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GREENFIELD DEVELOPMENT OF CANAL-BASED SMALL HYDROPOWER IN UZBEKISTAN: SITE SCREENING, PPP RISK ALLOCATION AND CLIMATE RESILIENCE THROUGH THE WATER-ENERGY-FOOD NEXUS

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Abstract: Uzbekistan is seeking to expand hydropower while modernizing an irrigation system that supports rural livelihoods and dominates national water use. Existing canals create a distinctive greenfield opportunity: small plants can add distributed renewable generation with limited new inundation, but their output remains subordinate to irrigation schedules, water rights and climate uncertainty. This paper develops an integrated framework for converting a large site list into an investable portfolio. It combines policy and project-document review with a two-stage multi-criteria model, hydrological stress testing and normative public-private partnership risk allocation. Stage 1 applies fatal-flaw gates for water access, irrigation non-impairment, grid and land feasibility, and environmental-social eligibility. Stage 2 ranks eligible sites by water reliability, energy yield, irrigation compatibility, cost, connection, impact and sponsor readiness. An illustration shows why a high-head location can rank below a more water-compatible site. The financing design links concessional wholesale funding and local banks to project companies, standardized contracts and verified operating data. Climate parameters remain scenarios: the severe case tests a 30–40 percent water-availability decline with a 25 percent irrigation-demand increase. The paper reconciles the 8–12 GW resource range and 5.5–6 GW target range by distinguishing assessment boundaries, technical potential, program staging and date. The central finding is that canal hydropower should be developed as a governed portfolio of water-compatible infrastructure. Transparent screening, irrigation-first operating rules and efficient risk assignment can reduce development attrition and improve resilience.

Keywords: canal-based small hydropower; Uzbekistan; public-private partnership; water-energy-food nexus; multi-criteria screening; climate resilience

JEL codes: Q25; Q42; Q48; L94; G32

1. Introduction

Uzbekistan’s electricity transition must meet rising demand, reduce thermal dependence and improve supply reliability. The World Bank expects electricity demand to exceed 120 billion kWh by 2030 and reports unmet demand of about 10 percent [1]. Variable solar and wind increase the value of controllable, distributed generation. Small hydropower can aid daily balancing and local supply, while canal schemes use existing irrigation infrastructure and often require no new reservoir.

The opportunity is substantial but easily overstated. A canal is first a water-service asset; cropping patterns, allocations, closures, upstream conditions and water-authority decisions determine its flow. An attractive hydraulic drop can therefore produce weak debt coverage outside

the irrigation season. Construction can disrupt delivery, and an artificial channel can still create livelihood, safety, biodiversity, cultural-resource and land impacts. Reservoir avoidance does not remove the need for due diligence.

Current policy creates a practical opening for private participation. In 2023 the Government of Uzbekistan reported an initial national hydropower potential of 8 GW, around 2.2 GW then utilized, and an objective of reaching 6 GW by 2030. It also described 20-year land leases for small and micro hydropower investors, guaranteed state purchase of their electricity and an intention to attract private capital [2]. In 2025 the World Bank approved a USD 150 million concessional credit to support small hydropower through local developers and financial institutions. The associated project targets up to 150 MW across existing irrigation canals and anticipates USD 38 million of commercial co-financing [3,4]. These measures shift the central managerial question from whether canal hydropower is technically possible to how a heterogeneous site pipeline should be screened, contracted and financed.

This paper addresses that question through the water-energy-food (WEF) nexus. The nexus perspective recognizes that one cubic meter of canal water can simultaneously support food production, require pumping energy, embody ecological obligations and generate electricity. The appropriate objective is therefore not maximum annual hydropower output. It is maximum risk-adjusted public value subject to reliable irrigation and environmental constraints. Three research questions guide the analysis:

1. How can public agencies, developers and banks screen canal-based small hydropower sites consistently before expensive feasibility work?
2. Which allocation of construction, hydrology, irrigation, offtake, financial and environmental risks is most likely to produce bankable public-private partnership structures?
3. How should climate and irrigation stress be incorporated without treating uncertain scenario values as deterministic forecasts?

The contribution is a policy-to-practice framework that integrates project development, multi-criteria decision analysis (MCDA), PPP design and climate resilience. It also resolves two statistical ambiguities that can distort investment decisions. First, the 8 GW government estimate and the approximately 12 GW figure reported in the World Bank's 2025 project appraisal materials are different resource concepts and vintages, not values that should be averaged [2,4]. Second, the 5.5 GW hydro component cited in a 2025 renewable-energy program document and the 6 GW national hydropower objective cited by the government represent different program scopes or staging [2,4]. Transparent treatment of such differences is essential when targets are converted into project pipelines.

