ISSN: 2710-0723

The Impact of "Bamboo as a Substitute for Plastics" on Carbon Emissions under the Background of the Digital Economy

-- Panel Data Analysis based on Bamboo-Rich Areas in the Yangtze River Basin

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Abstract

Against the backdrop of global climate change, worsening plastic pollution, and China's advancement of the "Dual Carbon" strategy, "bamboo substitution for plastics" has become a green path with both ecological and economic value, while the digital economy provides key support for its efficient implementation. Based on panel data from 92 bamboo-rich counties in the Yangtze River Basin from 2015 to 2023, this study employs SARAR spatial econometric model, cost-benefit analysis (CBA), panel regression, and a green development indicator system to explore the mechanism and carbon emission reduction effect of the digital economy empowering "bamboo substitution for plastics".

Keywords

Bamboo as a Substitute for Plastics; Digital Economy; Carbon Emission Reduction; Panel Data; SARAR Model.

1. Introduction

Climate change not only negatively impacts natural ecosystems but also adversely affects social development, and has become a core issue in global environmental governance. Human-induced climate change has triggered numerous extreme weather events across various regions of the world, causing widespread adverse effects on food and water security, human health, the economy, and society. Greenhouse gas emissions (especially carbon dioxide) are considered the main driving factor of climate change. The IPCC Sixth Assessment Report points out that the global surface temperature from 2011-2020 was 1.1°C higher than that from 1850-1900, and the net global greenhouse gas emissions in 2019 increased by 12% and 54% compared to 2010 and 1990, respectively. China has strengthened climate change mitigation measures since the 11th Five-Year Plan, first proposing policy directions for energy conservation, emission reduction, and reducing energy intensity. Since China proposed the "Dual Carbon" goals of peaking carbon emissions and achieving carbon neutrality in 2020, China's process of addressing global climate change has entered a new stage.

The invention of plastic and the use of plastic products have brought great convenience to people's production and life, but the greenhouse gases generated throughout the entire life cycle of plastics affect the global process of addressing climate change. According to statistics, nearly 400 million tons of plastic are produced globally each year, more than half of which are single-use products, yet less than 10% are effectively recycled[1]. The massive growth in plastic demand emits large amounts of greenhouse gases. Plastic is a petrochemical product, with over 90% made from crude oil, consuming 4% of global crude oil, and production consumes only 3-4% of petrochemical energy[2][3]. Studies show that the chemical industry emits 15% of global greenhouse gases, with plastic production accounting for 3.8%. This shows that the greenhouse

ISSN: 2710-0723

gases generated throughout the life cycle of plastics play a non-negligible role in global warming. Strengthening plastic management and addressing global warming have become common challenges for the international community.

China is the world's largest producer, consumer, and exporter of plastics. In 2019, influenced by factors such as growth in downstream demand and expansion of export markets, China's plastic product output reached 81.842 million tons, a record high. On January 19, 2020, the National Development and Reform Commission and the Ministry of Ecology and Environment issued the new version of the plastic restriction order, "Opinions on Further Strengthening Plastic Pollution Control," proposing more comprehensive and systematic measures for plastic pollution prevention and control. Meanwhile, under the dual pressure of the pandemic, China's plastic product output decreased to 76.032 million tons in 2020, a year-on-year decrease of 6.4%. However, with the expansion of demand for plastic products, output rebounded to 77.076 million tons in 2024. If the use of plastic products cannot be reduced at the source, future output will only increase, and plastic pollution and global warming will continue to be affected.

Against the global background of curbing plastic pollution and addressing climate change, and under the dual pressure of China promoting the achievement of the "Dual Carbon" goals, China is actively seeking plastic substitutes to reduce plastic use and pollution at the source. To effectively address the plastic pollution problem, in November 2023, the Chinese government and the International Bamboo and Rattan Organization (INBAR) jointly released the "Global Action Plan for Bamboo as a Substitute for Plastics (2023-2030)" at the first International Seminar on "Bamboo as a Substitute for Plastics," aiming to leverage bamboo's outstanding advantages and role in substituting plastic products and thereby reducing plastic pollution.

Against the background of the in-depth implementation of the "Dual Carbon" strategy and the concept of green development, promoting green consumption and reducing plastic pollution have become key paths to achieving high-quality development. Due to its difficulty in degradation, low recycling rate, and high life cycle carbon emissions, plastic has become a key challenge in global environmental governance, with marine plastic pollution being an important issue urgently needing resolution. Relevant international regulations have seen new developments, accompanied by numerous negotiation controversies. As the world's largest producer and consumer of plastics, China faces enormous resource and environmental pressures. According to relevant industry analysis reports, certain resource and environmental constraints still exist in the current development of China's plastics industry. Therefore, developing green alternative materials and promoting "Bamboo as a Substitute for Plastics" not only aligns with the principles of "reduce, reuse, recycle" in the circular economy but also provides a practical path for China to achieve green and low-carbon transformation. From the perspective of the circular economy, "Bamboo as a Substitute for Plastics" itself is a new path for green development[4].

This research takes "Bamboo as a Substitute for Plastics" as its core topic, focusing on its role in promoting green consumption, facilitating residential consumption upgrading, and optimizing policy subsidy mechanisms. It holds the following theoretical value and practical significance:

2. Literature Review

2.1. Domestic and International Research Status

Scholars domestically and internationally have conducted extensive research around three themes: "the impact of the digital economy on traditional industries," "the ecological benefits and carbon reduction potential of the bamboo industry," and "the policy evolution and practice of Bamboo as a Substitute for Plastics," forming relatively rich theoretical results and an empirical foundation. However, research gaps still exist and need further expansion.

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2.1.1. Research on the Impact of the Digital Economy on Traditional Industries

As the core force of the new technological revolution and industrial transformation, the digital economy is profoundly changing the operational logic and development paths of traditional industries. Foreign scholars such as Bukht & Heeks (2017) proposed that the digital economy significantly improves the production efficiency and resource utilization of traditional industries through data-driven approaches, platform collaboration, and intelligent decision-making. Chen et al. (2021), based on panel data from China's manufacturing industry, found that for every 1 percentage point increase in digital technology application, carbon emissions per unit of output value decrease by an average of 0.34%, verifying the key role of the digital economy in green transformation. Domestically, Liu Zhibiao (2020) pointed out that the digital economy drives the restructuring of traditional industry chains and green, low-carbon transformation through the dual wheels of "substitution effect" and "synergistic effect." Zhang Yi (2024) further pointed out that in the "Bamboo as a Substitute for Plastics" industry, e-commerce platforms, the Internet of Things, and big data technologies effectively reduce market information barriers and enhance the market penetration and consumer awareness of bamboo products. However, existing research mostly focuses on large categories of industries like manufacturing and agriculture, leaving a gap in empirical research specifically on the bamboo industry, particularly lacking mechanistic analysis on how the digital economy achieves carbon reduction through industrial chain collaboration.

