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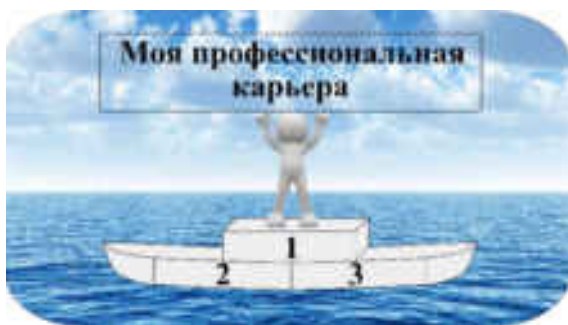


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**Международный научно-образовательный электронный журнал
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OGUZ HAN ENGINEERING AND TECHNOLOGY UNIVERSITY OF TURKMENISTAN

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Abstract

Turkmenistan, a landlocked Central Asian nation endowed with substantial hydrocarbon reserves but confronting acute challenges of water scarcity, arid climate conditions, and limited biodiversity in its aquatic ecosystems, presents a compelling and underexplored case study for the intersection of bioeconomy development and aquaculture innovation. Positioned at the convergence of the Karakum Desert and the Caspian Sea basin, Turkmenistan's geographic and hydrological profile necessitates creative and technology-driven approaches to food security, economic diversification, and sustainable resource utilization. This paper examines the strategic role of artificial fishing pools—purpose-built controlled aquaculture environments designed to optimize fish production under arid and semi-arid conditions—in advancing the nation's bioeconomy objectives. Drawing on the theoretical frameworks of Bioeconomy Strategy, Blue Economy principles, and Ecological Modernization Theory, the paper analyzes how artificial fishing pools can function as integrated bioeconomy instruments, simultaneously generating protein food supplies, creating rural employment, reducing pressure on wild fish stocks in the Caspian Sea and the Karakum Canal, and enabling the valorization of biological waste streams through integrated aquaponics and circular production systems. The paper further evaluates the policy architecture, institutional prerequisites, and technological requirements for scaling artificial pool-based aquaculture as a pillar of Turkmenistan's broader economic diversification agenda. Findings suggest that with appropriate investment in technology transfer, water management innovation, and governance capacity, artificial

fishing pools represent a strategically viable and economically significant instrument for advancing sustainable bioeconomy development in Turkmenistan.

Keywords: *bioeconomy, aquaculture, Turkmenistan, artificial fishing pools, Central Asia, Caspian Sea, food security, economic diversification, blue economy, circular aquaculture, water management*

1. Introduction

The global bioeconomy—broadly defined as the production and conversion of biological resources, including biomass, biological processes, and principles, for sustainable provision of food, energy, products, and services—has emerged as a central paradigm in twenty-first-century economic development policy. As nations worldwide confront the intertwined challenges of climate change, biodiversity loss, food system fragility, and the imperative to transition away from fossil fuel dependence, bioeconomy strategies offer integrated pathways toward sustainable growth that align ecological preservation with economic value generation. Aquaculture—the controlled cultivation of aquatic organisms including fish, crustaceans, mollusks, and aquatic plants—constitutes one of the most rapidly expanding sectors within the global bioeconomy, with the Food and Agriculture Organization of the United Nations (FAO) projecting that aquaculture will supply over 60 percent of global fish consumption by 2030.

Within this global context, Turkmenistan occupies a paradoxical position. The country possesses the world's fourth-largest natural gas reserves and substantial oil resources, generating per capita income levels that place it among the upper-middle-income tier of developing economies. Yet this hydrocarbon wealth coexists with severe structural challenges: an arid to hyper-arid climate covering approximately 80 percent of the national territory, chronic water scarcity exacerbated by the progressive desiccation of the Aral Sea basin, limited agricultural productivity outside irrigated zones, and an economic structure characterized by pronounced dependence on hydrocarbon export revenues that exposes the national economy to commodity price volatility.

The imperative for economic diversification has been recognized at the highest levels of Turkmen national policy, with successive government development programs articulating ambitions for expanded agricultural productivity, food self-sufficiency, and the development of non-hydrocarbon export sectors. Aquaculture—and specifically the development of artificial fishing pools as controlled production environments adapted to the country's hydrological and climatic constraints—represents a strategically coherent instrument for advancing these diversification objectives while simultaneously contributing to food security, rural development, and sustainable natural resource management.

