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Sustainability Analysis of Jute-Based TongTang Innovation for Erosion Control and Potato Cultivation

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ABSTRACT

This study aims to analyze the sustainability level of TongTang (Potato Bag) innovation made from jute as a dual-function technology, erosion protection, and potato cultivation media on terraced land. TongTang was developed to address the challenges of land degradation and erosion that threaten national food security by offering solutions based on the circular economy and good agricultural practices (GAP). The Rapid Appraisal for Fisheries (RAPFISH) approach, modified for the agricultural context, was used to assess sustainability in five dimensions: ecology, economy, society, technology, and institutions. The data were collected from 26 respondents consisting of farmers, industry partners, and academics through an ordinal scale questionnaire. The results of the analysis showed that the average sustainability index value was 51.7, which is classified as moderately sustainable. The ecological dimension received the highest score (64.2), followed by technology (57.8), social (48.6), institutional (46.3), and economic (44.7). Stress values < 0.21 and

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$R^2 > 0.95$ in all dimensions indicate that the model has a high level of suitability and reliability. The leverage analysis results reveal that the attributes most sensitive to changes in the index are increases in soil organic matter, improvements in the root microenvironment, women's involvement, and increases in farmer income. Meanwhile, the Monte Carlo analysis shows that the ecological and technological dimensions are relatively stable against uncertainty, while the social and institutional dimensions are still fluctuating.

Keywords: Sustainability; TongTang; Goni; Circular Economy; RAPFISH (Rapid Appraisal for Fisheries); Food Security

1. Introduction

National food self-sufficiency and security is one of Indonesia's strategic national development agendas [1–3]. However, efforts to achieve this have been challenged by hydrometeorological disasters, such as floods and landslides. These disasters are becoming more frequent due to climate change and have a direct impact on the productivity of the agricultural sector, especially in geographically vulnerable areas such as terraced land [4–6]. Terraced fields are an important agricultural ecosystem widely used for cultivating food commodities [7]. However, high rainfall intensity in these areas often causes erosion and damage to terraces, disrupting the national food supply if not anticipated through technology-based adaptation strategies [8, 9].

One of the technologies that has developed in society is the use of plastic planter bags for agriculture. However, plastic has very low porosity and is impermeable [10,11]. When it rains, water tends to be trapped inside the plastic planter bags because it cannot drain optimally. This can accelerate the root decay process [12]. In plant cultivation, the soil used must not only be fertile but also healthy. Plastic does not allow air exchange for the survival of soil microorganisms such as aerobic and anaerobic bacteria that support soil health [13,14]. These bacteria play a role in the decomposition of organic matter and biological control of plant pathogens [15,16].

This study re-adopts existing technology in plastic planter bags. Based on previous research on the use of jute as a biodegradable material in seed *bag* production, jute sacks have been proven to be permeable, which makes the soil fertile and healthy because it allows water and air to pass through efficiently [17]. Jute has high porosity (>90%), which supports natural drainage and optimal aeration [18,19]. This is very important in creating a healthy root environment and supporting soil microbial respiration. This aerated environment allows aerobic and anaerobic bacteria to live in balance, which in turn improves soil structure, accelerates the decomposition of organic matter, and increases the natural availability of nutrients.

The technological modification in this study is the creation of a jute planter bag called TongTang (Potato Bag), where the focus of food research in this study is potatoes [17]. The main advantage of TongTang, as well as the novelty of this research, is its ability to provide a dual function: first, as protection against erosion of terraced land and second, as a medium for potato cultivation. With the permeable nature of jute, excess rainwater can be channeled in a controlled manner to drainage channels, thereby reducing direct pressure on the terraced walls [20]. In practice, TongTang will be installed on terraced contours that are prone to heavy rainwater runoff. When it rains, water will flow through the permeable jute structure, slowing down the flow rate and directing it towards the available drainage channels. Thus, the kinetic energy of the water can be reduced, and the risk of erosion is significantly reduced. This practice will result in dual-function intensification, serving not only as a place for potato cultivation but also as protection for the land from erosion. In its application, TongTang also supports Good Agricultural Practices (GAP) by encouraging the use of environmentally friendly planting media, maintaining cultivation sanitation, and improving the efficiency and sustainability of agricultural systems [21,22]. This study aims to analyze the sustainability of the TongTang innovation from economic, social, environmental, institutional, technological, and circular economy dimensions, in order to formulate its development strategy as a model of sustainable agricultural innovation that supports national food security.

2. Research Method

This study uses a quantitative descriptive approach with the Rapid Appraisal for Fisheries (RAPFISH) method modified for the context of sustainable agriculture. RAPFISH is a multidimensional scaling (MDS) analysis technique used to assess the sustainability level of a system based on a number of attributes or indicators across various dimensions [23]. In this study, RAPFISH was used to analyze the sustainability of the TongTang (Potato Bag) innovation from economic, social, environmental, institutional, and technological aspects. The research was conducted in a highland horticultural development area, specifically in an area with terraced land prone to erosion. Data collection was carried out by distributing questionnaires to 26 respondents, involving various agricultural actors such as farmers, industry partners (CV Plantamor), and academics.

The main research instrument was the RAPFISH questionnaire, which contained sustainability indicators in six dimensions, each containing 10 assessment attributes. Each attribute was assessed using an ordinal scale of 0–3, with the following categories:

- 0 = highly unsustainable,
- 1 = unsustainable,
- 2 = moderately sustainable,
- 3 = sustainable.

