ACTIVITY-BASED COSTING OF CONVENTIONAL AND DIGITAL DIRECT-TO-MARKET CHILI SUPPLY CHAINS: A CASE STUDY FROM CENTRAL JAVA, INDONESIA

CUSTEIO BASEADO EM ATIVIDADES DAS CADEIAS DE SUPRIMENTO CONVENCIONAIS E DIGITAIS DIRETAS AO MERCADO DE PIMENTA: UM ESTUDO DE CASO DE JAVA CENTRAL, INDONÉSIA

ACTIVITY-BASED COSTING OF CONVENTIONAL AND DIGITAL DIRECT-TO-MARKET CHILI SUPPLY CHAINS: A CASE STUDY FROM CENTRAL JAVA, INDONESIA

CUSTEIO BASEADO EM ATIVIDADES DAS CADEIAS DE SUPRIMENTO CONVENCIONAIS E DIGITAIS DIRETAS AO MERCADO DE PIMENTA: UM ESTUDO DE CASO DE JAVA CENTRAL, INDONÉSIA

Nur Muttaqien Zuhri[1] | Nun Maulida Suci Ayomi[2]
Nanda Wanifa[3]

[1] PhD in Agribusiness Management (UNS).
Doctor at Muhammadiyah University of Semarang.
Semarang City, Indonesia.
Email: nurmuttaqien@unimus.ac.id

[2] M.Sc. in Agribusiness Management (UNDIP).
Lecturer at Muhammadiyah University of Semarang,
Semarang City, Indonesia.
Email: nurmaulida@unimus.ac.id

[3] Student of the Department of Agribusiness.
Student at Muhammadiyah University of Semarang.
Semarang City, Indonesia.
Email: nandawanifa@gmail.com

ABSTRACT

Price instability in Indonesia's chili market remains a persistent challenge due to inefficient logistics in conventional supply chains, characterized by multiple intermediaries and fragmented distribution. This study quantifies and compares the logistics cost efficiency between conventional distribution and a digital cooperative-based Direct-to-Market (DTM) model in Central Java, Indonesia. Employing Activity-Based Costing (ABC), the study calculates per-kilogram logistics costs across six core activities and uses the Mann–Whitney U test to assess statistical differences. Data were collected from 80 farmer groups through structured surveys, cost documentation, and field observations. Results reveal that the DTM model significantly lowers logistics costs, particularly transportation and storage, while enhancing coordination via digital platforms. Statistical analysis confirms the cost difference is significant ($p < 0.05$), with the DTM scheme yielding higher farmer margins. The integration of ABC with nonparametric testing provides a novel analytical framework for mapping cost inefficiencies at the activity level, which is rarely applied in horticultural logistics research. These findings offer actionable insights for policymakers and agri-logistics actors to support digital transformation, improve farmer welfare, and enhance supply chain efficiency. The approach is adaptable to other perishable commodities, contributing to more inclusive, transparent, and resilient food distribution systems.

RESUMO

A instabilidade de preços no mercado de pimentas na Indonésia continua sendo um desafio persistente devido à logística ineficiente nas cadeias de suprimento convencionais, caracterizadas por múltiplos intermediários e distribuição fragmentada. Este estudo quantifica e compara a eficiência dos custos logísticos entre a distribuição convencional e um modelo Direto-ao-Mercado (DTM) baseado em cooperativa digital na Java Central, Indonésia. Utilizando o método de Custeio Baseado em Atividades (ABC), o estudo calcula os custos logísticos por quilograma em seis atividades principais e aplica o teste U de Mann–Whitney para avaliar diferenças estatísticas. Os dados foram coletados de 80 grupos de agricultores por meio de questionários estruturados, documentação de custos e observações de campo. Os resultados revelam que o modelo DTM reduz significativamente os custos logísticos, especialmente em transporte e armazenamento, além de melhorar a coordenação por meio de plataformas digitais. A análise estatística confirma que a diferença de custos é significativa (p < 0,05), com o modelo DTM proporcionando margens mais elevadas para os agricultores. A integração do ABC com testes não paramétricos oferece uma estrutura analítica inovadora para mapear ineficiências de custos em nível de atividade, raramente aplicada em pesquisas de logística hortícola. Esses resultados fornecem insights práticos para formuladores de políticas e atores da agro-logística, visando apoiar a transformação digital, melhorar o bem-estar dos agricultores e aumentar a eficiência das cadeias de suprimento. A abordagem é adaptável a outras commodities perecíveis, contribuindo para sistemas de distribuição de alimentos mais inclusivos, transparentes e resilientes.

