Economic Value Transformation of Soil and Water Conservation Ecological Products in Check-Dam-Controlled Watersheds: A Literature Review

Qi Ren[1], Yuefeng Guo[1,*], Jing Feng[2], Zhiqiang Shang[2], Lina Gao[2], Tiegang Zhang[3], Wei Qi[4]
[1]College of Desert Control Science and Engineering, Inner Mongolia Agricultural University, Hohhot, Inner Mongolia, China
[2]Inner Mongolia Autonomous Region Water Conservancy Science Research Institute, Hohhot, Inner Mongolia, China
[3]Institute of Animal Husbandry, Academy of Agricultural and Animal Husbandry Sciences, Inner Mongolia Autonomous Region, Hohhot, Inner Mongolia, China
[4]Inner Mongolia Autonomous Region Water Conservancy Development Center, Hohhot, Inner Mongolia, China
**Corresponding Author*

Abstract: In addition to soil and water conservation, which is the primary function of check dams, the dams on the Loess Plateau produce other ecological products – carbon sequestration, arable land replenishment, flood regulation and biodiversity maintenance – that are multi-dimensional in nature. In the context of China's dual-carbon goals and the new system of ecological product value realization, the valuation and exchange of these products in the market has become a cutting-edge issue in the fields of soil and ecological economics. This paper will provide a structured review of the four dimensions: conceptual boundaries, valuation methodologies, economic transformation pathways and institutional safeguards. It integrates advances in emergy analysis, replacement cost approaches, spatially explicit modeling and carbon accounting approaches specifically developed for check-dam systems. Four fundamental transformation models are identified and analyzed using representative cases: carbon credit trading model, farmland quota trading model under requisition-compensation balance mechanism, concession-based watershed operation model and green financial collateralization model. The review also identifies several chronic gaps: the lack of integration of accounting standards, lack of mechanisms to aggregate value and share revenues across different scales, lack of empirical evidence on pricing efficiency, lack of benefit-reinvestment feedback mechanisms, and a virtual absence of research on value stability in the face of extreme-event shocks. The shift from demonstration to scale implementation has begun, but the field still faces significant challenges to make further progress and reach institutional maturity in the areas of standardized accounting frameworks, cross-agency governance arrangements, and long-lasting incentive-compatible mechanisms.

Keywords: Check Dam; Soil and Water Conservation; Ecological Products; Value Transformation; Carbon Trading; Payments for Ecosystem Services; Loess Plateau

1. Introduction

The Loess Plateau is unique in its support of the highest rates of soil erosion anywhere in the world. Over the past six decades, there have been more than 58, 000 check dams built in this area and these have collectively trapped 7. 4 billion tons of sediment, as well as altering watershed hydrology and regional microclimate to a large extent beyond the engineering expectations[12]. Since the Grain-for-Green Program was introduced in the late 1990s, the annual sediment load of the Yellow River has decreased from about 1. 6 billion tons to about 186 million tons[3]. Today, check dams and revegetation are the two cornerstones of the Platform's soil conservation system.

Yet, a structural challenge has always been a hurdle in the current governance model: ecological values are largely held back as unpriced positive externalities and conservation investments rely heavily on fiscal transfers from the central government. The circular relationship of economic development and ecological protection, with conservation itself providing returns that can be invested in natural protection, has been missing in action[4]. The services provided by the check dam to retain sediments, control streamflow and sequester carbon have been well documented in the scientific literature, but have traditionally stayed hidden in the check dam's dormant asset register.

