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Review

Research Progress on Forest Eco-Product Value Realization and Eco-Industry: The Inspiration for Planted Forests in Karst Desertification Control

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Abstract: Karst desertification (KD) is a phenomenon in which the surface of the karst region presents a landscape similar to desertification, which restricts the social development of the karst region. How to develop values based on karst desertification control is the focus of current research, with the continuous promotion of karst desertification control (KDC). Planted forests for KDC are an important part of the value realization of ecological products (EPs) and ecological industry (EI) in karst areas. The statistical analysis of 265 relevant papers in this paper shows the following: (1) the literature focuses on EP and EI research; (2) the overall research shows a year-on-year growth trend. It includes three stages: budding (2001–2006), fluctuating growth (2007–2015) and rapid development (2016–2023), with 6, 58 and 211 articles published in each stage, respectively; (3) China is the country with the largest number of articles published, followed by the United States and then Canada, accounting for 47.74%, 11.93% and 6.17%. This paper summarizes the landmark results and key scientific issues to be solved in the study directions of EP supply capacity, EP value accounting, eco-products value realization (EPVR) and EI, taking into account the above results.

Keywords: ecological product; ecological industry; planted forests; karst desertification control; forest

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1. Introduction

Karst is a variety of landscapes and phenomena formed on the surface and underground by the dissolution of soluble rocks by water [1]. The East Asian region is one of the three major karst type areas in the world [2]. Karst desertification (KD) is a phenomenon in which the surface of the karst region presents a desertification-like landscape, due to the fragile ecological environment, under the influence of unreasonable human socio-economic activities. It has become one of the three major ecological and environmental problems in China [3–5]. KD is a constraint to the economic and social development of karst areas in southwest China [6]. Therefore, many ecological restoration projects, including stone desertification control projects, have been carried out in the karst areas of southwest China. Closing Mountain for Afforestation and planted forests are indispensable means for KDC [7]. Planted forests are the rapid creation of forests through artificial seeding, planting, cuttings and other methods and technical measures. It can effectively promote ecological restoration. Therefore, the development of ecological products (EPs) and ecological industry (EI) to promote plantation forestry to realise ecological value is of great significance to karst desertification control (KDC). On the one hand, its development can sustain the process of ecological restoration; on the other hand, it can also attract more policy and financial investment. The results of ecological construction and KDC can be consolidated through planted forests development.

EPs have emerged as a promising approach to safeguarding and rejuvenating the ecological environment while fostering a sustainable economy. This topic has garnered significant attention in the field of ecology, with researchers worldwide delving into its complexities [8–12]. Some scholars have studied ecosystem services since the early days. Their research laid the foundation for the development of EP. They argued that ecosystem services not only support human livelihoods, but also create and maintain the Earth's ecological support systems and create the environmental conditions for human survival [13–15]. Ecosystem services have long been studied in international research neighbourhoods [16]. The United Nations Environment Programme Economics of Ecosystems and Biodiversity further examines ecosystem services and defines them as 'the direct or indirect contribution of ecosystems to human benefits' [17]. In 2010, the Chinese government interpreted EPs from a product perspective in the National Zoning of Major Functions. It states that EPs refer to natural elements that maintain ecological security, guarantee ecological regulation functions and provide a healthy living environment, including natural elements such as fresh air, clean water and a pleasant climate. Chinese scholar Ding Xianhao [18] defines 'ecological goods' in terms of social attributes and suggests that ecological goods have significant externalities that distinguish them from ecosystem services and goods in the traditional sense. Other Chinese scholars have also interpreted EPs from a product perspective outside the context of ecosystem services [19–21]. Meanwhile, research on the concept of EPs and the valuation of EPs in natural asset projects has been fruitful [22]. This further validates the feasibility of EP research. Based on existing research, we believe that EPs are terminal products that originate from ecological protection or restoration by human labour, condensing in the natural environment and ecosystem services on which humans' survival relies, and can ultimately be consumed or used by human society.

The implications of the EI have been explored continuously. Wang Rusong proposed that EI refers to a group of industries that are organised according to ecological and economic principles and laws, based on the carrying capacity of the ecosystem and have efficient ecological processes and harmonious ecological functions [23]. Wu Cheng [24] proposes that EI is an industrial model that provides ecological services in accordance with socialized mass production and market-based management, thus establishing a virtuous cycle of ecological construction inputs and benefits. Other scholars believe that EI should be a form of industry that addresses the unbalanced development of urban and rural areas and promotes the realization of the value of rural ecological resources [25]. EI is a type of industry that operates in alignment with ecological economy principles and economic laws, taking into consideration the ecosystem's carrying capacity. It aims to convert the value of ecological resources into practical value that benefits the environment, while also fostering a harmonious relationship between the economy and ecology.

Ecological product value realization (EPVR) and eco-industry (EI) research are scientific issues that relate to the effectiveness of KDC outcomes. It is observed that the market development prospects of a specific product are influenced by the product reserves and dominant products available. Additionally, the development of a particular industry is influenced by the scale and aggregation post realization of product value. Therefore, in the process of researching the ecological value of planted forests in KD regions, clarifying the supply capacity and value volume of EPs is the precondition for the EPVR; in the process of researching the EI, clarifying the mechanism by which the EPVR promotes the development of the market, and revealing the guiding mechanism of the value realisation on the formation of the industry is the focus of the research. Huang [26], Liang [8] and Robertson et al. [27] have focused on the research concerning the EPVR, in terms of system and path, while the investigation on EP supply capacity and value volume remains unaddressed. Johansson [28], Ljusk et al. [29] and Yihongde [30] primarily delved into the economic development of the EI, without constructing the EI from the perspective of EPVR. In the context of sustainable forest development, we believe that assessing the supply capacity and value of EPs, enhancing the stability and supply capacity of ecosystems and understanding how the realization of EP value impacts EI formation are key areas of future research. Additionally, exploring how EI contributes to ecological restoration and promotes EPVR is crucial and urgent in this research field.

This study addresses the urgent need to realize the ecological value of plantation forests in KDC, highlighting the insufficient development of ecological protection functions. It focuses on the cutting-edge scientific challenges in ecological protection and restoration for KDC, as well as the crucial technological hurdles in unlocking ecological value. By integrating the strategy of ecological economy development in global karst regions and the demands of science and technology, the study employs a technical approach that involves literature classification, identification of landmark achievements and key scientific problems through bibliometric research methodology. It delves into research hotspots and future trends, shedding light on landmark achievements and essential scientific issues related to forest EPs and EI. These include assessing the supply capacity of EPs, accounting for their value, realizing their value and fostering the development of EI. Ultimately, this research aims to provide a scientific foundation for advancing KDC, enhancing ecological restoration and promoting the sustainable development of the ecological economy.

2. Materials and Methods

2.1. Research Materials

The main databases for our study come from WOS (Web of Science) (https://webofscience.clarivate.cn/wos/woscc/basic-search, accessed on 10 January 2024) and CNKI (China National Knowledge Infrastructure) (https://www.cnki.net, accessed on 10 January 2024), of which WOS is a global and authoritative literature database. The articles from WOS are used to study the trend of development with strong credibility. Still, since the content of our study is mainly carried out in China, we also include articles from CNKI, the most extensive literature database in China, in our literature study. The combination of these two databases is able to present a more comprehensive picture of the content of our research.

2.2. Research Method

2.2.1. Method

The criteria for determining the scope of the studies were as follows: (1) studies in WOS and CNKI databases; (2) articles that matched the search keywords; (3) articles whose research practice was before 31 December 2023; and (4) types of studies including research papers, review papers, master's theses, doctoral dissertations, conference papers, newspapers and proceedings. The criteria for excluding papers were as follows: (1) duplicated literature; (2) literature inconsistent with subject knowledge; and (3) literature with low relevance to the study. The specific screening process is shown in Figure 1.

