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Integrating Circular Economy Principles into Rice Value Chain in the Mekong Delta, Vietnam

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ABSTRACT

In the context of a circular economy, value chains must shift from a linear model to a circular perspective, where circular economy principles are integrated into the entire process from input to consumption, waste reuse and recycling. Employing a combined methodological approach integrating circular economy principles with value chain analysis, supplemented by secondary data and three focus group discussions with the categories of rice-farming households, enterprises, and experts/local officers, with each group comprising six participants, this article applies circular economy tenets to the analysis of the rice value chain in the Mekong Delta - Vietnam's largest rice-producing region. Based on a comparative analysis and in alignment with the strategic development goals of the Mekong Delta, the five rice straw-based circular models are prioritized as follows: rice straw mushroom cultivation, organic fertilizer production, animal feed ingredient production, high-tech applications for energy and industrial product production, and rice straw return for soil restoration. Supportive government policies play a critical role, encompassing investment in research and development and technology transfer, development of markets for circular-based products, provision of investment/financial incentives, and undertaking communication initiatives and stakeholder engagement to raise awareness regarding reuse, recycling, and treatment of waste/by-products from rice production in the Mekong Delta.

1. INTRODUCTION

Climate change, resource depletion, biodiversity loss, escalating waste generation, and environmental contamination are recognized as formidable global challenges that have intensified over recent decades as the world economy continues its trajectory of growth [1, 2]. The linear economy, predicated on the "take-make-dispose" paradigm, is widely regarded as an economic framework that inherently tends to degrade natural ecosystems, exacerbate pollution, and drive climate change [3]. Conversely, the circular economy, which is constructed upon three fundamental tenets - designing out waste and pollution, keeping products and materials in use at their highest utility and value, and regenerating natural systems - is championed as a superior alternative to the linear model, as it facilitates the attainment of comprehensive economic, social, and environmental sustainability [4].

Agriculture plays a pivotal role in the global economy, accounting for a contribution of 4.18% (in 2012) and 4.31% (in 2021) to global GDP [5]. Agriculture furnishes food supplies, generates employment, and serves as the primary source of income for the majority of the population residing in rural areas [6]. Nevertheless, prevailing linear agricultural paradigms are disproportionately consuming land and water resources and generating considerable environmental externalities due to the excessive application of pesticides, fertilizers, and other chemical inputs [7]. Consequently, the agri-food system stands out as a critical domain necessitating a shift towards a more sustainable development model, one that aligns with circular economy tenets. This transition mandates addressing pressing issues such as resource depletion, soil degradation, greenhouse gas emissions, food waste and loss, waste generation across the value chain, energy recuperation, resource use efficiency, and material reprocessing [8]. Therefore, the integration of circular economy principles across the various stages of the agri-food value chain is instrumental in establishing a truly regenerative circular agri-food system [9].

Rice constitutes a staple food crop and a dominant agricultural commodity across Asia [10]. The rice-based agricultural economy inherently generates a considerable volume of agricultural waste/by-products (such as straw, husks, and bran) derived from production, processing and consumption. Conventionally, linear models of rice production invariably place an environmental burden through waste and concurrently deplete valuable resources by failing to fully capitalize on their inherent worth, given that these waste/by-products possess the potential to be converted into other high-value products. Consequently, rice production must increasingly focus on maximizing the utilization of its by-products for the manufacture of value-added goods, based on the principles of the circular economy [11].

Agriculture constitutes a critical economic sector in Vietnam's development, effectively serving as the backbone of the national economy, providing employment for a substantial portion of the population and ensuring food security [12]. Vietnam maintains a competitive advantage in rice production and export, with the Mekong Delta being designated as the nation's largest rice-producing region [13]. The rice value chain is consequently a topic of intensive research interest within the agri-food sector of the Mekong Delta. However, existing studies on the rice value chain in this region have largely been confined to analyzing the prevailing challenges/barriers and proposing measures for value chain enhancement, while in-depth research specifically addressing the circular rice value chain remains absent.

This paper applies the principles of the circular economy to the analysis of the rice value chain in the Mekong Delta of Vietnam. The specific objectives of this research are fourfold:

Firstly, to delineate the current state of the rice value chain in the Mekong Delta.

Secondly, to critically analyze the limitations of the Mekong Delta's rice value chain from the perspective of managing agricultural waste/by-products generated along the chain.

Thirdly, to examine the opportunities for the integration of circular economy principles into the Mekong Delta's rice value chain.

Fourthly, to propose supportive government policies to promote circular rice value chain models in the Mekong Delta.

This paper is anticipated to make substantive contributions in both the theoretical and practical domains concerning the rice value chain. From a theoretical perspective, the article will advance knowledge by providing insight into the integration of circular economy principles into rice value chain analysis. On the practical front, the study will contribute to resolving the issue of agricultural waste/by-products from rice cultivation in the Mekong Delta, a region that discharges an estimated 26-27 million tons of rice straws and roots annually but only 30% is collected, leaving 70% to be burned or buried in fields [14]. It achieves this by informing policymakers of the potential strategies for applying circular economy principles within the Mekong Delta rice value chain, alongside necessary accompanying supportive government policies. The research findings bear significant implications for the sustainable development of the Mekong Delta's rice value chain, steering it toward generating additional employment, boosting farmer incomes, and simultaneously mitigating environmental pollution and greenhouse gas emissions.

2. LITERATURE REVIEW

2.1 Value chain

Porter's value chain [15] is one of the most widely recognized concepts originating from business literature. A value chain is essentially a sequence of activities through which a product progresses systematically, and at each juncture, the product accrues a certain amount of value. It encompasses a series of interconnected actors and activities performed sequentially that collectively enhance the product's value from production to consumption. Thus, Porter's conceptualization of the value chain fundamentally centers on the notion of added value as the core element throughout the chain of activities from input to final use. The execution and orchestration of these activities are decisive factors in determining costs and profoundly influence a firm's profitability. Consequently, the ultimate objective of value chain analysis is to bolster the competitive advantage of the enterprise.

Following Porter's delineation of the value chain in 1985, an extensive body of research emerged globally, focusing on value chain analysis for specific sectors and industries, such as the fisheries value chain and the agricultural value chain. However, Porter's original concept primarily addressed strategy at the firm level, rather than economic development strategies operating on a broader scale and within a broader context. Consequently, subsequent concepts related to the value chain have expanded beyond the scope of a single company, becoming applicable to entire supply chains and distribution networks at both national and global scales. Noteworthy examples include the global commodity chain (1994), the chain network (2001), the business model (2005), and the global value chain (from the 1990s to the present) [16].

2.2 Agricultural value chain and rice value chain

Agriculture constitutes the livelihood for the majority of the world's poor, thus remaining a fundamental instrument for achieving sustainable development and poverty reduction, particularly within developing nations [6]. Although a formal definition for the agricultural value chain is yet to be established, Miller and Jones [17] characterized it as an aggregation of actors and activities extending 'from farm to fork'. The agricultural value chain encompasses the actors (suppliers and supporting services) and the sequentially performed activities (inputs, production, collection, processing, packaging, storage, transportation, distribution, and consumption), whereby the agricultural product's value is incrementally augmented at each intermediary stage. Consequently, an agricultural value chain can be conceptualized as either a vertical linkage or a network of independent actors participating in all phases, from production to consumption. Adopting this approach, FAO and UNIDO [18] posited that the food value chain comprises all stakeholders engaged in coordinated, value-adding activities designed for the production and consumption of food.

