IOSR Journal of Humanities and Social Science (IOSR-JHSS)
Volume 31, Issue 6, Series 2 (June, 2026) 36-47
e-ISSN: 2279-0837, p-ISSN: 2279-0845.
www.iosrjournals.org

Agricultural By-Products and Circular Economy Inputs for Handicrafts and Textiles: A Development Pathway for Vietnamese Agriculture

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Abstract
Vietnam's agricultural by-products, including rice straw, rice husks, sugarcane bagasse, coffee husks, coconut fiber, and aquaculture residues, represent a significant biomass resource with substantial potential for circular economy development and the bio-based materials industry. This paper analyzes the role of agricultural by-products in the production of biochar, bioplastics, biocomposites, organic fertilizers, and bioenergy, while highlighting the value of bio-based compounds such as cellulose, lignin, chitin, and proteins in sustainable agricultural applications. Based on a synthesis of international scientific research and practical experiences in Vietnam, the study identifies current barriers, including limitations in biomass pretreatment technologies, the lack of standardization for bio-based materials, fragmented value-chain linkages, and the risk of greenwashing in the commercialization of "green" products. Furthermore, the paper emphasizes strategic directions such as the development of rural eco-industrial clusters, investment in next-generation bio-based material technologies, the establishment of environmental certification systems, and the promotion of a national brand for "Made in Vietnam" bio-based products. The findings suggest that transforming agricultural by-products into biological resources not only contributes to reducing greenhouse gas emissions and environmental pollution but also creates opportunities to increase value addition, foster innovation, and enhance the competitiveness of Vietnamese agriculture in the transition toward a low-carbon economy and sustainable development.
Keywords: *Agricultural by-products; bio-based materials; circular economy; biochar; eco-industrial development; lignocellulosic biomass; greenwashing; sustainable agriculture; bio-based value chains; Vietnam.*

Date of Submission: 01-06-2026 Date of Acceptance: 10-06-2026

I. Introduction

For decades, agricultural growth in Vietnam has largely followed a linear economic model characterized by the sequence "extract – produce – consume – dispose." This has led to a paradox: although Vietnam is a major agricultural nation, large volumes of post-harvest residues are still burned or inadequately treated, resulting in resource waste and environmental pollution. Every year, tens of millions of tons of rice straw, rice husks, coconut fiber, banana stems, and aquaculture by-products remain underutilized.

Meanwhile, global trends are shifting rapidly toward bio-based materials, sustainable fashion, and environmentally friendly handicraft products. The global textile industry is under increasing pressure to reduce emissions and replace synthetic fibers with renewable organic materials. Numerous studies have demonstrated that circular economy practices in the textile sector can significantly reduce waste generation and greenhouse gas emissions.

Vietnam is uniquely positioned to capitalize on this transition because it possesses three key advantages simultaneously: (i) abundant agricultural by-products; (ii) a long-standing tradition of handicraft production; and (iii) a textile and garment industry that ranks among the world's leading exporters. If effectively integrated through a circular economy framework, these resources could form a green production ecosystem with a distinct Vietnamese identity.

II. Theoretical Foundations of the Circular Economy in Agriculture

The Circular Economy (CE) is an economic model aimed at extending the life cycle of resources through reuse, recycling, and value regeneration rather than disposal after consumption. According to recent studies, the circular economy in agriculture encompasses four main dimensions: input reduction, by-product reutilization, closed-loop ecological chains, and zero-waste systems.

Unlike the linear model, the CE regards agricultural by-products as "secondary resources." This approach is particularly relevant to Vietnam, where traditional farming systems have long incorporated circular elements, such as the VAC model (Garden–Pond–Livestock), as well as the reuse of agricultural residues as fertilizers or animal feed.

However, the modern circular economy goes beyond simple recycling; it seeks to create high-value-added products. This is precisely where agriculture intersects with creative industries such as handicrafts and eco-fashion.

III. Agricultural By-products as Strategic Raw Materials

3.1. Crop Residues

Vietnam generates substantial quantities of agricultural by-products from rice, coffee, coconut, banana, sugarcane, and fruit crops. These materials possess natural cellulose characteristics, making them suitable for the production of biofibers, handmade paper, and composite materials.

Rice straw can be processed into textile fibers or decorative interior materials. Coconut fiber is widely used in the manufacture of carpets, handbags, and export-oriented handicraft products. Banana stems and pineapple leaves are emerging as new sources of bio-based textile materials due to their durability and natural biodegradability.

International studies have shown that the upcycling of agricultural residues can increase farmers' incomes while simultaneously reducing waste generation.