2. Literature and Policy Review

2.1 Small hydropower, MCDA and the nexus

Hydropower research increasingly distinguishes installed capacity from sustainable value. Moran et al. argue that planning must internalize ecological, social and governance effects [5]. Small scale can reduce some impacts, yet a dispersed program creates cumulative land, labor, safety and water-allocation risks. The World Bank identifies livelihood, labor, community-safety, stakeholder-exclusion and financial-intermediary capacity risks in Uzbekistan's program [6]. Portfolio controls are therefore necessary.

The WEF nexus supplies the conceptual basis. Hoff links it to resource efficiency and visible cross-sector externalities [7], while Rasul warns that sector optimization can displace costs [8]. Central Asian research calls for explicit indicators, participation and interdisciplinary decisions [9]. UNECE also identifies benefits from data exchange and coordinated operation in the Syr Darya basin. Uzbekistan did not formally associate itself with that assessment, so it is regional evidence rather than an official national position [10].

MCDA translates these ideas into screening. AHP and weighted-sum models compare technical, economic, social and environmental criteria while recording judgment [11,12]. Hydropower rankings change when environmental and stakeholder criteria supplement energy and cost [13], which matters where unreliable flow or irrigation conflict offsets theoretical generation.

MCDA remains dependent on data, weights and thresholds; final approval still requires measurement, design, consultation and financial appraisal.

2.2 Uzbekistan's policy and project context

The Green Economy Strategy 2019–2030 and Uzbekistan–2030 strategy frame cleaner energy and infrastructure objectives [14,15]. Decree DP-6024 emphasizes water accounting, modernization and efficient management [16]. The 2025 Water Code governs water administration and permits transfer of water-management facilities under PPP law [17]. Hydropower rights therefore remain inseparable from the water-management mandate.

Implementation experience is expanding. ADB's Sustainable Hydropower Project includes three run-of-river plants and mini/micro capacity development [18]. The 1.48 MW Ugam-1 plant is reported to produce 11.8 million kWh annually using domestic materials and equipment [19]. Localization creates durable value only where suppliers meet efficiency, safety, automation and spare-parts requirements.

The 2025 World Bank program directly addresses canal development. Appraisal materials describe about 3,000 prospective locations, screening of up to 400 sites and analytical support for feasibility studies [4]. Local banks lend through a credit facility, complemented by pipeline and institutional assistance. Reservoir avoidance does not eliminate environmental-social screening or the World Bank policy on international waterways [4,6]. Dispersed private investment on public canals therefore needs common eligibility rules and data.

2.3 Reconciling potential and target statistics

Four headline numbers appear in authoritative documents: approximately 8 GW and 12 GW for potential, and 5.5 GW and 6 GW for policy ambition. They should be reported as ranges with definitions.

The government's 2023 communication calls 8 GW an "initial estimate" of hydropower potential [2]. The World Bank's 2025 project document cites approximately 12 GW, drawing on an older 2013 small-hydropower assessment [4,20]. A higher technical-potential figure may include more locations, different plant-size thresholds, gross hydraulic resources, updated mapping or sites that are not economically, environmentally or institutionally developable. The 8–12 GW range therefore signals uncertainty in assessment boundaries and data vintage. It is not a single bankable resource estimate. Site-level dependable energy, construction cost and water compatibility determine the economically developable subset.

The 6 GW figure is an official national objective for total hydropower capacity by 2030 [2,19]. The 5.5 GW figure appears in the World Bank appraisal document as the hydropower component of a first-stage 25 GW renewable-energy plan [4]. A 0.5 GW difference can result from program staging, cut-off date, classification or inclusion of projects outside the initial renewable package. For project governance, the prudent approach is to retain both cited values, disclose their source and use a 5.5–6 GW target band until a single updated official planning baseline is published. Neither target implies that thousands of canal sites should pass directly into construction.

3. Methodology and Analytical Framework

This is an applied conceptual study rather than an ex post evaluation. It uses four methods. First, a structured review covers Uzbekistan's energy and water policies, official statements, IFI project documents, regional nexus studies and international guidance on hydropower, PPPs and environmental and social management. Sources were selected for institutional authority, direct relevance and traceable publication. Second, the paper maps a conventional greenfield development sequence from opportunity identification through screening, feasibility, procurement, financing, construction and operation. Third, it develops a two-stage MCDA model suitable for a large canal-site inventory. Fourth, it applies stress scenarios to show how water constraints should enter energy and debt analysis.

Stage 1 is a fatal-flaw screen. A candidate proceeds only if it has a legally credible water-use pathway, does not materially impair irrigation service, can obtain land and canal access, has a feasible grid connection, and falls within the environmental and social eligibility of the financing

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program. Failure is coded as zero and the site is deferred or rejected regardless of generation potential. This prevents a weighted average from concealing a non-negotiable constraint.