Rice stands as one of the principal staple foods regularly consumed in Vietnam (alongside maize, potatoes, and cassava). Consequently, the rice value chain represents a topic of intensive research interest within the agri-food sector, both across Vietnam generally and specifically within the Mekong Delta. Studies by Loc [19], The Anh et al. [20], and Dung et al. [21] analyzed the stakeholders (input suppliers and support services) and activities (inputs, cultivation, collection, milling, polishing, packaging, transportation, and wholesale/retail) engaged in the rice value chain in the Mekong Delta. These analyses systematically identify the limitations or bottlenecks at each stage of the rice value chain, ultimately proposing solutions to overcome these constraints and upgrade the Mekong Delta's rice value chain. Furthermore, these investigations also provide separate analyses for both the domestic and export rice value chains. However, the circular perspective of the rice value chain in the Mekong Delta has not been included in these studies.

2.3 Circular agricultural value chain and circular rice value chain

Within the context of a circular economy, instead of examining linear value chains, these chains necessitate being viewed through a cyclical lens throughout the entire process, from input provision to product consumption, waste reuse and recycling, and can be analyzed at varying scales. Notwithstanding this shift, there remains a paucity of dedicated research and specific conceptual frameworks concerning the circular value chain. Notably, Eisenreich et al. [22] and Gillai [23] had applied circular economy principles to analyze the impact of circular solutions across all stages of the corporate value chain, extending from input sourcing to final consumption.

Regarding the circular agricultural value chain, there is generally no explicit, universally accepted definition, yet existing studies consistently address the application of circular economy principles within agricultural value chains. Miranda et al. [9] posited that organizations are currently not widely adopting circular principles in agri-food value chains, primarily due to the oversight of the governance aspect of the chain; they subsequently proposed various governance dimensions pertinent to establishing circular agri-food value chains. The study by Santana et al. [24] assessed the potential for implementing circular principles in Ecuador's agri-food value chain during 2019-2021 across nine dimensions: material sourcing, design, production, economic cycle, distribution and sales, consumption, waste reduction-reuse-recycling-recovery, remanufacturing, and sustainability. In essence, the circular agricultural value chain refers to the application of circular economy principles throughout the processes of input supply, production, processing, consumption of agricultural products, and waste management, with the ultimate goal of optimizing and augmenting the value of agricultural products from farm to fork.

With respect to the circular rice value chain, Reardon et al. [10] noted that substantial volumes of valuable waste are generated from rice production and processing, and these waste streams require investigation for the sustainable extraction of valuable components. Illankoon et al. [11] highlighted that the volume of organic waste generated by the agricultural sector is continuously escalating. However, many stakeholders adhere to a linear economic model, which imposes a burden on the environment and destroys valuable resources without realizing their intrinsic value. These by-products can be converted into high-value products; therefore, waste should be viewed as a key resource.

Kumar et al. [25] asserted that rice straw management is one of the major challenges in Asian countries. If effectively managed through several alternative measures such as the production of livestock feed, bioethanol, biochar, biogas, electricity, mushrooms, and paper, rice straw possesses the potential to safeguard the sustainability of agro-ecosystems and enhance the economic security of farmers. The authors also underscore the necessity of raising awareness among stakeholders regarding these alternative economic options. Singh and Brar [26] point out that Southeast Asian countries produce approximately 80% of the world's rice output, consequently generating a vast volume of annual rice straw waste. Environmentally friendly alternatives to open-field straw burning are investigated, including bedding material for cattle, mushroom cultivation, nutrition in the soil, power generation, pellet making, bio-gas, bio-ethanol, biochar, packaging materials, production of bio-composite, cement bricks, and handmade paper. The authors contend that the proper utilization of rice straw is not solely the responsibility of farmers. The government needs to promulgate appropriate laws and regulations to control straw burning. It is also necessary to elevate public awareness concerning rice straw management and to mandate training for farmers on this issue. In Vietnam, several circular economy models using rice straws have been implemented in the Mekong Delta, such as rice straw mushroom cultivation, animal feed processing, bio-fertilizer production and industrial products [14]. Thus, the incorporation of circular economy principles into the rice value chain will be instrumental in addressing the challenges of resource management, environmental protection, and climate change mitigation within rice production activities.

Generally, the literature review reveals two significant observations. Firstly, regarding conceptual and practical clarity, while the theoretical and practical issues surrounding the circular economy and circular agriculture are well-established and have received considerable academic attention, the corresponding issues for circular value chains, circular agricultural value chains, and circular rice value chains remain ambiguous and insufficiently studied. Secondly, with respect to research depth in the Mekong Delta, studies focusing on the rice value chain in the Mekong Delta have primarily been confined to analysing prevailing challenges or barriers and suggesting solutions for conventional value chain development, while in-depth research into the circular rice value chain is conspicuously absent. This paper, therefore, seeks to address this gap by systematically applying circular economy principles to the analysis of the rice value chain within the Mekong Delta in Vietnam.

3. RESEARCH METHODOLOGY

3.1 Research approach

The research leverages a combined analytical framework merging circular economy principles [3] with value chain analysis [27] to study the rice value chain in the Mekong Delta. Specifically, the paper applies the circular economy principles to the analysis of each stage of the rice value chain in the Mekong Delta to identify constraints at each stage from the perspective of managing waste/by-products derived from rice production. This subsequently helps to uncover potential strategies for upgrading the rice value chain in the Mekong Delta toward a circular one. Furthermore, value chain analysis also serves as a crucial policy tool to pinpoint the bottlenecks requiring support for actors participating at various stages of the chain, thereby providing a basis for proposing supportive government policies tailored to the value chain.

Based on the aforementioned approach, a qualitative research methodology was deemed the most appropriate for this study. Qualitative research is typically used to explore little-known socio-economic issues, understand community perceptions of a particular socio-economic problem, and identify suitable interventions or emerging issues [28]. The qualitative approach was adopted for this study because, to date, no research exists on the circular rice value chain in the Mekong Delta, Vietnam. Therefore, gathering exploratory information was essential before delving deeper into the topic. By employing the qualitative method, the study successfully obtained comprehensive and in-depth information regarding the specific issues and stakeholders involved in the rice value chain across the Mekong Delta, Vietnam.

3.2 Context and study area

Given the prevailing context of intensifying climate change and diminishing natural resources, the transformation of Vietnam's rice industry toward a circular-based model represents a compelling necessity. Adopting the circular models, grounded in sustainable and ecologically sound practices, is expected to facilitate the optimal use of resources, significantly curb wastage, mitigate greenhouse gas emissions, and enhance value creation across the Vietnamese rice sector.

The Mekong Delta, comprising five provinces - Dong Thap, Vinh Long, An Giang, Can Tho, and Ca Mau - is situated in the southernmost part of Vietnam and is the country's largest rice production region. Rice cultivation spans all provinces within the Mekong Delta region, a result of propitious factors including rich alluvial soil, a plentiful freshwater system, and extensive experience in intensive cultivation [19-21]. Given the vast volume of agricultural by-products generated, the Mekong Delta is uniquely positioned to adopt widespread, effective circular agricultural practices aimed at enhancing socio-economic welfare, safeguarding the environment, and mitigating greenhouse gas emissions. It is anticipated that circular models will propel the region's rice sector toward a state of modernity, sustainability, and heightened competitiveness on the global stage.

3.3 Data sources and collection

The research utilized a dual data strategy, drawing on both secondary and primary sources. To ensure a robust and holistic dataset concerning the rice value chain in the Mekong Delta, multiple data collection methodologies were deployed. Data acquisition occurred between April and August 2025, encompassing both literature review (desk research) and empirical fieldwork.