Respondents provided assessments based on their perceptions of the performance and sustainability potential of TongTang innovations in the field.

The unit of analysis in this study was 26 respondents, divided into:

- 15 farmers (F1–F15),
- 5 industry partners (M1–M5),
- 6 academics (A1–A6).

Each unit was analyzed to see the variation in perceptions among actors regarding the sustainability dimensions of TongTang innovation.

The RAPFISH ordination is placed on a curve that has an x-axis and a y-axis. In RAPFISH, the axis used, which plays a significant role in measurement, is the x-axis in the ordination. Meanwhile, the y-axis has no relation to the level of sustainability. The y-axis is merely a variation in the measurement indicator (arbitrary). The algorithm used in RAPFISH is the ALSCAL MDS (Multidimensional Scaling) algorithm. The scale in MDS is useful in categorizing an indicator into bad (0%) and good (100%) ratings. The ALSCAL MDS algorithm then generates unit scores in two dimensions using the following formula:

$$\zeta \{S\} = D^2 + E \quad (1)$$

The sustainability status categories are presented in **Table 1**:

Table 1. Measure of the Strength of the Relationship between Sustainability Dimensions.

Index Value	Category
0.00–25.00	Poor: Not sustainable
25.01–50.00	Poor: Less sustainable
50.01–75.00	Sufficient: Sufficiently sustainable
75.01–100.00	Good: Very sustainable

Source: Nurmalina (2018).

RAPFISH also has another feature called Leveraging. In principle, leveraging is used to determine the most dominant indicator in a model. The Leveraging calculation shows changes in ordination positions when indicators in the model are removed one by one. Thus, this feature allows us to determine the level of indicators in the model that have the greatest influence. The Leveraging value in RAPFISH has a scale of 2% to 6%, measured in Root Mean Square (RMS) (**Table 2**).

Table 2. Rapfish Dimension Measurement Indicators.

Rapfish Dimension	Measurement Indicators
Economy	The cost of producing TongTang is commensurate with the benefits gained
	Increased potato productivity per unit of land
	Improved potato harvest quality
	Reduced risk of crop failure
	Increased overall farmer income
	Creation of new business opportunities (production, distribution, and support services)

Table 2. *Cont.*

Rapfish Dimension	Measurement Indicators
Economy	Large market potential for TongTang products
	Affordable TongTang prices for smallholder farmers
	Stable and sustainable availability of jute raw materials
	Increased potato commodity competitiveness due to the implementation of TongTang
Social	Farmer acceptance of the TongTang innovation
	Ease of understanding how to use TongTang
	Improved farmer skills in land management
	Perceived benefits of TongTang for farmers
	New job opportunities created at the village level
	Women's involvement in TongTang production or use
	Village youth interest in the TongTang innovation
	Strengthening cooperation between farmers
	Strengthening relationships between farmers and industry partners (CV Plantamor)
Environment	TongTang's effectiveness in reducing erosion rates on terraced land
	Ability to maintain soil moisture for longer
	Increased water infiltration into the soil
	Maintaining soil structure and stability
	Increasing soil organic matter content
	Creating a microenvironment that supports root growth
	Reducing the use of chemical fertilizers
	Reducing the use of chemical pesticides or herbicides
	No soil or water pollution
	Contributing to long-term environmental quality improvements
Institutional	Government support for environmentally friendly agricultural innovations
	Supporting regulations for the use of biodegradable materials
	Access to financing or incentives for innovations such as TongTang
	The existence of active farmer support organizations
	CV Plantamor's commitment to supporting TongTang distribution
	Opportunities for integrating TongTang into government conservation programs
	Support from research institutions and universities for TongTang development
	Potential Intellectual Property Rights (IPR) or patent protection
	Availability of a distribution network for TongTang distribution
Technology	The simplicity and clarity of the TongTang design
	The strength of the TongTang material to withstand the weight of the soil and plants
	The resistance of TongTang to high humidity
	Ease of production with simple, local equipment
	Reusability across multiple cropping cycles
	Compatibility with conventional potato cultivation practices
	Ease of harvesting using the TongTang
	Additional functional features (e.g., harvesting holes or windows)
	Potential for mass production with uniform quality
	Integrability with other agricultural products

3. Results

3.1. Respondent Data

As presented in **Table 3**, this study involved 26 respondents from various social and professional backgrounds relevant to the development of TongTang innovation. Based on demographic data, most respondents were in the productive age group of 36–45 years (42.31%), followed by the 46–55 age group (38.46%), while respondents aged 25–35 years only accounted for 11.54% and respondents over 55 years accounted for 7.69%. This shows that the majority of respondents were active age groups with experience in agricultural activities and technical decision-making in the field.

Table 3. Percentage of Respondent Data.

Indicator		Percentage(%)
Age	25–35 years old	11.54
	36–45 years old	42.31
	46–55 years old	38.46
	>55 years old	7.69
Gender	Male	76.92
	Female	23.08
Education	Elementary	11.54
	Junior High School	15.38
	High School	19.23
	D3/S1	30.77
	Master’s	7.69
	Doctorate	15.38
Occupation	Farmer	57.69
	Industry Partner	19.23
	Academics	23.08

Source: Processed Data, 2025.