INTRODUCTION

The horticultural sector stsrategically supports national food security, particularly in emerging economies where perishable commodities such as chili peppers contribute substantially to household consumption and market volatility (Lestari *et al.*, 2024; Mei *et al.*, 2024; Purnama; Pradono; Yudoko, 2025; Tziolas *et al.*, 2022)including in the organic farming sector. Over a long term period, this problem can disrupt the productivity of agricultural crops. This research aims to analyze the production and marketing efficiency of organic cabbage farming in the Kopeng agropolitan area, Indonesia. We utilized a Cobb–Douglas production efficiency analysis with the Stochastic Frontier Analysis (SFA. Chili is among Indonesia's most widely consumed and culturally embedded vegetables, yet it remains highly vulnerable to price instability (Al-Aziz; Suryani, 2024; Andani; Nusril; Wardoyo, 2024). According to the SCentral Statistics Agency (2024), national chili production reached 1.56 millison tons in 2024, with Central and East Java contributing over 36% of the supply. Despite this volume, chili is a tsop

contributor to food inflation, particularly during religious holidays, suggesting that inefficiencies in the distribution system, rather than production constraints, are the primary drivers of volatility (Poudyal *et al*., 2023; Reardon *et al*., 2024)e.g., with rice combine harvesting services in China and Myanmar for domestic and export markets; (2.

The inefficiencies stem from conventional supply chains characterized by long, fragmented, and intermediary-dense structures (Clavijo-Buritica; Triana-Sanchez; Escobar, 2023; Singh; Agrawal; Kumar, 2025; Zuhri; Nurcahyono; Puspita, 2025). In most regions of Indonesia, chili distribution involves four to six layers between farmers and end consumers, including local collectors, regional traders, wholesalers, and market intermediaries (Kusmiati *et al*., 2024; Susanawati; Noviyanti, 2024). Each actor introduces additional handling, repackaging, transportation, and storage costs, often without adding commensurate value (Wang *et al*., 2025; Zhang *et al*., 2025)the drastic fluctuations in agricultural commodity prices significantly impact producers' motivation and consumers' quality of life, further exacerbating market uncertainty and unsustainability. The ability to scientifically and effectively predict agricultural commodity prices is of great significance for the rational deployment of market mechanisms, the timely adjustment of supply chains, and the promotion of food policy adjustments. This paper proposes a sustainable hybrid model SV-PSO-BiLSTM which integrates Seasonal-Trend decomposition procedure based on Loess (STL. This structure not only inflates consumer prices but also erodes farmer income and increases post-harvest losses, which the FAO (2024) estimates at 20–30% nationally for chili commodities. Moreover, the lack of real-time market access and digital infrastructure limits farmers' bargaining power and amplifies information asymmetry in price formation (De; Singh, 2022; Deng *et al*., 2024; Marcel *et al*., 2025)virtual retailing trends, and smart logistics and warehousing services. The post-COVID worldwide growing demand for regional agri-products has increased the competitiveness in logistics outsourcing. Motivated by these changing notions, this paper addresses two major questions—whether the competitiveness in logistics outsourcing allows the supply chain drivers (supplier, retailer, and 3PL.

