RESEARCH ARTICLE

China's Bamboo Forest Management Policies in the Era of Artificial Intelligence: Resources, Regulation, and Sustainable Development Prospects

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Abstract

Bamboo forests constitute a strategic resource within China's forest ecosystem, encompassing approximately 6.416 million hectares, which represents nearly 2% of the total forested area. This paper presents a comprehensive review of bamboo forest management policies in China, tracing the evolution of macro-level policy frameworks, organizational structures, and incentive mechanisms from the 1950s to the present. The Chinese bamboo sector has transformed from a marginal forestry subsector into a nationally prioritized industry, with the total output value projected to exceed one trillion yuan by 2035. Key policy milestones, including the 2008 reform of collective forest rights, national bamboo industry development plans, and the 2021 establishment of the first bamboo carbon sink trading center, are analyzed within the context of China's dual carbon goals to peak emissions by 2030 and achieve carbon neutrality by 2060. Furthermore, the study examines structural challenges such as fragmented land tenure, low mechanization levels, and shortages of skilled personnel, while proposing policy recommendations to enhance sustainable bamboo forest management. These findings provide valuable implications for bamboo-producing regions at earlier stages of policy development, particularly in Africa and Latin America.

Keywords: bamboo forest management, forest policy, carbon sequestration, collective forest rights, China, sustainable development.

1 Introduction

Bamboo occupies a distinctive position in both the natural environment and human civilization. For the general public, bamboo evokes images of practical products, such as furniture, flooring, and handicrafts, or the distinctive beauty of bamboo groves in traditional gardens. However, the significance of bamboo extends far beyond its aesthetic and

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commercial appeal. At the ecological level, bamboo forests play an indispensable role in maintaining ecological balance by regulating hydrology, conserving soil and water, moderating microclimate, and purifying the atmosphere [1, 2]. At the economic level, bamboo is a resource of extraordinary versatility, with commercial applications ranging from edible shoots to processed building materials, charcoal, fiber textiles, and industrial feedstocks. At the cultural level, bamboo carries profound aesthetic and symbolic meaning in Chinese civilization, underpinning a rich tradition of art, literature, and material culture.

Data from China's 9th Forest Resources Survey (2018) reveals that the nation possesses a total of 6.416 million hectares of bamboo forest, with Moso bamboo (Phyllostachys pubescens) accounting for 4.678 million hectares of this area. In southern China specifically, bamboo forests dominate the landscape in various counties, rendering them a critical asset for local farmers' economic sustenance and regional carbon inventory. Research suggests that between 1999 and 2003, China's bamboo forests sequestered a total of 631.58 million tonnes of carbon, while the aggregate carbon stock has demonstrated a persistent rising trajectory throughout the last century [3].

During the 75th session of the United Nations General Assembly in September 2021, China unveiled significant climate goals, committing to reach peak carbon dioxide emissions prior to 2030 and to attain carbon neutrality by the year 2060. Against this policy backdrop, bamboo forests have emerged as a priority asset. Their rapidly expanding area, fast growth cycle, and outstanding carbon sequestration capacity position bamboo as a key instrument in China's low-carbon transition [4–6]. The bamboo forest carbon market has begun to take shape, with the first national bamboo forest carbon sink trading center established in Anji County, Zhejiang Province, in December 2021.

Despite the growing academic and policy interest in bamboo, the subject remains underrepresented in forest policy science as an independent research domain. Studies have predominantly addressed bamboo within the broader framework of non-timber forest products, without developing a dedicated analytical lens that integrates policy history, industrial economics, and regional society. This paper addresses this gap by providing a systematic and comprehensive review of bamboo forest management policies in China, covering macro policy frameworks, organizational structures, incentive mechanisms, and training programs. The findings aim to inform bamboo policy development not only within China but also to offer lessons for bamboo-producing countries at earlier stages of industry development.

2 Research Background

Climate change has been recognized as a defining challenge to ecological sustainability and human welfare. Scientific consensus identifies the rapid accumulation of greenhouse gases, particularly CO_2, as the primary driver of global warming. Forest ecosystems play a critical role in global carbon cycling by fixing an estimated 86% of the global vegetation carbon pool and 73% of the soil carbon pool [3, 7, 8]. Consequently, the protection and expansion of forest ecosystems are central to climate mitigation strategies.

Within the family of forest ecosystems, bamboo forests exhibit exceptional carbon sequestration capacity, particularly Moso bamboo. The above-ground carbon sequestration rate of Moso bamboo reaches 5.097 $t \cdot hm^{-2} \cdot a^{-1}$—1.46 times that of Cunninghamia lanceolata in its fast-growing stage, 1.33 times that of tropical montane rainforest, and 2.16 times that of 27-year-old Chinese fir forest in southern Jiangsu Province [9]. This positions bamboo forests as powerful tools for achieving regional and national carbon neutrality targets.