3.3.1 Secondary data

The study employed desk research to acquire secondary data from extant sources. Specifically, this involved collecting paddy production statistics of Vietnam and the Mekong Delta (area, yield, and output) from the Statistical Yearbook of Vietnam 2025 published by the National Statistics Office as well as sourcing policies related to rice value chain development and agricultural by-product management from governmental mandates, academic studies and reports issued by research institutions and relevant regulatory agencies.

3.3.2 Primary data

To gather primary information, the research adopted a qualitative methodology. This type of research typically relies on three main data collection techniques: in-depth interviews (both unstructured and semi-structured), group discussions (focused and unfocused), and observation and documentation (visuals and descriptive notes). In this study, the focus group discussion method was implemented, bringing together a range of key stakeholders operating within the Mekong Delta rice value chain. This diverse group included input providers, rice-producing farmers, collectors, milling and polishing plant operators, wholesalers, retailers, representatives from seed research and agricultural extension centers, market support organizations, and local agricultural authorities.

The participants comprised individuals with direct experience and specialized expertise across various stages of the circular rice value chain in the Mekong Delta. Specifically, representatives from rice-farming households were required to have a minimum of five years of cultivation experience and to have previously implemented or be currently practicing circular rice production models. Selected enterprises included those involved in the collection, processing, and trading of rice at various scales, specifically engaging in several circular rice value chain activities such as producing mushrooms, animal feed, or organic fertilizers from rice straw, or converting rice husks into briquettes. The cohort of agricultural experts and local officers consisted of officers from agricultural extension centers and agricultural divisions at the commune level with expertise in agronomy, economics, and environmental science. In total, three focus group discussions, each comprising six participants, were conducted with the categories of rice-farming households, enterprises, and experts/local officers. The representativeness of participants within each group - concerning their roles, expertise, geographical location, and operational scale - was strictly considered during the selection process.

The core discussion points covered in these focus group discussion sessions were the present status of the rice value chain in the Mekong Delta, the constraints of the rice value chain specifically concerning the management of agricultural waste/by-products, viable strategies for transitioning to a circular rice value chain and necessary government policies to facilitate this circular transition in the Mekong Delta.

3.4 Analytical methods

The research objectives are achieved through the application of the following analytical methods.

Desk research: Utilized to synthesize the literature review and identify the existing research gap.

Descriptive and comparative analysis: Applied to secondary data to chart the development of the rice sector in the Mekong Delta across the 2020–2024 timeframe.

Value chain analysis: Employed to thoroughly examine the current state of the rice value chain in the Mekong Delta and identify bottlenecks within the chain from the perspective of waste/by-product management.

SWOT analysis: Applied to specifically evaluate the Strengths, Weaknesses, Opportunities, and Threats associated with potential strategies for the reuse and recycling of by-products from rice production in the Mekong Delta. The SWOT analysis criteria center on the technological feasibility (e.g., availability or applicability of technology), economic feasibility (e.g., costs, capital investment, employment opportunities, income generation and profitability), environmental impact and scalability of the potential strategies. Information for the SWOT analysis was collected through focus group discussions with various stakeholders in the Mekong Delta's rice value chain.

The results and discussion in this article are structured around four key dimensions. The initial focus is on describing the evolution of the rice sector in the Mekong Delta from 2020 to 2024 to highlight the region's indispensable role in Vietnam's rice production and export landscape. The second aspect involves analyzing the rice value chain in the Mekong Delta to pinpoint limitations relating to the management of waste/by-products throughout the chain. A SWOT analysis is then conducted to identify potential strategies for integrating circular economy principles into the rice value chain in the Mekong Delta. Finally, the article proposes supportive government policies geared towards establishing a circular rice value chain in the Mekong Delta.

4. RESULTS AND DISCUSSION

4.1 The development of the rice sector in the Mekong Delta in the period 2020–2024

Rice constitutes the primary crop within Vietnam's cultivation sector. Relative to its regional peers in ASEAN, Vietnam maintains a significant competitive edge in both rice cultivation and export. Vietnam's paddy cultivated area ranks third among ASEAN nations, trailing only Thailand (11.829 million hectares in 2023) and Indonesia (10.270 million hectares in 2023). Notably, Vietnam achieves the highest rice yield in the entire ASEAN region. Consequently, the country's rice output is the second largest in the region, surpassed only by Indonesia. Between 2019 and 2023, Vietnam's annual rice exports ranged from 6 to 8 million tonnes, escalating the export turnover from $2.8 billion (2019) to $4.67 billion (2023). Rice is fundamentally a major national export commodity, contributing 17.5% to the total export value of the agricultural sector and 8.8% to Vietnam's overall export value in 2023 [13].

Table 1. Some indicators of paddy production in the Mekong Delta, Vietnam (2020-2024)

Indicators	2020	2021	2022	2023	2024
1. Cultivation area (1,000 ha)					
Vietnam	7,278	7,238	7,109	7,119	7,127
Mekong Delta	3,963	3,898	3,802	3,838	3,858
2. Yield (tons/ha)					
Vietnam	5.88	6.06	6.00	6.11	6.10
Mekong Delta	6.01	6.24	6.19	6.29	6.35
3. Output (1,000 tons)					
Vietnam	42,764	43,852	42,660	43,497	43,451
Mekong Delta	23,827	24,327	23,536	24,156	24,517

The Mekong Delta serves as Vietnam's foremost rice granary. On average, during the 2020–2024 period, the Delta was responsible for 54% of the country's total rice cultivation area. Critically, the region's rice yield exceeded the national average, resulting in its output contributing 55.7% of the entire national rice volume (Table 1). The region's dominance is further highlighted in trade, where rice exports from the Mekong Delta held a crucial role, accounting for 90% of Vietnam's national rice export volume [21]. These figures collectively demonstrate the indispensable contribution of the Mekong Delta to securing Vietnam's domestic food supply and its role as a key supplier to the international rice market.

4.2 Value chain analysis of the rice sector in the Mekong Delta, Vietnam

4.2.1 Rice value chain mapping in the Mekong Delta

The rice value chain in the Mekong Delta encompasses several main stages such as input provision, production (rice cultivation), collection, processing (drying, milling, polishing, packaging), distribution, and consumption (domestic and export) (Figure 1). This chain is characterized by thousands of input supply establishments, tens of thousands of traders procuring paddy, and thousands of enterprises operating in the milling, polishing, exporting, and domestic consumption segments. However, the number of enterprises with sufficient capacity to directly purchase paddy from farmers or cooperatives and possessing the necessary drying, milling, and polishing facilities to produce finished rice products remains limited [20]. Input providers are primarily cooperatives and supply agents/stores. Producers are predominantly small-scale farmers. Collectors/procurement agents are mainly local agents and dealers. Processors are predominantly enterprises. Consumers acquire rice products via retail channels (markets, stores, supermarkets) or through export. Support services, spanning from rice production to consumption, include technical and business training services, specialized services, and financial services.

