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Review

To Achieve a Win–Win Situation: Reorganizing and Enhancing Agroforestry Ecosystem Assets and Productivity to Inform Karst Desertification Control

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Abstract: The ongoing degradation of fragile ecosystems increasingly diminishes the availability of natural resources. Consequently, the conservation and utilization of ecosystem assets have emerged as a focal point of global research. This study focuses on integrating agroforestry ecosystem assets (AEA) with their capacity to provide ecosystem services, aiming to explore their interconnections and enhance their optimization. We employed a comprehensive literature review method, utilizing the Scopus database to select, analyze, and include 61 pertinent studies on AEA globally. The systematic literature review results show the following: (1) The overall number of published papers is showing an upward trend, indicating that research in this field is gradually expanding. The geographical focus of the literature is primarily in Europe and Asia, with academic institutions being the main contributors to this research. (2) Landmark research findings are mainly concentrated in the areas of identification, quantitative assessment, and decision management. Among these, quantitative assessment is the main focus, while the research on identification, decision management, and influencing factors is relatively limited and explores the relevant key scientific questions. (3) The above information highlights the key areas for improvement in the karst desertification control agroforestry ecosystem, focusing on two aspects: fragile habitats and human–land relationships. Furthermore, this review furnishes essential recommendations for agroforestry practitioners and policymakers across various regions, emphasizing the critical need to thoroughly evaluate and leverage the connections between the quantity and quality of ecosystem assets. Such an approach is pivotal for facilitating the strategic restructuring and optimization of agroforestry ecosystems. This, in turn, aims to elevate the sustainability of AEA utilization and enhance their ability to provide ecosystem services (ES).

Keywords: agroforestry; natural capital; supply capacity; systematic review; ecosystem services

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1. Introduction

Ecosystems constitute the fundamental basis for human survival and play a pivotal role in underpinning sustainable economic and social progress. They offer an array of ecosystem services, both direct and indirect, that are vital to human society's advancement [1–3]. Nonetheless, to accommodate the demands of population expansion, agricultural intensification, and societal progress, there has been a global over-exploitation of natural resources provided by ecosystems, including forests, grasslands, and wetlands. This exploitation has led to substantial adverse effects on ecosystems [4–6]. Essentially, these challenges stem from irrational social production activities that exploit and deplete ecosystems beyond their capacity to replenish resources, including goods and services provision [7–10]. Consequently, the resource status of numerous ecosystems, such as agroforestry systems, has been overlooked in terms of species composition, structure, functioning [11,12], and environmental conditions, indicating not only the loss and degradation of ecosystem asset stocks due to environmental disturbances but also impacting the quantity and quality of these ecosystems' asset stocks in goods and services provision. Quantitative impacts result in reduced resource quantity, evidenced by diminished vegetation area and species count, whereas qualitative impacts entail degraded resource quality, including soil deterioration and biodiversity loss [13,14]. The concept of restructuring, derived from resource allocation and circular economy theories, seeks to enhance resource use efficiency by rational allocation and integration of existing resources. It emphasizes the reorganization of ecosystem asset stocks and optimally boosting their productive capacity to achieve sustainable utilization levels and sustain ecological goods and services provision [15–17]. Nonetheless, while research in this field is deepening [18–23], there remains a gap in understanding the correlation between the extent of asset restructuring and sustainable utilization levels. While a variety of studies have underscored the importance of ecosystem assets from multiple perspectives [19,21,24–27], examining both the threats of degradation and the viability of management strategies, the methodologies for reorganizing these assets are still not thoroughly investigated [28–33]. Addressing this gap, particularly in enhancing their capacity to provide ES, is an urgent area of focus.

Ecosystem assets, encompassing natural elements such as ecosystems, species, freshwater, land, minerals, air, and oceans, directly or indirectly generate value for humans [34,35]. These assets include both biotic components (living organisms and organic material like leaf litter) and abiotic components (such as rocks, minerals, air, water), which collectively facilitate essential ES for human well-being. Often, these services require additional inputs from social, human, financial, or manufactured capital assets [36–38]. Ecosystem assets, integral as natural resources, contribute to the production of ecological goods. In desertified regions, however, the interplay between ecosystem assets and services may be suboptimal. For instance, in karst regions, desertification is caused by irrational human economic activities, which lead to the destruction of vegetation and soil erosion, thus exposing rocks and decreasing land productivity, resulting in a desert-like landscape [39]. This process underscores the conflict between humanity and the natural environment [40]. Despite the emphasis on karst desertification (KD) and subsequent ecological restoration efforts [41–45], the semi-natural ecosystems emerging post-restoration lack effective management, policy support, and sustainability [46,47]. This deficiency hampers the livelihoods of local farmers, leading to constrained exploitation of ecosystem assets for conservation and inadequate maintenance of their service provisioning capacities [48,49]. Fundamentally, this scenario reflects an absence of necessary reorganizing ecosystem assets to facilitate optimal asset allocation, thereby hindering the enhancement of ecosystem service provision in KD areas.

Agroforestry, an ecological restoration management approach, offers an effective solution for smallholder farmers facing contemporary environmental challenges. It constitutes a sustainable land use system that combines various components such as woody perennial plants, crops, and livestock breeding on a single land unit [50–53]. This semi-natural ecosystem, blending ecological and social attributes, provides a novel framework for optimizing the ecosystem asset inventory and enhancing the capacity for ecosystem service provision. In comparison to other semi-natural ecosystems in rock desertification control areas, such as artificial economic forests and grasslands, agroforestry systems not only improve and protect the ecological environment but also concurrently bolster food production and sustainable economic growth. This synergy results in the harmonization of ecological, economic, and social benefits [54]. Agroforestry is lauded as a 'win–win' approach. Well-designed agroforestry systems fulfill the requirements for food, fiber, and fuel production while also restoring and augmenting the stock of ecosystem assets, consequently boosting the provision of various ES, including carbon fixation and biodiversity conservation [55–60]. Hence, these multifunctional agroforestry ecosystems, geared towards the realization of multiple ES, present a more viable marginal land use model, particularly suitable for scaling up in karst desertification areas.

Researchers and policymakers are unanimously optimistic about the potential of agroforestry in achieving a balance between ecological restoration and socio-economic development in desertification control areas [61,62]. Extensive research has been conducted in this field, with a particular emphasis on utilizing agroforestry as an ecological restoration strategy in managing karst desertification. This approach involves developing agroforestry tailored to local conditions and establishing a sustainable, ecologically and socially harmonious agroforestry industry [63,64]. This strategy has proven to be an effective model for the comprehensive management of karst desertification. Studies have shown that the implementation of agroforestry in such areas not only significantly mitigates soil erosion [65] but also enhances the economic and ecological benefits of the region [66]. However, the tasks of ecosystem asset restructuring and enhancing service provision capacity present more complex challenges in these regions. These challenges encompass the effectiveness and sustainability of converting ecological resources into economic resources, especially in ecologically fragile zones like KD areas.

