International Journal of Social Science and Economic Research

ISSN: 2455-8834

Volume:10, Issue:05 "May 2025"

Developing the mushroom production industry in Vietnam in the context of a circular economy

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DOI: 10.46609/IJSSER.2025.v10i05.019 URL: https://doi.org/10.46609/IJSSER.2025.v10i05.019

Received: 5 May 2025 / Accepted: 25 May 2025 / Published: 3 June 2025

ABSTRACT

Amid the transition toward a sustainable development model, the circular economy has increasingly emerged as a key strategic orientation for the agricultural sector. The mushroom production industry in Vietnam, characterized by its use of organic materials and the generation of highly reusable by-products, is considered a promising sector for the application of the circular economy. This paper systematizes the theoretical framework of the circular economy (CE) in mushroom production, provides an overview of the mushroom cultivation industry, and analyzes the current state of the sector in the context of the CE using the 5R strategic framework (Refuse – Reduce – Reuse – Recycle – Regenerate). Based on the identified challenges, the study proposes specific solutions to optimize the mushroom value chain, enhance resource efficiency, reduce emissions, and increase added value. The research findings contribute both theoretical and practical foundations for policy orientation in developing the mushroom industry under the circular economy model in Vietnam.

Keywords: Development, mushroom producing, Vietnam, circular economy, 5R

1. Introduction

The mushroom industry is emerging as a vital segment within modern agriculture, driven by growing consumer demand for clean, nutritious food and its wide-ranging applications in medicine, functional foods, and organic fertilizer production. According to the Food and Agriculture Organization (FAO, 2024a), from 2012 to 2024, global production of mushrooms and truffles increased by over 34%, highlighting the rising prominence of this market in recent years. In 2022, the top ten producers were concentrated in Asia, Europe, and North America, with China leading the way at over 45 million tons, followed by Japan with approximately

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470,000 tons (FAO, 2024b). The largest import markets for fresh mushrooms were the United States—with mushroom imports valued at USD 348 thousand—followed by the United Kingdom and Germany. One of the key growth drivers is the increasing interest in medicinal mushrooms, known for their high micronutrient content and immune-boosting properties. Germany, Italy, France, the United Kingdom, the Netherlands, and Poland offer significant market opportunities for suppliers from developing countries (Mordor Intelligence, 2024).

The surge in global mushroom production and consumption is rooted in the numerous health and nutritional benefits that mushrooms provide. They are low in calories, rich in nutrients, and contain a variety of vitamins, minerals, and antioxidants that promote well-being. Different mushroom species offer varying nutritional profiles. The growing consumption of mushrooms is not only influenced by the increasing cultural impact of Asian cuisine in many countries but also by rising demand for sustainable, healthy, and affordable food options. (Schneider, 2023)

In Vietnam, the mushroom production industry has been rapidly expanding and plays an increasingly important role in both agriculture and export activities. With an annual output of approximately 250,000 tons and export revenues reaching 25–30 million USD, the industry contributes significantly to the national economy (SGGP, 2019). In the context of depleting natural resources and rising environmental pollution, the circular economy offers a sustainable model for optimizing resource use, minimizing waste, and enhancing the added value of mushroom production. Vietnam has unique climatic conditions, favorable for the development of mushroom products.

- Regarding input materials: The mushroom production industry can utilize agricultural waste (straw, sawdust, coffee husks, sugarcane bagasse) as raw materials for growing mushrooms. This helps reduce waste and increase the value of waste products. Many models in Vietnam have been successful in using straw to produce straw mushrooms and sawdust for oyster mushrooms.

- Regarding output products: After harvesting mushrooms, the waste can be recycled into organic fertilizer or animal feed, promoting the resource cycle. Some facilities in Vietnam have turned waste from mushroom production into microbial organic fertilizer, reducing input costs for agriculture.

- Regarding the process and energy consumption: Mushroom production is more economically and environmentally efficient than traditional agriculture. Mushroom production requires less land and water than traditional agriculture, in line with the goal of efficient resource use of the circular economy.

Although the industry has many characteristics suitable for different stages of the circular economy, in Vietnam, most mushroom production facilities are small-scale, with outdated

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technology. Applying the circular economic model in this industry is necessary, but the application of the circular economic model is difficult to achieve high efficiency. The objectives of the research are: (1) to systematize the theoretical basis of circular economy and the 5R framework as a basis for applying circular economy in the mushroom production industry, (2) to evaluate the potential and current status of the mushroom production industry in Vietnam in the context of a circular economy according to the 5R framework, (3) to propose solutions to develop the mushroom industry according to the circular economic model.

2. Theoretical basis

2.1. Circular economy overview

The concept of circular economy has undergone a long process of formation and development, associated with changes in perception of the relationship between economy, resources and environment. The initial foundation for developing the theory of circular economy was mentioned by Pearce, D., & Turner, R. K. (1990) emphasizing the exploitation of natural resources and post-consumer product disposal in the unsustainable linear economic model, requiring a shift to a closed-cycle model where waste from one cycle can become input for another cycle. Ellen MacArthur Foundation (2024) defines: “A circular economy is a system that is restorative and regenerative. In circular economy, products and materials are kept in a circular cycle through processes such as maintenance, reuse, renovation, remanufacturing, recycling and composting”. Circular economy addresses climate change and other global challenges such as biodiversity loss, waste and pollution by decoupling economic activity from the consumption of finite resources. In this way, it reduces the extraction of raw materials from nature, reduces waste along the chain and thus creates more value in the product cycle through better management and process optimization.