This paper proceeds as follows. Section 2 establishes the theoretical frameworks informing the analysis. Section 3 characterizes Turkmenistan's aquatic resource base and the ecological context for aquaculture development. Section 4 examines the concept, design principles, and operational characteristics of artificial fishing pools. Section 5 analyzes the bioeconomy potential of artificial pool-based aquaculture in the Turkmenistani context. Section 6 addresses the policy, institutional, and technological enablers of aquaculture sector development. Section 7 explores integration with circular economy and sustainable development frameworks. Section 8 presents conclusions and strategic recommendations.

2. Theoretical Frameworks

2.1 Bioeconomy Strategy and Policy Frameworks

The bioeconomy concept, systematized in policy frameworks by the European Commission (2012, 2018), the Organisation for Economic Co-operation and Development (OECD, 2009), and the FAO (2019), encompasses the sustainable production and conversion of biological resources to deliver food, health, fiber, industrial products, and energy while creating economic value and employment. Bioeconomy strategies typically identify aquaculture as a priority sector, given its capacity to produce high-value protein through biologically efficient conversion processes while maintaining substantially lower carbon footprints than terrestrial livestock systems. For resource-constrained developing economies such as

Turkmenistan, bioeconomy frameworks offer a particularly compelling development model by linking ecological asset stewardship with economic productivity.

2.2 Blue Economy Principles

The Blue Economy framework, advanced by international development institutions including the World Bank and the Commonwealth Secretariat, extends bioeconomy principles to marine and freshwater environments, emphasizing the sustainable use of ocean and aquatic resources for economic growth, improved livelihoods, and ecosystem health preservation. Applied to landlocked or semi-landlocked contexts such as Turkmenistan—which accesses the Caspian Sea and possesses extensive irrigation canal networks—Blue Economy principles provide a normative foundation for aquaculture development that prioritizes productivity optimization, ecosystem service conservation, and integrated water resource management.

2.3 Ecological Modernization Theory

Ecological Modernization Theory (EMT), associated with the work of Mol (1995) and Hajer (1995), posits that environmental challenges can be addressed through technological innovation, institutional reform, and market mechanisms without requiring fundamental abandonment of industrial development ambitions. Applied to aquaculture development in Turkmenistan, EMT suggests that artificial fishing pools—as technologically sophisticated, resource-efficient production systems—can deliver significant improvements in food system sustainability and ecological footprint relative to conventional extensive fishing practices, while simultaneously advancing economic development objectives. This theoretical perspective supports the argument that bioeconomy transition and economic development are mutually reinforcing rather than fundamentally contradictory goals.

3. Turkmenistan's Aquatic Resource Base and Ecological Context

3.1 The Caspian Sea and Its Fisheries

Turkmenistan's western border runs along approximately 1,768 kilometers of Caspian Sea coastline, providing access to the world's largest enclosed body of water and one of the most biologically significant aquatic ecosystems in the Eurasian

landmass. The Caspian Sea harbors exceptional endemic biodiversity, including 101 endemic fish species, and has historically supported some of the world's most valuable commercial fisheries—most notably the beluga, Russian, and starred sturgeon populations that once produced the majority of global caviar supply. Turkmenistan has traditionally engaged in Caspian fisheries, with Turkmenbashi (formerly Krasnovodsk) serving as the principal fishing port and fish processing center.

However, the Caspian's fisheries have been subjected to severe and in some cases catastrophic pressure from overfishing, pollution, habitat degradation, and hydrological changes associated with Volga River regulation and Aral Sea desiccation. Caspian sturgeon populations have declined by an estimated 90 percent over the past three decades, prompting the Convention on International Trade in Endangered Species (CITES) to regulate sturgeon product trade and Caspian littoral states—including Turkmenistan—to implement fishing moratoriums and restocking programs. This ecological context both constrains the expansion of wild capture fisheries and creates urgent imperative for aquaculture development as an alternative protein production pathway.

3.2 Inland Water Resources and the Karakum Canal

Turkmenistan's most significant inland water resource is the Karakum Canal, the world's longest irrigation canal at approximately 1,375 kilometers, which diverts water from the Amu Darya River across the Karakum Desert to supply agricultural zones in the south and west of the country. The canal and its associated irrigation network support cotton, wheat, and vegetable cultivation across approximately 1.8 million hectares of otherwise arid land, representing the backbone of Turkmenistan's non-hydrocarbon agricultural economy. The canal system also supports a degree of artisanal fishing activity, as incidental fish populations have established themselves in the irrigation infrastructure over decades of operation.

