalized as a 20% increase in both marginal information costs (β) and institutional barriers (θ). The resulting shift in q_i^* values demonstrates varied resilience profiles. Portugal displayed high resilience, maintaining non-zero q_i^* levels across all actors, including the vulnerable sanitation sector. Spain showed declining but still functional engagement. Italy revealed selective resilience, where small farmers remained engaged while utilities and civil society actors regressed to zero. Greece collapsed entirely under stress: no actor retained any meaningful information adoption capacity. These results illustrate that institutional robustness, rather than sheer economic input, is the critical buffer against climate shocks. Portugal's integrated governance system serves as a reference model, while Greece's fragility highlights the need for foundational institutional investment.

4.2.5. Equity Implications of Governance Capacity

To evaluate the distributional effects of governance reforms (Table 2), Gini coefficients were calculated based on the equilibrium utility values (q_i*) across stakeholder groups in each country. These coefficients indicate the level of inequality in actor influence under different governance scenarios. Higher Gini values correspond to a greater concentration of influence among a few actors, while lower values suggest a more equitable distribution of participation. The calculations followed standard procedures for normalized influence distributions, as detailed in Appendix B.

Table 2. Summary of reform impacts by country.

Country	Avg. Gain in q_i^*	Gini Coefficient	Climate Stress Resilience	Most Benefited Actors	Main Limitations
Greece	Very Low (collapse without integrated reform)	0.750 (extreme inequality)	None—all actors reach $q_i^* = 0$	None engage meaningfully without systemic reform	Severe fragmentation, poor data, low stakeholder trust
Italy	Low to Moderate	0.582 (high inequality)	Low—several actors collapse under stress	Farmers in regions with river contracts	Institutional overlap, weak national inclusion
Portugal	High (all actors maintain $q_i^* > 0$)	0.188 (high equity)	High—all sectors remain functional	Small farmers, rural utilities, NGOs	Regional gaps in digitalization and investment
Spain	Moderate to High	0.259 (moderate equity)	Medium—partial decline, q_i^* remains positive	Farmers, NGOs with medium engagement	Fragmentation between regions and national government

Notes: q_i^* denotes an actor's equilibrium information use propensity. Lower Gini values reflect greater equity in governance capacity. Climate resilience reflects performance under a +20% shock in θ_i and β_i. Source: Sections 4.2.1–4.2.5 and Appendices A and B Table A5.

Greece exhibits extreme inequality (Gini = 0.750) and experiences total collapse without integrated reform, driven by severe fragmentation, systemic distrust, and a lack of meaningful actor engagement under stress. Italy also shows high disparity (Gini = 0.582), with capacity concentrated among a few actors—particularly farmers in regions with river contracts—and limited resilience due to institutional overlap and weak vertical coordination.

By contrast, Spain (Gini = 0.259) and Portugal (Gini = 0.188) display more balanced and resilient governance structures. Portugal achieves high average q_i* values and strong resilience despite regional digitalization and investment gaps, benefiting small farmers, rural utilities, and NGOs. Spain performs moderately well, maintaining positive actor engagement but facing challenges from fragmentation between regional and national governments.

These findings underscore that while governance reforms are viable in Portugal and Spain without worsening inequality, addressing structural exclusion and fragmentation is crucial in Italy and Greece to enable meaningful stakeholder participation. Understanding these equity dynamics is essential for designing governance interventions that are effective, resilient, and socially inclusive.

4.3. Integrated Framework for Reform

The empirical modeling of stakeholder utility under different governance configurations reveals that effective reform in water governance—particularly under climate stress—must be approached as a multidimensional process. The three structural parameters of the model—α_i (marginal benefit), β_i (marginal cost), and θ_i (institutional friction)—are not merely theoretical constructs, but directly map onto concrete policy domains. The integration of these dimensions into a coherent reform strategy can substantially enhance both efficiency and equity in water resource management.

