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Deconstruction of China's agricultural bioeconomy policies in the context of sustainable systems transition – Based on policy texts analysis

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Abstract: Countries are calling for a sustainable transition of agri-food systems due to the volatility of food security in the context of climate change, and the agricultural bioeconomy may be a more dependable solution. By capturing, coding, and displaying word clouds of Chinese agricultural bioeconomy policy texts, this study deconstructs the development framework of China's agricultural bioeconomy policies based on the agricultural biosystem dimension, the policy instrument dimension, and the comprehensive dimension. It concludes that there is a clear trend of sustainable transformation and cross-sectoral linkage in China's agricultural bioeconomy policies. Overall, China's agricultural bioeconomy policies have the following comprehensive features: first, the policy is deeply integrated, considering both economic development and environmental friendliness; second, the policy is safety-oriented, taking into account competitiveness and strategy; and third, the policy is innovation-driven, taking into account fundamentality and foresight. Efforts should be made in the future to enhance the competitiveness of the agricultural bioeconomy within the framework of an all-encompassing approach to food and to help China's agricultural bioeconomy on the road to sustainable transition by improving fiscal and tax support, advocating the use of financial instruments, creating an alliance for the agricultural bioeconomy, and promoting international trade exchanges and cooperation.

Keywords: bio-economic agricultural; systematic sustainable transformation; public policy

The continued deterioration of global food insecurity is largely attributable to a vicious cycle of geopolitical conflict, climate change and economic recession (FAO; IFAD; UNICEF; WFP; WHO 2024). The efficiency of the sustainable use of agricultural resources, a central tool in the fight against climate change, needs to be further improved, with value added in agriculture increasing by 84% between 2000 and 2021 to reach USD 3.7 trillion. At the same time, however, pesticide use increased by 62%, agricultural land was reduced by 86 million hectares, and greenhouse gas emissions from agri-food systems increased by 10% (FAO 2023a). Therefore, against the backdrop of climate change and food security demands, the sustainable transition of agri-food systems is urgent, with agricultural biotechnology emerging as a vital engine of innovation and a catalyst for steering the transition to greater sustainability (FAO 2023b).

The urgency of the future demand for food, fibre and biomass energy has led to a gradual increase in the attention paid by international organisations and countries to bio-economy policies, with the 19th G20 Summit

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in 2024 making the bio-economy a highlight of the summit, and convening the Bio-Economy Initiative in the first instance, to promote bio-economy strategies to achieve a sustainable transition to a circular bio-economy. Bioeconomy competition among countries is also intensifying, accelerating the seizure of the bioeconomy commanding heights through the strategic layout of the agricultural bioeconomy, such as the EU's 2020 European Green Deal for the farm-to-table strategy, the Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Secure and Competitive Future of the United States in 2022, and the 14th five-year plan for bioeconomic development of China (hereinafter referred to as the Plan), which aims to achieve sustainability in agriculture and food systems and to promote a comprehensive green transition in the agricultural sector.

In the face of the urgent need for sustainable agricultural transition and the intense international competition in the bioeconomy, it is reasonable and necessary to study the logical thinking, framework setting and development characteristics of China's bioeconomy strategy in sustainable agricultural transition policies, and to provide a relatively novel prospective investigation for developing countries to use bioeconomy strategy to find their position and enhance their competitiveness in agricultural transition. The main question addressed in this study is: what are the types and trends of agricultural bioeconomy policies in China based on the dimensions of agri-bio systems and policy instruments? Addressing this question helps us to interpret the strategic vision and policy system architecture of China's agricultural bioeconomy. The goal of our study is to provide some evidence on the quantification of policy texts for research on agricultural bioeconomy policies and to help comparative analyses among countries.

Literature review

Characterisation and conceptual research of the agricultural bioeconomy. The bioeconomy originated from the molecular-genetic revolution caused by genomics, and the combined development of 'biotechnology' and 'economy' has led to the reorganisation and convergence of industries such as pharmaceuticals and health, agricultural and food, energy and environment (Enríguez 1998). This multidimensional nature of industrial convergence has led to a tendency for the industrial technology oriented stream to focus on research and innovative applications of biotechnology (The White House 2012), whereas the public goods oriented stream focuses more on the use of renewable energy resources in conjunction with agro-ecosystems, and in the perspective of agricultural transition, on the production of biofuels as well as food and fibre (Ganesh 2008), the focus is more on the link between bioeconomy and energy saving and emission reduction, green product manufacturing, and green transition of the economy (European Parliament 2012).

In addition to the sustainable inter-industry integration mentioned above, the agricultural bioeconomy is also characterised by cross-sectoral linkages between systems. The agricultural bioeconomy encompasses new food systems, bio-based resource systems and environmental ecosystems, and the gradual deepening of development will lead to the dilution of industry boundaries (Deng et al. 2017). For example, food-water-energy or biomass-bioresources-waste stream system cycle linkages can contribute to the sustainable development of agricultural systems (Rosegrant et al. 2013; Muizniece et al. 2016; European Commission 2018).

Therefore, combining the views of many scholars and research organisations, the agricultural bioeconomy can be defined as a sustainable economy that uses cutting-edge biotechnology as the driving force for innovation, is based on the protection, exploitation and utilisation of biological resources, and makes use of renewable biological resources, highly efficient bioprocesses and eco-industrial clusters to achieve multi-industry integration and cross-sectoral linkage development.

Research on mechanisms of the agricultural bioeconomy to advance a sustainable transition. First, based on the perspective of improving the cost and environmental benefits of the plantation industry, agricultural biotechnology can drive breeding, agricultural materials and other links to improve production quality and land use efficiency, thus reducing the input costs of traditional plantation industry (Dale et al. 2010; O'Brien et al. 2015). The integration of perennial biomaterials into food production systems can reduce the greenhouse gas effect of agriculture and contribute to a sustainable transition to a 'net-zero' agricultural bioeconomy (Giacomelli and Schneider 2008; Ni et al. 2021). However, this also poses a dilemma in terms of the choice of land for food and biomass cultivation and requires a balanced relationship between agricultural space (Pfau et al. 2014; Grossauer and Stoeglehner 2020). Secondly, based on the perspective of recycling efficiency enhancement through industrial undertaking synergy, agricultural biomass, matter and energy as important raw materials for the bioeconomy, and its recycling and externalisation process can help to promote the effective interface between agricultural bio-systems and the food and materials industries to achieve sustainable supply of bioproducts and to solve

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the regional green transition dilemma (Simon-Rojo 2023; Tardy et al. 2023; Galiana-Carballo et al. 2024). Thirdly, based on the perspective of ecosystem upgrading in the transition to renewable energy sources, utilising the biomass potential of agricultural waste contributes to cleaner agricultural production and is an effective pathway to gradually complete energy substitution (Askarova et al. 2022; Liobikiene et al. 2023).

