Theme: Sustainable Agricultural Innovations for One Health and Environmental Resilience

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Implementation of the Bio-Circular-Green (BCG) Economy Model and Influences on Natural Resource Sustainability: A Case Study of Oil Palm Smallholders in Southern Thailand

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ABSTRACT

Background: This study aims to analyze the level of implementation of the Bio-Circular-Green (BCG) Economy Model and the factors influencing natural resource sustainability among smallholder oil palm farmers in Songkhla Province, Thailand.

Methods: The study adopts the Sustainable Livelihood Framework developed by the Department for International Development (DFID). Data were collected from 186 farming households and analyzed using multiple regression analysis.

Result: The results indicate that farmers exhibit a high level of practices in the Green Economy dimension. However, the levels of implementation in the Bio economy and circular economy dimensions remain very low. This is primarily due to key constraints, including high investment costs and uncertainty regarding the cost-effectiveness of precision agriculture technologies. The regression analysis reveals that water resource conservation and oil palm frond management are critical factors significantly affecting sustainability (R^2 = 0.41). These findings are consistent with Sustainable Development Goal 15 (SDG 15), which emphasizes the protection, restoration and sustainable use of terrestrial ecosystems. Policy recommendations suggest that the government should accelerate the promotion of low-cost innovative technologies that are compatible with family-based farming systems. This would help reduce the gap in access to innovation and enhance tangible sustainability outcomes.

Key words: Bio-circular-green (BCG) economy model, Natural resource sustainability, Oil palm, SDG 15, Smallholder farmers.

INTRODUCTION

Oil palm is a major economic crop in Southeast Asia due to its higher yield per unit area compared to other oil crops. Thailand, the world's third-largest producer, has a total cultivated area of 6,751,372 rai, of which 86.24% is concentrated in the southern region (Agricultural Economics Office, 2024a). Songkhla, Southern Thailand is considered a key strategic area with continuous oil palm cultivation, covering 84,807 rai of harvested area (Agricultural Economics Office, 2024a). However, the production structure is predominantly driven by smallholder farmers, accounting for more than 272,514 households and contributing over 80.00% of the country's total oil palm production (Department of Agricultural Extension, 2024). This structural characteristic highlights the critical role of smallholders in sustaining national production while also reflecting inherent challenges such as limited access to capital, technology and market information. Smallholder-dominated systems often face constraints in adopting advanced management practices, which may affect productivity and long-term sustainability. At the same time, their widespread presence offers significant potential for scaling sustainable practices if appropriate support mechanisms are implemented.

Despite being a major producer, Thai farmers have limited bargaining power in price determination, resulting in income volatility influenced by global market fluctuations (Sae-Charoensuk, 2023). This situation was further exacerbated in the second quarter of 2024 due to the El Niño phenomenon, which caused the agricultural economy to contract by 1.5% (Agricultural Economics Office, 2024b). Therefore, development approaches must focus on improving production efficiency and reducing costs while simultaneously conserving natural resources. This aligns with Sustainable Development Goal 15 (SDG 15), which emphasizes halting ecosystem degradation. Amid the ongoing biodiversity crisis in Thailand, sustainable oil palm plantation management has become an urgent priority for restoring soil and water resources at the grassroots level (Office of Natural Resources and Environmental Policy and Planning, 2025). In this context, the dual challenge of economic vulnerability and environmental degradation underscores the need for integrated development strategies. Enhancing resilience requires not only

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improving farm-level productivity but also strengthening farmers' capacity to cope with external shocks such as climate variability and market instability. Moreover, unsustainable practices may accelerate soil degradation, water scarcity and biodiversity loss, further threatening long-term production potential. Addressing these issues necessitates a balance between short-term economic gains and long-term ecological sustainability.