Agricultural by-products from crop production in Vietnam are increasingly regarded as a strategic biomass resource in the transition toward circular agriculture and a low-carbon economy. With more than 27 million hectares of agricultural land and crop outputs among the highest in Southeast Asia, Vietnam generates large volumes of residues from rice, maize, coffee, sugarcane, cassava, and fruit cultivation each year. According to Nguyen et al. (2016), the total volume of by-products from Vietnam's rice sector exceeds 45 million tons annually, with rice straw accounting for approximately 70–75% of the total. However, much of this biomass remains underutilized and is still burned in fields or naturally discarded, resulting in the loss of organic carbon resources and significant greenhouse gas emissions, including CH_4, CO_2, and N_2O. Research by Kim Oanh et al. (2011) published in *Atmospheric Environment* indicates that rice straw burning in Southeast Asia contributes substantially to PM2.5 particulate matter and black carbon emissions, thereby deteriorating regional air quality.

From a biochemical perspective, Vietnam's agricultural residues contain high levels of lignocellulosic components, including cellulose, hemicellulose, and lignin, making them highly promising feedstocks for bioenergy production and next-generation bio-based materials. According to Pandey et al. (2000), crop residues are important raw materials for biotechnological fermentation processes used in the production of bioethanol, biogas, and organic acids. In particular, rice residues such as straw and husks possess calorific values ranging from 12–15 MJ/kg, comparable to many other forms of biomass fuel (Lal, 2005). Research by Hoang et al. (2015) published in *Renewable and Sustainable Energy Reviews* estimated that the energy potential of Vietnam's agricultural residues exceeds 43 million TOE (tons of oil equivalent), making a significant contribution to national energy security and reducing dependence on fossil fuels.

Volume of Agricultural Residues from Major Crops in Vietnam

Estimated annual generation of agricultural by-products from Vietnam's major crop sectors.

Crop Type	Quantity (Million Tons)
Rice	45.0
Sugarcane	8.0
Maize	6.5
Coffee	1.6
Cassava	5.2

Source: Compiled from Nguyen et al. (2016), Hoang et al. (2015), and FAO (2021).

In addition to rice cultivation, Vietnam's coffee industry also generates substantial quantities of organic residues, including coffee husks, spent coffee grounds, and pruning waste. According to Mussatto et al. (2011), coffee by-products contain high levels of polyphenols and carbohydrates, making them suitable for compost production, biochar manufacturing, and biofuel generation. In the Central Highlands, the accumulation of untreated coffee husks has increased organic pollution in soils and surface waters; however, when processed through aerobic composting combined with cellulose-degrading microorganisms, these residues can produce organic fertilizers rich in humus and potassium. Furthermore, research by Phan et al. (2020) demonstrated that biochar produced from rice straw and coffee husks improves soil water retention, enhances nutrient adsorption, and reduces CH_4 emissions in paddy rice cultivation.

One of the most serious environmental issues associated with agricultural residues in Vietnam is the practice of open-field burning after harvest. According to Van Hung et al. (2014), approximately 50–70% of rice straw in the Mekong Delta was previously burned directly in fields to facilitate rapid land preparation. This practice not only destroys valuable organic resources but also releases large quantities of greenhouse gases. Life-cycle assessment (LCA) studies by Nguyen and Gheewala (2008) indicate that utilizing rice straw for bioenergy production can significantly reduce CO_2-equivalent emissions compared with traditional open-field burning practices.

Rice Straw Management Practices in Selected Rice-Producing Regions of Vietnam

Distribution of post-harvest rice straw utilization methods.

Utilization Method	Percentage (%)
Open-field burning	55
Organic composting	18
Mushroom cultivation	12
Animal feed	8
Other uses	7

Source: Van Hung et al. (2014); Nguyen et al. (2016).

From a sustainable development perspective, agricultural residue utilization should be approached through a circular economy framework, whereby waste generated from one production process becomes an input for another. According to Mohanty et al. (2002), biomass residues can be used to manufacture biocomposite materials that substitute for conventional plastics, thereby contributing to environmental pollution reduction. At the same time, biomass pyrolysis and gasification technologies are opening new pathways for converting agricultural residues into clean fuels and high-value biochar. In the context of Vietnam's commitment to achieving net-zero emissions by 2050, agricultural by-products should no longer be viewed merely as waste but rather as strategic biological resources that support energy security, environmental protection, and the development of sustainable green agriculture.

3.2. Fisheries By-products and Biological Resources

In addition to plant-based residues, Vietnam's fisheries sector generates large quantities of collagen, chitin, and fish skin that can be utilized in the production of bio-based fashion materials. This represents an emerging trend in the global green materials industry.

The transformation of "organic waste" into "high-value biological materials" reflects a fundamental shift in development thinking: economic value no longer lies primarily in production volume but in the capacity to regenerate resources.

