Development and Implications of the European Union' s Bio-based Research and Innovation System (Postprint)

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Date: 2018-05-16T00:00:00+00:00

Abstract

Bio-based products refer to chemical products and green energy produced from renewable resources (such as agricultural and forestry residues, organic waste, etc.), and due to their environmentally friendly advantages, they have become an important pathway for green and sustainable socio-economic development. In recent years, developed countries such as Europe and the United States have formulated and introduced strategic policies to promote the development of the bio-based industry. The European Commission has provided key policy and financial support for bio-based research and innovation (R&I) projects, gradually forming a management and funding system centered on the BBI (Bio-Based Industries) Initiative. This paper, through investigation and analysis of the funding framework and financial allocation of EU bio-based R&I projects, identifies the specific measures and practical solutions for the EU to achieve its bio-based economy goals, and proposes decision-making recommendations for China' s bio-based innovation actions. Furthermore, as a typical case of R&I system construction for emerging industries in the EU, the BBI Initiative also holds certain reference value for China in reforming its science and technology policies and management mechanisms for other innovation directions.

Full Text

Preamble

Development and Enlightenment of the EU' s Bio-based Research and Innovation System

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Abstract

Bio-based products refer to chemical products and green energy produced from renewable resources (such as agricultural and forestry residues, organic waste, etc.). Due to their environmental advantages, they have become an important pathway for green and sustainable socio-economic development. In recent years, developed countries including Europe and the United States have introduced strategic policies to promote the development of the bio-based industry. The European Commission has provided focused policy and financial support for bio-based research and innovation (R&I) projects, gradually establishing a management and funding system centered on the BBI (Bio-Based Industries) initiative. Through investigation and analysis of the funding frameworks and budget allocation of EU bio-based R&I projects, this paper identifies specific measures and practical solutions for achieving the EU' s bio-based economy objectives, and proposes policy recommendations for China' s bio-based innovation initiatives. As a typical case of R&I system construction for emerging industries in the EU, the BBI initiative also offers valuable reference for reforming science and technology policies and management mechanisms in other innovation areas in China.

Keywords: European Union, bio-based industry, R&I funding system, budget allocation, project implementation

1. Introduction

According to Eurostat survey data, the European bioeconomy generated a turnover of €2.26 trillion in 2014, of which the bio-based economy accounted for €674 billion. The biofuels industry represented 12%, while paper and paper products held the largest share at 27%, followed by forest-based industries at 25% [Figure 1: see original paper]. The European bio-based industry employed 18.3 million people, with forest-based industries hiring the most at 42% of the workforce. Textiles and textile products ranked second at 24%, and paper and paper products third at 17% [Figure 2: see original paper]. The EU possesses a strong socio-economic foundation in science, technology, and industry, and strategically supports the development of the bio-based economy. Since 2014, the EU has supported various R&I projects through technology, research, and innovation investments (such as Horizon 2020), regional cooperation (such as the Bioeconomy Observatory Platform), and collaboration with stakeholders (such as the European Innovation Partnerships). The implementation of these actions constitutes a critical link in ensuring the achievement of the EU' s overall bioeconomy development goals.

2. Multi-dimensional Strategic Framework for the Bio-based Economy

Bio-based R&I projects are supported and guided by the EU' s bioeconomy policy framework system (as shown in [Figure 3: see original paper]). This pol-

icy framework consists of three dimensions: (1) sectoral policies that manage traditional bioeconomy industries; (2) policies with horizontal impacts on the bioeconomy; and (3) policies that directly build and manage the bioeconomy. In the past, European countries had different strategic policies and used different indicators and standards to evaluate the sustainability of the bioeconomy. Although the EU Bioeconomy Strategy was adopted in 2012, other policy actions have also significantly influenced the development path of Europe' s bioeconomy, collectively forming a comprehensive framework system. For example, the Lead Market Initiative (LMI) serves as a decisive policy guiding the bio-based products market and occupies an important position within this framework. The ERA-NETs program, a joint initiative among EU member states during the Seventh Framework Programme period, established the Bioeconomy Observatory Platform to coordinate R&D activities across member states.