Stage 2 ranks eligible sites. For site *i*, the composite score is:

where is the normalized score from 0 to 100 on criterion *j* and is its weight. Quantitative indicators are normalized against published portfolio thresholds, while qualitative scores use anchored rubrics. Weighting combines the AHP principle of pairwise comparison with a policy constraint that water reliability and irrigation compatibility together receive at least 35 percent. Sensitivity testing reruns rankings after varying each weight by ±20 percent and under climate scenarios. A site whose rank is highly unstable is not discarded, but marked for additional measurement.

Annual energy is estimated from time-step canal flow rather than an annual average:

subject to turbine minimum and maximum flow, canal operating constraints, required bypass, irrigation priority and planned closures. Financial screening then tests debt-service coverage under P50 and conservative-flow cases. No empirical site data are claimed in this paper; the numerical comparison in Section 4.3 is an illustrative demonstration of the method.

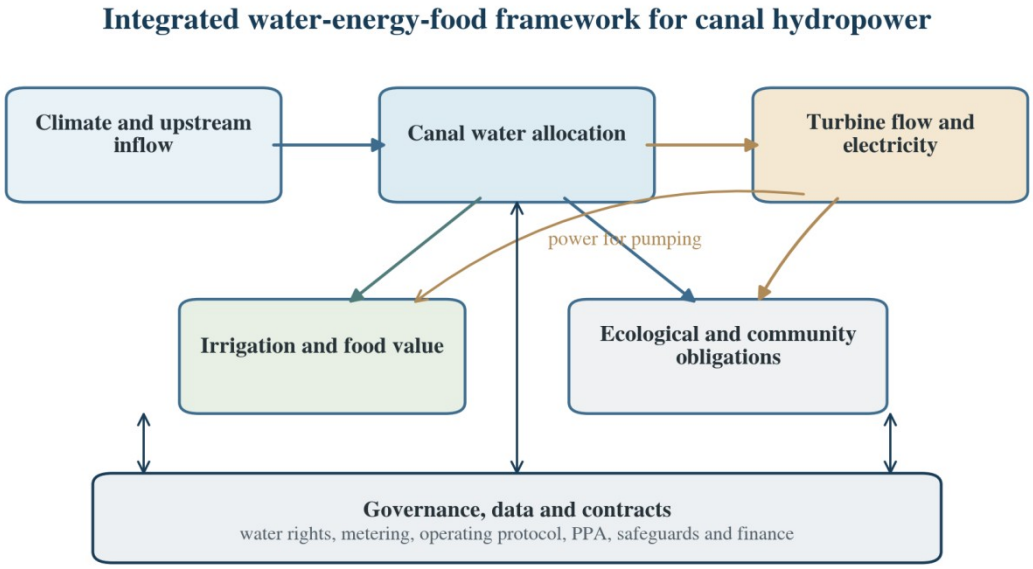

Figure 1. Integrated water-energy-food framework for canal hydropower development

Source: Author's construction based on Hoff [7], UNECE [10], the Uzbekistan Water Code [17] and the World Bank water-security assessment [21].

4. Multi-Criteria Site Screening Framework

4.1 Stage 1: fatal-flaw gates

The first gate is legal and operational water access. The developer must identify the canal authority, generation right, irrigation priority and data owner. At least one measured irrigation cycle is desirable, supplemented by longer reconstructed records and operating schedules. Modeled-only flow warrants additional development contingency.

The second gate is irrigation non-impairment: authorized volume, timing and hydraulic level must be preserved through bypass and safe shutdown arrangements. The third gate requires a preliminary grid opinion covering voltage, capacity, protection, curtailment and reinforcement. The fourth covers land, rights of way and canal-compatible construction access. The fifth applies environmental-social exclusions, cumulative-risk review, engagement and grievance arrangements [6,22].

