

Article

The Dual Structure of Ecological Damage Liability Alternative Fulfillment in China: Based on AHP-Fuzzy Comprehensive Evaluation Method

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Abstract

The alternative fulfillment mechanism for ecological and environmental damage liability represents a pivotal institutional innovation. Its principal function is to enable liable parties—under exceptional circumstances—to flexibly fulfill their ecological and environmental damage liability. This study adopts an empirical research method to systematically investigate the judicial application of the alternative performance mechanism. Findings reveal that under the guidance of the restorative justice concept, courts increasingly subsume diverse alternative performance modalities under the category of “alternative restoration”, leading to the gradual distortion of the alternative restoration centered on the concept of “equivalent restoration” into a “universal solution” for ecological damage cases. This practical tendency significantly weakens the actual effectiveness of ecological restoration. The purpose of this study is to establish a dual mechanism of alternative fulfillment—distinguishing between alternative restoration and alternative compensation—based on ecological principles and within the framework of the dual responsibilities of “restoration—compensation” for ecological environmental damage. The effectiveness of the dual mechanism is quantitatively evaluated using the AHP-fuzzy comprehensive evaluation. The evaluation results show that, after distinguishing between the two types of alternative responsibilities, the comprehensive evaluation scores for ecological damage remedy in cases of ecological destruction, water pollution, and soil pollution increased from 5.155 to 8.935, from 6.406 to 9.116, and from 6.137 to 9.108, respectively, effectively correcting the functional deviation of the current single-dimensional remedy model. This study clarifies the independent application criteria of alternative restoration and alternative compensation, and provides targeted optimization paths for the judicial application of ecological damage remedy.

Keywords: liability for restoration; liability for compensation; alternative restoration; alternative compensation; restorability

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1. Introduction

1.1. Research Question

Ecological and environmental damage encompasses the detrimental alterations to environmental components such as the atmosphere, surface water, groundwater, soil, and forests, as well as biological elements such as plants, animals, and microorganisms, caused by environmental pollution and ecological destruction, as well as the degradation of the functions of the ecosystems composed of these elements. Ecological and environmental security is closely related to the health and development of all mankind. Therefore, how to effectively remedy ecological and environmental damage through legal means has become a global focus. In 2004, the European Union passed the Environmental Liability Directive on the Prevention and Remediation of Environmental Damage (hereinafter referred to as the “Environmental Liability Directive”). This legislation established a unified European framework for environmental liability, with the primary objective of preventing and remedying harm to air, water, land, protected species, and natural resources [1]. Similarly, China has made substantial progress in this domain. In 2015, the Chinese government officially launched the pilot program for the reform of the ecological and environmental damage compensation system, establishing an ecological and environmental damage compensation system based on the principle of “full compensation”. The core of this system lies in following the logic of “restoration as the main approach and compensation as a supplement” for damage remediation, and comprehensively filling the ecological and environmental damage through the combined use of “restoration” and “compensation” as two remedial measures to maintain the stability of the ecosystem [2]. After the promulgation of the Civil Code in 2020, the legislative level officially confirmed the dual responsibility system of “restoration—compensation” for ecological and environmental damage, marking the completion of the full cycle from procedural construction to substantive empowerment of China’s judicial remedy system for ecological and environmental damage [3].

The responsibility for ecological and environmental damage needs to be put into practice through specific forms of liability. Within the current system of ecological and environmental damage liability in China, there are two ways to assume the responsibility for ecological restoration: direct restoration and alternative restoration. The former entails rehabilitating the damaged area in situ, ensuring that its ecological service functions are restored to a state comparable in type and quality to the baseline conditions prior to damage [4]. The latter is a supplementary and extended form of restoration that differs from direct restoration, offering flexibility when direct restoration is impractical or insufficient [5]. In recent years, in order to implement the damage remedy system centered on “ecological environment restoration”, judicial authorities have continuously explored diversified restoration methods. Due to the flexibility and wide range of “substitution”, alternative restoration has become the most active field of innovation. However, given that some of the methods deviate from the goal of ecological recovery and are difficult to genuinely restore ecosystem service function, it has thus triggered widespread controversy over their effectiveness and legitimacy.

This study, by using the China Judgments Online and the “PKULAW” legal database, conducted a full-text search with the keyword “alternative restoration” from the promulgation of the Civil Code of the People’s Republic of China in 2020 to January 2026, and selected 140 valid cases that applied the “alternative restoration liability”. The statistical results show that the practical scope of alternative restoration presents diversified characteristics: including tree replanting (22.15%), fish stocking (17.14%), construction of wetlands or artificial habitats (5.71%), participation in public welfare labor (27.14%), purchase of carbon credits (23.57%), and technological transformation (4.29%), etc. (see Figure 1).

Empirical research indicates that some alternative restoration methods, such as participation in public welfare labor and technological transformation, are not aimed at restoring the ecological environment and its service functions, but rather tend to reduce or replace monetary compensation through behavioral performance. In fact, they play the role of alternative fulfillment of ecological environment damage compensation liability rather than restoration liability (see Table 1). These methods being included in the category of “alternative restoration” not only fail to achieve the restoration goal but also easily lead to substitution or confusion between restoration liability and compensation liability (for example, in Case 1, the court regarded alternative restoration as a way to fulfill compensation liability and in Case 6, the court regarded cash compensation as an alternative restoration plan). To avoid this predicament, this article believes that it is necessary to reflect on judicial practice and conduct systematic research on the legal attributes and application standards of various alternative fulfillment methods.

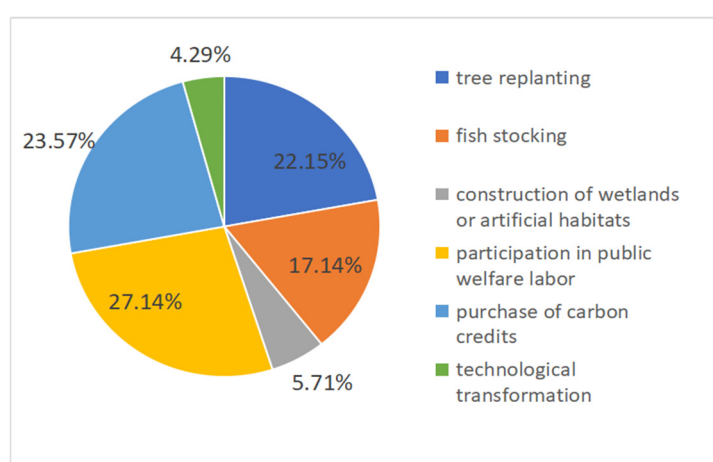


Figure 1. Distribution of “Alternative restoration” methods from 2020 to 2026.

Table 1. Confusion of remediation liability and compensation liability in some alternative restoration cases.

Case Name	Alternative Restoration Methods	Facts and Reasons, Judgment Result
Case 1: The Supreme People’s Court released the fifth typical case of maritime trials across the country in 2022: The Civil Public Interest Litigation Case of the People’s Procuratorate of Ningde City, Fujian Province v. Lin Mou et al. Regarding Marine Natural Resources and Ecological Environment [6]	participation in public welfare labor	Lin instructed Gao to drive a vessel to illegally extract sea sand 17 times. The court presided the parties involved to reach a mediation agreement on the compensation for the losses involved in the case, which is adopting an “alternative restoration” approach to fulfill the compensation liability: the remaining compensation shall be fulfilled by the two defendants through public welfare labor compensation.
Case 2: The second of the 10 typical cases of ecological environment procuratorial work released by the Supreme People’s Procuratorate: The Public Interest Civil and Criminal Attached Litigation Case of the People’s Procuratorate of Jiujiang District, Wuhu City, Anhui Province against Huang et al. (24 individuals) and Anhui Certain Technology Co., Ltd. et	technological transformation	Eight enterprises discharged 23,125 tons of hazardous waste directly into the Yangtze River, resulting in ecological damage with estimated environmental losses exceeding 106 million yuan. Facing financial constraints that prevented immediate payment of the full environmental compensation, the court granted an alternative restoration plan involving technological upgrades to fulfill the part of compensation obligation.

al. (8 enterprises) for Environmental Pollution [7]

Case 3: The Sichuan Higher People's Court released the eighth of the top ten typical cases of ecological environment judicial protection in 2023: The Civil Public Interest Litigation Case of the People's Procuratorate of Guangyuan City v. a Slaughterhouse in Guangyuan City for Environmental Pollution [8]

technological transformation

The Intermediate People's Court of Guangyuan, taking into account the enterprise's actual operational and developmental circumstances, facilitated a mediation agreement between the public interest litigation plaintiff and the defendant slaughterhouse: the slaughterhouse is obligated to fulfill its alternative restoration responsibilities through technological upgrades.

Case 4: The Third of the Top Ten Typical Cases Released by Qingdao Maritime Court for World Oceans Day 2024: The Civil Public Interest Litigation Case of Qingdao People's Procuratorate v. Zhang Moumou Regarding Marine Natural Resources and Ecological Environment—Adhering to the Restorative Justice Concept and Promoting the Improvement of Protective Compensation System in Marine Environmental Public Interest Litigation [9]

Purchase carbon credits

Zhang Moumou and six other crew members operated a fishing vessel in the Yellow Sea, where they illegally harvested 7955 kg of wild scallops. The Qingdao Maritime Court determined that Zhang Moumou could fulfill restoration liability by purchasing the corresponding carbon credits through the blue carbon trading market or by investing the compensation into suitable carbon sequestration projects.

Case 5: Xiong Mou Illegal Hunting, Purchasing, Transporting and Selling of Terrestrial Wildlife Case [10]

participation in public welfare labor

Defendant Xiong Mou engaged in illegal hunting of terrestrial wild animals without obtaining the required hunting license or following proper legal procedures. The court ruled that the defendant should pay the remaining amount by participating in mandatory public-interest labor, using it as a form of alternative restoration.

Case 6: The Supreme People's Court released the third typical case of environmental resource trial for 2024: Criminal and civil public interest litigation case involving a certain resin technology company, Xue and others for environmental pollution [11].

technological transformation

A technology company violated national regulations by directly discharging over 20,000 tons of hazardous waste, namely waste acid liquid, into the main stream of the Yangtze River through concealed pipes. The company should pay a huge amount of ecological environment restoration fees. However, the People's Court held multiple discussions and deliberations with the procuratorial organs, environmental protection departments, the involved enterprise, and the South China Institute of Environmental Sciences under the Ministry of Ecology and Environment to explore and verify alternative restoration plans: cash compensation plus technological transformation.

1.2. Literature Review

In foreign research, the EU's Environmental Liability Directive (ELD) establishes a series of preventive and remedial measures for environmental damage, demonstrating strong foresight and modernity. Remedial measures means any action, or combination of actions, including mitigating or interim measures to restore, rehabilitate or replace damaged natural resources and/or impaired services, or to provide an equivalent alternative to those resources or services as foreseen in Annex II [12]. As indicated in Annex II: Remedying of environmental damage is achieved through the restoration of the environment

to its baseline condition by way of primary, complementary and compensatory remediation. Primary remediation is any remedial measure which returns the damaged natural resources and/or impaired services to, or towards, baseline condition. Complementary remediation is any remedial measure taken in relation to natural resources and/or services to compensate for the fact that primary remediation does not result in fully restoring the damaged natural resources and/or services. Compensatory remediation is any action taken to compensate for interim losses of natural resources and/or services that occur from the date of damage occurring until primary remediation has achieved its full effect [13]. The remedial measures in the “Environmental Liability Directive” are roughly equivalent to the restoration measures in the US’s “Oil Pollution Act”. The “restoration” clause in the US “Oil Pollution Act” encompasses four measures: restoration, reconstruction, replacement, or acquisition [14]. Acceptable alternative measures for “restoration” include any one of these four measures or a combination of them [15]. In 1996, the National Oceanic and Atmospheric Administration of the United States issued the “Natural Resource Damage Assessment (Final Rule)”, which stipulated the natural resource damage assessment procedures under the “Oil Pollution Act” of the United States [16]. The restoration process in the natural resource damage assessment procedure consists of two parts: primary restoration and compensatory restoration. Primary restoration refers to restoring degraded natural resources and ecosystem services to baseline conditions through natural recovery processes or by applying human interventions that accelerate this process. Compensatory restoration refers to measures taken to compensate for damage to natural resources and their service functions during the recovery period [17]. When considering how to determine primary restoration measures, government agencies serving as trustees should evaluate whether any proposed primary restoration measure is necessary to achieve certain physical, chemical, and biological conditions that are required for the natural or artificial recovery of damaged natural resources (e.g., replacing sand or vegetation, or altering hydrological conditions) [18]. Additionally, the agency should assess whether restoration measures focused on specific natural resources and service functions represent an effective means of achieving baseline conditions. Given its extensive experience in natural resource damage compensation related to oil pollution, the United States has developed various restoration approaches, including on-site and in-kind restoration, off-site and in-kind restoration, on-site and out-of-kind restoration, off-site and out-of-kind restoration, and the acquisition of equivalent existing natural resources or service functions [19].

The experiences of the European Union and the United States offers valuable insights for advancing China’s ecological damage compensation system. In 2015, China’s Supreme People’s Court introduced the Interpretation on Several Issues Concerning the Application of Law in the Trial of Environmental Civil Public Interest Litigation Cases, which explicitly states that where a plaintiff requests restoration of the ecological environment, the people’s court may, in accordance with the law, rule that the defendant restore the ecological environment to its condition and function prior to the occurrence of damage. Alternative restoration may be permitted when the ecological environment cannot be fully restored to its state and function before the damage occurred. Thus, China’s ecological restoration measures include both direct and alternative restoration methods. According to the Environmental Resources Trial Division of the Supreme People’s Court, “alternative restoration methods” apply when it is impossible to restore the damaged ecological environment to its pre-damage structure, function, and services on-site. These methods include various situations such as restoration at a different location within the same region, replacement with a different species serving the same function, substitution with a different quantity of equivalent quality, or use of resources of equal value but different grades [20]. This classification precisely corresponds to the “alternative restoration model” in

China's Technical Guidelines for the Identification and Assessment of Ecological Environment Damage—General Provisions [21], and is functionally equivalent to a special form of “primary restoration” under the U.S. Oil Pollution Act (including one or both of reconstruction or replacement, or some combination thereof), and also equivalent to “complementary remediation” under the EU Environmental Liability Directive [22]. It can be seen that alternative restoration refers to any remedial measures related to restoring natural resources and/or ecosystem services taken to achieve overall ecological balance, when it is factually impossible to restore damaged natural resources and their functions to baseline conditions within the original area. The original intention of alternative restoration is to achieve the overall recovery of regional ecological functions, by providing an alternative ecological environment that is roughly equivalent to the original state and function of the damaged ecological environment when the damaged ecological environment is difficult to be restored [23]. Status refers to the physical, chemical, and biological conditions of environmental components—such as air, water, and soil—while function refers to the services and functions provided by ecological systems to other ecosystems and the public.