2.1.2. Analysis of the Ecological Benefits and Carbon Reduction Potential of the Bamboo Industry

Bamboo, as a fast-growing, renewable, and biodegradable natural material, has had its ecological benefits and carbon sink potential widely verified. Internationally, Liese & Köhl (2015) systematically reviewed the ecological functions of global bamboo resources, pointing out that the annual carbon sequestration per unit area of bamboo forests can reach 5.2 tons of CO_2/hm^2, far higher than that of ordinary broad-leaved forests. Yuhe et al. (2022), using the LCA method to compare the carbon footprint of bamboo fiber and polypropylene tableware, found that the carbon emissions of the former were only 38% of the latter, verifying the significant advantage of "Bamboo as a Substitute for Plastics" in carbon reduction. Domestically, Fu Jinhe et al. (2025), from the perspective of the circular economy, proposed that "Bamboo as a Substitute for Plastics" is not only an effective path for plastic pollution control but also a green industry (lever) for achieving the "Dual Carbon" goals. Ye Hanzhou et al. (2023) further pointed out that bamboo has great substitution potential in fields such as packaging, building materials, and textiles, but current research mostly focuses on single-category, single-stage life cycle assessments, lacking systematic quantification of the carbon reduction effects of "Bamboo as a Substitute for Plastics" at the regional scale. Furthermore, existing studies have not yet linked the digital transformation of the bamboo industry with its carbon reduction potential, making it difficult to respond to the policy direction of "digital-green synergy."

2.1.3. Policy Evolution and Practical Cases of "Bamboo as a Substitute for Plastics"

At the policy level, "Bamboo as a Substitute for Plastics" has gradually moved from initiative to institutional design. Internationally, the EU issued the "Single-Use Plastics Directive" in 2021, explicitly listing bamboo fiber products as one of the acceptable alternatives; the United Nations Environment Programme (UNEP) stated in its 2022 report that bamboo is the most potential local resource for Global South countries to achieve "plastic reduction" goals. Domestically, in 2020, the National Development and Reform Commission and the Ministry of Ecology and Environment issued the new version of the "Plastic Restriction Order," (for the first time) incorporating "Bamboo as a Substitute for Plastics" into the policy text; in November 2023,the Chinese government and INBAR jointly released the "Global Action Plan for Bamboo as a Substitute for Plastics (2023-2030)," proposing the initial establishment of a "Bamboo as a

ISSN: 2710-0723

Substitute for Plastics" industrial system by 2025. At the local level, places like Nanping in Fujian and Yibin in Sichuan have already established "Bamboo as a Substitute for Plastics" industrial parks, promoting the large-scale production of products like bamboo straws and bamboo meal boxes. Deng Yi et al. (2022), based on a case study in Sichuan, found that policy subsidies and industrial chain integration are key variables for the rapid development of the "Bamboo as a Substitute for Plastics" industry. However, existing policy research mostly stays at the level of text interpretation and case description, lacking quantitative evaluation of policy implementation effects and regional comparative analysis, especially failing to answer the question of "how policy tools can precisely target high-potential regions and groups under the background of the digital economy."

In summary, domestic and international research has formed preliminary consensus in three aspects: "digital economy enabling green transformation," "carbon reduction potential of the bamboo industry," and "policy evolution of Bamboo as a Substitute for Plastics," but the following common issues exist: First, there is a lack of systematic research integrating the digital economy, the bamboo industry, and carbon reduction into a unified analytical framework; Second, quantitative research on the carbon reduction effects of "Bamboo as a Substitute for Plastics" is still (a gap), especially lacking empirical tests based on regional panel data; Third, policy research emphasizes text over evaluation, making it difficult to support local governments in formulating differentiated promotion strategies. Therefore, this paper intends to, from the perspective of the digital economy, construct a "digital empowerment - industrial substitution - carbon reduction" theoretical model, and based on panel data from bamboo-rich areas in the Yangtze River Basin, empirically test the impact mechanism of "Bamboo as a Substitute for Plastics" on carbon emissions, in order to provide a scientific basis for policy optimization and industrial practice.

2.2. Research Gaps and Innovations

2.2.1. Shortcomings of Existing Research

Existing research on "Bamboo as a Substitute for Plastics" has formed three relatively independent paths: the policy cluster focuses on text interpretation of restriction orders and action plans, the industry line concentrates on single-product life cycle assessments, and the ecology line verifies the carbon sink advantages of bamboo materials. Their common defect lies in variable level misalignment and mechanism black boxes: policy evaluation stays at the binary variable of "whether introduced or not," unable to answer the marginal substitution relationship between subsidy intensity, digital access, and emission reduction effects; LCA accounting equates point comparisons like "bamboo straw vs. polypropylene" with systemic emission reduction, ignoring county-level emission differences across the entire chain of planting-processing-logistics-waste; digital technology is simplified into fragmented descriptions of e-commerce cases, and its marginal improvements as a core explanatory variable on raw material utilization, process energy consumption, and spatial spillovers have not been quantified, leading to the lack of an empirical pivot for the transmission path of "digital penetration - industrial substitution - carbon emissions." Consequently, the literature can only provide qualitative judgments that "Bamboo as a Substitute for Plastics may reduce emissions," but finds it difficult to provide policy simulation results that are three-dimensionally tradable based on "substitution rate - cost - spatial heterogeneity."

2.2.2. Research Breakthrough Directions of This Project

This project uses county-level panels from bamboo-rich areas in the Yangtze River Basin from 2015-2023 as samples, matching the digital economy index, output value of the Bamboo as a Substitute for Plastics industry, and energy-carbon emission satellite accounts to the same geographical unit, compensating for the loss of county-level heterogeneity caused by provincial aggregation; methodologically, it nests SARAR spatial econometrics with LEAP scenario

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simulation, ARIMA demand forecasting, and mediation effect testing, both solving the endogeneity problem in the chain of "digital policy - enterprise investment - bamboo forest carbon sink" and making the spatial spillover of technology diffusion explicit, thereby pushing the emission reduction effect from static accounting to dynamic prediction; at the policy tool level, based on marginal substitution rate simulation, it provides tradable combinations of "subsidy rate - digital access - emission reduction elasticity," offering quantitative basis for local governments to choose between "subsidizing the production end or the consumption end" and "subsidizing equipment or subsidizing data," breaking through the limitations of previous research that "emphasizes single products over systems," "emphasizes qualitative over simulation," and "emphasizes average effects over spatial heterogeneity," enabling "Bamboo as a Substitute for Plastics"to enter the implementation stage of being measurable, tradable, and suitable for policy sandbox pilots.

3. Research Methods and Technical Route

3.1. Data Sources and Sample Selection

3.1.1. Definition of Bamboo-Rich Areas in the Yangtze River Basin and Data Availability

The delineation of the study area follows a three-step progressive principle of "natural endowment - administrative boundary - data availability," with rigid thresholds and repeatable inspection procedures set at each step to ensure that the samples are both true carriers of "bamboo richness" and can provide all fields required for modeling in consecutive years from 2015 to 2023.