The Bio-Circular-Green (BCG) Economy Model has been adopted as a strategic approach to enhance sustainability through the integration of bioeconomy, circular economy and green economy principles (Ministry of Higher Education, Science, Research and Innovation, 2021). This study applies the Sustainable Livelihood Framework proposed by the Department for International Development (DFID, 1999) to analyze livelihood outcomes resulting from farmers' strategic choices in implementing the BCG model. The focus is placed on achieving sustainable use of natural resource-based systems, which refers to the integration of economic efficiency and ecological resilience, ensuring that oil palm cultivation generates income while maintaining the natural resource base. The integration of the BCG model with the Sustainable Livelihood Framework provides a comprehensive analytical lens that captures both economic and environmental dimensions of sustainability. While the BCG model emphasizes resource efficiency and value creation, the SLF highlights the role of livelihood assets and institutional contexts in shaping farmers' decision-making. Together, these frameworks enable a more holistic understanding of how sustainable practices can be adopted and sustained at the farm level.

Therefore, this study aims to examine the implementation of the BCG Economy Model and its influence on natural resource sustainability among oil palm farmers in Songkhla Province. By applying the (DFID, 1999) sustainable livelihood framework and comparing levels of practices and outcomes, the findings provide empirical evidence to support the design of context-specific policy measures that strengthen both livelihood security and sustainability for farmers in a tangible manner. Furthermore, the study contributes to the existing literature by providing empirical insights into the practical application of the BCG model within smallholder agricultural systems. The results are expected to inform policymakers, extension services and development agencies in formulating targeted interventions that are both feasible and scalable. Ultimately, the study seeks to bridge the gap between policy frameworks and on-the-ground practices, ensuring that sustainability initiatives translate into measurable improvements in farmers' livelihoods and resource conservation.

MATERIALS AND METHODS

Study area

This study was conducted by researchers from the Faculty of Natural Resources, Prince of Songkla University, Hat Yai Campus, Thailand, among oil palm smallholders in Songkhla Province, Southern Thailand. The research was conducted during 2023-2025, including study design, field data collection, data analysis and interpretation.

Research design and respondents

The population consisted of registered oil palm farming households in Songkhla Province, totaling 5,264 households. These were classified into two groups: 4,559 monocropping households and 705 households practicing integrated farming systems (Department of Agricultural Extension, 2024).

The sample size was determined using the formula proposed by Yamane (1973), with a confidence level of 90% and a margin of error of 0.10, resulting in a total sample of 186 households. This included 98 monocropping households and 88 integrated farming households. Stratified sampling was employed across districts, followed by convenience sampling at the final stage.

Data collection

The research instrument was a structured interview questionnaire, divided into three parts:

Part 1: Personal characteristics and socio-economic conditions of farmers, consisting of both open-ended and close-ended questions.

Part 2: Implementation of the BCG Economy Model, comprising three dimensions: Bio Economy, Circular Economy and Green Economy. A five-point Likert scale (1-5) was applied, based on Likert's concept.

Part 3: Livelihood outcomes in terms of sustainable use of natural resource-based systems. This included indicators such as soil fertility in oil palm plantations, water sufficiency for oil palm cultivation, forest abundance surrounding plantations and the adoption of environmentally friendly agricultural practices. A five-point Likert scale (1-5) was applied, based on Likert's concept.

RESULTS AND DISCUSSION

Personal and socio-economic characteristics

A total of 186 farmers participated in the study, comprising 124 males (66.70%) and 62 females (33.30%). The majority were Buddhist and had completed primary-level education. The average oil palm cultivation area was 8.66 rai. The mean yield was 2,944.05 kg per rai per year. The average income from oil palm cultivation was 28,285.48 THB per rai per year, while the average production cost was 4,457.56 THB per rai per year [6.25 Rai≈1 Hectares (ha)].

These findings indicate that oil palm farming in the study area is predominantly operated by smallholder farmers with relatively limited landholdings. The relatively low level of formal education suggests that farmers may rely more on experiential knowledge and informal learning rather than advanced technical training. This may influence the adoption of innovative practices, including those aligned with the BCG model.

Moreover, the gap between income and production costs reflects a positive net return; however, the profitability may still be vulnerable to fluctuations in market prices, input costs and climatic conditions. This highlights the importance of improving resource use efficiency and reducing production risks to ensure stable livelihoods.

