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Adoption of Circular Economy Practices and Sustainable Performance: Empirical Evidence of Rice Farmers in the Mekong Delta, Vietnam

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Abstract: In recent years, Vietnam has demonstrated increasing interest in developing circular economy models in agriculture, particularly in rice production and related business activities. The implementation of circular economy practices is crucial in promoting sustainable development among farmers. This study aims to examine the effects of applying circular economy practices on sustainability performance. A covariance-based structural equation model with Bootstrap analysis was applied to data gathered from 370 rice farming households in the Mekong Delta region of Vietnam. The findings revealed that there are five key factors that influence farmers' adoption of circular economy practices: confidence in the benefits, evaluation of social response, perceived behavioral control, belief, and motivation. Furthermore, the study also demonstrated that the application of circular economy practices by farmers has a positive impact on economic, environmental, and social performance. These findings offer valuable insights for policymakers, extension agencies, and agricultural managers seeking to accelerate the transition toward sustainable and circular agricultural systems in the Mekong Delta and beyond.

Keywords: adoption of circular economy practices; sustainability performance; Covariance-Based Structural Equation Modeling (CB-SEM); Bootstrap; Vietnam

1. Introduction

In recent years, the concept of the circular economy (CE) has gained increasing attention from society, companies, and public authorities around the world (Korhonen et al., 2018). The traditional economic model, which is based on continuous growth and intensive resource use (Jackson et al., 2014; Ghisellini et al., 2016), has been the most well-known model to date. However, the CE has emerged as an alternative to this paradigm due to its positive impact on the environment, its functions, and its interaction with the economic system. Despite its potential, the development of a circular economy model in Vietnam has only recently attracted policy attention, especially since 2021. Nevertheless, its implementation still faces significant challenges, such as low levels of participation and uneven uptake among different localities and regions. This poses a challenge for researchers and policymakers to find solutions. To effectively address this issue, it is crucial to first gain a thorough understanding of the various factors that influence the adoption of circular economy practices. Additionally, it is important to consider the impact of these practices on sustainability performance. This study aims to develop a quantitative model that examines the relationship between these factors and provides valuable policy implications based on the research

findings. The study collected data from 370 rice farmers in the Mekong Delta to serve as the basis for the model analysis. The Mekong Delta is a significant region in Vietnam, playing a crucial role in politics, economy, society, defense, security, and trade with the Association of Southeast Asian Nations and the Mekong River sub-region. It covers a natural area of 39,734 km^2, accounting for 12.2% of the country's total area, and is home to approximately 18 million people, making up 19% of the country's population. The region consists of around 150 district-level units and nearly 10 million farming households. In 2022, the Gross Regional Domestic Product (GRDP) reached approximately 970 trillion VND, accounting for 11.95% of the country's total Gross Domestic Product (GDP). The per capita GDP in the area is 56.02 million VND per person per year, with a trained worker rate of 62.8%. The Mekong Delta is not only the largest rice granary in the country, but also a major producer of fruits and seafood, contributing 31.37% to the agricultural sector's GDP. It accounts for more than 50% of the country's rice output, 65% of aquaculture output, 70% of fruit production, 95% of rice exports, and 60% of seafood exports. This region plays a crucial role in ensuring national and export food security. Furthermore, the Mekong Delta is renowned for its intricate system of rivers and canals, as well as its vast gardens and forests. It is home to four biosphere reserves, national parks, and natural reserves that have been recognized as Ramsar sites by the Secretariat of the Ramsar Convention (Tho and Thanh, 2023).

2. Literature Review

2.1. Concepts for Circular Economy and Circular Economy Practices

The concept of Circular Economy (CE) was first officially introduced by Pearce and Turner (1990). It refers to a new economic model grounded in the fundamental principle that "everything is an input to something else", which stands in stark contrast to traditional economic perspectives. Simply put, CE involves transforming the waste output of one industry into input resources for another industry or facilitating the circulation of resources within a business itself. CE contributes to increasing value for businesses and producers, reducing resource exploitation, lowering waste treatment costs, and minimizing environmental pollution.

According to Bai et al. (2020), the circular economy is a growing economic and business model that promotes efficient resource usage by adding value through resource conservation and innovation at the end of a product's life cycle. This approach has been shown to enhance company performance by increasing product flows and closing material loops, thereby reducing energy losses, emissions, pollution, and overall operational costs. Throughout the production and consumption process, the circular economy follows the 3R concept of "reduce", "reuse", and "recycle" materials (de Sousa Jabbour et al., 2019). This concept has gained significant attention from both scholars and practitioners due to its potential to decrease material usage, save time, minimize negative impacts and external pressures, and create economic benefits through the establishment of new companies and jobs (Gupta et al., 2019). The circularity of matter, the sustainable use of natural resources, and the longevity of products in circular economy-based production systems are all associated with sustainable growth (Calisto et al., 2020). The circular economy is also closely aligned with the United Nations Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 7 (Affordable and Clean Energy), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on Land). By promoting efficient resource utilization, agricultural waste valorization, and reduced environmental impacts, circular economy practices contribute to sustainable agricultural development and support the global transition toward a more sustainable and resilient food system (United Nations, 2015).

In Vietnam, the "1 must 5 reductions" method is commonly used in rice production to reduce the reliance on chemicals and inorganic fertilizers. This approach consists of a set of practices, including the use of high-quality certified varieties, sparse or row sowing to reduce planting density, fertilizer application based on recommended guidelines combined with leaf-color chart assessment, integrated pest management, reduced irrigation, and the minimization of post-harvest losses (Plant Protection Department, 2011). In the Mekong Delta, the implementation of circular economy practices, such as utilizing recycled rice by-products, not only generates new products with high economic value, but also provides employment opportunities for rural workers, increases farmers' income, and helps protect the ecological environment. According to Vu and Thao (2024), the utilization of rice straw by-products by farmers in the Mekong Delta is demonstrated as follows:

- When harvesting 1 hectare of rice, processing the straw into organic fertilizer can provide the soil with the equivalent nutritional value of 100 kg of nitrogen fertilizer, 50 kg of phosphate fertilizer, and 200

kg of potassium fertilizer. This not only increases the value of the straw, but also helps to reduce greenhouse gas emissions. Despite the numerous benefits, such as increased soil fertility and reduced waste, many farmers still choose to dispose of these by-products through traditional burning methods, causing harm to the environment and degradation of the soil.