However, as the concept of restorative justice gains broader acceptance, innovative methods to “alternative restoration”, such as purchasing carbon credits, participating in public welfare labor, and technological upgrades have emerged in practice. Yet since these methods cannot fully achieve ecological equilibrium, their validity as alternative restoration approaches has been questioned [24]. Scholarship in China has predominantly crystallized two distinct perspectives on this matter: The first viewpoint maintains that the concept of alternative restoration should not be abused. Innovative approaches such as participating in public welfare labor and technological transformation should respectively serve as typical representatives of the fulfillment methods of restoration liability and compensation liability [25]. In other words, when forms such as public service labor are used to fulfill the liability for compensation, this approach should be referred to as an alternative form of compensation [26]. For instance, Li Xingyu (2023) holds that “alternative restoration” — which cannot be calculated through the cost of restoration method and whose actual compensatory value for the ecological environment is difficult to estimate is, in fact, merely a variation in the form of payment of “compensation for losses” [27]. However, there are also some scholars who hold the opposite view. For instance, Zhang Bao and Yin Jiawei (2022) hold that alternative restoration is essentially a fictitious form of restoration, and the new ways of fulfilling responsibilities that are constantly being explored in practice are responding to this view [28]. Qin Xuanyu (2024) holds that “the concept of alternative restoration should be purposefully expanded in its interpretation at present, alternative restoration can be broadly understood as a general term for a series of methods other than direct restoration, including but not limited to technological transformation and carbon sink purchase, among others [29].

An analysis of the current research landscape reveals that “Alternative restoration” is not an original concept from China; it corresponds to a specific form of Primary restoration under the U.S. Oil Pollution Act, and is equivalent to “complementary remediation” in the EU's Environmental Liability Directive. The objective of this measure is to provide a similar level of natural resources and service functions as would be provided if the damaged site were restored to baseline conditions [30]. Considering the interests of the affected populations, alternative sites should be geographically connected to the impacted sites whenever possible or appropriate. However, in recent years, with the practical application of innovative approaches such as “off-site restoration,” “technical transformation,” and “carbon sink purchase,” judicial practice has gradually deviated from the original goal of ecological restoration in its understanding and application of alternative restoration measures. Scholars have conducted theoretical research on alternative resto-

ration, achieving rich results, yet significant gaps and controversies still remain: 1. Domestic scholars' research primarily focuses on whether specific approaches (such as purchasing carbon credits) qualify as alternative restoration measures and how to apply them accurately, resulting in a fragmented state with a lack of systematic study. 2. Although domestic scholars have proposed the need for a scientific definition of alternative restoration, there are still differences among scholars regarding their understanding and definition (for instance, some consider alternative restoration as a fictitious form of restoration that does not require substantive restoration). This has caused confusions in determining liability and conducting assessments in judicial practice. 3. Currently, some studies have re-examined the concept of "alternative restoration" by returning to its fundamental restorative purpose. These examinations contend that certain judicial practices labeled as alternative restoration fail to satisfy the essential elements of restoration liability and cannot accomplish the fundamental objective of ecological equivalency—whether through reconstruction or replacement of damaged environments. Therefore, they should not be classified as alternative restoration [31]. At this point, their legal attribute should be positioned as an alternative fulfillment method of compensation liability with monetary payment as its content [32]. However, the lack of a clear distinction between restoration and compensation makes it difficult to establish strict legal boundaries. 4. Current research on alternative restoration consists of case studies or theoretical discussions, lacking quantitative studies on their rationality and effectiveness. This makes it difficult to objectively verify the validity, efficacy, and sustainability of related systems—such as whether to limit the scope of alternative restoration or distinguish between alternative restoration and alternative compensation—leaving these issues unresolved and critical.

To this end, this study has made the following contributions on the basis of existing research: First, through systematic analysis of innovative liability fulfillment approaches, we formally propose and theoretically elaborate the superordinate concept of "alternative fulfillment", thereby advancing conceptual construction in this domain. Second, building upon the dual liability framework for ecological and environmental damage, we develop a theoretical model that rigorously distinguishes between "alternative restoration" and "alternative compensation" based on their respective legal foundations (restoration liability vs. compensation liability), establishing clear conceptual boundaries to prevent definitional overreach. Third, the superiority of this system is quantitatively evaluated through the AHP-fuzzy comprehensive evaluation method, proving that it can more effectively remedy ecological environmental damage. It can more effectively remedy ecological damage. Finally, a systematic analysis of "alternative restoration" and "alternative compensation" is carried out from multiple dimensions such as legal connotation, implementation methods, and application rules, thereby promoting the standardized application of environmental judicial innovation achievements.

2. Theoretical Construction of the Dual Mechanism for Alternative Fulfillment of Ecological Environmental Damage Liability in China

2.1. The Conceptual Formation of "Alternative Fulfillment"

At the end of the 20th century, the United States established the Supplemental Environmental Projects policy (SEPs), which permits violators to execute environmentally beneficial initiatives that surpass mandatory compliance standards in exchange for partial mitigation of administrative penalties [33]. As an alternative means of fulfilling environmental administrative fines, SEPs accomplish dual objectives of assuming liability for violations and pursuing environmental benefits, and satisfy the dual purposes of the punitive and remedial purposes of environmental legal liability [34]. In recent years, while maintaining the adverse assessment of violators' conduct, China's judicial practice has

continuously explored alternative approaches to fulfill the responsibility for ecological and environmental damage, including “participating in public welfare labor”, “technological transformation”, and “purchasing carbon credits”. This series of practices indicates that it is necessary to introduce the concept of “alternative fulfillment” into the relevant theoretical system of ecological and environmental damage liability.

The explanation of the concept of “alternative fulfillment” can be divided into two aspects: Firstly, from a legal nature perspective, innovative approaches such as carbon sink procurement fundamentally constitute a modality of liability fulfillment [35]. The legal rationale for this approach rests on two fundamental premises: 1. The implementation of innovative liability fulfillment mechanisms such as carbon credit procurement, must be predicated on an effective court judgment that the responsible party should bear the responsibility for ecological damage (encompassing both restoration obligations and compensatory liability). 2. These measures are essentially specific actions or methods, taken by the responsible party to fulfill the legally confirmed responsibility content. Their functional goal is always to achieve the statutory responsibility content of “restoration” or “compensation”, thereby ensuring that the “ecological environmental damage compensation system” is effectively implemented. This is in line with the essence of the way of fulfilling responsibilities.

Secondly, in terms of institutional functions, these approaches demonstrate a breakthrough and innovation in traditional fulfillment models, featuring an “alternative” characteristic. Specifically, the direct motivation for courts to innovatively apply methods such as purchasing carbon credits is that the responsible party is unable to directly undertake the restoration obligation or pay the ecological environment damage compensation, due to insufficient fulfillment capacity or restricted fulfillment conditions. Therefore, alternative performance mechanism are needed to ensure the fulfillment of responsibility and prevent the ecological damage liability from being merely formal. This indicates that such innovative attempts are not the first choice for the responsible party to fulfill their responsibilities, but rather “alternative” measures under special circumstances. For instance, when it is impossible to directly restore a damaged ecological environment, ecological service functions of the same type and quality can be provided in areas outside the damaged zone, to achieve a balance in the total amount of the ecological environment. Similarly, when it is impossible to fully pay the compensation for ecological damage, the ecological value generated by public welfare labor can be used to offset partial compensation obligations. The existence of this “alternative feature” has become the basis for the application of these innovative achievements. Consequently, the concept of “alternative fulfillment” effectively captures the shared essence of practices like “purchasing carbon sinks” and “technological upgrades”. This conceptualization provide a unified conceptual basis for the systematic development of related research.

This paper introduces “alternative fulfillment” as a superordinate concept, whose theoretical innovation is primarily reflected in the following aspects: 1. “alternative fulfillment” aims to integrate the diverse innovative measures used in judicial practice to substitute for fulfilling ecological and environmental damage liabilities—such as “off-site restoration,” “technological upgrades,” and “carbon offset purchases.” This concept unifies these specific measures into a unified conceptual framework.” Alternative fulfillment methods” differ from “liability implementation forms” (traditional civil law), which are legally prescribed mandatory modes of liability implementation. In contrast, “alternative fulfillment” emphasizes a flexible, innovative approach permitted by courts when the liable party finds it difficult to fulfill obligations through conventional means—such as direct restoration or compensation—allowing for substitute measures in practice. 2. “alternative fulfillment” transcends the conceptual scope of “alternative restoration” and operates at

a higher theoretical level. As mentioned previously, the objective of “alternative restoration” is to provide a similar level of natural resources and service functions as would be provided if the damaged site were restored to baseline conditions. It is equivalent to a specific form of “primary restoration” under the U.S. Oil Pollution Act, and “complementary remediation” in the EU’s Environmental Liability Directive. In judicial practice, certain innovative measures fail to achieve the objective of alternative restoration and are often more inclined toward reducing or replacing monetary compensation through the performance of specific actions (alternative fulfillment of compensation liability). Such approaches are not suitable for inclusion within the scope of alternative restoration. “Alternative fulfillment” semantically encompasses not only alternative measures in the restoration of natural resources (alternative restoration), but also extends to alternative fulfillment of compensation liability. The introduction of this concept helps clarify the boundary between alternative restoration and compensation, providing new theoretical support for the realization of ecological and environmental responsibilities.

2.2. *The Theoretical Basis for Constructing a Dual Mechanism of Alternative Fulfillment*

In China, the concept of ecological environment damage liability encompasses both restoration liability and compensation liability. However, the relationship between them has always been a subject of controversy. One perspective maintains that restoration liability and compensation liability are independent of each other. This is because restoration and compensation have essential differences [36]. Their application characteristics, value orientation, and remedy functions differ in the Civil Code; thus, they are mutually independent civil liabilities [37]. Another view holds that under China’s ecological damage compensation system, “restoration” and “compensation” are both responsibility methods aimed at restoring the damaged environment rather than compensating for economic losses—the latter being subordinate to the former and lacking independence [38]. Therefore, monetary compensation is not an independent way of liability assumption parallel to ecological restoration, but a specific form of ecological restoration costs [39]. Against this background of controversy, this study conducts an in-depth theoretical exploration of the relationship between restoration liability and compensation liability, thereby providing a theoretical foundation for establishing a dual mechanism of alternative fulfillment.

This paper sides with the former proposition and elaborates the theoretical basis from two dimensions: First, the former proposition draws theoretical support from restoration ecology. Research in restoration ecology demonstrates that ecosystems possess intrinsic value attributes, which differ fundamentally from traditional exchange values. Instead, their significance lies in the ecological service functions they provide, reflecting their unique and irreplaceable role in sustaining environmental balance [40]. This principle establishes that the remedy of ecological environmental damage must prioritize the restoration of damaged environments and their associated ecosystem services as its fundamental objective. Such an approach is essential for preserving the structural integrity and functional stability of ecological systems. From an ecological perspective, the imbalanced state of ecosystem can be gradually restored through technological interventions. This technical approach is known as ecological restoration. Ecological restoration is an ecological construction activity based on ecological principles, which integrates science and technology with the original laws of the ecosystem, restoring ecosystems through the adoption of necessary and reasonable natural or artificial measures [41]. Therefore, the ecological and environmental damage remedy system in China adheres to the center of “ecological environment restoration”. However, from the perspective of environmental science, not all damaged ecosystems are “restorable”. Take species extinction as an example. The associ-

ated ecological service functions include providing habitats, food and other biological resources, recreation, groundwater recharge, flood control, etc. These functions are irreplaceable due to the uniqueness of biological elements. This indicates that specific ecological service functions will still be lost with the extinction of the original species. Such irreversible damage can only be remedied through loss compensation in the sense of private law. At this point, “compensation” as a supplementary remedy means that its main purpose is to “compensate for the loss of (unrestorable) ecological service functions”, rather than to “restore the original state of the ecosystem”. Once the monetary payment is completed, the liability is terminated [42]. It can be seen that in the remedy of ecological environment damage, “restoration” and “compensation” are two means with completely different functions, which are independent of each other and complementary.

Second, this dual-liability structure inherits the traditional tort remedy logic from continental civil law. The liability for ecological and environmental damage does not emerge arbitrarily, but rather is an adaptive evolution of the traditional civil liability concepts of “restoration to the original state” and “compensation for losses” in the field of ecological environment. Fundamentally, the relationship between these two forms of liability perpetuates the inherent connection between “restoration to the original state” and “compensation for losses” in traditional civil law. “Restoration to the original state” originated from the term “restitution in integral” in Roman law. At the end of the 19th century, German civil law scholars creatively introduced this concept into the field of damages compensation, establishing it as a fundamental remedy for property rights infringement. Subsequently, this concept was generally adopted in the tort liability system of civil law countries. From the perspective of legal texts, the concept of “restoration to the original state” in the German Civil Code admits both broad and narrow interpretations. In a broad sense, “restoration to the original condition” serves as a standard for damages, requiring that “a person liable for damages shall restore the state that would have existed had the damage not occurred,” articulated in § 249 BGB [43]. In this context, “restoration to the original state” should be understood as a concept, embodying the fundamental principle of “full compensation and comprehensive remedy”. The narrow sense of restoration to the original state, on the other hand, is manifested as a specific method of damages compensation: to give effect to “full compensation” principle, articles 250 to 251 of the German Civil Code establish two distinct modes of liability assumption: physical restoration of the damaged asset and monetary payment when restoration becomes impracticable. Narrow-sense restoration and monetary compensation stand side by side as two independent liability forms with a sequential application order [44].

The relevant provisions of the German Civil Code have profoundly influenced China’s ecological environment damage compensation system. The remedy for ecological environment damage in China must adhere to the principle of full compensation. This entails a dual-track system combining “restoration” and “compensation” to provide differentiated remedies for ecological environment damage: the restoration responsibility in Article 1234 of the Civil Code focuses on the physical recovery of the ecological environment; the compensation responsibility under Article 1235 targets unrecoverable ecological losses. There is a sequential order in their application, and they form a complementary relationship in function, jointly building a complete chain of remedy for ecological environment damage.

In conclusion, within the framework of the liability for ecological and environmental damage, restoration responsibility and compensation responsibility are neither subordinate nor mutually inclusive. Instead, they are independent forms of liability established based on different remedy objectives. On this basis, the alternative fulfillment mechanism for the liability of ecological environmental damage should not merely be a one-way path of alternative restoration. Instead, it should be based on the dual structure of restoration

responsibility and compensation responsibility, clearly distinguishing between alternative restoration and alternative compensation (see Figure 2). This distinction not only conforms to the normative intent of Articles 1234 and 1235 of the China's Civil Code, but also ensures the logical consistency and practical rationality of the remedy system for ecological environmental damage, through the precise matching of the degree of damage and the remedy methods.

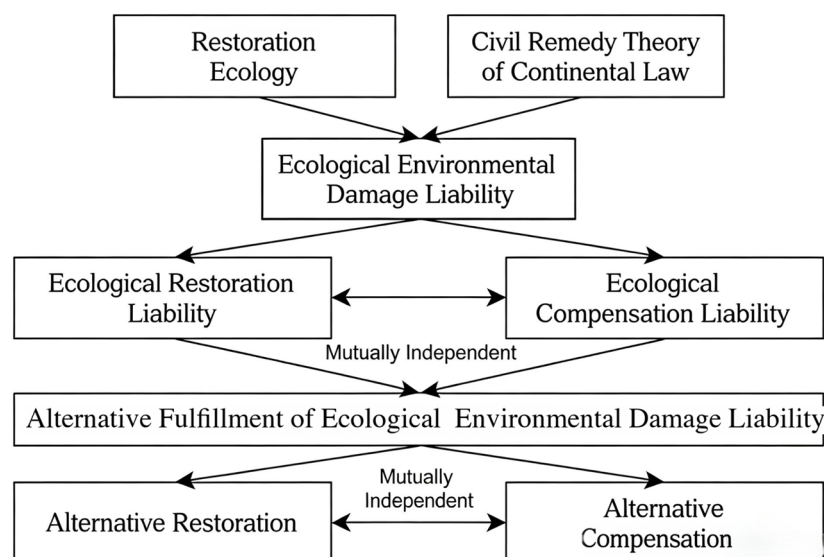


Figure 2. Theoretical analysis framework (schematic diagram drawn by the author).