Current research in AEA has laid a crucial foundation for discussing their reorganizing and enhancing service provisioning capacity. This research primarily includes the following: assessing the value of individual service functions and overall ES from a flow perspective [67–69]; comparing the outputs and revenues of agroforestry systems with those of other forestry sectors; and refining the 'agroforestry accounting system' through comparisons with other forestry economic accounts [70]. Additionally, analyses have been conducted on the contribution of agroforestry systems to farmers' economic income, compared to single agro-ecosystems [71,72]. While the primary goal of these studies is to support and motivate farmers to adopt agroforestry practices and expand ecosystem accounting in the SEEA framework, they also aim to develop an effective methodology for public service accounting, establish a comprehensive account system for ecological assets (encompassing both stocks and flows), and assess the sustainability of agroforestry systems [73,74]. However, a systematic overview addressing the research advancements and critical scientific challenges in restructuring AEA for improved service provisioning capacity is lacking. To address this knowledge gap, we utilize the Systematic Literature Review (SLR) framework to thoroughly review global research progress and significant findings in agroforestry ecological assets. We aim to highlight the urgent scientific issues, shed light on research pertaining to the management of karst desertification control in agroforestry ecosystems, and strengthen our understanding of these assets. Our work provides vital insights for enhancing ecosystem assets and service provisioning capacity in globally fragile ecological areas, contributing to a synergistic relationship between agroforestry and ES. This endeavor offers reliable and necessary developmental pathways for improving local ecosystems in areas with weak KD, ultimately fostering sustainable socio-economic development.

2. Methodology

This paper employs qualitative content analysis through Systematic Literature Review (SLR) [75], defined as a systematic, explicit, and reproducible method for identifying, evaluating, and synthesizing the existing body of work by researchers, scholars, and practitioners. Initially developed in the healthcare field, SLR offers a comprehensive and accurate understanding, surpassing traditional literature review methods in terms of transparency and comprehensiveness. It has been widely adopted in various fields, including conservation and environmental management [76,77], due to its ability to provide a more nuanced and accurate level of insight. Its robustness, independence, and reproducibility ensure the reliability and validity of research findings. The SLR methodology is particularly advantageous in systematically evaluating and providing science-based knowledge from available evidence. In this study, we utilize SLR to methodically gather and analyze publications pertinent to the ecological assets of agroforestry. The framework for this study is delineated as follows:

Protocol: This entails defining the study's scope and objectives.

Search: The strategy includes developing a comprehensive search plan, determining precise search phrases, and selecting appropriate databases.

Assessment: This stage involves a rigorous quality assessment of the literature sourced, establishing criteria for the inclusion and exclusion based on quality.

Synthesis: It encompasses data extraction, quantitative categorization and description of results, and a summary of key advancements and milestones.

2.1. Protocol Development

Before initiating the search in the Scopus database, a detailed protocol was established to ensure a systematic literature review (SLR) characterized by transparency, transferability, and replicability. The most crucial step in this protocol development was defining the review's purpose, which facilitated the formulation of specific, answerable research questions and established the scope of the research. The refined research questions addressed in this study are as follows: (1) What is the year of publication and regional distribution? (2) Which research topics are most and least prevalent? (3) What are the major advances and landmark results in existing research? (4) What key future scientific questions need addressing? (5) What insights will AEA gain from participating in improving KDC governance ecosystems? This study endeavors to answer these questions utilizing the Systematic Literature Review (SLR) methodology.

2.2. Literature Search Sources

Literature sources were selected from the comprehensive database of SCOPUS, with the search encompassing all available records up to November 2023. Scopus, recognized as the world's most extensive database, encompasses abstracts and citations from peer-reviewed literature [78]. It boasts a vast collection of research that spans multiple subject areas and has a global reach. The database is renowned for its high-quality indexing, reviewing, and classification methods, making it an ideal resource for conducting literature reviews and meta-analysis studies. However, it is important to note that SCOPUS does not encompass grey literature. This paper aims to provide a systematic review of the research advancements and seminal findings related to the ecological assets of global agroforestry ecosystems. Based on this review, it will inform the research on agroforestry ecosystem assets in the management of karst desertification. Accordingly, the term 'karst' is not included as a keyword. The search parameters included article titles, abstracts, and keywords.

The scope of the search achieved is as follows:

-title, keywords, abstract:

○ ("agroforestry" or "agrosilvopastoral")

○ and ("natural capital" or "assets" or "ecosystem services")

The search yielded 1378 articles published in scientific journals, after excluding duplicates and retractions.

2.3. Publication Selection Criteria

The 1378 documents retrieved from the search engine were screened following the procedure outlined in Figure 1 for the systematic literature review. The screening criteria varied at each stage. Additionally, inclusion and exclusion criteria were applied to the initial search results, and papers meeting the inclusion criteria were selected for further review and content assessment. The methods were screened based on the following criteria:

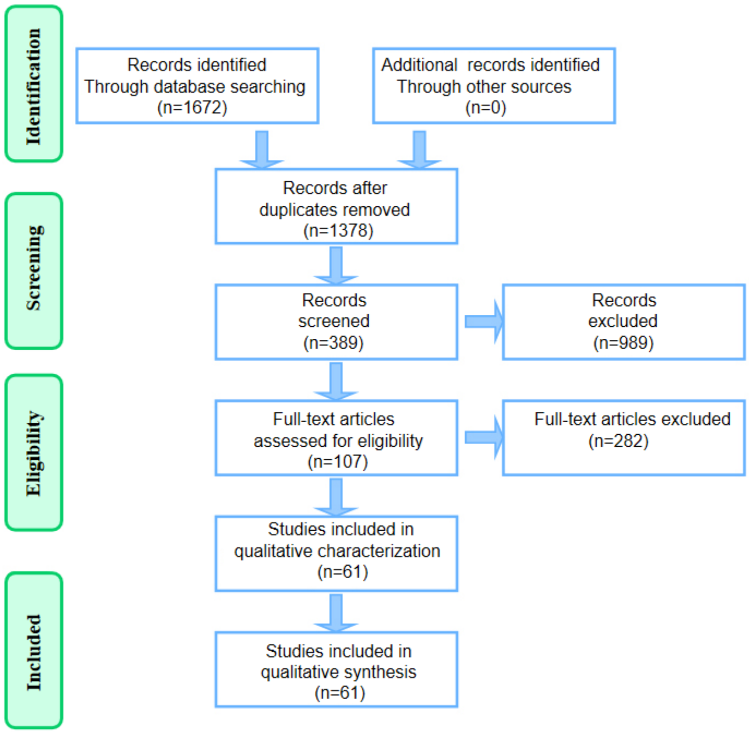

Figure 1. Systematic mapping process of the study.