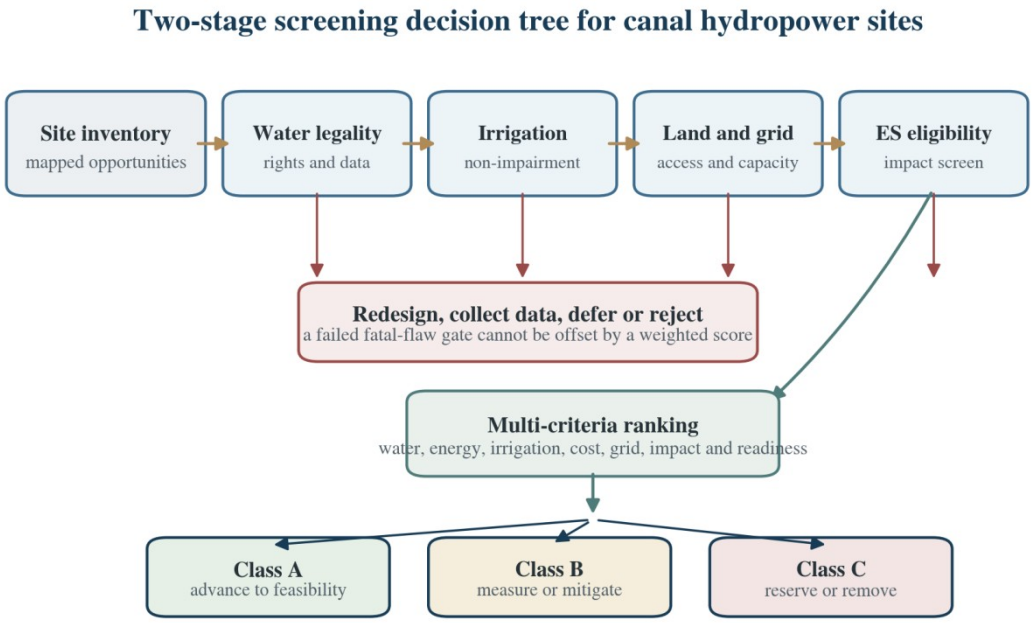

Figure 2. Two-stage site-screening decision tree for canal hydropower sites

Source: Author's construction based on the World Bank project appraisal and environmental and social documents [4,6], MCDA literature [11–13] and the Water Code [17].

4.2 Stage 2: weighted ranking

Table 1 gives water reliability the largest weight because flow determines generation and service conflict. Irrigation compatibility is separate because reliable water is not necessarily turbine-available water. Other criteria capture net energy, economics, connection, impact and execution. The weights require validation by energy and water agencies, canal and grid operators, banks, developers, farmers and environmental specialists.

Table 1. Proposed MCDA criteria for eligible canal-based small hydropower sites

Criterion	Weight	Principal measures	Anchored interpretation
Water reliability	0.22	Monthly measured flow, dependable flow, closure duration, data completeness	High score requires stable dry-season availability and auditable records
Usable head and energy yield	0.16	Net head, hydraulic losses, turbine efficiency curve, P50/P90 energy	High score reflects dependable energy, not only installed MW
Irrigation compatibility	0.16	Delivery timing, bypass capacity, backwater effect, outage coordination	Any material service reduction fails Stage 1; higher scores add operational flexibility
Capital cost and economics	0.13	Unit CAPEX, lifecycle O&M, LCOE, contingency, DSCR	High score requires robust economics under conservative flow
Grid and access	0.11	Connection distance/capacity, road access, construction logistics	High score indicates limited reinforcement and low interface risk
Environmental and social exposure	0.12	Land, livelihood, safety, biodiversity, cultural heritage, cumulative effects	High score indicates manageable impacts with verified mitigation
Sponsor and execution readiness	0.10	Equity capacity, governance, EPC/O&M competence, permits, data room	High score requires evidence, not declarations
Total	**1.00**		

Source note: Author's proposed weights, informed by Saaty [11], Belton and Stewart [12], Vassoney et al. [13], the World Bank project framework [4,6] and IFC Performance Standards [22]. Weights require local stakeholder validation before operational use.

4.3 Illustrative portfolio comparison

Table 2 applies the framework to three fictional sites. Site A has moderate head but reliable flow, a short connection and a manageable construction interface. Site B has the highest head and expected annual energy, yet its seasonal flow, longer outage and irrigation interface reduce its total score. Site C has lower technical potential but strong land and stakeholder conditions. The example demonstrates why a single indicator such as MW, annual kWh or unit construction cost should not determine priority.

Table 2. Illustrative scoring of three fictional canal sites

Criterion	Weight	Site A: stable main canal	Site B: high-head seasonal drop	Site C: low-head district canal
Water reliability	0.22	88	58	74
Usable head and energy yield	0.16	72	94	55
Irrigation compatibility	0.16	90	52	82
Capital cost and economics	0.13	78	82	62
Grid and access	0.11	85	60	76
Environmental and social exposure	0.12	80	68	90
Sponsor and execution readiness	0.10	75	80	70
Weighted score	**1.00**	**81.3**	**70.5**	**72.7**
Indicative class		**A: feasibility**	**B: measure/mitigate**	**B: optimize design**

Source note: Author's illustrative calculation using Table 1. The site descriptions and scores are fictional and do not represent an appraisal of any location in Uzbekistan.

Before procurement, a Class A site needs independent review of measured flow and energy, credible sediment and maintenance assumptions, defined connection and curtailment terms, and a climate-irrigation downside test. Publishing criteria, data vintage and rejection reasons discourages speculative site reservation and directs expenditure toward credible projects.

5. PPP and Financing Design

5.1 Contract architecture

A canal plant intersects public water infrastructure, a regulated buyer, private construction and bank finance. The project company needs coordinated land/facility, water, grid, PPA, EPC, O&M and financing instruments. A lender direct agreement should establish notice, cure and step-in rights, while the canal authority signs a binding operating protocol.