3. Validity Test of the Dual Mechanism of Alternative Fulfillment

3.1. Evaluation Sample

The effectiveness assessment of the dual mechanism of alternative fulfillment can adopt the comparative research method: Identifying representative judicial precedents under both the dual-mechanism model and the single-mechanism model. Comparing their differentiated outcomes in remedy of ecological environment damage. The feature of the single model of alternative fulfillment lies in blurring the application boundary of the restoration responsibility and the compensation responsibility, and generally incorporating various alternative performance methods into the alternative restoration category for application (such as case 1, 3, 5). The characteristic of the dual model can be explained in the following way: According to the dual liability system of “restoration + compensation” for ecological and environmental damage, the alternative fulfillment methods are precisely classified into alternative restoration (can restore ecological service functions) and alternative compensation (cannot restore the ecological environment but can replace monetary payment), thereby establishing a clearly stratified alternative fulfillment mechanism (as in Case 2, 4, 6).

To ensure the objectivity of the research, the selection of cases in this study adheres to the principle of uniform common features and distinct alternative fulfillment models, which can fully guarantee the neutrality and scientific nature of the comparative study. The specific basis is as follows: 1. All cases are guidance cases released by the Higher People's Courts, ensuring they reflect authoritative judicial practices and possess precedential value. 2. This study selected three groups of cases, covering different types of damage (water pollution, soil pollution, and ecological degradation), with each group involving the same type of damaged object (both Case 1 and Case 2 focus on forest resource destruction; both Case 3 and Case 4 focus on water pollution; both Case 5 and Case 6 focus on soil pollution). This consistency in the subject matter of damage meets the requirement of

consistency in the basic conditions of the cases in the comparative study, and effectively avoids the interference of variables caused by different damaged objects. 3. In each case group, the parties fulfilled their ecological and environmental damage liabilities through the same alternative fulfillment methods. There are only differences in the legal nature of the alternative fulfillment methods, e.g., Case 1 recognizes “participating in public welfare labor” as an alternative restoration method, while Case 2 recognizes it as an alternative compensation method and applies it concurrently with the alternative restoration method of tree planting. This design avoids the impact of different types of alternative fulfillment methods on the objectivity of the comparative results. Based on the above multiple common features, the two cases selected in this study only have core differences in the application rules of alternative fulfillment methods, and other key variables remain consistent, which can maximize the objectivity and scientific nature of the comparative study, and directly verify the differences in ecological remedy effects between the two alternative fulfillment models.

Case 1: The defendant unlawfully felled and sold the trees on both sides of the farm road and on the ridges of the contracted farmland without obtaining a logging permit. According to expert assessment, the defendant’s actions resulted in ecological value losses totaling 6240 yuan and replanting costs of 734 yuan. The proposed restoration measure involves replanting *Metasequoia glyptostroboides* (dawn redwood) either at the original site or an alternative location. However, considering the defendant’s financial hardship, the court ultimately ruled that the defendant should carry out alternative restoration by engaging in forest management and protection work [45].

Case 2: The defendant discarded a cigarette butt in the forest, which ignited a wildfire resulting in widespread tree mortality. Following investigation, the forestry administrative department issued a restoration plan and quantified the loss of forest ecosystem service functions at 15,818 yuan [46]. Following judicial proceedings, the court ruled that the defendant should implement restorative measures by planting trees at an alternate location, in compliance with the afforestation guidelines prescribed by the forestry administration. At the same time, considering the defendant’s personal circumstances, it was allowed for the defendant to substitute compensation for the loss of ecological service functions amounting to 15,818 yuan through participation in public welfare labor.

Case 3: Eight companies, including Anhui Technology Co., Ltd., discharged 23,125 tons of hazardous waste directly into the Yangtze River, causing ecological and environmental damage amounting to over 106 million yuan. Citing an inability to fully cover the compensation costs at once, Anhui Technology Co., Ltd. applied to the Jiujiang District Court for alternative restoration through technological upgrades and cost offsetting. The court approved the application and recognized it as a typical case of alternative restoration.

Case 4: Due to illegal dumping of waste hydrochloric acid, Defeng Chemical Company caused severe pollution in the Jindi River. The government filed a lawsuit, and the Intermediate People’s Court of Puyang ruled that since the water pollution had naturally recovered, the responsible party would not be required to undertake restoration measures. However, Defeng Company must compensate 4,047,394 yuan for ecological damage calculated using the virtual treatment cost method. If the company reduces byproduct acid generation and carries out harmless treatment through technological upgrades during production, then the costs incurred on such technological improvements may offset the remaining environmental damage compensation amount of 2,023,697 yuan [47].

Case 5: A slaughterhouse in Guangyuan City had stored untreated pig manure and pig hair on its premises for a long time without implementing purification measures, resulting in soil pollution. The People’s Procuratorate of Guangyuan City filed a civil public interest lawsuit for ecological and environmental protection. During the trial, the operator

of the slaughterhouse requested to offset damages through technical upgrades. With mediation hosted by the Intermediate People's Court of Guangyuan and participation from the Water Resources Bureau and the Agriculture and Rural Affairs Bureau, the public interest litigant reached a settlement agreement with the involved slaughterhouse. As part of the agreement, the slaughterhouse had to carry out alternative restoration by upgrading its facilities through technical improvements.

Case 6: The overflow of wastewater used for ground flushing at a sulfuric acid plant caused excessive levels of arsenic, copper, zinc, and lead in nearby soil. Based on the assessment of damage to soil environmental quality, the court ruled that alternative restoration measures for the agricultural land should be coordinated and implemented by relevant government departments. In accordance with the fundamental principle of environmental protection, the defendant was ordered to compensate 200,000 yuan for the costs of alternative restoration. For the irreversible loss of ecological service functions, the court determined that the defendant should pay a total of 400,000 yuan as compensation for environmental damage to ecological service functions, with technical renovation expenses allowed to be offset accordingly [48].

3.2. Construction of the Evaluation Model

3.2.1. Evaluation Methods and Approaches

To verify the effectiveness of the binary mechanism of alternative fulfillment, this study will construct an evaluation model for the remedy effect of ecological and environmental damage through the Analytic Hierarchy Process (AHP)-Fuzzy Comprehensive Evaluation Method. It will compare and analyze the differences in remedial effectiveness between two judicial rulings: distinguishing alternative restoration and alternative compensation from non-distinguishing approaches.

The Analytic Hierarchy Process (AHP) is a systematic methodology designed to decompose complex decision problems into multiple simpler factors by integrating quantitative and qualitative analysis, thereby addressing multi-layered complex issues [49]. The fuzzy comprehensive evaluation method is an approach that transforms non-quantifiable factors into precise mathematical expressions through mathematical relationships and matrix models, and quantified through membership functions, then comprehensively evaluated using weighted operations and normalization methods, suitable for integrated assessment of multi-factor and multi-level indicators.

To select an evaluation model suitable for assessing the effectiveness of ecological damage remedy, this paper compares objective weighting methods, principal component analysis (PCA), single fuzzy comprehensive evaluation, and the AHP-fuzzy comprehensive evaluation coupled model. The effectiveness evaluation of ecological and environmental damage relief is a multidimensional and complex systems project involving multiple influencing factors, with the construction of evaluation indicator systems characterized by ambiguity and difficulties in quantification. In comprehensive evaluation studies, objective weighting methods are widely used because they determine indicator weights based on data characteristics themselves and avoid subjective human interference. However, these methods are unsuitable for handling uncertain information and have limitations such as sensitivity to extreme values and neglecting the actual importance of evaluation indicators. Principal component analysis can reduce the dimensionality of multi-indicator data but cannot convert vague qualitative ecological indicators into quantitative measures. Pure fuzzy evaluation can handle uncertain information but lacks a mechanism for scientifically assigning weights to multi-level indicators. In addition to the comparative analysis mentioned above, several mainstream multi-criteria decision-making (MCDM) approaches are widely applied in comprehensive evaluation research, including TOPSIS, DEMATEL, ANP, VIKOR and PROMETHEE. TOPSIS ranks alternatives by

measuring distances from positive and negative ideal solutions, which features simple calculation but lacks the capacity to quantify ambiguous qualitative indicators. DEMATEL mainly identifies the causal interrelationships among evaluation factors and performs poorly in overall scoring and sorting. ANP breaks the independence assumption of AHP and considers the feedback between criteria, yet it involves cumbersome computation and unstable weight results. VIKOR balances group utility and individual regret to obtain compromise rankings, but it cannot effectively address fuzzy uncertain information. PROMETHEE relies on customized preference functions for ranking, which introduces strong subjective bias and faces obstacles in fuzzy index quantification. In contrast, the AHP-fuzzy comprehensive evaluation method aligns well with the characteristics of this study: the Analytic Hierarchy Process (AHP) breaks down complex evaluation systems into hierarchical indicators and determines their weights through expert judgment, reducing subjectivity; building upon this, fuzzy mathematical evaluation enables the quantification of ambiguous information that is difficult to measure precisely, thus obtaining an evaluation result that is objective and stable.

In recent years, the AHP-fuzzy comprehensive evaluation method has been widely applied in the field of ecological environment restoration. For instance, Li Jianlin (2025) utilized the AHP-fuzzy comprehensive evaluation method to conduct a comprehensive assessment of the ecological restoration plan for Panshitou Reservoir, demonstrating that the improved AHP-fuzzy comprehensive evaluation method can provide a new and more effective approach for the evaluation of ecological environment restoration [50]. Tian Yanqing (2026) [51] combined AHP and entropy value method to assign weights to the indicators and constructed a restoration evaluation model using the fuzzy comprehensive evaluation method. This evaluation index system and model can scientifically and effectively assess the benefits of geological environment restoration in abandoned mines, and provides a reference for the benefit evaluation of similar projects. Wei Shengyun (2023) systematically assessed the geological environment of the Chama Valley Mine by employing the AHP-fuzzy comprehensive evaluation method, and then proposed strategies and countermeasures for ecological restoration and environmental management [52].

Building upon existing research practices, this study conducts a systematic evaluation of existing comprehensive assessment approaches, with particular attention to their respective applicability conditions, comparative advantages, methodological limitations, and distinctive characteristics. Guided by the principles of scientific validity, practical applicability, and logical rationality, we selected the AHP-fuzzy comprehensive evaluation method to conduct a comparative study on the ecological environment damage remedy effects under the “single alternative restoration model” and the “dual distinction of alternative restoration and alternative compensation model”. AHP can scientifically assign weight to multi-dimensional evaluation indicators, while fuzzy evaluation can quantify ambiguous, qualitative ecological damage indicators. This combined model fits well with the fuzziness and multi-index characteristics of ecological environmental damage remediation effect assessment, which fully justifies our method selection.

3.2.2. Construction of the Evaluation Index System

Based on the practical requirements of AHP, we invited 20 experts to determine evaluation indicators for assessing the effectiveness of ecological and environmental damage remedies. To ensure the objectivity and rationality of these indicators, experts were selected according to the following methods and criteria: 1. Expert selection was conducted through multiple channels relying on authoritative industry resources. Experts were chosen through reviewing publicly published papers, project experiences, and professional profiles, considering their academic achievements, practical experience, and influence in relevant fields to select those with rich experience and profound expertise. 2. Experts

should come from diverse professional backgrounds, including specialists involved in compilation of the “Ecological and Environmental Code,” researchers in environmental law and environmental science and engineering who have published relevant papers in core domestic and international journals, as well as practitioners in ecological and environmental administrative enforcement, environmental judiciary, and ecological damage assessment. 3. In “National Social Science Fund Projects” related to environmental law, expert consultation samples typically range between 15 and 25 individuals. So we decided to select 20 experts to fall within the optimal sample size range for the field. Following these methods and criteria, a stratified sampling approach was used to select the following 20 experts: 10 academic researchers (6 from the field of ecological and environmental law, including 4 who participated in a compilation of the “Ecological and Environmental Code”, and 4 from the field of environmental science and engineering) and 10 legal professionals (2 in ecological environmental administrative enforcement, 5 in environmental judiciary, and 3 in ecological damage assessment).

After completing the expert selection process, we invited these 20 experts to participate in indicator screening. Combined with a systematic literature review and national ecological remedy policy norms, this study constructed and refined the evaluation indicator system through multiple rounds of questionnaire consultation and expert argumentation. Ultimately, six evaluation indicators for the effectiveness of ecological and environmental damage remedies were summarized, namely: the pertinence of remedial measures; the matching degree of responsibility and damage; the rationality of alternative solutions; the feasibility of implementation; the compliance of judgments; and the results of social education and prevention. The specific meanings are shown in Table 2.

Table 2. Evaluation indicators.

Evaluation Indicators	Meaning
The pertinence of remedial measures.	This index measures the correlation between interventions and the damaged ecological environment. It determines whether restoration measures can restore the damaged natural resources and/or services.
The matching degree of responsibility and damage.	This index measures the appropriateness of assigned responsibility relative to the scale and nature of environmental damage. It determines whether responsibility as determined by the court can fully cover the ecological and environmental damage (including the repairable part as well as the irreparable part), helping to ensure fairness in accountability and promoting the rationality of responsibility pursuit.
The rationality of alternative solutions.	This index measures whether the alternative fulfillment methods adopted (such as replanting trees in other areas, participating in public welfare labor, etc.) can fully implement the responsibility for ecological and environmental damage, ensuring that their effects are equivalent to or more socially beneficial than direct restoration or monetary compensation.
The feasibility of implementation.	This index measures the feasibility of the proposed measures in actual operation, including whether there are limitations such as technology, cost, and time, and whether there is a reasonable supervision mechanism. It reflects the difficulty of implementing the plan in practice and determines whether remedial measures for ecological and environmental damage can be effectively implemented.
The compliance of judgments.	This index measures whether the court’s judgments strictly adhere to the legal application conditions of ecological and environmental damage liability. It reflects the legality and accuracy of the judgment, and determines whether legal protection exists for ecological and environmental damage remedy.
The results of social education and prevention.	This index measures whether the judicial outcome has legal deterrent force and social educational significance. It determines whether responsibility as determined by the court can effectively reduce the illegal motives of potential offenders and

prevent the recurrence of similar ecological and environmental damage incidents. This indicator primarily focuses on the preventive effect of judicial judgments, emphasizing long-term ecological environmental protection and educational significance.

3.3. The Operation of the AHP-Fuzzy Comprehensive Evaluation Method

This subsection elaborates the specific operation steps of the AHP-fuzzy comprehensive evaluation method. As illustrated in Figure 3, the implementation steps of the AHP-fuzzy comprehensive evaluation method are divided into two core stages: AHP weight calculation and fuzzy comprehensive evaluation calculation.