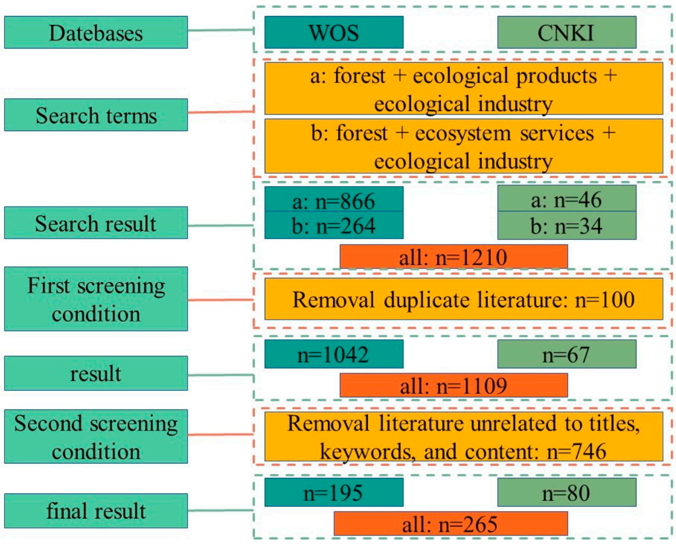

Figure 1. The process of literature retrieval.

This paper is based on the CNKI and Web of Science database platforms, with the search category of "topic", and the final search date is 31 December 2023. The study used "forest + ecological products + ecological industry" and "forest + ecosystem services + ecological industry" as the topic of the literature search and obtained a total of 1210 literature articles. A total of 265 documents were retrieved through software screening and manual selection of retrieved literature (firstly, the article uses Excel 16 software to eliminate duplicated literature; then, by reading the literature manually, the literature that do not contain "forest", "ecosystem services", "eco-products", "eco-industry", etc. in the title, abstract and keywords are eliminated.) [31]. Among them, 80 were in Chinese and 195 in other languages, including 217 journal articles, 37 master's theses, 7 proceedings, 5 newspapers and 4 conferences (Figure 2).

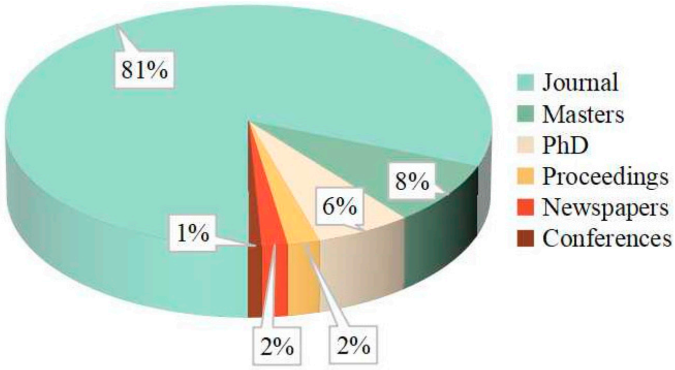

Figure 2. The distribution of literature types.

2.2.2. Research Comprehensive Report

We use bibliometrics as the basis for careful statistical analysis of the literature within the scope of the study, and, in Section 3.1, we use Excel 2016 software to create charts and display the time distribution of the literature's publication, classify the main content of the study and define the main stages of the study; secondly, by reading a large number of works in the literature within the scope of the study, we distil the landmark results achieved in the current research direction and elucidate the experiences of KDC planted forests in Section 3.2; and finally, in Section 4.1, we created global and institutional literature distribution maps using Excel 2016 and ArcMap 10.5. We then analysed the factors influencing the pattern of literature distribution based on the statistical results, and in Section 4.2 reveals the key scientific problems to be solved at present and discusses their implications for KDC planted forests.

3. Results

3.1. Literature Statistics Results

3.1.1. Distribution of Literature Publication Time

As shown in the figure (Figure 3), the study of forest EPVR and EI can be broadly divided into three phases during the period 2001–2023. In the nascent period 2001–2006, the first technical design meeting of the Millennium Ecosystem Assessment (MA) program in the Netherlands in 2001 and the Ecosystems and Human Well-being—Biodiversity Synthesis Report published by the United Nations in 2005 paved the way for the study of EPs and EI [32,33], but the number of papers published globally each year was low. This was followed by a period of fluctuating growth in the number of publications from 2007 to 2015, during which the Gross Ecosystem Product (GEP) accounting system constructed by Ouyang Zhiyun et al. further promoted research development [34]. The period of 2016–2023 was a period of rapid development, during which governments jointly established the Intergovernmental Science-Policy Platform on Biodiversity and EP, and the Chinese government issued opinions on the Establishment of a Sound Mechanism for EPVR [35,36]. These two achievements have contributed to the rapid development of the study of EPVR and EI. A total of 211 publications were published during this period, accounting for 84.75% of the total literature, which shows that there was considerable enthusiasm for its study at home and abroad during this period.

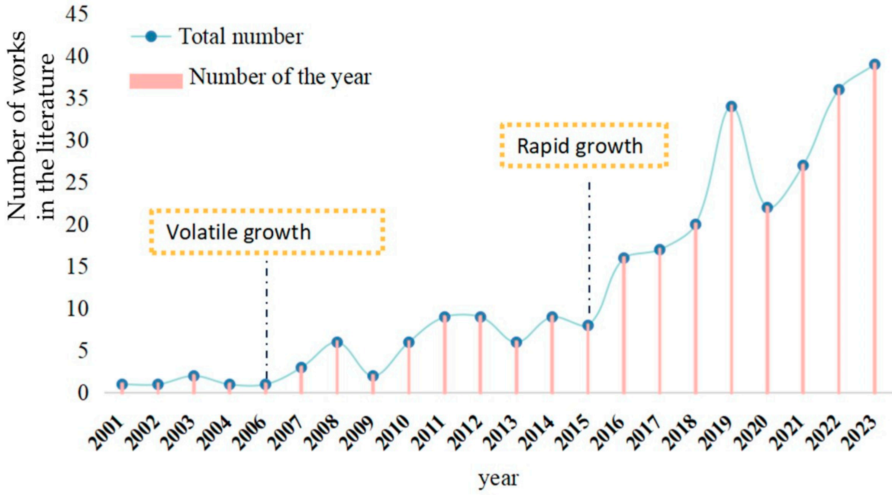

Figure 3. Distribution of domestic and foreign research literature.

3.1.2. Classification of Study Content

In this study, the 265 documents obtained from the search were classified into five categories: eco-product supply capacity, EPVR, eco-product value accounting, EI and other study (Figure 4). EPVR mechanisms occupy a larger proportion of the total literature at 30.98%, followed by supply capacity at 24.58%, EI at 15.49%, value accounting at 17.17% and others at 11.78%. In summary, research on Eps and EI is now mostly focused on preliminary study; that is, on the supply capacity and value accounting of EPs. Therefore, based on research on supply capacity and value accounting, it is a trend to explore EPVR and eco-industrialization in the future.

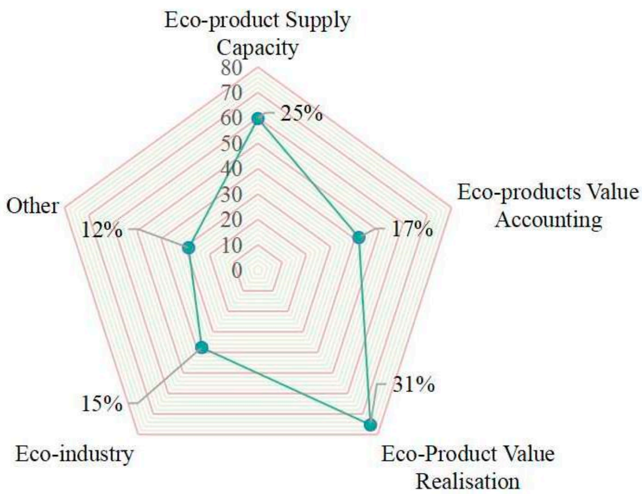

Figure 4. Literature analysis content classification.