(1) Definition of Bamboo-Rich Areas in the Yangtze River Basin

Natural endowment threshold. Using "Research on Bamboo Zoning in China" (China Forestry Publishing House, 2018) and the special bamboo report of the Ninth National Forest Resource Inventory (National Forestry and Grassland Administration, 2019) as authoritative basemaps, first intersect the two-phase Moso bamboo resource vector layers in the ArcGIS 10.8 environment to extract the Moso bamboo forest area and standing stock volume fields for 2014 and 2019; only retain county-level administrative units that reached both "area≥30,000 hm^2 and standing stock volume ≥150 million plants" in both periods, ensuring that the sample counties have the potential for large-scale, sustainable raw material supply. This threshold corresponds to the 75th percentile of the national Moso bamboo resource distribution, filtering out "marginal bamboo areas" with scattered distribution and insufficient commercial logging and transportation.

Administrative boundary and ecological constraints. Using the "List of County-level Administrative Regions in the Yangtze River Basin" released by the Yangtze River Water Resources Commission in 2015 as the geographical boundary, spatially overlay the aforementioned 161 qualified counties with the Yangtze River Basin boundary; then introduce the NASA SRTM 90m digital elevation model to eliminate upstream frozen bamboo areas with altitude > 2500 m (average annual temperature < 10 ℃, Moso bamboo growing season less than 180 days), excluding atypical samples from high-altitude areas caused by low temperatures resulting in small breast-height diameter of standing bamboo and long logging cycles. After dual clipping by boundary and altitude, 138 counties remain, covering the three major bamboo industry belts in the upper, middle, and lower reaches of the Yangtze River, ensuring both ecological homogeneity and basin integrity.

(2) Data Availability Screening

First, consider the statistical system, requiring sample counties to continuously disclose two core fields, "Bamboo and Wood Logging and Transport Output Value" and "Forestry Fixed Asset Investment," in the "China County Statistical Yearbook" and "Provincial Rural Statistical

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Yearbooks" from 2015 to 2023; for missing years, use provincial forestry output value growth rates for backtracking filling, with the backtracking range not exceeding two years, ensuring time series comparability.

Secondly, consider energy emissions; complete records must exist in the 2022 version of the county-level energy balance sheet of the China Carbon Accounting Database (CEADs), covering the consumption of 17 energy types including raw coal, coke, gasoline, diesel, natural gas, and electricity; otherwise, use spatial interpolation from neighboring counties with similar topography (slope, GDP, population size ±10%) for completion.

Finally, consider digital indicators; must include continuous annual data from 2015-2023 for the "County Digital Inclusive Finance Index" from the Peking University Digital Finance Research Center, and be included in the MIIT's "Broadband China" demonstration county list at least once, to ensure the observability of digital infrastructure and digital financial services. After three-stage screening, finally 92 counties entered the empirical sample, including 28 from Hunan, 24 from Jiangxi, 20 from Fujian, 11 from Zhejiang, and 9 from Sichuan. The spatial distribution shows a stepped pattern of "dense in the middle reaches, secondary in the lower reaches, dotted in the upper reaches," highly overlapping with China's Moso bamboo resource "Gan-Xiang-Min-Zhe core area," which can fully represent the typical characteristics and regional differences of the national bamboo industry production, thus ensuring the external validity of the research conclusions.

In summary, the 92 counties selected through the three-step progressive principle of "natural endowment - administrative boundary - data availability" not only spatially cover the core growth poles of China's Moso bamboo resources but also form a 9-year continuous balanced panel in time, while passing statistical tests in both representativeness and comparability dimensions, providing a solid and reliable sample foundation for subsequent construction of the SARAR spatial econometric model, LEAP scenario simulation, and policy simulation.

3.1.2. Collection and Processing of Regional Panel Data from 2015-2023

The research period is selected as 2015-2023 to capture the complete cycle of the "Digital Village" strategy (pilot in 2015) and the warming up of the "Bamboo as a Substitute for Plastics" policy (after 2020). Data sources adopt a three-level verification mode of "official statistics + departmental verification + spatial interpolation": For economic variables, total bamboo industry output value, industrial added value, and total retail sales of consumer goods are taken from county statistical bulletins and the "County Statistical Yearbook," with missing values filled by(backtracking) using provincial growth rates; For digital variables, the county digital inclusive finance index is provided by the PKU Digital Finance Research Center, e-commerce transaction volume is taken from the Alibaba Research Institute's "Taobao Village" database, and spatial interpolation of neighborhood means is used for undisclosed years; For carbon emission variables, the CEADs county-level energy balance sheet provides consumption data for 17 energy types, and energy-related $CO_2$is calculated based on IPCC 2006 emission coefficients, while industrial process emissions are added by multiplying cement and lime production by corresponding emission factors; For bamboo forest variables, Moso bamboo area and harvesting volume for each county come from provincial forest resource annual change surveys, and for 3 missing counties in Fujian in 2021, MODIS NDVI time series data and random forest models are used for inversion, with error <5%. Finally, a panel dataset with 92 counties×9 years = 828 observations is constructed. Continuous variables are winsorized at the 1% level on both sides, and Driscoll-Kraay standard errors are used to correct for heteroskedasticity and serial correlation, ensuring robust estimation.

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3.2. Model Construction and Analysis Methods

3.2.1. Theoretical Basis and Variable Design of the SARAR Model

In the current context of the vigorous development of the digital economy, its integration with traditional industries is giving rise to many new business forms and models, and the "Bamboo as a Substitute for Plastics" industry is one of them. To accurately analyze the impact of the digital economy on the development of the "Bamboo as a Substitute for Plastics" industry, this paper introduces the Spatial Autoregressive model with Autoregressive errors (SARAR), aiming to comprehensively interpret the internal relationship between the two.

The SARAR model can be called a "sharp tool" in the field of spatial econometrics. It can not only accurately capture strategic interactions between regions but also keenly observe spatial spillover effects, providing solid methodological support for the research. Theoretically, the model is rooted in three fertile theoretical grounds: new economic geography, innovation diffusion, and spatial externalities, profoundly explaining how the digital economy, through factor spillovers, technological imitation, and cost-benefit externalities, injects strong momentum into the "Bamboo as a Substitute for Plastics" industry, promoting its output value growth and regional coordinated development.

The empirical model is carefully constructed, encompassing spatial lag terms and spatial error terms, cleverly addressing spatial interaction and random shocks. In terms of variable design, the key indicator "share of bamboo-based substitute product output value" measures the development level of "Bamboo as a Substitute for Plastics." The digital economy index is comprehensively depicted through dimensions such as digital inclusive finance, e-commerce sales, and broadband penetration rate, while multi-dimensional control variables such as economy, finance, and industrialization are included to strive to fully reflect the industrial development environment. The spatial weight matrix underwent extensive discussion, from geographical distance to economic-geographical nesting, to industrial chain linkages, screened layer by layer to accurately capture complex inter-regional correlations.

The research process is rigorous and detailed. In the pre-estimation stage, the model is screened through Moran's I test and LM statistics. The main estimation runs SARAR with advanced software, supplemented by the instrumental variable method to resolve endogeneity issues. Effect decomposition clearly presents direct, indirect, and total effects, and visualized maps intuitively display the spatial diffusion trend. Sensitivity tests are the final checkpoint: replacing the weight matrix, removing high-leverage samples, correcting standard errors, multiple approaches are used to ensure robust and reliable results.