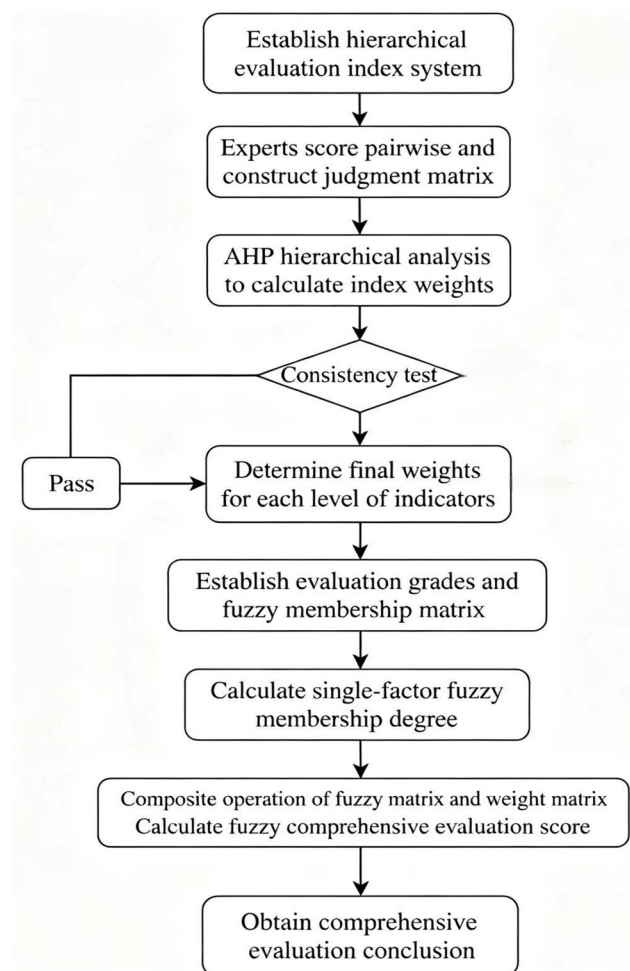


Figure 3. Flowchart of the method (schematic diagram drawn by the author).

3.3.1. The Operation of the AHP Hierarchical Analysis System

The calculation principle of the AHP lies in pairwise comparison of evaluation elements and assigning weight values to each index according to their relative importance. The main steps are as follows:

First, establish the judgment matrix. In this study, 20 domain experts were invited to assess the relative importance of each evaluation index based on the 1–9 scale method proposed by Saaty, and the final summary was used to form an $n \times n$ order judgment matrix A (see Table 3):

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ a_{12} & \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix}$$

Here, a_{ij} represents the importance score of element i relative to element j , and the data in the upper right and lower left corners are in a reciprocal symmetrical format.

Table 3. 1–9 Scale theory.

Scale Value	Comparison Rules
1	Two factors are equally important.
3	Factor A is slightly more important than B.
5	Factor A is somewhat more important than B.
7	Factor A is significantly more important than B.
9	Factor A is absolutely more important than B.
2, 4, 6, 8	The intermediate value between adjacent judgments.

According to the 1–9 scale method, if an expert considers element i to be more important than element j , they will score a_{ij} as 1, 2, 3, 4, 5, 6, 7, 8 or 9; if the expert deems i to be less important than j , they will score a_{ij} as 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8 or 1/9. Based on the scores given by 20 experts, the judgment matrix (as shown in Table 4) can be obtained.

Table 4. Judgment matrix.

Index	the Pertinence of Remedial Measures	the Matching Degree of Responsibility and Damage	the Rationality of Alternative Solutions	the Feasibility of Implementation	the Compliance of Judgments	the Results of Social Education and Prevention
The pertinence of remedial measures.	1.000	0.200	2.000	0.500	0.143	5.000
The matching degree of responsibility and damage.	5.000	1.000	4.000	2.000	0.200	7.000
The rationality of alternative solutions.	0.500	0.250	1.000	0.333	0.167	2.000
the feasibility of implementation.	2.000	0.500	3.000	1.000	0.250	4.000
The compliance of judgments.	7.000	5.000	6.000	4.000	1.000	9.000
The results of social education and prevention.	0.200	0.143	0.500	0.250	0.111	1.000

Second, perform normalization on the data in the judgment matrix to calculate the weight vector (as shown in Table 5). The calculation formula for the weight vector is as follows (1) (2):

(1) Normalize each column:

$$a_{ij}' = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}}$$

(2) Calculate the average value of each row as the weight:

$$w_i = \frac{1}{n} \sum_{j=1}^n a_{ij}'$$

Table 5. AHP hierarchical analysis results.

Index	Eigenvector	Weighted Value	Eigenvalue of Maximum	CI Value
The pertinence of remedial measures.	0.530	8.8317%	6.388	0.078
The matching degree of responsibility and damage.	1.306	21.7703%		
The rationality of alternative solutions.	0.329	5.4910%		
The feasibility of implementation.	0.780	12.9986%		
The compliance of judgments.	2.865	47.7547%		
The results of social education and prevention.	0.189	3.1537%		

As shown in Table 5, the weight values of each evaluation index are as follows: the pertinence of remedial measures (8.8317%); the matching degree of responsibility and damage (21.7703%); the rationality of alternative solutions (5.4910%); the feasibility of implementation (12.9986%); the compliance of judgments (47.7547%); the results of social education and prevention (3.1537%). Meanwhile, the maximum eigenvalue is calculated to be 6.388, the CI value is obtained as 0.078. The CI value is used for the consistency test described below.

Third, perform consistency verification. During the expert evaluation process, pairwise comparisons in the judgment matrix may introduce subjectivity and logical inconsistencies, such as the situation where A1 is considered more important than A2, A2 more important than A3, but A3 more important than A1. Therefore, consistency checks are necessary to ensure the rationality of the judgments. Consistency checks require the calculation of the consistency ratio CR: $CR = CI / RI$. The CI value has been calculated, and the RI value can be obtained by referring to Table 6 (in this study, a 6th-order judgment matrix was constructed, and the corresponding RI value from Table 6 is 1.260). When $CR < 0.1$, the judgment is considered acceptable in terms of consistency. The results of the consistency check are shown in Table 7.

Table 6. Random consistency RI table.

Nth-Order	3	4	5	6	7	8	9	10	11	12	13	14	15	16
RI value	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49	1.52	1.54	1.56	1.58	1.59	1.5943
Nth-order	17	18	19	20	21	22	23	24	25	26	27	28	29	30
RI value	1.6064	1.6133	1.6207	1.6292	1.6358	1.6403	1.6462	1.6497	1.6556	1.6587	1.6631	1.6670	1.6693	1.6724

Table 7. Summary of consistency test results.

Eigenvalue of Maximum	CI Value	RI Value	CR Value	Consistency Check Results
6.388	0.078	1.260	0.062	pass

3.3.2. The Operation of the Fuzzy Comprehensive Evaluation Method

The fundamental principle of fuzzy comprehensive evaluation lies in quantifying the uncertain and fuzzy qualitative indicators based on the theory of fuzzy mathematics and

then systematically transforming subjective judgments into measurable outcomes via hierarchical operations. The main steps include:

Firstly, using the fuzzy comprehensive evaluation method, the evaluation grades are divided into five levels, namely $V = \{\text{excellent, good, qualified, poor, very poor}\}$. Score ranges for classification: Excellent: 10–8; Good: 8–6; Qualified: 6–4; Poor: 4–2; Very Poor: 2–0.

Then, 20 domain experts are invited to score the six evaluation indicators of cases respectively, and the proportion of expert choices for each of the five evaluation grades is statistically analyzed. For example, for the “the pertinence of remedial”, if 10/20 experts rated an indicator as “Excellent,” then the proportion of “excellent” is 0.5. Eventually, the weight judgment matrix R (see Tables 8–13) is obtained:

$$R = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1m} \\ r_{21} & r_{22} & \dots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \dots & r_{nm} \end{bmatrix}$$

Here, r_{ij} represents the membership degree of the i -th indicator under the j -th evaluation.

Table 8. Weight judgment matrix R_1 (Case 1).

Index	Weight	Excellent	Good	Qualified	Poor	Very Poor
The pertinence of remedial measures.	8.83%	0	0	0	0	1
The matching degree of responsibility and damage.	21.77%	0	0	0.25	0.5	0.25
The rationality of alternative solutions.	5.49%	0.1	0.25	0.25	0.3	0.1
The feasibility of implementation.	13.00%	0.35	0.15	0.4	0.1	0
The compliance of judgments.	47.76%	0	0.3	0.25	0.3	0.15
The results of social education and prevention.	3.15%	0.3	0.2	0.35	0.15	0

Table 9. Weight judgment matrix R_1 (Case 2).

Index	Weight	Excellent	Good	Qualified	Poor	Very Poor
The pertinence of remedial measures.	8.83%	0.9	0.1	0	0	0
The matching degree of responsibility and damage.	21.77%	0.85	0.2	0.15	0	0
The rationality of alternative solutions.	5.49%	0.95	0.05	0	0	0
The feasibility of implementation.	13.00%	0.35	0.15	0.4	0.1	0
The compliance of judgments.	47.76%	0.75	0.2	0.15	0	0
The results of social education and prevention.	3.15%	0.35	0.15	0.2	0.15	0.15

Table 10. Weight judgment matrix R_1 (Case 3).

Index	Weight	Excellent	Good	Qualified	Poor	Very Poor
The pertinence of remedial measures.	8.83%	0.1	0.1	0	0.8	0
The matching degree of responsibility and damage.	21.77%	0.3	0.1	0.5	0.1	0
The rationality of alternative solutions.	5.49%	0	0.05	0.15	0.8	0
The feasibility of implementation.	13.00%	0.35	0.15	0.4	0.1	0
The compliance of judgments.	47.76%	0.2	0.15	0.3	0.25	0.1
The results of social education and prevention.	3.15%	0.35	0.15	0.2	0.15	0.15

Table 11. Weight judgment matrix R1 (Case 4).

Index	Weight	Excellent	Good	Qualified	Poor	Very Poor
The pertinence of remedial measures.	8.83%	0.75	0.15	0.1	0	0
The matching degree of responsibility and damage.	21.77%	0.8	0.2	0	0	0
The rationality of alternative solutions.	5.49%	0.9	0.1	0	0	0
The feasibility of implementation.	13.00%	0.4	0.1	0.4	0.1	0
The compliance of judgments.	47.76%	0.75	0.1	0.15	0	0
The results of social education and prevention.	3.15%	0.6	0.2	0.2	0	0

Table 12. Weight judgment matrix R1 (Case 5).

Index	Weight	Excellent	Good	Qualified	Poor	Very Poor
The pertinence of remedial measures.	8.83%	0.1	0	0.1	0.8	0
The matching degree of responsibility and damage.	21.77%	0.2	0	0.6	0.2	0
The rationality of alternative solutions.	5.49%	0	0.05	0.15	0.7	0.1
The feasibility of implementation.	13.00%	0.35	0.15	0.4	0.1	0
The compliance of judgments.	47.76%	0.2	0.15	0.15	0.5	0
The results of social education and prevention.	3.15%	0.2	0	0.5	0.3	0

Table 13. Weight judgment matrix R1 (Case 6).

Index	Weight	Excellent	Good	Qualified	Poor	Very Poor
The pertinence of remedial measures.	8.83%	0.8	0.1	0.1	0	0
The matching degree of responsibility and damage.	21.77%	0.75	0.1	0.15	0	0
The rationality of alternative solutions.	5.49%	0.8	0.2	0	0	0
The feasibility of implementation.	13.00%	0.35	0.15	0.5	0	0
The compliance of judgments.	47.76%	0.7	0.3	0	0	0
The results of social education and prevention.	3.15%	0.7	0.2	0.1	0	0

Third, calculate the fuzzy comprehensive evaluation weights. Based on the weight vector matrix A and the weight judgment matrix R, the calculation of the fuzzy comprehensive evaluation weights can be directly carried out. The calculation of the fuzzy comprehensive evaluation weights involves multiplying each index weight W_i by the judgment matrix R, and the result is processed through the weighted average calculation method to obtain the membership degrees of each evaluation grade (see Table 14). According to the principle of maximum membership degree, the final evaluation result can be determined. The formula for the weighted average calculation is as follows:

$$Y_k = \min(1, \sum_{j=1}^m a_j r_{jk}), k = 1, 2, \dots, n$$

Table 14. Weight calculation results.

Item	Grade	Excellent	Good	Qualified	Poor	Very Poor
Case 1	membership degrees	0.0604	0.1828	0.2506	0.2863	0.2199
	membership degree	0.0604	0.1828	0.2506	0.2863	0.2199
	normalization [weight]					
Case 2	membership degrees	0.6680	0.1589	0.1506	0.0177	0.0047
	membership degree	0.6680	0.1589	0.1506	0.0177	0.0047
	normalization [weight]					
Case 3	membership degrees	0.2262	0.1292	0.3187	0.2735	0.0525
	membership degree	0.2262	0.1292	0.3187	0.2735	0.0525
	normalization [weight]					
Case 4	membership degrees	0.7189	0.1293	0.1388	0.0130	0
	membership degree	0.7189	0.1293	0.1388	0.0130	0
	normalization [weight]					
Case 5	membership degrees	0.1997	0.0936	0.2871	0.4139	0.0055
	membership degree	0.1997	0.0936	0.2871	0.4139	0
	normalization [weight]					
Case 6	membership degrees	0.6649	0.2285	0.1067	0	0
	membership degree	0.6649	0.2285	0.1067	0	0
	normalization [weight]					

Fourth, the comprehensive scores are calculated (as shown in Tables 12 and 13). The calculation of the comprehensive score is achieved by multiplying the membership degree with the score of the evaluation comment and then summing them up. Through the comprehensive score, the superiority and inferiority of the two schemes can be compared intuitively. The formula for calculating the comprehensive score is as follows:

$$\text{comprehensive score} = \sum_{j=1}^m (b_j \times v_j)$$

Among them, b_j represents the membership degree of the j th comment. v_j is the score corresponding to the j th comment (for example, “excellent” = 10, “good” = 8, “qualified” = 6, “poor” = 4, “very poor” = 2). The final comprehensive score can be used to describe the overall situation of the evaluation, facilitating comparisons among different evaluation systems. The overall scores of all samples are shown in Table 15.

Table 15. Calculation of the comprehensive score for case.

Comprehensive Score	Excellent	Good	Qualified	Poor	Very Poor
Case 1 5.155	10	8	6	4	2
Case 2 8.935	10	8	6	4	2
Case 3 6.406	10	8	6	4	2
Case 4 9.116	10	8	6	4	2
Case 5 6.137	10	8	6	4	2
Case 6 9.108	10	8	6	4	2

3.4. Evaluation Results and Sensitivity Analysis

Analysis of the fuzzy comprehensive evaluation results reveals significant differences in the effectiveness of ecological damage remedies between the “unified alternative restoration” model and the “dual distinction between alternative restoration and alternative compensation” model. In the “unified alternative restoration” model, based on the maximum membership degree rule, the comprehensive evaluation results

for Case 1, Case 3, and Case 5 are, respectively, poor (0.2863), qualified (0.3187) and poor (0.4139). In the “dual distinction between alternative restoration and alternative compensation” model, the comprehensive evaluation results for Cases 2, 4, and 6 were all excellent (the maximum membership degrees are respectively 0.6680, 0.7189, and 0.6649). The comparative scores of the comprehensive evaluation under the two modes are as follows: 1. Natural resource damage cases (Case 1 and Case 2): 5.155 vs. 8.935; 2. Water pollution case (Case 1 and Case 2): 6.406 vs. 9.116; 3. Soil pollution case (Case 1 and Case 2): 6.137 vs. 9.108.

The index weights determined by the AHP-fuzzy comprehensive evaluation method rely on expert subjective scoring, which may introduce parameter uncertainty. To verify the stability and reliability of the evaluation results and explain the score gap between each group of cases, a single-factor sensitivity analysis was conducted. Six empirical cases are included in this study. To avoid redundant calculation and redundant content, only the first set of cases was selected for single-factor sensitivity analysis. In sensitivity analysis, we reduce the weight of the indicator “compliance of judgments” from 47.76% to 18.00%, and proportionally redistribute the removed weight among the other five indicators. The analysis results are shown in Table 16.

Table 16. Sensitivity test for the high-weight indicator.