3.1.3. Main Research Stage Division

In this paper, we analyse the research literature on EPVR and EI of forests in conjunction with the literature's annual distribution maps. It was found that, from 2001 to 2006, China initially elaborated on the value of forests from the perspective of eco-products, while the literature on related research in karst regions was relatively limited. From 2007 to 2015, global scholars explored the supply capacity of EPs in the context of ecosystem function and ecological restoration. The overall number of articles published during this period increased, but the increase was marked by fluctuations. From 2016 to 2023, the pace of research increased. During this period, research mainly explored the EPVR and actively constructed industrialization pathways. Therefore, this paper divides the development of the study into three stages, namely the budding stage, the fluctuating growth stage and the rapid development stage (Table 1). Through analysis of the development trends, it is found that the development of forest eco-products and EI is becoming more and more mature. However, there is still a lack of research on EPVR and industrialization of planted forests in KDC areas. Scientific guidance on value realization and EI formation is urgently needed.

Table 1. Main research stages.

Study Phase	Study Content	Development Context	Key Features
Budding stage (2001–2006)	Exploration of ecological compensation and the value of forest EPs.	With the development of industry, society is beginning to pay attention to the fragile ecological environment and to consider the path to green and sustainable economic development.	During this phase, the literature was published in no more than six articles per year, and the content was based on the perspective of ecological conservation and synergistic development, analyzing the content of EPs.
Fluctuation growth stage (2007–2015)	Research on the attributes, supply capacity and value accounting systems of EPs in forests.	Countries are gradually studying the function of ecosystems. China has also implemented many major ecological restoration projects.	The relevant research literature shows fluctuating growth, with studies focusing on the services of ecosystems to people.
Rapid growth stage (2016–2023)	Research on value realization, marketing and eco-industrialization of EPs in forest.	Mankind has realized that the development of ecological economy is the way to sustainable human development, especially the KD areas where it is difficult to develop agriculture and industry.	Since 2016, the number of articles issued has been increasing year by year. The consequences of industrial development leading to environmental damage are beginning to come to the fore. Humanity is in urgent need of a sustainable EI that meets the needs of economic and ecological synergistic development.

3.2. Main Research Developments and Landmark Achievements

3.2.1. Eco-Products Supply Capacity

(1) Biomass assessment methods were used to reveal the resource endowment of different forest ecosystems.

Ecological resources are the advantage of economically underdeveloped regions. It is necessary to clarify the stock of ecological resources to explore new development paths for the region. Biomass assessment is an effective way to identify ecological resource endowments. It mainly includes the average wood method [37], carbon dioxide balance method [38], clear cutting method [39], relative growth method [40], forest storage estimation algorithm [41] and the spatial assessment method, using remote sensing technology (RS) and geographic information system (GIS) [42]. Among them, Fang Jinyun et al. [41] found that forests play an important role in the functional contribution of China's carbon pool using the forest stock projection method, and also analysed the ecological advantages of different forest types. Chen, Erxue [42] proposed the use of advanced tools such as remote sensing (RS) and geographic information systems (GIS) to determine forest biomass at different spatial scales, from stand to region. These two methods analyse the ecological resource endowment from different forest types and spatial scales, respectively, which are essential references for assessing the resource endowment of forest EPs in habitat-complex environments.

In order to understand the biomass of native forests in karst environments, Yang Hankui and Cheng Shize (1991) [43] used the harvesting method to measure the Maolan karst forest community. They found a relatively significant correlation between biomass and tree species. Karst forests are low-biomass forests, and the recovery of community structure is faster than the recovery of community function (biomass) compared with other environmental forests [44]. Planted forests have been widely used in both northern and southern KDC in China. Still, there is a lack of research on the assessment and enhancement of the EP supply of artificial planted forests. The southern KDC presents challenges for assessing and improving EP, including steep topography, diverse forest types and issues with utilization and mixing. In contrast, the northern KDC hinders forest succession by impacting soil organic matter, precipitation and cold climate, as well as limiting the selection of tree species for planting. The biomass assessment method should be utilized to determine the resource potential of EPs from KDC planted forests in both the northern and southern regions. The focus in the south should be on adjusting the forest structure, while, in the north, the emphasis should be on optimizing the structure of planted forests with high-quality, fast-growing native tree species (see Figure 5). This approach aims to enhance the biomass of planted forests, leverage the advantages of the resource potential of EP and establish a model for assessing and enhancing the supply of EP from KDC planted forests.

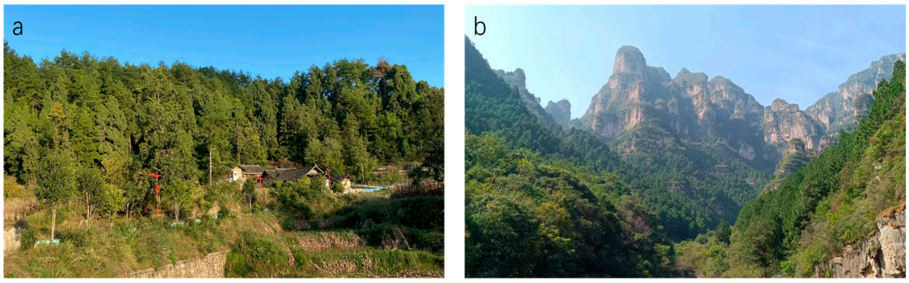

Figure 5. Planted forests landscapes: (**a**) southern KDC planted forests; (**b**) northern KDC planted forests.

(2) Explain the relationship between ecological restoration and the supply capacity of forest Eps, based on the factors affecting ecological restoration.

As an essential component of terrestrial ecosystems, the forest provides different types of EPs on different scales [45]. At the same time, it also satisfies the material needs and environmental conditions for human survival and development [46]. Laobingli et al. (2020) [47] reconstructed the damaged tropical rainforest ecosystem in Sanda Mountain with the help of restoration methods such as group-building plants, pioneer plants and sanda composites and assisted natural regeneration by adopting the overall idea of dynamic succession at the point-line-plane level. They assessed the value of ecosystem service functions before and after restoration by using the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model. Luo Jing et al. (2023) [48] study forest restoration in Deqing County, Zhejiang Province, as an example. After identifying potential forest restoration areas, they assessed the benefits of ecosystem services and restoration costs. They proposed an ecological restoration process and methodology of "identification of restoration areas, assessment of restoration benefits, and preference of high-benefit restoration areas".

The karst region is a two-layer 'binary three-dimensional' alkaline geochemical environment, where water loss and soil conditions lead to frequent ecological problems such as drought, flooding and KD [49]. In this environment, ecosystems are fragile, with slow positive succession rates and easy interruption of positive succession, and rapid malignant reverse succession rates that make ecological recovery difficult [50]. Meanwhile, the ecosystem of karst areas has a tendency to gradually deteriorate due to the disturbance of human socio-economic activities and natural conditions [51]. Ecological restoration has played an essential role in the history of ecological development [52]. Karst rock exposure affects the stability of forest systems and thereby affects the supply capacity of EPs [53]. Therefore, ecological restoration is the main method to improve the supply capacity of forests in karst areas, and the construction and restoration of vegetation is an essential method of ecological restoration [54,55]. In KDC areas, it is important to explore the factors that affect ecological restoration by utilizing dynamic succession theory and the identification-evaluation-optimization framework. In future research should focus on the supply capacity of EP derived from planted forest in KDC.

(3) Factors affecting the supply capacity of forest EPs are identified based on the input–output relation analysis.

The supply of EPs is a complex process. There are trade-offs or synergies between different products, in terms of relationships within the EP supply [56,57]. The EP supply is also influenced by factors external to the system, such as the supply and distribution of EPs by forest cover and other natural factors [58]. The EPs' supply and biodiversity are enhanced by a positive succession of forest ecosystems [59]. Resource input is a positive factor in promoting forest restoration, from which it can be inferred that resource input is an essential external driver of capacity enhancement in EP supply. Policy funding inputs have the greatest impact on the output efficiency of forest EP supply [60]. The efficiency of EP supply can be effectively improved by strengthening the top-level design of the EP supply system and rational planning of resource input [61].