Prior scholarship has examined bamboo forest management from several angles. Sun et al. [10] investigated the management, production, and stand structure of Moso bamboo forests in Yixing City, Jiangsu Province, China. Huang et al. [11] analyzed support policies for smallholder bamboo farmers in China, recommending the abolition of nursery fund requirements and harvesting approval burdens, expanded access to credit, and improved forest land transfer and insurance subsidy systems. These studies, while valuable, have focused on specific sub-dimensions of the bamboo policy landscape rather than offering a holistic framework. The present paper synthesizes and extends this body of work through a comprehensive review of the full policy ecology governing bamboo forestry in China.

3 Global Bamboo Forest Resources

Bamboo belongs to the subfamily Bambusoideae of the family Gramineae. As a perennial plant characterized by rapid growth, high biomass production, a short harvesting cycle, and extraordinarily broad

utility, bamboo occupies a unique ecological and economic niche among the world's plant resources. Recent research has confirmed that bamboo forests, especially Moso bamboo forests, possess strong carbon sequestration capacity, making them significant contributors to the global carbon cycle and important instruments for addressing climate change [12].

3.1 Geographical Distribution of Bamboo

Bamboo has a wide natural range, spanning from approximately 46°N to 47°S in tropical and subtropical regions, from sea level to elevations of up to 4,300 m (Figure 1). The world's bamboo forests cover about 32 million hm^2, representing approximately 1% of total global forest area [13]. Importantly, while the area of tropical rainforests has declined over the past decade, bamboo forest area has been expanding, and Figure 2 shows that the total global area of bamboo forests nearly doubled in the 30 years from 1990 to 2020 [14].

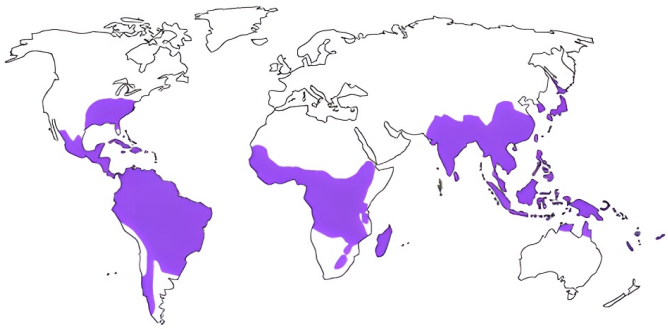

Figure 1. Global Geographical Distribution of Bamboo Species.

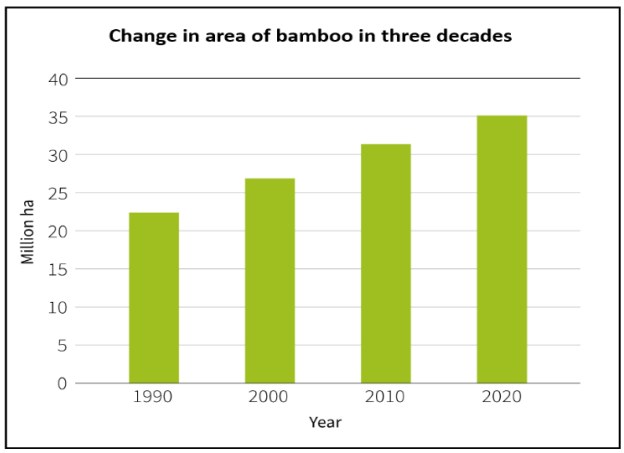

Figure 2. Change in Total Bamboo Forest Area 1990–2020.

According to the World Checklist of Bamboos and Rattans, more than 1,663 species of bamboo in 123 genera have been documented worldwide [15]. This remarkable diversity reflects bamboo's adaptability to a wide range of ecological conditions and underlies the richness of bamboo-based cultural and economic traditions across its range.

3.2 Classification of Bamboo Products

Bamboo supports an exceptionally diverse range of product categories, from raw structural poles to sophisticated engineered materials, food products, and cultural artifacts. The fast growth cycle and high lumbering rate of bamboo allow exploitation of the plant from leaves to roots. Table 1 provides a systematic classification of major bamboo product categories.

3.3 Biological Characteristics of Bamboo

The biological characteristics of bamboo confer upon it a distinct competitive advantage as an industrial and ecological resource. Bamboo is notably fast-growing, as from the emergence of a bamboo shoot to the formation of a complete bamboo culm, loose bamboo species require only 25–65 days, while clumped bamboo species require 3–6 months. The full growth cycle of bamboo spans only 3 to 5 years, in stark contrast to the decades or even centuries required for most commercial timber species. This compressed production cycle, coupled with the capacity for sustainable harvesting without replanting, establishes bamboo as a uniquely renewable resource.

The tensile strength of bamboo is 1–3 times that of conventional timber, and its combination of flexibility and resilience makes it an excellent building material. Unlike trees, bamboo culms do not regenerate after cutting; instead, new culms emerge from the rhizome system, which requires that harvesting be managed carefully to maintain forest health. Importantly, if bamboo is not harvested for a prolonged period, excessive culm density and senescence can trigger decline across the entire bamboo stand. Reasonable, periodic harvesting is therefore not merely economically desirable but ecologically necessary for the long-term health and productivity of bamboo forests.