Digital cooperative-based Direct-to-Market (DTM) models have emerged in several horticultural centers to address these systemic issues (Chauhan; Nunes, 2025; Kamau Mathuva; Ndiritu, 2025; Shirwa *et al*., 2025; Yang *et al*., 2023). These models leverage digital platforms to enable farmers to

aggregate, coordinate, and deliver produce directly to end markets, ranging from modern retailers to institutional buyers and online consumers. By bypassing intermediaries, the DTM model is designed to reduce logistics costs, enhance coordination, and increase value capture at the producer level (De; Singh, 2022; Hansika; Wijerathna, 2021)virtual retailing trends, and smart logistics and warehousing services. The post-COVID worldwide growing demand for regional agri-products has increased the competitiveness in logistics outsourcing. Motivated by these changing notions, this paper addresses two major questions—whether the competitiveness in logistics outsourcing allows the supply chain drivers (supplier, retailer, and 3PL. The National Food Agency (2025) has identified the promotion of digital cooperatives as a strategic pathway to stabilize prices and enhance supply chain resilience.

Numerous studies have emphasized the need to redesign perishable agri-supply chains through digitization, cooperative integration, and logistics restructuring in global contexts such as India, China, and Latin America. For instance, (Chauhan; Nunes, 2025) highlighted that India's fresh produce supply chains suffer from uncoordinated transport and a lack of cold-chain investment, leading to over 30% post-harvest losses. In China, (Liu; Zhang, 2023) documented that the digital economy significantly enhances horticultural cooperatisves' cost efficiency and market integration, yet also noted that logistics transparency remains underdeveloped. Clavijo-Buritica; Triana-Sanchez; Escobar, 2023), Focusing on Colombia's coffee network, hybrid models for resilient agri-logistics were proposed but did not quantify activity-level cost differentials. Despite growing international interest, few studies apply a micro-activity costing lens to horticultural logistics in developing countries. This study contributes to this gap by integrating Activity-Based Costing (ABC) with statistical validation to identify logistical inefficiencies and model the economic impact of cooperative-led digital distribution systems in Indonesia, a significant yet underrepresented case in the global logistics efficiency literature.

Despite the increasing policy interest and conceptual promise of DTM schemes, empirical evidence evaluating their cost efficiency, particularly through a structured logistics costing framework, remains scarce. Most existing studies on horticultural distribution in Indonesia focus on output prices, marketing margins, or supply chain behavior (Ma *et al*., 2024; Reardon *et al*., 2024; Susanawati; Noviyanti, 2024)it is crucial to conduct a scientific investigation of the relationship between fiscal policy, fiscal decentralization, green digital management, and contract selection. This research develops an

analytical framework for the application of fiscal policy and the choice of cooperative association contracts based on the contract theory. On the basis of a theoretical analysis of the external factors that influence the choice of residents' cooperative association contract and behavior, it goes on to investigate the interest game relationship and stability of three different cooperative associations (production type, service type, and industrial chain type, rather than quantifying logistics activities or identifying inefficiency drivers at the operational level. The Activity-Based Costing (ABC) method offers a granular, activity-specific approach to measure logistics costs and capture the performance gaps between conventional and digitally coordinated distribution systems. However, the method remains underutilized in agri-food logistics studies across Southeast Asia.

This study seeks to fill that gap by calculating and comparing the logistics cost per kilogram of chili between conventional and DTM distribution systems using the ABC approach, and statistically validating cost differences using the Mann–Whitney U test. The research aims to generate empirical evidence on logistics cost structure, efficiency levers, and farmer-level economic impacts. By revealing activity-level cost drivers, the study provides actionable insights for cooperatives, policymakers, and digital platform developers to optimize agri-food logistics and promote more inclusive, efficient, and resilient food distribution systems.