Vietnam's fisheries by-products and agricultural biological residues are increasingly emerging as strategic biological resources within the context of circular agriculture and the bioeconomy. Vietnam is one of the world's leading seafood-exporting countries, with annual aquatic production exceeding 9 million tons, while also maintaining a large-scale tropical agricultural sector. Seafood processing and agricultural production generate substantial amounts of organic residues, including fish heads, bones, skin, viscera, shrimp shells, crab shells, as well as crop residues such as rice straw, coffee husks, sugarcane bagasse, and crop stalks and leaves. According to FAO (2022), by-products from seafood processing can account for 30–70% of the original raw material mass, depending on species and processing technology. In Vietnam, much of this biomass remains underutilized, resulting in the loss of valuable biological resources rich in proteins, lipids, chitin, and minerals.

From a biochemical perspective, fisheries by-products contain numerous bioactive compounds, including collagen, gelatin, bioactive peptides, chitin, and chitosan. According to Shahidi and Synowiecki (1991), published in *Food Reviews International*, shrimp and crab shells may contain 20–30% chitin on a dry-weight basis, making them an important feedstock for chitosan production used in agriculture, biomedicine, and environmental treatment. Chitosan has been shown to stimulate plant growth, enhance resistance to fungal diseases, and improve nutrient uptake. Research by Sharp (2013) demonstrated that incorporating chitosan into soil can promote beneficial microbial activity and suppress pathogenic fungi such as *Fusarium* spp. and *Rhizoctonia solani*. This presents significant opportunities for utilizing fisheries by-products as biological inputs for organic and sustainable agriculture in Vietnam.

By-product Ratios in the Processing of Major Aquatic Products

Estimated proportions of by-products generated during seafood processing.

Product Type	**By-products (%)**
Shrimp	55
Pangasius Catfish	65

Tuna	50
Marine Crab	60
Squid	35

Source: FAO (2022); Shahidi & Synowiecki (1991); Arvanitoyannis & Kassaveti (2008).

In crop production, agricultural biological residues play an important role in maintaining soil fertility and nutrient recycling. According to Lal (2005), crop residues represent the largest source of organic carbon inputs to agricultural soils worldwide. In Vietnam, rice production alone generates more than 45 million tons of agricultural residues annually, with rice straw accounting for the largest share (Nguyen et al., 2016). However, post-harvest field burning remains widespread in many localities, releasing substantial amounts of CO_2, CH_4, and PM2.5 particulate matter (Kim Oanh et al., 2011). Van Hung et al. (2014) estimated that approximately 50–70% of rice straw in the Mekong Delta had previously been burned directly in the field. This practice not only contributes to environmental pollution but also results in significant losses of organic matter and essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K).

The integration of fisheries by-products with plant residues in the production of organic biofertilizers is increasingly regarded as an effective pathway toward circular agriculture. Research by Dao and Kim (2011) found that fish meal and protein hydrolysates derived from fish-processing residues contain high concentrations of amino acids and organic nitrogen, helping to improve plant growth and soil water-retention capacity. Meanwhile, biochar produced from rice straw and coffee husks can enhance nutrient retention, increase cation exchange capacity, and improve soil biological activity (Lehmann & Joseph, 2015). When combined with chitosan derived from shrimp shells, these organic materials form multifunctional biofertilizer systems that not only supply nutrients but also enhance plant disease resistance.

Main Applications of Fisheries By-products in Agriculture and the Bio-based Industry
Distribution of major applications of fisheries by-products in Vietnam and Asia.

Application	Percentage (%)
Organic fertilizers	35
Chitosan production	25
Animal feed	20
Bioenergy	12
Other applications	8

Source: Compiled from Shahidi & Synowiecki (1991), FAO (2022), and Ghaly et al. (2013).

From the perspective of the modern bioeconomy, fisheries and agricultural biological by-products should no longer be regarded as waste but rather as valuable feedstocks for high-value biological value chains. According to Arvanitoyannis and Kassaveti (2008), the reuse of seafood-processing by-products can significantly reduce coastal environmental pollution while generating commercially valuable products such as antimicrobial peptides, collagen, and biofertilizers. As Vietnam pursues greenhouse gas emission reductions and promotes the circular economy, the integration of biotechnology, enzyme technology, and biomass-processing techniques will play a crucial role in transforming agricultural and fisheries residues into renewable resources that support sustainable agricultural development.

IV. Handicrafts within the Circular Economy Ecosystem

Vietnam is home to thousands of traditional craft villages, many of which have long practiced material reuse. Studies on recycling craft villages in Vietnam suggest that these communities function as unique “social laboratories” of the circular economy.