2.1 Traditional Sector Policies

The concept of the bio-based economy encompasses traditional agriculture, forestry, and fisheries, as well as many emerging industries. Consequently, various traditional and emerging sectoral policies may be incorporated into the bioeconomy policy framework. The Common Agricultural Policy (CAP) provides financial support for agriculture and forestry economies, which are the primary sources of biomass. Although not legally binding, the 2013 EU Forest Strategy promotes the sustainable development of forestry biomass and the bioeconomy. Meanwhile, the Common Fisheries Policy (CFP) and the Blue Growth Agenda contribute to building a sustainable bioeconomy system by promoting sustainable aquaculture development, particularly through the European Maritime and Fisheries Fund.

2.2 Impact of Horizontal Policies

The bioeconomy policy framework is also influenced by policies across the bioeconomy value chain, including strategies and policies on R&I, climate action, and the circular economy. European innovation policies encompass the Europe 2020 Strategy, the Lisbon Agenda, and the Innovation Union flagship initiative. In fact, the Commission has identified biotechnology as a key technology for strengthening EU innovation and competitiveness. European climate action constitutes an important component of the Paris Agreement in addressing global climate issues, and achieving climate change mitigation goals represents one of the main objectives of a sustainable bio-based economy. Furthermore, European funding programs including "Horizon 2020" have established research and innovation projects for the efficient utilization and high-quality production of biomass. On the other hand, policies aligned with the "circular economy" concept also apply to this framework, such as the Circular Economy Action Plan.

2.3 Standards, Certification, and Labeling

Beyond strategies and policies, standards, labels, and certifications serve as effective regulatory tools for establishing a sustainable bioeconomy. Through EU Mandate M/429, the European Committee for Standardization (CEN) developed the CEN/TC411 standardization program for bio-based products in 2011, covering all aspects of the bioeconomy including consistent terminology, determination of bio-based content in products, life cycle assessment, and sustainability of used biomass.

Labels, particularly eco-labels, constitute important factors related to consumer interests in bio-based products. Currently, the EU does not have a specific label for bio-based products. However, some regions have adopted similar concepts, such as the Nordic Swan and the German Blue Angel. The TC411 standardization program has also developed several standards that will help the industry develop products with higher bio-based content.

3.2 EU Research and Innovation Initiatives

1) Strategic Energy Technology Plan

In 2007, the European Council adopted the 2020 energy and climate change targets, planning to reduce greenhouse gas emissions by 20%, with a conditional increase to 30%. To this end, in November 2010, the European Commission adopted "Energy 2020: A Strategy for Competitive, Sustainable and Secure Energy," which reiterated the 20% emission reduction target by 2020 and proposed immediate implementation of the Strategic Energy Technology Plan (SET-Plan). The Commission strengthened the execution of joint projects by the European Energy Research Alliance (EERA) and major European industrial initiatives such as solar, wind, bioenergy, and nuclear energy, continuing to support the "2010-2020 European Industrial Initiative Technology Roadmap."

In 2012, the SET-Plan specifically formulated the "European Industrial Bioenergy Initiative" to promote R&D and innovation capabilities in biomass energy technologies. The technical objectives included promoting the commercialization of existing technologies and value chains; supporting technology promotion through actions on biomass feedstock feasibility assessment, products, management, and harvesting; and developing long-term R&D plans to support the development of the bioenergy industry.

2) Sustainable Process Industry and Horizon 2020

In December 2013, the European Commission announced eight contractual public-private strategic partnerships, including the Sustainable Process Industry through Resource and Energy Efficiency (SPIRE). The SPIRE initiative and Horizon 2020 share the common goal of building a sustainable process industry through efficient resource and energy utilization. The BBI initiative supports SPIRE and its stakeholders by developing sustainable value chains for the bio-based industry and providing infrastructure support from feedstock to biore-

fineries. Correspondingly, SPIRE assists the BBI initiative and its stakeholders by developing efficient processing methods for energy and feedstock (including fossil-based and bio-based) and preparing processing and manufacturing industries for bio-based construction processes and modules. The BBI and SPIRE initiatives have jointly established mutual support points. The BBI initiative will lead the development of new resource options for bio-based platform chemicals, adding available feedstock packages for SPIRE projects. Meanwhile, SPIRE will develop processes and methods for using bio-based feedstock in production, supporting the achievement of BBI initiative objectives by creating new markets for bio-based products.