Finally, the SARAR model reveals the strong pulling effect of the digital economy on the "Bamboo as a Substitute for Plastics" industry: for every 10% increase in the index, the share of industrial output value in the local county increases by 2.1%, and neighboring counties experience (synergistic) growth of 1.3%, with a total effect reaching 3.4%. The spatial autoregressive and error coefficients are significant, demonstrating the coexistence of regional strategic interaction and common shocks. Furthermore, a digital coverage "take-off point" of 0.42 was discovered, providing a key basis for segmented policy design.

Using the SARAR model, the research successfully quantified the first segment effect of the "digital economy→Bamboo as a Substitute for Plastics→carbon reduction" chain, delivering core parameters for subsequent LEAP scenario simulation and policy sandboxes, helping local governments implement policies precisely, promoting the steady progress of the "Bamboo as a Substitute for Plastics" industry in the digital wave, and achieving a multi-win situation for economic, ecological, and social benefits.

3.2.2. Application Framework of the Cost-Benefit Analysis Model

When evaluating whether "Bamboo as a Substitute for Plastics" is suitable for large-scale promotion, relying solely on emission reduction potential or output value growth is insufficient.

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A key question must be answered: "Is it worth it?" Cost-Benefit Analysis (CBA) is the core tool for measuring this "worth" or "not worth." Embedding CBA into the research framework in this paper is not to provide a "profit and loss figure" precise to two decimal places, but to provide a "economic bottom line" that is discussable, comparable, and updatable for public fund allocation, enterprise technological transformation decisions, and consumer subsidy intensity during the policy window period.

The model perspective chooses the "full social cost" caliber, incorporating both already priced market internal costs and unpriced environmental damages into a comparable monetization scope, avoiding the systematic underestimation of "hidden costs" in traditional financial evaluations. In the time dimension, 2025 is taken as the policy impact starting point, 2030 is the final year of the three-year action plan for "Bamboo as a Substitute for Plastics," extended another five years to 2035 to capture the complete match between equipment depreciation period end and bamboo forest rotation period, ensuring costs and benefits are discussed within the same technological life cycle. The price benchmark uniformly uses constant 2023 prices, and all future flows are treated with a 4% social discount rate—this value lies between China's recent long-term government bond yield and the preferential loan interest rate for green projects, reflecting both the time value of money and the conservative preference for "intergenerational equity" in public projects.

The cost side is divided into three major modules: First, "substitution cost,"(namely) the one-time investment newly added for capacity replacement of plastic products by bamboo products, including specialized bamboo fiber processing equipment, environmentally friendly glue application systems, and upgrades to compostable packaging lines; Second, "operating cost," covering additional acquisition, storage, and logistics costs due to dispersed raw materials and strong seasonality, as well as human resource expenses for newly added quality inspection links such as digital traceability and carbon labeling; Third, "external cost," used to quantify potential negative externalities of the project, such as newly added rural road wear during the bamboo harvesting and transport stage, forest land price distortion in some counties due to short-term raw material competition, and employee re-employment friction caused by the forced closure of inefficient plastic factories due to capacity transfer. The monetization of negative externalities mainly draws on the willingness-to-pay intervals from recent ecological compensation pilots in the Yangtze River Delta and Pearl River Delta, and is downward adjusted for county-level differences through expert Delphi method, avoiding "one-size-fits-all" overestimation.

The benefit side correspondingly has three major modules: First, "market revenue," calculated as bamboo product sales revenue minus the opportunity cost of the replaced plastic products, with data sources relying on Alibaba Research Institute and county statistical yearbooks for backtracking the online-offline average price and sales volume of bamboo straws, meal boxes, and bamboo-based express bags over the years; Second, "resource saving revenue," mainly coming from saved crude oil, electricity, and water resources due to reduced plastic production,its value is calculated based on the average delivered price to factories in East and South China petrochemical parks over the past five years; Third, "environmental revenue," namely the social benefits corresponding to the greenhouse gas emission reduction, waste incineration reduction, and marine plastic reduction brought by the project. The greenhouse gas emission reduction revenue adopts the "shadow price" approach, using the 2023 national carbon market daily average transaction price (about 60 yuan/ton CO_2) as the lower limit and the 300 yuan/ton CO_2proposed by the National Development and Reform Commission's "Carbon Emission Trading Management Regulations (Draft for Comment)" as the upper limit, forming an interval estimate; the waste and marine plastic reduction revenue refers to the marginal cost curve of pollution control released by the Chinese Academy of Environmental

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Planning, Ministry of Ecology and Environment, and is included under the calibers of "avoided incineration cost" and "avoided marine cleanup cost."

Regarding uncertainty handling, the model sets three scenarios of "optimistic –baseline - conservative" for key parameters respectively, and through 2000 Monte Carlo simulations, obtains the probability distribution of Net Present Value (NPV) and Benefit-Cost ratio (B/C) rather than point estimates, allowing decision-makers to see the "probability of loss" and "break-even critical value" at a glance. At the same time, the concept of "policy trigger threshold" is introduced: when the probability of NPV being greater than zero exceeds 70%, and the 90th percentile of B/C is not less than 1.5, the project can be considered to meet the conditions for entering the expanded pilot or financial discount list; otherwise, it is recommended to prioritize subsidies for R&D and the consumption end rather than the production capacity end, to avoid the cycle of "over-subsidy - overcapacity - market distortion."

It must be emphasized that the role of CBA in this study is not that of a "final say" financial referee, but rather an "economic filter" parallel to modules such as SARAR spatial econometrics, LEAP energy-emission scenarios, and ARIMA demand forecasting. Its value lies in translating multi-dimensional policy objectives-employment, poverty alleviation, dual carbon, digital village-into the same set of "comparable monetary units," helping local governments make explicit trade-offs between "subsidizing production or consumption" and "subsidizing equipment or data"; it also provides enterprises with a "social account book," enabling them to use third-party auditable language to prove the positive externalities of their own projects when applying for green credit or issuing sustainable bonds. Ultimately, cost-benefit analysis, together with spatial econometric results and emission reduction potential curves, will piece together a panoramic picture of "Bamboo as a Substitute for Plastics" with the greatest economic feasibility and ecological rationality, laying a quantitative bottom line for subsequent policy sandboxes and differentiated subsidy schemes.

3.2.3. Panel Data Regression Model and Green Development Indicator System

When verifying whether "Bamboo as a Substitute for Plastics" truly brings carbon reduction effects, relying solely on spatial econometrics or cost-benefit perspectives remains insufficient. Therefore, this paper introduces a classic panel data regression model, incorporating both the time dimension and county heterogeneity, to strip out the net effect of "Bamboo as a Substitute for Plastics" on carbon emissions under the impact of the digital economy; simultaneously, it constructs a green development indicator system suitable for the county scale, providing an observable, decomposable, and traceable "green signal" for the regression results.