The protocol should prioritize irrigation, safety and lawful ecological obligations, then govern generation from eligible flow. It specifies schedules, closure notice, emergency control, metering, data and damage responsibility. It also separates natural variability from discretionary curtailment. Compensation applies only where authorized; open-ended public indemnities create poor incentives and fiscal exposure.

Common feasibility terms, metering, PPA clauses, safeguard templates and minimum specifications reduce transaction cost. Site schedules should still address flow, head, land and community obligations because canals differ.

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5.2 Risk allocation

Risk belongs with the party best able to control, mitigate or absorb it [23]. Full private transfer of uncontrollable hydrology can raise tariffs or destabilize sponsors, while public assumption of construction performance weakens discipline. Table 3 balances these concerns.

Table 3. Recommended risk allocation for a canal-based small hydropower PPP

Risk	Primary allocation	Principal mitigation and contractual treatment
Site data and baseline flow	Public/shared before award	Public data room; independent verification; bidder due diligence; disclosed uncertainty band
Hydrological variability	Private within agreed band; shared for exceptional events	Conservative P90 case, reserve account, relief-event thresholds, insurance where available
Irrigation scheduling	Public canal authority for discretionary changes; private for compliance	Binding water protocol, notice periods, irrigation-first rule, auditable metering
Design, construction and performance	Private	Fixed-date EPC terms, performance tests, contingency, liquidated damages and security
Land, facility right and key permits	Public enabling role; private compliance	Conditions precedent, clear site boundary, coordinated approvals
Grid connection	Shared by defined scope	Connection study, cost boundary, commissioning interface and curtailment provisions
Electricity offtake and payment	Public offtaker, subject to contract	Bankable PPA, payment security permitted by law, lender direct agreement
Foreign exchange and interest rate	Shared	Local-currency revenue and debt where feasible, indexed tariff only if authorized, hedging assessment
O&M, availability and equipment	Private	Lifecycle plan, spare parts, remote monitoring, availability incentives
Environmental, social, labor and safety	Private implementation with public oversight	ESMS, management plans, consultation, grievance mechanism, incident reporting
Change in law, force majeure and political event	Public or shared according to control	Defined relief, restoration plan, termination and compensation rules

Source note: Author's construction based on the World Bank PPP Reference Guide [23], the Uzbekistan Water Code [17], the World Bank project and environmental-social documents [4,6], and IFC Performance Standards [22].

5.3 Financing structure and bankability

Local developers need long-tenor capital, while local banks face maturity and appraisal constraints [1,4]. Concessional wholesale funds can reach eligible projects through participating banks that retain credit responsibility and co-finance. Sponsors supply equity and borrow against PPA revenue after technical, financial and environmental-social appraisal. Concessionality must not replace sound underwriting.

The base case should use time-step water and planned closures; the downside case should use dependable flow. Coverage covenants, debt-service and maintenance reserves, and distribution lock-up absorb volatility. Drawdown requires executed water/grid agreements, approved

safeguards, independent engineering, equity and a fixed completion budget. Tenor and amortization should match seasonal cash flow.

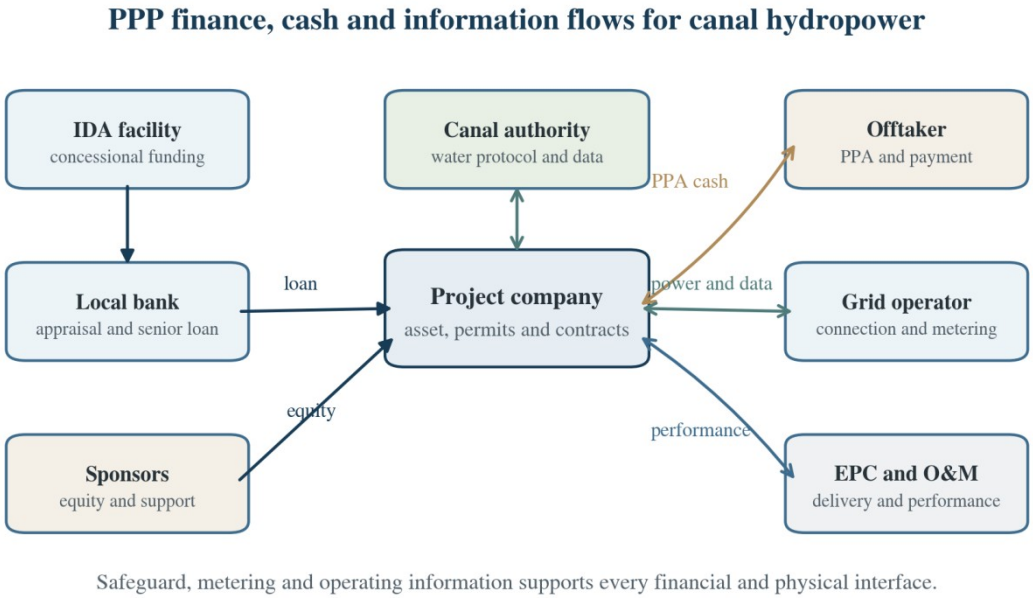

Figure 3. PPP finance, cash and information flows for canal hydropower

Source: Author's construction based on the financing and institutional arrangements described for the Uzbekistan Small Hydropower Development Project [1,4,6] and the PPP Reference Guide [23].