A transformational change implied by the CE concept means changing linear modes of production and consumption to “a regenerative system in which resource inputs and waste, emissions and energy leakage are minimized” (M. Geissdoerfer, et al., 2017). This transformational change is envisioned to contribute to the achievement of many of the United Nations Sustainable Development Goals (SDGs) (P. Schroeder, et al, 2019) with a key focus on SDG 12, responsible consumption and production. The urgency of implementing CE comes from resource scarcity, disruption of biochemical flows, climate change and biodiversity loss globally (P. Ghisellini., et al, 2016). In a circular economy, the value of products, materials and resources is maintained in the economy for as long as possible and the economy operates to produce minimal waste (EC, 2018).

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In Vietnam, before 2020, the circular economy principle has been integrated into a number of Vietnam's economic models, typically models in the fields of agriculture and ecological economy. After 2020, in the National Socio-Economic Development Strategy 2021–2030, vision to 2045, circular economy is emphasized as a solution to harmonize the relationship between economic development and natural resource consumption (Manh L.V. & Anh., P.H, 2023). Therefore, the concept of Circular Economy was introduced for the first time into the Law on Environmental Protection 2020. In Article 142, Law on Environmental Protection 2020: *"Circular economy is an economic model in which design, production, consumption and service activities aim to reduce the exploitation of raw materials and materials, extend product life cycles, limit waste generation and minimize negative impacts on the environment"* (National Assembly, 2020). Thus, Vietnam aims to implement a circular economy model based on three basic principles: design to optimize and extend the life cycle of materials; minimize waste and polluting emissions; and restore natural ecosystems. According to this model, design, production, consumption and service activities aim to reduce raw materials, extend product life, reduce waste generation and minimize negative impacts on the environment.

2.2. Mushroom production and its potential for development in the circular economy

Mushrooms are a group of organisms belonging to the Fungi kingdom, unable to photosynthesize like plants because they do not contain chlorophyll, but develop by absorbing organic matter from the environment (Chang, S., & Miles, G. P. (2004). In agriculture and food industry, mushrooms are classified into two main groups: edible mushrooms and medicinal mushrooms.

- Cultivated edible mushrooms including straw mushrooms (Volvariella volvacea), oyster mushrooms (Pleurotus), button mushrooms (Agaricus bisporus), shiitake mushrooms (Lentinula edodes), and enoki mushrooms (Flammulina velutipes)... This is a food group rich in protein, fiber, B vitamins, minerals (selenium, copper, potassium) and natural antioxidants, playing an important role in improving nutrition and public health (Valverde, M. E., et al., 2015).

- Medicinal mushrooms such as Ganoderma lucidum and Cordyceps (Cordyceps sinensis), Lion's mane mushroom (Hericium erinaceus), Agaricus blazei Murill contains biological compounds such as beta-glucans, triterpenoids and polysaccharides, which have immune-supporting, anti-inflammatory, antioxidant, anti-cancer and blood sugar-regulating effects (Wasser, S.P., 2010). These mushrooms are commonly used in traditional Chinese and Japanese medicine and are being widely studied in modern medicine.

Globally, the circular economy has emerged as a solution to today's environmental challenges, aiming to use resources more consciously and efficiently (Maluf, G. B., 2024). Circular agriculture focuses on creating closed-loop systems, where waste from one part of the system

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becomes a resource for another part. Mushroom farming is circular because it utilizes organic waste, minimizes inputs and recycles by-products.

Mushroom production is a sector with potential for sustainable development and effective integration into the circular economic model. Mushroom cultivation involves converting agricultural and agro-industrial waste into highly nutritious food; it stands out as an environmentally sustainable option (Pontes., et.al., 2018). In Vietnam, research by Loc., N.Q et al, (2024) is the first study to comprehensively investigate the potential of circular economy (CE) principles to enhance the sustainability of mushroom production, focusing on resource efficiency and waste minimization. The study conducted a systematic review of studies on the topic of CE applications in mushroom cultivation, with emphasis on eight species commonly grown in Vietnam: Lentinula edodes, Ganoderma lucidum, Trametes versicolor, Hericium erinaceus, Cordyceps militaris, Auricularia heimuer, Pleurotus ostreatus và Volvariella volvacea. This study reviewed 42 articles from Scopus and 46 articles from Web of Science, showing that the focus was mainly on the use of spent mushroom growing media (SMS), with limited attention to water recycling, renewable energy, plastic recycling, and circular business models. In addition, the study conducted 20 in-depth interviews with stakeholders across the mushroom production chain in the Central Highlands of Vietnam, identifying existing CE activities and opportunities for optimization. The novelty of the study lies in the pioneering integration of systematic review and field research in the mushroom industry in this region. On that basis, CE recommendations to enhance resource use and reduce environmental impacts and greenhouse gas emissions in the agricultural sector are proposed.

Another study by Yen., T.T et al, (2024) used the life cycle assessment method - ReSOLVE to find and quantify the main environmental impacts occurring along the mushroom production chain. Data on these hotspots were used to evaluate the ReSOLVE framework to identify appropriate circular activities to improve the environmental impact of mushroom cultivation. The results showed that electricity consumption and plastic baskets are the main hotspots causing environmental impacts, especially greenhouse gas emissions. Based on a focus on a mushroom production facility as a case study, the study found that the greenhouse gas emissions during the cultivation of shiitake mushrooms (Lentinula edodes) were 2.38 kg CO2e/kg mushrooms, of which energy use contributed 72.87% of the emissions. The assessment findings obtained from the ReSOLVE framework indicate that the facility is currently implementing 17 of the 42 circular activities. Based on this, it is proposed to implement circular economy solutions to assess the effectiveness of using both the ReSOLVE framework and CE solutions.