Currently, Vietnam ranks among the world's leading nations in paddy production and rice export. Numerous regions have established integrated rice value chains, encompassing production, processing, and consumption through various forms of linkage. However, several constraints within the rice value chain in the Mekong Delta have been identified, based on focused group discussions. In terms of rice production, production primarily operates on a small-scale farming household model, which impedes the effective application of mechanization and technical advancements. At the same time, production practices are unsustainable with the intensive use of inputs (seeds, fertilizers, pesticides, irrigation water) which leads to wastage, increases production costs, and causes environmental damage while the income of rice farmers remains low. Regarding rice processing, drying, storage, and processing facilities are not fully synchronized with the production areas, which negatively affects rice quality and the level of deep processing remains low. In addition, investment in and the application of science and technology for rice cultivation remain low. In terms of linkage and branding, the rice value chain is fragmented and lacks cohesion/linkage, making traceability or quality standard certification difficult. Rice brands are generally underdeveloped, with a low proportion of branded rice products.

4.2.2 Limitations of the Mekong Delta's rice value chain from the perspective of agricultural waste/by-products management

The domestic rice value chain in the Mekong Delta encompasses various stages and generates a range of waste products/by-products from farm to table (Table 2).

Table 2 demonstrates that the domestic rice value chain in the Mekong Delta largely exhibits a linear value chain for several reasons. Firstly, input spillage and packing materials are mostly uncollected or partially collected before being disposed of in landfills. Secondly, the majority of straw and root residue from rice production (70%) is currently underutilized, being instead incinerated or buried directly in the fields. The Mekong Delta cultivates paddy in three crops annually, with a total paddy cultivation area of approximately 3.858 million hectares, yielding a total paddy output of over 24.517 million tonnes in 2024 (Table 1). Given the straw-to-paddy harvest ratio of 1.1−1.2, the resulting straw and root residue amounts to roughly 26-27 million tonnes [14]. Of this, 70% of the straws and roots is incinerated in the fields or ploughed back into the soil; the remaining 30% is collected and utilised for diverse purposes, for example, mushroom cultivation (30%), mulching for crops and cushioning for fruit transport (35%), animal feed processing (25%), and other applications constituting approximately 10% [14].

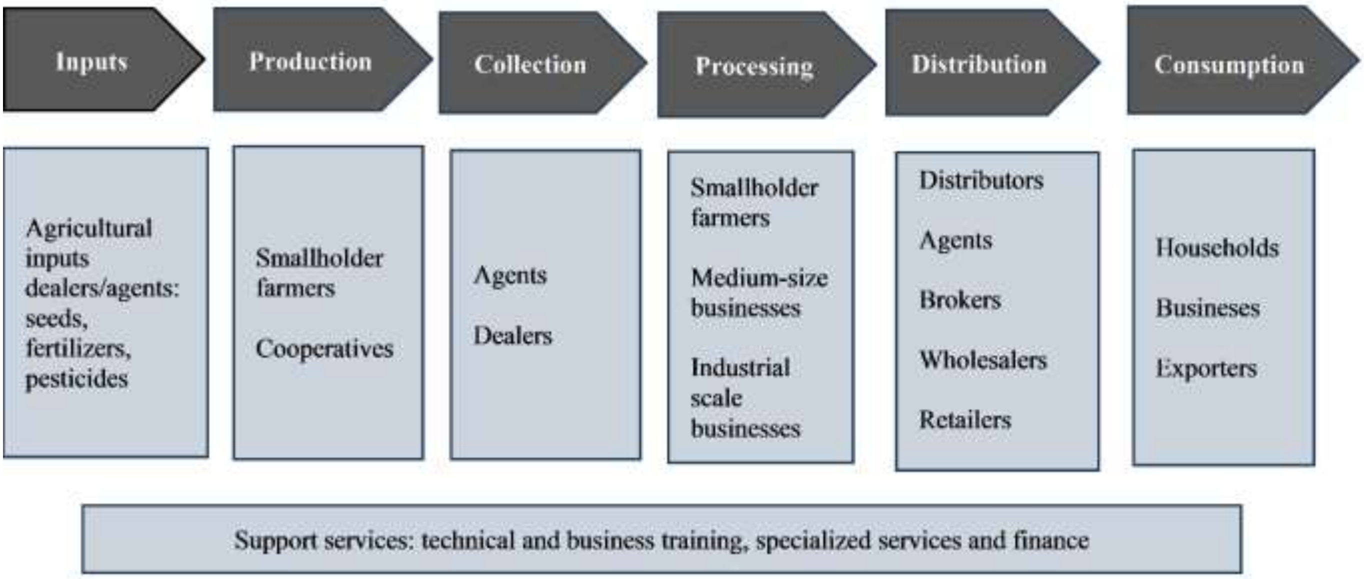

Figure 1. The rice value chain in the Mekong Delta, Vietnam

Although the utilisation and processing of agricultural by-products in the Mekong Delta have yielded some results, these efforts remain inconsistent, ineffective, and fail to generate high-value-added products. Burning straw constitutes a resource wastage, leading to the loss of soil nutrients, alteration of the soil's mechanical composition, and environmental pollution. Conversely, incorporating straw into submerged fields increases the emission of methane (CH_4) and other greenhouse gases, and causes organic toxicity for the subsequent rice crops [29].

During the recent past, the government of Vietnam has promulgated numerous laws, strategies, and policies aimed at the sound management and utilisation of agricultural by-products. Key examples include the Law on Cultivation (2018), the Law on Animal Husbandry (2018), the Law on Environmental Protection (2020), the Socio-Economic Development Strategy 2021-2030, the National Strategy on Green Growth (2021-2030), the Strategy for Sustainable Agricultural and Rural Development 2021-2030 with a vision to 2050, the Decree 57/2018/ND-CP on incentive policies for enterprises investing in agriculture and rural development sector, the Plan for Agricultural Sector Restructuring 2021-2025, the Decision 885/QD-TTg 2020 approving the scheme on organic agriculture development in the period of 2020-2030, the Circular No. 12/2021/TT-BNNPTNT guiding the collection and treatment of livestock waste and agricultural by-products for reuse for other purposes, the Circular Economy Development Scheme (2022), and Decision No. 540/QĐ-TTg dated June 19, 2024 appproving the Scheme on research and development, application of, and technology transfer to promote a circular agriculture until 2030. However, a rigorous review of these policies reveals that they remain predominantly directional in nature and are constrained by several inherent limitations. Firstly, a legal framework for circular agriculture and the recycling of agricultural by-products has not yet been established. Secondly, there is a lack of a system of standards, evaluation tools for agricultural by-product utilisation, and a focal agency to manage this issue. Thirdly, policies designed to attract enterprises, organisations, and individuals to invest in the reuse and recycling of agricultural by-products are absent. Fourthly, policies supporting production linkages do not yet prioritise the utilisation of agricultural by-products.

Findings from focus group discussions in the Mekong Delta indicate that a major impediment to effective rice by-product management in the Mekong Delta stems from the fact that an estimated 70% of rice straws and roots remain uncollected and are either burned or directly ploughed back into the paddy fields. There are several reasons that straws from rice cultivation have not been fully utilised.

Firstly, farmers adhere to a traditional practice of burning straw in the soil or burning it to produce ash fertilizer and loosen the soil after harvest. They perceive this method as time- and labour-saving. This customary practice stems from farmers' lack of knowledge or inadequate awareness concerning the detrimental environmental and health impacts of straw burning, coupled with insufficient information, awareness campaigns, and technical guidance on alternative straw management methods.

Secondly, the practice of three paddy crops per year in the Mekong Delta, involving a short turnaround period between crops, necessitates rapid field clearance by farmers to meet the planting schedule. This results in a very limited window for manual straw collection. Driven by the pressure to prepare the soil promptly for the subsequent crop, farmers resort to burning or directly incorporating the straw in the field.