The policy landscape began to shift decisively after 2020. China's dual-carbon pledge created an institutional channel through which the value of carbon sequestration could be measured, certified, and traded[5]. In 2024, three central ministries jointly issued an opinion on establishing mechanisms for realizing the value of soil and water conservation ecological products in clean small watersheds, marking the first national-level policy framework for pricing and trading these products[6] In December 2025, the methodology for check-dam carbon sinks under the China Certified Emission Reduction (CCER)program was officially released, granting check-dam carbon credits formal access to the national voluntary carbon market[7] A group standard for carbon sink accounting in small watershed management on the Loess Plateau was approved in September 2025, and the national technical specification for soil and water conservation carbon sink evaluation took effect in June 2026. On the ground, 35 transactions of soil and water conservation ecological products had been completed across the Yellow River Basin by May 2026, with a total transaction value of 243 million yuan—all proceeds earmarked for further erosion control and rural revitalization A rough projection suggests that basin-wide carbon trading based solely on existing conservation achievements could generate approximately 40 billion yuan in ecological revenue, without additional investment[8].

This paper undertakes a structured review of the emerging literature on economic value transformation of soil and water conservation ecological products in check-dam-controlled watersheds. It unfolds across four dimensions of analysis: conceptual delineation, valuation methodology, pathways of transformation, and enduring challenges, and to provide a base framework for future studies.

2. Conceptual Foundations and Analytical Framework

2.1 Check-Dam-Controlled Watersheds and Their Ecological Products

Here the term "check-dam-controlled watershed" is used as an operational construct to describe a hydrological catchment unit defined by a single check dam (or more often a nested system of dams)as a hydrological node. It usually corresponds to the gully-channel network which drains to one or more important dams. The dam controlled watershed is more causally connected than administrative boundaries for the purposes of conservation interventions and the resulting supply of ecological products – the dam provides control over water and sediment inputs from upstream slope and gullies, which reshaped spatiotemporal water–sediment transport patterns and, in turn, altered biogeochemical cycling of carbon, nitrogen, and phosphorus[9].

The location of the check dams on the Loess Plateau, where gully densities vary between 3 and 6 km/km2 and dam systems are based on the premise of 'numerous small dams supported by key backbone dams[10] dictates the ecological product supply heterogeneity among different watersheds. This "dam-type–function–product" relationship is a major analytical theme throughout this review. Ecological products from soil and water conservation can be classified using the tripartite framework established by the 2022 national guidelines for gross ecosystem product (GEP)accounting: material supply (agricultural and forestry products, water resources), regulating services (carbon sequestration, water conservation, soil retention, flood mitigation), and cultural services (ecotourism, health and wellness)[11] This framework is broadly isomorphic with the Millennium Ecosystem Assessment taxonomy[12]. When projected onto the check-dam watershed setting, six subcategories emerge: (a)carbon sink products—tradeable credits derived from sediment-trapped carbon preservation and post-siltation biomass increment; (b)arable land replenishment products—high-fertility dam-fields and their associated land quota indicators under China's farmland requisition-compensation balance system; (c)water provisioning products—irrigation and drinking water supplied by micro-reservoirs impounded behind check dams; (d)flood regulation products—downstream risk reduction from peak attenuation by dam cascades; (e)sediment regulation products—costs avoided in reservoir dredging and channel maintenance; and (f)cultural and recreational products—wetland landscapes and agro-ecological park systems derived from dam-formed environments. The first two categories enjoy the most mature institutional channels and exhibit the highest degree of marketization.

2.2 Theoretical Underpinnings of Value Transformation

The origins of ecological product value transformation lie in three lines of scholarship. The first is the theory of externalities, which dates back to Pigou and Coase, and which was the source of the efficiency argument for transformation. The Pigouvian route – correcting positive externalities by means of subsidy or fiscal transfers – is the one that is reflected in the implementation of ecological compensation schemes; the Coasean route – internalizing externalities through market transactions based on well-defined property rights – is that on which carbon and water rights trading are based. The existing policy regime of the check-dam products in China is actually a combination of both[1314]. The second lineage is the ecosystem services valuation tradition, galvanized by Costanza et al. 's landmark 1997 Nature paper that placed a global price tag on natural capital and subsequently refined by de Groot et al. and the TEEB (The Economics of Ecosystems and Biodiversity)initiative[15-17]. The third lineage Ostrom's institutional analysis of common-pool resources. Ostrom's institutional analysis of common-pool resources is resource governance, that addresses directly. There are challenges in collective-action in the management of The check dams systems with carbon sequestration constitutes a pure public good, dam-fields are used to represent common-pool resources, and irrigation water is a "toll goodError! water is a toll good Unknown switch argument. These three lineages, combined, Respond to the motivational question, respectively, The measurement question (how many, how much, how long, far, how fast, etc.)would also be included. Which of the following do you think is important? a lot, a little, not much, none)and governance question (who decides and to whom)[18].