In terms of gender, male respondents dominated at 76.92%, while females contributed 23.08%. This proportion reflects the actual conditions in the highland horticultural sector, where men still play a dominant role in cultivation and land management, while women are generally involved in post-harvest and product processing stages. In terms of education level, respondents showed considerable diversity. Approximately 30.77% had a D3/S1 education, 19.23% had a high school education, 15.38% had a junior high school education, and 11.54% had only completed elementary school. In addition, there were respondents with master's degrees (7.69%) and doctorates (15.38%), who generally came from academic circles. This composition shows that most respondents have good technological literacy to understand and assess sustainable agricultural innovations such as TongTang.

Based on occupation, the majority of respondents were farmers (57.69%), followed by industry partners (19.23%), and academics (23.08%). This composition is in line with the research design, which involved various key actors in the agricultural innovation system: farmers as direct users of technology, industry partners as product manufacturers and developers (such as CV Plantamor), and academics as parties involved in scientific research and validation. This diversity of backgrounds strengthens the quality of the perception data collected in the TongTang innovation sustainability analysis using the RAPFISH approach, as it reflects cross-sector perspectives relevant to sustainable agriculture and circular economy development.

3.2. TongTang Sustainability Level

The sustainability level of TongTang as assessed by all respondents can be seen in **Table 4**. The results of the RAPFISH analysis show that the average sustainability index value of all respondents is 51.7, which falls into the "moderately sustainable" category. This index value is obtained from the average of five dimensions of sustainability, namely ecology, economy, social, technology, and institutional. Based on the data distribution, 11 respondents (42.3%) were in the moderately sustainable category with an average score range of 52.3–74.1, while 15 respondents (57.7%) were in the less sustainable category with a score range of 36.4–50.1. No respondents reached the highly sustainable category (score > 75), indicating that the implementation of the TongTang innovation is still in its early stages of development.

When analyzed by dimension, the ecological dimension had the highest average of 64.2, indicating that most respondents considered TongTang effective in reducing erosion and maintaining soil quality. The technological dimension ranked second with an average of 57.8, showing appreciation for its functional design, the durability of the jute material, and its ease of application in the field. Meanwhile, the social dimension has an average of 48.6, which shows that farmers’ acceptance of innovation is still moderate. The economic dimension has an average of 44.7, indicating that production costs and market access are still considered inefficient. The institutional dimension ranks lowest with an average of 46.3, reflecting limited policy support, farmer institutions, and access to financing for environmentally friendly innovations.

Table 4. TongTang Sustainability Level.

Respondents	Sustainability Index					Average	Category
	Ecology	Economy	Social	Technology	Institutional		
P1	42.95	45.2	69.35	14.73	45.82	43.61	Less sustainable
P2	30.23	31.26	63.82	35.45	21.71	36.49	Less sustainable
P3	57.86	31.59	43.89	68.85	59.53	52.34	Sufficiently sustainable
P4	87.88	38.21	36.62	67.26	59.53	57.9	Sufficiently sustainable
P5	73.34	22.03	45.11	73.15	56.35	54	Sufficiently sustainable
P6	69.69	50.68	64.7	32.7	19.91	47.54	Less sustainable
P7	49.25	31.09	21.18	74.58	51.88	45.6	Less sustainable
P8	50.66	33.3	19.3	50.99	33.68	37.59	Less sustainable
P9	49.46	42.31	72.71	41.11	35.72	48.26	Less sustainable
P10	54.91	62.42	76.72	44	41.83	55.98	Sufficiently sustainable
P11	88.29	33.01	29.58	69.83	56.79	55.5	Quite sustainable
P12	79.55	44.26	31.56	59.43	67	56.36	Sufficiently sustainable
P13	70.33	33.01	29.58	73.42	52.88	51.84	Sufficiently sustainable
P14	64.81	44.26	31.56	62.16	62.87	53.13	Sufficiently sustainable
P15	91.74	64.31	48.2	95.69	70.5	74.09	Sufficiently sustainable
M1	88.29	56.76	56.5	56.38	49.55	61.5	Sufficiently sustainable
M2	71.27	59.29	49.43	22.2	31.71	46.78	Less sustainable
M3	68.82	61.4	47.4	36.18	36.73	50.11	Less sustainable
M4	68.1	29.79	40.02	72.31	67	55.44	Sufficiently sustainable
M5	54.95	29.79	30.36	80.47	67	52.51	Sufficiently sustainable
A1	60.63	54.04	44.36	52.15	67	55.64	Sufficiently sustainable
A2	68.16	54.04	52.15	84.58	67	65.19	Sufficiently sustainable
A3	48.43	46.9	42.86	26.69	32.79	39.53	Less sustainable
A4	49.24	46.9	59.08	27.9	46.37	45.9	Less sustainable
A5	49.32	51.07	42.86	33.41	36.73	42.68	Less sustainable
A6	36.58	60.88	37.53	63.89	51.58	50.09	Less sustainable

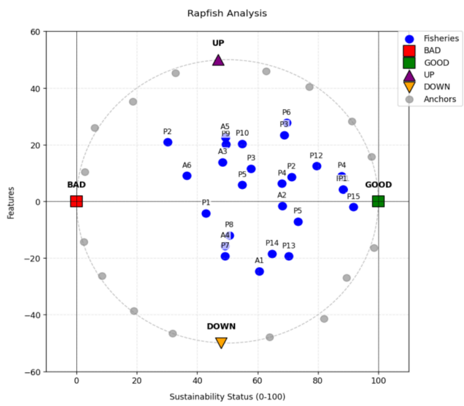
Source: Processed Data, 2025.