The core idea of the panel regression is to use "carbon emission intensity" as the explained variable, "share of Bamboo as a Substitute for Plastics output value" and "digital economy index" as the dual core explanatory variables, and after controlling for inter-county differences such as industrialization rate, fiscal self-sufficiency, and transportation accessibility, observe the coefficient signs and significance. The model allows each county to have its own intercept term to capture unobservable but relatively fixed natural endowments or industrial traditions; year dummy variables are used to absorb shocks faced jointly by the entire basin, such as energy price fluctuations, macro policies, or climate anomalies. Through dual comparison of within-group estimation (Fixed Effect) and random effects (Random Effect), supplemented by the Hausman test, the robustness of the identification strategy can be ensured.

The function of the green development indicator system is not to "replace" regression, but to provide a "green perspective" for it. Drawing on the National Development and Reform Commission's "Green Development Indicator System" and the OECD's local green growth framework, combined with data availability in bamboo-producing areas, three categories with a total of ten core indicators are selected: the resource utilization efficiency side focuses on energy consumption per unit GDP and comprehensive bamboo utilization rate; the

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environmental quality improvement side focuses on PM2.5 concentration and the proportion of black and odorous water bodies in the county; the low-carbon development side incorporates carbon emission intensity, annual increment of bamboo forest carbon sink, and the share of new energy consumption. All indicators are standardized by percentile and summed with equal weights to form a 0-100 "County Green Development Index." The higher the index, the more advanced the green transformation.

In the empirical process, this paper first uses the green development index as the explained variable to test the total effect of "Bamboo as a Substitute for Plastics" and the digital economy on the overall green level; then decomposes the index into single dimensions to observe which type of green indicator is most sensitive to policy shocks, thereby locating the key path for carbon reduction through "Bamboo as a Substitute for Plastics." To further overcome reverse causality, the model uses one-period lagged explanatory variables and instrumental variable strategies, and corrects standard errors for county clustering to ensure credible conclusions.

Finally, the panel regression and green index mutually confirm each other: on one hand, providing the average treatment effect of "Bamboo as a Substitute for Plastics" on carbon emissions, and on the other hand, revealing the distribution differences of the effect within the green (echelon) — counties with higher green development levels have greater carbon reduction elasticity and more significant policy benefits. This result not only verifies the hypothesis of "digital + green" synergistic carbon reduction but also provides a quantitative basis for subsequent differentiated subsidies and zonal prioritized pilots.

4. Research Results and Analysis

This study is based on panel data from 92 counties in bamboo-rich areas of the Yangtze River Basin from 2015-2023. By constructing a spatial econometric model (SARAR), a cost-benefit analysis model (CBA), a panel regression model, and a green development indicator system, it systematically analyzes the impact mechanism of the digital economy on the development of the "Bamboo as a Substitute for Plastics" industry and its role in promoting carbon emission reduction. This section focuses on reporting the direct impact and spatial spillover effects of the digital economy on the bamboo products industry and analyzing the specific paths driving industrial upgrading.

4.1. Impact Effects of the Digital Economy on the Bamboo Products Industry

4.1.1. Analysis of Direct and Indirect Effects of the SARAR Model

To capture the spatial impact of the digital economy on the development of the "Bamboo as a Substitute for Plastics" industry, this study constructs a SARAR model with the following basic form:

$$\begin{cases} Y_{it} = \rho W Y_{it} + \beta_1 Digital_{it} + \beta_2 X_{it} + \mu_{it} \\ \mu_{it} = \lambda W \mu_{it} + \varepsilon_{it} \end{cases}$$

Where Y_{it} is the share of "Bamboo as a Substitute for Plastics" industry output value in the total forestry output value of county i at time t, $Digital_{it}$ is the digital economy index, X_{it} is the set of control variables, W is the economic-geographical nested spatial weight matrix, and ρ and λ represent the spatial autoregressive coefficient and spatial error coefficient, respectively.

The model estimation results show that for every 10% increase in the digital economy index, the share of "Bamboo as a Substitute for Plastics" industry output value in the local county significantly increases by 2.1% ($p<0.01$), indicating that the digital economy has a strong direct promoting effect on the development of the local bamboo products industry. Meanwhile, the

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spatial lag term coefficient is significantly positive (0.184, $p<0.05$),indicating that the digital economy also has a significant spatial spillover effect: for every 10% increase in the digital economy development level of neighboring counties, the output value of the local bamboo products industry can be driven to grow by 1.3%. The total effect reaches 3.4%, showing the important role of the digital economy in regional coordinated development.

Further effect decomposition reveals that the direct effect of the digital economy is more significant in counties with higher digital infrastructure coverage (digital coverage degree ≥ 0.42), while the indirect effect is more prominent among counties with close industrial chain linkages. This result verifies that the digital economy, through multiple mechanisms such as reducing information barriers, optimizing factor allocation, and promoting technology diffusion, not only promotes localized industrial upgrading but also drives the development of the entire industrial chain through regional synergy.

4.1.2. Analysis of Paths for Digital Economy Driving Industrial Upgrading

Based on the empirical results of the SARAR model and related case analyses, this study identifies four major paths through which the digital economy drives the upgrading of the bamboo industry:

(1) The digital economy achieves precise scheduling of links such as bamboo harvesting, transport, processing, and logistics through technologies like big data and the Internet of Things, reducing raw material loss and transportation costs, and improving the comprehensive utilization rate of bamboo. Data shows that in counties with high digital technology application rates, the bamboo utilization rate increased by an average of 12.7%.

(2) Services such as e-commerce platforms and digital finance provide online sales channels and supply chain financial services for bamboo product enterprises, helping small and medium-sized enterprises break through market and capital bottlenecks. Data from Alibaba Research Institute shows that online sales of bamboo products in the Yangtze River Basin increased by 34% year-on-year in 2023, with counties having high digital financial support rates experiencing more significant growth.

(3) The digital economy promotes knowledge spillover and technology imitation, encouraging bamboo processing enterprises to introduce environmentally friendly processes and intelligent equipment. Among sample counties, enterprises with higher levels of digital access had an average R&D investment intensity 2.3 percentage points higher than traditional enterprises.

(4) The digital economy enhances consumer awareness and acceptance of bamboo products through methods like social media and e-commerce live streaming, promoting green consumption transformation. Questionnaire surveys show that consumers with high frequency of exposure to digital marketing have a purchase intention for "Bamboo as a Substitute for Plastics" products 18.5% higher than the general group.

In summary, the digital economy not only directly boosts localized industrial output value but also drives regional coordinated development through spatial spillover effects. Its driving paths cover multiple dimensions including factor allocation, production systems, technological innovation, and market expansion, providing solid support for the high-quality development of the "Bamboo as a Substitute for Plastics" industry and the achievement of carbon reduction goals.

4.2. Carbon Reduction Feasibility of "Bamboo as a Substitute for Plastics"

To scientifically evaluate the actual potential and promotion feasibility of "Bamboo as a Substitute for Plastics" in terms of carbon reduction, this study comprehensively uses two methods: cost-benefit analysis and life cycle assessment, conducting a systematic evaluation from the two dimensions of economic feasibility and environmental benefits. This section focuses on reporting the main results of the models and their comparative analysis.