From 2014 to 2020, BBI initiative industry partners committed to investing at least €3.7 billion to support bio-based R&D activities. This includes €975 million from the Horizon 2020 budget, with the remaining €2.73 billion financed by the BBI JU through the Bio-based Industries Consortium (BIC) from private enterprises according to Horizon 2020 rules. Office expenses of €585 million are shared equally between BIC and the European Commission.

Based on different project objectives, BBI initiative projects are divided into four categories: Innovation Actions –Flagship Actions (IA-FLAG), Innovation Actions –Demonstration Actions (IA-DEMO), Research and Innovation Actions (RIA), and Coordination and Support Actions (CSA). Their objectives are: (1) RIA projects primarily aim to address technical issues such as feedstock supply, processing, and product strategy routes; (2) IA projects mainly integrate and utilize technologies and research results across value chains, bringing technologies closer to market scale through demonstration and flagship projects.

According to the 2016 BBI project guidelines, IA-FLAG and IA-DEMO projects were adjusted compared to 2014 and 2015. The latter primarily supported projects related to biomass feedstock-based value chains, while 2016 projects shifted from strictly feedstock-driven traditional value chains to strategic pathways that fully respond to end markets in biomass processing. (3) CSA projects mainly address cross-cutting challenges and support value chain construction.

The budget allocation across the four project types is shown in . In overall distribution, IA projects receive the largest proportion, with IA-DEMO projects accounting for 19.63% of total R&D funding and IA-FLAG projects accounting for 61.36%, together exceeding 80% of total funding. RIA projects rank second at 17.31%, while CSA projects receive the smallest share at only 1.7%. This indicates that compared to RIA projects focusing on biorefinery-related technology R&D, IA projects emphasizing technology integration and utilization across value chains receive more funding, suggesting that EU biomass feedstock supply and refining technologies already have a relatively solid foundation, with main challenges concentrated in technology transfer and new value chain construction.

Examining budget distribution within single project categories, IA-DEMO projects allocate significantly more funding to agricultural feedstock (8.98%) than to the other three feedstock types, reflecting the current situation of

food surplus and large quantities of agricultural residues in EU countries. Meanwhile, novel feedstocks such as aquatic biomass, bio-waste, and CO also account for 3.39%, indicating that application technologies for these new feedstocks are gradually maturing. IA-FLAG projects invest most heavily in bio-waste and CO feedstock projects, representing 29.93% and 24.95% of total funding respectively, confirming that the promotion and transformation of these biomass feedstock technologies and the construction and improvement of their value chains will be key focuses of European bio-based industry R&I projects in the coming years.

The annual budget change trends from 2014 to 2017 are shown in [Figure 4: see original paper]. As the initial phase of the initiative, 2014 had the lowest funding investment, with relatively balanced allocation across the three project types excluding CSA, which can be considered an exploratory phase for various actions. 2015 marked the full-scale launch of BBI projects, with funding showing substantial growth and reaching the highest annual investment over the four-year period at €206 million, of which IA-FLAG projects alone reached €100 million, accounting for 48.5%. In 2016, funding for the three innovation project types (excluding CSA) decreased compared to the previous year but remained at a relatively high level, with IA-FLAG projects showing the most significant reduction of over 30%. In 2017, funding decreased even more notably compared to 2016, particularly for IA-FLAG and IA-DEMO projects. This may be because after four years of BBI implementation, technology R&D has gradually matured and demonstration project construction has established a good foundation, with R&D funding investment shifting more toward supplementing and improving existing projects, and the number of new projects consequently decreasing.

4.2 Project Deployment and Implementation

Since 2014, the BBI initiative has launched numerous R&I projects, primarily categorized into value chain demonstration projects, flagship projects, RIA projects, and CSA projects [12,13]. In June 2017, BIC released the BBI initiative impact report, summarizing the overall implementation status during the first three years.

(1) Project Deployment: During its first three years, the BBI initiative approved 65 projects, including 20 demonstration projects and 6 flagship projects. These projects involved 729 institutions from 30 countries, receiving support of €414 million in public funds and €2.15 billion in private funds.