When grouped by profession, the farmer group (P1–P10) had an average score of 48.2, which indicates a perception of sustainability at a less-than-sufficient level. The industrial partner group (M1–M5) showed an average score of 53.5, while the academic group (A1–A6) had an average of 49.5. These results confirm that the highest perception of sustainability comes from the industrial sector, which sees the commercialization potential and added value of TongTang products, while farmers and academics believe that sustainability still needs systemic support.

3.3. Goodness of Fit Analysis

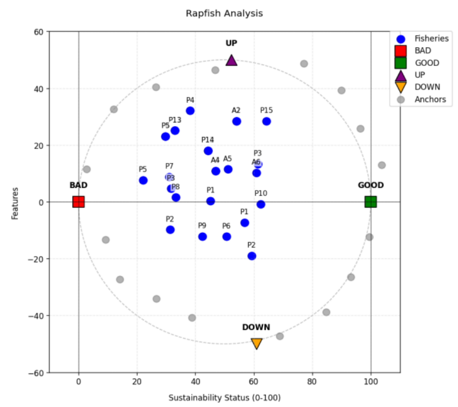
The results of the RAPFISH analysis of the five dimensions of TongTang (Potato Bag) innovation sustainability show that overall, the model has a very good level of reliability and suitability, as indicated by relatively low stress values and high R-squared values across all dimensions. The stress value is used to measure the level of distortion between the actual position and the position of the multidimensional scaling (MDS) ordination results, where the smaller the stress value (ideally < 0.25), the better the visual representation of the sustainability of the analyzed system. Meanwhile, R-squared (coefficient of determination) indicates the proportion of data variance that can be explained by the model; the closer it is to 1, the more accurate and reliable the ordination results are.

In detail, the ecological dimension has a stress value of 0.1647 and R^2 of 0.9729, indicating excellent and reliable results in describing data variation in environmental aspects. This dimension has the best representation compared to other dimensions, which means that ecological attributes such as erosion control, soil moisture, and goni porosity are very consistent in explaining TongTang's sustainability. The economic dimension obtained a stress value of 0.1842 and an R^2 of 0.9661, which is still in the good category; this shows that the aspects of cost, productivity, and market opportunities can be strongly explained by the model. The social dimension showed a stress of 0.1933 and an R^2 of 0.9626, indicating a good fit despite slight variations in respondents' perceptions of technology acceptance in the community. Meanwhile, the technological dimension had a stress value of 0.2035 and an R^2 of 0.9586, which means that although its representation was still relatively good, technical aspects such as durability, ease of use, and replication of TongTang had slightly higher heterogeneity of perception compared to other dimensions. The institutional dimension shows a stress of 0.1654 and an R^2 of 0.9726, which is almost equivalent to the ecological dimension, so it can be concluded that institutional factors—including policy support, the role of industry partners, and institutional assistance—are very well described in the model. All dimensions have stress values < 0.21 and R^2 > 0.95, indicating that the RAPFISH ordination results are very suitable for assessing the sustainability of TongTang innovation. These values show that the model has a high level of accuracy (≥96%) and low distortion, so that the interpretation of sustainability results can be trusted for use (**Figure 1**).



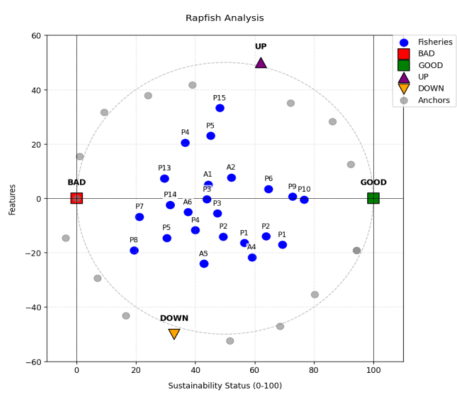
(**a**)

Stress: 0.1647
R-squared: 0.9729



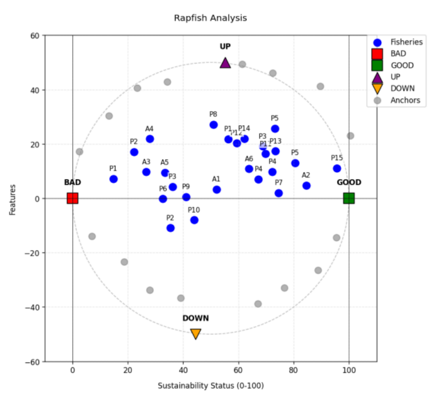
(**b**)

Stress: 0.1842
R-squared: 0.9661



(**c**)

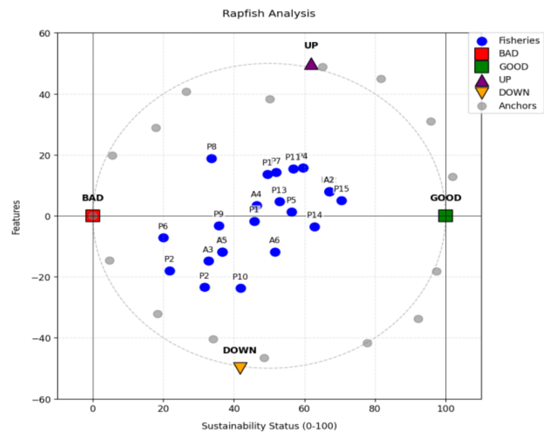
Stress: 0.1933
R-squared: 0.9626



(**d**)

Stress: 0.2035
R-squared: 0.9586

Figure 1. *Cont.*



(**e**)

Stress: 0.1654
R-squared: 0.9726

Figure 1. Goodness of Fit for TongTang Sustainability: (**a**) Ecology; (**b**) Economy; (**c**) Social; (**d**) Technology; (**e**) Institutional.
Source: Processed Data, 2025.