Scenario	Weight of Judgment Compliance	Case 1 Score	Case 2 Score	Score Gap
Original Weights	47.76%	5.155	8.935	3.780
Adjusted Scheme	18.00%	4.756	8.840	4.084

As shown in Table 16, after substantially reducing the weight of the Judgment Compliance indicator from 47.76% to 18.00%, the absolute score gap between Case 1 and Case 2 slightly expanded from 3.780 to 4.084. This result indicates that the large disparity of comprehensive scores is not solely dominated by this single high-weight index. Although this indicator widens the gap to a certain extent, the divergence mainly comes from the differences in membership values of multiple evaluation indicators between the two cases. Even when we cut down the weight of this core item, Case 2 still maintains obvious advantages in other indexes, so the score gap remains stable and even slightly increases. Meanwhile, Case 2 always maintains a higher score than Case 1 under extreme weight disturbance, and the ranking of the two cases was not reversed. This stricter sensitivity test verifies the good robustness of the AHP-fuzzy comprehensive evaluation model. The empirical conclusion will not be overturned by subjective adjustment of indicator weights.

It was verified that the constructed AHP-fuzzy comprehensive evaluation model is robust and stable. Subjective weight deviation does not affect the final evaluation result, which ensures the scientificity and credibility of the research findings. This fully demonstrates that in judicial rulings, the model distinguishing between alternative restoration and alternative compensation can achieve better results in remedying ecological environmental damage. The main reason for this result is that alternative restoration was originally a supplementary and extended substantive restoration measure compared to direct restoration. However, a critical concern emerges when various alternative fulfillment methods—regardless of their actual capacity to restore the ecological environment—are indiscriminately categorized under the broad umbrella of “alternative restoration.” In the long run, those so-called “alternative restoration methods” that fail to restore the ecological environment will easily undermine the precise application of alternative restoration methods that are strongly related to the damaged

ecological environment and truly quantifiable (such as restocking fish and replanting trees), ultimately undermining the actual effect of ecological environment damage remedy.

From this analytical perspective, it becomes evident that not all forms of liability are suitable to be classified under the category of “ecological and environmental restoration liability” (including direct restoration and alternative restoration). At the level of ecological and environmental damage remedy, establishing a dual mechanism of alternative performance (scientifically defining the connotation of alternative restoration and distinguishing it from alternative compensation liability) is more advantageous than indiscriminate expansion of “alternative restoration” to encompass all forms of alternative fulfillment.

4. Clarification of the Responsibilities for Ecological Environment Restoration and Ecological Environment Damage Compensation

Clarifying the normative boundaries between restoration liability and compensation liability constitutes a logical prerequisite for distinguishing between alternative restoration and alternative compensation. While Articles 1234 and 1235 of the Civil Code adopt a parallel enumeration approach to establish a basic framework for differentiating restoration liability and compensation liability, their substantive scopes exhibit significant overlap. Specifically, Article 1234 positions the “costs of ecological environment restoration” as an alternative fulfillment method coexisting with restoration obligations, whereas article 1235 includes “ecological environment restoration costs” within the scope of ecological environment damage compensation. This legislative inconsistency directly leads to a blurred and overlapping boundary between restoration liability and compensation liability [53]. To remedy this structural deficiency, it is necessary to break through the current provisions and reconstruct the system of restoration liability and compensation liability, clarifying their normative boundaries, thereby providing the original logic for the dual construction of the alternative performance system of ecological environment damage liability.

4.1. The Distinction Criteria Between Restoration Liability and Compensation Liability

Traditional law takes the social relations among people as the object of legal regulation, with their normative objective centered on maintaining legal order. In contrast, environmental law exhibits distinct ecological attributes, and its regulatory objects have expanded to the relationship between human society and the natural environment. Consequently, environmental law pursues dual normative objectives: the preservation of social order and the protection of ecological integrity. This feature determines that the establishment of legal liability for ecological and environmental damage must fully consider the objective possibility of the ecosystem, reflecting respect and compliance with natural laws. In the practice of environmental rule of law in China, this concept has been fully demonstrated.

In recent years, the Chinese government has successively issued a series of technical norms such as the “Technical Guidelines for the Appraisal and Assessment of Ecological and Environmental Damage”. These documents based on ecological principles provide precise definitions for core concepts such as “environmental restoration” and “ecological and environmental recovery”. More importantly, they incorporate environmental science, ecology and other disciplines’ technologies and professional knowledge to establish a set of environmental damage appraisal techniques and quantification standards in line with ecological laws. The core of these standards lies in assessing the degree of ecological and environmental damage based on objective criteria such as “restorability,” and propose

targeted restoration or compensation plans. Consequently, ecological and environmental damage appraisal opinion has evolved into indispensable technical support and evidence based on damage compensation negotiations and litigation. It is significant for determining compensation for ecological and environmental damage, selecting restoration plans, and establishing liability. This institutional design requires that research on the ecological and environmental damage liability focuses on interactive integration with technical standards, achieving an organic unity between scientific, technical and legal norms. Only in this way can we ensure the achievement of ecological restoration goals. And ecological environmental damage, as a typical “technical plus law” challenge, can be effectively addressed.

In the “Technical Guidelines for Identification and Assessment of Ecological Environment Damage—General Principles and Key Components Part 1: General Principles” (hereinafter referred to as “General Principles”), the “restorability of the damaged ecological environment” is a pivotal criterion for determining the remedy methods of ecological environment damage. This process is manifested as follows: after the ecological environment is damaged, an investigation of the extent of the damage and an assessment of its restorability should be conducted first. Objectively, complete restoration is only an ideal state, so the interpretation of “restorability” should break through the rigid dichotomy of “all or nothing”, and include three technical scenarios: “completely restorable”, “partially restorable”, and “unrestorable”. When the ecological environment damage is only partially restorable, the restorable part and the unrestorable part should be distinguished. If the damaged ecological environment is (completely or partially) restorable, or restorable in part, an ecological restoration plan should be developed, with costs calculated using the restoration cost method. If the damaged ecological environment is (completely or partially) unrestorable, then an appropriate environmental value assessment method should be selected to quantify the lost value of the “unrestorable part” [54]. This standardized technical path indicates that a key principle of ecological environment damage remedy is to adopt targeted and differentiated response strategies based on the degree of damage—prioritizing restoration where feasible and resorting to compensation for irreversible losses. Corresponding to the assessment of ecological and environmental damage, the division between restoration liability and compensation liability is primarily determined by the core criterion of whether the ecological and environmental damage is restorable. In the application of the ecological and environmental damage assessment system within judicial proceedings, the logical approach should be to rely on scientific and technological evaluations to ascertain the factual occurrence of ecological environment damage, and then the court can make further value judgments to determine the legal responsibilities that the responsible parties should bear. In order to achieve the integration of legal norms and technical standards in judicial rulings, it is essential that the distinction between restoration liability and compensation liability be consistent with the technical logic of ecological damage assessment opinions, that is, using the restorability of ecological environment damage as the core judgment criterion.

Of course, to prevent judicial overreach in integrating technical assessment reports (scientific facts) into judicial rulings (legal facts), it is also necessary to improve the standards for admitting ecological and environmental damage appraisal opinions. 1. In judicial rulings, judges should carefully evaluate ecological and environmental damage assessment opinions from both formal and substantive perspectives. Formal review should focus on legality including, but not limited to, whether the appraiser holds proper qualifications, whether the appraisal commissioning process was conducted in accordance with the law, and whether the collection, handling, and storage of evidence materials followed procedures. Substantive review should not only examine the

admissibility, authenticity, and relevance of the assessment opinion as evidence, but also consider review standards of scientific evidence—such as whether all relevant matters have been properly assessed and whether the scientific and technological methods applied are reliable and valid. 2. The supportive and safeguarding role of technical consultation and technical review in the acceptance of ecological and environmental damage assessment opinions should be fully leveraged. For example, judicial technicians or technical experts specializing in environmental damage assessment should be appointed to provide technical advice to judges, assisting them in reviewing specialized issues related to damage assessments. 3. The cross-examination process should be improved. First, allow parties to request that individuals with specialized knowledge testify in court. Courts may comprehensively consider the opinions of expert assistants and consulting experts when deciding whether to accept the content of an ecological and environmental damage assessment report. Second, permit parties to apply for a new appraisal, and further refine procedural rules regarding supplementary appraisals, or re-appraisals.

The constraints on the restorability of the ecological environment include: the necessity of restoration, technical feasibility, and economic rationality. (1) The necessity of restoration refers to the degree to which it is necessary to restore the damaged ecosystem and its service functions to the baseline state through artificial intervention measures. In ecological research, the restoration of ecosystems mainly includes two approaches: natural recovery and artificial restoration. Natural recovery refers to the process by which an ecosystem evolves towards a natural state through its own succession laws and self-recovery. Artificial restoration, on the other hand, refers to the adoption of necessary and reasonable artificial measures to accelerate the restoration process of the ecosystem [55]. Ecological restoration should respect natural ecosystem succession processes and avoid excessive human interference with them. Therefore, it usually adheres to the basic concept of “natural recovery as the main approach and artificial restoration as a supplementary one”. In principle, artificial restoration measures should only be initiated when environmental pollution or destructive ecological behaviors exceed the ecological threshold for natural recovery or when the environmental risks are unacceptable. (2) Technical feasibility assesses whether currently available scientific and technological methods can effectively restore the damaged ecological environment and its service functions to their state before the damage occurred. The judgment of technical feasibility requires a comprehensive consideration of multiple factors: First, the extent of ecological damage must be clearly identifiable. According to the “General Outline”, after ecological damage occurs, it is necessary to analyze the degraded state of the affected ecosystem and its service functions relative to baseline conditions, and determine the type, scope, and severity of the damage. If the damage is difficult to determine due to data deficiency or delayed investigation and other reasons, the restoration practice will be difficult to carry out. Secondly, fundamental environmental conditions must be adequate. Effective ecological restoration requires that the damaged area maintains certain baseline environmental conditions, including suitable soil structure, hydrological conditions, climatic characteristics and a foundation of biodiversity. If there are extremely harsh natural environments, it may lead to the ineffectiveness of restoration measures [56]. For instance, in cases of severely degraded soil, reforestation efforts may fail due to the difficulty for plant seedlings to survive. Therefore, the assessment of “restorability” also needs to identify the “limiting environmental factor” [57], and comprehensively evaluate whether the environmental basic conditions of the damaged area are appropriate. Thirdly, the feasibility of restoration techniques. Ecological restoration is highly dependent on scientific understanding and technological levels. If the degree of damage to the ecological environment exceeds the restoration capacity of existing technical means, it will directly

affect the feasibility of ecological restoration. For instance, some new types of pollutants may be difficult to remove with current technical means. (3) Economic Viability. Ecological restoration must undergo rigorous cost-benefit analysis to evaluate both implementation costs and projected benefits, ensuring that the restoration activities are economically feasible and sustainable. It is important to note that the ecological environment is a typical public resource, so the assessment of restoration benefits should abandon the evaluation method that only focuses on economic components and pay attention to its multiple values, including ecological value, social value, aesthetic value, scientific value, cultural value, etc. At the same time, in the measurement of restoration costs and expected benefits, attention should also be paid to the balance between short-term and long-term interests, overall and local interests, and individual and social interests [58]. In summary, when the damaged ecological environment has the necessity, technical feasibility and economic rationality for artificial restoration, it is determined to be restorable.

4.2. Normative Adjustment of Ecological Environment Restoration Liability and Ecological Environment Damage Compensation Liability

Based on the evaluation results of “ecological environment restorability”, ecological environment damage can be classified into three categories: completely restorable damage, partially restorable damage, and non-restorable damage. Completely restorable damage should apply restoration liability; non-restorable damage should apply compensation liability; for partially restorable damage, the restorable and non-restorable parts should be distinguished and restoration liability and compensation liability should be applied respectively.

4.2.1. Definition and Scope of Ecological Environment Restoration Responsibility

The responsibility for ecological environment restoration refers to the restorative remedy responsibility that the infringer shall undertake within a reasonable period of time when the damaged ecological environment (in whole or in part) can be restored, to restore the “restorable part” to the baseline state or the acceptable risk level. The “baseline state” refers to the original state of the ecological environment and its service functions before the damage occurred. The “acceptable risk level” refers to the risk level that human health or the ecosystem can tolerate. In principle, the practice of ecological restoration should take the baseline state as the main goal, but in specific circumstances, that is, when there are economic, technical or operational obstacles to restoring to the baseline, it is possible to choose to restore the damaged ecological environment to the acceptable risk level.

The scope of ecological and environmental restoration responsibility not only includes the implementation of ecological and environmental restoration actions but should also cover the assumption of ecological and environmental restoration costs. Ecological and environmental restoration costs mainly refer to the implementation costs of the restoration plan, including direct and indirect costs. Direct costs include the costs of the main equipment, materials, and implementation of the restoration project, while indirect costs include the costs of monitoring, quality control, safety protection, secondary pollution prevention, and assessment of the restoration effect of the restoration project. Restoration costs should be calculated in accordance with the following restoration cost calculation methods in order of priority: a) detailed cost method; b) reference to guidelines or manuals; c) contractor quotation method; d) case comparison method. From the concept, it can be understood that the cost of restoration is the embodiment of ecological restoration costs. Its fundamental purpose is to ensure that the funds for ecological restoration are sufficient, rather than to compensate for value losses [59]. Therefore,

although the cost of restoration has the external manifestation of economic responsibility, it is more in line with the intrinsic nature of the responsibility for restoration.

In conclusion, the responsibility for ecological environment restoration must transcend the constraints of the traditional behavioral responsibility framework and establish a compound responsibility system that combines “implementing restoration actions and bearing restoration costs”. While both behavioral responsibility and economic responsibility aim to achieve ecological restoration, they focus on different aspects. So the responsible party should first actually fulfill the restoration obligation, and only when they are truly unable to do so should they instead bear the restoration costs.

4.2.2. The Definition and Scope of Ecological and Environmental Damage Compensation Responsibility

The compensation responsibility for ecological and environmental damage can be defined as when the ecological environment and its service functions are damaged and complete restoration is impossible or only partially achievable, the liability for compensation that the right holder requests the infringer to bear for the value loss of the ecological environment that cannot be restored, including liability for compensation for interim losses, permanent losses, and liability for compensation that should be borne during natural recovery. Specifically:

(1) Compensation liability for losses during the period

The General Principles stipulate that if the duration from the occurrence of ecological and environmental damage to the restoration to the baseline exceeds one year, damage during the period must be calculated. This term refers to the loss or reduction in the ecosystem's service functions during the period from the occurrence of ecological and environmental damage to the restoration to the baseline. It is related to the path and time required for basic restoration (the process of restoring the damaged ecological environment and its service functions to the baseline by taking necessary and reasonable natural or artificial measures). As shown in Figure 4, if artificial restoration measures are taken, the damage can be restored to the baseline relatively quickly, and the corresponding damage during this period is represented by area A in the figure. If natural restoration is adopted, it will take a longer time for the damaged to return to the baseline, and the corresponding damage during this period is represented by area A + B in the figure. Therefore, when the ecological damage can be restored, a basic restoration plan should be formulated simultaneously and the damage during the period should be quantified. If the damage during the period can be filled through artificial repair measures, a compensatory restoration plan should be formulated [60]. When the damage during the period cannot be filled through artificial repair measures, an appropriate environmental value assessment method should be selected to quantify the loss of ecological service functions. The compensation liability for losses during the period represents the responsibility to compensate for the loss of ecological service functions during the basic restoration period when the damage during the period cannot be restored through the implementation of a compensatory restoration plan [61].