- In agriculture, the practice of plowing and incorporating straw into the soil is crucial for farmers. This method is highly effective as it reduces costs and improves the thickness of the cultivated layer, ultimately restoring soil fertility. Furthermore, the use of straw rolling machines in recent years has not only allowed rice farmers to increase their income by 600–700 thousand VND/ha through selling straw, but has also contributed to the growth of various rural industries. The stable supply of straw has particularly led to significant development in the straw mushroom industry in the Mekong Delta. Additionally, utilizing straw as feed for the livestock industry brings numerous benefits to farmers.
- After harvesting and milling rice, the remaining husk can be used to produce gas. On average, husk accounts for about 20% of the weight of rice grains, meaning that with current rice production, Vietnam has the potential to produce 8.7 million tons of husk. Studies have shown that husk consists of 25–33% cellulose, 18–21% hemicellulose, and 25–31% lignin. Although using husk for gas production can bring many benefits, it is important to properly manage this by-product to avoid potential hazards. Improper management can lead to soil and water pollution, as well as increased methane (CH4) emissions. Furthermore, rice husk can serve as an energy source in fermentation to cultivate microorganisms for various agro-industrial applications, such as animal feed, paper production, and the creation of polymer plastic products or wood-polymer composite plastics by combining crushed rice husk with polymer plastics (Vietnam Rice Knowledge Bank, 2024).
- Finely ground rice husk is combined with other ingredients such as coco peat, foam beads, cement and additives to create lightweight materials for the construction industry. These materials have soundproofing, heat insulation, waterproofing and are environmentally friendly.
- Rice husk ash is a byproduct of burning rice husk in an industrial boiler. This ash contains silica, which can be extracted to create biochar. The biochar is then activated using a combination of NaOH, ultrasonic techniques, and vacuum drying, resulting in activated carbon. This activated carbon has a unique porous and hollow structure with varying pore sizes. The new process of synthesizing activated carbon has shown great potential for use as an adsorbent material in both water and gas environments, making it a promising option for environmental remediation (Huynh Thanh Luu et al., 2024).
- Most rice farmers in the Mekong Delta are associated with the rice-garden-pond-livestock model. Rice by-products are used for livestock, while fruit trees on garden land are linked to export processors and local handicraft producers to create products for export and tourism. Livestock manure is also used as feedstock for biogas stoves, providing energy for households. This combination represents a circular economy for rice farmers in the Mekong Delta, Vietnam.

These practices are consistent with the broader global trend of agricultural waste valorization within the circular bioeconomy. Recent studies have further emphasized that agricultural residues such as rice straw, rice husk, and livestock manure are valuable feedstocks for producing bioenergy and other value-added products within the circular bioeconomy. However, realizing these opportunities depends not only on technological innovation but also on supportive policies and farmers' willingness to adopt circular economy practices (Mehdizadeh et al., 2025).

2.2. Background Theories

2.2.1. Theory of Circular Economy

The concept of Circular Economy (CE) aims to replace the traditional linear economic model. Its primary objectives are to promote the reuse of resources and reintroduce them into the economy, thereby reducing waste generation and decreasing the consumption of non-renewable resources (Kristoffersen et al., 2020). CE models advocate for the sustainable use of natural resources, resulting in decreased impacts on ecosystems and human well-being (López and Requena, 2005). The goal of CE is to create a zero-emission economic system with a closed production cycle, transitioning from environmental exploitation to industrial transformation, and ultimately reaching final consumers through clean energy sources. The material cycle in CE operates on the philosophy of viewing waste as a resource, aiming to minimize waste through the design of materials, products, technical systems, and even business models (Nobre and Tavares, 2021). This model is applicable to any economic sector. For instance, in agriculture, CE allows for the retention of residues from agricultural biomass and food processing within the food system as renewable

resources (inputs), thereby reducing the need for new inputs from outside the system (Schouten, 2020). The adoption of CE solutions is essential for achieving food security and agricultural sustainability (Nordin et al., 2022). By applying CE principles in agriculture, nitrogen losses can be minimized, while carbon dioxide (CO_2) and other greenhouse gases can be absorbed and sequestered (Johnson et al., 2007). In recent years, the agricultural sector in developed countries has implemented various sustainable technologies focusing on circular agriculture, which contributes to reducing waste and greenhouse gas emissions while producing high-quality food.

2.2.2. Theory of Planned Behavior

The theory of planned behavior (TPB) is a well-known model used to explain human behavior (Han et al., 2010; Ashaduzzaman et al., 2022). According to TPB, individuals are more likely to engage in a behavior if they have a positive attitude towards it, believe that important people in their lives approve of it (subjective norm), and feel that they have enough control over performing the behavior (perceived behavioral control) (Ajzen, 1991).

This theory emphasizes the importance of attitudes, subjective norms, and perceived behavioral control in shaping human behavior. The Theory of Planned Behavior (TPB) is commonly used to predict and influence behavior, including behaviors related to technology use (Omar and Owusu-Frimpong, 2007; Schiffman and Kanuk, 2007; Brahmana et al., 2018; Nomi and Sabbir, 2020).

Extending TPB in the Context of Circular Economy Adoption

According to the Theory of Planned Behavior (Ajzen, 1991), attitudes, subjective norms, and perceived behavioral control are the primary determinants of behavioral intentions. However, in the context of circular economy adoption in agriculture, these broad dimensions can be operationalized into more specific constructs that better reflect farmers' decision-making processes.

Rather than directly employing the original TPB dimensions, this study adopts an extended TPB perspective in which the broad attitudinal and normative components are translated into context-specific constructs relevant to circular agriculture. Confidence in benefits (CON) and belief (BEL) represent farmers' attitudinal evaluations of circular economy practices, while evaluation of social response (SCOR) captures the influence of social and institutional environments. Perceived behavioral control (PBC) is retained directly from TPB and reflects farmers' perceptions of their capability, resources, and opportunities to implement circular economy practices.

Previous studies have suggested that perceived behavioral control may also indirectly influence attitudes toward innovative agricultural practices by shaping farmers' perceptions of feasibility and expected outcomes (Yu et al., 2012; Yusuf & Zulfitri, 2021). Therefore, this study adopts an extended TPB perspective to explain farmers' adoption of circular economy practices.

2.2.3. Diffusion of Innovation Theory

According to Rogers (1995), two key factors, compatibility and advantages, have a significant impact on the adoption of new technology. This theory outlines five stages through which ideas and technologies are disseminated and accepted: awareness, persuasion, decision-making, implementation, and validation. The decision to adopt a new technology is influenced by factors such as perceived benefits, adaptability, accessibility, ease of experimentation, and ease of observation. Therefore, when extension systems transfer new technologies in agriculture, they should consider the decision-making process of farmers in selecting these technologies.

Diffusion of Innovation Theory further suggests that adoption decisions are shaped not only by perceived advantages but also by communication channels, information exposure, and motivational drivers that encourage individuals to embrace new practices. These mechanisms are particularly relevant to the adoption of circular economy practices, which require farmers to modify traditional production methods and learn new approaches to resource utilization.

2.2.4. Integration of Theoretical Perspectives

This study integrates Circular Economy (CE) Theory, the Theory of Planned Behavior (TPB), and Diffusion of Innovation Theory (DOI) to explain farmers' adoption of circular economy practices in rice production. CE Theory provides the contextual foundation by emphasizing resource circularity, waste

reduction, and the transformation of agricultural by-products into valuable resources (Kristoffersen et al., 2020; Nobre & Tavares, 2021). However, CE Theory primarily explains the principles and benefits of circular systems rather than the behavioral mechanisms underlying farmers' adoption decisions.