3.4. Factors Affecting TongTang Sustainability

The results of the RAPFISH leverage analysis show that the sustainability of TongTang's innovation is influenced by a number of key factors that differ in each dimension, with the Root Mean Square Deviation (RMSD) value indicating the level of sensitivity of each attribute to the sustainability index. In the ecological dimension in **Figure 2a**, the most influential attributes are the increase in soil organic matter content (RMSD Y = 32.33), the ability to create a microenvironment that supports root growth (Y = 32.12), and the reduction in the use of chemical fertilizers and pesticides (Y = 31.9). This confirms that TongTang's ecological sustainability is primarily determined by its ability to improve soil health and maintain microbial balance through the permeable and biodegradable properties of goni. Thus, the environmental aspect is a key advantage that reinforces TongTang's role as a conservation innovation and an environmentally friendly growing medium.

In the economic dimension (**Figure 2b**), the leverage results show that sustainability is greatly influenced by increased farmer income (RMSD Y = 35.30), the market potential of TongTang products (Y = 35.20), and affordable product prices (Y = 26.18). These findings indicate that the economic sustainability of TongTang depends not only on production costs, but also on commercialization opportunities and the added value generated. The greater the market potential and financial benefits received by farmers, the higher the level of economic sustainability that can be achieved.

Meanwhile, the social dimension (**Figure 2c**) shows the highest level of sensitivity compared to other dimensions. The attributes with the highest RMSD values are women's involvement in the production and utilization of TongTang (Y = 88.10) and the ease of understanding how to use TongTang (Y = 78.61). This shows that social sustainability is highly dependent on community acceptance of innovation and the extent to which this technology is able to empower vulnerable groups such as women and rural youth. The factor of collaboration between farmers and industry partners (Y = 29.64) also plays an important role in strengthening social networks and expanding technology adoption at the local level.

In terms of technology (**Figure 2d**), the most influential factors include the material's resistance to soil and crop loads (Y = 36.46), suitability for conventional potato cultivation practices (Y = 35.13), and resistance to high humidity (Y = 30.34). These results indicate that the technological sustainability of TongTang will be largely determined by its reliability in the field and its ability to adapt to the agricultural systems already implemented by farmers. Ease of production and potential reusability are also important factors in supporting the efficiency and replication of this innovation in various regions.

In the institutional dimension (**Figure 2e**), the most sensitive attributes are the availability of distribution networks (Y = 19.65), support from research institutions and universities (Y = 8.19), and the existence of government regulations related to biodegradable materials (Y = 11.01). This illustrates that the institutional sustainability of TongTang is still highly dependent on the supporting ecosystem, including government policies, continued research support, and partnerships between industry and academic institutions. Overall, these leverage results show that the social and ecological dimensions are the main determinants of the sustainability of TongTang innovation, followed by economic and technological aspects, while institutions play a supporting role in strengthening the innovation system. Thus, strengthening the sustainability of TongTang must be directed at three main strategies: improving ecological functions and technical efficiency, optimizing economic benefits for farmers, and expanding institutional networks through collaboration between government, industry, and academia in supporting circular economy practices in the sustainable agriculture sector.