Additionally, the Turkmen Lake (formerly the Golden Age Lake), an artificial reservoir constructed in the Karakum Desert to receive agricultural drainage water, has been developed as a potential site for aquaculture pilot projects and wildlife habitat restoration. While the lake's high salinity and variable water quality present significant

technical challenges for conventional aquaculture operations, they also illustrate the scope for innovative, technology-adapted approaches to water resource valorization in desert environments.

4. Artificial Fishing Pools: Concept, Design, and Operational Characteristics

4.1 Definition and Typology

Artificial fishing pools, as employed within the aquaculture context, refer to purpose-constructed, controlled aquatic environments designed to optimize the production of fish and other aquatic organisms under conditions that can be systematically managed to maximize biological productivity, resource efficiency, and product quality. Distinct from natural lake or river-based fisheries, artificial pools provide operators with direct control over water temperature, oxygen levels, feed inputs, stocking densities, disease management, and harvest scheduling—enabling year-round production cycles independent of seasonal climatic variability that is particularly pronounced in Turkmenistan's continental desert climate.

Typologically, artificial fishing pools in aquaculture applications span a spectrum from simple earthen ponds—low-cost excavated basins suitable for extensive or semi-intensive production of hardy species such as common carp and tilapia—to sophisticated recirculating aquaculture systems (RAS) employing advanced filtration, aeration, and monitoring technologies to achieve intensive production of high-value species in minimal water volumes. Intermediate system types include lined concrete or geomembrane pools, cage aquaculture installations within reservoirs, and flow-through raceway systems. The appropriate system type for Turkmenistan's context varies significantly by location, available water source, target species, investment capacity, and market orientation.

4.2 Species Selection for Arid-Zone Aquaculture

Species selection is among the most critical determinants of artificial pool aquaculture viability in Turkmenistan's environmental and market context. Common carp (*Cyprinus carpio*) and silver carp (*Hypophthalmichthys molitrix*) have historically constituted the primary aquaculture species in Central Asian systems and remain technically well-suited to earthen pond production given their tolerance of variable

water quality, omnivorous feeding habits, and robust growth performance under semi-intensive management. Grass carp (*Ctenopharyngodon idella*) offers additional complementary value through its consumption of aquatic vegetation, enabling integrated weed management in irrigation canals and reservoirs.

Higher-value species present compelling market opportunities for more sophisticated artificial pool systems. Sturgeon aquaculture—producing both meat and caviar—represents a particularly high-value opportunity aligned with Turkmenistan's Caspian heritage and the global scarcity of wild sturgeon products following decades of overfishing. Pilot sturgeon aquaculture programs have been established in several Central Asian countries including Kazakhstan and Uzbekistan, demonstrating technical feasibility under regional conditions. Tilapia (*Oreochromis niloticus*), while non-native, demonstrates exceptional performance in warm-water systems and high market acceptance in domestic and regional food markets.

4.3 Water Efficiency and Recirculating Aquaculture Systems

In Turkmenistan's water-scarce environment, the water efficiency characteristics of artificial pool systems are of paramount strategic importance. Conventional flow-through pond systems require substantial volumes of fresh water per unit of fish produced—a significant constraint in regions where agricultural water demand already strains available resources. Recirculating Aquaculture Systems (RAS), by contrast, recycle 95 to 99 percent of water through biological filtration, mechanical solids removal, ultraviolet sterilization, and aeration systems, achieving production intensities of up to 100 kilograms of fish per cubic meter of water volume. While RAS installation requires substantially greater capital investment than earthen pond systems, their superior water efficiency makes them strategically appropriate for arid-zone production contexts and for high-value species where intensive management is economically justified.

5. Bioeconomy Potential of Artificial Pool Aquaculture in Turkmenistan

5.1 Food Security and Protein Supply Contributions

Turkmenistan's food security profile is characterized by dependence on imported food commodities—including significant volumes of fish and seafood—that represent

a structural vulnerability in the national balance of payments and an impediment to dietary quality improvement for lower-income population segments. Expanding domestic aquaculture production through artificial fishing pools offers a direct pathway to improved food self-sufficiency, reducing import dependence for animal protein while providing nutritionally superior dietary options relative to the red meat products that currently dominate Turkmen protein consumption patterns. The FAO (2022) identifies increased aquaculture production as a primary instrument for achieving SDG 2 (Zero Hunger) targets in countries where wild fish stocks are limited and terrestrial livestock production is constrained by water and feed availability—a description directly applicable to Turkmenistan's situation.