- First, the parameter θ_i captures institutional complexity and fragmentation. High values of θ_i indicate administrative inefficiencies and coordination failures, which are particularly prevalent in Greece and Italy. The model results, corroborated by observed governance patterns, suggest that reducing θ_i through institutional coordination—such as mandate consolidation, cross-agency data sharing, and basin-level integration—is essential. Spain's river basin agencies offer a successful precedent, where binding authority across jurisdictions has helped reduce coordination failures. These models could be adapted to countries with fragmented governance structures to reduce transaction costs and improve responsiveness.
- Second, the parameter β_i reflects the marginal cost of accessing or processing water-related information. Countries and agents with high β_i—such as rural utilities in Greece and NGOs in Italy—face significant barriers to adopting data-driven practices. Reforms aimed at reducing β_i should focus on investments in digital infrastructure, including low-cost sensors, open data platforms, and real-time monitoring systems. Evidence from Portugal shows that even modest investments in SCADA and metering systems can produce high marginal returns when institutional conditions are supportive.
- Third, the parameter α_i quantifies the benefit perceived by agents from using information. Increasing α_i requires incentive structures that reward data-informed and cooperative behavior. Examples include dynamic water pricing, subsidies for digital adoption, participatory budgeting processes, and payments for ecosystem services. Such mechanisms are especially impactful for traditionally marginalized agents such as smallholder farmers and NGOs, whose low initial utility levels can be sharply increased by policies that improve both perceived value and accessibility.

The simulation results demonstrate that reforms targeting any one of these dimensions yield positive but limited gains. However, the most substantial and equitable improvements emerge when reforms are applied simultaneously. In the scenario combining all three interventions—a reduction in θ_i, a decrease in β_i, and an increase in α_i—all countries, including those with initially low governance performance such as Greece, show marked improvements in q_i^*. Notably, agents previously at $q_i^* = 0$, such as regulators and civil society in Greece and Italy, become functionally engaged.

Therefore, the integrated framework for reform is not just additive but synergistic. Coordinated interventions across institutional, economic, and incentive domains produce compounded benefits. This integrated approach aligns the normative principles of good water governance—efficiency, equity, and transparency—with the operational mechanics of the decision model. It ensures that agents are not only willing but also capable of acting upon high-quality information.

Ultimately, an integrated reform strategy enhances governance capacity and resilience across all agent types, particularly under the growing pressures of climate stress. By treating

θ_i, β_i, and α_i as levers of change, policy-makers can craft scalable interventions tailored to their country's institutional architecture, technological base, and socio-economic context.

5. Discussion

5.1. Main Findings

This study reveals three structural governance constraints that systematically undermine effective and equitable water management across Southern Europe: institutional fragmentation (high θ_i), elevated information costs (high β_i), and misaligned incentives (low α_i). These barriers are not evenly distributed: Portugal displays relatively balanced values, while Greece and Italy show sharp disparities, reflected in elevated Gini coefficients and disengagement of key actors ($q_i^* = 0$) under baseline and stress scenarios.

The simulation results demonstrate that individual reforms targeting only one structural constraint produce limited improvements. In contrast, integrated reform packages—combining institutional streamlining, digitalization, and incentive realignment—generate synergistic effects. Notably, actors that were previously inactive (e.g., NGOs and regulators in Greece and Italy) become functionally engaged when all three levers are applied simultaneously. These findings support the broader discourse on climate adaptation, where improvements in governance equity and data infrastructure yield co-benefits in drought resilience and long-term water security.

5.2. Analytical Implications

The use of normalized parameters (α_i, β_i, θ_i) not only enables cross-country comparison but also operationalizes complex institutional and informational asymmetries. These structural variables serve as proxies for deeper political–economic dynamics, such as stakeholder exclusion, institutional inertia, and digital divides. By embedding equity diagnostics (via Gini coefficients) into a formal simulation framework, the model moves beyond efficiency analysis to include questions of distribution, legitimacy, and adaptive capacity. This aligns with the critical water governance literature, which emphasizes power asymmetries, informal institutions, and the socio-political construction of water access. The results highlight how technical reforms (e.g., sensor networks) must be embedded in inclusive and coordinated institutional settings to deliver meaningful change.

5.3. Policy Relevance

The findings underscore that climate-resilient water governance depends on more than technology or funding. Targeted reforms must achieve the following:

- Reduce institutional friction (θ_i) through mandate clarification, inter-agency coordination, and basin-level integration;
- Lower information costs (β_i) by investing in interoperable, open-access digital infrastructure;
- Increase incentive alignment (α_i) via participatory mechanisms, performance-based subsidies, and transparent allocation rules.
- Isolated reforms—such as deploying digital tools without institutional reform—are insufficient to activate marginalized actors or build systemic resilience. The simulations show that even moderate climate shocks (+20% in θ_i and β_i) cause governance systems in Greece and parts of Italy to collapse unless reforms are multidimensional.