3. Advances in Valuation Methodology

3.1 A Comparative Overview of Valuation Approaches

There are four general classes of valuation approaches that have been used for ecosystem services in the context of the check-dam, and each have different spheres of application. Replacement cost approaches are the simplest, in which the value of an ecosystem function is based on the cost of an engineered alternative that provides the same function. For example, the shadow engineering method was used to estimate the flood storage capacity of the Kuye River Basin and determine that the flood storage capacity of the check dams accounted for 48. 9% of the total flood storage capacity of the basin, totaling 463 million yuan based on the construction cost of a unit reservoir[19]. While convenient for computational purposes and easy to understand for policy audiences, these estimates systematically underestimate the co-benefits that are generated from natural systems

The core idea of emergy analysis, pioneered by Odum, is to measure all energy, material and monetary flows in the ecological-economic system in a common unit, solar emjoules (sej), and to bypass the distortions of market prices[20]. This framework was applied to typical check dams in Jingbian County, Shaanxi, and an indicator system was built which included renewable resource emergy, non-renewable resource emergy, purchased inputs and outputs divided into the sediment retention benefits, flood control benefits, irrigation benefits, aquaculture benefits, and land creation benefits. The results ranked outputs as irrigation > sediment retention > land creation > aquaculture > flood control, with emergy investment ratios and environmental loading ratios in reasonable ranges but sustainability indices consistently below unity—indicating persistent dependence on external inputs[21]. While emergy analysis elegantly sidesteps the problem of missing or distorted markets, the unit emergy values assigned to resource inputs carry considerable subjectivity; the same resource element can exhibit several-fold variation across published studies, and the sej-denominated output resists direct conversion into the monetary price tags required for market transactions.

Spatially explicit models, exemplified by the InVEST suite developed by Stanford's Natural Capital Project, quantify multiple ecosystem services at the raster scale and generate spatial supply maps that can inform the delineation of trading boundaries[22]. Hu et al. 's analysis of the Loess Plateau demonstrated that when check-dam construction and the Grain-for-Green Program are jointly implemented, inter-regional flows of carbon sequestration, water conservation, flood regulation, and soil water retention exhibit statistically significant enhancement ($p < 0.01$), with synergistic effects most pronounced in the western portion of the study area[23]. The limitation of InVEST and its analogues is their sensitivity to input parameterization and their inability to directly output monetized valuations. Stated- and revealed-preference methods, including contingent valuation and travel cost approaches, have seen limited application in the check-dam context thus far, although they hold potential for valuing the cultural and recreational services of dam-formed landscapes[24].

3.2 Methodological Breakthroughs in Check-Dam Carbon Accounting

Carbon accounting represents the subfield of greatest policy urgency within check-dam ecological product valuation. The traditional approach assumed spatial homogeneity—equal thickness and equal carbon content across the dam's sediment profile. Field investigations led by Zhang Yi's research group revealed a previously overlooked phenomenon: the "upturned tail" effect, wherein the sediment deposition surface extends progressively upstream from the dam body, with varying energy conditions and sorting mechanisms at different positions generating pronounced heterogeneity in the horizontal and vertical distribution of organic carbon[25]. The team replaced the homogeneity assumption with an energy-dynamics framework: because sediment particle sorting follows the attenuation law of flow kinetic energy, and organic carbon preferentially binds to clay fractions, a particle-size–energy–carbon-content linkage model can be constructed to estimate carbon stocks on a physically grounded basis. For vegetation biomass carbon, the team abandoned the conventional diameter at breast height (1. 3 m)in favor of basal diameter at 20 cm above ground, better suited to the irregular tree forms characteristic of unmanaged plantations in semi-arid environments, and established growth curves for over 20 endemic tree and shrub species in Pengyang County, Ningxia[26].