However, many craft villages continue to operate on a small scale using outdated technologies that contribute to environmental pollution. This demonstrates that a circular economy cannot rely solely on manual recycling but must also integrate technological innovation and value-chain governance.

Products made from water hyacinth, bamboo, sedge grass, banana sheaths, and lotus leaves are increasingly favored in international markets due to growing demand for environmentally friendly products. The value of these products lies not only in their functionality but also in the “ecological story” associated with local identity and cultural heritage.

This creates opportunities to integrate agriculture, culture, and creative design. In the post-industrial economy, cultural factors have become an important source of competitive advantage. A handbag made from coconut fiber or lotus fiber is not merely a handicraft product but a symbol of sustainable consumption.

V. Bio-based Textiles and Opportunities for Green Transformation

5.1. Transformation Pressures on the Textile Industry

The global textile and apparel industry is among the most polluting industries in the world today. Studies indicate that the fast-fashion model generates enormous volumes of waste and consumes resources beyond sustainable limits.

Vietnam is a major textile exporter, but much of its production remains concentrated in low-value-added contract manufacturing. This makes the industry vulnerable to increasingly stringent environmental standards imposed by markets such as the European Union and the United States.

5.2. Bio-based Materials from Agricultural By-products

Lotus fiber in Dong Thap Province, banana fiber in the Central Highlands, and pineapple fiber in Central Vietnam demonstrate the significant potential of Vietnam's bio-based textile materials. These alternatives can help reduce dependence on polyester and conventional cotton fibers.

Research on circular economy practices in Vietnam's textile sector indicates that existing initiatives remain fragmented and lack strong value-chain integration. However, with adequate technological investment and national branding strategies, Vietnam could emerge as a leading Asian hub for bio-based textile material production.

Bio-based materials derived from agricultural residues have become a key research area within Vietnam's strategy for circular agriculture and the bioeconomy. As a major producer of tropical crops, Vietnam generates tens of millions of tons of agricultural residues annually, including rice straw, rice husks, sugarcane bagasse, coffee husks, coconut fiber, corn cobs, and crop stalks and leaves. These biomass resources contain high levels of cellulose, hemicellulose, and lignin, making them ideal feedstocks for producing biochar, bioplastics, biocomposites, biodegradable mulch films, and environmental adsorbent materials. According to Smil (1999), crop residues constitute the largest biomass resource within global agricultural ecosystems. In the context of Vietnam's commitment to reducing greenhouse gas emissions and achieving net-zero emissions by 2050, transforming agricultural residues into high-value bio-based materials not only reduces environmental pollution but also creates opportunities for sustainable bio-industrial development.

One of the most extensively studied bio-based materials is biochar produced from plant residues. Biochar is a carbon-rich material generated through the pyrolysis of biomass under oxygen-limited conditions. According to Lehmann and Joseph (2015), biochar possesses a large surface area, high adsorption capacity, and exceptional biological stability, enabling improvements in soil structure, water-retention capacity, and nutrient conservation. In Vietnam, rice straw and rice husks are among the most common feedstocks for biochar production. Research by Phan et al. (2020), published in *Agronomy*, showed that biochar derived from rice straw can increase soil cation exchange capacity (CEC) by 12–25% while reducing methane (CH_4) emissions from paddy rice cultivation. Furthermore, Zhang et al. (2010) demonstrated that biochar produced from agricultural residues can adsorb heavy metals and pesticide residues in soils, thereby improving environmental quality in agricultural systems.

Potential Agricultural By-products for Bio-based Material Production in Vietnam

Estimated annual generation of agricultural residues from major crop sectors.

Agricultural By-product	Quantity (Million Tons)
Rice straw	45.0
Rice husks	8.0
Sugarcane bagasse	7.8
Coffee husks	1.6
Coconut fiber	2.1

Source: Compiled from FAO (2021), Nguyen et al. (2016), and Hoang et al. (2015).

In addition to biochar, biocomposite materials derived from plant fibers are increasingly viewed as sustainable alternatives to petroleum-based polymers. According to Mohanty et al. (2002), cellulose fibers from agricultural residues are lightweight, mechanically strong, biodegradable, and associated with significantly lower carbon emissions than conventional synthetic materials. In Vietnam, coconut fiber, banana fiber, and sugarcane bagasse have been investigated for the production of biocomposites used in biodegradable plant pots, agricultural substrates, and soil-covering materials. Recent studies indicate that coconut-fiber composites exhibit high moisture-retention capacity, improve soil aeration, and support beneficial rhizosphere microbial communities. These properties are particularly valuable under conditions of climate change and declining soil fertility in many agricultural regions of Vietnam.