Agricultural bioeconomy strategy and policy research. The highly political nature of agricultural bioeconomy strategies determines that governments are crucial in the process of sustainable transition (Hausknost et al. 2017), and different strategic visions of the bioeconomy (biotechnology, bioresources, and bioecology visions) will determine whether the role of government is that of a dominant player or a facilitator (Bosman and Rotmans 2016; Scordato et al. 2017). The policy framework for the agricultural bioeconomy under the concept of sustainable transition places the mix of supply-side and demand-side policies at the centre of accelerating the speed and quality of transition (Marvik and Philp 2020). Specific policy studies for the agricultural bioeconomy are more abundant, mainly focusing on the intellectual property rights perspective, which creates external positives for the agricultural bioeconomy through the provision of public research grants, R&D subsidies etc. (Ollikainen 2014); the regional co-operation perspective, which enhances the effectiveness of innovation co-operation in terms of the talent factor (de Besi and McCormick 2015; Anekwe et al. 2024; Kardung and Drabik 2024); the institution-building perspective, by improving the regulatory environment (Töller et al. 2021), applying fiscal mechanisms to incentivise sustained investment (Zilberman et al. 2013; Meisterl et al. 2024); and the market demand perspective, by improving investment platforms and other investment and financing instruments and the development of carbon trading (Clifton-Brown et al. 2023); and a subsequent focus on policy feedback (Duque-Acevedo et al. 2020; Feindt et al. 2020; Thraen et al. 2020).

Research on agricultural bioeconomy through policy texts. Quantitative analysis of policy texts can transform unstructured textual information into structured quantitative data, which is objective, systematic and quantitative. Existing studies on policy texts related to agricultural bioeconomy are mainly scattered in comparing and analysing policy texts on bioeconomy strategic vision, sustainable development goals, carbon neutrality goals etc. (Ronzon and Sanjuan 2020; Chen et al. 2024; Proestou et al. 2024), while most of the studies from China's perspective focus on the perspective of policy tools and capture the relevant texts of the No. 1 Document of the Central Government to interpret policies related to agriculture and rural areas, such as sustainable transition (Teng et al. 2018) and rural revitalisation (Zhang and Liu 2024), and precise studies of agricultural bioeconomy policy texts have yet to appear.

Research gap of agricultural bioeconomy. As scholars continue to investigate agricultural bioeconomy policies, it can be carried out that the development of bioeconomy policy frameworks emphasises the significance of innovation, cross-sectoral coordination, and regional cooperation; the government must act in line with its strategic vision and moderately alter its role as the transition progresses; and the supporting policies must be backed by a variety of policy tools, and the establishment of investment and financing platforms and the leadership of social groups on the demand side, and so on. It is a general and scientific practice to sort out the policy framework based on the policy text study as there is a research gap in the policy-oriented research on China's agricultural bioeconomy, and how the strategic choice of agricultural bioeconomy policy, policy framework and the characteristics of the policy implementation in the process of China's sustainable system transition are a worthy topic of research.

Theoretical framework

Agricultural bioeconomy is an important guarantee to support national food and energy security and promote the sustainable transition of agri-food systems. The Plan of China emphasises five basic principles: innovation-driven, systematic promotion, win-win cooperation, benefit to the people, and controlled winds, as it shifts from solving the problem of food and clothing to nutritional diversification, developing bio-agriculture for agricultural modernisation in key areas, is a significant symbol of China's scientific planning and systematic promotion of bioeconomy strategies. This section will analyse the policy framework of China's agricultural bioeconomy, based on a realistic and logical analysis of the Plan from the perspective of core contents and policy instruments.

The realistic logic of China's agricultural bioeconomy policies in the systems dimension. According to the Plan, the essence of the agricultural bioeconomy system under China's bioeconomy strategy is to rely on the innovation and iteration of biotechnology, and through the integration of cutting-edge biotechnology and agricultural factors, to improve the quality of agri products, increase the efficiency of green production in agriculture, and strengthen the momentum of green

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and sustainable transition in agriculture. This demonstrates that the strategic vision of China's agricultural bioeconomy is not limited to a particular direction, but is systemic. As shown in Figure 1, the agricultural bioeconomy industry, on the one hand, takes over the bio-food sector, which is in line with 'the big food concept' proposed by China's General Secretary Xi Jinping, and achieves the strategic objective of diversifying food resources and varieties to meet the increasingly diversified food consumption needs; on the other hand, it will continue the bio-energy industry to transform bio-agricultural raw materials to solve the main difficulties of clean agricultural production and rural environment. The following directions have been identified.

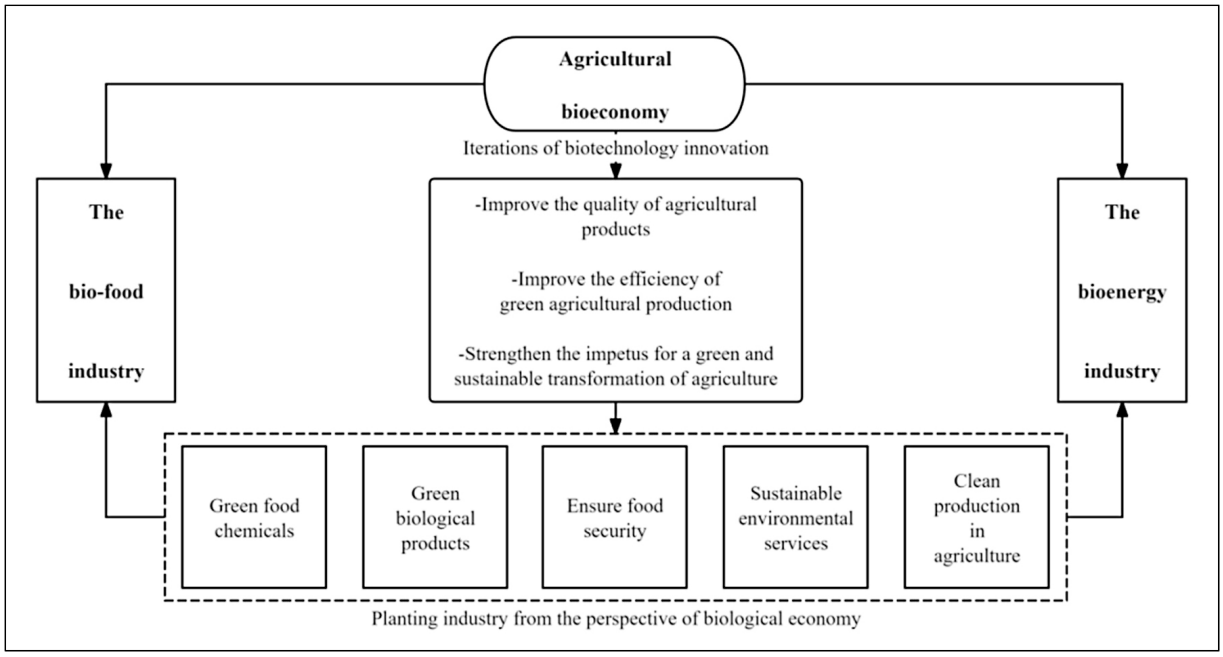

Figure 1. The realistic logic of China's agricultural bioeconomy policies in a system dimension
Source: Authors' own elaboration

