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Article

Water Resource Management and Transition to a Green Economy: Institutional and Economic Mechanisms in Uzbekistan

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Abstract: Uzbekistan faces one of the most acute water resource crises in Central Asia, characterised by shrinking freshwater availability, the ecological catastrophe of the Aral Sea, and intensifying pressure from irrigated agriculture that consumes approximately 92% of total water withdrawals. Simultaneously, the country's commitment to the Paris Agreement and its National Green Economy Strategy has elevated water governance to a strategic policy priority. This article analyses the institutional and economic mechanisms governing water resource management in Uzbekistan, with a particular focus on their alignment with green economy principles. Applying a mixed-methods approach — combining secondary data analysis, institutional mapping, and a multi-criteria assessment framework — the study evaluates six core mechanisms: the basin-level Water User Associations (WUAs), economic water pricing instruments, green investment financing, transboundary water cooperation within the ICWC framework, digital water monitoring (IoT/remote sensing), and integrated water–energy–food (WEF) nexus governance. Quantitative findings reveal that irrigation efficiency stands at only 53–58%, implying a potential water-saving of 11–14 km³/year if best practices are adopted. Green bonds for water infrastructure remain nascent (USD 47 million issued by 2023), while the gap between required and actual investment in water infrastructure is estimated at USD 1.8–2.3 billion annually. The article proposes a five-pillar institutional reform agenda and presents a quantified scenario analysis for 2030, projecting that a comprehensive green transition could raise irrigation efficiency to 72–75%, reduce water-related GDP losses by 3.2 percentage points, and mobilise USD 4.6 billion in climate finance. These results provide evidence-based guidance for policymakers, development banks, and academic researchers engaged in water–climate–economy nexus studies.

Keywords: Water resource management; green economy; Uzbekistan; institutional mechanisms; water pricing; Aral Sea; WEF nexus; Central Asia; irrigation efficiency; climate finance.

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Introduction

Water scarcity has emerged as one of the defining challenges of the 21st century, particularly in arid and semi-arid regions where population growth, agricultural expansion, and climate change converge into compounding pressures on freshwater systems. Uzbekistan — the most populous country of Central Asia with approximately 36.3 million inhabitants (UN DESA, 2023) — occupies a paradoxical position: it is simultaneously a country of significant water resources and a country in deep water crisis. The Amu Darya and Syr Darya rivers, which traverse the region, provide the bulk of water supply for five riparian states, yet their combined flow has declined by an estimated 30%

over the past four decades owing to upstream glacier retreat, increased agricultural withdrawals, and land-use change (World Bank, 2023a). The environmental legacy of Soviet-era irrigation expansion is most dramatically illustrated by the Aral Sea, once the world's fourth-largest inland body of water[1]. By 2023, the sea had lost more than 90% of its volume and split into disconnected remnant basins, creating a desertification zone of approximately 60,000 km² (UNEP, 2022). The economic cost of the Aral Sea crisis to the five Central Asian states is estimated at USD 1–1.5 billion annually in lost fisheries, public health costs, and agricultural productivity decline (ADB, 2023).

Against this backdrop, Uzbekistan has pursued an ambitious dual agenda: reforming the institutional architecture governing water allocation while simultaneously building the foundations of a green economy. The country's National Green Economy Strategy (NGES, 2019–2030) sets binding targets for energy efficiency, renewable energy penetration (25% by 2030), and sustainable water use, with total green investment requirements estimated at USD 8–12 billion (UNDP Uzbekistan, 2022). However, the degree to which institutional reforms have been operationalised, and the extent to which economic mechanisms align with green economy principles, remain empirically underexplored[2].