Thirdly, the low selling price of straw is compounded by the difficulties associated with its transportation and storage. Paddy is harvested using combine harvesters, which leave the straw scattered directly in the field. Given the bulky volume of straw, transporting it from the fields to production sites and preserving the dry straw to prevent moisture damage or decomposition presents a significant challenge for smallholders. The low straw selling price does not offset the high collection, transportation, and storage costs, thereby disincentivising farmers from collecting it.

Fourthly, the limited availability, lack of widespread distribution, and frequent unavailability of straw balers, combined with farmers' inability to afford the equipment themselves, and lack of storage facilities for straw after harvest, constitute major obstacles to straw collection.

Finally, despite the explicit prohibition of rice straw burning under the Law on Environmental Protection (2020), local monitoring and enforcement mechanisms remain inadequate, leading to the continued prevalence of this practice for most rural farmers in Vietnam in general and in the Mekong Delta in particular.

Table 2. Waste/by-products generated along the Mekong Delta's domestic rice value chain

	Stakeholders	Concrete activities	Wastes produced	Existing waste treatment
1. Inputs	Agricultural inputs dealers/agents: seeds, fertilizers, pesticides	Storage → Transportation →	Fallen wastes	Collected or uncollected for the landfills
2. Production (Rice cultivation)	Smallholder farmers Large-scale farmers	Pre-cultivation: land monitoring, land preparation, weed control, fertilizer placement → Planting and Transplanting → Post planting: use of pesticides and fertilizers → Harvest →	Packages of used inputs (chemicals, fertilizers, pesticides) Rice straws and roots	- A portion is collected - A portion is burned - The majority is uncollected - A portion is used as an animal feed ingredient - A portion is used for bedding in animal farms - A portion used for producing organic fertilizers - A portion is used for cultivating rice straw mushrooms - A portion remains on the field - The majority is burned in the field for land preparation for the next crop
3. Collection (Trading)	Agents Brokers	Selling paddy →	Low-quality paddy	All are used as animal feed ingredients
4. Processing	Smallholder farmers Medium-size businesses Industrial-scale businesses	Paddy → Boiling paddy → Milling → Polishing → Pakaging →	Paddy husks Rice bran	- A large portion is used for energy purposes (direct burning for cooking, making rice husk pellets) - A portion is used for producing organic fertilizers - A portion is used for bedding in animal farms - A portion is used for producing construction materials - The majority is collected and sold as animal feed ingredients - A portion is crushed for oil
5. Distribution	Large-scale distributors Agents Brokers Wholesalers Retailers	Transportation → Wholesale → Retail →	Bad rice Spilled rice Expired rice	All is collected and sold as animal feed ingredients
6. Consumption	Households Businesses	Storage → Cooking	Bad rice Expired rice Rice sacks Cooked rice leftovers	All is collected and sold as animal feed ingredients Collected or non-collected

Addressing these issues would unlock opportunities for applying the circular economy principles to resolve the challenge of rice straw management in the Mekong Delta. The utilization of by-products from rice production holds significant importance in extending the Mekong Delta's rice value chain, contributing to job creation, income generation, environmental protection and sustainable development in the Mekong Delta.

4.3 SWOT analysis of potential models for integrating circular economy principles into the domestic rice value chain in the Mekong Delta

Table 2 indicates that a substantial volume of valuable waste products/by-products is generated from rice production, harvesting, and processing. These materials warrant further investigation for the creation of value-added products. Through focused group discussions with stakeholders in the Mekong Delta's domestic rice value chain, the utilization of straws to generate high-value-added products emerged as the most pressing and contextually relevant issue for the region, specifically through the development of rice straw-based circular economy models.

The opportunities for applying the rice straw-based circular economy models within the Mekong Delta rice value chain, as illustrated in Figure 2, are categorized into two groups. The first one includes models that are technically feasible, economically efficient, and scalable for widespread adoption. The second one consists of models that offer long-term benefits but currently face significant capital and technological barriers, requiring robust government support. The subsequent SWOT analysis for each model is presented below, based on the results of the focus group discussions.

4.3.1 Technically feasible, economically efficient, and scalable for widespread adoption models

The rice straw-based circular economy models that have been assessed as technically feasible, economically efficient, and encouraged for widespread adoption in the Mekong Delta involve the collection of straw from the fields, followed by its processing to create diverse rice straw-based products. These models facilitate the generation of high-value products (e.g., mushrooms, organic fertilizers, animal feed ingredients), thereby directly enhancing farmers' incomes while simultaneously mitigating greenhouse gas emissions, specifically methane (CH_4).

(1) Rice straw mushroom cultivation

The collected straw is subjected to water immersion and then combined with mushroom spawn to produce rice straw mushrooms [30]. This model is considered the most prevalent and easiest to implement in the Mekong Delta.

Strengths: The abundant supply of rice straw ensures a stable and consistent source of raw material for production due to its constant availability. The technique for cultivating rice straw mushrooms is straightforward and well-suited to household-scale operations. Furthermore, mushroom farming generates supplementary employment and income for farmers from two primary sources: the mushrooms themselves, which are a high-value food product, and the spent mushroom substrate, which serves as an essential input for organic fertilizer production. Critically, this model provides a direct solution to eliminate open-field rice straw burning, thereby mitigating air pollution and reducing CO_2 emissions.

Weaknesses: Despite the low cost of straw itself, the mechanization expenses associated with the collection and transportation of straw from the fields to the mushroom cultivation facilities constitute a significant cost burden for households. Furthermore, rice straw mushrooms are a fresh product with a short shelf life, necessitating expedited harvesting, transportation, and consumption, which consequently increases overall logistics costs. Straw sourced from traditional farming areas carries the risk of containing pesticide residues, which can potentially compromise the quality and food safety of the cultivated mushrooms. Finally, outdoor rice straw mushroom production is highly susceptible to climatic conditions (e.g., temperature and rainfall), resulting in unstable yield and inconsistent quality, making continuous market supply challenging. Small-scale, household-based rice straw mushroom cultivation often relies on empirical experience and lacks automated climate control systems. This deficiency in regulating temperature and humidity frequently results in suboptimal quality, inconsistent yields, and volatile market outlets, ultimately leading to financial instability.

Opportunities: The escalating market demand for clean and safe rice straw mushrooms, both in the domestic and export sectors, creates an opportunity for higher selling prices. The rice straw mushroom cultivation model serves as an ideal stepping stone for the production of organic fertilizers from the spent mushroom substrate, leading to a more sustainable income stream from the waste product. Furthermore, the expansion of industrial-scale indoor mushroom farming models, utilizing controlled temperature and humidity measures, will help mitigate seasonality and ensure stable and year-round productivity. Finally, the government's current policy priorities on the promotion of circular agriculture and the reduction of greenhouse gas emissions will generate support for utilizing straw for mushroom cultivation.

Threats: Unpredictable meteorological shifts, including atypical rainfall and drought, directly impede rice straw procurement and conservation efforts, often leading to degradation through moisture-induced mold growth. Farmers face difficulties in accessing capital to invest in high-cost, indoor mushroom cultivation models, which consequently leaves the current model vulnerable to natural conditions. Furthermore, the rise of alternative production models utilizing straw (such as biomass pellets or animal feed ingredients) will lead to fierce competition in straw procurement, potentially driving up the raw material price. Rice straw mushrooms are also highly susceptible to diseases, particularly when grown outdoors or when using substandard spawn, which can result in total crop loss or a severe decline in productivity.