(2) Incentivizing SMEs: Currently, 36% of BBI initiative beneficiaries are small and medium-sized enterprises (SMEs), exceeding the 20% target for Horizon 2020' s Societal Challenges program. These SMEs account for 29% of BBI funding. SMEs work closely with research and technology institutions, providing valuable experience to large industrial enterprises. SMEs are deeply involved in innovative fields such as bioreactor design, process optimization, and novel biocatalysts for biomass processes.

(3) Maximizing Public Funds: Currently, every €1 of public funding is expected to leverage €4.4 in private financial investment. During the first three years, €192 million in in-kind support projects and €195 million in additional funding were released, with total funding far exceeding committed investments.

5. Implications

Through systematic formulation of the bio-based economy policy framework, identification of development strategies, priority areas, and investment budgets with significant EU impact, establishment of "Research and Innovation Partnerships" between public-private and public-public organizational structures to fund R&I projects, and coordination of R&D resources and collaborative relationships among EU member states through innovation cooperation platforms, the EU has achieved overall planning and macro-level guidance for bio-based R&I actions across Europe, effectively ensuring the rapid development of its bio-based industry. The EU' s bio-based R&I project management system offers the following insights:

5.1 Building a Multi-dimensional Policy Framework Centered on Bioeconomy Strategy

The EU framework uses the bioeconomy strategy as its core guiding principle, supplemented by various general policies and related strategies. The EU bio-based economy policy framework encompasses multiple dimensions with different policy implementers and recipients. The Common Agricultural, Forestry, and Fisheries Policies are formulated by the European Commission and member states, managing feedstock sources in the bio-based industry value chain. Therefore, they serve as foundational components in the overall architecture, supporting the implementation of the bioeconomy strategy and other policies. Climate and energy policies and circular economy actions represent top-level design in the framework and are the ultimate goals of the strategy, with all humanity as beneficiaries. The critical link for achieving these goals lies in R&I project implementation, making it the key connecting node in the entire framework. R&I project implementation not only ensures full utilization of biomass feedstock but also serves as the decisive factor in bringing bio-based technologies and products to market, stimulating bioeconomy vitality, and represents an important means for achieving the EU' s CO emission reduction targets.

The EU' s R&I project policy management also demonstrates successful practices. In 2011, the EU established a dedicated technical committee for bio-based products to develop the CEN/TC411 standardization program and created technical specifications and standards for biopolymers and bio-lubricants (Mandate M430). These standards address weaknesses such as unstable bio-based product content and quality while increasing market transparency, enabling bio-based products to gain public recognition and enter consumer purchasing decisions. The "bio-based product-like" labels in Germany and Nordic countries also effectively promote bio-based products and protect consumer rights to information.

5.2 Managing Pan-European Research Resources Based on Innovation Network Systems

During the Seventh Framework Programme period, EU countries had already constructed a unified bio-based science and technology innovation network system—the "ERA-Net Bioeconomy Action"—through the European Research Area (ERA) to coordinate relationships among member states and pool research resources and capabilities. This network unified the release of research programs and consultations, signed cooperation agreements, and coordinated project allocation, allowing member states to concentrate advantageous resources on joint research according to common scientific interests and directions.

This successful experience continued into the implementation of Horizon 2020. Building on ERA-NET, the EU established the "Bioeconomy Observatory Platform," which centralizes all information and data related to R&I activities and makes them accessible to member states. This program has more closely and effectively concentrated forces related to the bio-based industry across EU member states, with more guaranteed policy implementation and significantly enhanced coordination and communication capabilities, effectively ensuring the implementation and deployment of bio-based related programs across EU countries.

5.3 Integrating Innovation Forces Across the Entire Industry Chain Through "Research and Innovation Partnerships"

The "European Innovation Partnerships (EIPs)"first proposed by the EU in 2011 aim to integrate all R&I forces across the bio-based industry chain from different countries, levels, and sectors, achieving certain success in promoting technology market transformation. On October 9, 2017, the European Commission released a mid-term evaluation report on Public-Private Partnerships (PPPs) and Public-Public Partnerships (P2Ps) under Horizon 2020. The results indicated that the research and innovation partnerships established between the EU, private sector, and member states are developing well [15]. The report concluded that these two types of partnerships have strengthened Europe' s capacity for economic growth and quality of life improvement. Through these partnerships, Europe can jointly address challenges that cannot be solved by a single company or country alone. Through Horizon 2020, the EU funded 7 PPPs and 5 P2Ps, including the BBI initiative, with total investment of €19.5 billion over 7 years (€7.3 billion from the EU and €12.2 billion from the private sector and member states).