This study also contributes to the fields of management and regional development by demonstrating how digital cooperative-based Direct-to-Market (DTM) systems restructure logistics governance and improve operational efficiency in rural supply chains. From a management perspective, integrating Activity-Based Costing (ABC) with digitally coordinated distribution provides an evidence-based framework for cost control, decision-making, and performance improvement at both the farmer and cooperative levels. From a regional development perspective, the DTM model enhances local economic competitiveness by reducing transaction costs, increasing the farmer's income share, strengthening rural institutions, and supporting digital transformation in agri-food distribution. These linkages underline the relevance of this research to broader regional development strategies aimed at improving welfare and market stability in horticultural-producing areas.

RESEARCH METHODS

A: Research Design:

This study adopts a quantitative comparative design to assess logistics cost efficiency between two chili distribution models: the conventional supply chain and the digital cooperative-based Direct-to-Market (DTM) model. The comparative design enables objective measurement and statistical testing of cost differentials across distinct distribution mechanisms. This approach is particularly suitable given the measurable nature of logistics cost activities and the aim to generate generalizable, evidence-based insights.
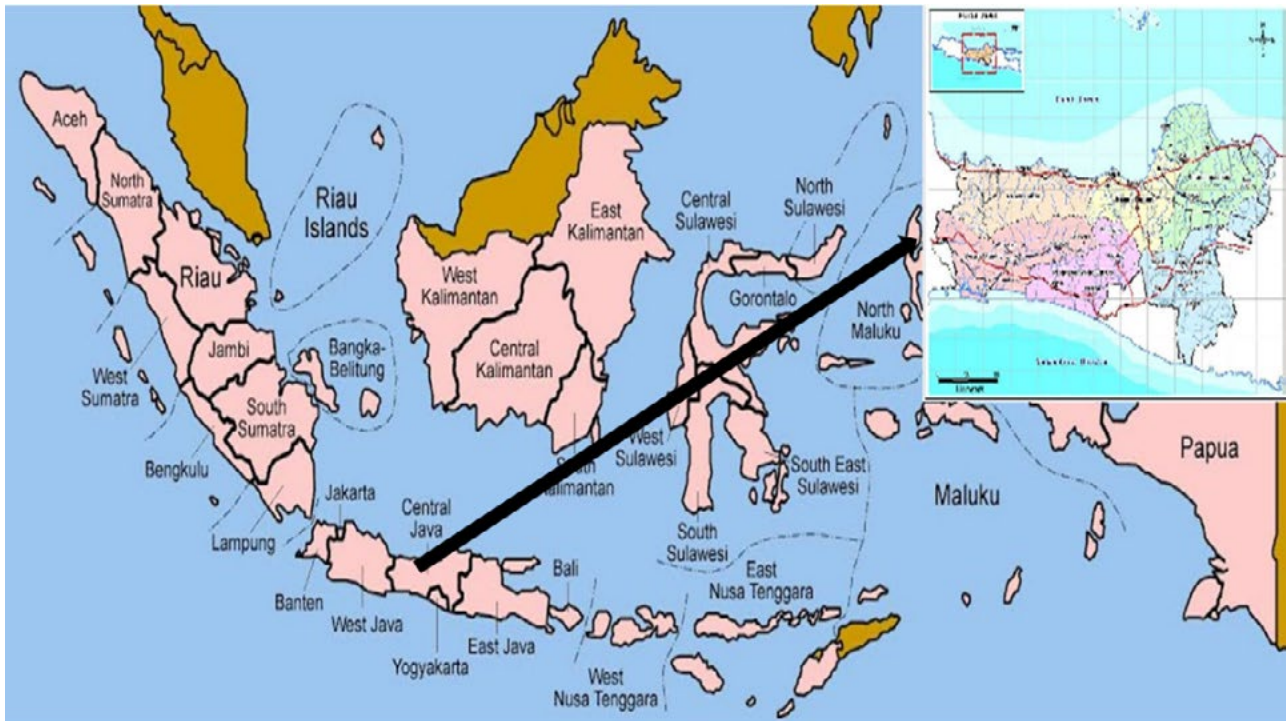
B: Study Area and Sampling:

The research was conducted in two major horticultural production centers in Central Java Province: Brebes Regency and Temanggung Regency, which are known for their significant chili production and active farmer cooperative involvement. The February to April 2025 study period aligns with the post-harvest season to ensure data representativeness during peak distribution activities.