6. Climate Resilience and Irrigation Constraints

Uzbekistan's water exposure makes backward-looking hydrology insufficient. The World Bank reports a climate scenario in which water availability could decline by 30–40 percent and irrigation demand could increase by 25 percent, reflecting glacier change, evapotranspiration, rainfall variability and drought [24]. These values are scenario estimates, not a forecast that every canal will experience the same change or that the two effects will occur uniformly. Their purpose in this paper is to define a severe stress envelope for investment testing.

Three cases are recommended. The reference case uses the best available measured record, current irrigation rules and planned efficiency improvements. A moderate-stress case can test a 15 percent reduction in available canal flow, a 10 percent rise in irrigation requirement and longer maintenance or drought-related interruption. The severe case tests the cited 30–40 percent water decline together with a 25 percent irrigation-demand increase. Site-specific studies should refine the timing of these shocks because monthly distribution matters more to turbine production than an annual percentage alone. Each case should report annual energy, monthly minimum generation, irrigation delivery, curtailment, operating margin and debt-service coverage.

Climate resilience begins with selection [26]. A plant located on a canal with diverse upstream sources, reliable records and flexible bypass arrangements may be more resilient than a technically larger site dependent on a narrow seasonal window. Design measures include modular turbine units with broad efficiency ranges, adequate bypass, variable-speed or multiple-unit configurations where economic, sediment and debris management, flood-safe electrical equipment, remote monitoring and physical provision for changing water levels. Contract measures include periodic review of operating curves, shared data, drought and flood protocols, and clear relief-event thresholds. Financial measures include conservative leverage, reserves, covenant headroom and staged portfolio deployment.

Irrigation modernization can create both synergies and rebound effects. Rehabilitation may reduce conveyance losses and pumping energy, improving reliability and releasing operational head at selected structures. Yet efficiency gains do not automatically leave more water for power if saved water is allocated to expanded irrigation. The World Bank's water-security assessment notes

outdated infrastructure, weak efficiency and the need for cost recovery and better operations and maintenance [21]. A 2025 irrigation project emphasizes modernization across a sector that accounts for around 90 percent of national water use [24]. Accordingly, any claimed hydropower benefit from water-saving investment should be based on an enforceable allocation and measured delivery, not on an assumed “saved” volume.

The transboundary dimension also matters. Many Uzbek water resources are connected to the Amu Darya and Syr Darya systems. Canal plants ordinarily do not determine basin releases, but their output depends on them. The Water Code subjects transboundary water use to international treaties [17], and World Bank regional programs emphasize data sharing, coordinated water-energy operation and transparent institutions [25]. Project documents should therefore avoid allocating regional inflow risk through unrealistic private guarantees. At portfolio level, geographic diversification across basins and canal systems can reduce correlated hydrology risk, while government and regional institutions retain responsibility for interstate coordination.

7. Discussion and Managerial Implications

The analysis supports five managerial conclusions. First, the national site inventory should be managed as a funnel. Thousands of mapped hydraulic opportunities may produce hundreds of screenable sites, dozens of full feasibility studies and a smaller number of financed plants. Attrition is evidence of screening quality, not program failure. Development budgets should fund early data and remove weak sites before procurement.

Second, water governance is part of project finance. A bankable PPA cannot compensate for an ambiguous canal operating right. Developers, water authorities and lenders need a common record of flow, closures and irrigation obligations. Digital metering should capture upstream flow, turbine flow, bypass flow, head, energy, outages and instructed curtailment. Data should be accessible to the project company, canal operator, offtaker and lenders under agreed rules. This creates a factual basis for operations, dispute resolution and future resource planning.

Third, procurement should reward lifecycle value. Lowest upfront tariff or construction cost can encourage optimistic flow assumptions and weak equipment. Bid evaluation should test energy under the same public hydrological dataset, require a lifecycle O&M plan, and adjust for connection scope and environmental-social obligations. Where sites are very small, bundling several geographically coherent plants may spread transaction and O&M costs, but packages should avoid excessive concentration and correlated canal risk.