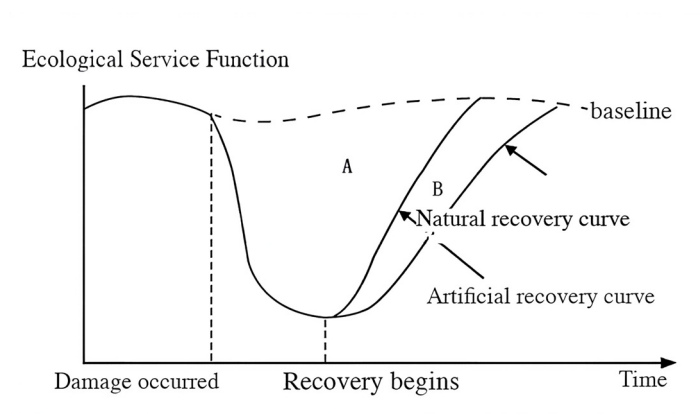


Figure 4. The damaged area during the period (schematic diagram drawn by the author). A: Ecological loss under natural recovery; B: Ecological loss under artificial recovery.

(2) Compensation liability for permanent loss.

When the physical, chemical or biological characteristics of the ecological environment undergo irreversible adverse changes, permanent damage occurs. Permanent damage refers to the situation where the damaged ecological environment and its service functions are difficult to recover, and its ability to provide services to the public or other ecosystems is completely lost [62].

As illustrated in Figure 5, permanent damage consists of two parts: 1. the irrecoverable part when the damaged ecological environment is not restorable, represented by area D; 2. the unrestorable part between the acceptable risk level and the baseline when the damaged ecological environment can only be restored to the acceptable risk level, represented by area C. According to the “General Principles”, once permanent damage is established, conventional restoration measures become impracticable. In such cases, a scientific environmental value assessment method should be adopted to quantify the value of ecological environment damage and provide economic compensation for it. Liability for permanent loss compensation specifically refer to the economic compensation for these irreversible loss of ecological service function—a legal obligation arising from the irreversible degradation of ecological functionality.

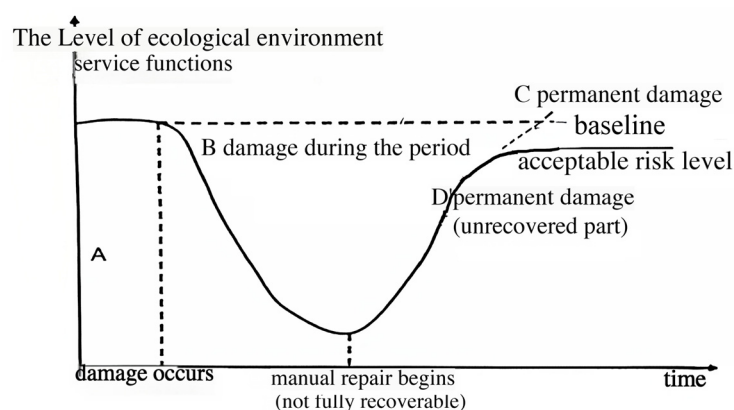


Figure 5. Permanent damage area (schematic diagram drawn by the author). A: Initial damaged zone; B: Temporary damage during recovery period; C: Permanent damage exceeding acceptable risk level; D: Unrecoverable permanent damage part. Arrows in the figure represent the changing trend of ecological environment service functions over time.

(3) Compensation liability persists in cases of natural recovery.

The obligation to compensate for ecological and environmental damage remains valid when the damaged environment has recovered naturally without human intervention. A notable example is the high-profile Taizhou environmental public interest litigation case: After the illegal discharge of waste acid into the involved river, the water quality at the discharge point and nearby areas was restored due to the river's flow and self-purification. However, the court nevertheless upheld the compensation claim. The judgment was based on the quantified value of ecological and environmental damage calculated by the appraisal institution using the “virtual governance cost method”, and the polluter was ultimately held liable for compensation [63]. This case embodies the value concept that “the environment is valuable and those who cause damage should be held accountable”, demonstrating that the natural recovery of the ecological environment does not absolve polluters of their liability for damages. However, it is important to emphasize that when the “virtual governance cost method” is applied during natural recovery, the result still represents the loss of ecological service functions rather than the cost of ecological environment restoration [64].

In conclusion, based on the types and restorability of ecological and environmental damage, the liability system of Articles 1234 and 1235 of the Civil Code can be restructured as follows: The ecological and environmental restoration liability refers to the restorative remedy liability that the infringer bears when the damaged ecological and environmental system (in whole or in part) can be restored, including behavioral liability (restoring the ecological and environmental system) and economic liability (covering restoration costs). The compensation liability for ecological and environmental damage, which applies when restoration is impossible or only partial, requiring the infringer to compensate for irreversible ecological service losses, including liability for permanent loss compensation, liability for compensation during the period of damage, and liability for compensation when natural restoration occurs.

5. The Distinction Between “Alternative Restoration” and “Alternative Compensation”

Following the clarification of the types and applicable boundaries of restoration and compensation liability, the alternative fulfillment of liability for ecological and environmental damage should explicitly differentiate between “alternative remediation” and “alternative compensation”, and respectively regulate them (see Table 17).

Table 17. Distinction between alternative restoration and alternative compensation.

Differentiating Factors	Alternative Restoration	Alternative Compensation
Standard positioning	Alternative fulfillment methods for direct ecological environment restoration responsibilities.	Alternative fulfillment methods for liability for ecological environmental damage compensation.
The content of “alternative”	Select new locations or introduce new species for restoration.	Replace traditional monetary payment with behavioral methods.
legal nature	A supplementary and extended substantive repair approach as opposed to direct repair.	Special usage methods of ecological and environmental damage compensation funds.
core goal	Equivalent restoration of damaged ecological environment.	To resolve the predicament of responsibility fulfillment due to insufficient payment capacity and balance the remedy for ecological and environmental damage with the defendant's right to survival and development.
specific way	“Equivalent reconstruction or replacement of damaged ecological environment”: replanting trees, releasing fish, and building artificial habitats (wetlands), etc.	“Alternative fulfillment of compensation obligations or offset ecological service function losses within a certain proportion range”:

		Technological transformation, participation in public welfare labor, purchase of carbon credits.
applicable scenarios	Damaged ecosystems can be restored, but due to objective reasons, direct restoration is not feasible.	The ecological service function losses need to be compensated, but the payment capacity is insufficient.
application condition	1. The selection of “repair areas or elements” must strictly follow the “principle of the closest connection”; 2. Develop alternative repair plans; 3. It is necessary to establish an effective supervision mechanism and evaluate the repair effect.	1. In essence: It can effectively improve the environment and generate predictable preventive environmental benefits. 2. Procedurally: It requires the responsible party or the procuratorial organ to initiate it proactively, and the court to review and decide. 3. Operationally: Clear and reasonable quantification mechanisms and offset ratios should be determined.
Order of application	Recoverable part (direct restoration—alternative restoration) Non-recoverable part (monetary compensation—alternative compensation)	

5.1. *Alternative Fulfillment Methods for Direct Ecological Environment Restoration Responsibility—Alternative Restoration*

5.1.1. The Normative Positioning of Alternative Restoration

Ecological environment restoration responsibility can be categorized into direct restoration and alternative restoration. Direct restoration refers to the identification and assessment of the polluted or damaged environmental elements, biological elements, ecosystems, and followed by the implementation of artificial restoration measures to restore the damaged areas and elements to their pre-damage state and functions. When the ecological environment is damaged, the most directly affected area is the location where the ecological environment damage occurs. If direct restoration is possible, not only can the complex process of assessing the scale of restoration be avoided, but the ecological environment can also be restored in a timely and effective manner, enhancing both the efficiency and quality of restoration efforts. Consequently, within the framework of ecological restoration responsibility, there is an inherent preference for prioritizing direct restoration. Whenever practicable, restoring the damaged environment to its original structure, function, and condition through direct intervention remains the optimal approach. Alternative restoration is a compromise and supplement when direct restoration is unattainable. Only when the original ecological functions and state of the damaged environment cannot be fully recovered, can alternative restoration methods such as restoration in other locations be adopted through systematic engineering considerations.

It is crucial to recognize that responsibility for ecological and environmental restoration (including direct restoration and alternative restoration) encompasses both behavioral and economic dimensions. Therefore, although the law stipulates that the implementation of the responsibility should follow the principle of “direct restoration as the main approach and alternative restoration as a supplement”, this does not encourage courts to bypass the judgment of direct restoration costs and directly requires the responsible party to carry out alternative restoration. The proper procedure should be as follows: when direct restoration is possible but the responsible party lacks implementation capacity, courts should require them to bear the costs of direct restoration, which will be carried out by a third party. Alternative restoration should only be ordered when direct restoration is objectively unachievable due to technical or physical constraints.

5.1.2. The Legal Connotation of Alternative Restoration

The fundamental purpose of alternative restoration lies in its capacity to “rebuild or replace the damaged ecosystem with equivalent value”. This necessitates that the ecological environment and its service functions after alternative restoration should be equivalent or roughly equivalent to those of the original damaged ecological environment [65]. From the perspective of environmental science, to achieve this “equivalent restoration” value function, the “alternative” in alternative restoration should be strictly limited to the “restoration object” level, which can be further concretized as “restoration area and restoration elements”. From the perspective of the restoration area, if in situ restoration is unfeasible due to spatial or ecological constraints, the same type—or a different type but of equal value of ecological service functions as the baseline of the damaged ecological environment—can be restored in an alternative location. For instance, when the construction of a hydropower station damages the aquatic ecological environment, the restoration can be achieved by restoring a natural flowing water habitat of the same length in a different location. From the perspective of restoration elements, when the original elements of the damaged ecological environment cannot be restored, leading to the impairment of ecological service functions, the same value but different

type of ecological service functions as the baseline of the damaged ecological environment can be restored in situ or in a different location. For example, when the destruction of the ecosystem leads to a reduction in a certain fish species (non-endangered) in the ocean, the ecological environment can be restored by releasing fish fry of other species [66].

Therefore, the determination of whether a measure qualifies as alternative restoration lies in whether it can provide an alternative ecological environment that is roughly equivalent to the original state and function of the damaged ecological environment. Legally, alternative restoration encompasses four normative categories: same region but different location, same function but different species, same quality but different quantity, and same value but different grade. These situations can be specifically manifested in judicial practice as afforestation and greening, release of fish fry, and construction of artificial habitats, etc. For instance, in *An Environmental Research Institute v. A Power Company* (2023), the construction of a hydropower station by a certain power company in Beijing led to the complete loss of the ecological environment of a river in a protected area, the court ruled that the infringer should carry out a habitat reconstruction and restoration project for the Chinese mitten crab in the protected area, and restore an equivalent length of natural flowing water habitat in another location [67]. In addition, in *The Qingdao People's Procuratorate's prosecution of Zhang Mouhai* (2024), the defendant's illegal fishing of aquatic products caused damage to the marine ecosystem and the People's Procuratorate of Qingdao, Shandong Province suggested that alternative restoration plans such as restocking and coastal planting could be adopted to regulate the damaged fishery resources and ecological environment [68].

5.1.3. Legal Application Rules for Alternative Restoration

Article 20 of the "Interpretation on the Application of Law in the Trial of Civil Public Interest Litigation Cases Involving the Environment" stipulates that the application of alternative restoration is based on the criterion of "inability to fully restore". From the overall normative context, "inability to fully restore" can be specifically understood as "incapacity to return the damaged ecosystem to the state and function before the damage occurred". This original state and function specifically correspond to the direct restoration standard of "original area, original volume, and original appearance" in practice. Consequently, when natural constraints, technical limitations, or similar factors prevent the achievement of this direct restoration standard, the legal precondition for applying alternative restoration measures is satisfied.

At the same time, the application of alternative restoration must satisfy the following essential conditions: (1) The selection of the "restoration area or element" must strictly adhere to the "principle of closest connection". Specifically, the ideal restoration area should have a close spatial connection with the damaged area. For example, it should be within the same watershed or the same ecological region. This is because the effect of ecological restoration shows a significant negative correlation with spatial distance. When the distance between two areas exceeds a certain threshold, the restoration measures will be difficult to bring about substantial improvement to the ecological environment of the damaged area. Secondly, the restoration elements and the damaged elements should be homogeneous in terms of ecological service functions. When choosing alternative elements, a systematic assessment of their service functions should be conducted to ensure that they match the damaged elements in terms of ecological service value, ecological function categories, etc. Such methodological rigor ensures the effective transference of ecological benefits. (2) It is necessary to formulate scientific and reasonable alternative restoration plans guided by the goal of ecological restoration. The alternative restoration plans should meet three important requirements: in terms of ecological function, it should ensure the equivalent restoration of ecosystem service functions; in terms of ecological

structure, it should maintain the original ecosystem structure and species diversity pattern; in terms of ecological benefits, it should achieve equivalent compensation for the ecological benefits of the damaged area and its surrounding areas. (3) An effective supervision mechanism should be established and the restoration effect should be evaluated. This is an important measure to ensure the effectiveness of restoration and avoid formal restoration.

5.2. *Alternative Fulfillment Methods for Ecological and Environmental Damage Compensation Liability—Alternative Compensation*

5.2.1. The Legal Theoretical Connotation of Alternative Compensation

Alternative compensation is essentially a variation of “compensation for losses” in terms of the mode of payment. Its concept can be defined as a remedial measure that, after ecological damage occurs, when it is objectively impossible to fully compensate for the loss of ecological service functions, fulfills the compensation obligation (includes compensation for temporary losses, permanent losses, and losses that should be borne after natural recovery) through some behavior that can generate environmental benefits or offsets the ecological environment damage compensation within a certain proportion range [69].

From a legal perspective, “alternative compensation” can be regarded as a special way of using ecological and environmental damage compensation funds. Specifically, in judicial practice, the application of alternative compensation is premised on the court’s judgment that the defendant shall bear the responsibility for ecological and environmental damage compensation and specify the exact amount of compensation [70]. Upon full payment by the obligor, these funds must be centrally managed and allocated for the restoration-related work carried out at the location where the ecological and environmental damage occurred, as mandated by Article 8 of the Management Measures for Ecological and Environmental Damage Compensation Funds [71]. Notably, such “restoration-related work” does not refer to the “point-to-point” restoration of the damaged ecological environment, but rather an “overall restoration” aimed at enhancing the overall ecological environment benefits of the area where the damage occurred. This includes building legal popularization stations or environmental judicial education bases as required by policy. This “overall restoration” is of the same nature as the actions taken by the liable party to offset the ecological environment damage compensation funds, which can bring environmental benefits (such as actively participating in the ecological environment governance projects of relevant waters, etc.), all aiming at “improving the overall environmental quality” [72]. Therefore, from a legal-operational perspective, “alternative compensation” constitutes an innovative utilization mechanism for ecological remediation funds—the responsible party uses the ecological and environmental damage compensation funds they should have paid by participating in environmental public welfare projects. From the perspective of the practical operation of the judiciary, this approach is beneficial for the simple and efficient use of ecological and environmental damage compensation funds, thereby alleviating the problem of idle funds for ecological and environmental damage compensation.

5.2.2. Practical Forms of Alternative Compensation

The core feature of alternative compensation methods lies in the fact that although they cannot directly achieve the goal of ecological restoration, they can maintain and promote environmental public interests. After being approved by the court, they can replace monetary compensation or offset part of the ecological environment damage compensation based on the ecological or economic value they generate. In current judicial practice, the alternative compensation methods mainly include technological

transformation and upgrading, participation in environmental public welfare projects, and purchase of carbon credits.