Initially, a comprehensive screening of the literature was conducted to identify and remove duplicates, resulting in a collection of 1378 relevant papers.

Subsequently, a review based on the titles, abstracts, and keywords of the literature was carried out, leading to the elimination of documents with low relevance to the themes of reorganizing and service provision research.

Furthermore, the literature retained after the initial screening underwent a comprehensive review to ensure that it included at least one study related to AEA. This review process involved verifying the following criteria: (1) the presence of predefined keywords, either throughout the publication or specifically in the title, keywords, or abstract; (2) inclusion of the publication in the Scopus database; and (3) coverage of relevant AEA topics within the publication's content. This thorough assessment was crucial for determining eligibility.

Ultimately, after three rounds of rigorous screening, 61 articles were identified as highly pertinent to the study's focus and were selected for the final sample.

2.4. Synthesis Report

This phase involved extracting and categorizing key variables from the 61 selected scientific publications, a process essential for synthesizing knowledge and drawing conclusions. As a consequence of persistent resource exploitation driven by economic development and population growth, ecological degradation has resulted in reductions in both the extent of ecosystems and the quality of their ecological features. This, in turn, has led to a progressively constrained capacity for providing ES [79–82]. Current research on agroforestry ecological assets tends to focus more on the quantitative valuation of these assets rather than on their stock (both in quantity and quality) and the resultant capacity to deliver ES [32]. Therefore, we argue that there is a need to reorganize the stock of agroforestry ecological assets to enhance both their quality and quantity, aiming to alleviate the limited supply of agroforestry ecosystem services (AES). Based on AEA research, we identified four main areas of interest: identification, quantitative assessment, decision management, and impact factors. These areas are interrelated and collectively influence the sustainability of ecological assets. The integration of these aspects—identification, quantitative assessment, impact analysis, and decision management—is pivotal for the sustainability of ecosystem assets. Accurate identification is central to ecological asset management, providing a foundation for further assessment and management. Through quantitative assessment, the non-market value of ecosystems is transformed into measurable data, aiding policymakers and managers in developing effective strategies. Moreover, the decision making and management aspect is crucial for the sustainable utilization of ecological assets. A comprehensive understanding of the factors influencing adversely affect these assets. To clarify the results of these analyses, we present them separately in Section 3.

3. Results

3.1. Annual Distribution and Research Contents of the Literature

Figure 2 illustrates the distribution of the amount of research on ecosystem assets published between 2001 and 2023. Research in this area began in 2001, coinciding with the publication of key papers such as Costanza et al.'s (1997) work on the classification and valuation of ES [83], which contributed to the increase in research on AEA. Over time, the amount of research dealing with agroforestry ecosystem assets has experienced fluctuating growth. In particular, after 2016, the amount of research in the literature increased significantly as researchers emphasized the importance of ecosystem assets [84], and the number of studies peaked in 2020 (n = 12), reflecting the development of the field in close relation to the importance of ecosystem services.

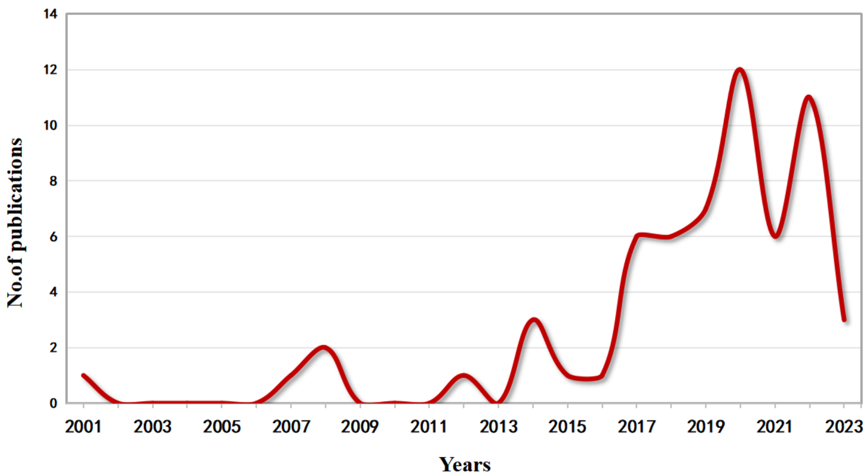

Figure 2. Annual distribution of the literature.

The history of the development of research on agroforestry ecological assets can be divided into two main phases, and the number of publications has shown a fluctuating increase over time. The initial phase, termed the 'budding period' (2001–2010), primarily concentrated on the singular ecosystem service of agroforestry. This period was marked by a relative homogeneity in research content, likely attributable to the absence of standardized assessment criteria and diverse evaluation methodologies, coupled with the inherent complexity and conceptual vagueness of ecological assets. This resulted in limited academic discourse on agroforestry ecological assets prior to 2010. Subsequently, TEEB (2010) [84] emphasized the importance of biodiversity and specifically categorized ecological services. In this framework, support services are regarded as ecological processes, while habitat services are seen as an adjunct concept. This categorization underscores the criticality of ecosystem assets, accentuating the pivotal role of ecological processes and habitats in sustaining biodiversity and ecological equilibrium. Consequently, the focus on agroforestry ecosystem assets has intensified, propelling research into a phase of accelerated advancement. This latter phase witnessed extensive attention and detailed exploration of agroforestry ecological assets. Research extends beyond monitoring and assessing ecological assets to include developing, applying, and refining ecological asset accounting systems, which support decision-making and management processes. Consequently, the research content has become more diverse and profound. Despite a late start, the research on agroforestry ecological assets has shown considerable progress over time, with significant advancements particularly in the last decade.

To identify prominent research themes, we employed visualization techniques for word frequency analysis (https://www.weiciyun.com (accessed on 23 November 2023)). By analyzing the titles and keywords of selected articles, a word cloud was generated to highlight key areas in Agroforestry Ecosystem Asset (AEA) research. As shown in Figure 3, excluding the subjective effects of the previous literature search, words such as agroforestry, ecosystem service, environmental asset, accounting, etc., as well as carbon, land use, change, economic value, total income, and related topics, have emerged as prominent themes in AEA research, constituting the primary focus of study. The next hot topics are sustainable agriculture, crazing, benefit, management, Landsat, and so on.