Taking a deeper and more technical approach to one of the solutions related to the mushroom growing industry, the study by Huyen., H.T.K, et al, (2025) proposes a way to turn mushroom waste into high-quality fertilizer with oyster shell additives, promoting sustainable agriculture

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and supporting circular economy principles. Over a period of 50 days, the decomposition process is closely monitored, under suitable environmental conditions. This study suggests a practical approach to mushroom waste management, which has the potential to contribute to sustainable agricultural practices and circular economy applications. The economic potential of the project has also been estimated, demonstrating that the return potential makes it a worthwhile investment.

From the above research overview, the mushroom production industry plays an important role in the circular economy thanks to the following factors:

- Advantages of utilizing agricultural waste: Mushrooms are natural decomposers, eating dead organic matter, helping to recycle nutrients and reduce the need for artificial inputs. The mushroom growing industry uses many organic materials such as straw, sawdust, bagasse, corn cobs, coffee grounds, wood chips - which are waste products in agricultural production (Royse., D.J., et al., 2017). These materials are selected as basic substrates or supplements, turning what is waste into valuable growing materials, contributing to saving resources and also contributing to building a circular economic model in agricultural production.

- Reduce the amount of waste burned or released into the environment, contributing to reducing air and soil pollution. Mushrooms have a short production cycle (30–60 days) and can be grown in small spaces (due to being grown on vertical racks), and are water-efficient (requiring 75–90% less water than most vegetables). This feature makes the mushroom industry easily accessible to small-scale farmers, household economic models, urban agriculture, especially suitable in the context of climate change and urbanization (Chang, S., & Miles, G. P., 2004). With advanced production technology (such as mushroom houses that automatically control temperature and humidity), productivity and product quality are increasingly improved. In addition, mushrooms can be grown indoors, reducing the risk of exposure to pests and limiting the need for chemical treatments, synthetic fertilizers or heavy pesticides.

- Creating organic fertilizer from waste after mushroom cultivation. Along with the increasing mushroom yield, the amount of post-harvest waste (waste substrate) also increases significantly. Waste is mainly used growing media – often containing cellulose, lignin and organic matter that can be further decomposed or reused as fertilizer, organic fertilizer or animal feed (Minh., N.T., 2016) or raw materials for bioenergy production (Xiaoyu Ma., et al, 2024). In India, the mushroom industry generates more than 130,000 tonnes of post-harvest waste each year (Yen, T.T. et al., 2024). If not properly managed, this waste can cause environmental pollution or waste of resources.

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- Mushrooms are a high economic value mushroom production industry, especially medicinal mushroom products and organic mushrooms. According to Grand View Research Market Report (2023), the global mushroom market size is expected to reach US$115 billion by 2030, with an average growth rate of 9.7%/year. The mushroom industry has great export potential, creating jobs for rural workers, especially women and the elderly.

2.3. Strategic frameworks for implementing circular economy

The circular economy model is an economic system that aims to reduce waste, extend product life cycles and reuse resources through strategies such as Reduce, Reuse, Recycle, and recovery and regeneration activities. Circular economy is not only about choosing the right raw materials as the basis for operations, but also about correctly identifying all the relevant actions at each stage of production, to reuse the waste generated in the production process Plotting et al. (2017)

According to Ellen MacArthur Foundation (2013), Circular Economy is built on three core elements:

- Reduce: Reduce the use of raw materials, energy, and waste in production and consumption.

- Reuse: Reuse products or materials without complex processing.

- Recycle: Convert waste or by-products into new materials for reuse.

These are simple, easy-to-implement strategies that focus on basic waste and resource management. Suitable for industries with short value chains or small businesses. From these strategies, subsequent strategic frameworks have been gradually expanded from 5R, 7R, to now 9R, providing more detailed levels for implementing KTTH.

- 5R Strategic Framework. The 5R Strategic Framework is an extension of the 3Rs, adding two elements: Recover (Recovering energy or materials from waste) and Redesign (Redesigning products or processes to increase circularity and reduce environmental impact). These strategies are suitable for industries with potential for technological innovation or requiring more complex by-product management. Therefore, to implement 5R, it is necessary to invest in technology and design. For example, businesses recover heat from the mushroom substrate incubation process (Recover), design environmentally friendly mushroom packaging (Redesign).

- The 7R strategic framework is extended from the 5R, adding 2 more elements: Rethink (Re-evaluate the entire value chain to optimize circularity) and Repair (Extend the life of products or equipment by maintenance and repair). This model is more complex, requiring comprehensive strategic thinking and supply chain management capabilities; suitable for large-scale industries or those that require integration of multiple stakeholders.