As an important means of KDC in the region, the ecosystem of planted forests is an essential ecological barrier in the area, and the ecological function it shoulders is particularly significant. In China's karst regions, planted forests is challenging in both the southern and northern karst regions. In the southern karst, water and heat resources are abundant at the foot of mountain slopes, but the utilization rate is low. In the northern karst, mountain water resources are scarce and difficult to develop. However, the lack of research on the input–output ratio of KDC makes it difficult to quantify the amount of EPs from planted forests. This hinders the exploration of the realization of the value of EPs from planted forests [62]. Therefore, based on the study of the relationship between forest inputs and outputs, the output rate should be used as a guide to increase ecological restoration inputs and promote the development of suitable planted forests. In the southern region, species like red Douglas fir, teak and yellow sandalwood are recommended for planting, while in the northern KDC area, species such as persimmon, chestnut and oleander cypress can be selected. This will enhance the structure and stability of artificial forests, facilitate forest succession in KDC artificial forests, overcome geographical and hydrothermal limitations, boost EP supply and address the challenge of balancing long-term and short-term benefits in planted forests [63].

3.2.2. Eco-Product Value Accounting

(1) Accounting for the value of EPs based on localization parameters, value coefficients combined with value substitution methods and valuation model methods.

The value of EPs is an important indicator of the transformation of ecological advantages into economic resources, but how to account for the value of EPs has consistently been a difficult problem for academics. Accounting for the value of EP is a major step forward in solving the accounting problem by considering localization parameters, value coefficients and value substitution methods, according to local conditions. Costanza R. [16] and Ouyang Z. Y. et al. [13,34] quantified global EPs and their values using biophysical processes and global parameters combined with an engineered alternative value approach. Daily [64] initiated the Natural Capital project which developed the ecological valuation software In VEST 3.5.0 specifically. Kenter [65] proposed a methodology for assessing cultural values based on shared pluralism, based on the 'ecological meta'. Cao Shixiong et al. (2016) [66] proposed a method for assessing the net value of ecosystem services as an example of plantation forestry projects in Kyoto City. They compared the size of the net benefits generated by different types of plantation land-use practices through this method.

KDC planted forests are particularly fragile due to their poor soil quality, water loss caused by "binary three-dimensionality" and its own structural attributes, and the development of its ecological value requires a more accurate accounting method as a guide. After conducting a thorough analysis of the localization parameters, value coefficients and non-market currency equivalent substitution method of KDC planted forests eco-systems, it is imperative to consider the fragile characteristics of these ecosystems as a starting point for research. Developing a system of value accounting with ecological security as a central focus will be crucial in advancing the realization of the value of KDC EPs.

(2) Accounting for the value of forest EPs by constructing a value accounting system based on the needs of the dominant ecosystem function.

Forest EPs' value accounting should be a goal-oriented accounting system. Chinese scholars have proposed the concept of gross ecosystem product (GEP) to establish an assessment and accounting indicator that can measure ecological status [67]. The European Commission et al. [68] in their "Experimental Ecosystem Accounting—White Paper" state that GEP is the total value of products and services provided by ecosystems to human beings. The GEP is currently imperfect and needs to be orientated towards the dominant ecosystem functions to establish a real and effective value accounting system. The accounting project of the Environmental Planning Institute of China's Ministry of Ecology and Environment is a typical application of dominant function-oriented GEP accounting, and the department has continued to carry out research on accounting for the value of EPs and has completed GEP accounting for 31 provinces (autonomous regions and municipalities directly under the central government) across the country for the period of 2015–2019 [69]. These studies provide a solid foundation for establishment the EP trading market.

Different functional ecosystems have been established in KDC areas due to climatic, geomorphological and topographical conditions. For example, planted forests and ecological forests are established in areas with poor terrain conditions, large slopes and high erosion potential, and economic forests are found on slopes with better terrain conditions and flatter terrain, using famous, unique and superior bamboo, medicine, fruit, rattan and other tree species [70]. In the southern KD region, where rainfall is abundant, artificial planted forests focus on soil and water conservation, while in the northern KD region, with scarce rainfall, the emphasis is on windbreaks, sand fixation and the cultivation of fruits and economic crops. By developing an accounting system for the value of Eps, based on varying land conditions, the ecological forests in artificial planted forests can fully utilize their regulating service function and the material supply function of economic forests. Leveraging the regulating service function of plantation ecological forests and the material supply function of economic forests can further enhance the realization of the value of EP (Figure 6).

3.2.3. Eco-Product Value Realization

(1) Explore the paths and modes of realising the value of forest EPs by studying the factors of ecological market demand.

EPs are natural environmental conditions and utilities upon which ecosystems form and sustain human existence. How to effectively apply EPs' value is a hot research topic. It is an important way to realize EPs' value by commercializing the marketable part of the various beneficial services that ecosystems provide to people. In Fujian Province, the "forest ecological bank" was implemented to realize ecological value through ecological resource indicators and property rights trading [26]. The EPVR was promoted in Weihai through the eco-restoration of mine pits and the development of cultural tourism industries [71]. The city of Lishui uses ecological industrialization to transform ecological resource advantages into commodity advantages and brand value gains, thus releasing ecological dividends and realizing ecological values [8,72]. In the Dongjiang River source region of Jiangxi, an ecological protection compensation standard was established based on the cost of environmental protection and ecological construction in the valley; moreover, ecological compensation was used to address the socio-economic imbalance between regions and to ensure the ecological security of water resources in the valley [73].

Karst environment space fragmentation, vegetation type diversification and the formation of functionally diversified planted forests' EPs should adopt diversified value realisation paths. Through market path regulation, the scattered property rights of planted forests should be aggregated and traded; for the ecological function of the ecosystem, under the premise of meeting the ecological function to develop its value, there are obvious ecological advantages it should play to its advantage to achieve the industrialisation of the ecological advantages into economic advantages to achieve brand gain; for the ecological safeguard role of the inter-regional links between the region, to take the main regulation of the government to allocate the resources and wealth. The government should be the main regulator of the distribution of resources and wealth.

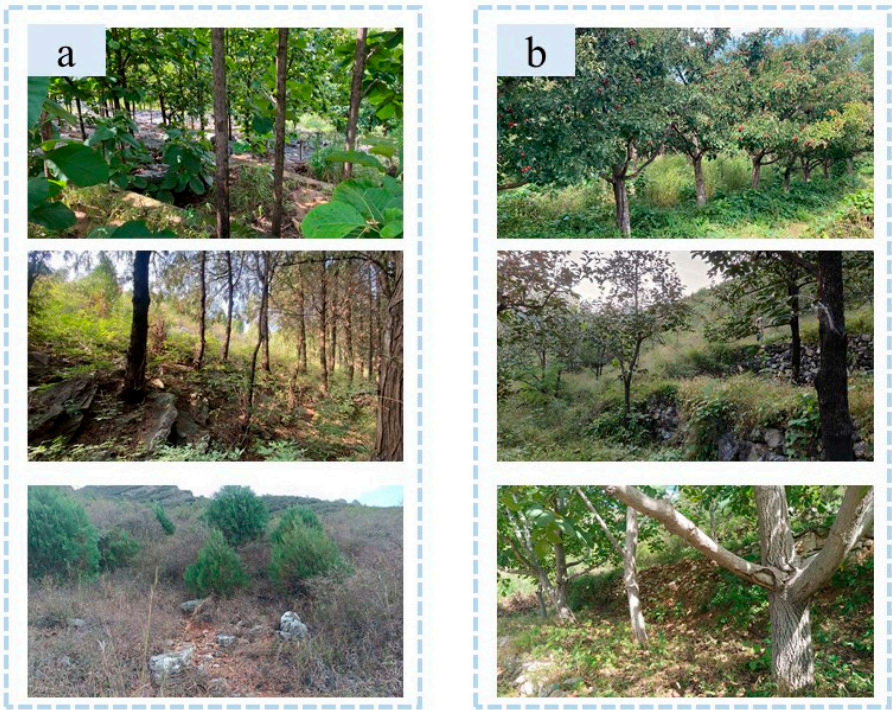

Figure 6. Planted forests landscapes: (**a**) regulatory services function; (**b**) material goods supply function.