As such, this model reinforces the importance of equity, transparency, and coordination as core pillars of drought adaptation. Strengthening these dimensions produces not only governance gains but also co-benefits for climate resilience, infrastructure performance, and social inclusion.

6. Policy Implications and the Proposed Governance Model

The combined empirical findings—especially the high Gini coefficients, agent-level simulations, and structural parameter analysis—lead to a stark conclusion: without comprehensive institutional reform, water governance in Southern Europe will not withstand escalating climate pressures. Fragmented mandates, asymmetric information flows, and weak incentives for collaboration leave critical actors inactive ($q_i^* = 0$), particularly in Greece and Italy. The governance model below translates these insights into a parameter-sensitive, climate-resilient roadmap grounded in EU law yet adaptable to national contexts.

6.1. Reducing Institutional Friction and Information Costs

The simulation results show that high marginal information costs (β_i) and high coordination barriers (θ_i) are the main causes of institutional inertia. In Greece and Italy, where administrative fragmentation is extreme, key actors remain inactive unless both dimensions are addressed. Therefore, reforms must achieve the following:

Reduce θ_i through river basin-level mandate consolidation, formalized inter-agency coordination, and legally binding multi-actor governance bodies.

Lower β_i by deploying low-cost sensor technologies, machine-readable data portals, and interoperable monitoring platforms that democratize access for NGOs, small farmers, and under-resourced regulators.

Without such interventions, actors structurally lack the capacity to engage. Simulations show that partial fixes (e.g., digital tools without institutional reform) are insufficient to trigger activation in high-friction environments.

6.2. Governance Model Anchored in Equity, Transparency, and Innovation

The governance model builds on polycentric theory and OECD water principles but is now empirically grounded in measured inequalities and simulated reform outcomes. It rests on three interconnected pillars:

Equity through Inclusion: Gini analysis reveals stark disparities in access to information and decision-making. Portugal's low Gini (0.188) correlates with active multi-level governance, while Greece's high Gini (0.750) reflects systemic exclusion. To reverse this, reforms must embed stakeholder participation into decision authority---through river basin committees, civic observatories, and user councils with co-decision powers. Equity is no longer a normative goal—it is a condition for system survival.

Transparency to Reduce Friction: Open data mandates must cover hydrological, financial, and regulatory datasets, published in machine-readable, openly licensed formats. This reduces asymmetries, catalyzes peer learning, and curbs corruption, directly lowering θ_i and β_i and activating latent capacity.

Innovation through Localized Experimentation: Decentralized actors should be enabled—and funded—to trial adaptive permitting systems, digital twins, or precision irrigation schemes. Regulatory sandboxes and performance-based grants provide safe channels for rapid testing. These tools allow α_i (incentive sensitivity) to increase where baseline motivation is weak. Importantly, simulations confirm that these three levers must converge: only integrated reform packages moved agents from $q_i^* = 0$ to adoption.

6.3. Modular Scalability Within an EU-Compatible Framework

Reform must be scalable across basins and nations but tailored to institutional maturity. A modular approach allows for the following:

- Pilot-first deployment in one or two basins.
- Iterative learning via structured monitoring and adaptive design.

- Embedding into national strategies aligned with the Water Framework Directive, Floods Directive, and updates to the Urban Waste Water Treatment Directive.
- The implementation of EU instruments—including the Common Implementation Strategy and the European Green Deal's Adaptation Mission—which offer not only funding but also built-in infrastructure for cross-country learning.

While this study focuses on national governance structures, the model could also inform transboundary water governance efforts under the EU's Common Implementation Strategy (CIS). Its structural parameters—particularly institutional friction and information cost—are highly relevant for diagnosing coordination challenges in shared river basins such as the Tagus (Portugal–Spain) or the Evros (Greece–Bulgaria). By offering a standardized diagnostic framework, the model could support basin-level cooperation, the alignment of monitoring protocols, and equitable burden-sharing across national boundaries.

6.4. Urgency, Implementation, and Political Economy Constraints

Recent stress test simulations show that even moderately adverse climate scenarios (+20% in β_i and θ_i) cause governance systems in Greece and Italy to collapse. This transforms reform from a policy improvement into a structural necessity.