(2) Organic fertilizer production

Straw is collected, then blended with other nutrient-rich materials (such as animal manure and rice husk ash), and subsequently composted using microbial preparations to produce organic fertilizers [31].

Strengths: The Mekong Delta region generates in excess of 26–27 million tons of straws and roots annually, providing a stable and abundant raw material source for organic fertilizer production. The process of converting straw into organic fertilizer is manual and straightforward. If this model is implemented in a closed-loop system, where the produced organic fertilizer is applied back to the paddy fields, it will reduce farmers' costs for chemical fertilizers and enhance their self-sufficiency. Crucially, transforming straw into organic fertilizer offers a comprehensive solution to the issue of rice straw burning, thus mitigating air pollution and reducing greenhouse gas emissions (CO_2, CH_4).

Weaknesses: The mechanization costs associated with straw collection (especially wet straw) and the subsequent transportation of the straw from the fields to the production facilities or workshops remain substantial, thereby inflating the final price of organic fertilizers. Furthermore, small-scale organic fertilizer production often struggles to rigorously monitor the composting process (temperature, moisture, and duration), resulting in inconsistent fertilizer quality (e.g., incomplete decomposition or the presence of pathogens). The natural decomposition of rice straw requires several months, which impedes production speed and the capacity for timely seasonal supply. Finally, organic fertilizers typically possess large volume and low density, leading to high logistics expenses compared to concentrated chemical fertilizers, which ultimately diminishes their competitive advantage.

Opportunities: The model has the potential to utilize spent rice straw substrate (which has already undergone preliminary processing) from mushroom production as a primary input, effectively reducing the composting time required for organic fertilizer and yielding a superior-quality product. Furthermore, the paddy fields in the Mekong Delta are facing severe organic matter depletion following years of intensive farming and inorganic fertilizer application, which has created a substantial demand for organic fertilizer to restore soil fertility. The advancement of microbial preparations and rapid composting technology serves to substantially enhance the quality of organic fertilizer. The reduction of straw burning and subsequent soil restoration using organic fertilizer are recognized as greenhouse gas mitigation activities, enabling the model to generate revenue from carbon credits. In addition, should the government implement stringent policies mandating a reduction in greenhouse gas emissions and chemical fertilizer usage, while simultaneously promoting organic fertilizer application, it will create a captive market and ensure significant resource support for the production of rice straw-based organic fertilizer.

Threats: The production cost of rice straw-based organic fertilizer is often higher than or equivalent to that of chemical fertilizers, which makes farmers hesitant to transition their fertilizing habits. Furthermore, shifting from chemical to organic fertilizers requires time, knowledge, technical proficiency, and patience to realize the long-term benefits while farmers are typically focused on short-term efficiency. Additionally, the risk of pesticide residue contamination in the rice straw sourced from the fields can compromise the quality and erode confidence in the finished organic fertilizer product. Finally, if government support policies are solely concentrated on organic fertilizer production without synchronous assistance for farmers' capital investment to purchase the fertilizer and robust quality control measures, the model will likely struggle to establish a sustainable market presence.

(3) Animal feed ingredient production

Rice straw is collected, compacted into bales, and subsequently processed to enhance its nutritional value and digestibility as roughage for livestock (especially cattle and buffalo) [32]. The resulting animal manure is then utilized to produce organic fertilizer, which is reapplied to rice fields or other cultivated crops. This model not only converts straw into animal feed ingredient, but also establishes a novel value chain - one that integrates crop cultivation and livestock farming.

Strengths: The Mekong Delta possesses a vast and consistent supply of rice straw, ensuring a stable raw material source for the production of roughage animal feed. Processing straw into animal feed enables livestock farmers to reduce roughage costs and decrease their reliance on expensive industrial feed or imported grass. This model serves as an ideal nexus connecting crop cultivation and animal husbandry, whereby straw is converted into animal feed, and the resulting manure is processed into organic fertilizer and returned to the rice fields. This action replenishes organic nutrients in the soil and restores fertility. Critically, the collection of straw for feed processing resolves the issues of open-field burning and submerging straw in flooded fields, thereby significantly reducing CH_4 emissions.

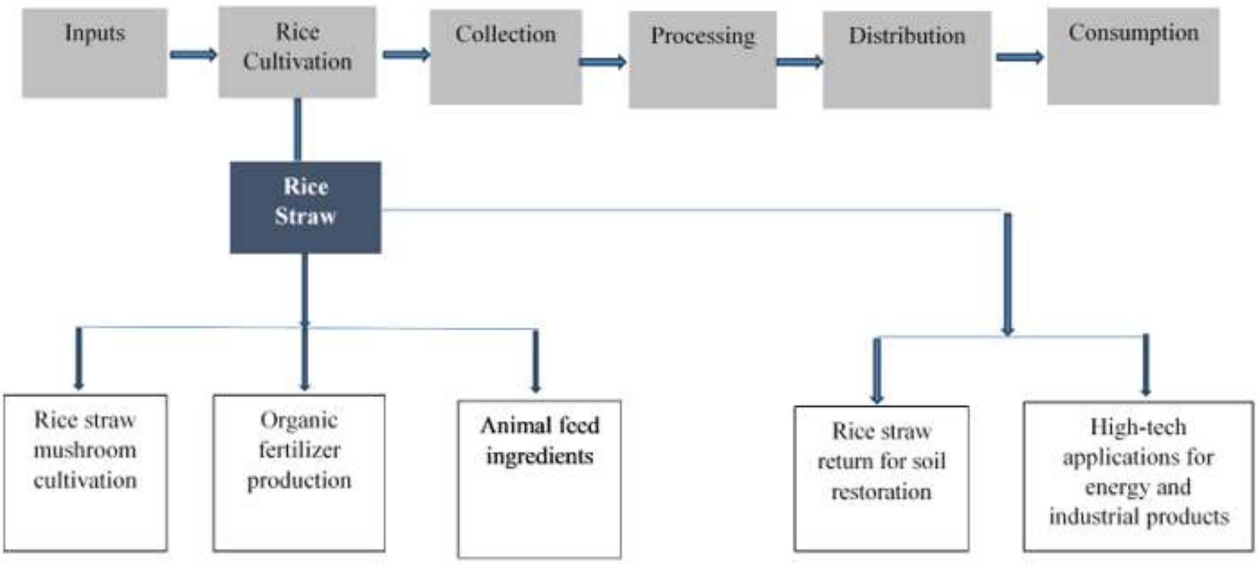

Figure 2. The rice straw value chain in the Mekong Delta, Vietnam

Weaknesses: Rice straw in the Mekong Delta is often harvested under humid conditions, making it susceptible to mold and mycotoxin contamination, which poses a significant health risk when processed into animal feed for livestock. Furthermore, straw is a bulky raw material, necessitating extensive storage space and incurring high transportation costs from the rice fields to processing facilities or livestock farms. The linkage between rice farming cooperatives (straw suppliers) and cattle farms (feed consumers) remains tenuous, lacking long-term procurement contract mechanisms, which hinders scalable expansion. To ensure the straw meets animal feed standards, it requires chemical or biological treatment to enhance its nutritional value and digestibility, yet the technological investment and operational costs for this step are substantial. Finally, to complete the circular cycle, the livestock waste must be treated using biogas digestion or composting technology before the nutrients can be returned to the rice fields.

Opportunities: In the context of growing consumer concern regarding the quality of meat and milk, animal feed derived from clean straw, with controlled chemical residue levels, will help elevate the brand reputation of livestock products from the Mekong Delta. Furthermore, the ruminant livestock sector, particularly beef and dairy cattle farming, is expanding towards a farm-based model, thereby creating a large and stable demand for quality roughage. The model also holds the potential to generate carbon credits through the cessation of straw burning and field incorporation, which could provide a novel revenue stream to offset straw collection and processing costs.