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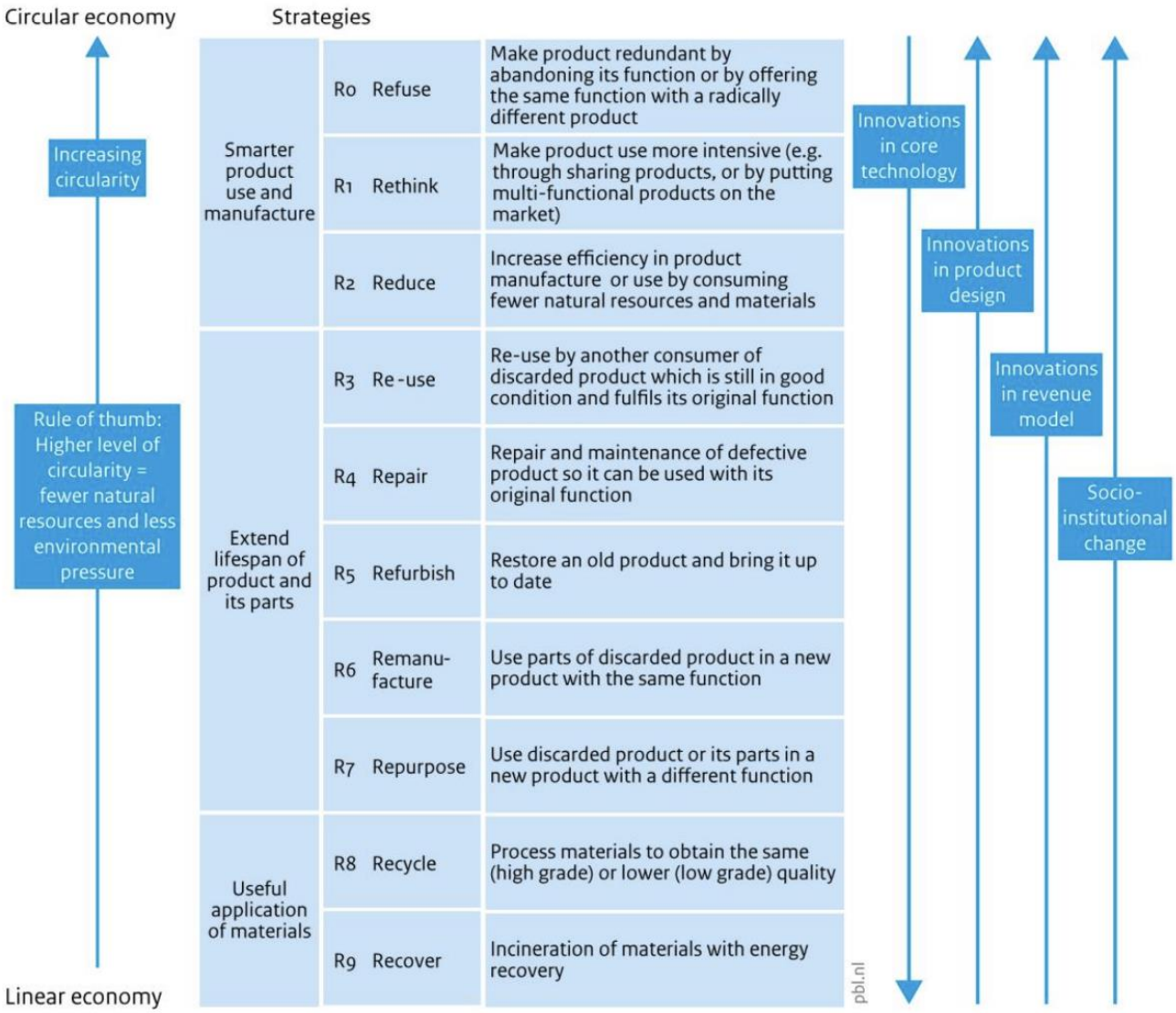
- 9R Strategy Framework. The most comprehensive model, including 10 strategies. In addition to the contents of 7R, this model also adds: Refuse (Avoid using materials or products that are harmful to the environment; Repurpose (Use products or by-products for new purposes) and Refurbish (Renovate products or equipment to extend their lifespan). The 9R Framework integrates all aspects of circular economy, requiring high technology, supportive policies, and multi-stakeholder engagement (businesses, governments, consumers). Therefore, this comprehensive model is suitable for large industries or industries with complex value chains.

Figure 1. The 9R Framework



Source: Plotting et al. 2017, et Rli (2015)

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To date, the 9R framework is the most comprehensive framework applied to mushroom production, helping to extend product life cycles, reduce waste and optimize resource use. The 9R framework is more suitable for large enterprises or complex value chains, but requires large investments in management and technology (such as Rethink, Repair), requires high-tech infrastructure and multi-disciplinary coordination (Refuse, Repurpose, Refurbish). Meanwhile, in reality, the Vietnamese mushroom industry is mostly small and medium-sized, depending on manual labor and average technology. Combined with the characteristics of the mushroom growing industry, the article approaches the 5R strategy (a foundation model to move towards 7R or 9R in the future, when the mushroom industry has enough resources and a supporting legal framework) with the elements in Table 1. The 5R strategy (Reduce, Reuse, Recycle, Recover, Redesign) is comprehensive enough to cover all aspects of the mushroom industry (from by-product management to process optimization) but not as complex as the 7R or 9R; at the same time, it is not so basic that it does not exploit the full potential of mushroom by-products (such as energy recovery or product redesign) like the 3R.

Table 1. The 5R Framework

Factors	**Meaning**
Reduce	Optimizing water, energy, and raw materials (straw, sawdust) in mushroom production, reducing costs and environmental impact. Increasing efficiency in product design or manufacturing by using fewer natural resources and materials as inputs. Strategies to reduce a product's ecological footprint by increasing resource efficiency can involve varying levels of ambition in the product transformation process.
Re- use	Reuse of mushroom substrate after treatment, increasing resource efficiency.
Redesign	Develop bio-based packaging or improve production processes to increase sustainability, meeting green consumption trends.
Recycle	Using mushroom growing waste as fertilizer, organic fertilizer or animal feed or raw material for bioenergy production.
Recover	Combustion of materials with energy recovery. Energy recovery (biogas, heat) from the composting process, especially suitable for large production facilities.