It should be emphasized that existing research indicates that “purchasing carbon sinks” is not merely an alternative compensation method. In cases of ecological and environmental damage where there is a direct loss of carbon sinks, such as those involving the destruction of forest, grassland, wetland, and farmland, purchasing carbon sinks can also serve as an effective restoration approach [73]. This is because the ecological service functions of forests and grasslands inherently include carbon sink services. When such ecological elements are damaged, guiding the responsible party to purchase carbon sinks (such as investing in carbon sink projects) can increase the total carbon sink capacity of the ecosystem, thereby restoring the ecosystem’s carbon sequestration and emission reduction, as well as ecological regulation service functions. In this context, regarding “purchasing carbon sinks” as an alternative restoration measure is also in line with the scientific principles of ecological restoration. Therefore, it must be expressly recognized that “carbon sink procurement” possesses dual legal functionality [74]. If the damage directly impairs the carbon sequestration function of an ecosystem (e.g., deforestation), it is alternative restoration; otherwise, it is alternative compensation.

5.2.3. Legal Application Conditions of Alternative Compensation

As an alternative fulfillment method for the liability of ecological environment damage compensation, the application scenarios of alternative compensation should be strictly limited to situations where the right holder of compensation should compensate for the loss of ecological service functions but lacks the payment capacity. Its application conditions include three aspects: 1. The substantive condition. Alternative compensation must be able to effectively improve the environment in substance and generate expected preventive environmental benefits. This determines whether the alternative compensation method is operable and has practical significance. 2. Procedural conditions. Judicial practice shows that alternative compensation is not a mandatory way of fulfilling liability, and the responsible party has the right to choose to give it up and continue to pay the full amount of ecological and environmental damage compensation. Therefore, the application of alternative compensation should be based on the principle of consensus reached through consultation between the responsible party and the procuratorial and judicial authorities. Generally, the court is responsible for reviewing and deciding, and it cannot apply it on its own initiative. 3. Quantification conditions. Alternative compensation is not a way to reduce liability, so its application requires a clear and reasonable quantification mechanism and offset ratio to prevent “liability evasion”. For instance, when using funds invested in technological transformation to offset compensation, first of all, the requirements for technological transformation must exceed the mandatory environmental protection obligations [75]. Otherwise, it may lead to disputes over the exemption of administrative liability. Secondly, the funds must be audited and evaluated by a third-party institution to ensure their equivalent value to the offsetting compensation amount.

6. Conclusions

This study reveals a paradoxical development in environmental adjudication where the proliferating use of alternative fulfillment mechanisms—reflects both the ingenuity of judicial innovation and the latent risks of overextended judicial discretion. Just as judicial practice is accustomed to indiscriminately incorporating diversified alternative fulfillment methods into the category of alternative restoration, this has led to the gradual generalization of alternative restoration, which aims at “equivalent recovery”, into a “panacea” for all types of ecological damage cases. In the long run, this tendency not only

causes disorder in the liability system but may also breed the hidden danger of evading restoration responsibilities by “innovative restoration methods”, ultimately undermining the practical effect of ecological environment damage remedy. To address these challenges, a more restrained application of alternative restoration is warranted—one that maintains judicial flexibility while insisting on scientifically validated methods, robust monitoring mechanisms. At present, the Civil Code has established the basic framework for distinguishing the responsibility for ecological environment restoration from that for ecological environment damage compensation. Theoretically, the alternative performance methods should correspond to the dual structure of restoration responsibility and compensation responsibility, and be classified into “alternative restoration methods that can restore the ecological environment to its original state” and “alternative compensation methods that substitute actions for monetary payments”. This study conducts a comparative analysis of the effectiveness of ecological environment damage remedy under two models of alternative fulfillment (single-dimensional alternative restoration and binary distinction of alternative restoration and alternative compensation) through the AHP-fuzzy comprehensive analysis method. The analysis results reveal that, compared with the single-dimensional alternative restoration, the binary distinction model has more institutional advantages in providing remedy for ecological environment damage. Building upon these findings, this article proposes that the concept of alternative restoration should be defined as “equivalent reconstruction or replacement of the damaged ecosystem” in accordance with the logical basis of restoration responsibility and compensation responsibility, and the alternative restoration and alternative compensation should be distinguished from multiple dimensions such as legal connotation, implementation methods, and application rules. The main significance of this distinction lies in the following reasons: First, it prevents the arbitrary and excessive application of alternative restoration in judicial practice by establishing clear operational boundaries. Second, it is conducive to maintaining the systematic relationship between alternative performance methods and ecological environment damage liability, clarifying the relationship between alternative restoration and compensation for losses, and constructing a clearer ecological environment damage relief system.

This study still has several obvious limitations. First, the selected judicial cases are mainly concentrated in a few provincial administrative regions in China, which leads to regional bias in sample sources. The evaluation results may not be fully applicable to ecological damage cases in other regions with different ecological environments and judicial traditions. Second, the AHP-fuzzy comprehensive evaluation model adopted in this paper is a static assessment tool. It only evaluates the remedy effect at a single time node and cannot reflect the dynamic evolution of ecological restoration over years. In addition, the index weight depends on expert subjective scoring. Although we have passed the sensitivity test to verify model robustness, subjective deviation cannot be completely eliminated. On this basis, future research can be carried out from four dimensions: 1. researchers can collect judicial rulings from more provinces and cities nationwide to break the restriction of regional sample bias and test the universality of the evaluation framework; 2. the static AHP-fuzzy model can be upgraded into a long-term dynamic evaluation model, so as to continuously monitor the changing trend of ecological remedy effects in different years; 3. subsequent studies can add more quantitative ecological monitoring data to improve the indicator system, reduce the dependence on expert subjective scoring, and make the assessment results more objective and accurate; 4. subsequent studies can explore differentiated application standards for alternative liability under different types of ecological damage.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Medical Ethics Committee of Kunming University of Science and Technology (KMUST-MEC-2026-114) on [2 March 2026].

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References

1. Sretic, Z. Environmental Damage Liability Regime under the EU Law (Review of the Environmental Liability Directive 2004/35). *Rev. Eur. Law* **2006**, *8*, 39.
2. Guo, H. Review the Progress of the Compensation System for Ecological and Environmental Damage in China. *Int. J. Law Soc.* **2020**, *3*, 189–194.
3. Gao, X. The Realization Path of Environmental Law of the Compensation Liability for Ecological and Environmental Damage. *Front. Sustain. Dev.* **2023**, *3*, 15–26. <https://doi.org/10.54691/fsd.v3i6.5124>.
4. Wu, Y.R. Liability and Implementation of Ecological Restoration in Environmental Damage Compensation Litigation. *J. Law Appl.* **2019**, *21*, 34–43. (In Chinese)
5. Wang, L.; Chang, Q.Q. Clarification of the Legal Nature and Reconstruction of Rules for Alternative Restoration of Ecological Environmental Damage. *J. Jiangxi Univ. Sci. Technol.* **2023**, *44*, 22–33. (In Chinese)
6. Supreme People’s Court (2022) Case No. 5 of Ten National Maritime Trial Typical Cases in 2022: Ningde People’s Procuratorate, Fujian Province v. Lin Moumou et al. (Marine Natural Resources and Ecological Environment Civil Public Interest Lawsuit) (2022) Min 72 Min Chu No. 40. Available online: <https://hffgh5ab2f745edf64504sfvwbnp0o5k569w5ffgb.erms.cwkeji.cn/pfnl/08df102e7c10f20633ff85b2a795db7ff8951a35d2e673cfbdfb.html?keyword=最高人民法院发布 2022 年全国海事审判典型案例之五：福建省宁德市人民检察院与林某某等海洋自然资源与生态环境民事公益诉讼案&way=listView> (accessed on 11 April 2026).
7. Supreme People’s Procuratorate (2022) Case No. 2 of Ten Typical Ecological Environment Procuratorial Cases: Jiujiang People’s Procuratorate, Anhui Province v. Huang Mou et al. (24 Individuals) and Anhui A Technology Co., Ltd. et al. (8 Enterprises). Available online: <https://hffgh5ab2f745edf64504sfvwbnp0o5k569w5ffgb.erms.cwkeji.cn/pfnl/c7ed112b8012f816d7369e1d2c941e4ac2a0276606090cdfbdfb.html?keyword=最高人民检察院发布 10 件生态环境检察典型案例之二：安徽省芜湖市鸠江区人民检察院诉黄某等 24 人、安徽某科技有限公司等 8 家企业污染环境刑事附带民事公益诉讼案&way=listView>. <https://hffgh5ab2f745edf64504s590qx5ovq5p06fc0ffgb.erms.cwkeji.cn> (accessed on 11 April 2026).
8. Sichuan High People’s Court (2023) Case No. 8 of the Top Ten Typical Judicial Protection Cases on Ecological Environment in 2023: Guangyuan People’s Procuratorate v. A Slaughterhouse in Guangyuan (Environmental Pollution Civil Public Interest Lawsuit). Available online: <https://hffgh5ab2f745edf64504sfvwbnp0o5k569w5ffgb.erms.cwkeji.cn/pfnl/08df102e7c10f206d4d5d8fa8ad36d017d4191dba9fdab3fbdfb.html?keyword=四川省高级人民法院发布 2023 年度生态环境司法保护十大典型案例之八：广元市人民检察院诉广元市某屠宰场环境污染民事公益诉讼案&way=listView> (accessed on 11 April 2026).

9. Qingdao Maritime Court (2024) Case No. 3 of the Top Ten Typical Cases for “World Oceans Day” 2024: Qingdao People’s Procuratorate v. Zhang Moumou (Marine Natural Resources and Ecological Environment Civil Public Interest Lawsuit)—Upholding Restorative Justice Concepts to Improve Compensation Systems for Marine Environmental Public Interest Litigation. Available online: hffgh5ab2f745edf64504sfvwbnp0o5k569w5ffgb.erms.cwkeji.cn/pfnl/08df102e7c10f206a4a227b4e1ce3334b4793c67bde2e5e6bdfb.html?keyword=青岛海事法院发布 2024 年度“世界海洋日”十大典型案例之三： 青岛市人民检察院诉张某某海洋自然资源与生态环境民事公益诉讼案——坚持恢复性司法理念%20 推动完善海洋环境公益诉讼保护性补偿制度&way=listView (accessed on 11 April 2026).
10. Xiong Moujiu (2025) Criminal Judgment of First Instance for Illegal Hunting, Purchasing, Transporting, and Selling Terrestrial Wildlife (2025) Gan 0925 Xing Chu No. 36. Available online: hffgh5ab2f745edf64504sfvwbnp0o5k569w5ffgb.erms.cwkeji.cn/pfnl/c7ed112b8012f816afb17ff694f8c77f566ca74710aaf5dfbdfb.html?way=listView (accessed on 11 April 2026).
11. Supreme People’s Court (2024) Case No. 3 of Five Typical Environmental Resources Trial Cases in 2024: A Resin Technology Company, Xue Mou et al. Available online: hffgh5ab2f745edf64504sfvwbnp0o5k569w5ffgb.erms.cwkeji.cn/pfnl/08df102e7c10f206ac9186ceb0c032ed4762f9b53305d4c5bdfb.html?keyword=最高人民法院发布 2024 年度环境资源审判典型案例之三： %20 某树脂科技公司、薛某等污染环境刑事附带民事公益诉讼案&way=listView (accessed on 11 April 2026).
12. Brans, E.H.P. The environmental liability directive: Legal background and requirements. In *Equivalency Methods for Environmental Liability*; Lipton, J., Özdemiroğlu, E., Chapman, D., Eds; Springer: Dordrecht, The Netherlands, 2018; pp. 3–20. https://doi.org/10.1007/978-90-481-9812-2_1.
13. European Parliament and Council. Directive 2004/35/EC of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage. *Off. J. Eur. Union* **2004**, L 143, 56.
14. Brans, E.H.P. *Liability for Damage to Public Natural Resources: Standing, Damage and Damage Assessment*; Kluwer Law International: Hague, The Netherlands, 2001; p. 73.
15. Mazzotta, M.J.; Opaluch, J.J.; Grigalunas, T.A. Natural resource damage assessment: The role of resource restoration. *Nat. Resour. J.* **1994**, 34, 153–178. [https://doi.org/10.1016/0169-2046\(94\)90049-3](https://doi.org/10.1016/0169-2046(94)90049-3).
16. Seever, J.R.J.S. NOAA’s new natural resource damage assessment scheme: It’s not about collecting money. *Wash. Lee Law Rev.* **1996**, 53, 1513–1569.
17. National Oceanic and Atmospheric Administration. Natural resource damage assessments (Final rule). *Fed. Regist.* **1996**, 61, 440–441.
18. Wickham, D.A.; Kahl, C.C.; Mayer, G.F.; Reinharz, E. Restoration: The goal of the Oil Pollution Act natural resource damage actions. *Bayl. Law Rev.* **1993**, 45, 405–421.
19. Mariachiara, A.; Luciano, B.; Marco, C. Environmental damage: A new challenge for China, continuing challenge for western legal systems. *Environ. Policy Law* **2011**, 41, 42–51.
20. Supreme Court Environmental Division. *Interpretation and Application of the Supreme Court’s Judicial Explanation on Environmental Civil Public Interest Litigation*; People’s Court Press: Beijing, China, 2015; p. 296.
21. Technical Guidelines for Ecological and Environmental Damage Assessment—General Principles and Key Sections (GB/T 39791.1—2020), Section 7.3.2 Restoration Strategies. Available online: <https://law.wkinfo.com.cn/legislation/detail/MTAwMTM4MzE1MDU%3D> (accessed on 18 April 2026).
22. Wang, X.G. Conceptual Clarification of Ecological Restoration and Alternative Restoration: Based on the Goal of Ecological Recovery. *J. Nanjing Tech Univ.* **2019**, 18, 35–43+111. (In Chinese)
23. Liu, D.Y.; Zhang, Q.; Feng, B. Grasping the Conditions for Applying Alternative Restoration Methods in Environmental Public Interest Litigation. *People’s Procur. Semimonthly* **2024**, S1, 62–63. (In Chinese)
24. Lin, Z.M. Construction of Judicial Application System for Alternative Restoration Responsibility of Ecological Environment. *J. Nanjing Tech Univ.* **2025**, 24, 76–85+213–214. (In Chinese)
25. Wang, C.F.; Wang, Y.T. Reflection and Improvement on Liability Forms in Ecological Damage Compensation Litigation. *Environ. Prot.* **2022**, 50, 14–17. (In Chinese)
26. Du, J.X.; Zeng, Y. Research on Alternative Restoration Liability in Ecological Damage Compensation. *J. Nanjing Tech Univ.* **2024**, 6, 67–72. (In Chinese)