The CCER methodology for check-dam carbon sinks, released in December 2025, incorporated these advances, specifying baseline scenarios, additionality demonstration, carbon pool selection (with soil organic carbon and vegetation biomass as primary pools), leakage calculation, and monitoring requirements[7]. A field validation in Gaoxigou Village, Mizhi County, Shaanxi—involving UAV remote-sensing interpretation combined with mechanical drilling to depths of 24 meters across five check dams—certified a net carbon preservation of 27, 620. 16 tCO_2 equivalent. The resulting 20, 000-ton credit sale at 75 yuan per ton set a national record for soil and water conservation carbon pricing[27].

3.3 Fragmentation in the Standards Iandscape

Notwithstanding these advances, the standards architecture remains fragmented. As of mid-2026, applicable standards include the national technical specification (SL/T 872–2026), the CCER-specific check-dam carbon methodology, at least one group standard for Loess Plateau small watersheds, and an assortment of provincial accounting protocols with divergent assumptions regarding system boundaries, eligible carbon pools, baseline-setting rules, and uncertainty treatment[28]. This fragmentation inflates transaction costs: the same check-dam project may yield materially different carbon estimates depending on the chosen methodology, undermining market credibility. A further problem is scale: most valuation studies focus on the individual dam or single small watershed, yet the carbon market, ecological compensation pools, and green financial instruments operate at provincial or basin scales. The mechanisms for aggregating project-scale valuations into tradeable asset packages, and for decomposing transaction revenues back to the dam-management entities responsible for ongoing maintenance, remain undertheorized.

4. Economic Transformation Pathways and Practice

4.1 Carbon Credit Trading

Carbon trading is the most well-institutionalized pathway. As simple as that, the more emissions it can save through the sediment carbon preserved by the check-dam, the more it can sell to compliance entities looking for carbon credits.

In 2024, the first soil and water conservation carbon trade in the Yellow River Basin was successfully completed in Licha Watershed, Pengyang County, Ningxia, with a total of 36, 000 tons of carbon credits valued at 1. 116 million yuan[29]. being traded. By the early of 2025, the transaction of Gaoxigou in Shaanxi had reached 75 yuan/ton, a price significantly higher than the 50-60 yuan/ton range of forestry CCER credits[27]. By 2026, 13 provinces had set up soil and water conservation carbon trades[30]. The price spread is worth investigating: it could be a scarcity premium due to the increased complexity of the check-dam methodologies, and a higher verification cost due to buyers' valuation of the ecological co-benefits associated with check-dam carbon, or a demonstration-effect premium on the first few policy-driven transactions. Understanding and separating the contribution of each of these is essential to an equilibrium in the market that is sustainable.

4.2 Farmland Quota Transfers under the Requisition-Compensation Balance

Dam-fields formed by siltation over decades, have deep soil profiles, high organic matter content and flat topography, and meet the requirements for quality for compensation farm land under the "occupy one, replenish one" policy in China. Ningxia was the first place to conduct a survey on 704 large and medium check dams, with about 1, 070ha of possible dam-field to be converted. In September 2025, 91. 76 mu of farmland from Fantai Check Dam, Haiyuan County was added to the farmland quota after passing provincial verification of the natural resources department[31]. The first transaction of farmland quotas created by a check dam took place the following month in Yulin, Shaanxi: 41. 38 mu of newly created farmland from the Yulingou Dam was sold for 2. 5035 million yuan[32]. The conceptual relevance of the pathway is that it recasts dam sedimentation, which has been considered up to now simply as a result of sediment management, as a land capital formation process. However, a thorny question remains unresolved: when the same dam-field parcel participates simultaneously in carbon trading (the sequestered carbon having been sold), farmland quota trading (the development rights having been transferred), and collective agricultural production (yielding crop income), how are the boundaries among these layered rights to be demarcated, and does concurrent participation constitute double counting?