4 Bamboo Forest Resources and Policies in China

4.1 Distribution of Bamboo Forest Resources

As the leading global producer of bamboo, China possesses 39 genera and over 500 bamboo species. The China Inventory of Forest Resources (CIFR), which has been carried out at five-year intervals

Table 1. Bamboo products classification.

Category	Product
Bamboo wood-based panel	Bamboo strip wood-based panels, bamboo strip wood-based panels, bamboo chips-based wood-based panels, bamboo reconstituted materials
Bamboo Flooring	Bamboo floor slab, reconstituted bamboo floor, bamboo wood composite floor, bamboo plastic composite floor, bamboo veneer floor, bamboo flattened floor
Bamboo Decoration Supplies	Bamboo strips, bamboo stairs (including railings, handrails, etc.), bamboo doors, bamboo wall panels
Bamboo Furniture Supplies	Weaving (bamboo curtains, bamboo carpets, bamboo blinds), mats (bamboo silk mats, mahjong mats, bamboo strips mats), kitchen items (bamboo tableware, bamboo cutting boards, bamboo toothpicks, bamboo sticks, bamboo placemats, bamboo tea set)
Bamboo Packaging Products	Bamboo woven packaging, bamboo pallet products
bamboo charcoal	Raw material bamboo charcoal (granular charcoal, powder charcoal), product bamboo charcoal (bamboo charcoal products for daily use, bamboo charcoal products for garden use)
Bamboo Extract	Bamboo Vinegar, Bamboo Leaf Flavonoids, Fresh Bamboo Liquor, Bamboo Juice Drink, Bamboo Juice Wine
Bamboo Fiber Products	Bamboo fiber towels, underwear and other bathroom apparel, home textiles, bamboo pulp
Bamboo crafts	Bamboo carving (root carving, bamboo tube carving, bamboo carving), bamboo weaving crafts (craft bamboo baskets, vases, calligraphy, and painting), bamboo musical instruments, bamboo fans, bamboo paintings, bamboo lamps
bamboo furniture	Original bamboo furniture, bamboo panel furniture, frame furniture, bamboo woven furniture, bamboo veneer furniture
bamboo shoot food	Fresh bamboo shoots (Moso bamboo shoots, hemp bamboo shoots, thunder bamboo shoots, square bamboo shoots, red bamboo shoots, green bamboo shoots), canned bamboo shoots, dried bamboo shoots, bamboo shoots

starting from 1973, serves as the fundamental empirical basis for developing forest policies. The most recent ninth inventory, finalized in 2018, provides the latest comprehensive data on bamboo distribution patterns.

Based on data from the ninth national forest inventory, the total coverage of bamboo forests in China reaches 6.416 million hectares (representing approximately 20% of global bamboo forest coverage), which constitutes 1.98% of the total forested land and 2.94% of the forested area. Specifically, Moso bamboo forests occupy 4,677,800 hectares (2.96%), while other bamboo forest types account for 1,733,800 hectares (27.04%). The vast majority (89.01%) of these bamboo resources are primarily located across eight provincial regions: Fujian, Jiangxi, Zhejiang, Hunan, Sichuan, Guangdong, Anhui, and Guangxi (Figure 3). Analysis of historical inventory data (Figure 4) reveals that China's bamboo forest coverage expanded from 2.9977 million hectares in 1976 to 6.4116 million hectares by 2018, demonstrating a net growth of 3.4139 million hectares across four decades, with a mean yearly expansion of 0.0813 million hectares and an average

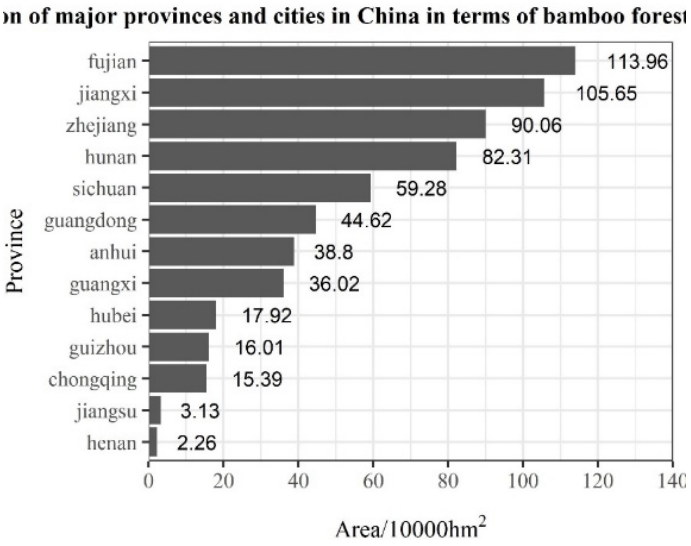

Figure 3. Distribution of Major Bamboo-Producing Provinces in China (2018).