To explain individual adoption behavior, this study draws upon TPB (Ajzen, 1991), which posits that behavior is influenced by attitudes, subjective norms, and perceived behavioral control. Building upon TPB, this study operationalizes its broad theoretical dimensions into context-specific constructs that better reflect circular economy adoption in agriculture. Specifically, confidence in benefits (CON), evaluation of social response (SCOR), perceived behavioral control (PBC), belief (BEL), and motivation (MOT) were incorporated to represent the cognitive, social, and behavioral mechanisms underlying farmers' adoption decisions. Rather than directly replicating the original TPB dimensions, the study adapts and extends these theoretical concepts by incorporating complementary insights from Diffusion of Innovation Theory and Circular Economy Theory to better capture the characteristics of circular economy adoption in the Mekong Delta context. These five constructs were selected because they collectively represent the key cognitive, social, and behavioral determinants consistently identified in the literature on technology adoption, agricultural innovation, and circular economy practices.

Importantly, SCOR is not conceptualized as a direct measure of subjective norms in the traditional TPB sense. Rather, it reflects farmers' evaluations of broader social and institutional influences toward circular economy practices, including government support, media communication, access to formal credit, and learning from successful adopters. These external influences contribute to the formation of farmers' overall attitudes toward circular economy adoption rather than representing normative pressure from family members, friends, or other important referents.

In addition, Diffusion of Innovation Theory (Rogers, 1995) complements TPB by emphasizing the importance of perceived advantages, information dissemination, communication channels, and motivational drivers in technology adoption.

Accordingly, motivation (MOT) is incorporated as an additional construct grounded in Diffusion of Innovation Theory to capture farmers' willingness, incentives, and readiness to engage in circular economy practices.

By integrating these three theoretical perspectives, the study proposes that confidence in benefits, social response, perceived behavioral control, beliefs, and motivation jointly influence farmers' adoption of circular economy practices, which subsequently contributes to economic, environmental, and social sustainability performance.

2.3. Empirical Studies

2.3.1. Attitudes towards, and Adoption of Circular Economy Practices

In Vietnam, the term "circular economy" has been defined in Article 142 of the Law on Environmental Protection 2020. According to this definition, a circular economy is an economic model that focuses on reducing the exploitation of raw materials, extending product life cycles, limiting waste generation, and minimizing negative impacts on the environment through the design, production, consumption, and services (Vietnam National Assembly, 2020).

Attitudes towards specific objects: According to Robbins (2001), attitudes are evaluative judgments about objects, people, or events that shape behaviors and evaluate marketing effectiveness. They represent an individual's evaluation, emotional attachment, perceived risk, and propensity to act towards certain objects or ideas. Attitudes also reflect an individual's evaluation, emotional attachment, perceived behavioral control, confidence in the benefits received, beliefs, and propensity to act towards specific objects or ideas (Kotler, 2003; Schiffman and Kanuk, 2007; Lee, 2009; Park et al., 2016; Meng et al., 2022; Lauwere et al., 2022; Dong et al., 2023). Research conducted by Tanveer et al. (2025) on aviation services revealed that economic benefits have a significant impact on customer attitudes. Furthermore, the study found that perceived behavioral control and subjective norms play a crucial role in the decision-making process when it comes to choosing products or services. Research conducted by Zhu et al. (2021) on farmers' decision to participate in the circular economy in China revealed that their attitudes greatly influence their willingness to recycle straw. Similarly, a study by Lauwere et al. (2022) on farmers in the Netherlands showed that their attitudes play a crucial role in their decision to participate in the circular economy. In a study conducted in Vietnam, Tran et al. (2022) found that individuals' attitudes towards the circular economy have a significant impact on their willingness to participate in it. Additionally, Patwa et al. (2021) discovered that consumer attitudes towards the circular economy also influence their willingness

to purchase products associated with it. In a separate study, Herrera et al. (2023) examined the attitudes of farmers in Europe and found that these attitudes play a crucial role in their adoption of emission reduction innovations. Additionally, Zhang and Wang (2024) found that farmers' attitudes towards ecological agriculture in China influence their decision to participate in a circular economy model. A study conducted in Indonesia by Prasetyo et al. (2024) also yielded similar results. Based on the literature reviewed above, this study proposes the following hypotheses:

H1: *The confidence in benefits of circular economy practices has a positive influence on the adoption of circular economy practices by farmers.*

H2: *Evaluation of social response has a beneficial impact on the adoption of circular economy practices by farmers.*

H3: *The perceived behavioral control positively influences the adoption of circular economy practices by farmers*.

2.3.2. Subjective Norm, and Adoption of Circular Economy Practices

Subjective Norms: According to Ajzen and Fishbein (1980), subjective norms are perceptions influenced by social environments, such as family, friends, colleagues, and public opinion, that can impact a person's decision to purchase a product or service (Omar and Owusu-Frimpong, 2007; Amin et al., 2011). These norms can increase trust and motivation, particularly in the workplace, where group dependence and personal relationships are highly valued (Venkatesh and Davis, 2000; Hillhouse et al., 2000; Pawlak et al., 2008; Husted and Allen, 2007; Rezaei et al., 2018; Meng et al., 2022). Studies conducted in Malaysia have shown that factors such as promotion, perceived usefulness, attitudes, and beliefs have a positive impact on individuals' intentions to purchase medical insurance (Guan et al., 2020). Subjective standards have been proven to significantly influence customer behavior in various industries and service sectors in Southeast Europe (Ham et al., 2015), healthcare services in China (Wu et al., 2022), and Islamic insurance, life insurance, and health insurance in Malaysia and India (Rahim & Amin, 2011). Studies in Pakistan, Bangladesh, Thailand, and Indonesia (Hassan & Abbas, 2019; Nomi & Sabbir, 2020; Nursiana, 2021) have also shown similar findings. Research conducted by Tran et al. (2022) on people's attitudes towards the circular economy in Vietnam found that subjective norms have a significant influence on individuals' willingness to participate in circular economy practices. Similarly, a study by Junco et al. (2023) on the Colombian service sector showed that subjective norms play a crucial role in the adoption of circular economy practices. Additionally, research on farmers' decision-making in the Netherlands by Lauwere et al. (2022) highlighted the importance of beliefs in shaping subjective norms. Similarly, a study on Emissions Reduction Innovation by Farmers in Europe by Herrera et al. (2023) found that government support creates incentives for farmers to participate in circular economy models. In Iran, a study on Participation in Food Safety Practices on Farmers' Farms by Rezaei et al. (2018) showed that subjective norms significantly affect farmers' intention to participate in the circular economy. In Malaysia, Hamzah and Tanwir (2021) found that subjective norms have a positive impact on green purchase intention. Additionally, research on Farmers' Decision to Participate in Circular Economy in China by Zhu et al. (2021) revealed that subjective norms play a crucial role in farmers' decision to recycle straw. Research conducted by Lauwere et al. (2022) on farmers' decision to participate in the circular economy in the Netherlands found that subjective norms play a crucial role in this decision-making process. Similarly, Herrera et al. (2023) studied emissions reduction innovation by farmers in Europe and found that government support serves as a significant incentive for farmers to engage in circular economy models. Dong et al. (2023) also examined the participation of farmers in environmental protection in China and concluded that subjective norms have a significant impact on their decision to participate. In a study by Zhao et al. (2023) on the recovery of discarded agricultural plastic films in China, it was found that subjective norms play a crucial role in influencing farmers' involvement in this process. Additionally, Zhang and Wang (2024) conducted research on farmers' willingness to adopt ecological agriculture practices in China. They found that subjective norms have a significant impact on the decision to adopt circular economy practices. Based on the literature reviewed above, this study proposes the following hypotheses:

H4: *Beliefs have a positive effect on the adoption of circular economy practices by farmers.*

H5: *Motivation has a positive effect on the adoption of circular economy practices by farmers.*

2.3.3. Circular Economy Practices and SUSTAINABLE PERFORMANCE

The study conducted by Dey et al. (2020) in Europe and the UK aimed to measure the impact of circular economy activities on sustainability performance, specifically in economic, environmental, and social terms. The study considered the closed-loop supply chain, which includes design, procurement, production, distribution, consumption, and recovery, as a latent variable for circular economy activities. To measure the performance of the circular economy, the study used revenue, business growth, and contribution to the local economy as measures for economic performance, good waste management for environmental performance, and worker welfare, health, and safety for social performance (Prieto-Sandoval et al., 2018; Mazzucchelli et al., 2022; Zhou et al., 2023). The use of renewable energy in production processes has been proven to have a positive impact on environmental performance, as evidenced by multiple studies (Liu et al., 2018; Malesios et al., 2018; Amin et al., 2024). A recent study by Yin et al. (2022) found that implementing circular economy measures can also have a significant impact on sustainability performance. Additionally, research conducted on small and medium enterprises in the UK by Chowdhury et al. (2022) and in Bangladesh by Zhou et al. (2023) also supports the notion that circular economy practices can lead to improved sustainability performance. A study conducted by Amin et al. (2024) on green garments in Bangladesh revealed that the implementation of circular economy practices has a significant impact on both economic and social performance. Similarly, a study on enterprises in Vietnam by Phan et al. (2025) demonstrated that the adoption of circular economy measures also has a significant impact on the financial performance of these enterprises.

In the agricultural sector, research conducted by Velasco-Muñoz et al. (2022) has shown that the adoption of circular economy practices has a positive impact on economic performance. Similarly, the study on the palm oil industry in Indonesia by the Firdaus and Alifiyah (2025) found that implementing circular economy practices leads to reductions in greenhouse gas emissions. Furthermore, Magnano et al. (2024) argue that the implementation of circular economy practices has a significant impact on economic, social, and environmental performance. This conclusion is based on a comprehensive review of 49 articles collected from the Web of Science and Scopus databases. Therefore, it can be concluded that sustainability performance encompasses economic, environmental, and social aspects. Research conducted by Prasetyo et al. (2024) has demonstrated that the implementation of Circular Economy measures has a positive impact on the income and social welfare of farmers, while also protecting the natural environment. Similarly, Ekonomou and Halkos (2024) have found that the adoption of Circular Economy practices leads to long-term benefits for the environment.

Based on the literature reviewed above, this study proposes the following hypotheses:

H6: *The adoption of circular economy practices by farmers has a positive effect on economic performance.*

H7: *The adoption of circular economy practices by farmers has a positive effect on environmental performance.*

H8: *The adoption of circular economy practices by farmers has a positive effect on social performance.*

2.4. Research Models

A theoretical overview and empirical research are necessary to further extend the theory, provide more empirical evidence, and explore the policy implications of the factors influencing circular economy practices and sustainable performance. Previous studies have provided insights into the impact of these relationships and have measured them using various independent quantitative models, such as exploratory factor analysis, linear regression, and binary logistic regression, as well as separate statistical tests. However, these studies do not offer a comprehensive analytical framework for understanding sustainability performance. Therefore, the purpose of this study is to build upon the findings of previous research and analyze the relationships between the adoption of circular economy practices and sustainability performance using a structural equation model. The research team has selected a model for the Mekong Delta, as shown in Figure 1.

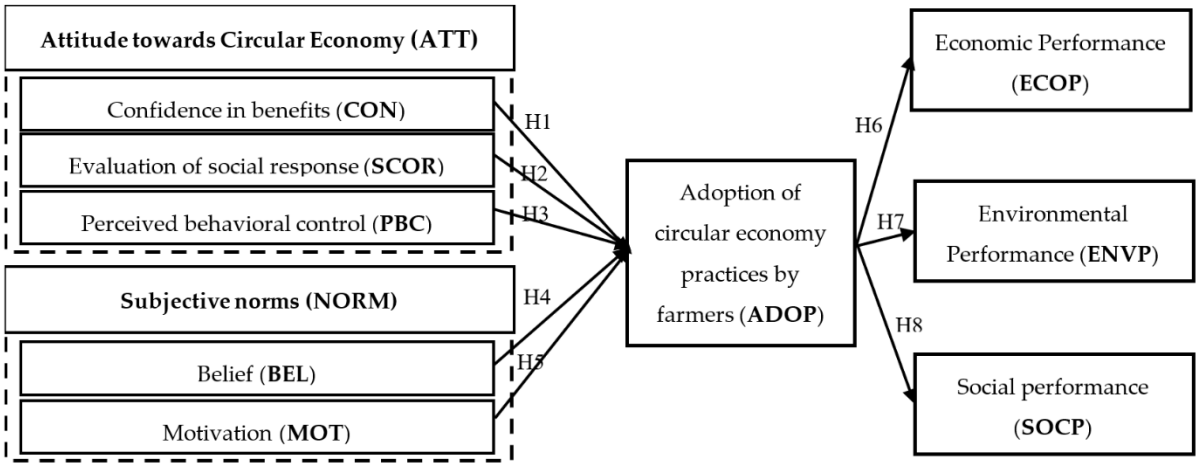

Figure 1. Theoretical research model.

3. Research Methods

3.1. Measurement

All scales were adapted from previous studies to fit the specific research context in Vietnam. To ensure the accuracy and relevance of the survey, we implemented three procedures. First, we utilized the expert method by consulting with agricultural management experts. This group consisted of 10 individuals with a minimum of five years of experience working in agencies related to the agricultural industry, such as department and branch leaders, as well as a group of 10 experts who manage agricultural enterprises in Can Tho City. Through these discussions, we were able to make necessary adjustments to the questionnaire to ensure its suitability for the Vietnamese agricultural industry. Next, we conducted a pilot survey with 20 respondents who are actively involved in agricultural production using the circular economy model. This was done to identify and correct any errors in the questionnaire and to ensure that the content was appropriate. The sample was selected based on the respondents' willingness to participate in the study. Finally, we conducted a comprehensive survey of farmers who are currently producing and trading rice products in five provinces and cities, namely Can Tho City, An Giang, and Soc Trang. A total of 400 respondents completed the questionnaire. The survey targeted rice farmers regardless of their level of engagement in circular economy practices. Consequently, the sample included respondents exhibiting varying degrees of circular economy adoption, ranging from limited implementation to more extensive adoption. This variation enabled the study to examine factors influencing the level of adoption behavior rather than focusing exclusively on farmers who had already adopted circular economy practices.