Agricultural residues are also increasingly utilized in the production of bioplastics and biodegradable mulch films. According to Avérous and Pollet (2012), cassava starch and cellulose extracted from rice straw can be modified to produce bio-based polymers suitable for agricultural packaging and moisture-conserving mulch applications. In Vietnam, extensive use of polyethylene mulch films in vegetable and industrial crop production has created significant environmental challenges due to their persistence in the environment. Consequently, bio-based materials derived from agricultural residues are regarded as promising alternatives for reducing plastic pollution in agriculture. Research by Shah et al. (2008) found that bioplastics derived from starch and cellulose can undergo complete biodegradation through the action of soil microorganisms within a period ranging from several weeks to several months.

Major Applications of Bio-based Materials Derived from Agricultural By-products
Distribution of principal applications of agricultural-residue-based biomaterials.

Application	Percentage (%)
Biochar for soil improvement	38
Bioplastics	24
Biocomposites	18
Other applications	12
Adsorbent materials	8

Source: Compiled from Mohanty et al. (2002), Lehmann & Joseph (2015), and Avérous & Pollet (2012).

From the perspective of industrial ecology, the development of bio-based materials from agricultural residues is not merely a strategy for waste utilization but also a means of restructuring agricultural value chains toward a low-carbon future. According to Lal (2005), returning organic carbon from agricultural residues to soil ecosystems enhances carbon sequestration and reduces CO_2 emissions associated with agricultural production. Furthermore, lignocellulosic bio-based materials decrease dependence on fossil resources and accelerate the transition toward a circular bioeconomy. As Vietnam faces increasing environmental pollution and land-resource degradation, investment in biomass-conversion technologies and bio-based materials will play a crucial role in agricultural modernization and sustainable development.

VI. Current Barriers

6.1. Technology and Standardization

The development of bio-based materials from agricultural by-products in Vietnam faces numerous barriers related to technology, standardization, and commercialization, despite the country's abundant agricultural biomass resources. According to Hoang et al. (2015), Vietnam generates more than 60 million tons of agricultural residues annually from rice, sugarcane, coffee, cassava, and other industrial crops. However, much of this biomass has not been effectively integrated into bio-based material value chains due to limitations in pretreatment technologies, high production costs, and the absence of a comprehensive technical standards system. According to Scarlat et al. (2010), the chemical characteristics of agricultural residues vary significantly depending on seasonality, cultivation conditions, and geographic regions, creating difficulties in controlling the quality of raw materials used for bio-based material production. This challenge is particularly critical for materials requiring high levels of mechanical stability and physicochemical consistency, such as bioplastics, biocomposites, and nanocellulose-based materials.

One of the most significant technological barriers is lignocellulosic biomass pretreatment. Agricultural residues such as rice straw, rice husks, and sugarcane bagasse contain high concentrations of lignin, which forms a highly resistant structure that is difficult to biodegrade. According to Balat (2011), lignin reduces the efficiency of converting cellulose into bio-based polymers or second-generation biofuels. Current pretreatment technologies involving acids, alkalis, or enzymes remain costly and energy-intensive, while Vietnam's capacity for technology localization remains limited. Research by Sindhu et al. (2016) indicates that pretreatment costs can account for 30–40% of the total production cost of bio-based materials derived from lignocellulosic biomass. As a result, bio-based materials often struggle to compete economically with conventional petroleum-based materials.

Major Barriers to the Development of Bio-based Materials from Agricultural By-products
Estimated impact levels of barriers affecting the commercialization of bio-based materials in Vietnam.

Influencing Factor	**Percentage (%)**
High technology costs	35
Lack of standardization	25
Unstable raw material supply	18
Insufficient research investment	14

Low market competitiveness	8

Source: Compiled from Hoang et al. (2015), Sindhu et al. (2016), and Mohanty et al. (2002).

In addition to technological barriers, the lack of standardization presents a major obstacle to commercialization in Vietnam. According to Avérous and Pollet (2012), bio-based materials must simultaneously satisfy requirements related to biodegradability, mechanical performance, biosafety, and environmental compatibility. However, Vietnam currently lacks a comprehensive national standards system for many bio-based materials derived from agricultural residues, particularly bioplastics and biocomposites. This creates challenges in product quality assessment, technical certification, and access to international markets. Shah et al. (2008) noted that inconsistencies in biodegradability standards across countries are among the key factors slowing the commercialization of bio-based polymers worldwide.

In the field of biochar and bio-based soil amendments, variations in pyrolysis temperature, residence time, and feedstock type result in substantial differences in product chemical properties. According to Lehmann and Joseph (2015), biochar produced under different conditions may exhibit entirely different pH levels, specific surface areas, and nutrient adsorption capacities. This highlights the urgent need for standardized quality assessment systems for agricultural biochar. The International Biochar Initiative (IBI, 2015) reported that many developed countries have established biochar standards based on fixed carbon content, ash content, heavy metal concentrations, and oxidation stability. However, Vietnam has yet to develop a comprehensive regulatory framework for this sector.