Three enablers are essential:

- High-level political commitment, particularly from environment and finance ministries, to drive inter-ministerial alignment.
- Resource decentralization, including trained personnel, IT infrastructure, and stable sub-national budgets.
- Regulatory coherence, avoiding contradictions between EU directives and national law.

Practical mechanisms include binding data exchange protocols; basin committees with budgetary power; and conditional grants tied to cooperation and transparency outcomes.

6.5. Limitations and Future Directions

While robust, the model simplifies real-world politics. It does not capture informal power dynamics, legal loopholes, or real-time shifts in public trust. Moreover, it abstracts from interdependencies with energy and food systems.

Future research should integrate field-based basin studies with stakeholder interviews and scenario analysis to improve the validation of parameter estimates. Expanding simulations to encompass the interconnections between energy, water, and food systems—as well as incorporating regional climate projections—will enhance system-level insights. Additionally, applying machine learning techniques to identify early warning signals of governance failure could offer proactive tools for adaptive management.

Despite its limitations, this framework marks a significant advance. By aligning each reform lever to structural barriers (α_i, β_i, θ_i) and stress testing it under climate disruption, it offers a viable, scalable, and equity-centered path toward resilient water governance in the Mediterranean.

7. Conclusions

This study demonstrates that water governance challenges in Southern Europe are fundamentally shaped by the interplay between information asymmetries and institutional fragmentation. Through a combined methodology—integrating comparative institutional analysis, equity diagnostics based on Gini coefficients, and a formal economic model—it shows that constraints such as high information costs (β_i), fragmented regulatory mandates (θ_i), and weak incentives for cooperation (low α_i) systematically undermine both efficiency and equity in water management. Crucially, the findings indicate that addressing these barriers in isolation delivers only partial gains, while integrated reform strategies generate compound improvements in performance, participation, and resilience.

Theoretically, this study contributes a novel framework by embedding the dynamics of information access, quality, and institutional capacity into adaptive governance models. It reconceptualizes governance not as a neutral delivery mechanism, but as an active infrastructure of adaptation—where data systems, participatory mechanisms, and institutional design co-evolve. Methodologically, it demonstrates how stylized simulations can inform strategic reform design, especially when real-time or primary data are limited.

Practically, the model reveals that certain agents—such as civil society organizations and regulators in Greece and Italy—remain structurally inactive ($q_i^* = 0$) unless multiple barriers are addressed simultaneously. This has profound implications: it suggests that without deliberate efforts to lower information costs, reduce institutional friction, and realign incentives, many governance actors will remain disengaged, regardless of climatic urgency. Conversely, Portugal's relatively balanced performance illustrates how modest investments in digital infrastructure and participatory platforms, when aligned with clear mandates and stakeholder trust, can yield outsized gains in resilience and equity.

Importantly, this analysis reframes governance capacity as a form of invisible infrastructure—equally vital to drought resilience as physical assets like reservoirs or irrigation networks. By treating α_i, β_i, and θ_i as policy levers, the model supports the design of targeted, scalable interventions. It also highlights the possibility of triggering virtuous cycles, where increased information use leads to greater engagement, which in turn generates more accurate data and stronger accountability.

While the model was specifically calibrated for Southern European contexts, its structural parameters—θ_i (institutional friction), β_i (information cost), and α_i (incentive strength)—are conceptually transferable. However, generalizing findings beyond this region requires caution. In Northern and Central Europe, where data infrastructures are often more advanced and institutional mandates more stable, baseline values for θ_i and β_i may be significantly lower, altering reform priorities. Outside the EU, especially in regions where informal governance and regulatory gaps prevail, the model would require substantial adaptation. Future work should explore recalibrating the framework in settings such as Eastern Europe, Latin America, or North Africa, where different institutional logics and socio-political constraints shape water governance outcomes.

Furthermore, this study does not aim to predict outcomes, but to generate hypotheses and support structured experimentation. It abstracts from local political dynamics, informal norms, and sectoral conflicts that often shape real-world implementation. Future research should combine field-based case studies, stakeholder interviews, and institutional ethnographies to refine parameter estimates, validate behavioral assumptions, and explore dynamics of trust and legitimacy. Cross-border governance—particularly in transboundary river basins—also merits further exploration, given the increasing salience of climate risks that transcend national jurisdictions.

In conclusion, this study offers a conceptual and empirical foundation for rethinking water governance in Southern Europe through an integrated lens of information systems, institutional design, and adaptive capacity. In an era of accelerating climate volatility, aligning digital innovation with equitable, well-coordinated institutions is not merely desirable—it is essential. Governance must be seen not as an afterthought to infrastructure, but as infrastructure itself.