Literature Review

The issue of water resource management in Uzbekistan has become one of the central themes in contemporary studies on sustainable development, climate adaptation, and green economic transformation. In the academic and policy literature, Uzbekistan is frequently described as a water-stressed country whose economic stability is closely linked to the efficient use of irrigated land, rational allocation of water, and modernization of resource governance. This is largely because agriculture remains heavily dependent on irrigation, while climate change, population growth, land degradation, and outdated infrastructure are intensifying pressure on available water resources. Recent World Bank assessments emphasize that irrigation and drainage are essential for sustaining agricultural production and rural livelihoods in Uzbekistan, but they also underline that the current model of water use is increasingly difficult to maintain under changing climatic and economic conditions.

A substantial part of the literature views water management not merely as a technical matter, but as a strategic institutional and economic issue. Scholars and international organizations argue that Uzbekistan’s water challenge is deeply connected with the structure of the national economy, especially the dependence of agricultural output on irrigated farming. In this context, water scarcity is interpreted as a factor that affects food security, export potential, employment, energy consumption, and regional environmental stability. The literature further notes that the degradation of water systems in Central Asia, including the long-term consequences associated with excessive irrigation and the Aral Sea crisis, has shaped the current discourse on sustainability in Uzbekistan. For this reason, modern studies increasingly position water governance at the intersection of environmental policy, agricultural reform, and long-term green growth strategy.

Another major theme in the literature concerns the institutional foundations of water governance. Existing research shows that Uzbekistan has historically relied on a centralized model of water administration, where state agencies play the dominant role in allocation, planning, operation, and monitoring. However, more recent reforms indicate a shift toward more coordinated and efficiency-oriented governance. Legal and policy developments in 2026, including new measures on rational water use in irrigation systems and the reduction of water losses, suggest that the government is strengthening its response to water scarcity through updated institutional mechanisms and tighter management practices. The literature generally interprets these changes as evidence that the state recognizes water management as a national development priority. At the same time, many authors argue that institutional modernization must go beyond legal reforms

and include stronger accountability, inter-agency coordination, basin-level management, and more effective monitoring systems.

In the literature, the concept of integrated water resources management occupies an important place in discussions about Uzbekistan's reform path. This approach is valued because it links economic efficiency, environmental protection, and social equity within one governance framework. Researchers argue that integrated management is particularly relevant for Uzbekistan because the country's water problems are not limited to one sector; they affect irrigation, ecosystems, energy use, local communities, and regional cooperation. Nevertheless, the literature also warns that the implementation of integrated approaches requires more than adopting international terminology. Effective reform depends on whether basin governance, local user participation, financing mechanisms, and data systems are sufficiently developed to support practical decision-making. Therefore, the scholarly consensus is that institutional adaptation to national realities is more important than the formal imitation of external models.

The economic literature on water management in Uzbekistan focuses strongly on efficiency, incentives, and investment. A recurring argument is that physical rehabilitation of canals, pumping stations, and irrigation networks will not generate lasting results unless supported by sound economic mechanisms. World Bank analyses note that irrigation and drainage in Uzbekistan are highly energy-intensive, and that improvements in water delivery and pumping efficiency can generate substantial savings while also contributing to decarbonization goals. This means that water sector reform is increasingly linked to the broader economic agenda of reducing waste, improving productivity, and lowering the energy burden of agriculture. In this perspective, economic instruments such as better cost recovery, performance-based management, more accurate water accounting, and investment in water-saving technologies are presented as key elements of sustainable resource governance.

The literature on Uzbekistan's green economy transition further broadens the discussion by placing water resource management within a larger framework of climate resilience and structural transformation. National and international policy documents describe the green transition as a process that requires more efficient use of land, water, and energy resources, combined with institutional reform and long-term investment planning. In this context, water is treated as one of the most critical resources for achieving sustainable growth, because it directly affects agricultural productivity, ecosystem stability, and rural welfare. The Country Climate and Development analyses related to Uzbekistan stress that the green transition must involve behavioral change, targeted policies, and better public and private investment decisions. Water management reform is therefore increasingly viewed not only as a sectoral necessity, but as a core condition for resilient economic development.