In addition, the moderate yield level suggests potential for further productivity improvement through better farm management practices, such as optimized fertilization, water management and harvesting techniques. To reduce economic vulnerability from high production costs, integrating localized organic fertilizers from oil palm residues can substitute synthetic inputs, thereby improving the net profitability and resilience of smallholder households (Wongkrachang and Anurut, 2025) Strengthening farmers' capacity through extension services and knowledge transfer could therefore play a crucial role in enhancing both productivity and sustainability.

From a broader perspective, these socio-economic characteristics underline the need to design context-specific interventions that are accessible and practical for smallholders, particularly under the BCG framework, which emphasizes inclusive, resource-efficient and environmentally sustainable agricultural development.

Compliance with the bio-circular-green economy (BCG) model among oil palm farmers

The findings reveal a structurally imbalanced implementation of the Bio-Circular-Green (BCG) model among oil palm smallholders (Table 1), characterized by the dominance of the Green Economy dimension (Mean = 4.03) and relatively weak adoption of the Bio Economy (Mean = 2.36). This pattern reflects an "awareness-implementation divergence," where farmers exhibit strong environmental awareness but face significant barriers in translating such awareness into technically intensive practices. This aligns with evidence indicating that sustainable agriculture adoption depends on socio-economic and structural factors beyond awareness alone (Ofosu-Ampong *et al.*, 2025).

High engagement in green practices suggests that farmers are responsive to environmental risks and sustainability concerns, consistent with findings that environmental awareness influences pro-environmental behavior and sustainable practice adoption (Nguyen *et al.*, 2024). However, limited adoption of bio-economic practices highlights constraints related to knowledge, technology and capital. Previous studies indicate that smallholders often delay adopting technologies due to high investment costs and uncertainty regarding economic returns (Kendall *et al.*, 2022), while BCG implementation also requires technological and institutional support (Isarangkun Na Ayuthaya *et al.*, 2023). This barrier to implementation aligns with the findings of (Singh, 2021), who revealed that despite over 90% of surveyed farmers perceiving severe climate change impacts and declining water levels, their actual capacity to execute risk-reduction strategies remained heavily restricted by baseline socioeconomic hurdles,

Table 1: Compliance with the bio-circular-green economy (BCG) model among oil palm farmers.

BCG model components	Mean	S.D.	Level
1. Bio economy			
Oil palm harvesting practices	2.94	0.29	Moderate
Use of chemical fertilizers	2.82	0.84	Moderate
Use of organic fertilizers in oil palm plantations	4.43	0.63	Highest
Use of bio-fertilizers in oil palm plantations	1.75	0.46	Lowest
Construction of drainage systems	1.66	1.14	Lowest
Water storage pond construction	1.70	1.15	Lowest
Planting of cover crops in oil palm plantations	1.24	0.68	Lowest
Overall bio economy	2.36	0.62	Low
2. Circular economy			
Use of oil palm leaves as animal feed	1.00	0.00	Lowest
Use of oil palm fronds for mulching (frond mulching)	3.51	1.37	High
Use of empty fruit bunches (EFB) for mulching in oil palm plantations	2.43	1.19	Low
Livestock raising within plantations for manure utilization	3.50	1.00	High
Overall circular economy	2.61	1.10	Moderate
3. Green economy			
Awareness of maintaining ecological balance	4.18	0.71	High
Water conservation	3.93	0.95	High
Soil conservation in oil palm cultivation areas	3.97	0.75	High
Overall green economy	4.03	0.68	High
Overall BCG Model	3.00	0.56	Moderate

Note: 1.00 - 1.80 Lowest 1.81 - 2.60 Low 2.61 - 3.40 Moderate
3.41 - 4.20 High 4.21 - 5.00 Highest

including institutional credit burdens and monocultural dependencies.

Within the circular economy dimension (Mean = 2.61), low-cost practices such as palm frond mulching and livestock integration were more widely adopted than practices requiring additional inputs, such as empty fruit bunch utilization. This supports previous findings that economic feasibility and technological constraints strongly influence adoption among smallholders (Cheah *et al.*, 2023).