Funding: This paper was financed by National Funds of the FCT—Portuguese Foundation for Science and Technology within the project «UIDB/04928/2020» and under the Scientific Employment Stimulus—Institutional Call CEECINST/00051/2018.

Data Availability Statement: All data presented in this study are included in the respective sections.

Conflicts of Interest: The author declares no conflicts of interest.

Appendix A. Data Sources and Summary Tables

This appendix presents summary tables used to inform the exploratory simulations and comparative institutional analysis conducted in this study. The data underlying these tables were compiled from publicly available secondary sources, including the national water regulators and the existing literature.

In Greece, national water governance is overseen by the Special Secretariat for Water (SSW), operating under the Ministry of Environment and Energy. The SSW is responsible for implementing the EU Water Framework Directive, coordinating inter-ministerial policies, developing River Basin Management Plans, and monitoring both the quantity and quality of water resources. Strategic oversight is provided by the National Council for Water (NCW), which validates national planning and ensures coherence with European legislation. At the local and operational level, water services are delivered primarily by large publicly owned utilities such as EYDAP in Athens and EYATH in Thessaloniki, alongside more than 200 smaller municipal companies (DEYA). More information can be found at https://www.eydap.gr/en (accessed on 9 June 2025).

In Italy, the regulatory authority responsible for the water sector is the Autorità di Regolazione per Energia Reti e Ambiente (ARERA), or the Regulatory Authority for Energy, Networks and Environment. The ARERA is an independent national agency that regulates a range of public utilities, including electricity, gas, waste, and integrated water services. In the water domain, the ARERA is tasked with setting tariffs, establishing service quality standards, promoting transparency, and safeguarding consumer rights. It supervises both public and private operators to ensure that service delivery aligns with performance, affordability, and efficiency goals, while also supporting the implementation of European policy frameworks. Additional details are available at https://www.arera.it (accessed on 9 June 2025).

In Portugal, water and wastewater services are regulated by ERSAR, the Water and Waste Services Regulatory Authority (Entidade Reguladora dos Serviços de Águas e Resíduos). ERSAR is an independent public institution responsible for overseeing the quality, economic efficiency, and sustainability of water supply, sanitation, and urban waste services across the country. It defines tariff models, certifies providers, benchmarks operator performance, and ensures public access to service data. ERSAR also plays a key role in enforcing compliance with EU directives and supports participatory governance through collaboration with other institutions such as the Agência Portuguesa do Ambiente (APA) and local basin forums. More information is available at https://www.ersar.pt (accessed on 9 June 2025).

In Spain, water governance is organized through a system of Confederaciones Hidrográficas (River Basin Authorities), which function as decentralized agencies under the Ministry for the Ecological Transition and the Demographic Challenge. Each authority manages a specific river basin, with responsibilities that include water allocation, infrastructure maintenance, quality monitoring, and the development of River Basin Management Plans in compliance with EU directives. A well-known example is the Confederación Hidrográfica del Ebro (CHE), which oversees one of the country's most complex and strategically important basins. This model emphasizes strong regional autonomy and active stakeholder engagement in decision-making processes. More information is available at http://www.chebro.es (accessed on 9 June 2025).

Table A1. Hydrological stress indicators by country and basin.

Country	Basin/Region	Avg. SPEI	Drought Recurrence (Years)	Reservoir Deficit (%)	Source
Greece	Thessaly	−1.7	2.4	38%	[29,30]
Italy	Po	−1.2	3.5	31%	[31,32]
Portugal	Alentejo	−1.4	3.2	28%	[33,34]
Spain	Guadalquivir	−1.6	2.8	35%	[35]

Table A2. Governance characteristics and institutional complexity (θ_i).

Country	Governance Feature	Fragmentation Score (0–1)	Legal Overlap	Coordination Level	Source
Greece	Dispersed authority across ministries	0.85	High	Very Low	[36,37]
Italy	Overlapping mandates (ATOs, regions)	0.75	High	Low	[38,39]
Portugal	Moderate decentralization via ERSAR/INAG	0.40	Low	Medium	[40,41]
Spain	Strong basin agencies, federal structure	0.55	Moderate	High	[26,42]

Table A3. Data access and information cost (β_i).