(2) Through the study of governmental rights and responsibilities and EP attributes in the realisation of forest ecological product values, the important role of the government-led pathway in realising values is clarified.

Ecologically fragile areas often lag in economic development due to their complex mountainous environments. The value of forest EPs faces challenges, due to economic underdevelopment and inadequate transportation infrastructure, making it hard to fully realize the value of public and semi-public ecological products that cannot be directly traded through market operations alone. In these regions, compensation in the form of transfer payments is provided for the non-directly tradable EPs formed for the protection and restoration of the ecological environment [74]. In the form of government purchases, the value of EPs is realised by purchasing forest rights, carrying out ecological projects, or cooperating with private enterprises to develop EPs to satisfy people's needs while improving the ecological environment [75–77]; in the form of ecological taxes and fees, the externality of natural resources is internalised to realise the EP value [78,79]; in the form of ecological compensation, through the clarification of regional property rights, the intensity of compensation, the target of compensation and the mode of compensation, the contributors of ecological protection are compensated and the value of EPs is realised [80,81].

Planted forests in KDC regions are faced with the problem of the difficulty of realising the value of EPs that are public and semi-public goods. On the one hand, due to the product zoning affected by the uneven distribution of terrain and landscape and other factors, the scope and boundaries of the zoning are relatively rough; on the other hand, the existence of disputes over forest rights in the mountainous areas of KDC leads to unclear management subjects and low compensation standards, which brings specific difficulties to the implementation of the fulfilment of the compensation for ecological benefits of forests [82]. Among them, the difficulties in southern karst region are mainly due to its conditions, such as interlocking topography and administrative scope, and those of the northern karst region are due to the insufficient attention paid to mountainous areas because of the government's shift in focus, which restricts the realisation of the value of EPs. Policy support should be strengthened to realise the value of EPs through transfer payments, government purchases, ecological taxes and fees, ecological compensation and other government-led forms to set up a practical research model for the realisation of the value of EPs of planted forests in KDC.

3.2.4. Eco-Industry Formation

(1) Reveal the form of EI development in ecologically fragile areas by analysing the impact of EI and traditional agroforestry on ecologically fragile areas.

Forest EPs are an essential pillar in the cause of rural revitalization in ecologically fragile areas, and the development of forest EPs enables the implementation of the EI. The Swedish Forest Manager programme operates on the premise of ensuring that harvesting is lower than growth, making it the largest timber producer in Europe [28,29]. Its model is the sustainable management of forest products. Mario et al. [59] found that ecological forestry can enhance biodiversity and the EP supply compared to traditional agriculture; it can be a sustainable industry in an underdeveloped region. The ecological degradation of ecologically fragile areas can be effectively halted through the development of an EI [83].

Karst ecological restoration has been related to forest industry research, in which the characteristic and efficient forest industry model formed in the process of KDC [55,84,85]; which lays the foundation for the development of an EI. However, its research did not focus on exploring the EI model that realises the value of planted forests' EPs. Planted forests play a pioneering role in ecological restoration in ecologically fragile areas, and their own economic characteristics and rapid forest formation characteristics have popularised them in ecologically fragile areas on a wide scale. An EI development model based on the characteristic and efficient forest industry should be constructed, with material products, regulating service products and cultural service products as the entry point, to lead the research on the ecological protection and synergistic development of planted forests.

(2) Reveal the mode of promoting the development of a forest EI in ecologically fragile areas, through the development of a suitable forest EI in ecologically fragile areas, according to local conditions.

Forestation in ecologically fragile areas has always been an important path for ecological restoration. As a result, these areas have created many forests to be developed, with great potential for economic development. The arid and semi-arid environment of Wuzhong City provides a unique geographical setting and resource advantages for the development of a special economic forestry industry. This industry focuses on the cultivation of fruits such as apples, wolfberries, grapes and jujubes, with the goal of generating economic benefits through forestry eco-construction. Ultimately, the aim is to enhance the efficiency of forestry practices and increase farmers' income [30]. The Sehamba region uses the ecological restoration plantation industry as the core to attract tourists and develop the ecotourism industry; this industry includes the tourism experience-type EI represented by driving eco-education, eco-picking and eco-breeding, which makes full use of the ecologically restored forests to drive the ecological and economic development of the region [86].

Due to the ecological fragility of karst areas, ecological protection was initiated earlier, paving the way for sustainable development. Xiong Kangning et al. [84] researched the essential elements of ecological restoration of vegetation communities. Then, they developed an EI and other suitable industries for synergistic and coupled development in karst areas. Li Liang et al. [87] found that diverse EIs were formed in the process of KDC, and summarized the key issues facing the development of these EIs. However, there still needs to be more research on the development of the plantation EI, and further research is needed. The development experience of ecological industries represented by biomedicine, bio-energy and mountain tourism formed during KDC [84] and forest ecological industries in other regions [30,86] should be taken into account, to coordinate the development of the EPs of artificial planted forests in KDC regions as the core and then lead the formation mechanism research of ecological industries of ecological forests and economic forests in KDC.

3.2.5. Summary

Research has been conducted both domestically and internationally on the EPVR and EI of forest; however, there is a lack of studies focusing on their value realization in KD. Existing research on this topic predominantly centres around value accounting and realization. Current accounting methods for EP value encompass the market value method, equivalent factor method and functional price method, yet none of these approaches specifically address the unique attributes of different ecosystems. The supply of forest ecosystem services in ecologically fragile areas like regions experiencing KD is influenced by a variety of forest attributes [88]. In future accounting processes, the accuracy of assessments can be enhanced by suggesting specific valuation methods for different EPs based on these forest attributes [89]. The selection of EPVR paths may not always be advantageous for ecological builders, hindering the advancement of ecological projects like the governance of regions experiencing KD. Future studies on EPVR paths should consider the clarity of property rights [90], and subsequently establish channels for value realisation by examining the origins, components and ideas for realising value in ecological products [91]. Forest ecological industrialisation is seen as a necessary step in realizing the value of ecological products within the forest industry [92]. Researching the production of forest ecological products with the aim of the fourth industrial revolution is considered a viable path for the future development of the ecological industry [93]. While the current forestry industry structure is mainly secondary, with the primary industry as its foundation, and the tertiary industry playing a complementary role, the forest ecological industry is evolving. It is anticipated that the structure of the forest industry will undergo continuous adjustments in the future towards a more rational framework.

4. Discussion

Planted forests for stone desertification control mainly consist of two types. One is ecological forests, which are mainly based on conditions in different ecological zones and involve the selection of tree species that can restore the area's ecology and are highly adaptable to building forests; the other type is economic forests, which are mainly based on the local natural conditions, economic development trends and market demands, and involve the selection of high-quality, high-yielding and high-efficiency economic tree species for building the forest. Planted forests (Figure 7) have been fruitful as an important means of ecological control and economic development in KD regions [94–97]. The development of EPs and EIs can consolidate the achievements of plantation construction and provide new impetus for KDC. Therefore, this paper summarises and analyses the distribution of the literature and key scientific issues to be addressed in the study of forest EPs and EI, with a view to providing scientific references for developing the value of planted forests and consolidating the achievements of KDC.

4.1. Literature Distribution

4.1.1. Main Institutions Studied

The study, which analysed 265 documents, found that research on forest EPVR and EI formation mechanisms has started to heat up in recent years, with a large number of research units, but the number of published articles per institution is not very high. Therefore, the study only counted the units with more than 3 (including 3) publications, totalling 48 papers and 12 units (Figure 8). Chinese universities and research institutions published the highest number of articles. Northeast Forestry University published the most articles, followed by Nanjing Forestry University, China Forestry Industry Conference, Beijing Normal University and China Academy of Forestry Science, etc. Only the US Forest Service published four articles in its foreign institutions. Forestry universities are the majority of the publishing institutions, which is presumably related to the higher ecological sensitivity of forestry academics.