5.2 Economic Diversification and Rural Employment

The development of a commercially significant aquaculture sector centered on artificial fishing pools offers meaningful contributions to Turkmenistan's economic diversification objectives. Aquaculture value chains—encompassing fingerling production, feed manufacturing, grow-out operations, processing, cold chain logistics, and retail distribution—generate employment across multiple skill levels and geographic locations, including rural areas where alternative employment opportunities are limited. Studies of aquaculture sector development in comparable Central Asian contexts, including Uzbekistan's ongoing aquaculture expansion program, indicate that well-designed sector development initiatives can generate employment multipliers of three to five indirect and induced jobs per direct aquaculture employment, substantially amplifying the sector's labor market contribution.

Export market development represents an additional economic opportunity of considerable strategic significance. Premium aquaculture products—including sturgeon caviar, processed fish fillets, and live fish—command high prices in regional markets including Russia, China, the Gulf Cooperation Council states, and the European Union. Turkmenistan's geographic position at the nexus of Central Asian trade routes, combined with improving transport infrastructure under China's Belt and Road Initiative, enhances the feasibility of premium aquaculture product export strategies that could generate meaningful non-hydrocarbon export revenues.

5.3 Circular Bioeconomy Integration and Waste Valorization

Artificial fishing pools, when designed within an integrated circular bioeconomy framework, offer opportunities for biological waste stream valorization that substantially enhance the economic and environmental efficiency of aquaculture operations. Aquaponics—the integration of recirculating fish production with hydroponic vegetable cultivation, using nutrient-rich fish waste water as plant fertilizer and plant root systems as biological filtration media—represents a particularly compelling circular system design for Turkmenistan's context, enabling simultaneous production of high-value fish and vegetables in water-efficient, controlled environments. Pilot aquaponics installations in arid-zone contexts including Israel, Saudi Arabia, and the United Arab Emirates have demonstrated commercial viability and strong economic returns, providing directly applicable technical precedents for Turkmenistan.

Fish processing waste—comprising up to 60 percent of harvested fish mass in the form of heads, viscera, scales, and bones—can be valorized through biorefinery approaches to produce fish meal and fish oil for aquaculture feed, biogas through anaerobic digestion, collagen and gelatin for pharmaceutical and food industry applications, and organic fertilizer for agricultural use. Integrating these waste valorization streams within artificial pool aquaculture operations transforms what would otherwise be disposal cost liabilities into additional revenue streams, improving overall system economics and reducing environmental impact.

6. Policy, Institutional, and Technological Enablers

The realization of artificial pool aquaculture's bioeconomy potential in Turkmenistan is contingent on the development of a coherent and adequately resourced policy and institutional architecture. At the national policy level, the establishment of a dedicated Aquaculture Development Strategy—aligned with Turkmenistan's broader National Programme for Socioeconomic Development and food security objectives—would provide the overarching framework for coordinating investment incentives, regulatory development, research programming, and international technical cooperation in the sector.

Regulatory frameworks governing water allocation for aquaculture, fish health and disease management, food safety certification, and environmental impact assessment must be developed or strengthened to provide the legal clarity and investor confidence necessary to attract private investment in aquaculture infrastructure. Turkmenistan's current regulatory environment for aquaculture is underdeveloped relative to regional comparators, creating uncertainty that has historically impeded private sector engagement. Benchmarking and adapting regulatory frameworks from more advanced regional aquaculture jurisdictions—including Kazakhstan, which has developed a relatively sophisticated aquaculture regulatory architecture—represents an efficient pathway for accelerated institutional capacity development.

Technology transfer partnerships with leading aquaculture technology providers from Norway, Israel, China, and Japan offer critical pathways for accessing RAS design expertise, feed formulation knowledge, disease management protocols, and genetic improvement programs for priority species. International organizations including the FAO, the Asian Development Bank, and the United Nations Development Programme (UNDP) have established technical assistance programs in Central Asian aquaculture development that Turkmenistan has yet to fully engage, representing an underutilized resource for capacity building and knowledge transfer.