Materials And Methods

This study employs a sequential mixed-methods design (Creswell & Plano Clark, 2018), combining: (a) systematic review of secondary data from authoritative international and national sources; (b) institutional mapping using the Institutional Analysis and Development (IAD) framework (Ostrom, 1990, 2009); (c) quantitative performance scoring via a Multi-Criteria Assessment (MCA) matrix; and (d) scenario modelling using the Water-Energy-Food (WEF) nexus accounting approach developed by the International Institute for Applied Systems Analysis (IIASA, 2021).

The IAD framework was applied to identify actors, rules-in-use, biophysical conditions, and outcomes at three governance levels: constitutional (national legislation), collective choice (basin organisations), and operational (irrigation systems and WUAs). Institutional performance was scored on five dimensions — coherence, capacity, accountability, adaptability, and financing — using a 1–5 Likert scale based on document analysis and expert validation (n=15 water governance specialists).

The MCA matrix evaluates six economic and institutional mechanisms against seven criteria: economic efficiency, environmental effectiveness, equity, administrative feasibility, political acceptability, scalability, and climate alignment. Each criterion was weighted using the Analytic Hierarchy Process (AHP), with weights derived from expert elicitation. The study has several limitations that should be acknowledged. First, WUA survey data were collected from four provinces, limiting the generalisability of operational findings to all 14 regions of Uzbekistan. Second, the MCA framework relies on expert judgements that may carry implicit biases. Third, scenario projections are contingent on policy assumptions that may not materialise. Fourth, transboundary data quality from upstream riparian states (Tajikistan, Kyrgyzstan) remains inconsistent, introducing uncertainty into volume balance calculations[3].

Results And Discussion

The institutional architecture of water resource management and green transition in Uzbekistan is built around a multilayered governance system in which strategic direction is set at the national level, sectoral coordination is exercised through specialized ministries, and implementation is carried out through basin, regional, and local administrative structures. In this system, governance is not confined to a single ministry; rather, it operates through an interdependent arrangement of executive authorities, sector regulators, territorial bodies, and project-based institutions. The overall logic of this architecture reflects Uzbekistan's broader state-led development model, where major environmental and resource decisions are guided by central policy priorities and then transmitted downward through a hierarchical administrative structure[4]. Recent official materials show that water policy is now increasingly linked to environmental protection, climate adaptation, and green economic modernization, indicating a gradual shift from narrow irrigation administration toward more integrated governance.

At the apex of this system stands the Cabinet of Ministers and the broader executive branch, which provide the overarching policy framework for water governance and the transition to a green economy. Their role is not limited to approving strategic documents; they also define institutional mandates, establish coordination mechanisms, and authorize reforms affecting ministries and subordinate agencies[5]. In the green economy sphere, official regulatory documents indicate that a dedicated management system for the transition to a "green" economy has been formally established, which means that green development is being treated as a cross-sector governance issue rather than an isolated environmental agenda. This is important because it places water management within a wider state coordination framework involving fiscal policy, economic planning, climate policy, and infrastructure modernization.

The governance architecture for water resources in Uzbekistan is a layered system spanning four levels: international, national, basin, and local. Figure 1 presents the institutional hierarchy based on IAD mapping[6].

Figure 1. Institutional hierarchy of water resource governance in Uzbekistan.

LEVEL 1 — INTERNATIONAL

ICWC *Interstate Commission for Water Coordination*	**IFAS** *International Fund for Saving the Aral Sea*	**UN Water / FAO** *SDG 6 Monitoring Framework*

↓

LEVEL 2 — NATIONAL

MWRWR	**MoEFP**	**Cabinet of Ministers** *National Green Economy Strategy (NGES)*

Ministry of Water Resources & Water Supply	*Ministry of Ecology, Environment & Climate*	

↓

LEVEL 3 — BASIN / REGIONAL

BWOs *Basin Water Organisations (4)*	**BISA** *Basin Irrigation System Administrations*	**Provincial Authorities** *Khokimiyats — Regional Water Depts.*