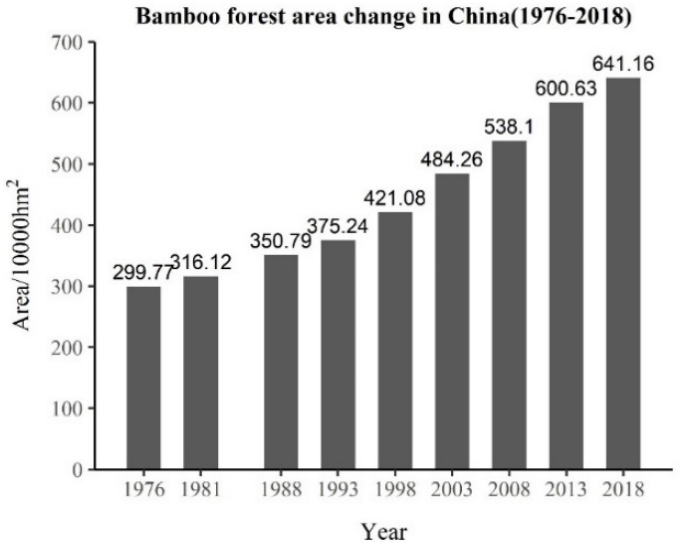

Figure 4. Bamboo Forest Area Change in China (1976–2018).

annual growth rate of 1.83%.

The distribution of bamboo in China is distinctly zonal and regional, shaped by variations in climate, soil, topography, and species-specific biological requirements. Bamboo resources are naturally distributed in the Yangtze River basin and the provinces south of it, with a few species extending northward to the Qinling, Hanshui, and Yellow River basins. van Dam et al. [17] delineated five major bamboo zones: the northern scattered bamboo zone, the southern mixed bamboo zone, the southwestern alpine bamboo zone, the southern clumping bamboo zone, and the Qiong-Tian climbing bamboo zone.

4.2 Bamboo Industry Output Value

China's bamboo industry has achieved significant improvements and tremendous development in the last decade, and the bamboo industry has gradually become an indispensable economic growth point for China's forestry development due to its increasing importance (Figure 5). 2009 China's bamboo output value was 70 billion RMB, and by 2020 China's bamboo output value is expected to grow to more than 300 billion RMB. The bamboo industry has made important contributions to promoting rural economic development, solving farmers' employment problems, increasing farmers' income, and improving the mountain economy.

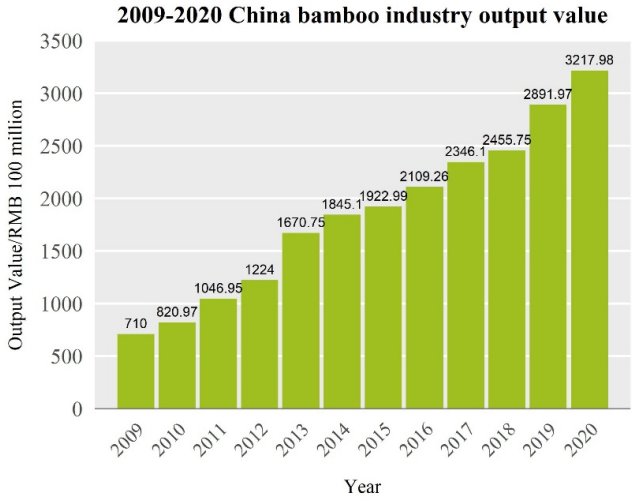

Figure 5. China Bamboo Industry Output Value (2009–2020).

4.3 Macro Policy Framework

The Chinese government has attached great importance to the protection, cultivation, and utilization of bamboo resources since the 1950s, providing sustained support in policy, economic, and technical dimensions(Table 2). The post-1980s period was particularly transformative, as the dual impetus of national economic development and the strategic substitution of bamboo for wood ("replacing wood with bamboo") catalyzed a new era of bamboo industry growth.

A key structural reform was initiated in June 2008, when China issued comprehensive Opinions on Advancing the Reform of the Collective Forest Rights System. This reform transferred forest land management rights and forest tree ownership rights from village collectives to individual farm

Table 2. Representative bamboo forestry industrial policies.

Years	Policy name	About Bamboo Forest
1981	Decision on Several Issues Concerning the Protection of Forests and the Development of Forestry	According to the requirements, reasonably determine the annual wood and bamboo cutting volume
1995	Forestry Action Plan for China's Agenda 21	Expand bamboo forest resources
2003	Decision on Accelerating Forestry Development	Gradually abolish the agricultural special product tax on logs and raw bamboo
2007	Forestry Industry Policy Highlights	Construction of bamboo and rattan bases and research and development of new bamboo and rattan products production technology
2008	Opinions on comprehensively advancing the reform of the collective forest tenure system	
2009	Measures for the Administration of Central Finance Discount Funds for Forestry Loans	Bamboo forest subsidy of 100 yuan per mu
2009	Forestry Industry Revitalization Plan	Encourage and support the development and upgrading of bamboo processing equipment and promote the effective use of bamboo
2015	"Overall Plan for Ecological Civilization System Reform"	
2016	Opinions on Improving the Collective Forest Tenure System	Support the construction of standardized production bases for the under-forest economy, characteristic economic forests, woody oilseeds, bamboo and rattan flowers, etc.
2017	Forestry Brand Building and Protection Action Plan	Promote the construction of regional characteristic brands of economic forest and bamboo and rattan flower industry
2021	Opinions on Accelerating the Innovation and Development of the Bamboo Industry	
2022	National Bamboo Industry Development Plan	