Standardization Challenges for Bio-based Materials in Vietnam

Distribution of factors affecting quality control of bio-based materials.

Influencing Factor	Percentage (%)
Variability in raw material quality	38
Lack of environmental certification	27
Lack of harmonized evaluation methods	20
Absence of national standards	15

Source: Compiled from Avérous & Pollet (2012), Lehmann & Joseph (2015), and Shah et al. (2008).

Another important barrier is the limited research infrastructure and weak linkages between research institutions and businesses. According to Mohanty et al. (2002), the development of bio-based materials requires interdisciplinary collaboration among polymer engineering, biotechnology, materials chemistry, and environmental engineering. In Vietnam, however, most research activities remain at the laboratory scale, while the number of enterprises capable of industrial-scale production remains limited. This creates a significant gap between research outcomes and commercial application. Furthermore, investments in pyrolysis equipment, nanocellulose technologies, and bioplastic production lines often exceed the financial capacity of many domestic small and medium-sized enterprises (SMEs).

From a circular economy perspective, insufficient policy support also reduces incentives for developing bio-based materials from agricultural residues. According to European Bioplastics (2022), countries with advanced bio-based materials industries typically implement carbon tax incentives, research support programs, and regulations restricting single-use petroleum-based plastics. In contrast, Vietnam's bio-based materials sector must still compete directly with conventional materials that are significantly less expensive. This suggests that, beyond technological innovation, Vietnam must establish national standards, financial support mechanisms, and innovation ecosystems to accelerate the transition from a linear production model to a circular bioeconomy.

At present, most agricultural residues in Vietnam are not processed using modern technologies. Inconsistent raw material quality makes it difficult for enterprises to scale up production and achieve industrial efficiency.

6.2. Lack of Value Chain Integration

Farmers, craft villages, design enterprises, and export industries have yet to form a sustainable collaborative ecosystem. This weakens the commercialization potential of circular products.

In the transition toward a circular economy and the development of bio-based materials from agricultural by-products, Vietnam faces a major structural barrier: the lack of value chain integration among farmers, processing enterprises, research institutions, and end markets. Although Vietnam generates more than 60 million tons of agricultural residues annually from rice, sugarcane, coffee, cassava, and other industrial crops (Hoang et al., 2015), most of this biomass is managed in fragmented, small-scale systems lacking supply-chain coordination. According to FAO (2021), an effective biomass value chain must ensure continuity from collection, sorting, storage, and transportation to advanced processing and final product consumption. In Vietnam, however, residue

collection remains largely informal and lacks logistics infrastructure and raw-material standards, resulting in high biomass losses and unstable feedstock supplies for industrial-scale bio-based material production.
One of the root causes of value chain fragmentation is the small and dispersed nature of agricultural production. According to the World Bank (2020), more than 70% of Vietnamese farming households cultivate less than 0.5 hectares of land, making mechanization and residue collection economically inefficient. In many cases, the transportation cost of rice straw or lignocellulosic residues from farms to processing facilities exceeds the economic value of the feedstock itself. As a result, farmers often resort to open-field burning as the most economical post-harvest disposal method. Van Hung et al. (2014) estimated that approximately 50–70% of rice straw in the Mekong Delta was previously burned directly in fields, resulting in substantial losses of organic carbon and significant greenhouse gas emissions.

6.3. The Risk of Greenwashing

As green consumption becomes increasingly popular, many businesses use "eco-friendly" imagery primarily as a marketing tool without genuinely transforming their production systems. Consequently, greenwashing has become a global challenge to sustainable development.

Barriers to Agricultural By-product Value Chain Integration in Vietnam

Estimated impact of factors hindering the development of agricultural biomass value chains.

Influencing Factor	Percentage (%)
Small-scale and fragmented production	32
Lack of collection logistics infrastructure	26
Weak farmer–enterprise linkages	21
Lack of raw material standards	13
Insufficient policy support	8

Source: Compiled from FAO (2021), World Bank (2020), and Hoang et al. (2015).

Alongside value chain fragmentation, the risk of **greenwashing**—the practice of making misleading or exaggerated environmental claims—has emerged as a major challenge for the bio-based materials sector and agricultural residue utilization in Vietnam. According to Delmas and Burbano (2011), greenwashing occurs when companies market products as "green," "bio-based," or "environmentally friendly" without scientific evidence or transparent certification. In the bio-based materials sector, many products are promoted as "biodegradable" or "eco-friendly" despite only degrading under specific industrial conditions or still containing substantial amounts of petroleum-based polymers. Such practices risk misleading consumers and undermining trust in the bio-based materials market.