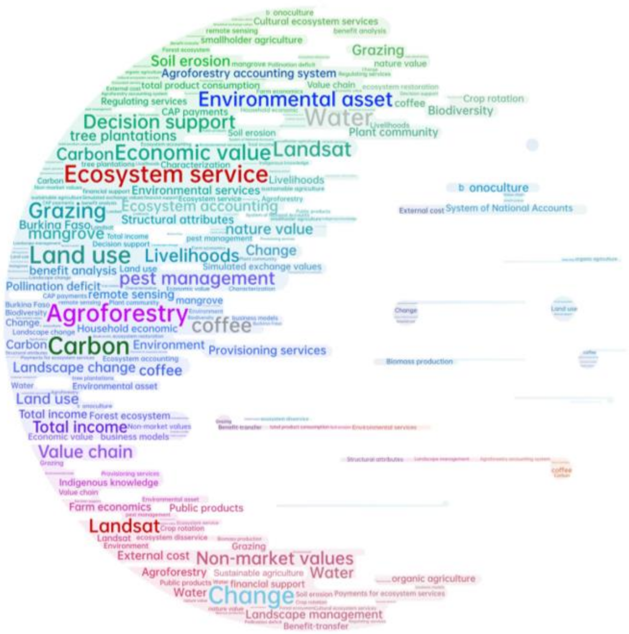

Figure 3. Word cloud visualization.

3.2. Distribution of Publications by Country and Organization

Figure 4 (below) illustrates the geographical and institutional distribution of Agroforestry Ecological Asset Assessment (AEA) research globally. Globally, AEA research exhibits significant regional imbalances and distinct characteristics. In Europe, countries such as Spain, France, Germany, the UK, and Italy dominate with the highest number of publications; in Asia, the main representative countries include China and India; in Africa, Kenya dominates; in North America, Mexico and Costa Rica have a high number of publications; in South America, Brazil is the main representative, and in Oceania, Australia is the most prominent in terms of the number of publications. Overall, Europe leads in publications, followed by Asia, Africa, and North America, with Oceania and South America having fewer publications. The color scale depicted in the graph corresponds to the quantity of distinct articles, with values extending from 0 to 16 articles. Progressing from left to right, the scale transitions from dark blue, denoting a smaller article count, to dark red, signifying a larger compilation of articles.

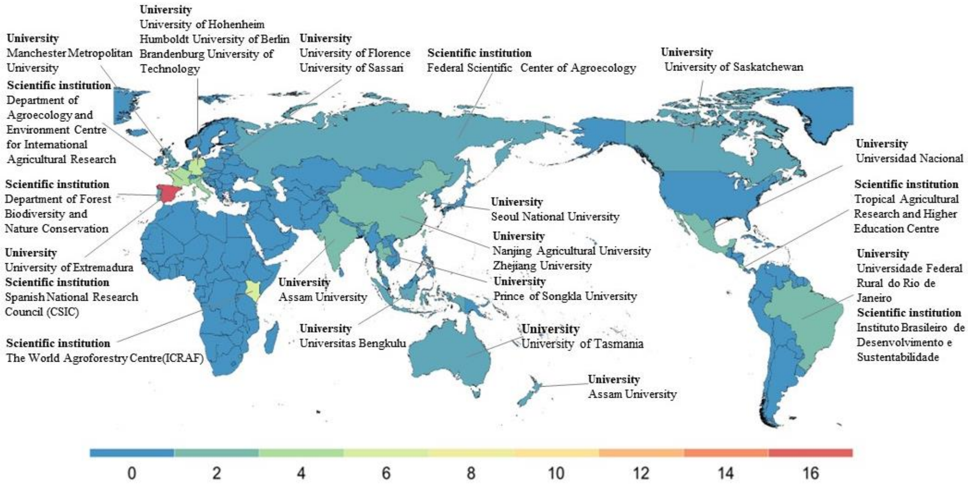

Figure 4. Regional distribution of the literature (the different-colored bands and numbers at the bottom indicate the number of publications; the redder the color, the higher the number of publications).

The global development of agroforestry is markedly uneven, displaying pronounced geographical distinctions. This disparity is primarily due to the varying degrees of emphasis placed on agroforestry ecological assets and the diverse natural socio-economic conditions prevalent in different regions. Notably, while agroforestry is more advanced in tropical areas, research enthusiasm in these regions lags behind that in temperate zones. This phenomenon stems not just from regional disparities in natural economic conditions and societal contexts, but also from the varying degrees of national policy support and institutional focus on research [85,86]. For instance, in Europe, agroforestry has garnered substantial support through the Common Agricultural Policy (CAP), which includes grants and subsidies. The European Union (EU) allocates financial assistance for restoring or developing new agroforestry ecosystems [87,88], thereby intensifying research efforts and publication output in this domain. In contrast, Asian countries, particularly developing nations like China and India, face more pronounced conflicts between resources, environment, and population, exacerbated by the drastic reduction in arable land and population surges. These regions are increasingly recognizing the critical role of efficient agroforestry composite ecosystems in achieving sustainable agricultural development on limited arable land, while preserving environmental quality [89–91]. Consequently, there is an increasing focus on the integrated benefits of agroforestry assets. In contrast, only 10% of articles in this field were published in Africa and 11% in North America, with even fewer publications in Oceania and South America. Overall, the substantial regional variations in agroforestry development are a result of a complex interplay of multiple factors, including natural elements (climate, topography, water, soil), social aspects (preferences, incentives, risks), economic conditions, and policy frameworks. In-depth study and understanding of these multifaceted factors are crucial for explaining and addressing the regional discrepancies in agroforestry development.

3.3. Distribution of Research Content of Publications

The 61 papers reviewed were classified into four main categories as depicted in Figure 5: identification, quantitative assessment, management strategies, and influencing factors. We used Hiplot (https://hiplot.com.cn, accessed 25 November 2023) for the visual presentation of the study content. Of these, 39% (24 articles) pertained to the quantitative assessment of agroforestry ecological assets; 36% (22 articles) to decision making and management studies; 18% (11 articles) to influencing factors; and only 7% (4 articles) to identification. This classification underpins the discussion of the current state of research and major milestones in Section 3.4 of the Results.