Fourth, localization should follow a capability ladder. Civil works, steel structures, control panels and routine maintenance may offer early domestic opportunities. Turbine runners, governors, generators and protection systems require performance standards, factory testing, warranties and quality assurance. The Ugam-1 experience shows policy interest in domestic content [19], while the World Bank credit-line model can widen local developer and bank participation [1]. Training, certification and supplier qualification are more durable than a nominal local-content percentage.

Fifth, a portfolio control unit should combine energy, water, finance and safeguard expertise. Its dashboard should report the number of sites at each gate, data completeness, expected P90 energy, irrigation-service effect, connection status, environmental-social risk, financing status and reasons for delay. Independent technical review is justified before financial close and after commissioning. Post-construction performance should feed back into weights, cost benchmarks and standard contracts. This learning loop converts scattered projects into an institutional capability.

The approach also clarifies the role of PPPs. Private participation is valuable where it introduces disciplined design, construction, financing and operation. Public agencies remain responsible for transparent water allocation, credible site rights, fair procurement, sector regulation and oversight. The goal is selective risk transfer, not maximum risk transfer. If a public party passes unpredictable irrigation scheduling or unobservable baseline-flow risk to a small developer, bidders will price uncertainty, rely on renegotiation or decline to invest. Conversely, public absorption of ordinary construction and availability risk would reduce accountability.

At the broader WEF level, canal hydropower can create a positive loop when its electricity supports local reliability and efficient pumping while preserving water delivery. It can create a

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negative loop if generation incentives distort irrigation timing or if new revenues bypass water-system maintenance and affected users. Transparent benefit reporting and stakeholder engagement are therefore economic controls as well as social obligations. Farmer representatives should participate when operating schedules are set, and the grievance mechanism should remain accessible throughout construction and operation [6].

8. Conclusion

Canal-based small hydropower offers Uzbekistan a practical route to distributed renewable electricity using existing water infrastructure. Its greenfield development logic differs from that of a stand-alone power plant because the commercial fuel, flowing water, is governed primarily for irrigation and is exposed to climate and transboundary conditions. The project-development system must place water legality, irrigation compatibility and environmental-social eligibility ahead of capacity maximization.

This paper proposes a two-stage process: fatal-flaw gates followed by transparent weighted ranking. It links the screening result to standardized PPP contracts, local-bank financing and climate stress tests. The 8–12 GW potential range should be understood as a difference in assessment scope, methodology and vintage; the 5.5–6 GW target range reflects program staging and planning definitions. Both ranges require disclosure rather than artificial harmonization. Likewise, a possible 30–40 percent decline in water availability and 25 percent increase in irrigation demand should be used as a severe scenario, not asserted as a uniform outcome.

For policymakers, the priority is a credible portfolio data room and cross-ministerial screening protocol. For developers, the priority is dependable flow, lifecycle performance and early stakeholder engagement. For lenders, the priority is conservative energy estimation, clear interface agreements and enforceable monitoring. If these disciplines are combined, small hydropower can contribute to energy security while reinforcing, rather than competing with, Uzbekistan’s water and food-security objectives.

9. Limitations and Future Research

The study is conceptual and relies on public documents; it does not use confidential canal records, tariff data or actual project cash flows. The weights and fictional site scores require validation through stakeholder workshops and field testing. National scenario values may not represent individual basins or months, and legal or market arrangements may change. Future research should apply the model to measured hourly or daily flows, compare AHP results with outranking or stochastic optimization, quantify cumulative effects across canal cascades, and test financing structures under local-currency, tariff and hydrology sensitivities. Longitudinal study of the first financed portfolio would allow the screening thresholds to be recalibrated against actual construction cost, generation, irrigation performance and debt service.

References:

[1] World Bank. (2025). *Uzbekistan to Enhance Energy Production through Hydropower with World Bank Support*. https://www.worldbank.org/en/news/press-release/2025/06/25/uzbekistan-to-enhance-energy-production-through-hydropower-with-world-bank-support

[2] Government of the Republic of Uzbekistan. (2023). *The Progress of Hydropower Projects and the State of Preparation for the Autumn/Winter Season Are Considered*. https://gov.uz/en/news/view/3347

[3] World Bank. (2025). *Uzbekistan Small Hydropower Development Project, Project Page (P509250)*. https://projects.worldbank.org/en/projects-operations/project-detail/P509250

[4] World Bank. (2025). *Uzbekistan Small Hydropower Development Project (P509250): Project Appraisal Document*. https://documents1.worldbank.org/curated/en/099052125205569067/pdf/P509250-157ae192-23c9-4a6c-ab9b-f2c8af10cce0.pdf

[5] Moran, E. F., Lopez, M. C., Moore, N., Müller, N., & Hyndman, D. W. (2018). Sustainable hydropower in the 21st century. *Proceedings of the National Academy of Sciences, 115*(47), 11891–11898. https://doi.org/10.1073/pnas.1809426115