Figure 7. KDC and artificial forested landscape: (**a**) KD in large slope area; (**b**) KD in gentle slope area; (**c**) KDC ecological forest; (**d**) KDC economic forest.

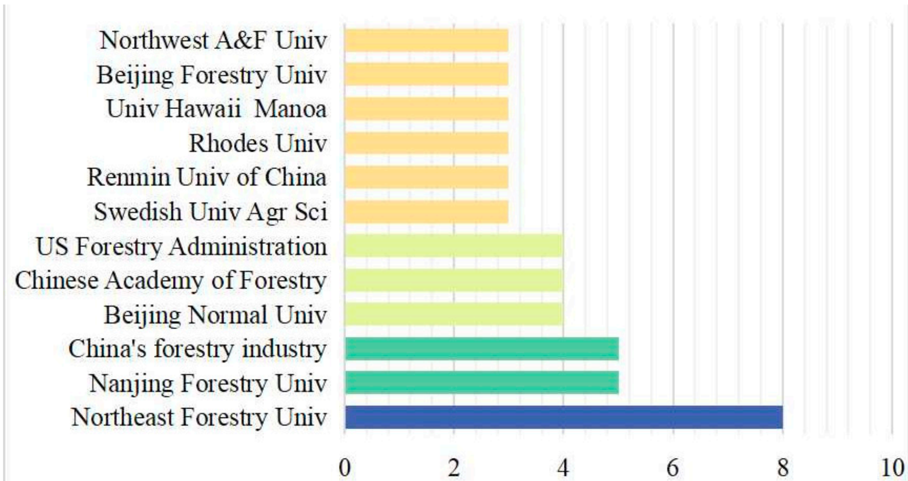

Figure 8. Literature distribution units.

4.1.2. Main Countries or Regions Studied

According to the analysis of the regional distribution for the 265 publications (Figure 9), it was found that most of the studies on forest EP value realisation and EI formation mechanisms were located in countries with temperate, subtropical and tropical climatic zones in the Northern Hemisphere. Among them, China has the highest number of publications, with 116 articles, accounting for 47.74% of the total, followed by the USA and Canada in North America, accounting for 11.93% and 6.17% of the total. China has the highest number of articles; we speculate that this is related to the implementation of policies on natural resource conservation, social welfare construction and eco-economic development.

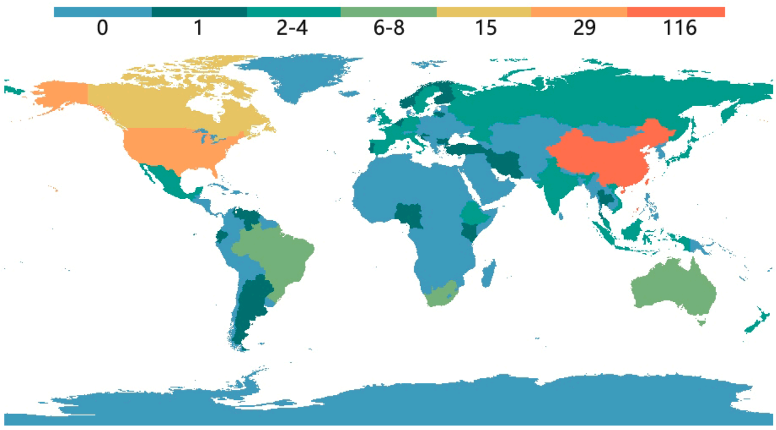

Figure 9. Global distribution of the number of publications on forest EPs and EI. A more reddish colour means a higher number of publications and vice versa.

4.2. Key Scientific Issues to Be Solved and Prospects

4.2.1. Eco-Product Supply Capacity

(1) To address the main problem of idle resources caused by the lack of consumer recognition of EPs, policy guidance and scientific and technological support for EP development should be strengthened, and the concept of EP recognition should be established to develop idle eco-resources.

There is an urgent need to realize forest EP values for conservation and development in ecologically fragile areas, but the economic, policy and social research corresponding to EPs is still lacking [98]. The forest ecological product supply capacity in karst regions is prone to decline, due to deforestation and degradation. It takes a lot of effort to maintain the forest EP supply capacity [99]. In the past, people invested a lot of money in ecological restoration from the perspective of soil and water conservation and improving vegetation cover. The investment of resources made it possible to improve the ecological environment, but a series of problems such as insufficient awareness and low use of ecological resources constrained regional development. For example, forestry in Jingbian County is primarily focused on ecological forestry. However, due to the lack of awareness of ecological products, the social benefits are not readily apparent, and the economic benefits are poor. This has led to a situation where the more forests are planted, the greater the liabilities become. As a result, there is low enthusiasm among the people to participate in the area's management, and it may even lead to further destruction [100].

The challenges mentioned above are also present in regions of KDC with extensive planted forests and poor living conditions. To fully realize the ecological value of these planted forests in KDC regions, a strategy for value realization should be developed, based on regional characteristics and the distinct ecological products themselves. For instance, the southern karst region could focus on initiatives like the national KD restoration project and other ecological projects, while the northern karst region could leverage projects such as the Three North Protective Forest Project and improving connectivity between mountainous and plain areas. It is crucial to tailor the theory of EPVR to the specific territorial units, enhance policy-level understanding of ecological products and utilize policies that promote compensated use of natural resources to support farmers in improving their livelihoods. This approach aims to achieve a balance between ecological protection and economic development.

(2) Regarding the critical problem of low supply capacity of EPs from planted forests, which limits the development of ecological industries, forest landscape structure planning and cultivation of high-quality tree species can be carried out, based on the theory of nature

management and the theory of landscape ecology, to enhance the supply capacity and break through the industrial dilemma.

The real way to helping poor regions to escape poverty is through industrial support, among which it is more important to develop EIs with local characteristics according to local conditions [101]. Ecologically fragile areas have been suffering from the problem that the supply capacity of plantation EPs can hardly meet the regional development. Niu Lanlan et al. [102] discovered that, in the Maowusu Sandy Land in Northwest China, there are high levels of wind and sand, minimal precipitation and strong evaporation. Additionally, they observed a single dominant plant species in the ecological restoration of plantations, resulting in low vegetation coverage and a disconnect between ecological and economic benefits. The scientific and technological aspects of ecological restoration were found to be lacking, with insufficient collaboration among farmers, herdsmen, the government and scientists. Such problems have seriously constrained the supply of EPs from planted forests, resulting in the need for more development of the EI.

The fragile ecological environment of KD areas suffers from problems such as thin soil, lean soil, little water and intermittent drought. The supply capacity of EP is limited, resulting in low output value for agricultural and forestry industries. This creates a situation where the soil and water resources are unable to adequately support the population. At the same time, there is also the problem of a single form of industry and a small scale of industry in the KD planted forests areas, which makes it difficult to form a regional brand effect and makes the market competitiveness of the products weak. In future development, concepts from nature management and landscape ecology should be utilized to modify forest structure and spatial layout by developing high-quality tree germplasm resources, selecting and breeding high-quality varieties of native tree species, and implementing landscape planning and design. By enhancing species diversity in planted forests, a stable supply capacity of ecological products is gradually established. This will facilitate the creation of diversified and sustainable forest ecological industries, development of ecological brands, expansion of industrial scale, and overcoming challenges related to low supply capacity and industrialization (Figure 10).