The first is the safeguarding of food security, including bio-breeding, improving germplasm resource protection, development and use, and building a more comprehensive whole-chain food safety monitoring system, such as biomass product testing, metrology, standardisation and certification and accreditation services. The second is green biological products, including the demonstration and promotion of green agricultural biological products such as bio-fertilisers, bio-feeds and bio-pesticides. The third is clean agricultural production, including biomass energy development and recycling, which can provide rural residents with cooking and heating energy, also be used as heating fuel for the agricultural product processing industry, facility agriculture and other industries, and to dissipate crop residues, edible mushroom residues, livestock and poultry manure, kitchen waste and other waste materials. Fourth, the green food chemical industry uses corn, cassava, straw and other renewable biological resources, made of polylactic acid and other bio-based, starch-based materials to achieve the purpose of new materials manufacturing. Fifth, sustainable environmental services, through technology development, consulting, exchanges and other activities in bio-agricultural engineering technology research and experimental development services, including bio-fertiliser slow-release, soil pollution bioremediation services, harmless agricultural organic waste elimination and other content.

Theoretical logic of China's agricultural bioeconomy policy in the dimension of policy instruments. As shown in Figure 2, this study adopts the more maturely developed three-dimensional classification of supply-type, environment-type and demand-type policy tools (Rothwell 1985), which downplays the coercive characteristics of government intervention and puts more emphasis on the government's role of creating the environment in the process of policy implementation, which is conducive to exploring the structural nature of policies. Supply-oriented policy tools refer to the government's direct expansion of supply through increased capital investment, facility

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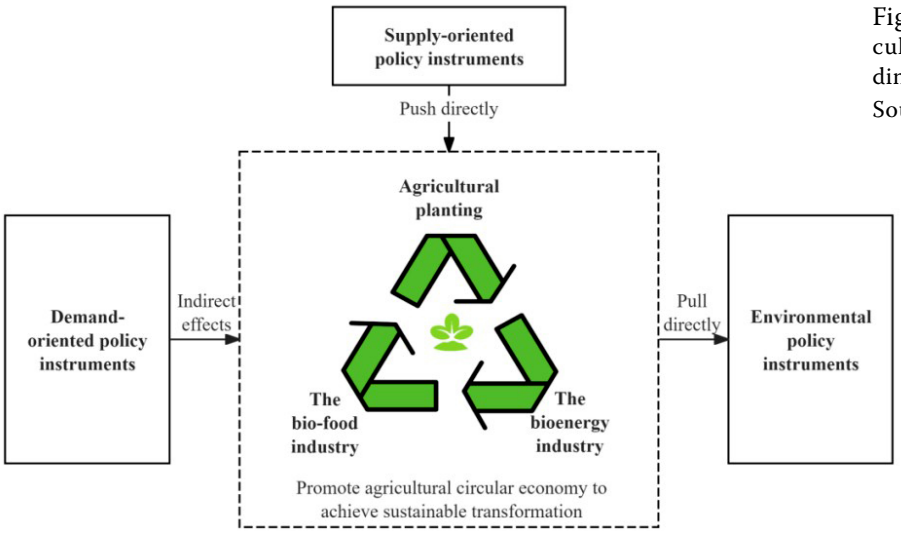

Figure 2. The logic of China's agricultural bioeconomy policy in the dimension of policy instruments
Source: Authors' own elaboration

construction, personnel training, information technology support, environmental remediation, spatial layout optimisation etc., which is the direct driving force for agricultural bioeconomy development. Environmental policy tools mean that the government indirectly provides a favourable development environment for the agri bioeconomy through the formulation of relevant planning, subsidies and other policies, which are specifically divided into target planning, legal regulation, organisational leadership, strategic initiatives, system construction, innovation incentives, financial subsidies and so on. Demand-oriented policy tools refer to the lower degree of government involvement and stimulate the development of the pulling force of demand, specifically including capital participation, social forces, improve the market, and demonstration construction.

The construction of China's agricultural policy framework under dual dimension. Agricultural bioeconomy policy instruments are closely linked to agricultural bioeconomy systems. Supply-, environment-, and demand-based policy instruments drive, influence, and pull various aspects of the agri bioeconomy system, respectively, and thus promote the agricultural bioeconomy towards sustainable development. Based on this, this paper constructs a dual framework from the dimensions of agri-bio system and policy instruments (Figure 3), and the next study will also analyse the policy texts from different perspectives based on this analysis framework.

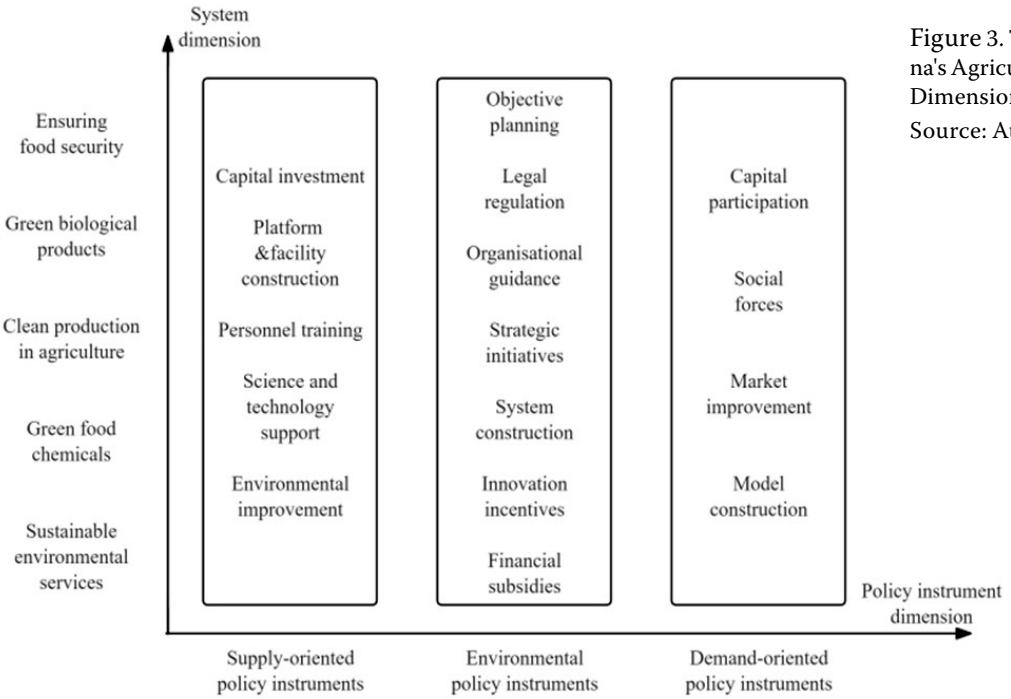

Figure 3. The Frameworks of China's Agricultural Policies in a Dual-Dimensional Context
Source: Authors' own elaboration

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MATERIAL AND METHODS

In this section, this study samples, filters, codes and categorises relevant regulatory texts based on China's agricultural bioeconomy policies in preparation for subsequent quantitative studies of policy texts.