households, establishing farmers as the primary business entities in bamboo forest management. Under the reformed system, farmers acquired rights to operate, dispose of, and earn income from contracted forest land and forest trees, and could subcontract, rent, transfer, mortgage, or contribute their rights as equity. This institutional transformation dramatically increased farmers' incentives to invest in bamboo forest management and protection.

In November 2012, the 18th National Congress of the Communist Party of China (CPC) integrated the concept of building an ecological civilization into the comprehensive national development strategy. This was notably realized through the 'five-in-one' layout, which unifies economic, political, cultural, and social progress. By elevating ecological issues to a constitutional level, this decision established a solid policy basis for the conservation and sustainable development of bamboo forests.

In July 2021, the bamboo sector was designated as a priority initiative to foster distinctive and advantageous industries within the 14th Five-Year Plan Outline for the Protection and Development of Forestry and Grassland. Subsequently, on November 11, 2021, ten government bodies headed by the State Forestry and Grassland Administration collectively released the Opinions on Accelerating the Innovative Development of the Bamboo Industry. This policy document set forth aggressive national benchmarks, aiming for a total industry output of over 700 billion yuan by 2025, and surpassing one trillion yuan by 2035.

At the subnational level, leading bamboo-producing provinces and counties have developed complementary policy frameworks. Notable examples include: the Fujian Provincial Government's seven measures to accelerate bamboo industry development

(2016); Zhejiang Province's opinion on high-quality bamboo industry development (2020); and Anji County's implementation opinion targeting total bamboo industry output of 25 billion yuan by 2026 with three or more listed enterprises (2022).

China's bamboo policy has also acquired an international dimension. At the 14th BRICS Leaders' Meeting (June 2022), China announced a joint "Bamboo Instead of Plastic" initiative with the International Network for Bamboo and Rattan (INBAR), targeting both plastic pollution reduction and climate change mitigation.

4.3.1 Bamboo Forest Carbon Policy

The establishment of China's bamboo forest carbon market marks a significant milestone in the country's low-carbon transition. On December 28, 2021, the first national bamboo forest carbon sink trading center was inaugurated in Anji County, Zhejiang Province. During the inaugural transaction, five entities, including Anji Dali Village, sold bamboo forest carbon rights valued at more than 1.08 million yuan. The bamboo forest carbon sink storage platform has developed an integrated system encompassing forest land transfer, carbon sink accumulation, base operation, and platform-based trading. This framework effectively translates the ecological functions of bamboo forests into quantifiable market value.

4.3.2 Harvesting Regulation Reform

Guangdong Province's new forest harvesting management measures (effective August 1, 2021) exemplify the shift toward lighter regulation of bamboo harvesting. Under the new framework, bamboo forests are no longer subject to strict logging quota management. For individual farmers applying to harvest artificial commercial forest with an accumulation not exceeding 15 cubic meters, a commitment-based notification system replaces prior approval processes. Harvesting of bamboo forests outside nature reserves no longer requires application for a harvesting permit. This deregulation has substantially increased farmers' incentives and is expected to improve bamboo forest productivity.

4.4 Organizational Structure

China's bamboo sector is supported by a developed organizational ecosystem at both national and regional levels. The China Bamboo Industry Association (CBIA), established in June 1993, serves as the national non-profit industry association for enterprises, institutions, social organizations, and individuals engaged in bamboo cultivation, production, processing, trade, research, education, and management.

The China Bamboo Culture Festival, inaugurated in 1997, has been held every two years and has completed eleven editions to date, making it the largest, highest-profile, and most influential brand event in China's bamboo sector. The festival serves as an authoritative platform for technological innovation, industrial cooperation, policy dialogue, and knowledge sharing. Table 3 documents all editions of the China Bamboo Culture Festival.

4.5 Incentive Policies

China's bamboo sector is underpinned by a layered system of financial incentive policies at both provincial and county levels. Anji County, Zhejiang Province, has been particularly innovative, implementing economic subsidies and loan interest subsidies from 2016 to encourage bamboo farmers to develop the bamboo economy. Specific incentives include: a one-time award of 3 million yuan for bamboo enterprises that establish national-level technology centers or key laboratories; a one-time award of 1 million yuan for enterprises obtaining nationally recognized trademarks or brands; and graduated fiscal incentive arrangements for enterprises achieving annual sales revenues of 300 million, 500 million, and 1 billion yuan.