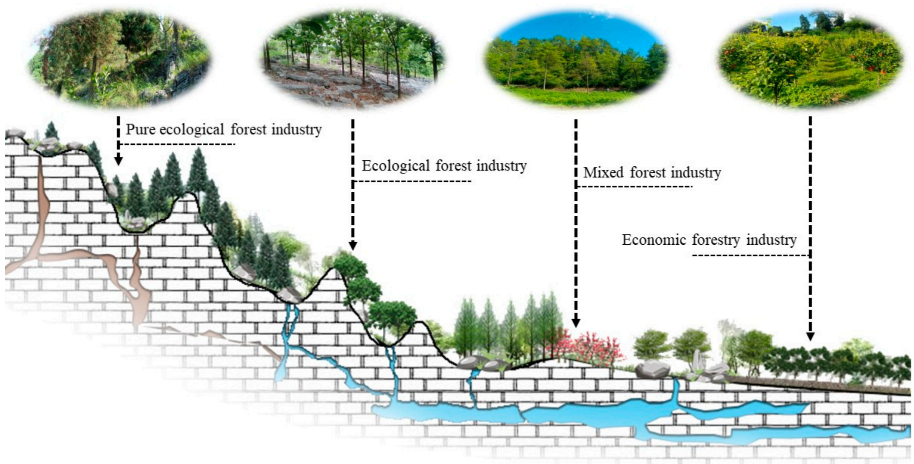

Figure 10. Schematic diagram of optimisation of ecological industrial layout and enhancement of ecological product supply capacity of KDC planted forests.

4.2.2. Eco-Product Value Accounting

(1) Aiming at the key technical problem of mismatch between the accounting method and the accounting objective of EP value, a value accounting method with regional characteristics should be established based on the functions, attributes and conditions of EPs, leading the value of EPs to be evaluated accordingly.

Methods such as market value and conditional value have been developed in international classical EP value estimation, and methods such as remote sensing, GIS and the

InVEST model have also been developed and utilised technically [103–105]. Overall, the current indicators and methods for accounting for the value of EPs in various regions do not match the accounting objectives, with the vast majority of areas unilaterally focusing on the value of natural regulation services or material products. In particular, for complex forest ecosystems, the accounting system based on the functional characteristics of forests is imperfect, leading to the fact that its value accounting still suffers from the difficulty of accurately measuring the value of EPs.

Species diversity is richer in KD areas, terrain conditions are complex and the ecological functions of planted forests vary. In future research, we should develop an assessment method that considers the ecological characteristics of ecological forests and economic forests. It will select appropriate indicators and methods based on their different ecological and economic functions. This study focus on constructing a technical and value accounting system for ecological products (EPs) and establishing a model for valuing ecological products that aligns with the ecological functions of planted forests.

4.2.3. Eco-Product Value Realization

(1) Aiming at the key scientific issue of how to drive the formation of EI by realizing the value of EPs, it should carry out surveys and assessments of the dominant functions to identify the mechanism of realizing the value of EPs of the dominant functions of different types of ecosystems and establish a sample model of transforming eco-advantages into economic advantages, using the mechanism of realizing the value of the chief parts.

Since the second industrial revolution, the conflicts between man and land and man and ecology have become increasingly prominent [106]. As an important path for ecological restoration, the primary function played by planted forests varies from region to region. However, the current realisation of the value of EPs does not consider the combination with the main functions of the ecosystem, making it difficult to realise a sustainable supply of EPs. As research progressed, forest management began to focus on multifunctional ecosystem services such as biodiversity conservation, ecosystem regulation services and microclimate regulation [102,107–109]. It has become an urgent and realistic problem to drive the formation of EIs by realising the value of EPs and transforming the ecological advantages of forests into economic resources [110].

The ecological environment capacity of KD areas is critical, and the mechanism for realising the value of EPs is stereotypical in form. It does not have a precise target, resulting in the ecological advantages of planted forests in KDC regions not being effectively transformed. A classification survey of EPs should be carried out to clarify the ecological dominant functions of different planted forests, such as ecological forests, economic forests, etc., to promote the confirmation of natural resources and to lead the research on the realisation of the value of EPs of dominant functions of different types of planted forests. Future research should focus on developing a model to convert the ecological benefits of planted forests into economic gains (Figure 11).

(2) Aiming at the main problem of weak ecological value premium effect, due to the imperfection of the operating mechanism for realising the value of forest EPs, the mechanism for recognising the value of EPs, such as forest management and development, ecological compensation and the implementation of safeguards should be clarified, to lead the research on realising the ecological value of forests and ensure the realisation of the ecological value of forests.

Forests are an important aggregator of terrestrial EPs, but they lack a precise mechanism for realising their value, and the EI cannot yet develop sustainably. The mechanisms to promote the development of ecological premiums, such as the ecological services market trading system, the ecological transfer payment system, the ecological compensation system and the environmental pollution liability insurance, need more scientific connection. Therefore, the main task of the current forest development should be to identify the mechanisms involved in surveying and monitoring, value assessment, management and development, ecological compensation and implementation guarantee for the realisation of the value of forestry EPs [111].

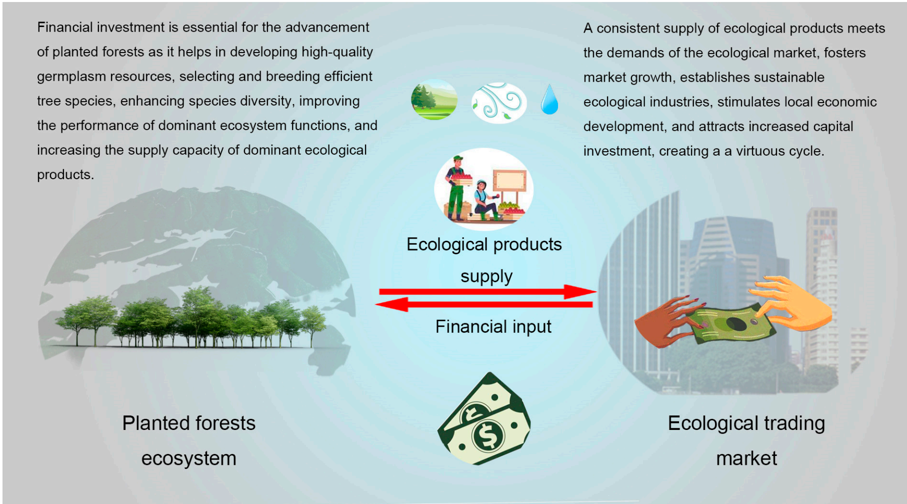

Figure 11. The eco-industrial cycle of ecological product value realisation for planted forests.

KDC forests consist mainly of planted forests and mountain closure forests. The planted forests have developed into various forest types, such as ecological forests and economic forests, in response to the needs of KDC and the influence of karst mountain landscapes. As a result, it is essential to diversify the mechanisms for EPVR. To address the current limitations in understanding this mechanism, it is crucial to explore standardized assessment methods, scientifically calculate ecological value-added premiums and establish an EI chain that encompasses the identification and classification of EP, value assessment, operational development, market trading and government-backed compensation. It should improve the mechanism for realising the value of EPs of planted forests in KDC regions and establish a model for realising the ecological value of forests.

(3) Aiming at the main problem of the lack of a long-term effective operation mechanism for ecological protection compensation, a stakeholder compensation mechanism should be proposed to realise the correspondence between protection and balance, leading to the study of improving the ecological compensation mechanism.

Ecological compensation is an important way to balance regional development and promote ecological protection and economic development. At the same time, ecological compensation also shoulders the important task of improving social welfare, changing the traditional production mode, adjusting the industrial structure and improving living standards. Therefore, the "blood transfusion" compensation should be changed to "blood creation" compensation [112]. In the development of ecological compensation, "who protects, who benefits" has been put into practice in some regions, while "who benefits, who compensates" has rarely been adopted [113]. Zhang et al. (2022) [114] studied the EP value realisation exploration of public goods in karst natural heritage sites and EP reserves, but their studies do not extend to eco-compensation studies of private attribute ecosystems such as economic forests. The research on ecological protection compensation needs to be improved urgently.