The target population includes actors involved in chili distribution: farmers, cooperative leaders, local collectors, and logistics providers. Purposive sampling was applied with inclusion criteria requiring respondents to have been actively involved in conventional or DTM distribution for at least six months before the study.

A total of 80 respondents were selected: 48 from conventional supply chains and 32 from DTM systems. The sample size meets the minimum requirement for conducting nonparametric statistical tests, as Hair *et al*. (2010) recommended, and ensures sufficient group representation.

Figure 1 | Map of selected research locations for the chilli supply chain in Central Java Province from the Central Statistics Agency (Indonesia), conditions reflected in 2024

Source: Indonesian Central Statistics Agency (BPS, 2024)

C: Data Collection Techniques:

Primary data were collected using Structured surveys focused on logistics activities and cost records, Direct observations of supply chain activities in real-time, and In-depth interviews with cooperative leaders and logistics actors. To strengthen validity, the study employed data triangulation by cross-verifying with transaction records, digital cooperative logs, and farmer bookkeeping documentation.

Enumerators were trained to track activity and ensure standardized data entry using logistics activity sheets, capturing labor hours, transport frequency, volumes, and direct costs. Secondary data were obtained from government agencies (e.g., agriculture and trade departments) to provide contextual inputs on production, prices, and regional supply chain characteristics.

D: Cost Analysis Using Activity-Based Costing (ABC):

The core analytical method used is Activity-Based Costing (ABC), which enables detailed allocation of logistics costs to specific supply chain activities. ABC is preferred over traditional costing methods due to its ability to capture indirect costs in complex, multi-stage logistics systems (Knebel *et al.*, 2023; Yang *et al.*, 2023).

The ABC analysis followed these steps:

- Identify core logistics activities, including: harvesting, sorting and grading, packaging, temporary storage, transportation, and digital coordination (exclusive to DTM).

- Determine cost drivers for each activity (kg handled, working time, labor count, number of trips).

- Calculate unit cost per activity using:

$$Cost\ per\ unit = \frac{Total\ activity\ cost}{Total\ output\ (e.g., kg)}$$

(1)

- Aggregate activity costs to obtain total logistics per kilogram of chili for each distribution model.

ABC results were validated using bookkeeping records and cross-checked with transaction data from cooperatives and buyers.

E: Statistical Analysis and Assumption Testing:

To statistically assess cost differences, the Mann–Whitney U test was applied. This nonparametric test is suitable for comparing two independent groups with non-normally distributed data. Before hypothesis testing, the Kolmogorov–Smirnov test evaluated the normality assumption, confirming it using a nonparametric approach.

The Mann–Whitney analysis involved:

- Ranking all cost values across both groups

- Computing U statistics and converting to Z-score for significance testing at $\alpha < 0.05$

- Effect size calculation using to assess the magnitude of differences

$$r = \frac{z}{\sqrt{N}}$$

$r =$ (2)