In Huoshan County, Anhui Province, differentiated subsidy rates are applied to bamboo forest cultivation: for operations of more than 50 mu using fertilization and other management measures, rewards of 400–800 yuan per mu are provided. New bamboo forest transport roads receive 40,000 yuan per kilometer. Leading bamboo enterprises receive recognition awards of 50,000 yuan (municipal level), 100,000 yuan (provincial level), and 300,000 yuan (national level).

4.6 Bamboo Farmer Training Policies

Human capital development is widely recognized as a critical enabler of performance in the bamboo sector. Consequently, multiple localities have implemented structured training programs to enhance the technical skills of bamboo farmers. A training initiative on bamboo cultivation techniques, which integrated theoretical instruction with field operations, was implemented in Daguan County, Yunnan Province, in March 2022. The curriculum covered bamboo species classification, seeding and seedling raising, productive

Table 3. Chronology of the China Bamboo Culture Festival.

Hold time		Organizers	Venue	Theme
First	1997	Zhejiang Provincial People's Government, Ministry of Forestry, International Bamboo and Rattan Organization	Anji County, Zhejiang	Promote bamboo culture, develop bamboo industry, develop bamboo economy, and let Chinese bamboo villages go to the world
second	1999	State Forestry Administration, Hunan Provincial People's Government, International Bamboo, and Rattan Organization	Yiyang City, Hunan Province	Promote bamboo culture and develop the bamboo industry
third	2001	State Forestry Administration, Sichuan Provincial People's Government, International Bamboo, and Rattan Organization	Yibin City, Sichuan Province	Promote bamboo culture, develop bamboo industry and develop the bamboo economy
Fourth	2003	State Forestry Administration, People's Government of Hubei Province, International Bamboo and Rattan Organization	Xianning City, Hubei Province	Promote bamboo culture, develop bamboo economy, and build a well-off society in an all-round way
Fifth	2006	State Forestry Administration, Fujian Provincial People's Government, International Bamboo, and Rattan Organization	Wuyishan City, Fujian Province	Green and common prosperity
Sixth	2011	State Forestry Administration, Jiangxi Provincial People's Government, and International Bamboo and Rattan Organization	Yichun City, Jiangxi Province	Promote Bamboo Culture, Low-Carbon I First
Seventh	2012	State Forestry Administration, People's Government of Jiangsu Province, International Bamboo and Rattan Organization	Yixing City, Jiangsu Province	Promote bamboo culture, develop the bamboo industry, and promote green growth
Eighth	2013		Huangshan City, Anhui Province	Promote bamboo culture, develop the bamboo industry, and build beautiful villages
Ninth	2016	State Forestry Administration, Sichuan Provincial People's Government, International Bamboo, and Rattan Organization	Meishan City, Sichuan Province	Promote bamboo culture, develop the bamboo industry, and realize the Chinese dream
Tenth	2018	State Forestry and Grassland Administration, Hunan Provincial People's Government, International Bamboo, and Rattan Organization	Taojiang County, Yiyang City, Hunan Province	Promote Chinese Bamboo Culture and Build a Beautiful New Home
Eleventh	2021	State Forestry and Grassland Administration, Sichuan Provincial People's Government, and International Bamboo and Rattan Organization	Sichuan Province	Zhufu Beautiful China promotes rural revitalization

cultivation, scientific management, pest control, and plantation establishment.

Similarly, in 2019, Matang Township, Shaoyang City, Hunan Province, organized training focused on technologies for transforming low-yield southern bamboo forests. Farmers were introduced to technical measures including selective cutting, specifically retaining large culms while removing small ones and eliminating weak plants in favor of strong ones. Additional measures included the removal of diseased and dead bamboo, weed and shrub clearance, deep tillage, and fertilization, all aiming to establish and maintain an optimized structure for southern bamboo stands.

5 Problems and Countermeasures of Bamboo Forest Development in China

5.1 Key Challenges

5.1.1 Inadequate Forest Infrastructure

Bamboo resource-rich areas are predominantly located in mountainous terrain, where natural conditions constrain the construction of roads, transport pipelines, and storage facilities. This infrastructure deficit imposes severe constraints on bamboo forest management and industrial development. Bamboo felling and transport in mountainous areas rely almost entirely on manual labor, substantially reducing efficiency. During bamboo shoot harvest seasons, most produce is carried down mountain by hand, with transport delays frequently compromising freshness

and market timing. For bamboo timber, manual harvesting and transport also increase cost and cause many mature culms to die in the forest unharvested. Additionally, the lack of digital infrastructure, such as IoT (Internet of Things) sensors and communication networks, prevents real-time monitoring of forest environments and logistics. The infrastructure deficit significantly reduces the economic returns from bamboo forest management and dampens farmers' motivation.