↓

LEVEL 4 — LOCAL / OPERATIONAL

WUAs *1,625 Water User Associations*	**ARIS** *Agency for the Reconstruction of Irrigation Systems*	**Farmers / Dehqan** *End-users: 4.28 million ha irrigated*

Note: MWRWR = Ministry of Water Resources and Water Supply of the Republic of Uzbekistan; ICWC = Interstate Commission for Water Coordination; IFAS = International Fund for Saving the Aral Sea; BWOs = Basin Water Organisations; WUAs = Water User Associations; ARIS = Agency for Reconstruction of Irrigation Systems.

The IAD analysis reveals that while formal institutional structures are well-established at constitutional and collective-choice levels, significant gaps persist at the operational level. Water User Associations, introduced under Presidential Decree No. UP-3072 (1997), now cover 1,625 systems serving approximately 3.6 million hectares. However, survey findings indicate that only 38% of WUAs have functioning metering infrastructure, 44% report chronic financial deficits, and merely 27% possess legally valid statutes aligned with the revised Water Code of 2020 (MWRWR, 2023). These structural deficiencies constrain the ability of local institutions to enforce water allocation decisions or implement conservation incentives[7].

Within the sectoral structure, the Ministry of Water Resources occupies the central operational position in the governance system. It functions as the principal state body responsible for water allocation, irrigation system administration, and the management of water infrastructure related to agriculture and land reclamation. Official and project documentation describe the ministry as the institution that allocates water among users, implements sector strategy, supervises irrigation facilities, and coordinates basin and regional departments[8]. Its institutional importance stems from the fact that Uzbekistan's economy remains highly dependent on irrigated agriculture; consequently, the ministry serves not only as a technical administrator but also as a key economic governance actor. In practice, its mandate connects water delivery, agricultural productivity, pumping station management, infrastructure rehabilitation, and increasingly, energy efficiency and public-private partnership initiatives[9].

Institutional performance assessment.

Table 1. Institutional performance scores by governance level (IAD Multi-Dimensional Assessment).

Governance Level / Institution	Coherence	Capacity	Account-ability	Adapt-ability	Financing	Composite Score
MWRWR (National)	4.1	3.8	3.2	3.5	3.0	**3.52 / 5.0**

ICWC (International)	3.8	3.5	2.8	2.9	2.5	**3.10 / 5.0**
Basin Water Organisations (BWOs)	3.6	3.2	2.9	3.1	2.7	**3.10 / 5.0**
Water User Associations (WUAs)	2.4	2.1	2.3	2.0	1.8	**2.12 / 5.0 ⚠**
ARIS (Infrastructure Agency)	3.5	3.0	2.7	2.8	2.4	**2.88 / 5.0**
System Average	3.48	3.12	2.78	2.86	2.48	**2.94 / 5.0**

Note: Scoring scale 1 (very poor) — 5 (excellent). ⚠ Scores below 2.5 indicate critical underperformance. Source: Authors' calculations based on expert survey (n=15) and document analysis.

Economic mechanisms: multi-criteria assessment. Six economic and institutional mechanisms were evaluated against seven criteria using the AHP-weighted MCA matrix. Table 4 presents the results. Water pricing and digital monitoring emerged as the two highest-performing mechanisms, while green bonds remained the lowest-scoring owing to nascent capital market development and limited investor familiarity[10].

A distinctive feature of Uzbekistan's institutional design is the use of a basin-based territorial structure under the Ministry of Water Resources. Official ministry information shows that the national water administration is implemented through a network of basin irrigation systems departments and regional units, including structures such as the Amu-Bukhara, Zarafshan, Norin-Syrdarya, Chirchik-Ohangaron, Lower Syrdarya, and other basin administrations. This arrangement reflects an attempt to align governance with hydrological realities rather than relying solely on conventional provincial boundaries. From an institutional perspective, basin structures play a crucial intermediary role: they translate central policy into operational water distribution, maintenance, and monitoring decisions, while also linking national authorities with district-level implementation. Such an architecture is especially important in a country where water allocation is both geographically uneven and economically sensitive[11].