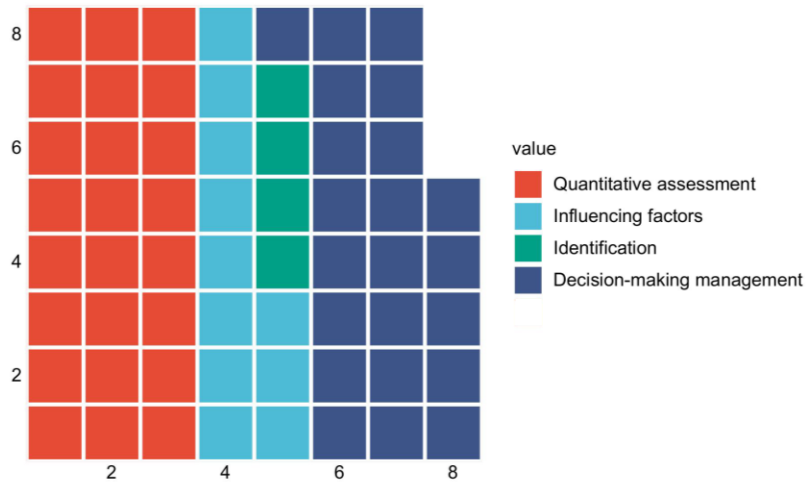

Figure 5. Research content division.

The field of ecosystem services has witnessed significant growth in recent decades. Since 1990, the volume of research papers in this domain has steadily increased. In particular, after 2000, with the publication of seminal studies by Costanza et al. (1997) [83] and Daily et al. (1997) [92], the field garnered widespread attention. Ecosystem services have emerged as a crucial area of current research, aligning with the expanded understanding of agroforestry. This research progress reflects the reconfiguration of agroforestry ecosystem assets and the augmentation of ecosystem service provisioning capacity. Our analysis suggests that achieving this restructuring requires several key steps: accurate identification of ecosystem assets through monitoring techniques to assess the scope and condition of ecosystem asset stocks in agroforestry, quantitative assessment methods for agroforestry ecosystem assets, analysis of the restructuring and management of ecosystem asset stocks through decision-making and management strategies to enhance service provisioning capacity, and an examination of the influencing factors affecting the restructuring and capacity enhancement. In the following sections, we will summarize these developments and significant results.

3.3.1. Identification

SEEA EEA [93] describes ecosystem condition as a characteristic of ecosystem assets, along with ecosystem extent. In another way, ecosystem extent reflects the quantity of the asset, while ecosystem condition reflects the quality of the asset. Therefore, the current identification of AEA including analyses of ecosystem extent and condition is carried out with both field surveys and remote sensing techniques. Field surveys primarily involve sample plot surveys, biodiversity monitoring, and environmental quality measurement to ascertain and monitor the condition of agroforestry ecosystems. This traditional, human-based approach to vegetation surveying allows for direct observation and detailed measurement of various ecosystem characteristics, yielding accurate and comprehensive data. Such data include vegetation type, tree height, diameter at breast height, planting density, and soil type, among others. Longitudinal and systematic vegetation surveys offer insights into spatial distribution and species composition of vegetation. They are instrumental in detecting changes in ecosystem areas and quality, thereby serving a pivotal role in the assessment of agroforestry ecosystem conditions [94]. This, in turn, lays a foundational basis for the reorganization of ecological assets and enhancement of ecosystem service capacities, furthering sustainable management and ecological conservation objectives. Field surveys also capture critical details unattainable through remote sensing, such as vegetation structure, species diversity, and ecological processes. Identifying ecosystem assets through large-scale vegetation surveys poses significant challenges, including variable field conditions, complex terrains, and resource constraints, rendering these surveys less cost-effective for comprehensive ecosystem asset identification. Despite these limitations, the high-resolution capability of such surveys is critical for the effective reorganization of AEA.

In contrast to field surveys, researchers have utilized the advantages of remote sensing technology such as high timeliness, wide range, multi-resolution, low cost, and large amount of information to delineate the extent of Agroforestry ecosystems globally [95]. Whereas Ahmad et al. (2016) [96] and Vikrant et al. (2018) [97] utilized remote sensing and GIS techniques to achieve estimations of the large-scale Ludhiana region of India and the Tehri region of northwestern Indian Himalaya agroforestry area, aiming to understand the status and utilization of agroforestry resources in the region. Furthermore, remote sensing images were used to decipher and map regional agroforestry resources, forming the foundation for developing land use, forest protection, and other related policies. This is critically important for the scientific management of agroforestry resources and the strategic reorganization of agroforestry ecological assets towards sustainable development. The application of remote sensing technology for an in-depth quantitative assessment of agroforestry ecosystems is therefore essential. Its benefits, such as high timeliness, wide coverage, diverse resolution options, cost-effectiveness, and extensive data, provide substantial support for large-scale, accurate monitoring and evaluation of agroforestry ecosystem conditions. This assessment is crucial not only for the effective reorganization and optimization of ecological resources but also holds significant value in managing and capitalizing ecological assets and enhancing the alignment between regional resources and the ecological environment. Furthermore, remote sensing technology lays a robust foundation for future trend analysis and predictive modeling of ecological assets, ensuring that ecosystem provisioning capacity and service levels can meet future demands.

3.3.2. Quantitative Assessments

Quantification of the stock of AEA and the ES they produce is a prerequisite for their assessment [98]. Initially, quantifying the quantity of these assets involves analyzing changes in their spatial extent. This analysis facilitates the identification of ecosystem trends, such as degradation or restoration, through temporal comparisons of area data. Secondly, qualitative assessments emphasize biomass density, a crucial measure of the total organisms per unit area, indicative of the productivity and health of ecological assets. Monitoring biomass density over time facilitates the tracking of changes in the health of agroforestry ecosystems, including aspects like ecological degradation, biodiversity shifts, or ecosystem recovery. Building upon these evaluations, it is vital to further quantify the ES provided by these assets, encompassing functions like carbon sequestration, water retention, and soil conservation.