Human capital development is a prerequisite for sustainable aquaculture sector expansion. Turkmenistan currently lacks a critical mass of trained aquaculture technicians, fish health specialists, and aquaculture business managers capable of operating sophisticated artificial pool systems. Establishing dedicated aquaculture training programs within the national agricultural university system, combined with international scholarship and exchange programs, would progressively build the human resource base necessary to support sector growth. Knowledge extension services connecting academic and research institutions with commercial producers are equally important for ensuring that emerging best practices in aquaculture technology and management reach operational-level practitioners.

7. Sustainability Integration and Circular Economy Alignment

The development of artificial pool aquaculture in Turkmenistan must be framed within a comprehensive sustainability architecture that addresses the environmental, social, and economic dimensions of sector development in an integrated manner. Water resource management represents the most critical sustainability challenge: aquaculture development must be designed and regulated to ensure that water withdrawals from the Amu Darya, the Karakum Canal system, and other sources do not exacerbate existing water stress or conflict with agricultural and municipal water demands. Prioritizing water-efficient RAS technologies, reuse of agricultural drainage water for less water-quality-sensitive aquaculture applications, and integration with water treatment infrastructure can substantially reduce the sector's freshwater footprint.

Biodiversity conservation considerations require that artificial pool aquaculture development avoid introduction of invasive species into natural water bodies, prevent genetic contamination of wild fish populations through escaped farmed fish, and maintain biosecurity protocols that minimize disease transmission risk between farmed and wild populations. The development of land-based, fully enclosed artificial pool systems—rather than open-water cage installations in the Caspian Sea or canal networks—substantially reduces these ecological risks while maintaining productive capacity, representing the environmentally preferable system design paradigm for Turkmenistan's specific ecological context.

Alignment with the United Nations Sustainable Development Goals provides a compelling normative framework for Turkmenistan's aquaculture bioeconomy strategy. SDG 2 (Zero Hunger) is directly advanced through expanded domestic fish protein supply; SDG 8 (Decent Work and Economic Growth) through rural employment creation and non-hydrocarbon sector development; SDG 12 (Responsible Consumption and Production) through circular aquaculture system design and waste valorization; SDG 14 (Life Below Water) through reduced wild capture fishing pressure on Caspian ecosystems; and SDG 6 (Clean Water and Sanitation) through water-efficient aquaculture technologies that reduce per-unit water consumption relative to conventional production systems.

8. Conclusion

This paper has demonstrated that artificial fishing pools represent a strategically compelling and technically viable instrument for advancing bioeconomy development in Turkmenistan, offering an integrated pathway toward improved food security, economic diversification, rural employment generation, and sustainable natural resource management. The convergence of ecological imperative—arising from the degradation of Caspian wild fisheries and the scarcity of natural water bodies suitable for conventional aquaculture—with economic necessity—driven by Turkmenistan's urgent need to reduce hydrocarbon revenue dependence—creates a powerful strategic rationale for artificial pool aquaculture development as a national priority.

The theoretical frameworks of bioeconomy strategy, Blue Economy principles, and Ecological Modernization Theory collectively provide robust justification for the proposition that technologically sophisticated, resource-efficient artificial pool systems can reconcile productive economic ambitions with ecological sustainability imperatives in Turkmenistan's challenging environmental context. The analysis of species selection, water management technology, circular system design, and waste valorization opportunities demonstrates that artificial pool aquaculture in Turkmenistan need not be conceived merely as a food production technology, but as a comprehensive bioeconomy platform capable of generating multiple, mutually reinforcing streams of economic, social, and ecological value.

Realizing this potential requires coordinated action across multiple policy domains: the development of an enabling regulatory and institutional architecture, strategic public investment in research and demonstration infrastructure, facilitated technology transfer from international partners, systematic human capital development programs, and the cultivation of market linkages connecting Turkmen aquaculture producers with domestic and regional consumer markets. The international development community—including the FAO, UNDP, and Asian Development Bank—represents an underutilized resource for accelerating this institutional development agenda through technical assistance and knowledge transfer.

Future research should prioritize site-specific techno-economic feasibility assessments for artificial pool aquaculture in key Turkmenistani regions, detailed environmental impact analyses of proposed system designs, consumer preference studies to guide species selection and product development, and comparative policy analysis evaluating the applicability of aquaculture governance models from regional comparators to Turkmenistan's institutional context. As global demand for sustainably produced aquatic protein continues to grow and water scarcity intensifies worldwide, the innovative aquaculture approaches being developed in arid-zone contexts such as Turkmenistan will acquire increasing relevance for the global bioeconomy research and policy communities.

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