Source: grow-circular.eu, 2025 and authors' synthesis

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3. Research methodology

Data collection methods

The group of authors used the document research method to systematize the theoretical basis of circular economy; characteristics of mushroom products and mushroom growing industry; the role of mushroom production industry in the circular economy. These studies were selected by the authors from the Report of the Ministry of Agriculture and Rural Development, data from the General Statistics Office, FAO, WTO. The main contents are analyzed by topic and analyzed through synthesis and narrative methods.

To study the current status of mushroom production in Vietnam, the research team focused on examining the following contents: scale, output, potential, and remaining challenges. To assess the current situation, the article collects data from domestic and foreign books and scientific journals, from aggregated data of the Ministry of Agriculture and Rural Development; reports of the General Statistics Office. A case study approach was used to provide a detailed and contextual analysis of sustainability practices in small-scale mushroom production chains. From the collected data, the authors synthesized and selected information suitable for the research content. The authors used case study and secondary data research method to clarify the research problem.

Data processing method

The collected data is summarized, calculated, and reflected in tables. To evaluate and analyze the data, the article also uses the comparison method, analyzing production results and the effectiveness of solutions that satisfy the characteristics of the circular economy (over time). From there, the research team made proposals to develop the mushroom production industry according to the circular economic model.

4. Current status of mushroom production industry in Vietnam in the context of circular economy

4.1. Current status of mushroom production industry in Vietnam

In Vietnam, the research and production of edible mushrooms began in the 1970s of the last century. Up to now, we have mastered the technology of breeding, cultivating, and processing edible and medicinal mushrooms.

(i) Mushroom production and export

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Mushroom production in 2021 was recorded at about 24,780 tons and is forecast to reach 26,620 tons in 2026 (Reportlinker, 2021). With a growth rate of 1.2-1.4% per year, the estimated output of mushrooms in Vietnam is about 25,000-27,000 tons/year. The size of the Vietnam mushroom market is expected to reach US$ 360.0 million by 2024 and the market is expected to reach US$ 600.0 million by 2033, representing a CAGR of 5.2% during the period 2025-2033 (IMARC, 2024). Major export markets include Japan, Hong Kong, Australia, Canada, the US and Thailand. Notably, Vietnam was the world's third largest exporter of straw mushrooms in 2000, with 40,000 tons per year (Vietnam Embassy, 2000).

Changing dietary preferences and growing trend towards healthier food options, government support for mushroom cultivation, rise of e-commerce, growing demand for sustainable and organic product variants, growing trend of vegetarianism and veganism, and research on medicinal mushrooms are driving the market growth. The Vietnamese mushroom industry produces many types of mushrooms, including straw mushrooms, oyster mushrooms, button mushrooms, reishi mushrooms, shiitake mushrooms, and wood ear mushrooms. Oyster mushrooms and straw mushrooms account for the largest proportion due to their suitability to climatic conditions and abundant agricultural by-products (straw, bagasse).

The Mekong Delta and the Southeast provinces (such as Dong Nai and Lam Dong) are major mushroom production centers thanks to favorable weather conditions and abundant agricultural by-products. An Giang, Dong Thap, and Hung Yen stand out with industrial mushroom production models (SGGP, 2019). Corresponding to the expansion of scale and application of technology to overcome the impacts of natural environmental conditions, the mushroom production area is increasingly expanding, mainly concentrated in provinces such as Hung Yen, Bac Giang, Ha Nam, Lam Dong, Tay Ninh.

(ii) Mushroom quality

Vietnamese mushrooms are not only delicious but also have high nutritional value (MOIT, 2024). In Vietnam, there are many prominent edible mushrooms such as straw mushrooms, enoki mushrooms, shiitake mushrooms, wood ear mushrooms, monkey head mushrooms, button mushrooms, sun mushrooms, lingzhi mushrooms, melaleuca mushrooms, abalone mushrooms, pine mushrooms and snow mushrooms. Each type of mushroom has its own characteristics, from shape, color to flavor, and is often used in many traditional dishes.

Favorable climatic conditions are soil factors that affect the quality of mushrooms. Vietnam has favorable climatic conditions for growing many different types of mushrooms, from tropical mushrooms such as straw mushrooms, oyster mushrooms to temperate mushrooms such as shiitake mushrooms, button mushrooms. Vietnam has weather conditions that allow mushroom