At the landscape scale, the majority of quantitative assessments of AEA depend on secondary data or spatial proxies, primarily derived from topographic or land use/land cover (LULC) datasets [67,99–101]. Although LULC-based estimates are suitable for broad, rapid assessments over large areas, they frequently lack precision in fine-scale analysis, like at the farm level, owing to the limited resolution of LULC data. This limitation can result in overlooking the actual spatial variability inherent in biophysical measurements of ES [102]. This limitation can compromise the precision of ecosystem assessments. At a more detailed scale, quantifying AES necessitates finer-resolution models and tools (e.g., Invest, APSIM, LUCI) [103–105], as service provision is closely linked to ecosystem conditions, including vegetation structure and composition. In particular, Invest can be used to quantify various dimensions of AES, such as timber production, carbon sequestration, biodiversity, pollination, and recreation. Its primary strength lies in integrating biophysical data with economic analyses for a comprehensive assessment of ES. However, the high data demands and computational intensity of Invest have limited its widespread use in valuing AEA. In contrast, APSIM's primary advantages include its modular and flexible design and its broad applicability, encompassing detailed modeling of agroforestry ecosystems, agricultural production, and simulations of complex carbon and nitrogen cycles in the subsurface. This versatility partly addresses Invest's limitations in capturing intricate ecosystem dynamics and processes. APSIM has gained international recognition, particularly in Australia, for modeling crop biomass, grain production, rangeland, and livestock productivity, among other uses. Despite its extensive application in agroforestry ecosystems, the simulation capabilities for trees, various crop types, pastures, and livestock in APSIM remain somewhat constrained. The third tool, LUCI, known for its straightforward algorithms and clear communication, plays a significant role in contemporary research. LUCI is primarily focused on quantifying ecosystem service trade-offs and is adaptable for use across various scales. It is effective in assessing both the supply and demand of AES at local, regional, and global levels. This approach aids decision makers in understanding the variability of ES across different geographic contexts, making it highly suitable for engagement with policymakers and stakeholders, including local governments and community-level resource managers. LUCI's application significantly supports policymaking and planning, assisting governments in formulating land use policies, ecological conservation strategies, and sustainable development frameworks for the effective management and preservation of agroforestry ecosystems. Additionally, certain tools are region-specific. For example, the 'i-Tree' online toolkit [106], developed by the USDA Forest Service, provides a range of models. However, the i-Tree suite is tailored specifically for North America, limiting its direct applicability in other regions. Its primary function is to estimate diverse ES provided by trees, such as pollution reduction, public health improvement, and carbon sequestration, using tree physical characteristics (e.g., diameter at breast height (DBH), species, total height) and environmental and locational factors. These tools and models, considering a broader array of local ecological inputs than secondary data or spatial proxy-based methods, offer greater reliability for detailed assessments of agroforestry ecosystems.

3.3.3. Decision-Making Management

Decision making in the management of ecological assets involves the process of protecting and restoring ecosystems, aimed at augmenting ecosystem service provision and achieving sustainable development across ecological, economic, and social dimensions. Decision management is particularly concerned with the management and sustainability enhancement of agroforestry assets. This entails evaluating and choosing the most valuable option from various alternatives to guarantee the long-term health and productivity of ecosystems. Valuation is inevitable and central to the decision-making process. For instance, Gianni so Poulos et al. [107] conducted a comparative valuation of agroforestry systems against farming and tree-based systems, underscoring the high economic value of agroforestry. This comparison aimed to encourage governments and managers to expand agroforestry acreage. Additionally, quantifying the social value of environmental benefits in such studies aids governments and other entities in establishing regulations or incentives that promote better farm management decisions. Sustainable agroforestry systems can be established in rural areas through the implementation of nitrogen-fixing woody plants within short-rotation propagation management strategies. These systems enhance biomass production and effectively ameliorate soil properties. For instance, Fernández et al. [108] developed an agroforestry system using nitrogen-fixing woody plants and Leucaena across two plots with comparable soil physicochemical characteristics, conducting periodic monitoring over a year. Their findings revealed that short-rotation propagation of nitrogen-fixing woody plants markedly improved biomass productivity and contributed to the rehabilitation of degraded soils.

Sustainability considerations require not only focusing on the value of the services they generate, but also tracking the condition of agroforestry assets to inform investment and operational decisions. The state of these assets plays a crucial role in decision making regarding ecosystem assets, especially in evaluating expenditure alternatives. This is vital to ensure that benefits extend beyond the immediate recipients, including future generations. Currently, three frameworks are available for tracking variations in the extent, condition, and monetary value of ecosystem assets over time within a specified spatial domain. The first, SEEA-EEA [109], stands out for providing time-series data, enabling the observation of changes in natural assets across temporal scales. Such data are essential for comprehending and managing the sustainability of natural resources. For example, the Wentworth Group's 'natural accounting' approach, currently adapted for farm-scale use [110] concentrates on developing 'asset condition accounts'. Another significant framework is the 'Ecological Balance Sheet' (EBS), notable for integrating natural capital accounts into existing accounting systems, thus facilitating the simultaneous tracking of financial and environmental performance [111]. This approach not only addresses the limitations of the SEEA-EEA framework in incorporating the economic value of ecological assets into standard accounting practices but also underscores the importance of merging economic and environmental data. Among the forefront of current research is the Agroforestry Accounting System (AAS) [112,113], which stands out by offering a comprehensive valuation framework. This framework includes the quantification of ecological services and the assessment of revenues from both market and non-market products, thereby advancing the field of ecological asset management. These frameworks enhance informed decision making by offering comprehensive insights into the status and worth of natural assets. The integration of financial and ecological data within these frameworks yields a holistic view, crucial for balancing economic development with environmental conservation.

3.3.4. Influencing Factors

Developing and executing scientifically sound and rational management strategies for AEA requires not only a robust monitoring system but also an understanding of the key drivers behind their long-term maintenance. Research has indicated that natural factors like climate, soil, topography, elevation, and slope significantly influence the provision of AES. Simultaneously, the impact of human factors on the supply of these services to AEA has also been examined.

Concerning natural factors, the influence of frequent extreme climatic events, including unusual and erratic rainfall, extended droughts, and significant diurnal temperature variations, profoundly impacts plant growth, soil fertility, and pest and disease prevalence in agroforestry systems [114]. These factors consequently affect both the quantity and quality of AEA, along with their capability to provide ES. In the global tropics, regions predominantly cultivating coffee, climate change and habitat loss disrupt the ecological balance [115]. Specifically, climate change heightens the risk of terrestrial bird species' extinction [116], significantly impacting the biodiversity vital for pollination services. For instance, in her study, A Chain-Guadarrama (2019) [117] explored those environmental changes such as increased temperatures and altered precipitation patterns with climate change affect pollination vectors such as bees and birds. They experience fluctuations such as population migration, reduction in numbers, and changes in activity patterns. Such fluctuations mean that the loss of pollinating insect diversity will not only further affect coffee fruit set and quality, but will also lead to a decrease in the asset species composition and pollination efficiency of the overall AF. Such changes not only threaten coffee production, but also have long-term impacts on biodiversity and overall ecosystem health [118–121].

Secondly, the delivery of ES is intricately linked to the health of ecological assets, such as vegetation structure and composition. Additionally, environmental conditions like hydrothermal variations, topographic landscape differences, soil quality, and slope orientations play a crucial role in determining the quality of agroforestry's ecological assets [122]. For instance, Mokondoko et al. (2022) [123,124] discovered that both temperature and precipitation negatively impact pest and disease control in coffee agroforestry systems, with increased incidence at higher altitudes and rainfall levels. As research continues to expand, some scholars have integrated climate, topography, elevation, slope, and other characteristics to explore the drivers of ecological assets in agroforestry ecosystems [124,125]. This research has established that these assets are influenced not by a single element, but by myriad natural environmental factors. Significantly, studies have delved into the factors driving biodiversity within agroforestry ecological assets [126,127]. For instance, in cocoa agroforestry systems, the presence of ant colonies underscores their crucial role in these ecosystems [128,129]. These ants not only provide essential ecological services like pest control but also the diversity within ant communities positively impacts cocoa yields, thereby boosting the ecosystem's food supply services. Such observations underscore the intricate relationship between environmental variables and biodiversity in agroforestry ecosystems, notably affecting crop yield and quality.