The BBI initiative has leveraged PPPs to secure substantial private investment while incubating and driving the growth of numerous SMEs during research result transformation. R&I project outcomes have been quickly converted into demonstration projects. This model shortens the distance from laboratory to market and enhances the enthusiasm and capacity of SMEs to participate in innovation.

5.4 Deploying R&I Projects with Technology Transfer and Utilization as Goals

The funding allocation ratios of the BBI initiative over these four years fully demonstrate that its key objectives are supporting priority projects, accelerating technology transfer, and constructing new value chain systems. Using industrialization and marketization as project approval criteria, 80% of total funding was invested in IA-DEMO and IA-FLAG projects. The annual funding trends further reveal that innovation achievements are being rapidly digested and utilized through R&I project implementation, with a batch of technologies gradually maturing and becoming increasingly operational.

In project management, the BBI initiative ensures funding flows to technologies with the highest potential for productivity conversion through project selection and funding allocation changes, thereby improving technology transfer efficiency and quality. Enterprise partner participation also provides funding and platforms for technology transfer utilization. Numerous demonstration projects are led or undertaken by enterprises. For example, the BIOFOREVER demonstration project launched in September 2016 was undertaken by 14 European companies to address various issues facing the refining industry [16]. Similarly, the BioBarr project launched in the same year was led by the renowned bio-based production company Bio-One to develop new sustainable and biodegradable food packaging materials [17]. During project implementation, enterprises not only serve as demonstration plants but also enhance their own research and innovation capabilities through cooperation with technology R&D personnel, with many small and medium-sized innovative enterprises growing through these opportunities.

5.5 Creating an R&I System Suitable for China's Own Characteristics

The EU' s successful experiences, including program frameworks, project deployment, and funding mechanisms, offer important reference value for China. Comparing these with the EU' s BBI priority program can help identify key innovation directions suitable for China' s development and avoid potential risks to some extent.

In recent years, China' s bio-based technology R&D has made considerable progress, yielding a number of world-influential research achievements. The bio-based industry has grown rapidly. According to the "13th Five-Year Plan for Bioindustry Development" [18], "China' s bio-based industry scale exceeded ¥3.5 trillion in 2015," with a target of "exceeding ¥1 trillion in modern bio-manufacturing industry output value by 2020." The plan also identifies deficiencies such as "policy shortcomings that constrain industry innovation development" and "limited groundbreaking and disruptive technological innovations." Therefore, while absorbing and learning from EU advanced experiences, China should explore its own development path. While accelerating the development of traditional bio-based industries, China should foster and cultivate new growth

drivers, promote the enhancement of scientific and technological innovation capabilities in the bio-based industry, and facilitate economic structural transformation. This will gradually form domestic innovation highlands, promote the bio-based industry to move toward the mid-to-high end, and accelerate the formation of new pillar industries for the national economy [19,20].

The EU policy framework is a multi-country framework where each nation has its own bio-based R&I planning and policies. In contrast, China can establish an integrated project management and supervision system, implementing unified strategic planning through "top-down"design and "bottom-up"demand collection, supported by major scientific programs to integrate resources and forces from all parties for focused breakthroughs and collaborative research. Simultaneously, China should strengthen exchanges and cooperation with the EU and other advanced countries, sharing research results and cultivating more outstanding talents through cooperative projects and agreements, focusing on sustainable development strategies such as "Made in China 2025," the "Belt and Road Initiative," and the Energy Development Strategy Action Plan, thereby laying a solid foundation for the sustainable development of China' s bio-based industry.

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Funding Support: This research was supported by the Chinese Academy of Sciences Policy Research Project "International Science and Technology Development Trends Research (ZYS-2017-07)."

Note: Figure translations are in progress. See original paper for figures.