At the same time, the water governance system is not purely sectoral, because it intersects with the mandates of other institutions. The Ministry of Ecology, Environmental Protection and Climate Change plays an increasingly important role in environmental oversight, ecological restoration, wetland preservation, and climate adaptation agendas related to water systems[12]. Recent government publications show regular joint engagement between the ecology authorities, water management bodies, local authorities, scientific institutions, and international organizations on issues such as river basin resilience, environmental flows, and adaptation planning. This demonstrates that the institutional architecture is moving toward a more integrated model in which water is recognized not only as an agricultural input but also as a component of ecosystem governance and climate policy[13].

Table 2. Multi-criteria assessment of water governance mechanisms (AHP-Weighted Scores).

Mechanism	Economic Efficiency	Environmental Effectiveness	Equity	Admin. Feasibility	Political Accept.	Scalability	Weighted Score
(M1) Water pricing reform	4.5	4.2	2.9	3.8	2.5	4.0	**3.73**
(M2) Digital monitoring (IoT/RS)	4.2	4.5	3.5	3.2	4.0	4.3	**3.90**
(M3) WEF Nexus planning	3.8	4.0	3.8	2.8	3.5	3.7	**3.60**
(M4) WUA institutional reform	3.5	3.3	4.0	3.0	3.8	3.5	**3.51**
(M5) Transboundary cooperation	3.2	3.8	3.5	2.5	2.8	3.0	**3.13**
(M6) Green bond financing	3.0	3.5	2.8	2.3	3.0	2.5	**2.85**
AHP criterion weights →	0.22	0.20	0.14	0.15	0.13	0.16	**CR = 0.04 ✓**

Note: Scores 1–5. CR = Consistency Ratio (CR < 0.10 indicates acceptable AHP consistency). Source: Expert elicitation and authors' calculations.

Water pricing analysis. Water pricing is identified as the highest-impact economic mechanism (M1 composite 3.73). Uzbekistan currently operates a volumetric surface-water charge system introduced under Government Resolution No. 265 (2009), subsequently revised in 2015 and 2021. However, effective tariff rates remain substantially below cost-recovery levels, creating structural under-investment incentives[14].

Another major institutional pillar is the Ministry of Economy and Finance, whose role has expanded as green transition policy becomes more closely tied to budgeting, investment planning, and public-private partnership mechanisms. Official materials show that this ministry participates in the establishment of green economy governance arrangements and is also involved in PPP-related water infrastructure initiatives. This reveals an important institutional evolution: water governance is no longer framed solely in administrative or engineering terms, but increasingly in fiscal and investment terms as well. In other words, the governance system now includes not only those who distribute water, but also those who design incentives, mobilize capital, and structure long-term investment for modernization[15].

The governance map also includes project implementation and specialized coordination units, which are especially important in internationally financed reforms. Official project documents refer to a Center for the Implementation of Foreign Investment Projects in Water Resources and similar project-oriented structures that connect national ministries with donors, basin authorities, contractors, and affected communities. These bodies serve as institutional bridges between strategy and execution, particularly in large irrigation modernization, climate adaptation, and energy-efficiency programs. Their presence suggests that Uzbekistan's water governance architecture is becoming more hybrid: it remains state-centered, but it increasingly incorporates project management units, international financing arrangements, and donor-supported technical coordination[16].

Table 3. Water tariff structure and cost-recovery gap (2023).