Statistical analysis was conducted using IBM SPSS and validated manually using MS Excel for transparency and replication.
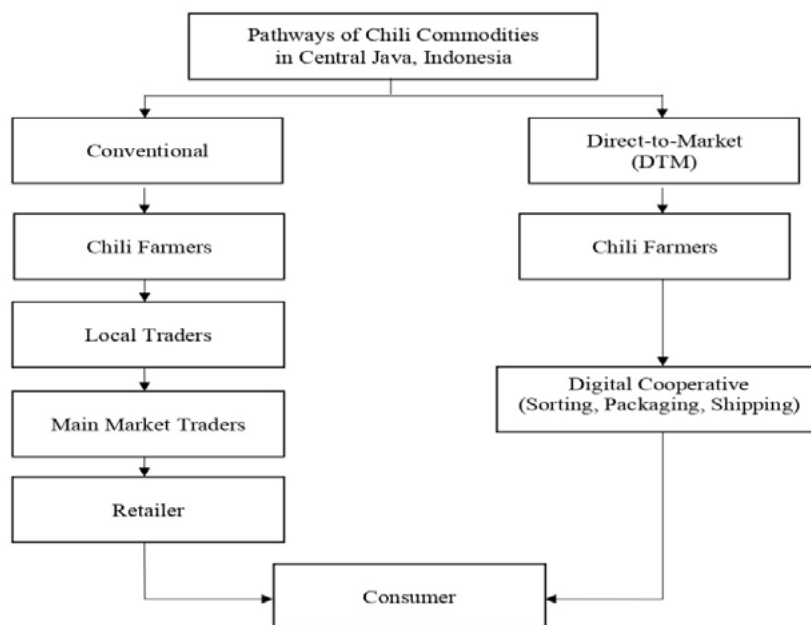
F: Ethical Considerations:

All respondents participated voluntarily after being informed of the study's purpose and confidentiality assurances. The institutional research ethics board approved the study.

RESULTS AND DISCUSSION

A: Chili commodity distribution channel in Central Java, Indonesia:

Figure 2 shows the conventional distribution flow of chili in Central Java, which involves several layers of intermediaries ranging from farmers, local intermediaries, leading market traders, to consumers. Such a supply chain structure reflects a long and inefficient distribution system. Each intermediary has its own logistics activities, such as collection, repacking, and transportation, contributing to the accumulation of logistics costs. The complexity of this distribution channel causes the travel time of products from the garden to the market to be longer. It increases the risk of deteriorating chili quality, including potential food loss at each movement point.

Figure 2 | Distribution lines of conventional and DTM chili commodities in Central Java Province, Indonesia (2025).

Source: Research Data (2025)

In the conventional scheme, the distribution flow of chili from farmers to consumers involves 4 to 6 intermediaries. A characteristic of this distribution is the high frequency of transport and unloading, as each intermediary performs sorting and repacking. Multiple storage occurs when the product waits for a load or prices rise. With minimal digitization, price and demand information is usually manual, not real-time. Logistics costs are formed from many inefficient activities: gradual transportation, intermediaries' costs, and post-harvest losses.

The results of field observations show that the high transportation and temporary storage costs directly impact this multi-tiered distribution structure. In addition, the lack of access for farmers to price information and market demand strengthens the dominant position of intermediaries in determining purchase prices at the producer level. This picture confirms that conventional distribution is still the leading cause of inefficiencies in chili logistics in Central Java, which impacts price instability and farmers' weak competitiveness in the horticultural value chain.

Figure 2 illustrates the distribution channel of chili through a digital cooperative-based Direct-to-Market (DTM) scheme in Central Java. This scheme shortens the distribution chain by involving only farmers, digital cooperatives as aggregators, and end markets (modern retail, parent markets, or online consumers). This system consolidates logistics functions at the cooperative level, from collection, sorting, and packaging to direct delivery to the end buyer. The visualization in Figure 2 shows the absence of layered intermediaries as in conventional distribution, so that the flow of goods becomes more compact, the delivery time is faster, and the risk of product damage can be significantly reduced.

Based on the results of field observationss and logistics cost analysis, the DTM approach provides real operational efficiencies. Digital cooperatives use applications to synchronize demand and supply in real-time, making the distribution process more coordinated. This figure supports the finding that DTM distribution can cut transportation and storage costs and increase price transparency at the farmer level (Zuhri; Nurcahyono; Puspita, 2025). This leaner logistics structure directly strengthens farmers' bargaining positions in the horticultural supply chain and supports price stability at the consumer level.