A five-point Likert scale, ranging from "strongly disagree" to "strongly agree", was utilized to measure all observed variables. The questionnaire included 20 observed variables to measure the scales of "Evaluation of Social Response", "Attitude towards Circular Economy", "Perceived Behavioral Control", "Motivation", and "Belief". These scales were developed by the authors to suit the context of Vietnam's agricultural development, based on a previous study on circular economy in Vietnam by Tran et al. (2022). The inclusion of these variables was the result of specialized discussions. Similarly, the scales of "Adoption of Circular Economy Practices by Farmers", "Economic Performance", "Environmental Performance", and "Social Performance" were measured using 14 observed variables in the questionnaire. These variables were also developed by the authors to suit the context of Vietnam's agricultural development, based on a previous study on circular economy in Italy by Mazzucchelli et al. (2022). The inclusion of these variables was also the result of specialized discussions. The detailed measurement tables for these scales and observed variables can be found in the Appendix A (Table A1).

3.2. Data Collection and Processing

The authors collected data from 400 observations in three provinces/City in the Mekong Delta: An Giang, Soc Trang, and Can Tho City. These provinces/City are renowned for their rice production and trading industries, as well as their capacity for rice exports. They are also known for their implementation of the circular economy model among local rice farmers. These localities represent the diverse ecological

sub-regions of the Mekong Delta, including alluvial freshwater, mangrove forests, and wetlands of Dong Thap Muoi. An Giang is situated in the basins of the Tien and Hau rivers, while Can Tho is known as the "cradle of the Mekong Delta" due to its alluvial freshwater ecosystem. On the other hand, Soc Trang is located in the lower reaches of the Hau river, where freshwater and mangrove forests converge, creating a brackish water environment with great potential for cultivating the renowned ST rice varieties. After data processing, we were left with 370 suitable observations for data analysis.

According to Gefen et al. (2011), when the focus of a study is to test a theory and explanatory model, Covariance-Based Structural Equation Modeling (CB-SEM) should be used. In this particular study, the authors have chosen to utilize CB-SEM. The recommended software for CB-SEM is AMOS (Sarker and Bhowmik, 2024). Structural Equation Modeling was performed in four steps: (i) Reliability test of the scale; (ii) Exploratory Factor Analysis (EFA); (iii) Confirmatory Factor Analysis (CFA); and (iv) Structural Equation Modeling (SEM). Data analysis was performed using SPSS and AMOS software version 26.0.

4. Results

4.1. Information about Survey Objects

Table 1 displays the specifics of the questionnaire. Out of 370 survey responses, 86% were from males. This distribution reflects the demographic characteristics of rice-producing households in the Mekong Delta, where major production and investment decisions are commonly undertaken by male household heads. Consequently, male respondents were more frequently identified as the most knowledgeable individuals regarding circular economy practices and farm management decisions. The age distribution was divided into four groups: under 30, 31–45, 46–55, and over 55, with 20%, 55%, 16%, and 9% respectively. The majority of survey participants were married (78%). The most common income range was 6–20 million VND per month, accounting for 62% of the responses. The average education level is 8th grade. The average household size is 4.

Table 1. Characteristics of survey objects.

	Frequency	**%**		**Frequency**	**%**
Sex			Marital status		
Male	318	85.9	Single	83	22.4
Female	52	14.1	Married	287	77.6
Total	370	100	Total	370	100
Ages			Average monthly income (million VND)		
<30	73	20	1–5	95	25.7
31–45	203	55	6–10	129	34.9
46–55	60	16	11–20	100	27.0
>55	34	9	>20	46	12.4
Total	370	100	Total	370	100
Years of formal schooling			Number of people in the household		
Minimum	Maximum	Mean	Minimum	Maximum	Mean
1	12	7.92	2	5	3.99

4.2. Common Method Bias Assessment

To evaluate the potential influence of common method bias (CMB), Harman's single-factor test was conducted following the procedure recommended by Podsakoff et al. (2003). All measurement items were entered into an unrotated exploratory factor analysis. The results indicated that the first factor explained 29.436% of the total variance, which is well below the commonly accepted threshold of 50%. These findings suggest that common method bias is not a significant concern in the present study.

4.3. Scale Reliability Analysis

The results in Table 2 indicate that all observed variables meet the criteria for reliability analysis of the scale, with an alpha coefficient greater than 0.6 and a variable-total correlation greater than 0.3 (Nunnally and Bernstein, 1994).

Table 2. Scale reliability test and rejected observed variables.

No.	Scale	Observed Variable Are Excluded	Alpha Coefficients	Conclusion
1	CON	None	0.795	Quality
2	SCOR	None	0.841	Good quality
3	PBC	None	0.814	Good quality
4	BEL	None	0.833	Good quality
5	MOT	None	0.838	Good quality
6	ADOP	None	0.845	Good quality
7	ECOP	None	0.824	Good quality
8	ENVP	None	0.832	Good quality
9	SOCP	None	0.852	Good quality

4.4. Exploratory Factor Analysis

Table 3 displays the five factors of ADOP, which align with the measured variables of the theoretical model. The total extracted variance was 66.420%, with an Eigenvalue of 1.770. The EFA of ADOP yielded three observed variables, with an extracted variance of 76.356% and an Eigenvalue of 2.291. Similarly, the EFA of ECOP resulted in four observed variables, with an extracted variance of 65.604% and an Eigenvalue of 2.642. The EFA of ENVP produced three observed variables, with an extracted variance of 74.946% and an Eigenvalue of 2.248. Finally, the EFA of SOCP yielded four observed variables, with an extracted variance of 69.319% and an Eigenvalue of 2.773, using the Promax rotation method.

Table 3. Pattern matrix.

	Component								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
SOCR4	0.848								
SOCR2	0.831								
SOCR1	0.815								
SOCR3	0.785								
MOT3		0.848							
MOT4		0.833							
MOT1		0.791							
MOT2		0.783							
BEL3			0.832						
BEL4			0.827						
BEL2			0.820						
BEL1			0.772						
PBC2				0.821					
PBC4				0.812					
PBC3				0.798					
PBC1				0.774					
CON4					0.824				
CON2					0.780				
CON3					0.778				
CON1					0.759				
ADOP2						0.898			
ADOP3						0.862			
ADOP1						0.861			
ECOP3							0.856		
ECOP2							0.847		
ECOP1							0.819		
ECOP4							0.709		
ENVP3								0.877	
ENVP1								0.877	
ENVP2								0.843	
SOCP3									0.860
SOCP2									0.840
SOCP4									0.830
SOCP1									0.800

Table 3. *Cont.*

	Component								
	1	2	3	4	5	6	7	8	9
Kaiser-Meyer-Olkin Measure					0.827	0.719	0.795	0.719	0.817
Bartlett's test					0.000	0.000	0.000	0.000	0.000
Eigenvalues					1.770	2.291	2.624	2.248	2.773
% of Extracted variance					66.420	76.356	65.604	74.946	69.319

Note: 0.5 < KMO < 1; Bartlett's test has a significance level less than 0.05; Factor Loading of observed variables (Factor Loading) > 0.5; extracted variance > 50%, and Eigenvalue > 1 (Hair et al., 2019).