[6] World Bank. (2025). *Uzbekistan Small Hydropower Development Project: Appraisal Environmental and Social Review Summary*.

https://documents1.worldbank.org/curated/en/099052025144541135/pdf/P509250-1ed37902-8be7-4e09-b731-362c96f78d9e.pdf

[7] Hoff, H. (2011). *Understanding the Nexus: Background Paper for the Bonn 2011 Conference*. Stockholm Environment Institute. https://www.sei.org/publications/understanding-the-nexus/

[8] Rasul, G. (2016). Managing the food, water, and energy nexus for achieving the Sustainable Development Goals in South Asia. *Environmental Development, 18*, 14–25. https://doi.org/10.1016/j.envdev.2015.12.001

[9] Hamidov, A., Daedlow, K., Webber, H., Hussein, H., Abdurahmanov, I., Dolidudko, A., Seerat, A., Solieva, U., Woldeyohanes, T., & Helming, K. (2022). Operationalizing water-energy-food nexus research for sustainable development in social-ecological systems: An interdisciplinary learning case in Central Asia. *Ecology and Society, 27*(1), 12. https://doi.org/10.5751/ES-12891-270112

[10] United Nations Economic Commission for Europe. (2017). *Assessment of the Water-Food-Energy-Ecosystems Nexus in the Syr Darya River Basin*. https://unece.org/DAM/env/water/publications/GUIDELINES/2017/nexus_in_the_Syr_Darya_River_Basin/Syr-Daria-FINAL-WEB-.pdf

[11] Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences, 1*(1), 83–98. https://doi.org/10.1504/IJSSCI.2008.017590

[12] Belton, V., & Stewart, T. J. (2002). *Multiple Criteria Decision Analysis: An Integrated Approach*. Springer. https://doi.org/10.1007/978-1-4615-1495-4

[13] Vassoney, E., Mochet, A. M., & Comoglio, C. (2021). Comparing multi-criteria decision-making methods for the assessment of flow release scenarios from small hydropower plants in the Alpine area. *Frontiers in Environmental Science, 9*, 635100. https://doi.org/10.3389/fenvs.2021.635100

[14] President of the Republic of Uzbekistan. (2019). *Resolution RP-4477: Strategy for Transition of the Republic of Uzbekistan to a Green Economy for 2019–2030*. https://lex.uz/en/docs/7582760

[15] President of the Republic of Uzbekistan. (2023). *Decree PF-158: Uzbekistan–2030 Strategy*. https://lex.uz/ru/docs/6600404

[16] President of the Republic of Uzbekistan. (2020). *Decree DP-6024: Concept for Development of the Water Sector of the Republic of Uzbekistan for 2020–2030*. https://lex.uz/en/docs/6973364?ONDATE=11.07.2020

[17] Republic of Uzbekistan. (2025). *Water Code of the Republic of Uzbekistan*. https://lex.uz/en/docs/7658590

[18] Asian Development Bank. (2019). *Uzbekistan: Sustainable Hydropower Project (50130-002)*. https://www.adb.org/projects/50130-002/main

[19] President of the Republic of Uzbekistan. (2024). *The President Reviews Hydropower Facilities*. https://president.uz/en/lists/view/7749

[20] United Nations Industrial Development Organization and International Center on Small Hydro Power. (2013). *World Small Hydropower Development Report 2013*. https://www.unido.org/sites/default/files/2014-03/WSHPDR_2013_0.pdf

[21] World Bank. (2024). *Uzbekistan General Water Security Assessment*. https://documents1.worldbank.org/curated/en/099062424121035288/pdf/P1700301356bad0519ce81fc808f542aeb.pdf

[22] International Finance Corporation. (2012). *Performance Standards on Environmental and Social Sustainability*. https://www.ifc.org/en/insights-reports/2012/ifc-performance-standards

[23] World Bank, Asian Development Bank, and Inter-American Development Bank. (2017). *Public-Private Partnerships Reference Guide, Version 3.0*. https://openknowledge.worldbank.org/entities/publication/e64a94b9-b0cb-51a3-b8dd-36bd7944284f

[24] World Bank. (2025). *Uzbekistan to Modernize Its Irrigation Infrastructure with World Bank Support*. https://www.worldbank.org/en/news/press-release/2025/05/21/uzbekistan-to-modernize-its-irrigation-infrastructure-with-world-bank-support

[25] World Bank. (2024). *Central Asia Water and Energy Program: Phase 4 Annual Report*. https://documents1.worldbank.org/curated/en/099746310292415198/pdf/IDU-a1a38767-7689-4aee-90be-01ace53921a1.pdf

[26] International Hydropower Association. (2019). *Hydropower Sector Climate Resilience Guide*. https://www.hydropower.org/publications/hydropower-sector-climate-resilience-guide