In Vietnam, the risk of greenwashing is exacerbated by the absence of standardized certification systems and independent verification mechanisms for bio-based materials derived from agricultural residues. According to European Bioplastics (2022), products must comply with international standards such as EN 13432 or ASTM D6400 to be recognized as fully biodegradable, meeting requirements related to degradation rates, toxicity, and biological conversion. However, many Vietnamese SMEs lack the financial resources necessary to obtain such certifications. Consequently, terms such as "bio-based," "organic," and "green" are often used more as marketing tools than as scientifically validated descriptions of product characteristics.

According to Lyon and Montgomery (2015), greenwashing not only poses risks to consumers but also creates unfair competition for companies that genuinely invest in clean technologies. Within Vietnam's agricultural residue value chain, this phenomenon may allow low-quality bio-based products to enter the market, thereby damaging the reputation of the domestic bioeconomy sector. Furthermore, the lack of traceability systems and Life Cycle Assessment (LCA) methodologies makes it difficult to determine the actual environmental footprint of supposedly "green" products. According to ISO 14040, life-cycle assessment is a critical tool for evaluating environmental impacts throughout a product's entire life cycle, from raw material extraction to disposal. However, the application of LCA within Vietnam's bio-based materials industry remains limited.

Main Drivers of Greenwashing Risks in Bio-based Materials

Distribution of factors contributing to greenwashing within bio-based material value chains.

Influencing Factor	Percentage (%)
Marketing claims exceeding scientific evidence	36
Lack of transparency in environmental data	28
Absence of certification standards	22

Lack of life-cycle assessments	14

Source: Compiled from Delmas & Burbano (2011), Lyon & Montgomery (2015), and European Bioplastics (2022).

From a bioeconomy perspective, weak value chain integration and the risk of greenwashing significantly reduce the effectiveness of transforming agricultural by-products into high-value biological resources. According to Kirchherr et al. (2017), the circular economy can only function effectively when there is coordinated collaboration among policymakers, businesses, research institutions, and raw-material producers. Therefore, Vietnam should establish a comprehensive national standards system for bio-based materials, develop traceability mechanisms, and promote life-cycle assessment practices to ensure environmental transparency. At the same time, regional partnerships linking feedstock-producing areas, processing enterprises, and consumer markets should be established to reduce logistics costs and increase the economic value of agricultural by-products within circular bio-based supply chains.

VII. Development Directions for Vietnam

In the context of transitioning toward a circular economy and implementing the commitment to achieve net-zero emissions by 2050, the development of rural eco-industrial clusters linked to the utilization of agricultural by-products is emerging as a key strategic direction for Vietnam. According to UNIDO (2017), eco-industrial parks are collaborative networks of enterprises designed to optimize material, energy, and waste flows through industrial symbiosis. For Vietnam, which generates more than 60 million tons of agricultural residues annually from rice, sugarcane, coffee, cassava, and fruit crops (Hoang et al., 2015), establishing eco-industrial clusters in raw-material-producing regions can reduce logistics costs, improve biomass utilization efficiency, and stimulate rural economic development. According to Geng et al. (2009), industrial symbiosis enables the waste stream of one enterprise to become the input resource of another, thereby reducing carbon emissions while increasing the economic value of biological resources.

Within the agricultural by-product sector, eco-industrial clusters can integrate multiple technological value chains simultaneously, including biochar production, organic fertilizers, bioplastics, biocomposite materials, and bioenergy generation. According to Lehmann and Joseph (2015), biochar derived from rice straw and rice husks not only improves soil quality but also serves as a long-term carbon sink within agricultural ecosystems. Meanwhile, lignocellulosic residues from sugarcane bagasse, coconut fiber, and corn stalks can be converted into bio-based polymers or second-generation bioethanol (Balat, 2011). Locating biomass-processing facilities directly within raw-material production areas can reduce post-harvest losses and enhance the efficiency of bio-based supply chains.

Another strategic direction involves investing in high-value bio-based material technologies to elevate the position of agricultural by-products within global value chains. According to Mohanty et al. (2002), biocomposite materials derived from plant cellulose have significant potential to replace petroleum-based polymers in packaging, construction, and agricultural applications. However, to compete internationally, Vietnam must invest heavily in lignocellulosic pretreatment technologies, nanocellulose technologies, bio-based polymers, and Life Cycle Assessment (LCA) systems. According to European Bioplastics (2022), the global bioplastics market is expected to exceed 7.5 million tons by 2028, reflecting the growing trend toward replacing fossil-based materials with biodegradable bio-based alternatives. This trend presents a substantial opportunity for Vietnam, provided that the country develops domestic technological capabilities and establishes bio-based value chains based on its abundant agricultural residues.