4.5. Confirmatory Factor Analysis

The measurement models that are consistent with the actual data must be consistent with five measures: (i) Cmin/df; (ii) TLI; (iii) CFI; (iv) NFI; and (v) RMSEA (Gefen et al., 2011). The results of the confirmatory factor analysis are presented in Figure 2.

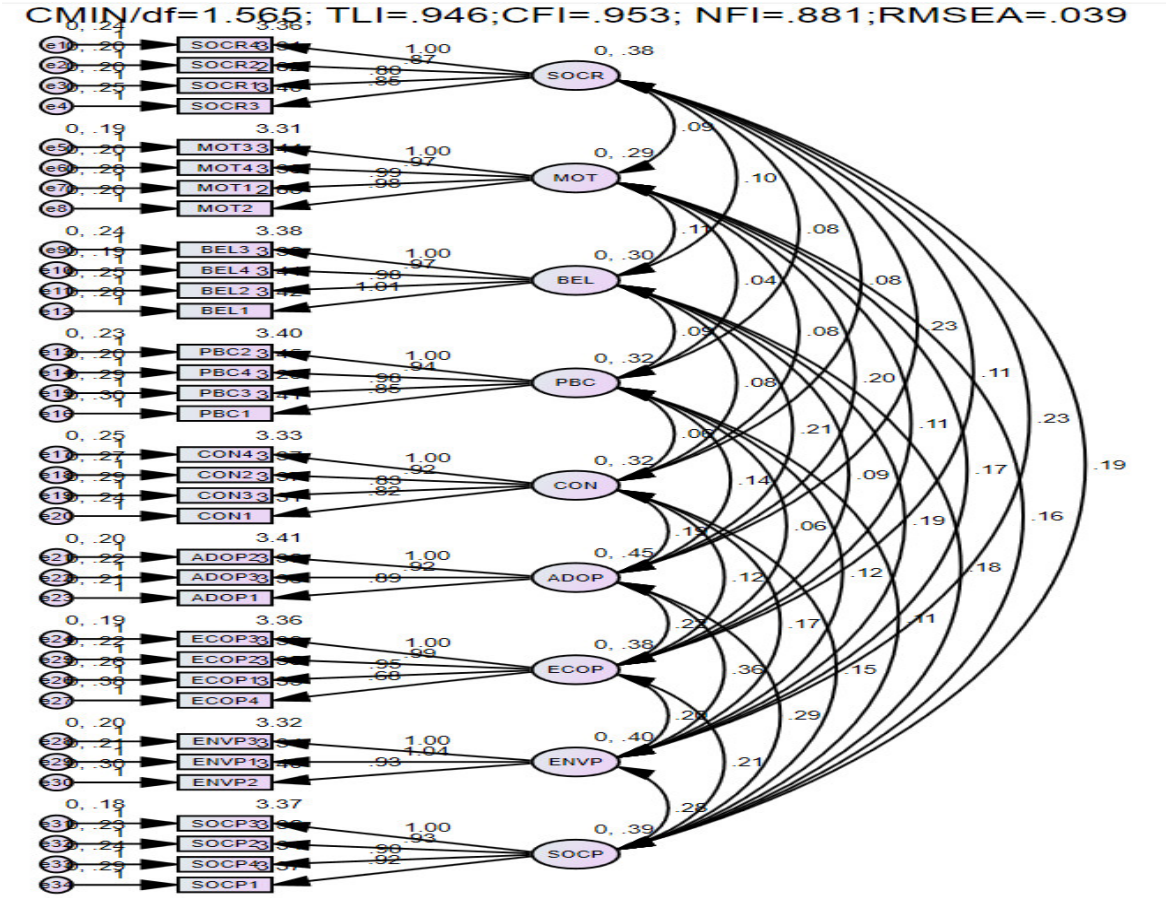

Figure 2. Confirmatory factor analysis results.

Table 4 shows that the measurement model is consistent with the actual data.

Table 4. The fit indices of the CFA.

No.	Measures	Indicator Standard values	Model Value	Results
1	Cmin/df	χ^2/d.f. < 3 good fit; < 5 accepted; the smaller the better (Bentler and Bonett, 1980; Bagozii and Jy, 1988)	1.565	Good
2	TLI (Tucker-Lewis Index)	TLI: the closer it is to 1, the more appropriate; TLI > 0.90 is consistent; TLI ≥ 0.95 is in good agreement (Hu and Bentler, 1995)	0.946	Good
3	CFI (Comparative Fit Index)	CFI > 0.90; 0 < CFI < 1, the closer to 1, the more suitable (Hu and Bentler, 1995).	0.953	Good

Table 4. *Cont.*

No.	Measures	Indicator Standard values	Model Value	Results
4	NFI (Normal Fit Index)	NFI, the closer it is to 1, the more suitable. NFI close to 0.90 is accepted; NFI > 0.95 is, a good fit (Chin and Todd, 1995; Hu & Bentler, 1995).	0.8781	Good
5	RMSEA (Root Mean Square Error Approximation)	RMSEA < 0.05, the model fits well; RMSEA < 0.08, accepted; the smaller the better (Browne and Cudeck, 1993)	0.039	Good

Convergent and Discriminant Validity

The convergent validity of the measurement model was assessed using Composite Reliability (CR) and Average Variance Extracted (AVE). As presented in Table 5, all constructs exhibited satisfactory internal consistency, with CR values ranging from 0.796 to 0.853, exceeding the recommended threshold of 0.70 (Hair et al., 2019). The AVE values ranged from 0.495 to 0.648. Although the AVE value of Confidence in Benefits (CON) was slightly below the recommended threshold of 0.50 (0.495), its Composite Reliability was 0.796, exceeding the minimum acceptable level of 0.60. Therefore, convergent validity for this construct was considered acceptable (Fornell & Larcker, 1981).

Table 5. Composite Reliability and Convergent Validity Assessment.

Construct	CR	AVE
SOCR	0.843	0.572
MOT	0.840	0.567
BEL	0.834	0.558
PBC	0.816	0.527
CON	0.796	0.495
ADOP	0.847	0.648
ECOP	0.826	0.548
ENVP	0.834	0.626
SOCP	0.853	0.592

Discriminant validity was evaluated using the Heterotrait–Monotrait ratio (HTMT). As shown in Table 6, all HTMT values ranged from 0.113 to 0.708, remaining well below the conservative threshold of 0.85 (Henseler et al., 2015). These results indicate that each construct is empirically distinct from the others, thereby confirming satisfactory discriminant validity.

Table 6. Heterotrait–Monotrait Ratio (HTMT) Results.

	SOCR	MOT	BEL	PBC	CON	ADOP	ECOP	ENVP	SOCP
SOCR									
MOT	0.234								
BEL	0.258	0.309							
PBC	0.192	0.113	0.246						
CON	0.177	0.217	0.217	0.142					
ADOP	0.475	0.475	0.471	0.323	0.425				
ECOP	0.246	0.256	0.209	0.141	0.260	0.430			
ENVP	0.497	0.424	0.454	0.303	0.383	0.708	0.389		
SOCP	0.424	0.406	0.44	0.276	0.347	0.586	0.463	0.602	

4.6. Structural Equation Modeling

The results presented in Figure 3 showed the model has a value of Cmin/df = 1.836; TLI = 0.921; CFI = 0.927; NFI = 0.853; and RMSEA = 0.048. Thus, the integrated model fits the actual data (Figure 3).