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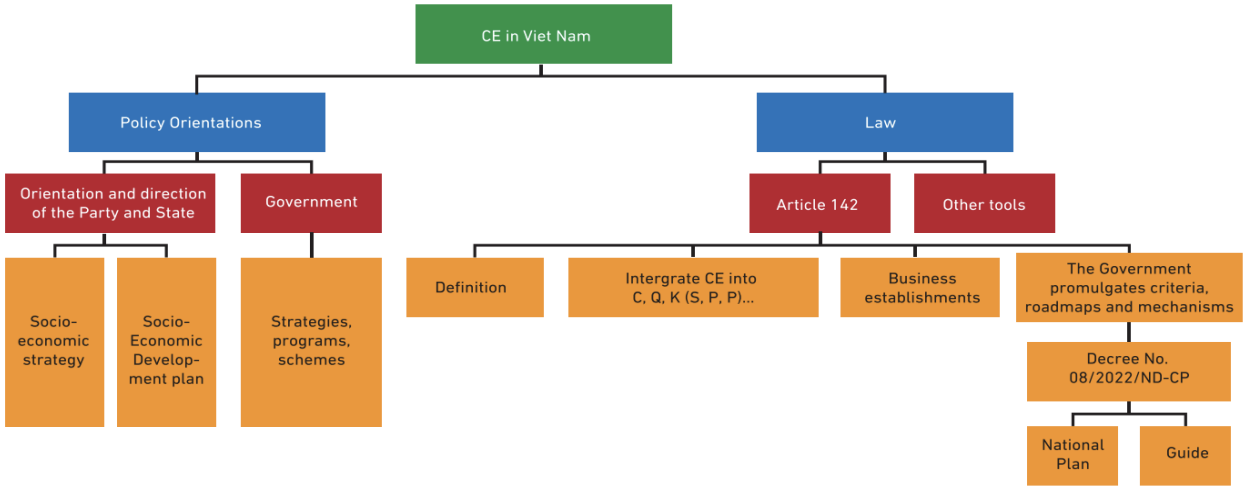
cultivation year-round in different areas with different mushroom strains such as thermophilic, cool-loving, and cold-loving… Available raw materials for growing mushrooms are also very abundant such as corn cobs, sawdust, bagasse, straw, and tree trunks… The output of this raw material can be up to 40 million tons and if only 10 - 15% of that is used to grow mushrooms, it will create 1 million tons of mushrooms/year and hundreds of thousands of tons of organic fertilizer (MOIT, 2024).

4.2. Circular economy in mushroom production in Vietnam according to the 5R strategic framework

The strategy for sustainable agricultural and rural development to 2030, with a vision to 2050 according to Decision No. 1520/QD-TTg of the Prime Minister, in its development perspective, has comprehensively mentioned circular agriculture including the following contents: *"Developing environmentally sustainable agriculture, using resources efficiently, developing ecological, organic, circular, low-carbon, environmentally friendly agriculture, adapting to climate change".* In agriculture, circular economy is a closed-cycle production process through the application of scientific and technological advances, biotechnology, and physical and chemical technology; products and by-products will be used, recycled, and used as input materials for the production and processing of agricultural, forestry, and aquatic products, creating safe, high-quality products, reducing waste and loss, minimizing waste, and increasing economic, social, and environmental efficiency (Ministry of Agriculture and Rural Development, 2022).

Figure 1. Policy and legal framework for the development of the circular economy in Vietnam



Source: Manh L.V. & Anh., P.H, 2023

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According to the 5R strategy framework, in general, the Reduce, Reuse and Recycle strategies have been widely deployed, contributing to reducing costs, increasing productivity and protecting the environment. However, Recover and Redesign are still limited due to lack of technology and capital. Specifically as follows:

(1) Reduce

Minimization in mushroom production focuses on optimizing the use of resources such as water, energy, and input materials (straw, sawdust, bagasse). In Vietnam, industrial mushroom production facilities have applied new technology to reduce costs and environmental impact [Box 1]. However, resource reduction is only being implemented in large production facilities. In households and small-scale mushroom production facilities (accounting for 69% of mushroom production households with a scale of less than 0.5 ha), the application of resource-saving technology is still limited due to lack of capital and technical knowledge. This requires policy support and technology transfer.

Box 1: Case study of Reduce solutions

- In 6 provinces (Hanoi, Hung Yen, Hai Duong, Hai Phong, Lam Dong, An Giang), 24 industrial-scale mushroom production models have reduced production costs per ton of raw materials from 9.3% to 26.2% thanks to the application of advanced technological processes. Enterprises use drip irrigation systems and automatic humidity control. Labor efficiency also increases from 1.3 to 4.85 times, contributing to reducing energy consumption in production.
- At the Van Giang Mushroom Production Experimental Station (Hung Yen), the Japanese technology automated mushroom production line (capacity of 1-4 tons of fresh mushrooms/day) has reduced 20% of water used during irrigation and 15% of electricity thanks to the intelligent control system. Mushroom product prices decreased from 12.5% to 33.3%, helping to increase competitiveness in the market.

Source: Trinh., N.D., et al, 2021

(2) Re-use

Reuse refers to the reuse of materials that have gone through a life cycle without changing their original nature. The mushroom growing industry currently applies a variety of technologies, from the simplest to the most advanced (Dhar, B.L., 2017). However, the entire production process starts from the selection of raw materials that will be used to produce compost/growing media. This is the starting point when researching the development of circular economy in mushroom production in Vietnam. In the mushroom industry, reuse is mainly reflected in the

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process of utilizing mushroom growing media after a growing cycle (such as straw, sawdust, etc.) to continue serving the next production cycles or switching to other growing activities such as sprouts, fertilizer.

According to Cu., N.N., & Mai., N.T.P., (2024), raw material costs often account for 50–60% of total input costs in agricultural production, therefore, reusing growing media has great economic significance. In large rice-growing areas such as the Mekong Delta, this model not only helps reduce production costs, but also contributes to solving environmental problems and creating jobs for local people. However, the rate of reused straw nationwide is still low (56.3%), while 45–60% is burned, causing serious environmental pollution. Expanding this model requires investment in substrate treatment technology and raising public awareness.

Box 2: Case study of reuse model in Binh Thuan and Dong Thap

- **Binh Thuan**: In Binh Thuan, sawdust is used as a growing medium for lingzhi and oyster mushrooms. After the cycle, the growing medium is reused to grow straw mushrooms, achieving a yield 5-7% higher than traditional straw. Water-saturated sawdust continues to be used to grow sprouts, saving costs on raw materials and irrigation water. Then, the substrate is mixed with cow manure, rice husk ash, and composted for 1 month to produce organic fertilizer for cultivation. Agricultural waste from crop cultivation is reused as mushroom substrate, creating a closed-loop cycle.