Sampling phase. Since the contents of China's agricultural bioeconomy are more scattered in different types of documents on biotechnology, bioenergy, and agricultural development, this study relies on the PKU-law platform to locate, screen, and categorise them, to construct a textbase of agricultural bioeconomy policies under the perspective of sustainable systems transition. This is done by taking the policies appearing in the same paragraph of agricultural bioeconomy, bio-agriculture, and agricultural biomass as the basis for initial screening, and setting the level of effectiveness of the policies as laws, administrative regulations, departmental regulations, departmental normative documents, and CPC (the Communist Party of China) regulations (Table 1), to judge the characteristics of the policy hierarchy of China's agricultural bioeconomy and the relationship of cross-sectoral coordination, which is the policy of the agricultural bioeconomy as a strategy for the transition of policies. It is also the centre of gravity of the agricultural bio-economy as a strategic transformation policy.

Screening phase. As this study focuses on the sustainable transition of agri-food systems, the policy text data suffered from irrelevant content and duplication of content in the directory category, which required manual cleaning and screening of the data, resulting in 149 policy documents with a high degree of relevance to be used as the base database for word frequency coding.

Coding phase. The work in this stage mainly includes the following: (*i*) manual reading and analysis of the policy texts in the basic database, and disassembling the relevant policy texts into paragraphs, with each paragraph being a piece of data, (*ii*) **f**irst-level coding and assignment of values in ascending order according to the order of effectiveness of the policy, with the laws, administrative regulations (normative documents of the State Council), departmental regulations, and departmental normative documents of the CPC assigned as categories 1 to 5, (*iii*) **s**econd-level coding and assignment of values according to the name of the policy, in ascending order according to the date of publication of the policy, (*iv*) **t**hird-level coding and assignment of values according to the order of paragraphs within the same policy; the overall coding logic is Policy Effectiveness Level Code – Policy Document – Policy Text Content; finally, a total of 359 policy codes were obtained, (*v*) importing the coded texts into the NVivo software for word frequency analysis under

Table 1. Classification of effectiveness levels of Chinese laws, regulations, and documents

Effectiveness levels	Definition
Laws	formulated by the National People's Congress and its Standing Committee, having the highest legal effect
Administrative regulations	formulated by the State Council in accordance with the Constitution and laws, they are normative documents formulated by the State Council for the purpose of enforcing laws and managing national administrative affairs; they have universal binding force and are second only to the Constitution and laws in terms of effectiveness, surpassing regulations and normative documents
Departmental regulations	formulated by the departments, commissions and committees of the State Council and the Audit Office of the State Council in accordance with the laws and administrative regulations, mainly adjusting the administrative relations within the scope of the relevant departments and have higher legal force than departmental normative documents
Departmental normative documents	formulated by departments of the State Council or organizations authorised by laws and regulations to manage public affairs, and their level of authority is lower than that of laws, administrative regulations, and departmental rules
CPC regulations	formulated by the central organisation of the CPC, the Central Commission for Discipline Inspection and the working organs of the Central Committee of CPC and the CPC committees of provinces, autonomous regions and municipalities directly under the Central Government, embodying the unified will of the CPC, regulate the activities of the CPC's leadership and construction, and rely on the CPC's discipline to ensure their implementation

CPC – the Communist Party of China
Source: Authors' own elaboration

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sentiment semantics, which was used as a data source for word cloud presentation.

Categorisation phase. At this stage, China's agricultural bioeconomy policies are classified into three policy tools: supply-oriented, environment-type and demand-oriented, mainly based on the definition of policy tools in the previous section, and frequency statistics of China's agricultural bioeconomy policy tools were formed by matching the policy tools with the agricultural bioeconomy system (Table 2).

From the perspective of policy tool categories, environmental policy tools dominate (50.14%), while supply-side and demand-side policy tools account for 26.18% and 23.68%, respectively. From the perspective of subcategories of policy tools, legal regulation (12.26%), system construction (10.86%), demonstration projects (10.86%), and innovation incentives (9.75%) are the most commonly used policy implementation measures. From the perspective of agricultural bioeconomy system categories, ensuring food security (42.34%) is the absolute core of China's agricultural bioeconomy policies. Green bioproducts, agricultural clean production, and sustainable environmental services are also important policy objectives, while policies currently focused on the green food chemicals sector are relatively scarce. For a multi-perspective in-depth analysis of China's agricultural bioeconomy policies, please refer to next section.

RESULTS AND DISCUSSION

Basic features of China's agricultural bioeconomy policy

Features of the distribution of policy effectiveness levels. In the sampling section of the preliminary research, we classified and screened the departments responsible for issuing agricultural bioeconomic policies in China (see Table 1 for the classification of policy effectiveness levels). The results are shown in Figure 4. The number of releases of Chinese agricultural bioeconomy policies during 2005–2024 basically remained at an annual average of about 10, highlighting the importance attached by the Chinese government. The number of laws and various departmental regulations released is low due to their comprehensive and macro nature, and the Circular Economy Promotion Law of the People's Republic of China (2018 Amendment) clarifies the biomass of circular economy's importance, sectoral regulations emerged in subsequent years as a supplement to the law. The distribution of party regulations is the most stable, mainly attributed to the fact that most of the annual No. 1 Central Documents are related to rural and agricultural development, in which the agricultural bioeconomy plays an essential role. The main sources of policies are the normative documents of the State Council (37 counts) and the departmental normative documents (81 counts) since the departmental normative documents are the further implementation and refinement of the normative documents of the State Council.