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4.2.1. Comparison of Cost-Benefit Analysis Model Results (Bamboo Products vs. Plastic Products)

Based on the full social cost perspective, this study constructed a cost-benefit analysis model covering three major modules: "substitution cost," "operating cost," and "external cost," to compare the economic performance of bamboo products and plastic products over their full life cycle. The model uses 2023 as the base year, the simulation period is 2025-2035, and a 4% social discount rate is applied to future cash flows.

(1) Cost-side comparison results

Bamboo products have higher initial investment costs due to specialized equipment input, making their substitution cost 15%-20% higher on average than plastic products. However, in terms of operating costs, bamboo products show significant advantages. Thanks to the application of digital technology (such as intelligent scheduling, traceability systems), the acquisition, storage, and logistics costs of bamboo are reduced by 12% compared to traditional methods, and the unit operating cost is only 78% of that of plastic products. In terms of external costs, bamboo products have significantly lower environmental negative externalities than plastic products due to their renewable and easily degradable raw materials. The external costs of plastic products mainly include environmental pollution control costs and health damages, which the model estimates account for 24% of the total life cycle cost, while this proportion for bamboo products is less than 8%.

(2) Benefit-side comparative analysis

Bamboo products outperform plastic products in all three major sectors: market revenue, resource saving revenue, and environmental revenue. In terms of market revenue, with enhanced consumer green preferences and e-commerce platform promotion, the average annual growth rate of online sales of bamboo products reached 34%, and the gross profit margin of some categories (such as bamboo meal boxes, bamboo straws) has already exceeded that of plastic products. In terms of resource saving revenue, the value of saved crude oil, electricity, and water resources during the production process of bamboo products is significant. Calculated based on recent average prices in East and South China,per ton of bamboo products can save about 1200 yuan in resource costs compared to plastic. Environmental revenue is the biggest advantage of bamboo products. Using the interval valuation method (carbon price 60-300 yuan/ton CO_2), the model calculates that per ton)of bamboo products can bring greenhouse gas emission reduction revenue of 180-900 yuan, waste treatment cost savings of 200 yuan/ton, and marine plastic pollution avoidance benefits of 80 yuan/ton.

(3) Comprehensive cost-benefit analysis

Through 2000 Monte Carlo simulations, the Net Present Value (NPV) distribution and Benefit-Cost ratio (B/C) for bamboo product projects were obtained. Under the baseline scenario, the probability of NPV being greater than zero for bamboo product projects is 82%, and the 90th percentile B/C ratio is 1.68, exceeding the preset policy trigger threshold (Probability NPV>0 is 70%, B/C≥1.5), indicating that "Bamboo as a Substitute for Plastics" has economic feasibility for large-scale promotion. Sensitivity analysis shows that the degree of digital technology application and the comprehensive bamboo utilization rate are the two most critical factors affecting project economics, with elasticity coefficients of 0.38 and 0.42, respectively.

4.2.2. Life Cycle Carbon Emission Calculation under the LCA Model

To quantify the carbon reduction effect of "Bamboo as a Substitute for Plastics," this study uses the LCA method, with "cradle to grave" as the system boundary, to compare the carbon emissions of bamboo products and plastic products over their full life cycle. The assessment scope covers five stages: raw material acquisition, production and processing, logistics and

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transportation, product use, and waste treatment. The functional unit is defined as "producing 1 ton of typical daily goods (represented by tableware)."

(1) Carbon emission calculation results show

The full life cycle carbon emissions of bamboo products are significantly lower than those of plastic products. The carbon emission equivalent per ton of bamboo tableware is 1.2 tons of CO_2, while that of similar polypropylene tableware is 3.2 tons of CO_2. The carbon emissions of bamboo products are only 37.5% of those of plastic products, consistent with the conclusion in the literature [Yuhe et al., 2022] (38%). Looking at stages: bamboo products show negative emissions (-0.8 tons of CO_2) in the raw material acquisition stage due to the carbon sink effect of bamboo forests (carbon sequestration 5.2 tons of CO_2/hm^2·year), while plastic products emit 1.5 tons of CO_2 due to crude oil extraction and refining; in the production and processing stage, bamboo products have higher energy consumption, emitting 0.9 tons of CO_2, compared to 1.2 tons for plastic products; in the waste treatment stage, bamboo products can be biodegraded or incinerated for power generation, with net emissions of 0.3 tons of CO_2, while plastic products, due to difficulty in degradation and greenhouse gas release during incineration, emit 0.5 tons of CO_2.

(2) Regional differences and digital empowerment effects

This study further combined county data and found that regions with high digital economy indices have more significant carbon reduction effects from bamboo products. Digital technology, by optimizing production processes (reducing energy consumption by 15%), improving bamboo utilization rate (from 60% to 72%), and reducing logistics empty load rate (by 12%), further reduces the life cycle carbon emissions of bamboo products to 1.0 ton CO_2/ton, increasing the emission reduction potential by 16.7%.

In summary, cost-benefit analysis shows that "Bamboo as a Substitute for Plastics" has significant economic feasibility, especially after considering environmental benefits, the social net benefit is positive; LCA calculations verify from an environmental perspective that bamboo products have significant carbon reduction advantages throughout their life cycle. Together, they indicate that "Bamboo as a Substitute for Plastics" is not only an effective strategy for addressing plastic pollution but also an important path for promoting regional green and low-carbon transformation and achieving the "Dual Carbon" goals.

4.3. Quantitative Evaluation of the "Bamboo as a Substitute for Plastics" Effect

To comprehensively evaluate the actual effect of "Bamboo as a Substitute for Plastics" in promoting green and low-carbon transformation, this study comprehensively uses panel data regression models and a green development indicator system to conduct quantitative evaluation from multiple dimensions including statistical significance, economic significance, and regional heterogeneity. This section systematically reports the empirical analysis results and regional differentiated performance.

4.3.1. Empirical Results of the Panel Data Regression Model

Based on panel data from 92 counties in the Yangtze River Basin from 2015-2023, this study constructs a two-way fixed effects model, using carbon emission intensity (tons of CO_2/10,000 yuan GDP) as the explained variable, with the core explanatory variables being "Share of Bamboo as a Substitute for Plastics output value" (Bamboo_Sub) and "Digital Economy Index" (Digital_Index), while controlling for variables such as industrialization rate, fiscal self-sufficiency rate, and transportation accessibility. The model form is as follows:

$$Carbon_{it} = \alpha + \beta_1 Bamboo\_Sub_{it} + \beta_2 Digital\_Index_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

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Where, μ_{it} is the individual fixed effect, λ_t is the time fixed effect, and X_{it} is the set of control variables.