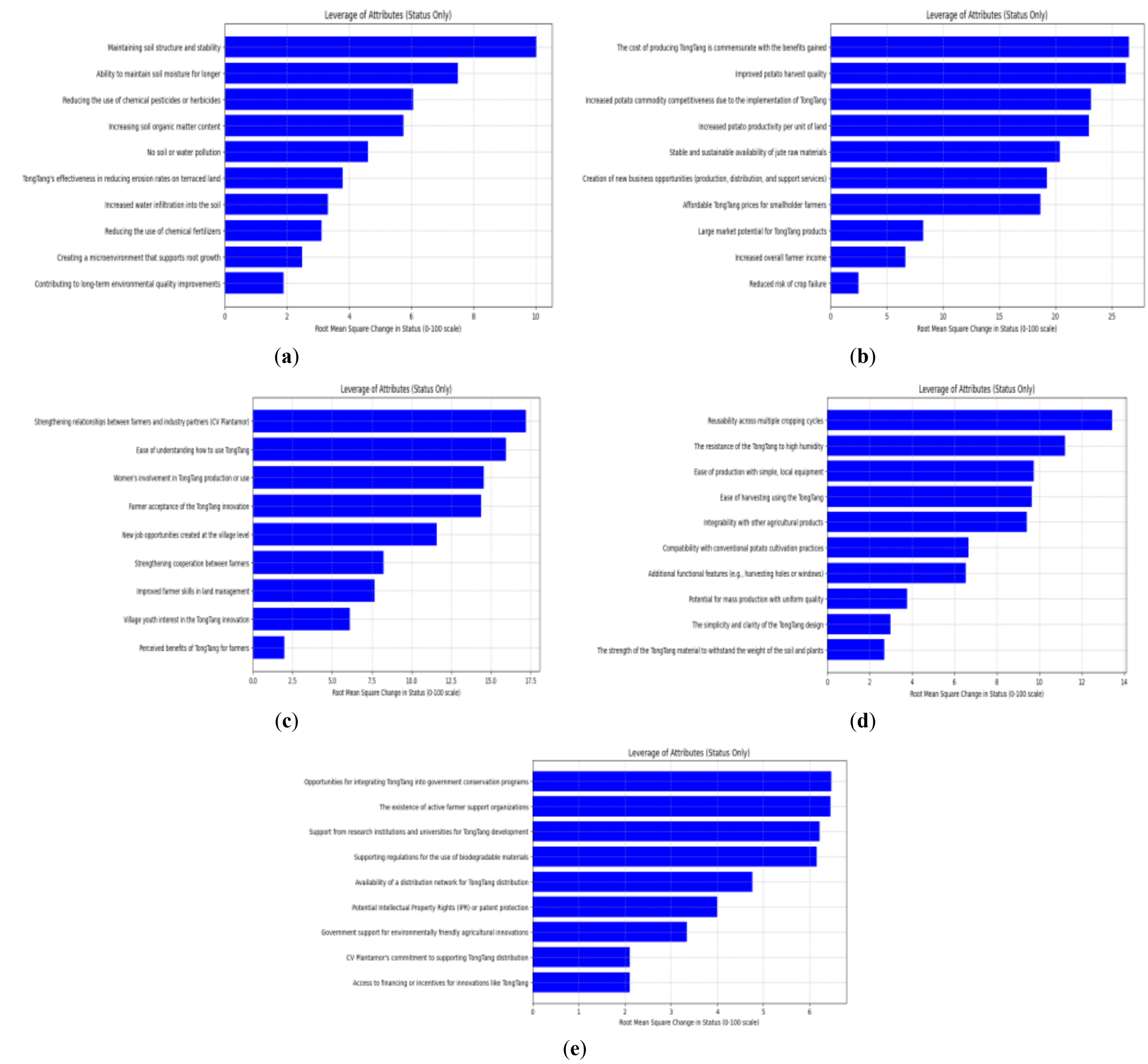


Figure 2. Results of TongTang Leverage Analysis: (**a**) Ecology; (**b**) Economy; (**c**) Social; (**d**) Technology; (**e**) Institutional.

Source: Processed Data, 2025.

3.5. Monte Carlo Analysis

Figure 3a shows the results of Monte Carlo analysis for ecological dimensions in the sustainability analysis of TongTang innovation. The distribution of points (gray and colored) illustrates the variation in respondents' positions after 1,000 random simulations, while the red dots indicate the average value (median) of each research object. The black lines are error bars that indicate the range of uncertainty (confidence interval 2.5%–97.5%) of each sustainability value.

In general, the majority of simulation results are in the middle-right quadrant, close to GOOD (sustainable), which means that the ecological aspects of TongTang are considered to be quite stable and relatively sustainable. This shows that respondents' perceptions of TongTang's ecological functions, such as its effectiveness in reducing erosion, maintaining soil moisture, and improving environmental quality, tend to be consistent despite slight variations between respondents. The distribution of results that did not spread too far toward BAD or DOWN indicates that the ecological dimension has a low level of uncertainty. The simulation points tend to be concentrated in the area with sustainability values between 50 and 80, which reinforces the main RAPFISH result that TongTang is ecologically in the "fairly sustainable" to "good" category. In addition, the relatively short length of the error bars indicates that small changes in respondent perceptions do not significantly affect sustainability results. Thus, these Monte Carlo results confirm that the ecological dimension of TongTang has high reliability and that this innovation has strong potential to maintain the balance of terraced land ecosystems and support sustainable environmentally friendly agriculture.