Importantly, the dominance of the Green Economy dimension is consistent with previous BCG-related studies showing that environmental awareness often exerts a stronger influence on sustainability outcomes than bio- and circular-economy practices. However, despite the availability of bio-based innovations such as biofertilizers, their adoption remains limited due to gaps in technical knowledge and extension support (Rosid *et al.*, 2026). Overall, the moderate level of BCG implementation (Mean = 3.00) suggests that the transition toward sustainable resource use remains incomplete and requires stronger support mechanisms, including extension services, innovation systems and financial incentives to facilitate sustainable agricultural transitions (Food Systems for the Future and Boston Consulting Group (BCG, 2024).

Livelihood outcomes regarding the sustainable use of natural resource base among oil palm farmers

The analysis of the level of natural resource sustainability among oil palm farmers (Table 2) reveals that the overall livelihood outcome in this dimension is at a high level, with a mean score of 4.01. When considering specific aspects, the key findings are as follows:

Provisioning services

Farmers rated soil fertility in oil palm plantations at the highest level among all indicators (mean = 4.15), followed by water adequacy (mean = 4.14), indicating the importance of natural capital for production efficiency and household livelihood stability. This finding is consistent with (Sukarman *et al.*, 2022), who reported that water stress significantly influences oil palm productivity and may reduce yields under unfavorable conditions. These findings suggest that effective soil and water management plays a critical role in reducing production risks and enhancing resilience among smallholders, particularly under climate variability. Furthermore, when external environmental shocks occur, communities heavily reliant on natural water sources can experience severe water scarcity and a rapid degradation of water quality, drastically increasing their livelihood vulnerability (Behera *et al.*, 2024). They also highlight the importance of natural capital within the Sustainable Livelihood Framework (SLF), as soil and water resources form the foundation for sustainable livelihood outcomes.

Environmental management and ecosystems

The adoption of environmentally friendly agricultural practices was high (mean = 3.89), reflecting farmers' efforts to minimize environmental impacts. Although forest abundance surrounding plantations received the lowest score (3.77), these areas still provide important ecosystem services such as moisture regulation and pollinator support. This finding is consistent with (Zemp *et al.*, 2023), who reported that maintaining vegetation complexity can enhance biodiversity without negatively affecting productivity. These findings indicate that both farm-level practices and surrounding ecosystems contribute to long-term sustainability and ecological resilience, suggesting that sustainable oil palm production requires not only improved on-farm management but also the conservation of supporting ecosystems.

Relationship between compliance with the bio-circular-green economy (BCG) model and the sustainable use of natural resource base among oil palm farmers

The Multiple Regression Analysis (Table 3), conducted to examine the relationship between BCG model implementation and natural resource sustainability among oil palm smallholders in Songkhla, revealed that the independent variables collectively explained 40%-41% of the variance in sustainable resource utilization (R^2 = 0.40-0.41). The remaining 60% is attributed to other factors not included in this model. The key findings are as follows:

Water resource conservation

Water resource conservation had the strongest influence on sustainability. Establishing water retention ponds helps ensure adequate water availability and reduce production vulnerability. This finding is consistent with (Thammachote and Chupradit, 2020), who identified water scarcity as a

Table 2: Indicators of livelihood outcomes regarding the sustainable use of natural resource base among oil palm farmers.

The sustainable use of natural resource	Mean	S.D.	Level
Soil fertility in oil palm plantations	4.15	0.80	High
Water adequacy for oil palm cultivation	4.14	0.75	High
Forest abundance surrounding oil palm plantations	3.77	0.98	High
Adoption of eco-friendly agricultural practices	3.89	0.78	High
Overall natural resource sustainability	4.01	0.76	High

Note: 1.00 - 1.80 Lowest 1.81 - 2.60 Low 2.61 - 3.40 Moderate 3.41 - 4.20 High 4.21 - 5.00 Highest

Table 3: Relationship between compliance with the bio-circular-green economy (BCG) model and the sustainable use of natural resource base among oil palm farmers.

	Unstandardized coefficients		Standardized coefficients	t	Sig.	Collinearity statistics	
	B	Std. error	Beta			Tolerance	VIF
(Constant)	1.481	.443		3.346***	.001		
1. Conservation of water resources for cultivation	.277	.048	.385	5.777***	.000	1.377	.726
2. Palm frond mulching around tree bases or between rows	.094	.027	.213	3.417***	.001	1.208	.828
3. Construction of water retention ponds	.122	.043	.206	2.843**	.005	1.621	.617
4. Oil palm harvesting management	.301	.137	.127	2.205**	.029	1.022	.979

F = 25.892***, p<0.001, SE_est = 0.52, Durbin-Watson = 1.72 R^2 = 0.41, Adjusted R^2 = 0.40;***p<0.001

Note: * statistically significant at p<0.05.