This model creates a cycle of maximum resource utilization, reducing production costs by reducing raw material costs, increasing income from mushrooms, sprouts and fertilizers, and reducing environmental pollution (Nguyen Phuong, 2024).

- **Dong Thap**: In Dong Thap, straw from 1 hectare of rice is reused to produce 250-300 kg of fresh mushrooms (straw mushrooms, oyster mushrooms), bringing in an additional income of 6-8 million VND. The substrate after growing mushrooms is composted into organic fertilizer, providing nutrients for rice or fruit trees. Agricultural waste from crop cultivation is reused as mushroom substrate, creating a circular chain. The model reduces 30% of the amount of straw burned, contributing to reducing greenhouse gas emissions. The result of this model is to help businesses increase income, save on fertilizer costs and protect the environment.

Source: Cu., N.N., & Mai., N.T.P., (2024)

(3) Recycle

Unlike reuse, recycling is the process of converting the nature of materials to form new products that can be used for other purposes. In the mushroom industry, recycling activities mainly

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involve converting agricultural waste such as straw, sawdust, and bagasse into mushroom growing media, organic fertilizers, or animal feed. Recycling spent mushroom substrate (Spent mushroom substrate- SMS) into high value products such as fertilizer, animal feed, energy or materials. SMS, a by-product of mushroom harvesting, has great potential in the circular economy. According to the study of Grimm., D & Han A B Wösten (2018), 1 kg of fresh mushrooms produces about 5 kg of SMS, equivalent to 2 kg of dry. The applications of SMS are presented in Table 2.

Table 2. Summary of recycling solutions for Spent mushroom substrate (SMS)

Application	Details
Organic Fertilizers	SMS improves soil structure, increases water retention and microbial activity.
Other Mushroom Substrates	SMS from oyster mushrooms can be used to grow oyster mushrooms with 20% higher yields when wheat bran is added.
Animal Feed	SMS contains nutrients and can be used as food for insects, fish or livestock. 10% SMS from oyster mushrooms increases calf growth by 8%.
Energy Production	SMS can be burned for heat generation or ethanol production (150 kg ethanol/ton SMS)
Materials	SMS is used to produce packaging and construction materials, with tensile strength of 5.1-9.6 MPa.
Enzymes and Bio-compounds	SMS contains lignocellulosic enzymes, reducing the cost of biofuel production (0.6-1.3 USD/gallon ethanol).

Source: Grimm., D & Han A B Wösten (2018)

Vietnam currently produces about 159 million tons of agricultural waste each year, of which 90 million tons are crop residues such as straw, corn stalks, and sugarcane bagasse. However, the collection and recycling rate is only 52.2%, while the majority of the rest is wasted or pollutes the environment (Cu., N.N., & Mai., N.T.P., (2024). In Lam Dong, the Dalat mushroom production cooperative has developed a model of recycling sawdust and sugarcane bagasse into growing media for growing lingzhi and button mushrooms. After each planting cycle, this growing medium is further processed into organic fertilizer, supplying organic vegetable farms in the area. Thanks to this model, input material costs are reduced, while generating additional revenue from fertilizers, with increased annual revenue**.** Recycling agricultural waste has demonstrated economic and environmental potential in mushroom production. However, the recycling process still depends on manual labor and simple technology, leading to low efficiency in small facilities. Lack of linkages between sectors (mushrooms, farming, livestock) also limits the possibility of large-scale recycling.

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(4) Recover

Recovery in mushroom production focuses on utilizing energy or materials from by-products, such as biogas production from mushroom substrates or heat recovery from composting of raw materials. SMS can be burned to generate heat or produce ethanol (150 kg ethanol/ton SMS) (Feng Chen., et al., 2013). However, the application of Recover in the mushroom industry in Vietnam is still very limited due to lack of technology and capital.

(5) Redesign

Redesign in mushroom production includes developing new products, packaging or processes to increase circularity and reduce environmental impact. Some businesses have begun researching bio-packaging from mushroom residue or straw to replace plastic bags. Innovation in materials such as plant-based bioplastics and mushroom-based packaging are gaining increasing attention. These materials help the packaging industry reduce its dependence on fossil fuels and limit waste thanks to their ability to biodegrade or be easily recycled (Ministry of agriculture and environment, 2025).

However, the cost of researching and developing bio-based packaging or new technologies is a major challenge for small businesses. Some startups in Vietnam have initially researched the use of mushroom residue (mycelium) combined with agricultural by-products such as straw, sawdust or coffee grounds to produce biological packaging materials, replacing plastic bags in product packaging. Packaging made from mushroom residue is biodegradable, has good insulation properties and can be used in the food industry or e-commerce. Although still on a pilot scale, mycelium packaging technology in Vietnam is assessed to have high application potential, in line with the orientation of cleaner production and reducing plastic waste (Loc, N.Q., et al., 2024)

5. Some issues and proposals for developing the mushroom production industry according to the circular economic model

5.1. Some issues raised

Mushroom production industry in Vietnam faces many challenges in transitioning to a circular economy model. Below are some of the issues facing the mushroom industry in the context of a circular economy:

(i) Institutional, cognitive and industry linkage challenges

Awareness of circular economy principles: In rural areas, awareness of circular economy practices is limited, hindering the adoption of strategies to reject unsustainable inputs, such as excessive use of chemical fertilizers or single-use plastics in mushroom cultivation. The cause

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comes from lack of information and training, especially among households and small businesses (Ninh., N.T.H., et al, 2023).