Regarding anthropogenic interference, the influence of human activities on agroforestry ecological assets primarily lies in management practices and species selection. To meet survival needs and achieve economic gains, human exploitation of these assets frequently results in varying levels of damage and degradation to agroforestry ecosystems. This, in turn, compromises the sustainable utilization of ecological assets and diminishes their service-providing capacity [130–132]. As a response, various management approaches have been implemented to rehabilitate and enhance the service functions of agroforestry ecosystems. The provision of ES in agroforestry is profoundly affected by elements such as shade cover and the management of plant density, a fact substantiated by extensive research. Shade cover, in particular, plays a pivotal role in preserving high ecosystem service levels by boosting surface carbon storage, biomass, overall species diversity, and pollinator abundance, alongside improving soil moisture, water content, and infiltration [133–135]. The management of plant density not only influences water infiltration and availability but also inversely affects pollinator richness, with higher densities typically resulting in lower richness [136]. Furthermore, the composition and age of tree species critically determine the biodiversity and ecological functionality of agroforestry ecosystems [124].

Secondly, human activities have exerted significant ecological pressure on species composition and agroforestry ecosystem processes, thereby affecting the quality and supply capacity of ecological assets such as food, medicine, and materials. Research indicates that the selection and distribution of species are critical determinants of both structural features and the ES rendered by agroforestry assets. Variations in growth rates, life cycles, tree heights, and canopy morphologies among different species markedly influence the development and progression of agroforestry ecosystem structures [137]. Take, for instance, small-scale coffee agroforestry systems, where the implementation of intercropping legumes with coffee creates a synergistic ecological effect that enhances both the quality and quantity of ecological assets [138,139]. The symbiosis between legumes and rhizobia facilitates atmospheric nitrogen fixation, while their extensive foliage provides essential shade for coffee plants, crucial for improving coffee growth quality. This synergistic relationship not only boosts the ecological service provision of the coffee agroforestry system but also significantly elevates the overall value of the ecological assets within the system.

In conclusion, comprehending how both natural and anthropogenic factors influence AEA is crucial for sustainable resource management and the provision of ES. Therefore, considering both natural and human factors holistically and implementing sustainable resource management practices are key to ensuring the long-term health and sustainable utilization of AEA.

3.4. Key Scientific Issues That Need to Be Addressed Urgently

Addressing the challenge of relying solely on a single method or a limited viewpoint for ecological asset monitoring, the integration of ground-based and remote sensing techniques offers a more effective approach for reevaluating ecosystem assets and enhancing ecosystem service capabilities. This integrated monitoring system, which merges ground-based observations with remote sensing, establishes a sophisticated, high-tech, and precise framework for ecological asset monitoring. Ground monitoring involves specific site sampling, observation, and experimentation to gather data on ecological environments, including metrics like water, atmospheric, and soil quality, as well as vegetation coverage. Remote sensing, on the other hand, employs technologies like satellites and aerial imagery to collect surface information, analyzing spatial patterns and temporal changes. Since the 1990s, researchers have consistently emphasized the importance of integrating high-quality field data with remote sensing analysis [140]. The synergy of these two methods enables a comprehensive understanding of ecological assets' status (both quantity and quality) across various temporal and spatial scales, supporting resource management, governmental decision making, and ecological restoration. By organically integrating ground monitoring with remote sensing, combining these two methods can enhance the reliability and repeatability of the data, while also controlling monitoring costs, thus achieving optimal monitoring effects.

In response to the current gap in research on AEA over different time scales, it is proposed to develop models for ecosystem service assessment. The model will evaluate temporal changes in AEA, employing a blend of geospatial techniques, transect field surveys, and economic valuation of natural capital [67]. ES are highly susceptible to anthropogenic land transformations, notably urbanization and intensive agriculture, which significantly alter ecosystem structure and function, thereby affecting ecosystem service provision. Research indicates that economic factors predominantly drive land use decisions, resulting in altered land use/cover (LUC) dynamics and a decline in ES quality. The longitudinal study by De Leijster et al. (2021) [141], examining 40 years of agroforestry ecosystem service trends in Colombia, offers insights for evaluating agroforestry ecosystem responses to land use changes. Consequently, the assessment of temporal changes in AEA, utilizing integrated methods, lays a scientific foundation for reorganizing ecosystem assets and formulating policies for sustainable ecosystem asset management

The use of ecosystem integrity as a measure of ecological status or the ability to maintain essential ecological functions and sustainably provide ES and resources has become an important topic in the discussion of how to effectively quantify agroforestry ecological assets in order to balance their use and conservation and to ensure the continued provision of AES [142–144]. Ecosystem integrity associates the sustainable provision of ES and resources with the fulfillment of both natural and human needs [145]. Consequently, augmenting research on ecosystem integrity is crucial for evaluating the capacity of agroforestry ecological assets to sustainably provide services and resources. To assess the ecological status of agroforestry ecosystems effectively, a regional index of ecosystem integrity, encompassing the composition, structure, and functional attributes of ecosystems, can be developed. This approach is not only instrumental in addressing ecological governance challenges in environmentally sensitive regions but also promotes the sustainable utilization of resources, thereby enhancing the capacity for ecosystem service provision.

Integrated models are crucial for addressing the limitations of existing models in thoroughly capturing and quantifying the interactions among environmental and socio-economic factors in agroforestry systems. These models enable a detailed analysis of the various interconnected and interdependent factors that influence the sustainable provision of AES. Given the inherent complexity of agroforestry systems, which are marked by intertwined elements and dynamic feedback processes [146], it is vital to dissect and understand these interrelationships. This understanding helps in identifying the key drivers that affect the sustainability of agroforestry systems, ensuring their continued ability to provide ecological assets and ES. Integrated models create a comprehensive analytical framework by merging theories and methods from diverse disciplines and collating data from multiple sources [147], thereby offering an accurate portrayal of both quantitative and qualitative factors affecting system assets. Dynamic computer simulations within these models are employed to forecast the system's response to environmental and human-induced changes. Consequently, these models can adeptly capture the interactions and feedback mechanisms of multifaceted factors within agroforestry systems, playing an essential role in reconfiguring the ecological assets of agroforestry and enhancing its capacity to provide ES.