Threats: Given that industrial animal feed is already widespread and possesses advantages in convenience and uniformity, straw-based feed must demonstrate superior economic and nutritional efficacy to achieve substitution. Furthermore, the increasing incidence of flooding and unseasonal rains makes straw collection and storage more challenging, heightening the risk of mold and mycotoxin contamination and consequently threatening the supply of clean raw material. Traditional livestock farmers may also lack proficiency in the techniques required for utilizing straw-based feed, leading to suboptimal livestock performance and an erosion of confidence in the product. Finally, the cost of testing for pesticide residues and mycotoxins is prohibitive. Without supportive government policy, these expenses will inevitably increase the production cost of straw-based animal feed, thereby reducing its market competitiveness.

4.3.2 Long-term benefit models

(1) Rice straw return for soil restoration

Rice straw is either partially collected or treated in situ with biological preparations to expedite its decomposition. The resulting decomposed straw acts as organic matter, which serves to retain soil moisture, improve soil structure, foster an increase in beneficial microorganisms, and cycle essential nutrients back into the soil for the subsequent rice cultivation [29]. This strategy is highlighted as a priority solution for mitigating greenhouse gas emissions.

Strengths: Farmers can avoid expenses related to hiring straw baling equipment or transportation, leading to considerable logistics cost savings. Rice straw return provides an exceptional source of organic matter for the soil, thus contributing to the restoration of fertility and the improvement of soil structure following extended periods of intensive chemical fertilization. This model is characterized by its simplicity and easy implementation. By eliminating the need for intricate connections with processing plants or markets for rice straw-based products, farmers gain complete autonomy in the management of rice straws. Over the long term, the enhancement of soil organic matter is projected to reduce the reliance on chemical fertilizers, resulting in substantial savings in rice production costs.

Weaknesses: Farmers incur supplementary costs for biological agents, and the more intricate rice straw return process extends the necessary land preparation period between successive crops. Critically, should the straw return fail to decompose completely under submerged conditions, it can produce organic toxins. These toxins can induce poisoning and inhibit the growth of subsequent young rice seedlings, consequently resulting in yield reduction. Moreover, straw return in flooded paddies creates an anaerobic environment that is highly conducive to methane-producing bacteria, leading to a significant increase in greenhouse gas emissions. This outcome directly contradicts the objectives of sustainable rice cultivation and emission reduction initiatives.

Opportunities: The Mekong Delta is currently grappling with the degradation of soil organic matter and fertility, establishing a considerable intrinsic demand for the recirculation of natural nutrients derived from rice straw. To support this, the government could provide subsidies or financial support for biological agents used in in-situ straw treatment, which would assist in minimizing the risk of organic poisoning for agricultural producers. The growing prevalence of Alternate Wetting and Drying (AWD) technology for efficient water management, when judiciously combined with straw incorporation, has the potential to significantly reduce CH_4 emissions, thereby effectively mitigating the most substantial environmental weakness of this practice.

Threats: The anaerobic decomposition of rice straw under flooded conditions generates significant quantities of methane (CH4), a process that fundamentally contradicts current global commitments to low-emission agriculture. In the intensive farming regions of the Mekong Delta, where triple-cropping systems prevail, the fallow period between harvests is exceptionally brief -typically less than 15 to 20 days. This interval is insufficient for the complete mineralization of organic matter. Consequently, sowing seeds before the straw has fully decomposed exacerbates the risk of organic acid toxicity, potentially jeopardizing the viability of the subsequent crop. This outcome often fosters reluctance and prompts a quick reversion to the practice of straw burning. Furthermore, the success of alternative rice straw-based circular economy models, such as mushroom cultivation, organic fertilizer production, or animal feed manufacturing, could actively disincentivize farmers from incorporating straw by creating a profitable market for its sale, thereby limiting the availability of organic matter to be returned to the soil.

(2) High-tech applications for energy and industrial product production

The adoption of modern technological solutions presents considerable potential for the valorization of rice straw into high-value industrial products and clean energy [33]. In the energy sector, rice straw can be processed into bio-pellets or employed in gasification technology for electric power generation. In the domain of construction and industrial materials, applications span the production of paper, cardboard, or pulp, as well as the manufacturing of non-fired bricks, insulation panels, and roofing sheets from compacted straw. Leveraging advanced technology serves to maximize the profitability of rice straw, facilitating a transformation from rudimentary agricultural outputs (e.g., mushrooms, organic fertilizers, animal feed ingredients) to sophisticated industrial and energy commodities. This transition is vital for expanding the market for rice straw at a significantly elevated value, surpassing the returns achieved through traditional uses.

Strengths: The strategy of converting rice straw into industrial commodities, construction materials, or energy generates a commercial return that is substantially higher than the value derived from traditional usages. This approach achieves its highest operational efficiency at an industrial scale, which is critical for minimizing unit production costs and ensuring stringent output quality control. The manufactured products can then be channeled to major industrial sectors (e.g., energy, construction, paper, etc.) or designated for export, thereby securing a stable market demand and significantly reducing dependency on volatile local agricultural markets.

Weaknesses: The expense associated with transporting the high-volume and bulky nature of rice straw from paddy fields to processing facilities represents a substantial logistics impediment, consequently diminishing the overall economic viability. The establishment of factories and the acquisition of complex, modern production lines necessitate a prohibitive initial capital outlay, often exceeding the financial scope of local cooperatives and enterprises. Moreover, the operation, equipment maintenance, and control of chemical or biological processes require either proprietary or intricate technology transfer, along with a highly skilled workforce of engineers and technicians. A further challenge is that these industrial procedures mandate a very high standard for the raw rice straw (specifically regarding moisture levels, cleanliness, and freedom from chemical residues) to guarantee the requisite quality of the end-product, thus exerting significant pressure on the straw collection and preservation logistics.

Opportunities: This model adheres to global environmental and sustainability criteria, which positions it favorably to attract green investment funds and Foreign Direct Investment (FDI) from developed economies. Products, particularly bio-pellets, are highly sought after in Japan, South Korea, and European markets for fossil fuel substitution, thereby establishing a broad export market potential. Additionally, facilities that mitigate straw burning or engage in the energy conversion of straw can yield considerable carbon credits, which represent a significant avenue for ancillary revenue generation.

Threats: The procurement price for straw feedstock faces upward pressure due to market competition among diverse utilization pathways (mushroom cultivation, animal feed production, and organic fertilizer production), which subsequently erodes factory profit margins. High-technology products must engage in price competition against traditional, incumbent market materials (such as coal, timber, and petrochemicals), which typically possess a lower cost base or benefit from highly robust supply chains. From a regulatory standpoint, the process of securing permits for factory construction, obtaining grid connection approval (particularly for biomass-derived electricity), and fulfilling environmental compliance can be unduly complex and protracted, thereby impeding timely project deployment. Finally, natural disasters pose a critical risk, capable of disrupting the stable and clean supply of raw materials, thus severely compromising the continuity of operations for large-scale industrial facilities.

Based on the SWOT analysis results, Table 3 presents a comparative analysis of five rice straw-based circular models, evaluated across four key parameters: technological feasibility, economic viability, environmental impact, and scalability.