Water Use Category	Current Tariff (UZS/m³)	Full Cost-Recovery Tariff (UZS/m³)	Cost-Recovery Ratio (%)	Annual Revenue Gap (USD mln)
Irrigation (cotton & grain)	12–18	85–110	**14–21%**	**~310**
Irrigation (horticulture)	20–30	85–110	**23–35%**	**~180**
Drinking water (urban)	640–850	1 100–1 500	**58–77%**	**~75**
Drinking water (rural)	210–380	1 100–1 500	**19–34%**	**~60**
Industrial withdrawal	320–420	500–650	**64–65%**	**~25**
TOTAL ANNUAL GAP	—	—	**~34% avg.**	**~USD 650 mln**

Note: UZS = Uzbek soum. Exchange rate used: 1 USD = 12,400 UZS (Central Bank of Uzbekistan, Dec. 2023). Sources: MWRWR tariff schedule 2023; authors' calculations.

Green finance and investment analysis. Green finance flows to the water sector remain substantially below requirement. The study identifies a structural financing gap of USD 1.8–2.3 billion per year between actual investment levels and the capital required to meet NGES 2030 targets (Figure 2).

Figure 2. Water sector investment gap analysis: actual vs. required (USD million, 2019–2023).

Water sector investment: actual vs. required (USD million per year)					
Category	**2019**	**2020**	**2021**	**2022**	**2023**
Required investment (NGES target)	2 350	2 490	2 680	2 890	3 100
Actual public investment	480	520	590	640	710
International climate finance	190	210	240	270	290
Private sector & green bonds	45	52	68	85	110
TOTAL ACTUAL	**715**	**782**	**898**	**995**	**1 110**
INVESTMENT GAP ▼	**▼ 1 635**	**▼ 1 708**	**▼ 1 782**	**▼ 1 895**	**▼ 1 990**

WEF nexus analysis and irrigation efficiency. The Water-Energy-Food nexus analysis reveals tightly coupled interdependencies that amplify the cost of water inefficiency beyond the water sector itself. Irrigation currently accounts for approximately 42% of total energy consumption in Uzbekistan's rural sector (pumping infrastructure), while food production depends almost entirely on irrigated cultivation (88% of crop output). A 10% reduction in irrigation water use, if achieved through efficiency gains, would reduce agricultural energy demand by an estimated 3.8–4.2 TWh annually (MoEFP, 2023), equivalent to the output of a 500 MW thermal power unit[17].

Table 4. WEF nexus interlinkage matrix for Uzbekistan's water sector.

Nexus Dimension	Key Indicator	Current Status (2023)	Green Economy Target (2030)
Water → Energy	Energy intensity of irrigation (kWh/m³)	0.38–0.52 kWh/m³	**< 0.25 kWh/m³ (−40%)**
Water → Food	Water productivity (USD/m³ irrigation)	0.08–0.12 USD/m³	**> 0.22 USD/m³ (+83%)**
Energy → Water	Renewable energy in water pumping (%)	< 4%	**> 30% (solar pumps)**
Food → Water	Agricultural water use per unit GDP (m³/$)	18.4 m³/$	**< 10 m³/$ (−46%)**
GHG — Water nexus	CH_4 from waterlogged soils ($MtCO_2e$/yr)	~8.3 $MtCO_2e$	**< 5.0 $MtCO_2e$ (drainage reform)**

Scenario analysis: 2030 projections. Three scenarios were constructed for 2030: Baseline (no additional policy intervention), Moderate Reform (partial implementation of NGES targets), and Optimal Green Transition (full implementation with structural reform). Key assumptions and quantitative outputs are presented in Table 5.

Table 5. Scenario analysis: water sector and macroeconomic outcomes by 2030.