Features of the distribution of policy documents by category and source. Agricultural management is, unsurprisingly, the policy category with the deepest involvement in China's agricultural bioeconomy, followed by comprehensive science and technology regulations and institutional reforms, agricultural science and technology and agricultural machinery, national industrial policy, and scientific research and science

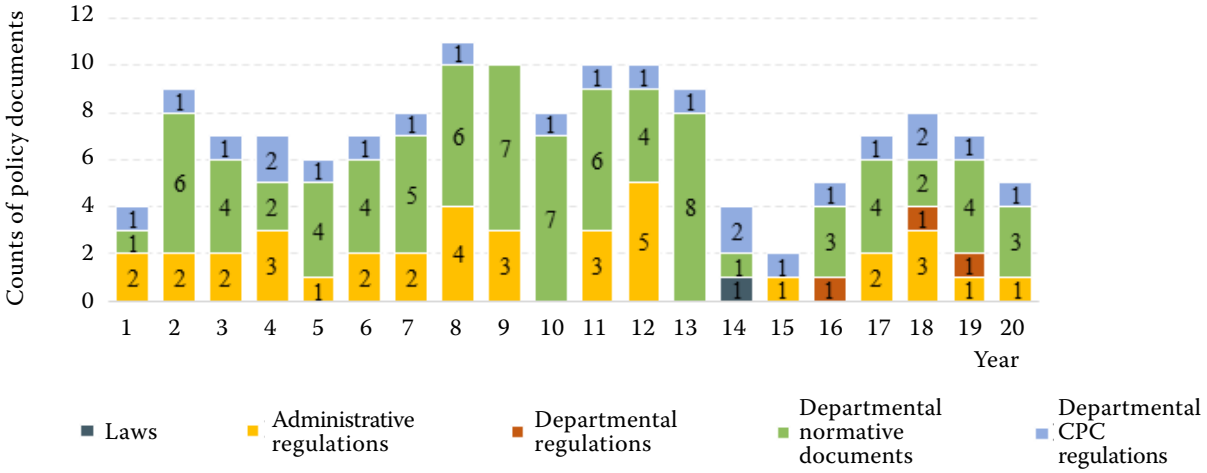

Figure 4. Characteristics of the distribution of policy effectiveness levels
Source: Authors' own elaboration

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Table 2. The frequency statistic table of China's agricultural bioeconomy policy tools

Policy instrument main category	Policy instrument subcategory	Ensuring food security	Green biological product	Cleaner production in agriculture	Sustainable environmental services	Green food chemicals	Subtotal	%
Supply-oriented	capital investment	8	3	1	1	0	13	3.62
	platform & facility construction	12	3	2	6	2	25	6.96
	personnel training	5	3	0	3	1	12	3.34
	science and technology support	17	1	2	1	2	23	6.41
	environmental improvement	6	2	5	8	0	21	5.85
Subtotal	–	48	12	10	19	5	94	26.18
Environmental	objective planning	9	5	3	3	0	20	5.57
	legal regulation	22	9	3	9	1	44	12.26
	organisational guidance	2	1	3	1	0	7	1.95
	strategic initiatives	13	0	13	0	0	26	7.24
	system construction	16	6	8	4	5	39	10.86
	innovation incentives	21	9	2	2	1	35	9.75
	financial subsidies	2	3	3	1	0	9	2.51
Subtotal	–	85	33	35	20	7	180	50.14
Demand-oriented	capital participation	3	2	2	2	1	10	2.79
	social forces	2	1	1	1	4	9	2.51
	market improvement	5	4	10	5	3	27	7.52
	model construction	9	13	5	6	6	39	10.86
Subtotal	–	19	20	18	14	14	85	23.68
Add up the total	–	152	65	63	53	26	359	100.00
(%)	–	42.34	18.11	17.55	14.76	7.24	100	–

Source: Authors' own elaboration

and technology projects (Figure 5). This suggests that the policy priorities of China's agricultural bioeconomy are to complete the overall layout of the agricultural bioeconomy institutional mechanisms from the science technology and industrial perspectives and rely on the driving force of large-scale projects. In addition, the high frequency of documents on rural construction, food management, trade and materials, standardisation, and higher education also highlights the importance of the rural environment, food and trade security, and high-quality human resources in the agricultural bioeconomy. The distribution of policy sources is based on the frequency statistics of 359 coded policy texts, the highest source is the Measures for the Administration of Agricultural Genetically Modified Organisms Safety Evaluation (revised in 2022), which was released in the same year as the Plan, which indicates the coordination of the Chinese government's layout of the agricultural bioeconomy and the implementation of policies. In addition, policy documents with a high degree of origin include the Catalogue of Straw Comprehensive Utilisation Technologies (2014), the Statistical Classification of Agricultural and Related Industries (2020), the Outline of the National Medium- and Long-Term Plan for Scientific and Technological Development (2006–2020), the Specialised High-Tech Industrialisation of Biological Breeding, and the Modern Agricultural Development Plan (2011–2015), which reflect the importance of planning policies and standards-based policies. Planning and standards-based policies are the centre of gravity of policy design for China's agricultural bioeconomy development.

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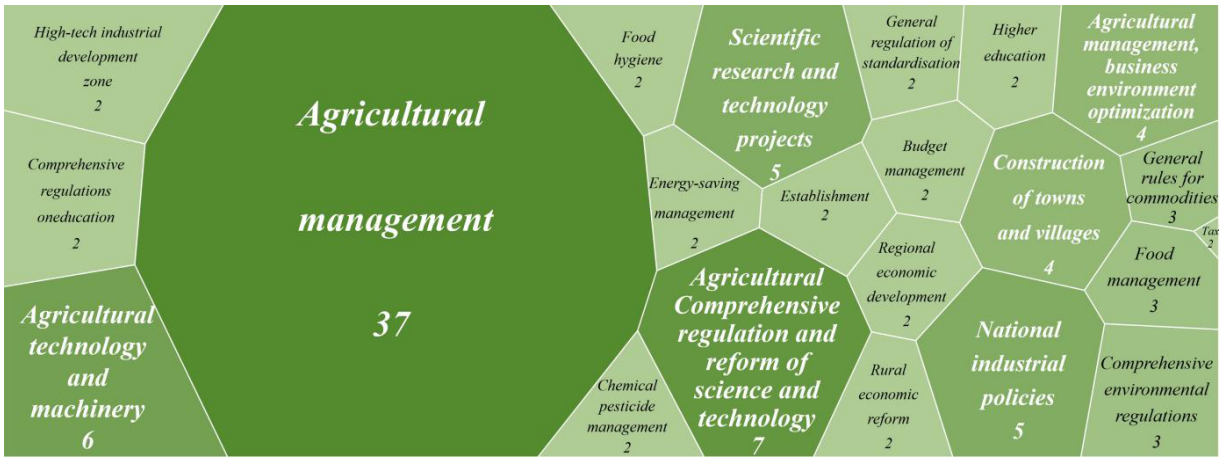