4.3 Concession-Based Operations and Green Finance

Unlike the single-element transactions described above, the concession-based integrated operation pathway treats the dam-controlled watershed as a bundled ecological asset portfolio, packaged for market through management right transfers, concession agreements, or joint development arrangements. In September 2025, Ningxia completed a batch of 12 ecological product transactions spanning agricultural products, cultural tourism, and health and wellness services, generating over 12. 4 million yuan and leveraging an additional 63. 8 million yuan in private investment for ecological and productive infrastructure[33]. In Gansu, the Shangping Watershed in Dingxi transferred its management rights for 31. 6 million yuan, and the Yaoshuigou Watershed in Lanzhou achieved a comprehensive transaction valued at 60. 16 million yuan Xiao Peiqing's team at the Yellow River Hydraulic Research Institute developed 16 region-specific ecological product accounting models for Ningxia, expanding the indicator set from 23 to 39 items spanning planting, tourism, and wellness industries.

The green finance pathway is based on other logic: green finance does not sell the ecological products, but instead uses the value of ecological products as the collateral to enhance credit. In Xiji County, Ningxia, the Longwangba Watershed was able to leverage their ecosystem service valuations as credit collateral to get a loan of 1 million yuan from the Bank of Ningxia, a small but significant proof of concept for the “resources → assets → capital → reinvestment” cycle. These are structural bottlenecks: financial regulators have not yet followed this development and have yet to recognise ecological asset appraisal standards for the purposes of collateral; there is no active market for the disposal of such collateral in case of default; and the risk of ecological asset value impairment, e. g. by extreme rainfall events that could breach check dams and release sequestered carbon, is not easily accommodated by conventional credit risk models.

4.4 Relationships among the Four Pathways

These four pathways are not mutually exclusive, but rather complementary, aligned to various types of ecological products and also different stages of value realization. Carbon and farmland quota trading apply to the market for standardisable goods with fairly clear rules for operating the market. In concession-based operations, integration creates value out of the premium that is hidden in the non-standardized element of the experiential value and where business model innovation and market cultivation have a greater influence. Green finance is about the temporal dimension, that is, monetising ecological revenues at the present in the future. The "bundle of rights" issue has been a theoretical puzzle: When carbon rights, land development rights, water rights and operational rights are placed together on the same check-dam watershed, which is the right of the owner, what are the limitations of the rights and how can these be separated for different rights transactions without double exploitation? Although the separation of mineral extraction rights, exploration rights and surface use rights in the mining industry shares some traits with the ecological products problem, the body of scholarship that treats it has been scant.

5. Regional Practice and Persistent Research Gaps

5.1 Divergent Provincial Approaches

Pathway selection is influenced by local conditions, as can be seen from the experiences of Ningxia, Shaanxi and Gansu. Ningxia took the "institutions first, standards driven" approach, having conducted a provincial carbon sink capacity survey, and worked with Tsinghua University and the Yellow River Hydraulic Research Institute to create 16 specific accounting models for the region, and seeing the first batch of 12 ecological product parcels in one signing event. Shaanxi focused on methodological innovations and high price in carbon markets, and Gaoxigou benchmarked at 75 yuan/ton indicated quality throughout the fledgling market[27]. Due to the geopolitical features of Gansu, where the province's watersheds are densely dammed and the size of each dam is relatively small, Gansu tended to be involved in comprehensive watershed-scale concession operations, with Dingxi and Lanzhou being among the largest transactions in the Yellow River Basin [8].

A provisional generalization emerges: pathway choice is jointly constrained by the structural composition of local dam inventories (the ratio of backbone to small dams), the degree of regional marketization, and local government institutional capacity. Densely networked, small-dam regions suit watershed-level bundled development; regions with a high proportion of large backbone dams enjoy pricing advantages in carbon markets; provinces with strong institutional supply capacity and access to external intellectual resources can achieve first-mover advantages in standardized batch trading. This typology offers an initial decision heuristic for regions contemplating their own pathway choices.