Indicator	Baseline (BAU)	Moderate Reform	Optimal Green Transition
Irrigation efficiency (%)	56–60%	64–68%	**72–75%**
Annual water saved (km³/year)	~1.5	~6.2	**~13.5**
Water-related GDP loss (% GDP)	5.1%	3.8%	**1.9%**
Green climate finance mobilised (USD bn)	1.2	2.8	**4.6**
Aral Sea sub-basin inflow increase (%)	−3% (continued decline)	+8%	**+18%**
Agricultural water productivity (USD/m³)	0.11	0.16	**0.23**
GHG reduction vs. baseline ($MtCO_2e$/yr)	—	−5.5	**−12.8**
Required additional annual investment (USD bn)	0.3	1.4	**3.2**
Cost-benefit ratio (NPV, 10-year, 6% discount)	0.8 : 1	1.9 : 1	**3.4 : 1**

Note: BAU = Business-As-Usual. Scenarios are based on WEF Nexus modelling and World Bank infrastructure cost benchmarks. All monetary values in 2023 constant USD. Source: Authors' scenario model.

At the subnational level, regional authorities, district structures, and local community institutions perform an auxiliary but important governance function. In practice, national and basin-level decisions require local coordination for implementation,

monitoring, land-use adaptation, social communication, and community-level compliance. Official project documentation also highlights the role of mahallas as recognized local community institutions that function as interfaces between state authorities and residents. This means that the governance system should be understood not simply as a vertical bureaucratic chain, but as a layered administrative network in which central ministries, basin authorities, district actors, and local communities interact around the allocation and use of water resources[18].

From an analytical point of view, the institutional architecture of Uzbekistan reveals both strengths and constraints. Its main strength lies in its administrative reach: the state possesses a formal chain of authority extending from national strategy to basin and regional implementation. This makes it possible to mobilize reforms quickly, coordinate infrastructure projects, and integrate water governance into broader economic and environmental programs. However, the same architecture may also create coordination challenges, especially when responsibilities overlap across water, ecology, finance, and territorial administration. The literature and official reform trajectory therefore suggest that the future effectiveness of this governance system will depend on how well Uzbekistan can improve horizontal coordination, strengthen basin-level decision-making, enhance data and monitoring systems, and align economic incentives with institutional responsibilities[19].

Interpreting institutional performance deficits. The IAD-based performance assessment reveals a consistent pattern of institutional degradation with depth: while national-level agencies demonstrate moderate coherence and capacity (composite scores 3.5/5.0), local-level institutions — particularly WUAs — score critically low across all dimensions (composite 2.12/5.0). This finding aligns with Ostrom's (2009) observation that polycentric governance systems frequently exhibit a 'last-mile' implementation gap where constitutional rules are formally enacted but operational rules remain weakly enforced[20]. In Uzbekistan's case, the disconnect appears to be amplified by three structural factors: chronic under-financing of local operations (WUAs depend on water fees covering only 18–22% of actual costs), a legacy of top-down administrative culture inhibiting participatory rule-making, and insufficient technical capacity for metering and data management.

These findings contrast somewhat with the optimistic assessments in earlier literature (Abdullaev & Rakhmatullaev, 2015; Dinar et al., 2021), which document the formal introduction of IWRM principles into Uzbek water law but do not rigorously assess the gap between de jure and de facto implementation. Our multi-dimensional scoring approach fills this analytical gap by distinguishing institutional design (where Uzbekistan performs reasonably well) from institutional practice (where significant deficits remain)[21].

Water pricing: balancing efficiency and equity. The pricing analysis (Table 5) demonstrates that current tariff levels — covering only 14–35% of full cost-recovery for irrigation — constitute a de facto subsidy to agricultural water users estimated at USD 490–650 million annually. From a standard welfare economics perspective, this subsidy distorts factor prices, suppresses conservation incentives, and creates a fiscal burden that constrains infrastructure investment. These findings are consistent with the broader literature on water tariff reform in transition economies (Tsur, 2005; Molle & Berkoff, 2007).

However, an important equity dimension must not be overlooked. Approximately 27% of Uzbekistan's rural population remains in poverty, and smallholder farmers — who constitute the majority of WUA members — face income volatility from climate-related crop failures[22]. A rapid move to full cost-recovery pricing without complementary safety nets could disproportionately harm the most vulnerable agricultural households. This tension between economic efficiency (pricing reform) and social equity is reflected in the

M1 (water pricing) MCA score on the equity criterion , the lowest of all criteria for that mechanism.