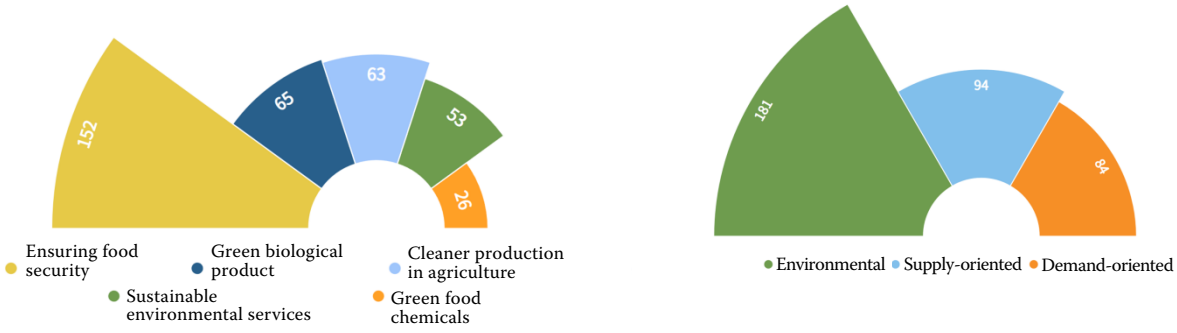
Figure 5. Features of the distribution of policy categories
Source: Authors' own elaboration

Basic features of China's agricultural bioeconomy policy under systematic and policy instrument dimensions

Based on the system dimension and the policy instrument dimension, this study combed the coded entries of policy texts for China's agricultural bioeconomy (Figure 6). Under the system dimension (Figure 6A), the highest policy tilt is the vision of guaranteeing food security, followed by a deeper focus on green bioproducts, cleaner agricultural production, and sustainable environmental services, while there is less policy radiation on green food chemicals. Under the policy instrument dimension (Figure 6B) environment-oriented policies outnumber supply- and demand-oriented policies combined, implying that the policy design intent of China's agricultural bioeconomy is primarily to create a positive and healthy policy atmosphere, with supply-side and demand-side policies to assist from the side-lines.

Characterisation of China's agricultural bioeconomy policy under dual dimensions

Under the framework of the dual dimensions of system dimension and policy instruments (Figure 7), the internal characteristics of China's agricultural bioeconomy policy distribution can be presented more explicitly. From the perspective of the agricultural bioeconomy system dimension, the strategic importance of guaranteeing food security among the five system elements is self-evident and is the underpinning of China's agricultural bioeconomy policies. The policies that account for a higher percentage of these policies are dominated by the environmental support policies of legal regulation, strategic initiatives, system construction and innovation incentives, supplemented by the supply-oriented policies of scientific and technological support and platform construction. Green bioproducts and clean agricultural production indicate the sustainable transition of China's agri bioeconomy, in which



A) System dimension category B) Policy tools dimension category

Figure 6. Policy instruments and policy distribution in agricultural bioeconomy systems
Source: Authors' own elaboration

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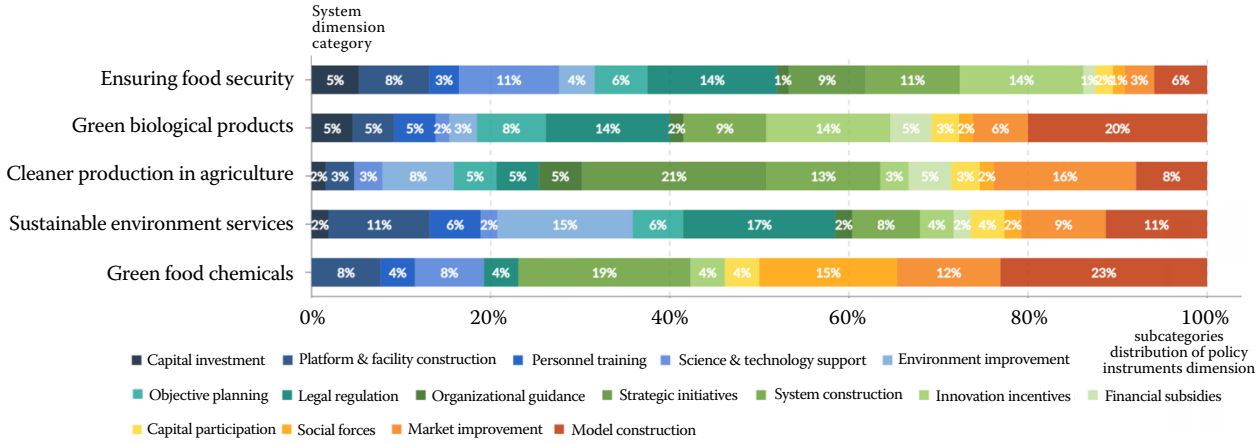

Figure 7. Distribution of agricultural bioeconomy policies in China based on dual dimensions
Source: Authors' own elaboration

green bioproducts embody the current tendency of China's new-quality productivity and kinetic energy transformation, and its 'cutting-edge, intelligent, and green' features are more in line with the policy requirements for green bioproducts. Agricultural cleaner production pays more attention to the improvement of the agro and rural environment by biomass energy conversion, which is more deeply integrated with China's rural revitalisation strategy and helps to promote agricultural carbon emission reduction and ecological environment optimisation. Sustainable environmental services have also been a particular focus of China's agricultural bioeconomy development in recent years, mainly concerning biodiversity conservation and ecosystem connectivity. The relatively low share of green food and chemical policies may be due to the scattered distribution of related policies among several comprehensive policies, which have not yet attracted the attention of well-connected direct policies.

Based on the perspective of policy tools, similar to the frequency distribution pattern, the proportion of environmental policies (green in Figure 7) is dominant, and strong legal regulation and system construction are the solid barriers constructed by the Chinese government, which demonstrates comprehensive and integrated systematic thinking represented by China's state-raising system. In the supply-side policies (blue in Figure 7), the construction of platforms and facilities, together with science and technology, is vital policy support, indicating high reliance on the investment in science and technology to optimise the quality of supply-side policies by improving the construction of platforms and infrastructures and that it needs to supplement the policies related to the investment in capital and the cultivation of human resources in the future. In the demand-oriented policies (yellow in Figure 7), the Chinese government mainly relies on demonstration construction to lead the way, supplemented by initiatives to improve the market to promote market liquidity, and the social forces and capital participation policies may be a bit lacking.

Discussion

Cross-sectoral linkage attributes evident. The word cloud of group institutional attributes of China's agricultural bioeconomy is shown in Figure 8, with the State Council and the Ministry of Agriculture (now the Ministry of Agriculture and Rural Development) being the most involved as the core departments issuing the master plan and related regulations, and the support and control of other national ministries and commissions, such as the

Figure 8. Policy word clouds by sectoral attribute words
Source: Authors' own elaboration

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Ministry of Finance, the Ministry of Science and Technology, the National Bureau of Statistics, and the National Forestry Administration, being an indispensable part of China's policy support for the agricultural bioeconomy. The participation of research institutes, agricultural universities, national defence and customs departments also demonstrates the technological integration and output attributes of the agricultural bioeconomy and the strategic security synergy attributes.