The regression results show that for every 1 percentage point increase in the "Share of Bamboo as a Substitute for Plastics output value," county carbon emission intensity significantly decreases by 0.24% ($p<0.01$), indicating that the substitution of bamboo products for plastics has a significant carbon reduction effect. For every 1 unit increase in the digital economy index, carbon emission intensity decreases by 0.18% ($p<0.05$), confirming the boosting role of the digital economy in green production and consumption. Particularly noteworthy, the coefficient of the interaction term between the digital economy and "Bamboo as a Substitute for Plastics" (Bamboo_Sub × Digital_Index) is negative and significant (-0.09, $p<0.05$), indicating that the digital economy can enhance the carbon reduction effect of "Bamboo as a Substitute for Plastics," i.e., digital technology empowerment of the bamboo industry further improves emission reduction efficiency.

To overcome endogeneity issues, the model lagged the explanatory variables by one period and used the instrumental variable method (using the neighboring county mean of the digital economy index as the instrument) for re-estimation, and the results remained stable. The Hausman test supported the fixed effects model, and the R^2 was 0.712, indicating good model fit.

4.3.2. Scoring and Regional Differences of the Green Development Indicator System

Drawing on the National Development and Reform Commission's "Green Development Indicator System" and the OECD's local green growth framework, this study constructed a county green development indicator system containing 3 categories and 10 indicators, and scored the 92 sample counties (2023 data). All indicators were percentile standardized and summed with equal weights, with a total score range of 0-100. A higher score indicates a higher level of green transformation.

(1) Overall scoring situation

The average score of the green development index for sample counties was 68.3 points, the median was 69.1, the minimum value was 42.5 (a county in Sichuan), and the maximum value was 86.2 (Anji County, Zhejiang), showing strong regional heterogeneity. Among the three major categories of indicators, resource utilization efficiency had the highest score rate (72.5%), environmental quality improvement was next (65.8%), and the low-carbon development dimension had a relatively low score rate (61.2%),indicating that bamboo-producing areas still have room for improvement in energy structure and carbon sink management.

(2) Regional difference analysis

Based on index scores, sample counties were divided into three tiers: high level (≥75 points), medium level (60-75 points), and low level (<60 points). Among them, high-level counties accounted for 22.8%, mainly distributed in digitally advanced regions with high levels of bamboo industry intensification like Zhejiang and Fujian; medium-level counties accounted for 53.3%, mainly in Hunan and Jiangxi; low-level counties accounted for 23.9%, mostly concentrated in upstream regions like Sichuan and Hubei. Further analysis of variance (ANOVA) found significant differences in the green development index between different tiers ($F=38.67$, $p=0.000$).

(3) Association analysis between green index and "Bamboo as a Substitute for Plastics"

Using the green development index as the explained variable in regression, it was found that for every 1 percentage point increase in the "Share of Bamboo as a Substitute for Plastics output value," the green index significantly increased by 0.33 points ($p < 0.01$), and it was most sensitive in the two dimensions of resource utilization efficiency (comprehensive bamboo utilization rate, energy consumption per unit GDP) and low-carbon development (carbon

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emission intensity, bamboo forest carbon sink). The moderating effect of the digital economy was also significant. The marginal contribution of "Bamboo as a Substitute for Plastics" to the green index in high-level digital counties was 42% higher than in low-level counties.

The results indicate that "Bamboo as a Substitute for Plastics" not only directly brings carbon reduction effects but also significantly enhances the comprehensive level of regional green transformation, and the higher the level of digital economy development, the stronger the promoting effect. The regional difference analysis provides an empirical basis for subsequently formulating differentiated policies according to local conditions.

5. Conclusion

5.1. Verification of the Digital Economy's Empowering Role for "Bamboo as a Substitute for Plastics"

Based on panel data from 92 bamboo-rich counties in the Yangtze River Basin from 2015-2023, this study systematically verified the comprehensive empowering role of the digital economy on the "Bamboo as a Substitute for Plastics" industry through the SARAR spatial econometric model, cost-benefit analysis, and mechanism decomposition. This role presents a three-dimensional characteristic of "direct driving - spatial spillover - multi-path synergy."

From the perspective of direct effects, the digital economy has a significant positive driving effect on the development of the local "Bamboo as a Substitute for Plastics" industry. SARAR model estimation results show that for every 10% increase in the digital economy index, the share of "Bamboo as a Substitute for Plastics" industry output value in the total forestry output value of the county significantly increases by 2.1% ($p<0.01$). This effect is more prominent in regions with higher digital infrastructure coverage (digital coverage degree ≥ 0.42), confirming the "threshold effect" of digital technology on enterprise development—when digital infrastructure reaches a certain level, its empowering efficiency for the bamboo industry achieves a leap-forward improvement. Further analysis found that the direct empowerment of the digital economy is mainly achieved through two core mechanisms: on one hand, big data and IoT technology optimize the whole-chain scheduling of bamboo harvesting, transport, processing, and logistics. In sample counties, regions with high digital technology application rates saw an average increase of 12.7% in comprehensive bamboo utilization rate, with raw material loss and transportation costs decreasing by 10%-15% year-on-year; on the other hand, e-commerce platforms and digital finance break the market boundaries of traditional bamboo products. In 2023, online sales of bamboo products in the Yangtze River Basin increased by 34% year-on-year, with counties having high digital financial support rates growing 18 percentage points faster than traditional regions, effectively solving the bottleneck problems of "difficult sales and expensive financing" for small and medium-sized enterprises.

From the perspective of spatial spillover effects, the empowerment of the digital economy for the "Bamboo as a Substitute for Plastics" industry has significant regional synergistic characteristics. The spatial lag term coefficientρin the SARAR model is significantly positive (0.184, $p<0.05$), indicating that for every 10% increase in the digital economy development level of neighboring counties, the output value of the local bamboo products industry can be driven to grow by 1.3%, with a total effect (direct effect + indirect effect) reaching 3.4%. This spatial spillover is most obvious in county clusters with close industrial chain linkages, such as the core bamboo industry areas of Nanping, Fujian, and Anji, Zhejiang, which have formed a synergistic network of "digital technology sharing - unified production standards - interconnected market channels." The underlying logic is that the digital economy reduces the cost of technology imitation and knowledge diffusion. Experiences in applying intelligent processing equipment and e-commerce marketing models from neighboring counties can be quickly replicated through online platforms, while cross-regional digital traceability systems achieve unified certification of bamboo quality, further strengthening the regional industrial synergy effect.

From the perspective of multi-dimensional empowerment paths, the digital economy not only promotes the scale expansion of the "Bamboo as a Substitute for Plastics" industry but also drives its quality upgrade and green transformation. At the technological innovation level, the digital economy promotes the popularization of environmentally friendly processes and intelligent equipment. Among sample counties, bamboo processing enterprises with higher levels of digital access had an average R&D investment intensity 2.3 percentage points higher than traditional enterprises, and the application rate of green technologies such as bio-based adhesives and bamboo fiber modification increased by more than 20%; at the consumption transformation level, digital marketing methods such as social media and e-commerce live streaming significantly enhance consumer awareness and acceptance of "Bamboo as a Substitute for Plastics" products. Questionnaire surveys show that consumers with high frequency of exposure to digital marketing have a purchase intention for bamboo products 18.5% higher than the general group and are willing to pay a 10%-15% premium for green attributes; at the management efficiency level, the introduction of digital platforms enables visual management of the entire life cycle of the bamboo industry. Some pilot counties, through the "bamboo forest carbon sink + digital monitoring" model, have improved carbon sink measurement accuracy to over 90%, laying a data foundation for subsequent carbon trading and green finance empowerment.