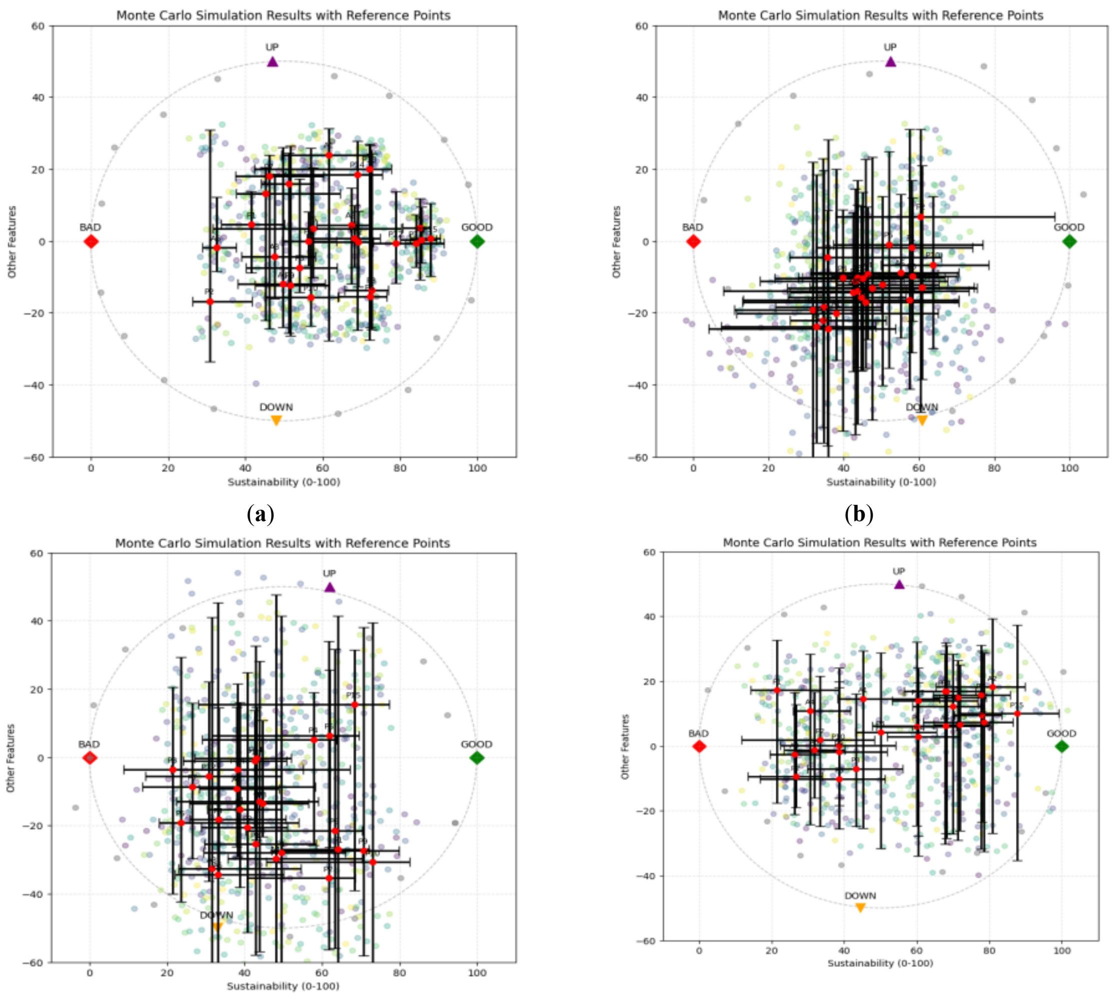
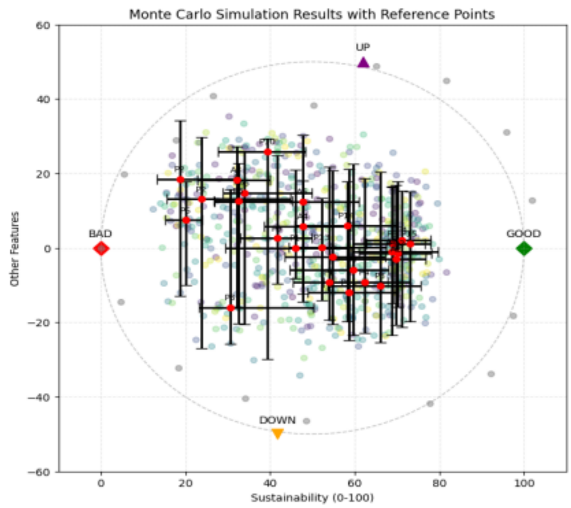


Figure 2. *Cont.*



(**e**)

Figure 3. Results of the TongTang Monte Carlo Analysis: (**a**) Ecology; (**b**) Economy; (**c**) Social; (**d**) Technology; (**e**) Institutional.
Source: Processed Data, 2025.

The results of the Monte Carlo analysis for the economic dimension in the TongTang innovation sustainability analysis are shown in **Figure 3b**. The distribution of points on the graph appears to be more spread out around the central axis (values 40–60) with some points extending towards the GOOD quadrant, indicating variation in respondents' perceptions of the economic aspects of TongTang. However, the median position (red dot) tends to be centered in the middle, indicating that in general the economic dimension is in the "fairly sustainable" category. The long error bar range on some points indicates a high degree of uncertainty in the assessment, particularly in relation to production costs, market potential, and increased farmer income. However, the concentration of most of the results in the positive area shows that TongTang has promising economic potential, especially if business development and market support can be optimized through partnerships with industry.

Based on the results of Monte Carlo simulations for social dimensions (**Figure 3c**), technology (**Figure 3d**), and institutional (**Figure 3e**), the distribution pattern of red dots (representing the median sustainability results) shows considerable variation, with most values in the middle to near the right side of the circle, indicating a fairly stable level of sustainability but still with potential for improvement. In the social dimension, the data distribution tends to spread towards the center-right with relatively long error bars, indicating variability in respondents' perceptions regarding the acceptance of TongTang innovation, social group involvement, and perceived economic and social benefits. Even so, the concentration of points in the 40–60 index range shows that the social aspects of TongTang are in the fairly sustainable category.

For the technological dimension, the scatter plot shows more consistent results, with the majority of data on the right-center of the graph (index 50–75). This indicates that the technical aspects of TongTang, such as the strength of the jute material, ease of production, and compatibility with potato cultivation practices, are considered stable and reliable. The shorter errors compared to the social dimension also indicate a lower level of uncertainty. Meanwhile, in the institutional dimension, the distribution of points tends to be directed to the upper right, approaching the "GOOD" point. This pattern indicates that institutional support for the implementation of TongTang is relatively strong, both in terms of collaboration with CV Plantamor, government support for environmentally friendly innovations, and the potential for integration into conservation programs. However, the presence of several points in the lower middle also indicates that policy support and financial incentives still need to be strengthened in order to optimize institutional sustainability.