One typical case of cross-departmental coordination in China's agricultural bioeconomy policy is the financial coordination mechanism for seed industry revitalisation. The policy is led by the Seed Industry Management Department and the Planning and Finance Department of the Ministry of Agriculture and Rural Affairs, in collaboration with the Agricultural Bank of China. The coordination mechanism is as follows. In terms of policy formulation, the main measures include jointly issuing the 'Financial Services Plan to Support the Revitalisation of the Seed Industry' and the 'Credit Policy to Support the Revitalisation of the Seed Industry', and establishing 'six major service models' (supply chain finance, government credit enhancement etc.). In terms of the implementation platform, a 'Financial Benefits for Seed Industry Live Broadcast Room' has been established to connect with national seed industry enterprises and provincial-level leading enterprises online, thereby providing a 'direct channel' for enterprise-friendly policies. In terms of capital circulation, through special interest subsidies from the Ministry of Finance and targeted loans from the Agricultural Bank of China, over two hundred billion US dollars in loans and funds were disbursed during the 14th Five-Year Plan period, covering the entire chain of seed company research and development and seed production base construction. The financial coordination mechanism for seed industry revitalisation is of great strategic significance to China's agricultural bioeconomy. It embodies a three-dimensional collaboration between government departments, financial institutions, and enterprises, leveraging fiscal resources to mobilise financial capital and address the critical financing challenges facing the seed industry, thereby directly supporting the implementation of the 'Seed Industry Revitalisation Action Plan'.

Clear policy trends for sustainable transition. Overall, the evolutionary trend of China's agricultural bioeconomy policies can be characterised as a budding period (before 2006), a growth period (2006–2016) and a high-quality transition period (2017–present), with the word clouds for each period brought together in Figure 9.

In the nascent stage of China's agricultural bioeconomy development, the policy focus was mainly on pest control and bioengineering and priority was given to the development of agri-biotechnology engineering through the technological introduction of cutting-edge results of agricultural bioeconomy in developed countries, and the adjustment of the structure of the layout of the life sciences and other basic sciences, so the purpose of technological catching up in the initial stage was relatively straightforward. The introduction of *Bt* insect-resistant cotton technology (from 1997 to 2005) serves as a compelling case study, highlighting the policy approach of 'pest control + biotechnology importation'. The Ministry of Agriculture and Rural Affairs (formerly the Ministry of Agriculture) collaborated with the Ministry of Science and Technology to introduce the *Bt* gene patent from Monsanto in the United States. The technology was then localised and improved by the Cotton Research Institute of the Chinese Academy of Agricultural Sciences. By 2005, domestically produced insect-resistant cotton accounted for 98% of the market share (replacing imported shares). The General Administration of Customs expedited

Figure 9. Policy word clouds by trends in time evolution
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the approval of importing the parent strain, while the Ministry of Finance provided specialised subsidies for seed replacement, forming a policy loop of 'technology introduction-domestic R&D-promotion subsidies'. The nascent Chinese agricultural biotechnology policy demonstrated the characteristic of 'achieving biological pest control through technology introduction', rapidly achieving the commercialisation of engineering achievements through interdepartmental collaboration.

From 2006 to 2016, with the emergence and deepening of research on agricultural bioeconomy in the world, international attention to the development of agricultural bioeconomy was generally high, and several countries began to explore and achieve some cutting-edge results. The pattern of evolution in this period is from biological control to the comprehensive use of microorganisms, on the one hand, technically exploring the role of microorganisms in bio-fertiliser to ensure food security and food safety, on the other hand, applying technological innovation to make microorganisms play a role in the improvement of the ecological environment, to promote the sustainable development. What is also noteworthy in this period is that China's agricultural bioeconomy policy emphasises the unity of the ecological environment, and adjusts the area and structure of agrarian cultivation through measures such as returning farmland to forests, which shows the systematic thinking and prudent development principle of China's agricultural bioeconomy strategy. In addition, during this period, China also began to encourage the development of trading markets for forest rights and carbon sinks using biological resources, to lay out a plan in advance for the bio-economy to open up the value chain. The circular agriculture model in Qingyang City (2008–2015) is a typical example from this period, with policies focusing on the resource utilisation of microorganisms and ecological integrity. Based on the State Council's 'Opinions on Accelerating the Development of Circular Agriculture' (2007) and the National Development and Reform Commission's 'Opinions on the Scientific Utilisation of Forest Land Resources' (2020), the Ministry of Agriculture and Rural Affairs, in collaboration with the National Energy Administration, promoted a closed-loop model of 'agriculture-livestock-fungi' in Qingyang, Gansu Province, with microorganisms serving as the link between 'fruit branches/livestock manure → mushroom logs → edible fungi' (projected annual output value of about 150 million US dollars by 2024). Meanwhile, by combining the 'biogas-forestry carbon sink' matching transaction, the comprehensive utilisation of microorganisms and the marketisation of ecological value can be promoted in parallel, covering resource usage and ecological compensation mechanisms.

After 2017, with the transition of the world economy to sustainability, the Chinese economy also showed a trend of kinetic energy transition to high-quality development, and the strategic position of the agricultural bioeconomy gradually increased. The use of biomass to guarantee food security has become the main line of China's agricultural bioeconomy strategy during this period, with terminology including the high priority given to food security, organic fertilisers, and safety ratings. Currently, the use of gene technology to strengthen biological breeding capacity and the exploration of new green biofarming materials to ensure the quality of food production have become the policy concerns of the Chinese government, in addition, the degradation and conversion of biomass and the exploration of bridging the renewable energy system have also become crucial manifestations of the transition thinking. The National Breeding Joint Research Program for the Four Major Crops is a typical example of this period, with policy priorities focused on leveraging biotechnology to ensure food security and implement end-to-end supply chain management. The Ministry of Agriculture and Rural Affairs led the development of the 'National Breeding Joint Research Program Master Plan', integrating 16 seed companies and 20 research institutions to establish a shared platform for resistance testing. The Ministry of Science and Technology established guidelines for gene editing technology, the Ministry of Finance provided seed production subsidies, and the National Bureau of Statistics established specialised statistical indicators. The policy design directly responded to the central government's initiative of seed industry revitalisation, piloting a results-oriented system for substantial derivative varieties (EDV) to address the issue of homogeneity in the seed industry. This reflects the characteristics of China's high-quality transformation period in agricultural biotechnology, utilising biotechnology innovations in breeding to ensure both quantitative food security (high yields and tolerance to high plant density) and qualitative food safety (disease resistance and low toxicity), thereby achieving the policy objective of upgrading safety level controls.