Because of their unique artificial attributes, the Eps of planted forests in KDC regions have resulted in fragmented property rights and ambiguous rights and responsibilities. The relationship between protection, benefit and compensation does not correspond to each other, and the compensation relationship is primarily vertical, making it difficult to form a virtuous circle. It is necessary to study diversified compensation mechanisms, including vertical and interprovincial horizontal compensation in the southern region and vertical and interprovincial horizontal compensation in the northern region, for planted forests in KDC areas. Scientific evaluations of the effectiveness of the implementation of compensation for ecological protection should be carried out, the scientific nature of compensation calculations should be further enhanced and standards for compensation for ecological protection should be determined, so as to achieve the goal of balancing protection and compensation.

4.2.4. Eco-Industry Formation

(1) Aiming at the main problem of the lack of organic connection between planted forests and EI development, scientific research, policy and economic inputs should be strengthened for the study of the mechanism of intrinsic linkage between planted forests and EI, to set up a model for guaranteeing the long-term development of EI.

Forest degradation caused by anthropogenic planted forests has damaged the structure and function of forest ecosystems and slowed down the process of sustainable forest development [115]. Since the beginning of the last century, China has implemented a series of large-scale planted forests and greening projects, and forest resources have been rapidly developed. However, there is a relative lack of research on the sustainable management of forest ecosystems, and there is an urgent need to explore how to achieve synergistic development of ecological resources restoration and ecological industrialization [116].

As a representative of ecological restoration in karst areas, the development of the forest industry in KDC planted forests also has the problem of organic connection. It is necessary to continue to strengthen the national investment in planted forests, to expand the ecological management results with scientific research and economic investment to consolidate the basis of EP supply and to elevate the protection of planted forests results to the level of arable land protection. It is necessary to strengthen the ecological management of planted forests, gradually reduce the situation in which the timber industry is the primary industry, increase investments in forestry, strengthen scientific forestry measures, standardise planted forests and forestation, improve the productivity and supply capacity of forest quality and forest EP and set up a model of long-term and healthy development of the EI for KDC and other ecological restoration areas.

(2) Aiming at the main problem that the main body responsible for forest EP is ambiguous and affects the formation of the EI chain, it is necessary to clarify the responsibility system, explore and improve the norms for realising the value of EP and guide decision-makers to correctly handle the relationship between various sectors, to form an EI that smoothly connects the upper and lower ports.

EI is the basis for realising the value of forest EPs. However, at present, the advantages and potentials of various regions are yet to be tapped, and there is a general lack of research on eco-industrialisation and industrial ecological economic systems, as well as a lack of market acceptance of EPs [117]. The formation of the forest EI requires a clear responsibility, but it also needs to improve the recognition of EPs to strengthen the stability of the industrial chain. Both the responsible body and the recognition of the product need government departments to act as the driving force and coordinate the joint efforts of various departments. With the public value of benefit-sharing, risk-sharing and full cooperation, diversified partnerships can be established with a single project or an overall "bundled" project in the region as a link.

China's KD areas have high mountains, steep slopes, fragmented land resources and decentralised smallholder business models, making it difficult to form an EI for planted forests; thus, exploring the main body responsible for EPs is the key to the development of the EI [118]. Both northern and southern KDC regions should, while clarifying the main body of responsibility, cultivate the consumer market for EPs, improve the recognition of EPs and guide and incentivise stakeholders to conduct transactions. However, northern KDC regions should also make excellent use of the advantages of enterprise development in the plains of the provinces, guide exchanges between the plains and mountain markets, form EI chains and allow KDC planted forests' EPs to produce and sell, to form a virtuous cycle of KDC.

4.2.5. Summary

The forest EPVR and the development of EI are particularly urgent at present, and economic, policy and social research is still insufficient in the literature of the forest sector [100]. However, research in the economic, policy and social aspects of the forest sector remains lacking, especially in KD regions. Many unresolved scientific questions persist in these regions, regarding the forest EPVR and EIs. Existing domestic and international research studies have not yet provided sufficient evidence to strongly support the EPVR and the protection of ecosystem integrity and functionality [22]. While many forests' EPs have high values per unit area, there remains a lack of models and pathways to fully realize the value of these EPs [71]. The current development of the forest industry continues to be primarily driven by decentralized farmer operations, which are unable to meet the market demand for large-scale and standardized production. As a result, true industrialization within the forest industry has not yet been achieved [119]. To sum up, the EPVR is hindered by challenges such as complex value assessment, limited supply, a lack of standardized accounting methods and inadequate research on value realization pathways. The development of the EI faces issues like unclear property rights in the forest industry, limited management experience among forest farmers and incomplete policies. Therefore, in the development of artificial forestation for KD regions, the above scientific problems and the ecological environment characteristics of KD areas should be taken into account, so as to make good preparations for basic research on property rights, value accounting, market soundness and supply enhancement of ecological products of artificial afforestation for KD, as well as to prolong the existing industrial chain, and to transform some traditional industrial modes into modernised, scaled-up and intensified modes of operation. Future research should further investigate these themes to enhance the promotion of planted forests, facilitate the implementation of KD control projects and achieve the harmonious development of ecological restoration and economic growth.

5. Conclusions

A good ecological environment is an important guarantee for the healthy development of the region. The planted forests formed in the process of KDC are an important support for the restoration of the ecological environment in the karst region. However, planted forests have played a solely ecological role for a long time. This has led to the lack of long-term guarantee for the economic development of KDC regions. It is difficult for residents to maintain their enthusiasm for planted forests and forest protection, and there is a risk that KD in karst areas will recur. Therefore, reviewing the research on forest EP and EI, and analyzing their inspiration in planted forests for KDC regions, can help enhance residents' interest in KDC areas to engage in planted forest development. This can contribute to preventing environmental degradation in KDC areas and promoting ecological restoration.

This paper systematically reviews the research lineage of the value realization of EPs and EI in planted forests of KDC regions, by analysing 265 pieces of literature, and draws the following conclusions: (1) the research started in 2001 and began to grow rapidly in 2016, with research divided into three stages, namely budding (2001–2006), fluctuating growth (2007–2015) and rapid development (2016–2023); (2) the regions with the most publications are Asia and North America, and the top three countries in terms of publications are China, the United States and Canada, accounting for 47.74%, 11.93% and 6.17% of the total number of publications, respectively; (3) the research results play a crucial role in addressing the challenges encountered by plantation forests in KDC areas. Key issues to be tackled for the sustainable development of plantation forests in KDC areas are highlighted, along with the following recommendations for resolving these issues: ① The low supply capacity of planted forests EPs in KDC regions and the lack of consumer recognition make it difficult to reach the level of conventional forest development. Drawing on the theory of nature management and using policy guidance and scientific and technological support to improve the supply capacity of EPs establishes the concept of EP recognition, and develops idle ecological resources to break through the dilemma of EI development. ② The method of accounting for the value of EPs does not match the accounting objectives, and a special value accounting method should be established, based on the geographical characteristics of karst and local parameters, and a special accounting method of value needs to be established that is based on the characteristics of the region and the local parameters. ③ the mechanism of realizing the EP value for planted forests is not sound, and the response relationship is unclear between the dominant ecosystem function and the EPVR efficiency. It is necessary to improve the operation mechanism and investigate, assess and identify the dominant ecosystem function, to guarantee the full realization of ecological value. ④ There is a lack of organic connection between ecological restoration and EI development in KDC areas, and the ecological protection compensation mechanism is not sound. The investment in artificial planted forests for KDC regions should be strengthened, the synergistic development mode of ecological restoration and EIs should be explored and the ecological compensation mechanism should be improved. In future research, it is important to establish an organic channel connecting EP recognition to the ecological restoration of the economy. This connection will improve the acknowledgment of ecosystem services, attract additional policy and financial investments, and accelerate the development of mechanisms for EPVR. By leveraging EPs and industries, we can drive economic development in ecological restoration, creating a positive cycle where ecological restoration fuels economic growth and economic development supports ecological restoration.

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