The prioritization of the aforementioned five models must be aligned with the strategic development orientation for the Mekong Delta, as articulated in Vietnam's current policy frameworks. These strategies emphasize the transition toward low-emission agriculture, the accelerated adoption of circular economy models, and the enhancement of economic value across the entire rice value chain. Consequently, the priority ranking for these rice straw-based circular models is as follows.

1. Rice straw mushroom cultivation: Despite lacking the massive capacity of processing rice straw, mushroom cultivation yields the highest value-added potential for smallholders and generates seasonal employment. This provides a substantial revenue stream that fosters livelihood diversification and optimizes farmer profitability.

2. Organic fertilizer production: This solution establishes a closed-loop circularity within the rice sector, where straw residues are returned to the paddies as organic fertilizer, thereby mitigating the over-reliance on imported chemical inputs.

3. Animal feed ingredient production: While facilitating cost optimization within the livestock sector, the viability of this solution is heavily contingent upon the scale and evolving demands of cattle and buffalo husbandry in the Mekong Delta.

Table 3. Comparative analysis of five rice straw-based circular models

Model	Technological Feasibility	Economic Viability	Environmental Impact	Scalability
1. Rice straw mushroom cultivation	**High:** the cultivation techniques are straightforward and highly adaptable at the household level	**High: c**reating high-value food products.	**Medium: s**traw is reused, but there are post-production residuals.	**Medium:** constrained by the mushroom market and seasonal cycles.
2. Organic fertilizer production	**Medium:** improper technical procedures may result in low-quality organic fertilizers	**Medium:** serving as a viable alternative to chemical fertilizers and reducing input costs	**High:** improvement in soil quality, reduction of the use of chemical fertilizers and emissions.	**Medium:** suitable for household and industrial scale.
3. Animal feed ingredient production	**Medium:** requirement of advanced ensiling or alkalization technologies, coupled with strategic linkages with commercial livestock farms	**Medium:** provision of essential roughage and reduction of concentrated feed cost	**Medium:** Straw is reused, but the straw must be of good quality	**Medium:** dependence on the scale and needs of livestock farming in the region.
4. Rice straw return for soil restoration	**Low:** the straw incorporation technique is simple, but improper technical procedures may result in CH4 emissions	**Low:** In-situ straw incorporation effectively mitigates fertilizer costs, but the soil restoration process is low	**High:** promotion of nutrient retention, enhancement of soil organic carbon sequestration, and contribution to greenhouse gas emissions mitigation	**Medium:** applicable directly in the field after harvest, but constrained by the crop interval time
5. High-tech applications for energy and industrial product production	**Low:** requirement of advanced technologies and technical experts for operation	**High:** higher added value compared to traditional usages, but large investment capital	**High:** replacement of fossil fuels and a significant reduction in greenhouse gas emissions	**Low:** limited by considerable capital and technological impediments.

4. High-tech applications for energy and industrial product production: Leveraging advanced technology to convert rice straw into diverse high-value-added products within a circular economy framework in the Mekong Delta is recognized as the

most effective and sustainable long-term strategy for maximizing the economic value of rice straws. This centralized solution optimizes the utilization of large-scale straw yields, yielding high-value energy outputs and ensuring the definitive elimination of surplus straw within the production cycle. Nevertheless, the model's current penetration is limited by considerable capital and technological impediments.

5. Rice straw return for soil restoration: This represents the most fundamental and readily implementable solution, offering the most significant and instantaneous environmental impact on a large scale. Although this model promises long-term environmental and soil fertility advantages, its widespread adoption in the Mekong Delta is currently hindered by significant technical challenges and demonstrably low economic returns in the short run.

4.4 Implications of supportive government policies towards the circular rice value chain in the Mekong Delta

The application of circular economy principles to the rice value chain in the Mekong Delta will generate opportunities for value enhancement along the chain and provide economic benefits such as optimizing the utilization of agricultural by-products, reducing waste treatment costs, increasing added value, creating employment, protecting the environment, and fostering sustainable economic development. The economic efficiency of potential rice straw-based circular models necessitates research that integrates issues related to the supply chain, appropriate technology, and quality management; consequently, these factors must be aligned with viable business models.

To align with the Mekong Delta's strategic orientation for low-emission agriculture, the following government-led initiatives are essential:

- R&D and standardization: Advance the research and application of science and technical standards for specialized residue processing.
- Technology transfer: Facilitate the transition of recycling technologies that convert by-products into high-value-added derivatives.
- Market development: Cultivate downstream markets to ensure stable consumption of straw-derived products.
- Financial incentives: Implement investment subsidies and credit preferences for enterprises specializing in reuse, recycling, and treatment of rice production waste/by-products.
- Strategic communication: Enhance public awareness regarding the benefits of circular rice production models.
- Stakeholder engagement: Strengthen the active collaboration of various stakeholders (farmers, enterprises, government, and relevant organizations) in the collection, reuse, recycling, and treatment of agricultural by-products from rice production.

5. CONCLUSIONS

Stemming from the limitations of the linear economic model, an alternative economic framework has been proposed based on the principles of the circular economy. Circularity within the agri-food system can help conserve resources, regenerate natural systems, prevent food waste and environmental pollution, and mitigate greenhouse gas emissions. The principles of the circular economy can be implemented across the entire rice value chain - from input supply, production, to consumption and waste management - necessitating a system-level perspective and the engagement of stakeholders at all levels.

The Mekong Delta has been strategically oriented towards high-quality, low-emission, and climate-resilient rice production. This is to be achieved through improving rice quality, expanding production and consumption linkages, and intensifying the application of circular agricultural models. Utilizing a qualitative research methodology through focus group discussions, the study identified opportunities for extending the rice value chain by leveraging rice straw to create various secondary products in the Mekong Delta. The transition from the traditional rice production model to the circular one, wherein rice straw is reclassified not as waste but as a feedstock for mushroom cultivation, organic fertilizer production, livestock feed processing, construction materials, biofuels, or for soil restoration through straw return, will yield socio-economic and environmental benefits, contributing to green growth and sustainable agricultural development in the Mekong Delta. Nevertheless, collecting and making full use of the substantial volume of rice straw poses a considerable challenge. The mitigation of greenhouse gas emissions and the improvement of soil quality cannot be resolved rapidly. Consequently, supportive government policies play a pivotal role in accelerating the implementation of rice straw-based circular economy models in the Mekong Delta.

Circularity represents both a responsibility and a business opportunity. High-quality rice production areas in the Mekong Delta will generate added value by mitigating greenhouse gas emissions, conserving resources, and reusing and recycling rice by-products in line with circular economy models. This approach offers sustainable benefits for smallholder farmers and, in turn, helps to establish and enhance the national rice brand for Vietnam.

In contrast to conventional studies on the rice value chains in the Mekong Delta, this paper offers a novel contribution by integrating circular economy principles into each stage of the rice value chain to identify systemic circular opportunities. Furthermore, the study provides a comparative analysis and establishes a strategic prioritization for five rice straw-based circular economy models within the Mekong Delta.

The limitation of this study is that it relied on a SWOT analysis derived from focus group discussions to identify potential rice straw-based circular economy models in the Mekong Delta, without evaluating economic viability of these models. Consequently, future research may fill this gap by assessing the economic effectiveness of these models to recommend their up-scaling in the Mekong Delta. Furthermore, prospective research directions could explore the determinants influencing the adoption intentions of households and enterprises toward circular rice models. Additional investigations might address the institutional and policy barriers hindering the scaling up of such initiatives, or extend the analytical scope to encompass rice value chains centered on husk and bran by-products.

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