4.7. Using BOOTSTRAP to Analyze the Reliability of CB-SEM

The analysis of structural functions often requires a large sample size (Anderson and Gerbing, 1988), which can be a limitation in academic research. In such cases, Bootstrap can serve as a suitable alternative (Schumacker and Lomax, 2010). Bootstrap is a repeatable sampling method in which the original sample is

treated as the population. This method generates random samples from the original sample, typically using 1000 observations. The estimated results from these samples are then averaged, providing an estimate that closely approximates the population estimate. The smaller the difference between the average value of Bootstrap regression coefficients and the model estimate using the original sample, the more reliable the model estimates can be considered.

The absolute value of CR is less than or equal to 2, indicating a small bias. This difference is not statistically significant at the 95% confidence level (Hair et al., 2019). The regression coefficient results before Bootstrap are reliable with a confidence level of 90% or higher. Table 7 shows that all CR values are less than or equal to 2.

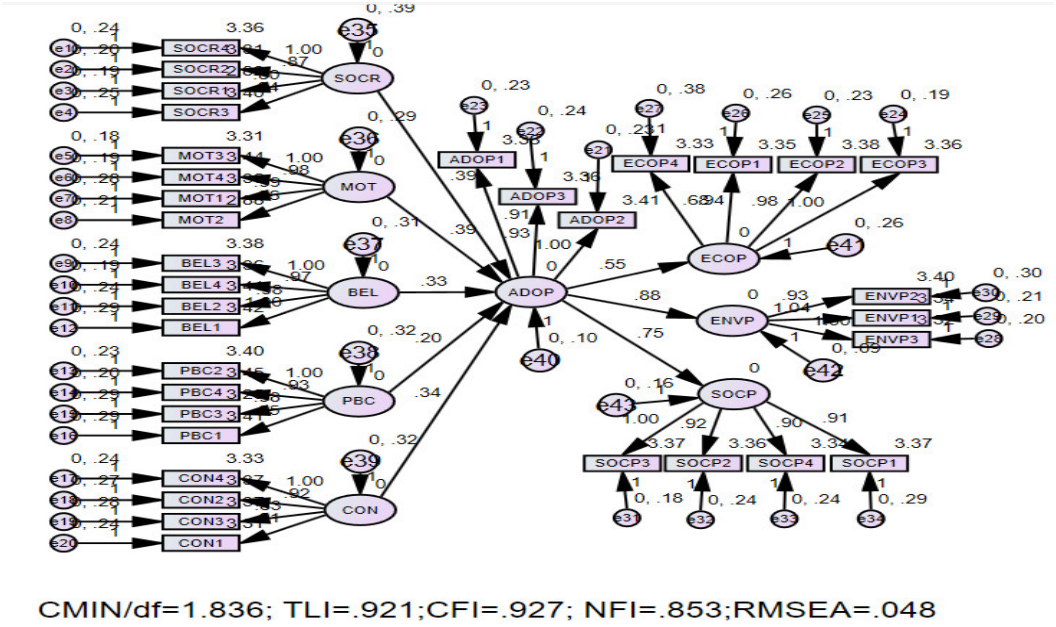

Figure 3. Results of structural equation modeling.

Table 7. Bootstrap implementation results.

Regression Weights: (Group number 1—Default Model)								
Parameter			**SE**	**SE-SE**	**Mean**	**Bias**	**SE-Bias**	***CR**
ADOP	←	SOCR	0.045	0.001	0.386	0.001	0.001	1
ADOP	←	MOT	0.055	0.001	0.385	0.000	0.002	0
ADOP	←	BEL	0.055	0.001	0.337	0.002	0.002	1
ADOP	←	PBC	0.048	0.001	0.203	0.003	0.002	1.5
ADOP	←	CON	0.060	0.001	0.341	0.001	0.002	0.5
ECOP	←	ADOP	0.071	0.002	0.557	0.004	0.002	2
ENVP	←	ADOP	0.062	0.001	0.877	0.002	0.002	1
SOCP	←	ADOP	0.066	0.001	0.752	0.002	0.002	1

*CR (Critical Ratios) = (Bias)/(SE-Bias).

In Table 8, all hypotheses are accepted with a 95% confidence level or higher (p-value ≤ 0.05).

Table 8. The model fits the actual data in this study.

Hypotheses				**Estimate**	**S.E.**	**C.R.**	***p***	**Results**
H2	ADOP	←	SOCR	0.385	0.046	8.380	***	Accept
H5	ADOP	←	MOT	0.386	0.051	7.503	***	Accept
H4	ADOP	←	BEL	0.335	0.050	6.754	***	Accept
H3	ADOP	←	PBC	0.200	0.046	4.370	***	Accept
H1	ADOP	←	CON	0.340	0.050	6.836	***	Accept
H6	ECOP	←	ADOP	0.553	0.070	7.901	***	Accept
H7	ENVP	←	ADOP	0.875	0.072	12.217	***	Accept
H8	SOCP	←	ADOP	0.750	0.069	10.868	***	Accept

Note: *** indicates statistical significance at the 0.001 level (p < 0.001).

Table 9 displays the factors that have an impact on ADOP, listed in order of their level of influence from highest to lowest: SOCR, MOT, CON, BEL, and PBC. Additionally, ADOP has an effect on ECOP, ENVP, and SOCP, as shown in Table 8.

Table 9. Relative Magnitude of Standardized Effects on ADOP.

Impacts			Regression coefficient	%	Position
Impact on ADOP ADOP = f (SCOR, PBC, CON, MOT, BEL)					
ADOP	←	SCOR	0.463	27.0	1
ADOP	←	PBC	0.207	12.1	5
ADOP	←	CON	0.332	19.4	3
ADOP	←	MOT	0.383	22.3	2
ADOP	←	BEL	0.33	19.2	4
Total			1.715	100	

Note: The percentage values indicate the relative share of each standardized regression coefficient in the total standardized effects on ADOP.

5. Discussion and Policy Implications

First, the study identified five factors that influence ADOP: Social Reaction Appraisal (SOCR), Motivation (MOT), Belief in Benefits (CON), Belief (BEL), and Perceived Behavioral Control (PBC). This result is consistent with the hypotheses of the study, as well as with similar circular economy studies conducted in Vietnam by Tran et al. (2022) and in China by Zhao et al. (2023). In order to improve ADOP, the agricultural sector should prioritize the following factors: Social Reaction Appraisal, Motivation, Belief in Benefits, Belief, and Perceived Behavioral Control.

Among the five antecedents, perceived behavioral control exhibited the smallest standardized effect on the adoption of circular economy practices. Although this finding appears to differ from the central proposition of the Theory of Planned Behavior, it may reflect the specific context of rice farming in the Mekong Delta. Most surveyed farmers already possess substantial farming experience and practical knowledge of utilizing agricultural by-products. Consequently, the primary barriers to adopting circular economy practices are less related to farmers' perceived capability and more closely associated with their perceived benefits, motivation, and the surrounding social and institutional environment. This finding suggests that strengthening farmers' confidence in the benefits of circular economy practices, together with supportive policies, communication, and extension activities, may be more effective than focusing solely on improving technical capability.