** statistically significant at p<0.01.

*** statistically significant at p<0.001.

ns not significant (p≥0.05).

major source of livelihood vulnerability among oil palm farmers. Effective water management may strengthen adaptive capacity under climate variability, particularly in rainfed systems, reflecting the green economy principle of efficient and sustainable resource use.

Oil palm frond mulching

Palm frond mulching had the second-highest influence on sustainability outcomes. As a circular economy practice, it improves soil moisture and organic matter while reducing production costs through the use of locally available resources. This finding is consistent with (Sang-an, 2021), who reported that mulching combined with fertilizer management based on leaf analysis generated the highest economic returns in oil palm production. Such practices also improve resource efficiency and support long-term soil productivity. Furthermore, organic amendments like palm frond mulching restore soil structure and mitigate the ecological impacts of synthetic pesticides. By increasing soil organic matter, microbial diversity and nutrient cycling, these practices sustain a healthy rhizosphere (Rawat *et al.*, 2025). Ultimately, this promotes ecological resilience and reduces dependency on synthetic inputs, driving long-term agricultural sustainability.

Oil palm harvesting management

Harvesting management also significantly influenced sustainability outcomes. Extended harvesting intervals may increase fruit losses and reduce production efficiency. This finding is consistent with (Nurfalah *et al.*, 2023), who reported that prolonged harvesting intervals among smallholders increase losses from overripe fruits. This practice reflects the Bio Economy dimension of the BCG model, which focuses on maximizing value from biological resources.

The findings indicate that the implementation of the Bio-Circular-Green (BCG) Economy Model among oil palm smallholders is structurally uneven, with strong adoption in the Green Economy but limited uptake in Bio and Circular dimensions. This reflects an “awareness–practice gap,” where environmental awareness does not translate into action, consistent with empirical evidence (Nguyen *et al.*, 2024).

Overall, the findings suggest that sustainability among oil palm smallholders is influenced more by specific resource-management practices than by broad BCG adoption. From the Sustainable Livelihood Framework (SLF) perspective, these outcomes may reflect constraints in livelihood assets, particularly financial and human capital, which affect technology adoption and adaptive capacity (DFID, 1999). Therefore, sustainability appears to emerge from interactions among livelihood resources, adaptive practices and external conditions rather than from uniform implementation of the BCG model.

CONCLUSION

This study reveals that the implementation of the Bio-Circular-Green (BCG) Economy Model among oil palm smallholders is structurally imbalanced, with strong performance in the Green dimension but limited adoption of Bio and Circular practices. This reflects a persistent “awareness-practice gap”, driven not by attitudes but by constraints in capital, technology and institutional support. Crucially, the findings demonstrate that sustainability is not determined by overall BCG adoption, but by specific high-impact practices. Water resource management and palm frond mulching emerge as key mechanisms enhancing soil fertility, moisture retention and climate resilience. This indicates that sustainability transitions in smallholder systems are practice-driven and context-specific, rather than model-wide. With BCG practices explaining only part of sustainability outcomes ($R^2 \approx 0.41$), the remaining variation highlights the critical role of vulnerability context, confirming that sustainability is inherently multi-scalar and system-dependent. Theoretically, this study advances the literature by integrating the BCG model with the Sustainable Livelihood

Framework (SLF), proposing that sustainability emerges from the interaction between livelihood assets, adaptive practices and external vulnerabilities. This provides a new analytical lens beyond linear adoption models. Policy and practice implications should therefore prioritize low-cost, high-impact interventions, strengthen technology access and extension systems and enhance institutional linkages for knowledge transfer. Future research should adopt longitudinal and mixed-method approaches to better capture dynamic adaptation processes.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct indirect losses resulting from the use of this content.

Informed consent

Not applicable.

Conflict of interest

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