5.1.2 Fragmented Management and Low Mechanization

Although the restructuring of the collective forest tenure system effectively designated farmers as the main operators, it inadvertently led to the fragmentation of bamboo forest management into scattered, small-scale household units. Unlike agricultural land, bamboo forest management remains far less mechanized; consequently, manual labor inputs are both heavily required and persistently insufficient. Furthermore, the application of smart agriculture technologies, including drone-based surveying, AI-driven growth prediction, and automated harvesting robots, remains virtually non-existent. Survey data indicate that more than 95% of bamboo stands are under extensive management practices, with the phenomenon of harvesting dependent on natural conditions being widespread. Although bamboo cooperatives and family forestry farms have emerged in some regions, scattered household operations continue to predominate. The limited and dispersed nature of individual bamboo forest plots significantly impedes the adoption of mechanized harvesting and management equipment, as well as the deployment of centralized digital management platforms.

5.1.3 Shortage of Professional and Technical Talent

A systemic talent deficit constrains the full development of China's bamboo industry along the entire value chain. In production, most bamboo processing enterprises are small and micro-scale operations, limited in their capacity to attract and retain technical talent. In management, the scarcity of professional managers restricts enterprise growth and governance quality. In research and development, the bamboo industry lags behind other sectors in innovation capability and technology-driven growth. Specifically, there is a critical shortage of personnel skilled in agricultural informatics, big data analysis, and Artificial Intelligence applications. These talent shortages are compounded by limited interaction between higher education institutions and bamboo industry enterprises.

5.2 Policy Countermeasures

5.2.1 Increase Infrastructure Investment

Government capital investment should be directed toward building roads, transport pipelines, and storage facilities in bamboo-producing mountainous areas. Investment strategies should also prioritize digital infrastructure, ensuring coverage of 5G networks and IoT (Internet of Things) devices to support smart forestry systems. Improved infrastructure will reduce production costs, extend the marketable life of bamboo products, and increase the economic attractiveness of bamboo forest management, thereby strengthening farmers' incentives to invest in and maintain their bamboo forests.

5.2.2 Expand Scale and Advance Mechanization

Given rising labor costs and the inherent limitations of household-scale bamboo management, the promotion of large-scale joint management models is imperative. Policies should encourage the consolidation of bamboo land management through cooperatives, family farms, and land transfer arrangements, enabling standardized operations encompassing planting, fertilization, irrigation, and harvesting at scales conducive to mechanization [16]. Policies must explicitly support the integration of Artificial Intelligence and smart agriculture tools, such as using remote sensing for resource inventory and AI algorithms for pest identification. For bamboo processing enterprises, policies should support scale expansion, skill enhancement, adoption of advanced equipment, and productivity improvement, particularly in sectors utilizing intelligent manufacturing and automation, with distinct local comparative advantages.

5.2.3 Strengthen Bamboo Industry Talent

Development Investment in bamboo sector human capital should operate at two levels. At the farmer level, systematic skills training should improve bamboo forest cultivation techniques and thereby increase unit yields. Training programs should also introduce digital literacy modules, enabling farmers to utilize smart management apps and precision forestry tools. At the professional level, school-enterprise cooperation mechanisms should be developed to supply the bamboo industry with both skilled technical workers and professional management talent. University programs in forestry, materials science, and industrial design should incorporate bamboo-specific curricula

and courses on agricultural digitalization to build a pipeline of talent capable of driving bamboo industry innovation.

5.3 Digital Transformation and Smart Forestry Opportunities

The integration of digital technologies represents a paradigm shift for the bamboo industry, offering pathways to overcome traditional constraints in management and processing. Smart forestry systems leverage data-driven decision-making to optimize resource allocation and enhance ecological outcomes. Remote sensing technologies combined with Geographic Information Systems enable precise inventory mapping and growth monitoring across vast mountainous regions where manual surveying is impractical. These tools provide accurate data on bamboo density, health status, and biomass accumulation, forming the foundation for sustainable harvest planning.

AI (Artificial Intelligence) and machine learning algorithms further enhance management precision by analyzing complex environmental datasets. Predictive models can forecast bamboo shoot yields based on historical climate patterns and soil conditions, allowing farmers to optimize harvest timing and market supply. Computer vision systems deployed on drones or ground vehicles can identify pest infestations and disease symptoms at early stages, enabling targeted interventions that reduce chemical usage and environmental impact. Automated harvesting robots guided by AI navigation systems are emerging as viable solutions for steep terrain where human labor is risky and expensive.

IoT (Internet of Things) sensors play a critical role in real-time environmental monitoring. Soil moisture sensors, weather stations, and growth monitors transmit continuous data to centralized platforms, enabling precision irrigation and fertilization. This connectivity extends to the supply chain, where blockchain technology ensures traceability from forest to consumer. Digital ledgers record harvesting dates, processing conditions, and transport logistics, enhancing product authenticity and supporting premium market positioning for certified sustainable bamboo products.