Although the present study focuses primarily on behavioral determinants of circular economy adoption, external market conditions may also influence farmers' implementation of circular economy practices. In particular, access to stable markets for rice by-products and supporting value chain infrastructure may facilitate the commercialization of agricultural residues and improve the economic feasibility of circular economy initiatives. Therefore, positive attitudes and favorable behavioral perceptions alone may not necessarily translate into higher adoption levels when market opportunities remain limited. In addition to strengthening farmers' awareness and motivation, policymakers should therefore consider developing market linkages and value chain infrastructure to enhance the long-term adoption of circular economy practices. Future research could further extend the proposed model by incorporating market access or value chain integration as contextual variables influencing farmers' adoption behavior.

Secondly, the adoption of circular economy practices (ADOP) has a significant impact on the environmental, economic, and social performance of the agricultural sector. This has been demonstrated in studies conducted in the UK by Chowdhury et al. (2022) and in research on small and medium enterprises in Bangladesh by Zhou et al. (2023). Therefore, in order to improve sustainability performance, it is crucial for the agricultural sector to prioritize the adoption of circular economy practices by farmers. This is the key to achieving sustainable agricultural development in the Mekong Delta and Vietnam as a whole.

For the ECOP scale, farmers rated the overall variable ECOP2 (Profit margins increase) with the highest score (3.38). For the ENVP scale, farmers rated the overall variable ENVP2 (Collect bags and put them in designated reservoirs and utilize manure from livestock to create clean energy for family activities.) with the highest score (3.40). For the SOCP scale, farmers rated the overall variables SOCP1 (Demand for hiring labor increases) and SOCP3 (Protect workers' health) with the highest scores (3.37). Therefore, the

Department of Agriculture supports farmers to apply circular economy measures towards improving profits compared to increasing costs, expanding labor employment and paying attention to protecting farmers' health when using chemicals.

6. Conclusions and Research Limitations

The present study extends the theoretical understanding of circular economy adoption by integrating Circular Economy Theory, the Theory of Planned Behavior, and Diffusion of Innovation Theory to explain farmers' adoption behavior and its effects on sustainability performance in the Mekong Delta, Vietnam. The findings demonstrate that confidence in benefits, evaluation of social response, perceived behavioral control, belief, and motivation significantly influence the adoption of circular economy practices, which in turn positively contributes to economic, environmental, and social performance.

Despite these contributions, several limitations should be acknowledged. First, the study was conducted in three provinces/city in the Mekong Delta, which may limit the generalizability of the findings to other regions with different agro-ecological and institutional conditions. Second, the cross-sectional research design does not permit definitive causal inference between circular economy adoption and sustainability performance. Third, the proposed model primarily focuses on behavioral determinants and does not incorporate contextual factors such as market access, value chain integration, household characteristics, or regional heterogeneity, which may also influence farmers' adoption decisions. Finally, the sample was predominantly composed of male respondents, and future studies should employ more gender-balanced samples to further examine potential differences in circular economy adoption behavior.

Future research is therefore encouraged to adopt longitudinal or mixed-methods designs, incorporate additional contextual variables, and conduct comparative analyses across different regions and demographic groups to provide a more comprehensive understanding of circular economy adoption in agriculture.

Author Contributions

Conceptualization, H.P.D. and T.T.M.Q.; methodology, H.P.D. and T.T.M.Q.; software, H.P.D.; validation, H.P.D. and T.T.M.Q.; formal analysis, H.P.D.; investigation, H.P.D.; resources, T.T.M.Q.; data curation, H.P.D.; writing—original draft preparation, H.P.D.; writing—review and editing, T.T.M.Q.; visualization, H.P.D.; supervision, T.T.M.Q.; project administration, T.T.M.Q. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Ethical review and approval were not required for this study because it involved a voluntary questionnaire survey of adult participants, without medical intervention, experimentation, or collection of sensitive personal data.

Informed Consent Statement

Informed consent was obtained from all participants prior to completing the questionnaire.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) solely to assist with English language editing, including grammar, spelling, and wording improvements. After using this tool, the authors reviewed and edited the manuscript as needed and take full responsibility for the content of the published article.

Appendix A

Table A1. Scales and observable variables.

No.	Scales and Observed Variables	Code
I	Confidence in benefits	CON
1	I know well the basic principles of circular economy	CON1
2	I clearly understand the economic and environmental efficiency compared to traditional economics	CON2
3	Circular economic efficiency brings benefits to utilizing all resources in agricultural production	CON3
4	I think farmers in the Mekong Delta are well aware of circular economy	CON4
II	Evaluation of social response	SOCR
5	Those who have been applying circular economy inspire me	SOCR1
6	I have heard about CE through the mass media	SOCR2
7	Localities and the government have policies to encourage farmers to convert the media economy to a circular economy	SOCR3
8	If the State supports me with a loan from formal credit institution, I will participate	SOCR4
III	Perceived behavioral control	PBC
9	I am eligible to participate in Circular Economy	PBC1
10	I have many ways to access information to choose from to implement Circular Economy	PBC2
11	Thanks to Agricultural Extension Officer 's training, I have enough knowledge to apply Circular Economy	PBC3
12	To participate in the implementation of Circular Economy, I have the support of friends and good farmers in the area.	PBC4
IV	Belief	BEL
16	The circular economy is a production and business method associated with harmony between economy, society and environment	BEL1
17	The Agricultural Extension staff is capable of guiding farmers in sustainable agricultural production	BEL2
18	Farmers' moral responsibility must be linked to technical innovation and agricultural technology	BEL3
19	The resulting product diversity is consistent with farmers' selection goals	BEL4
V	Motivation	MOT
20	I realize that nowadays consumers of agricultural products are concerned about product quality/product safety	MOT1
21	Because the government has supportive policies, I participate in the circular economy activities	MOT2
22	I think that the circular economy solves sustainable livelihoods for farmers	MOT3
23	I think the agricultural extension center provides technical support for circular economy.	MOT4
VI	Adoption of circular economy practices by Farmers	ADOP
24	I use the "1 right, 5 down" technology in production and utilize waste products	ADOP1
25	I apply the model of diversifying crop and livestock farming	ADOP2
26	I participate in agricultural supply chain models	ADOP3
VII	Economic performance	ECOP
27	Revenue increases per unit of farmland area	ECOP1
28	Total profit increased	ECOP2
29	Profit margins increase	ECOP3
30	The product is easy to consume due to increased product quality and meeting food safety and hygiene standards	ECOP4
VIII	Environmental performance	ENVP
31	Reduce the number of inorganic fertilizers and chemistry medicines	ENVP1
32	Collect bags and put them in designated reservoirs and utilize manure from livestock to create clean energy for family activities.	ENVP2
33	Utilize by-products from farming as raw materials for livestock	ENVP3
IX	Social performance	SOCP
34	Demand for hiring labor increases	SOCP1
35	Make optimal use of family labor	SOCP2
36	Protect workers' health	SOCP3
37	Contribute to expanding employment in rural areas	SOCP4

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