Country	Real-Time Monitoring	Data Interoperability	Public Access	Information Cost (0–1)	Source
Greece	Very limited	Very Low	Very Low	0.85	[37]
Italy	Fragmented	Low	Low	0.70	[38,43]
Portugal	Partial (SCADA pilots)	Medium	High	0.40	[44,45]
Spain	Variable by basin	Medium–High	Medium	0.50	[46,47]

Table A4. Incentive alignment and information value (α_i).

Country	Pricing Mechanism	Stakeholder Participation	Perceived Utility of Data	Incentive Score (0–1)	Source
Greece	Legacy pricing, top–down planning	Minimal engagement	Very Low	0.30	[30]
Italy	Flat rate in agriculture	Low national inclusion	Low	0.45	[32]
Portugal	Centralized, participatory	Basin forums (active)	High	0.75	[40,41]
Spain	Variable tariffs, reuse pilots	Medium basin engagement	Medium	0.65	[46,48]

Appendix B. Methods, Normalizations, and Simulation Tables

Appendix B.1. Indicator Construction and Normalization Procedure

Three core dimensions were used to assess each actor's strategic governance capacity:

- Influence (I): the actor's ability to shape decisions.
- Capacity (C): the technical or managerial competence of the actor.
- Legitimacy (L): its perceived social and political acceptability.

Each variable was normalized between 0 and 1 using min-max scaling:

$$x_{\text{norm}} = \frac{x - \min(x)}{\max(x) - \min(x)}$$

The composite indicator (S) was derived by applying a weighted aggregation of these components, emphasizing the balance between formal authority and social credibility.

Appendix B.2. Simulation Model Specification

To simulate agents' propensity to use information (q_i^*), three parameters were defined:

- α: marginal benefit of information use.
- β: marginal cost of information access/processing.
- θ: institutional cost or coordination barrier.

The baseline decision model is given by the following:

$$q_i^* = \frac{\alpha}{\beta + \theta}$$

A minimum threshold for θ was imposed to avoid division by zero or unrealistic behavior. Values outside plausible ranges were corrected using damping factors derived from empirical research.

Appendix B.3. Governance Reform Scenario Parameters

Reforms were modeled by adjusting β and θ according to three intervention types:

- Digitalization: reduced β.
- Institutional reform: reduced θ.
- Incentive alignment: reduced both β and marginal institutional cost.

Appendix B.4. Climate Stress Simulation

The stress test modeled a 20% increase in both β and θ for each actor. The recalculated q_i^* values under these stressors were compared to baseline to determine system resilience.

Appendix B.5. Equity Measurement: Gini Coefficients

To assess equity, the Gini coefficient was computed for each country:

$$G = \frac{1}{n}\left(n + 1 - 2\frac{\sum_{i=1}^{n}(n+1-i)q_i^*}{\sum_{i=1}^{n} q_i^*}\right)$$

where q_i^* is the utility of the i-th actor, ordered from lowest to highest.

Table A5. Raw and normalized governance parameters by country and actor.

Country	Actor	α_i (Raw)	β_i (Raw)	θ_i (Raw)	α_i (Norm)	β_i (Norm)	θ_i (Norm)	$q_i^* = \alpha_i/(\beta_i + \theta_i)$
Greece	Small Farmer	0.12	0.60	0.40	0.625	0.600	0.400	0.12
Greece	Water Utility	0.10	0.75	0.30	0.625	0.750	0.300	0.10
Greece	Regulator	0.12	0.70	0.50	0.625	0.700	0.500	0.10
Greece	NGO/Civil Society	0.13	0.70	0.60	0.625	0.700	0.600	0.10
Italy	Small Farmer	0.30	0.40	0.20	0.750	0.500	0.200	0.83
Italy	Water Utility	0.25	0.75	0.25	0.750	0.750	0.250	0.25
Italy	Regulator	0.28	0.60	0.40	0.750	0.600	0.400	0.35
Italy	NGO/Civil Society	0.24	0.70	0.50	0.750	0.700	0.500	0.27
Portugal	Small Farmer	0.40	0.30	0.30	1.000	0.500	0.300	0.57
Portugal	Water Utility	0.45	0.75	0.25	1.000	0.750	0.250	0.50
Portugal	Regulator	0.40	0.60	0.40	1.000	0.600	0.400	0.50
Portugal	NGO/Civil Society	0.35	0.70	0.50	1.000	0.700	0.500	0.44
Spain	Small Farmer	0.35	0.30	0.30	0.875	0.500	0.300	0.58
Spain	Water Utility	0.30	0.75	0.25	0.875	0.750	0.250	0.35
Spain	Regulator	0.32	0.60	0.40	0.875	0.600	0.400	0.40
Spain	NGO/Civil Society	0.28	0.70	0.50	0.875	0.700	0.500	0.35

Notes: Raw values were normalized using min-max scaling. Minimum threshold $\alpha_i^{min} = 0.05$ was applied. Values of q_i^* are computed using Equation (1).