4. Discussion

The results of TongTang's sustainability analysis show a promising pattern but also reveal systemic shortcomings that must be addressed in order for this innovation to be truly sustainable and scalable. The average index places TongTang in the moderately sustainable category (around 50–60 on many units per respondent), and leverage analysis confirms that the main driving force is not a single attribute but a set of mutually reinforcing attributes, such as soil health improvement (organic matter, aeration, infiltration), social acceptance (ease of use, women's involvement), technical performance (material durability and cultivation compatibility), and economic conditions (farmer income, market and affordable prices). This is consistent with the idea that climate-resilient modern agricultural technologies must simultaneously integrate ecological, social, technical, and economic aspects [2,23].

Leverage analysis provides a very useful signal, namely that the most "sensitive" attributes (high RMSD) are indicators that directly affect soil function, such as increased organic matter, root microenvironment, and reduced chemical inputs, as well as economic indicators related to tangible benefits for farmers [4–6]. This means that if TongTang cannot improve farmers' economic yields, sustainability scores will quickly decline [8,9]. Conversely, if TongTang is proven to significantly increase income and improve soil structure, the effects will accumulate. The soil will become healthier, harvests will be more stable, income will increase, and then adoption and the market will grow. This pattern is consistent with the literature on circular and integrated farming, where environmental and economic values support each other [2,23].

Monte Carlo analysis reinforces confidence in these findings. The results show relatively stable results for the ecological and technological dimensions (centered median, relatively narrow 2.5–97.5% interval), while the social and institutional dimensions show greater variability. In practical terms, this means that TongTang's ecological and technical claims (e.g., drainage through burlap pores, material durability, ease of local manufacture) are quite robust to assessment uncertainty, but claims concerning community acceptance, the role of women, distribution networks, and policy are still vulnerable to change depending on the local context and institutional support [18,19]. These results are in line with observations about implementation challenges in climate-sensitive terraced fields, where technology can work but without strong social-institutional networks, scalability remains limited [4,7].

Combining all these results, TongTang is a potential socio-technological innovation with tangible and stable ecological value; conditional economic value; and social-institutional value that needs to be developed. In other words, TongTang in this analysis has a core advantage that is ecological-technical in nature (porosity of jute, soil improvement) which can be the basis of its selling value, but to convert that value into real sustainability, intervention is needed on two fronts simultaneously: (1) business and market mechanisms so that the economic benefits are felt directly by farmers (e.g., product bundle model), and (2) institutional networks and social inclusion (intensive training, active role of women, extension support, integration into government programs). This approach shows similarities with recommendations for integrated agricultural systems and the circular economy. Technology must be paired with supporting value and governance models [3,24].

From a policy and practice perspective, there are several concrete implications that arise: first, pilot programs need to measure and communicate the real economic benefits per season (income delta, reduction in input costs) due to high economic leverage; second, scaling up programs must include support packages (stable access to raw materials, mass production of quality products by industry partners, and affordable pricing models) so that economic attributes do not become a bottleneck; third, adoption programs must prioritize training focused on women and youth because the social RMSD for these variables is very large, meaning that success is highly dependent on this inclusion [25]. These recommendations are parallel to the idea of strengthening farmer capacity and GAP to increase technology adoption [26,27].

From a circular economy perspective, TongTang offers a realistic way to add value to jute waste. However, to realize this, policy efforts are needed: regulations that encourage the use of biodegradable materials, incentives for the jute processing industry, and product quality standardization to build market confidence [15,16]. From a macroeconomic perspective, the literature shows that increasing recycling and reuse rates can add economic value while reducing environmental pressure, and this is a path that should be included in the TongTang roadmap [27,28].

5. Conclusions

The sustainability analysis of TongTang innovation shows that this jute-based technology has great potential to become a conservative and environmentally friendly agricultural solution in terraced areas. The overall sustainability index score is in the moderately sustainable category, with the most notable strengths in the ecological and technological dimensions. This confirms TongTang's effectiveness in reducing erosion, maintaining soil moisture, and supporting good aeration through the permeable properties of jute. However, the economic, social, and institutional aspects still need to be strengthened, especially in terms of market access, community involvement, and policy and financial support for innovation. The leverage analysis results show that sustainability is most influenced by improvements in soil health, farmer income, and women's involvement in the production and utilization of TongTang. Monte Carlo analysis confirms that this innovation has high stability in the ecological-technological aspect, but uncertainty is still evident in the social and institutional dimensions due to variations in the context of implementation in the field.

Author Contributions

Conceptualization, S.D.W.P.; methodology, S.D.W.P. and E.P.L.; software, T.W.Y.; validation, S.D.W.P., E.P.L. and I.F.; formal analysis, I.F. and A.G.M.; investigation, T.W., D.R.A. and N.F.; resources, A.G.M.; data curation, T.W. and D.R.A.; writing original draft preparation, T.W. and D.R.A.; writing review and editing, S.D.W.P. and E.P.L.; visualization, T.W.Y.; supervision, S.D.W.P.; project administration, A.G.M.; funding acquisition, S.D.W.P. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Universitas Negeri Semarang.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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Conflicts of Interest

The authors declare no conflict of interest.

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