The study therefore recommends a phased tariff reform pathway, beginning with larger commercial farms and gradually extending to smallholders with income-conditioned rebate schemes — a model successfully applied in Morocco's National Water Plan (Tber et al., 2022).

Green finance: closing the investment gap. The investment gap analysis (Figure 2) reveals a structural shortfall of USD 1.6–2.0 billion per year between actual and required water sector investment. Green bonds issued to date (USD 47 million cumulative through 2023) represent less than 1.5% of the annual gap, indicating that capital market instruments remain a peripheral financing source. This contrasts with comparable green economy transitions in Kazakhstan (green bonds: USD 1.2 billion by 2023) and Georgia (USD 380 million), suggesting that Uzbekistan's capital market development and sovereign credit infrastructure present binding constraints[23].

Three complementary financing pathways are identified in the literature and supported by scenario modelling: multilateral development bank (MDB) blended finance — which can leverage 3–5 USD in private capital per 1 USD of concessional public investment; climate payment-for-ecosystem-services (PES) schemes, particularly for upstream watershed protection and Aral Sea basin restoration; and diaspora bonds, leveraging the approximately USD 8.8 billion annual remittance inflow from Uzbek labour migrants to mobilise long-term domestic savings for water infrastructure.

Digital monitoring as a transformative enabler. Digital water monitoring (M2) achieved the highest composite MCA score, reflecting its cross-cutting enabling role across efficiency, accountability, and scalability dimensions. The deployment of IoT sensor networks, satellite remote sensing for evapotranspiration estimation, and SCADA systems for canal flow monitoring offers the potential to reduce non-revenue water losses — estimated at 28–35% of total canal delivery — by up to 40–50% within a 5-year investment horizon (World Bank, 2023b). Critically, digital monitoring addresses the enforcement deficit identified in WUA institutional performance: real-time meter data can reduce disputes over water allocation, enable transparent billing, and create a verifiable record for regulatory oversight.

Conclusion

This study has provided a comprehensive analysis of the institutional and economic mechanisms governing water resource management in Uzbekistan, situating these within the broader framework of green economy transition. Four principal conclusions emerge.

First, Uzbekistan possesses a formally adequate constitutional and collective-choice institutional framework for water governance, but faces a severe last-mile implementation gap at the operational level. Water User Associations — the primary vehicle for local water management — are systematically under-resourced, weakly accountable, and inadequately equipped for data-driven decision-making. Addressing this gap is the foundational prerequisite for any meaningful green economy transition in the water sector.

Second, water pricing remains the mechanism with the greatest untapped potential for economic efficiency gains, but reform must be sequenced carefully to protect smallholder welfare. The estimated annual subsidy of USD 490–650 million embedded in below-cost tariffs constitutes a major distortion that both suppresses conservation incentives and crowds out infrastructure investment.

Third, the investment gap — averaging USD 1.8–2.0 billion annually — cannot be closed by public finance alone. Mobilising private capital through green bonds, blended finance structures, and payment-for-ecosystem-services mechanisms is essential. Uzbekistan's nascent but growing capital markets, combined with strong MDB engagement, provide a credible platform for scaling these instruments.

Fourth, scenario analysis demonstrates that the optimal green transition pathway — if comprehensively implemented — could deliver a cost-benefit ratio of 3.4:1 over a 10-year horizon, increase agricultural water productivity by 83%, reduce water-related GDP losses by 3.2 percentage points, and mobilise USD 4.6 billion in climate finance. These returns underscore that green water governance is not merely an environmental imperative but a sound macroeconomic investment.

Future research should focus on disaggregated provincial analysis of WUA performance, dynamic modelling of climate change impacts on the Amu Darya and Syr Darya flows under SSP scenarios, and evaluation of pilot green bond issuances as natural experiments in capital market development.

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