China's agricultural bioeconomy policy faces external and internal challenges. Facing countries and organisations such as the EU and the US that have already begun to establish agricultural bioeconomy policies, China's agricultural bioeconomy policy framework is under triple external pressure. First, regulatory fragmentation

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barriers: the regulatory systems of Europe and the US are severely at odds (the EU adheres to the precautionary principle and implements full-chain approval, while the US promotes the principle of substantial equivalence and exempts low-risk technologies), forcing Chinese technology exports to bear high compliance costs and weakening China's influence in setting international standards. Second, control over the seed industry supply chain: giants like Bayer dominate global crop patents and use coordinated EU–US policies (EU's high direct payments and US federal insurance) to consolidate their monopolistic positions, exacerbating China's chokepoint issues in seed sources. Thirdly, distorted subsidy rules. The EU and the US jointly oppose the reduction of domestic support under the WTO (the EU maintains 'blue box' payments, while the US implements emergency loans), which lowers international grain prices and weakens the competitiveness of Chinese agricultural products. Additionally, new barriers such as carbon border taxes are squeezing policy space.

Self-reflectively, China agricultural bioeconomy policy framework also faces three internal upgrading challenges. First, the technological R&D system is weak, lacking high-value-added innovations in biological breeding, lagging infrastructure such as microbial germplasm repositories, and insufficient foundational innovation capabilities. Second, there is a competitiveness gap among industry players, with foreign seed companies dominating the high-end vegetable seed market, while domestic firms lag behind multinational corporations in R&D intensity, facing the risk of 'technological marginalisation'. Third, there is a structural lack of transformative momentum, with small-scale farmers exhibiting low awareness of biotechnology and low adoption willingness. Additionally, there is a scarcity of 'new farmers' who possess both scientific literacy and managerial capabilities, highlighting a human capital bottleneck.

Theoretical drivers and practical circumstances reinforce each other. From the perspective of the theoretical driving forces behind agricultural bioeconomy policies, advanced agricultural biotechnology can help reduce planting costs and enhance environmental benefits, while close integration between the primary and tertiary sectors can improve green circular efficiency. The application of biomass potential from agricultural waste can also contribute to the optimisation and upgrading of ecosystems. However, in the design of practical policies, countries often face dilemmas such as the selection of agricultural land and preferences for energy alternatives. This requires nations and organisations to prioritise policies from the perspective of their own agricultural bioeconomy strategic frameworks. China's agricultural bioeconomy policy regime exemplifies an institutionally coordinated, multi-actor governance framework leveraging the vertically integrated state apparatus for enforcement efficacy. Its temporal trajectory, progressing through embryonic (pre–2006), growth (2006–2016), and quality-transformation (2017–present) phases demonstrates strategic sequencing aligned with evolving national priorities. Policy instrumentation across these stages has generated synergistic dividends, reconciling economic productivity with ecological resilience through incentivised technological adoption and institutionalised resource circularity. In terms of germplasm resource conservation and utilisation, China's national agricultural germplasm resource census has collected 139 000 crop resources, 270 000 livestock and poultry resources, and 120 000 aquatic resources, establishing the National Crop and Marine Fisheries Germplasm Resource Repository to meet strategic conservation needs for the next 50 years. In terms of breakthroughs in the industrialisation of biological breeding, the National Breeding Joint Research Program has developed breakthrough varieties such as salt-alkali tolerant wheat and short-maturity winter rapeseed. In 216 national seed production base counties, the coverage rate of high-quality seeds for grain, cotton, oil, and sugar crops has reached over 75%. In terms of agricultural clean production, the 'vegetable waste classification – fermentation into fertiliser – return to fields for carbon reduction' model has reduced fertiliser usage and increased soil organic carbon storage. In terms of sustainable services, emission reduction efficiency has been significant, with the greenhouse gas emission intensity per unit of agricultural GDP reduced to 6.90 tonnes per USD, which is only 25.7% of that in the United States.

Currently, utilising gene technology to enhance biological breeding capabilities and exploring new types of green biological agricultural materials to ensure food production quality have become policy priorities for the Chinese government. In the future, biomass degradation and conversion, as well as exploring the integration of renewable energy systems, may become focal points of China's agricultural bioeconomy policy.

CONCLUSION

Policy trends in China's agricultural bioeconomy

China's agricultural bioeconomy policy is a deeply integrated policy that both economic development and environmental friendliness. Whether it is the cross-sectoral

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linkage emphasised in the policy, the cross-disciplinary layout of agriculture, biology and environment, or the systematic connection and circulation of the food and chemical industry, agricultural cultivation and bioenergy, they all reflect the integration-driven nature of China's agricultural bioeconomy.

China's agricultural bioeconomy policy is a security-oriented policy that balances competitiveness and strategy. On the one hand, China emphasises convergence with the biotechnology level of developed countries, while on the other hand, it stresses the stability and security of internal supply, which reflects the principle of prudent development of China's agricultural bioeconomy strategy.

China's agricultural bioeconomy policy is an innovation-driven policy that has both basic and future-oriented aspects. Embedding the agricultural bioeconomy with China's science and technology innovation development strategy and applying the new quality of productivity brought about by the driving force of science and technology innovation, can inject activity into the development of the agricultural bioeconomy.

Recommendations and research perspectives

In the future, China's agricultural bioeconomy policy will require further improvement of the relevant institutional mechanisms, especially the linkage and circulation with the food and chemical industries and the energy conversion system. Specific initiatives include: continuing to improve biotechnology under the framework of 'an all-encompassing approach to food' to link up the food production and food and chemical industry chain and value chain; increasing the financial support for agricultural bioeconomy, and continuing to improve financial support and tax incentives for agricultural bioeconomy; advocating financial instruments and social groups to assist in the development of agricultural bioeconomy through the creation of an agricultural bioeconomy policy; and promoting financial instruments and social groups to assist in the development of agricultural bioeconomy through the creation of an agricultural bioeconomy policy. Increase the financial support for agricultural bioeconomy and continue to improve the financial support and tax incentives for agricultural bioeconomy; advocate the power of financial instruments and social organisations, and promote the international trade, exchanges and cooperation of agricultural bioeconomy industries and technologies through the creation of the Agricultural Bioeconomy Alliance, to help the sustainable development of China's agricultural bioeconomy.

Research on agricultural bioeconomy strategies and policy frameworks is of considerable value. Future research extensions could explore comparative studies of agricultural bioeconomy policies among Chinese provinces and regions, and perhaps further explore the policy characteristics of intra-provincial and inter-provincial linkages. This will also obtain more detailed case material for studies related to agricultural bioeconomy policies.

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