Table A6. Effects of governance reforms on q_i^*.

Country	Agent	αnorm	βnorm	θnorm	q_i^* (Base)	Digital	Institutional	Incentives	All Combined
Greece	Small Farmer	0.625	0.60	0.40	0.06	0.69	0.68	0.69	0.83
Greece	Water Utility	0.625	0.75	0.30	0.00	0.65	0.63	0.67	0.78
Greece	Regulator	0.625	0.70	0.50	0.00	0.57	0.57	0.57	0.69
Greece	NGO/Civil Society	0.625	0.70	0.60	0.00	0.53	0.53	0.52	0.64
Italy	Small Farmer	0.750	0.50	0.20	1.25	1.18	1.14	1.20	1.41
Italy	Water Utility	0.750	0.75	0.25	0.00	0.83	0.79	0.85	0.99

Table A6. *Cont.*

Country	Agent	αnorm	βnorm	θnorm	q_i^* (Base)	Digital	Institutional	Incentives	All Combined
Italy	Regulator	0.750	0.60	0.40	0.38	0.83	0.82	0.82	0.99
Italy	NGO/Civil Society	0.750	0.70	0.50	0.10	0.69	0.68	0.68	0.83
Portugal	Small Farmer	1.000	0.50	0.30	1.67	1.38	1.35	1.38	1.65
Portugal	Water Utility	1.000	0.75	0.25	1.00	1.10	1.05	1.13	1.31
Portugal	Regulator	1.000	0.60	0.40	1.00	1.10	1.09	1.10	1.33
Portugal	NGO/Civil Society	1.000	0.70	0.50	0.60	0.92	0.91	0.91	1.11
Spain	Small Farmer	0.875	0.50	0.30	1.25	1.20	1.18	1.21	1.45
Spain	Water Utility	0.875	0.75	0.25	0.50	0.96	0.92	0.99	1.15
Spain	Regulator	0.875	0.60	0.40	0.69	0.96	0.95	0.96	1.16
Spain	NGO/Civil Society	0.875	0.70	0.50	0.35	0.80	0.80	0.80	0.97

Table A7. q_i^*. under climate stress (+20% β, θ).

Country	Agent	α (Norm)	β (Stress)	θ (Stress)	q_i^* (Stress)
Greece	Small Farmer	0.625	0.72	0.48	0.00
Greece	Water Utility	0.625	0.90	0.36	0.00
Greece	Regulator	0.625	0.84	0.60	0.00
Greece	NGO/Civil Society	0.625	0.84	0.72	0.00
Italy	Small Farmer	0.750	0.60	0.24	0.63
Italy	Water Utility	0.750	0.90	0.30	0.00
Italy	Regulator	0.750	0.72	0.48	0.06
Italy	NGO/Civil Society	0.750	0.84	0.60	0.00
Portugal	Small Farmer	1.000	0.60	0.36	1.11
Portugal	Water Utility	1.000	0.90	0.30	0.33
Portugal	Regulator	1.000	0.72	0.48	0.58
Portugal	NGO/Civil Society	1.000	0.84	0.60	0.27
Spain	Small Farmer	0.875	0.60	0.36	0.76
Spain	Water Utility	0.875	0.90	0.30	0.00
Spain	Regulator	0.875	0.72	0.48	0.32
Spain	NGO/Civil Society	0.875	0.84	0.60	0.06

Table A8. Gini coefficients and stakeholder utilities.

Country	Small Farmer	Water Utility	Regulator	NGO/Civil Society	Gini
Greece	0.06	0.00	0.00	0.00	0.750
Italy	1.25	0.00	0.38	0.10	0.582
Portugal	1.67	1.00	1.00	0.60	0.188
Spain	1.25	0.50	0.69	0.35	0.259

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