Beyond technology, the development of a national brand for agricultural by-products and bio-based materials is essential for enhancing export value and strengthening the international reputation of Vietnamese agriculture. According to Porter (1998), national competitive advantage depends not only on resource endowments but also on innovation capacity and branding capabilities. As green consumption and low-carbon economic models continue to expand globally, products labeled as “bio-based,” “carbon-neutral,” or “circular materials” are increasingly favored in international markets. However, the risks of greenwashing and insufficient certification systems may undermine consumer confidence in Vietnam’s bio-based products (Delmas & Burbano, 2011). Therefore, Vietnam should establish national standards for bio-based materials, implement traceability systems, and adopt international certification frameworks such as ISO 14040, EN 13432, and FSC to ensure environmental transparency.

Strategic Priorities for Agricultural By-product Development in Vietnam
Distribution of strategic priorities for the development of the bioeconomy and bio-based materials sector.

Strategic Priority	Percentage (%)
Standardization and certification	35

Development of eco-industrial clusters	28
National branding initiatives	22
Investment in bio-based material technologies	15

Source: Compiled from UNIDO (2017), European Bioplastics (2022), and Porter (1998).

From the perspective of the modern bioeconomy, the development of rural eco-industrial clusters is not merely a strategy for utilizing agricultural residues but also a pathway toward restructuring agricultural growth around high-value-added and low-carbon principles. According to Kirchherr et al. (2017), the circular economy can only function effectively when public policy, technological innovation, and value-chain integration are aligned. For Vietnam, agricultural by-products should no longer be regarded as "post-harvest waste" but rather as strategic national biological resources. The combination of technological investment, eco-industrial infrastructure development, and national branding efforts can provide the foundation for Vietnam to participate more deeply in global bio-based material markets while simultaneously increasing rural incomes and promoting sustainable development.

VIII. Conclusion

The circular economy is not merely an environmental solution; it is a comprehensive framework for restructuring Vietnamese agriculture. Within this model, agricultural by-products are no longer considered surplus waste but become strategic inputs for creative industries such as handicrafts and bio-based textiles.

Vietnam possesses unique conditions for developing this model through the combination of abundant biological resources, traditional craft knowledge, and industrial production capabilities. However, transforming this potential into a globally competitive advantage requires an integrated strategy that combines public policy, technological innovation, and green market development.

The future of Vietnamese agriculture may not depend solely on "producing more," but increasingly on its ability to create ecological value chains enriched with culture, technology, and innovation.

Agricultural by-products in Vietnam should no longer be viewed as "post-production waste" but rather as strategic biological resources capable of restructuring agricultural growth toward a circular, low-carbon, and high-value-added model. As a tropical agricultural country with abundant biomass resources, Vietnam possesses exceptional potential for developing bio-based industries based on agricultural residues, including biocomposite materials, biochar, organic biofertilizers, bioenergy, and biodegradable polymers. However, research and implementation efforts indicate that this transformation remains constrained by several systemic barriers, including dependence on imported lignocellulosic pretreatment technologies, insufficient standardization of bio-based materials, fragmented value chains, and limited mechanisms for transparent environmental certification.

In this context, future development strategies should focus on building an integrated bioeconomy ecosystem linking raw-material regions, rural eco-industrial clusters, technology enterprises, and research and innovation systems. Establishing biomass-processing centers in major production regions such as the Mekong Delta, the Central Highlands, and the Red River Delta would help reduce logistics costs, improve residue collection efficiency, and promote industrial symbiosis within agricultural systems. At the same time, Vietnam should prioritize investment in next-generation bio-based material technologies such as nanocellulose, biopolymers, and bio-carbon technologies to strengthen the international competitiveness of "bio-based made in Vietnam" products.

In addition to technological advancement, the establishment of national standards, traceability systems, and Life Cycle Assessment (LCA) frameworks is crucial for ensuring transparency and credibility in the bio-based materials market. These measures are not only technical requirements for accessing export markets with stringent environmental standards but also important tools for reducing the risk of greenwashing during commercialization. Simultaneously, Vietnam should develop a national branding strategy for agricultural by-products and bio-based materials based on the principles of "green – bio-based – circular," closely linked to indigenous cultural values and commitments to sustainable development.

In the long term, the competitiveness of Vietnamese agriculture will depend not only on the volume of raw agricultural production but increasingly on its ability to transform biomass into high-tech products, advanced bio-based materials, and knowledge-intensive ecological value chains. By effectively utilizing its abundant agricultural residues, Vietnam can not only reduce environmental pressures and greenhouse gas emissions but also position itself as a leading bioeconomy and bio-based materials hub in Southeast Asia in the future.

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