Limited policy and support: Limited government support for expanding production or modernizing facilities limits the growth of the industry. Policies to support the application of circular economy, such as subsidies or tax exemptions, are not yet fully developed, leading to a lack of motivation for stakeholders (UNDP, 2024).

Lack of industry linkage: Implementing circular economy in mushroom growing industry involves many stakeholders at micro level (farmers, cooperatives, businesses). However, most of these models emerged spontaneously without any coherent development between regions. Although the Vietnamese Government has introduced policies to promote green production and CE, guidance on promoting circular agriculture models at the micro level is limited (Ninh., N.T.H., et al, 2023). Lack of cooperation between government, business, farmers and scientists hinders the development of recycling infrastructure and policies (Kien., N.T., et al., 2024).

(ii) Technical and technological challenges

High energy consumption: Mushroom farms require significant amounts of energy for cooling, heating and lighting systems, increasing greenhouse gas emissions. This is a major obstacle to reducing the industry's environmental impact, especially when energy comes mainly from non-renewable sources. On the other hand, to reduce emissions, mushroom farms need to apply modern technology (Erica Dorr., et al, 2021).

Underutilization and diversification of SMS: The use of spent mushroom substrate (SMS) is mainly focused on composting, ignoring other potential applications such as bioenergy production, animal feed or construction materials (Loc, N.Q., et al, 2024).

Lack of value chain integration: The absence of a closed value chain limits the recyclability of mushroom products within the production cycle or other industries (Huyen, B.V., & Toan, N.N. (2021)).

(iii) Product and market challenges

Limited product diversification: The mushroom industry focuses mainly on fresh or dried mushrooms, with little investment in further processing, such as mushroom supplements, cosmetics or functional foods. This limits added value and competitiveness in international markets, especially in markets requiring high-value products.

Market competition and quality control: Fierce competition from China, with a 57.2% market share of mushroom imports into the EU, coupled with strict international standards (such as

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pesticide residue control, heavy metals) requires significant investment in quality assurance and certification. Many small producers cannot meet this demand, leading to limitations in exports and sustainable development.

5.2. Some recommendations

Based on the analyzed issues, the following recommendations are made to develop the mushroom production industry according to the circular economic model:

- Improving each strategy in the 5R framework, towards the 7R and 9R frameworks: In the current context, the 5R Framework (Refuse – Reduce – Reuse – Recycle – Rot) is the optimal solution for the mushroom production industry thanks to its ability to utilize agricultural by-products, reduce costs, increase value and align with the sustainable development orientation. Implementing this model will help the mushroom industry shift to circular production, reduce waste and improve resource efficiency.

- Policy support: The government needs to develop specific support packages such as subsidies, low-interest loans and tax exemptions to encourage investment in environmentally friendly technology and circular economy practices. This enables small businesses and cooperatives to access modern technology, such as automated climate control systems, and promotes the application of circular models throughout the production chain.

- Raising awareness and capacity: Implementing community education programs, technical training on KTTH for farmers and small businesses. Training content should focus on the long-term benefits of the circular economy, practical implementation methods in mushroom production, from raw material preparation to post-harvest processing.

- Stakeholder Collaboration: Establish cross-sectoral collaboration platforms to connect farmers, businesses, research institutes and policy makers. This cooperation will help share knowledge, resources, technology and create a closed value chain in sustainable mushroom production.

- Adopt green technology: Encourage the use of energy and water-saving technologies, such as solar cooling systems, energy-saving LED lights or water reuse. This helps reduce production costs, while limiting greenhouse gas emissions and meeting international market requirements for green development.

- Value chain integration: Promote the development of closed production systems, linking mushroom cultivation with other industries such as livestock and crop cultivation. In which, SMS can be reused as animal feed, organic fertilizer, or combined in the traditional VAC model. At the same time, encourage the conversion of SMS into high-value products such as biofuels or

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construction materials, creating the premise for cross-sectoral cooperation and reducing agricultural waste.

- Research and innovation: Increase investment in research and development (R&D) to expand the application of by-products in the mushroom industry. Potential research directions include production of functional foods, extraction of bioactive substances, green materials or renewable energy from SMS.

- Establish SMS processing centers: Establish regional SMS processing centers to support the collection, sorting and recycling of post-harvest mushroom materials. This enables small-scale farms to participate in circular value chains without large investments, while also creating incentives to scale up production.

- Investing in high-value products: Encourage businesses to invest in developing high-value-added products from mushrooms such as pharmaceuticals, functional foods or bio-cosmetics. This is a strategic direction to improve competitiveness in the international market and maximize the biological potential of mushrooms.

6. Conclusion

The article analyzed the potential for developing the mushroom production industry in Vietnam in the direction of circular economy, through an overview of the theory of circular economy and the 5R strategic framework, combined with the practice of production and use of by-products in the mushroom value chain. Research results show that the mushroom industry not only has high nutritional and economic value but also possesses a production cycle close to a circular model due to the ability to utilize agricultural by-products and create secondary products such as organic fertilizers, animal feed, and biofuel.... Applying circular economy to mushroom production will contribute to reducing waste, increasing resource efficiency and enhancing added value for the mushroom product chain. However, the article mainly relies on theoretical analysis and secondary research, there is no in-depth practical survey of the circular economic model in mushroom production in specific localities in Vietnam. In further studies, field surveys should be conducted in key mushroom production areas to assess the level of circular economy application and the actual effectiveness of existing models. At the same time, we should focus on building a set of criteria to evaluate the effectiveness of circular economic in the mushroom industry, thereby serving as a basis for proposing solutions on support policies.

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