Anji County in Zhejiang Province, recognized as the hometown of bamboo in China, provides a replicable case for digital transformation in the bamboo sector. In 2021, Anji established China's first county-level bamboo forest carbon sink storage and trading platform, which consolidates fragmented bamboo resources from individual forest owners, calculates carbon sequestration through professional management, and facilitates market transactions with revenue distributed to village collectives and farmers. The county's 58000 hectares of moso bamboo forests generate an annual carbon sink increment of 1.2 million tons. At a carbon price of 68 yuan per ton, full consolidation could yield annual carbon sink transactions of 340000 tons with a market value exceeding 23 million yuan. Currently, bamboo forest assets in all 119 administrative villages of Anji County exceed 10 million yuan each.

In terms of digital platform development, Anji County's media center independently developed and launched the digital agriculture platform Anji Premium Products Hub, which constructs a production and marketing model integrating platform services, village-owned enterprises, and smallholder farmers. Since its launch in July 2022, the platform has achieved sales exceeding 800 million yuan, increased village collective income by over 30 million yuan, and generated more than 40 million yuan in employment income for rural residents. The platform focuses on five flagship products including bamboo-related items. For instance, the bamboo forest chicken project, developed in collaboration with Zhejiang University, implements a 5+N breeding system with standardized protocols for chick selection, feed formulation, and husbandry practices. In 2023, the project sold 1.06 million bamboo forest chickens with total sales exceeding 50 million yuan.

Regarding industrial chain extension, Anji County promotes the adoption of intelligent production technologies in bamboo processing enterprises. For example, Mingzhu Bamboo Industry Technology Co., Ltd. produces 20 million bamboo toothbrushes annually, with bamboo materials substituting approximately 300 tons of plastic, generating an annual output value exceeding 10 million yuan. Its children's bamboo toothbrushes maintain the leading market position in South Korea. Enterprises such as Henglin Co., Ltd. have introduced photovoltaic power generation and digital energy management systems, achieving annual electricity generation of approximately 18 million kWh, equivalent to reducing carbon dioxide emissions by over 28000 tons annually, while decreasing energy consumption per product unit by approximately 5 percent. These practices demonstrate that the deep integration of

digital technologies with the bamboo industry can significantly enhance both economic and ecological benefits.

Digital transformation also strengthens carbon sequestration verification. Accurate measurement reporting and verification systems powered by remote sensing and AI are essential for integrating bamboo forests into carbon trading markets. Digital platforms can calculate carbon stocks dynamically, providing transparent data for carbon credit issuance. However, realizing these opportunities requires addressing barriers such as high initial investment costs, lack of data standards, and limited technical capacity among smallholder farmers. Future policies must support pilot demonstrations, subsidize digital equipment adoption, and foster public-private partnerships to build scalable smart forestry ecosystems.

6 Conclusion

Bamboo is an extraordinarily important forest resource characterized by wide distribution, rapid growth, functional versatility, ecological adaptability, and substantial economic and environmental value. Often recognized as a valuable strategic resource, bamboo occupies a distinctive position at the intersection of China ecological, economic, and cultural priorities.

China bamboo forest management policies have evolved substantially over the past seven decades, from early-stage resource protection through the transformative collective forest rights reform of 2008, to the present era of industry-scale development planning and carbon market institutional development. The macro policy environment, anchored by the dual carbon targets and supported by the National Bamboo Industry Development Plan, provides an unprecedented strategic foundation for bamboo sector growth.

The principal challenges facing China bamboo sector, such as inadequate mountain infrastructure, fragmented household management, low mechanization, limited digital connectivity, and systemic talent shortages, are well understood and amenable to targeted policy intervention. The countermeasures identified in this review, including infrastructure investment, scale consolidation, mechanization promotion, digital technology integration, and structured talent development, together constitute a coherent policy agenda for sustainable bamboo industry development.

Looking forward, four priority areas warrant continued policy attention. First, the bamboo carbon market requires further institutional development to translate bamboo substantial carbon sequestration capacity into consistent and scalable economic returns for forest managers. Second, the regulatory framework governing bamboo harvesting should continue to evolve toward lighter, more responsive mechanisms that align farmers operational incentives with sustainable forest management practices. Third, the integration of digital technologies including Artificial Intelligence and Internet of Things sensors should be accelerated to enable precision forestry and smart management systems. Fourth, China internationally oriented bamboo initiatives, such as the program promoting bamboo as a sustainable alternative to plastic, offer opportunities to embed Chinese bamboo forest management experience within a broader global sustainability agenda.

The experience accumulated by China in bamboo forest policy design, institutional development, and market construction contains valuable lessons for bamboo-producing countries in Africa, Latin America, and Southeast Asia that are at earlier stages of bamboo sector development. Systematic documentation and international sharing of China bamboo policy evolution represents a productive avenue for future research and development cooperation.

Data Availability Statement

Data will be made available on request.

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Conflicts of Interest

The authors declare no conflicts of interest.

AI Use Statement

The authors declare that no generative AI was used in the preparation of this manuscript.

Ethical Approval and Consent to Participate

Not applicable.

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