In summary, the empowerment of the digital economy for "Bamboo as a Substitute for Plastics" is not a single-dimensional technology overlay but rather achieves quality upgrading through direct driving to improve local industrial efficiency, spatial spillover to promote regional synergy, and multi-path synergy, forming a trinity empowerment system of "technology-market-management." This conclusion not only fills the gap in existing research on the "interaction mechanism between the digital economy and the bamboo industry" but also provides empirical support from the county scale for "digital + green" industry integration.

5.2. Carbon Reduction Effects and Promotion Value of "Bamboo as a Substitute for Plastics"

Through life cycle assessment (LCA), panel data regression models, and cost-benefit analysis, this study systematically quantified the carbon reduction benefits of "Bamboo as a Substitute for Plastics" from three dimensions: environmental benefits, economic feasibility, and regional adaptability, and verified its value and conditions for large-scale promotion, providing a precise basis for green industry policies under the dual carbon goals.

From the quantitative results of carbon reduction benefits, "Bamboo as a Substitute for Plastics" has significant low-carbon advantages throughout its life cycle, and the empowerment of the digital economy can further amplify this effect. Calculations based on the LCA model show that, using typical daily goods (tableware) as the functional unit, the full life cycle carbon emission equivalent per ton of bamboo products is 1.2 tons of CO_2, only 37.5% of that of similar polypropylene plastic products (3.2 tons of CO_2), with an emission reduction magnitude of 62.5%. Decomposing by stage reveals that this emission reduction advantage mainly stems from two core links: first, in the raw material acquisition stage, bamboo forests have a significant carbon sink function (annual carbon sequestration per unit area 5.2 tons of CO_2/hm^2), resulting in negative emissions of -0.8 tons of $CO_2$for bamboo products in this stage, while the crude oil extraction and refining stage of plastic products emits 1.5 tons of CO_2; second, in the waste treatment stage, bamboo products can be naturally degraded or recycled through biomass energy for carbon cycling, with net emissions of only 0.3 tons of CO_2, far lower than the 0.5 tons of CO_2generated by incineration or landfilling of plastic products. It is worth noting that the integration of the digital economy further enhances the carbon reduction

ISSN: 2710-0723

potential of "Bamboo as a Substitute for Plastics"—digital technology, by optimizing production processes (reducing energy consumption by 15%), improving material utilization rate (from 60% to 72%), and reducing logistics empty load rate (by 12%), further reduces the life cycle carbon emissions of bamboo products to 1.0 ton of CO_2/ton, improving carbon emission efficiency by 16.7% compared to non-digitally empowered regions.

From the perspective of economic feasibility, "Bamboo as a Substitute for Plastics" has significant promotion value after considering social costs and environmental benefits, and the digital economy can effectively lower its promotion threshold. Cost-benefit analysis (CBA) based on the social cost perspective shows that although the one-time investment in the initial substitution stage (equipment upgrade, process transformation) for bamboo products is 15%-20% higher than for plastic products, its comprehensive revenue advantage gradually emerges over the full life cycle (2025-2035): on the operating cost side, digital technology empowerment reduces the unit operating cost of bamboo products to 78% of that of plastic products; on the revenue side, the resource saving revenue of bamboo products (saving about 1200 yuan per ton in resource costs such as crude oil and electricity) and environmental revenue (180-900 yuan per ton from greenhouse gas reduction, 200 yuan waste treatment cost savings) are significantly higher than those of plastic products. Through 2000 Monte Carlo simulations, it was found that under the baseline scenario, the probability of a positive Net Present Value (NPV) for "Bamboo as a Substitute for Plastics" projects is 82%, and the 90th percentile Benefit-Cost ratio (B/C) reaches 1.68, both exceeding the preset policy trigger thresholds (Probability NPV>0 is 70%, B/C≥1.5), indicating that it meets the economic conditions for large-scale promotion. Sensitivity analysis further points out that the degree of digital technology application (elasticity coefficient 0.38) and the comprehensive bamboo utilization rate (elasticity coefficient 0.42) are key variables affecting project economics, which also means that improving industrial efficiency through digital empowerment can further enhance the economic competitiveness of "Bamboo as a Substitute for Plastics."

From the perspective of regional promotion value and adaptability, the carbon reduction benefits and economic value of "Bamboo as a Substitute for Plastics" show significant regional heterogeneity, requiring differentiated promotion strategies based on local endowments. Evaluation based on the green development indicator system shows that the average score of the green development index for sample counties is 68.3 points. Among them, in regions with advanced digital economies and high levels of bamboo industry intensification, such as Zhejiang and Fujian (e.g., Anji, Zhejiang, index 86.2 points), the carbon reduction elasticity of "Bamboo as a Substitute for Plastics" (the decrease in carbon emission intensity per unit increase in output value share) reaches 0.32%, significantly higher than that in upstream regions like Sichuan and Hubei (average 0.18%). The panel data regression model further verifies that for every 1 percentage point increase in the "Share of Bamboo as a Substitute for Plastics output value," county carbon emission intensity significantly decreases by 0.24% ($p<0.01$), and this effect is further amplified in regions with high levels of digital economy (interaction term coefficient -0.09, $p<0.05$). From the perspective of regional adaptability, the promotion of "Bamboo as a Substitute for Plastics" can be divided into three priority categories: The first category is the core bamboo industry areas in the middle and lower reaches of the Yangtze River (e.g., Zhejiang, Fujian), which can rely on the advantages of the digital economy to focus on developing high-value-added bamboo products (e.g., bio-based packaging, bamboo fiber composites), creating a "digital + green" industrial cluster; The second category is traditional agricultural areas in the middle reaches (e.g., Hunan, Jiangxi), which can focus on disposable bamboo products (e.g., straws, meal boxes), connect with consumer markets through e-commerce platforms, and simultaneously utilize bamboo forest carbon sinks to realize ecological value transformation; The third category is upstream ecological protection areas (e.g., Sichuan, Hubei), which need to control bamboo harvesting scale, focus on developing

ISSN: 2710-0723

bamboo cultural tourism and carbon sink trading, and achieve a balance between ecological protection and industrial development through digital monitoring.

In summary, "Bamboo as a Substitute for Plastics" is not only an effective means to address plastic pollution but also an important lever for green industry transformation under the dual carbon goals-its full life cycle carbon reduction magnitude exceeds 60%, and it possesses economic feasibility and regional adaptability under digital economy empowerment. This conclusion provides empirical support for the implementation of the national three-year action plan for "Bamboo as a Substitute for Plastics" and also provides a quantitative basis for local governments to formulate differentiated green industry policies.

Acknowledgments

This study was supported by the National College Student Innovation Training Project of Anhui University of Finance and Economics (Project No. 202410378231).

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