27. Li, X.Y. The Positioning and Realization of “Ecological Environment Restoration” Responsibility Under the Background of Cross-Domain of Public and Private Law. *J. Yunnan Univ.* **2022**, *21*, 135–144. (In Chinese)
28. Zhang, B.; Yin, J.W. Judicial Application of Alternative Restoration Liability: Reflection and Adaptation. *J. Nanjing Tech Univ.* **2022**, *21*, 49–59. (In Chinese)
29. Qin, X.Y. Normative Realization of Alternative Ecological Restoration from the Perspective of Interest Balance. *J. China Univ. Min. Technol.* **2025**, *27*, 82–97. (In Chinese)
30. Environmental Law Monthly Group. Environmental Liability Directive. *Environ. Law Mon.* **2014**, *24*, 1–4.
31. Wang, X.G.; Liu, Q.Y. Functional Positioning and Path Optimization of “Carbon Sink Purchase” in the Context of Rural Revitalization. *Issues Agric. Econ.* **2024**, *6*, 132–144. (In Chinese)
32. Li, Y.S.; Ye, X.; Yang, L. Justification and Implementation of Labor Substitution in Ecological Damage Civil Liability. *Admin. Law* **2024**, *10*, 80–93. (In Chinese)
33. Monti, G.; Deason, J.P. Applying an Ecosystem Services Approach to Supplemental Environmental Projects. *J. Environ. Plan. Manag.* **2012**, *55*, 1047–1057.
34. Liang, X.M. On the Standardization of “Technical Transformation” Liability in Environmental Litigation. *Polit. Law Sci.* **2022**, *5*, 128–140. (In Chinese)
35. Huang, Z.; Zheng, Y.H. Dual Normative Structure of Alternative Performance in Ecological Environmental Damage Compensation. *J. Beijing Adm. Inst.* **2025**, *3*, 118–128. (In Chinese)
36. Ning, Q.T. Research on the Connotation of Ecological Restoration Responsibility. *Academics* **2018**, *12*, 123–135.
37. Ren, H.T.; Tang, S.H. The Connection and Application of Ecological Environment Restoration Responsibility and Ecological Damage Compensation Responsibility: From the Perspective of Articles 1234 and 1235 of the Civil Code. *J. China Univ. Polit. Sci. Law* **2022**, *2*, 193–203.
38. Gong, G. Analysis of Ecological Damage Compensation Clauses in the Civil Code from the Perspective of Public Law. *Adm. Law Rev.* **2022**, *6*, 41–58.
39. Sun, W.; Zhang, X.W. Dilemmas and Solutions in the Judicial Application of Alternative Restoration of Ecological Environment. *J. North China Univ. Water Resour. Electr. Power* **2025**, *41*, 63–70. (In Chinese)
40. Palmer, M.A.; Zedler, J.B.; Falk, D.A. *Foundations of Restoration Ecology*; Island Press: Washington, DC, USA, 2016; p. 3.
41. Jiang, J.; Wang, Q.; Zhao, J.; Zhang, J.; Dong, B.; Huang, X. Construction and Application of Ecological Remediation Technology for Sandy Soils in Northwest China. *Sustainability* **2023**, *15*, 14730. <https://doi.org/10.3390/su152014730>.
42. Robert, C. The value of the world’s ecosystem services and natural capital. *Nature* **1997**, *25*, 3–15.
43. Du, J.L.; Lu, C. (Transl.). *German Civil Code*; China University of Political Science and Law Press: Beijing, China, 2014; p. 54.
44. Matthijs, K.; Tommi, P.; Elaine, W.; Paul, T.B. Actions for Damages in the Netherlands, the United Kingdom and Germany. *J. Eur. Compet. Law Pract.* **2018**, *9*, 55–73.
45. Anhui High People’s Court (2022) Case No. 5 of Six Typical Judicial Protection Cases on Environmental Resources: Chuzhou People’s Procuratorate v. Li Moufu (Ecological Damage Liability Civil Public Interest Lawsuit). Available online: [https://hffgh5ab2f745edf64504sfvwbno0o5k569w5ffgb.irms.cwkeji.cn/pfnl/08df102e7c10f20643861d6f26df7dd920894475815f7688bdfb.html?keyword=安徽省高级人民法院发布的环境资源司法保护典型案例\(2022\)之五——滁州市人民检察院诉李某富生态破坏责任民事公益诉讼案&way=listView](https://hffgh5ab2f745edf64504sfvwbno0o5k569w5ffgb.irms.cwkeji.cn/pfnl/08df102e7c10f20643861d6f26df7dd920894475815f7688bdfb.html?keyword=安徽省高级人民法院发布的环境资源司法保护典型案例(2022)之五——滁州市人民检察院诉李某富生态破坏责任民事公益诉讼案&way=listView) (accessed on 8 April 2016).
46. Chongqing High People’s Court (2022) Case No. 3 of the Top Ten Typical Environmental Resources Trial Cases in 2022: Chongqing People’s Procuratorate No. 2 Branch v. Liu Mouman (Ecological Damage Civil Public Interest Lawsuit). Available online: [https://hffgh5ab2f745edf64504sfvwbno0o5k569w5ffgb.irms.cwkeji.cn/pfnl/08df102e7c10f206937172a7a3c66d0decc37dc2428e876ebdfb.html?keyword=重庆市高级人民法院发布的\(2022\)环境资源审判十大典型案例之三：重庆市人民检察院第二分院诉刘某满生态破坏民事公益诉讼案&way=listView](https://hffgh5ab2f745edf64504sfvwbno0o5k569w5ffgb.irms.cwkeji.cn/pfnl/08df102e7c10f206937172a7a3c66d0decc37dc2428e876ebdfb.html?keyword=重庆市高级人民法院发布的(2022)环境资源审判十大典型案例之三：重庆市人民检察院第二分院诉刘某满生态破坏民事公益诉讼案&way=listView) (accessed on 8 April 2016).
47. Puyang Municipal People’s Government v. Liaocheng Defeng Chemical Company, a Dispute over Ecological and Environmental Damage Compensation Liability. Available online: <https://hffgh5ab2f745edf64504sc0b96ovpfbo969bfffgb.irms.cwkeji.cn/pfnl/95b2ca8d4055fce149c45987779f8417484ecfb8cfa4e0fbdfb.html?keyword=濮阳市人民政府诉聊城德丰化工公司生态环境损害赔偿责任纠纷案&way=listView> (accessed on 8 April 2016).

48. First-Instance Civil Judgment in a Civil Public Interest Lawsuit Concerning Environmental Pollution by an Environmental Research Institute in Beijing and a Mining Company in Jiangxi. Available online: [https://law.wkinfo.com.cn/judgment-documents/detail/MjA0MDQyNDIxODk%3D?searchId=88c98818c8ee490ba597085e9a1fbaa4&index=1&q=替代性修复%20水污染&module=&childModule=all&summary=被告作出罚款 40 万元的行政处罚决定。被告硫酸厂在未安装在线监](https://law.wkinfo.com.cn/judgment-documents/detail/MjA0MDQyNDIxODk%3D?searchId=88c98818c8ee490ba597085e9a1fbaa4&index=1&q=替代性修复%20水污染&module=&childModule=all&summary=被告作出罚款 40 万元的行政处罚决定。被告硫酸厂在未安装在线监#No_Plaintiff_999006) #No_Plaintiff_999006 (accessed on 11 April 2026).
49. Jewpanya, P.; Nuangpirom, P.; Nakkiew, W.; Pitjamit, S.; Jaichomphu, P. Optimizing Tourist Destination Selection Using AHP and Fuzzy AHP Based on Individual Preferences for Personalized Tourism. *Sustainability* **2025**, *17*, 1116. <https://doi.org/10.3390/su17031116>.
50. Li, J.; Hu, X.; Zhang, Y.; Deng, X.; Qi, Y.; Hao, C. Fuzzy-Improved AHP Evaluation of Ecological Restoration Schemes: A Case Study of Panshitou Reservoir. *J. Henan Polytech. Univ.* **2025**, *44*, 134–141. (In Chinese)
51. Tian, Y.Q.; Li, B. Evaluation of Geological Environment Restoration Benefits in Abandoned Mines Based on AHP-Entropy Method and Fuzzy Comprehensive Evaluation. *Min. Res. Dev.* **2026**, *46*, 202–210. <https://doi.org/10.13827/j.cnki.kyyk.20251226.001>. (In Chinese)
52. Wei, S.Y.; Wang, J.G.; Ju, K.P.; Xing, J.; Li, Y.; Hu, J.; Wang, Z.N. Application and Practice of AHP-Fuzzy Comprehensive Evaluation Method in Geological and Ecological Environment Restoration of Chamaogou Mine. *Nonferrous Met.* **2023**, *75*, 106–115. (In Chinese)
53. Wang, C.F.; Li, P.L. Interpretation of the Ecological Environmental Damage Compensation Liability System in the Civil Code. *J. Shandong Norm. Univ.* **2024**, *69*, 97–109. (In Chinese)
54. See Technical Guidelines for Identification and Assessment of Ecological Environment Damage—General Principles and Key Components Part 1: General Principles (GB/T 39791.1—2020), Section 8.1 “Principles for Selecting Value Quantification Methods”. Available online: <https://hffgh5ab2f745edf64504sfvwbnp0o5k569w5ffgb.erms.cwkeji.cn/chl/aca1b0db1be65118bdfb.html?keyword=生态环境损害鉴定评估技术&way=listView> (accessed on 18 April 2026).
55. Ding, H.; Leng, S.; Xin, H.; Zhu, H.; Sun, R. Disentangling the Impact of Climate and Ecological Restoration Measures on Ecosystem Service: A Case Study in Yimeng Mountains. *Appl. Geogr.* **2026**, *191*, 104008. <https://doi.org/10.1016/j.apgeog.2026.104008>.
56. Wingfield, J.C.; Kelley, J.P.; Angelier, F. What Are Extreme Environmental Conditions and How Do Organisms Cope with Them? *Curr. Zool.* **2011**, *57*, 363–374. <https://doi.org/10.1093/czoolo/57.3.363>.
57. Jingjie, N.; Qingtong, N. Analysis of the Applicable Conditions for Ecological Restoration Responsibility. *Nanhai Law Rev.* **2019**, *3*, 89–98. (In Chinese)
58. Liu, Y.; Wang, C.; Dong, J.; Zhang, J.; Fu, B. Grasp the Prior Ecosystem Services in Multi-Objective Ecological Restoration. *Trans. Earth Environ. Sustain.* **2023**, *1*, 55–67. <https://doi.org/10.1177/2754124X221127719>.
59. Brans, E.H.P. Liability and Compensation for Natural Resource Damage under the International Oil Pollution Conventions. *Rev. Eur. Community Int. Environ. Law* **2010**, *5*, 200–290. <https://doi.org/10.1111/j.1467-9388.1996.tb00293.x>.
60. Levrel, H.; Pioch, S.; Spieler, R. Compensatory Mitigation in Marine Ecosystems: Which Indicators for Assessing the "No Net Loss" Goal of Ecosystem Services and Ecological Functions? *Mar. Policy* **2012**, *36*, 1202–1210. <https://doi.org/10.1016/j.marpol.2012.03.004>.
61. Flores, N.E.; Graves, P.E. Money, who needs it? Natural resource damage assessment. *Contemp. Econ. Policy* **2002**, *20*, 171–178. <https://doi.org/10.1093/cep/20.2.171>.
62. Barbier, E.B. The Evolution of Economic Views on Natural Resource Scarcity. *Rev. Environ. Econ. Policy* **2021**, *15*, 24–44. <https://doi.org/10.1086/712926>.
63. Taizhou Environmental Protection Federation v. Taixing Jinhui Chemical Co., Ltd. (Environmental Pollution Tort Compensation Public Interest Lawsuit) (2015) Min Shen Zi No. 1366. Available online: <https://hffgh5ab2f745edf64504sfvwbnp0o5k569w5ffgb.erms.cwkeji.cn/chl/49ed69106365f7a4bdfb.html?tiao=3&keyword=泰州市环保联合会与泰兴锦汇化工有限公司环境污染侵权赔偿公益诉讼案> (accessed on 15 December 2025).
64. See Section 9.4.2 “Quantitative Assessment Methods for Ecological and Environmental Damage” of the Notice on Recommended Methods for Environmental Damage Assessment During Emergency Response to Sudden Environmental Incidents (Circular No. Huanban [2014] 118) issued by the former Ministry of Environmental Protection (MEP) in 2014. Available online: <https://hffgh5ab2f745edf64504sfvwbnp0o5k569w5ffgb.erms.cwkeji.cn/chl/9028a1a592afb8d5bdfb.html?keyword=突发环境事件应急处置阶段环境损害评估推荐方法&way=listView> (accessed on 18 April 2026).

65. Örnheim Gal, A.O.; Åström, M.E.; Filipsson, M.E. A Review of Selected Alternative Restoration Methods for PFAS Contamination. *Remediat. J.* **2025**, *35*, e70007. <https://doi.org/10.1002/rem.70007>.
66. Bladon, A.J.; Short, K.M.; Mohammed, E.Y.; Milner-Gull, E.J. Payments for Ecosystem Services in Developing World Fisheries. *Fish Fish.* **2016**, *17*, 839–859. <https://doi.org/10.1111/faf.12095>.
67. An Environmental Research Institute v. A Power Company (Ecological Environment Protection Civil Public Interest Lawsuit) (2023) Qian Min Zhong No. 557. Available online: [https://hffgh5ab2f745edf64504sc0b96ovpfbo969bfffgb.irms.cwkeji.cn/pfnl/08df102e7c10f2061a246689de087ee851cdc70dfc4c5c99bdfb.html?keyword=\(2023\)黔民终557号&way=listView#anchor-documentno](https://hffgh5ab2f745edf64504sc0b96ovpfbo969bfffgb.irms.cwkeji.cn/pfnl/08df102e7c10f2061a246689de087ee851cdc70dfc4c5c99bdfb.html?keyword=(2023)黔民终557号&way=listView#anchor-documentno) (accessed on 15 December 2025).
68. Qingdao People's Procuratorate, Shandong Province v. Zhang Mouhai (Ecological Environment Protection Civil Public Interest Lawsuit) (2024) Lu 72 Min Chu No. 4. Available online: <https://hffgh5ab2f745edf64504sc0b96ovpfbo969bfffgb.irms.cwkeji.cn/pfnl/08df102e7c10f20605b4f6639fe6b7b2a69686fd9ffa9aebdbdfb.html?keyword=%282024%29鲁72民初4号&way=listView#anchor-documentno> (accessed on 8 December 2025).
69. Zhang, G.; Chen, D. Environmental Justice and Corporate Green Innovation: The Role of Legitimacy Pressures. *Sustainability* **2024**, *16*, 5599. <https://doi.org/10.3390/su16135599>.
70. See People's Government of Puyang City v. A Chemical Company in Liaocheng (Ecological Environment Damage Compensation Lawsuit) (2020) Yu Min Zhong No. 1217. Available online: [https://hffgh5ab2f745edf64504sc0b96ovpfbo969bfffgb.irms.cwkeji.cn/pfnl/c05aeed05a57db0a057e0e76b9ce2f3a3b737d0706749bffbdfb.html?keyword=\(2020\)豫民终1217号&way=listView#anchor-documentno](https://hffgh5ab2f745edf64504sc0b96ovpfbo969bfffgb.irms.cwkeji.cn/pfnl/c05aeed05a57db0a057e0e76b9ce2f3a3b737d0706749bffbdfb.html?keyword=(2020)豫民终1217号&way=listView#anchor-documentno) (accessed on 9 January 2026).
71. Ministry of Finance (MOF). *Management Measures for Ecological and Environmental Damage Compensation Funds (Trial)*, Article 8; Ministry of Finance (MOF): Singapore, 2020.
72. Tang, S.J.; Wei, Y. On the Verification and Development of “Excess Technical Reform Deduction” in Civil Liability for Ecological Environmental Damage: An Investigation Based on the Use of Ecological Environmental Damage Compensation Funds. *J. China Univ. Polit. Sci. Law* **2022**, *3*, 24–33. (In Chinese)
73. Xu, Y.X.; Liu, J.Y. Legal Basis and Normative Construction of “Carbon Sink Purchase” in Judicial Practice. *J. Nanjing Tech Univ.* **2023**, *22*, 29–38. (In Chinese)
74. Hu, D.; Li, J.X. Judicial Application of Carbon Sink Purchase in Fulfilling Ecological Environmental Damage Liability: Clues from a Dual Application Perspective. *World For. Res.* **2024**, *37*, 131–136. (In Chinese)
75. Qiao, G. Legal Theory and Application of “Technical Reform Deduction” in Civil Liability for Ecological Environmental Damage. *Law Rev.* **2021**, *39*, 163–172. (In Chinese)

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