3.5. Implications for Enhancing the Provision Capacity of Agroforestry ES in Rock Desertification Control

The aforementioned progress and key scientific inquiries have yielded significant insights. The inherent ontogenetic vulnerability of karst regions [148] results in regional ecosystems having low resilience to external disturbances and poor stability [149], rendering ES in these areas particularly susceptible to the impacts of karst desertification. The escalating socio-economic demands, coupled with continuous resource extraction and imprudent agricultural practices in areas of karst desertification, have intensified habitat disturbances [150]. These practices negatively impact the conditions and ecological processes within agroforestry ecosystems, thereby threatening the sustainability of their ecosystem service provision [151]. Therefore, in order to respond to the work mentioned in the introduction, and taking into account the main progress and key scientific issues, insights into the enhancement of agroforestry ecosystem service provisioning capacity in the management of karstic desertification are provided, mainly in terms of fragile habitats of desertification control and human–land relations.

In karst desertification areas, fragile habitats characterized by low vegetation cover, significant soil erosion, and water scarcity lead to reduced species diversity and destabilized ecosystems. This, in turn, adversely impacts the state of agroforestry ecological assets and the provision of ES. The relationship between ecological assets and ES is deeply rooted in the environment, with the latter being heavily dependent on the former's condition, such as vegetation structure and composition [152]. Therefore, as mentioned above in this paper, based on the assessment of agroforestry ecological assets, combined with the special characteristics of rocky desertification habitats, we select suitable plants that are lithophyte, arid, calcium-loving and have high yields and good quality [153], carry out the optimal allocation of agroforestry structures, convert the combination of agroforestry industries, and at the same time, select stony woody plants for planting to solve the problem of limited growth of vegetation due to the special habitats [154], as well as the poor stability of the ecology of agroforestry, and improve the condition of the ecological assets of agroforestry to a certain extent.

In desertification control areas, the human–earth relationship is notably strained due to the ecosystems' vulnerability to anthropogenic disturbances and climate change [155]. A compromised ecosystem integrity and stability can lead to a deterioration in environmental quality. Consequently, it is imperative to reinforce the monitoring of agroforestry ecosystem conditions and establish an integrated system for tracking their health, enabling timely interventions. The strategies discussed earlier are crucial for effectively maintaining and optimizing agroforestry ecological assets. These efforts are key in enhancing the reorganization of these assets, strengthening desertification control management, and improving the pathways of agroforestry ecosystem service formation [156]. Regarding human–land relations, the natural resource scarcity and vulnerability in the karst region, exacerbated by increasing demands due to population growth and economic development, result in further resource depletion and ecosystem degradation [157]. Traditional agricultural methods are inadequate for local needs. Agroforestry in desertification control areas not only contributes to ecological restoration but also enhances land utilization efficiency in karst regions, thereby easing the tense human–land relationship [65,158]. To address ecological restoration and human–land tensions, it is essential to consider the ES and economic benefits of agroforestry in managing and restoring these areas. This approach promotes the capitalization of ecological assets and the realization of ecological product values. Strengthening the role of agroforestry in economic income generation and land use can alleviate the human–land relationship tensions in karst regions. Additionally, the high level of human involvement in agroforestry ecosystems means that changes in their assets are directly influenced by human activities [159,160]. Therefore, reorganizing agroforestry ecological assets through identifying and scientifically managing manageable attributes can enhance the quantity and quality of the system [32], ultimately boosting the capacity for agroforestry ecosystem service provision.

3.6. Comparison with Other Reviews and Limitations of the Study

Before this study, numerous synthesis studies have concentrated on agroforestry ecological assets, engaging in comprehensive discussions to address gaps and establish connections between these assets and the ES they offer. Notably, a review by Stewart et al. focuses on identifying and evaluating numerical tools for quantifying eight natural capital benefits in agroforestry systems, including timber production, carbon sequestration, agricultural output, microclimate regulation, air quality improvement, water management, biodiversity enhancement, pollination, and recreational value [161]. Similarly, a review by Marais et al. examines the current knowledge in natural capital accounting, analyzing its application in demonstrating the value of agroforestry assets at the farm level. This review also highlights the advantages of applying natural capital methods in agroforestry decision making and introduces a conceptual model for valuing agroforestry assets at the farm scale [162]. Building upon this foundation, the current study conducts a systematic review of research on agroforestry ecological assets. It primarily focuses on their identification, quantitative assessment, decision-making management, and influencing factors. This study summarizes the significant achievements in this field and identifies key scientific issues that need addressing. This work aims to guide future global research on agroforestry ecological assets and provide a theoretical foundation for enhancing the supply capacity of agroforestry ES.

Despite employing diverse search methods and screening strategies, the literature selection in this study may be constrained by several factors beyond our control. One primary limitation is the focus on English language publications, potentially neglecting significant agroforestry literature in other languages, such as French, Portuguese, Spanish, or Japanese. Additionally, subjective judgment during the literature screening process might have resulted in excluding some pertinent articles. For instance, in the 'Included' stage, personal bias could have affected the selection while evaluating the relevance of the literature on agroforestry and ecological asset assessment (AEA). Moreover, the search string utilized may not have been sufficiently comprehensive to encompass all relevant literature on the research topic. As a result, these limitations could impact the study's thoroughness and precision, despite the rigorous search and screening techniques employed.

4. Conclusions

This study provides a comprehensive review of the literature, examining 61 papers from the Scopus database to elucidate the enhancement and reorganization strategies for agroforestry ecosystem assets and productivity within the context of globally. The key insights are distilled into four main points:

First, an increasing trajectory in AEA research underscores the growing recognition and analysis in this area, particularly noticeable since 2010. This surge is attributed to the global acknowledgment of ecosystem services (ES) value and the imperative for sustainable management of agroforestry resources.

Second, the geographic focus of AEA research predominantly spans Europe and Asia, accounting for 58% and 13% of the literature, respectively. This distribution highlights the emphasis placed on agroforestry ecological asset research within the North Temperate Zone, reflecting regional priorities in addressing agroforestry challenges.

Third, prevalent themes in the literature include the economic valuation, land utilization, and sustainability of agroforestry assets. These focal areas underscore the critical need to balance asset quantity and quality with sustainable practices to bolster the AES's supply capabilities.

Lastly, the study identifies pivotal scientific gaps and proposes four avenues for future research: the development of integrated monitoring systems for ecological assets; the formulation of ecosystem service assessment models to monitor changes over time in AEA; the creation of a composite index for ecosystem integrity to evaluate ecological asset status; the integration of models to effectively capture and quantify the interactions between environmental and socio-economic factors in agroforestry systems. These directions aim to advance the sustainable management and utilization of ecological assets in agroforestry, contributing to the ongoing provision of ES and supporting the mitigation of karst desertification.

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