5.2 Persistent Problems and Research Gaps

Five clusters of problems emerge from the existing literature and practice. First, the comparability deficit in valuation methodologies: the absence of systematic controlled comparisons—applying multiple methodologies to the same set of check dams and quantitatively decomposing the sources of inter-method divergence—undermines the credibility of valuation data as a basis for pricing. Second, the cross-scale transformation lacuna: project-scale valuations and market-scale transactions are linked by aggregation and distribution mechanisms that remain conceptually specified but empirically unexamined. Third, the pricing efficiency gap: the observed range of carbon prices from approximately 31 to 75 yuan per ton[2729] cannot be decomposed into contributions from objective quality differences (permanence, monitoring precision), buyer willingness-to-pay heterogeneity, and bargaining-power asymmetries without micro-transaction-level data and hedonic price modeling. Fourth, the benefit-reinvestment design deficit: allocating transaction revenues in a manner that genuinely reaches dam-management entities rather than being absorbed by administrative overhead, and that avoids free-riding and collective-action failure, requires incentive-compatible allocation rules whose properties have not been systematically analyzed. Fifth, almost complete lack of value stability under extreme-event shocks: if an extreme rainfall event happens that breach a check dam and release sequestered carbon, it would be a "reversal" of a certified carbon sink and raise questions about permanence guarantees, insurance instruments, and the need for buyback or cancellation mechanisms in carbon contracts—all of which are not within the current research agenda.

6. Research Prospects and Concluding Remarks

A number of directions warrant attention in the near future. Systematic calibration experiments using different accounting methodologies over a common cohort of dams would greatly enhance the evidence base for standards harmonization, as the various methods are applied and differences are tracked back to their parametric and structural sources. These could be supplemented with Monte Carlo uncertainty propagation analysis to provide outputs from the valuation with confidence intervals, which would make the outputs more credible for market participants. The second is that the new 'bundle of rights' approach to ecological products needs to be developed theoretically. The carbon rights, land development rights, water abstraction rights and operational rights negotiated in a traditional dam-controlled watershed should be separately defined in terms of their beneficiaries, extent and transferability, which would lay the groundwork for the concept of "layered titling" and separate trading of different products from the same landscape unit.

Third, micro-transaction data could be collected and analyzed to decompose prices into the value of quality attributes and the institutional features, thereby moving from bilateral bargaining to benchmark pricing with quality premia. Fourth, quasi-experimental research designs using representative watersheds could be used to compare the causal impact of such alternative rules for distributing money on maintenance behavior, ecological performance and distributive equity, rather than making a normative statement. Finally, integrating the check-dam carbon story in the broader picture of water infrastructure carbon management—including organic carbon burial in the trunk and tributary reservoirs, clean energy displacement from hydropower, and energy savings from irrigation efficiency—methodologically would drive a shift in the domain of water infrastructure carbon management from assuming carbon neutrality toward comprehensive carbon footprint analysis.

Overall, the economic value transformation of soil and water conservation ecological products in check-dam-controlled watersheds is attributed to the cumulative ecological dividends provided by decades of large-scale soil and water conservation efforts on the Loess Plateau and it is a significant testbed for institutional innovation for ecological civilization in the dual-carbon strategy. The field has evolved from policy ice-breaker to standards scaffolding to on-the-ground transactions in just over two years and in several provinces. The four models of transformation – carbon trading, farmland quota transfer, watershed concession operations and green financial collateralization – have taken familiar shape. But there is a long road ahead from scattered successes to institutional success. The coordination of accounting rules, the delineation of layers of property rights, the improvement of market pricing efficiency, the design of incentive-compatible benefit reinvestment mechanisms, and the development of risk management rules for extreme events is the main research and policy agenda for the future. The change of the check dam from an engineering structure to a resilient institutional mechanism that transforms 'lucid waters and lush mountains' into 'invaluable assets' will occur only when a body of knowledge, based on empirical validation of the questions mentioned above, has been established.

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