B: Chili Logistics Costs per Activity:

The results of this study identify six main activities in the chili distribution system, both conventional and direct-to-market (DTM), in Table 1: harvesting, sorting, packaging, transportation, temporary storage, and distribution coordination. The Activity-Based Costing approach obtained an estimated logistics cost per kilogram of chili pepper for each activity.
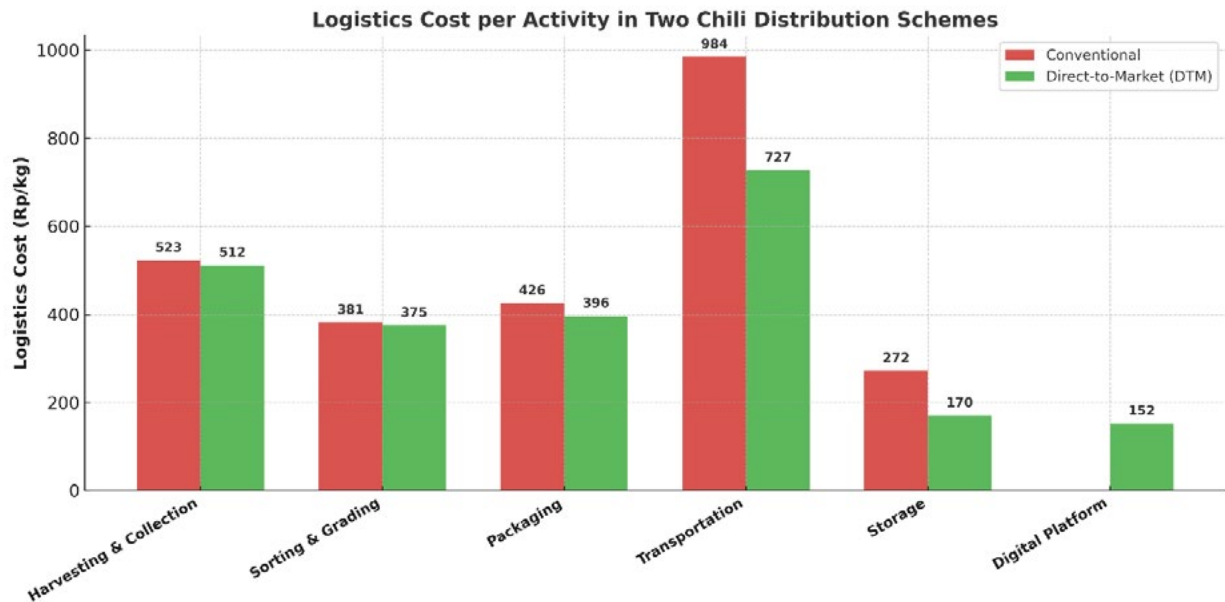
Table 1 | Logistics Costs per activity in conventional and DTM distribution models in Central Java Province, Indonesia (February to April 2025)

No	Logistics Activity	Conventional (IDR/kg)	Contribution (%)	DTM (IDR/kg)	Contribution (%)
1	Harvesting and Gathering	522.53	20.23%	511.51	22.17%
2	Sorting and Grading	381.34	14.79%	375.22	16.09%
3	Packaging	425.82	16.34%	396.49	16.96%
4	Transportation	984.24	38.13%	727.43	31.30%
5	Temporary Storage	271.83	10.50%	169.88	6.96%
6	Digital Coordination	–	–	152.11	6.52%
	Total Logistics Cost	2,585.76	100%	2,420.42	100%

Source: Research Data (2025)

The results in Table 1 show a difference in the cost structure of chili logistics between conventional distribution schemes and direct-to-market (DTM) schemes based on digital cooperatives. In conventional distribution, the most significant proportion of costs comes from transportation and storage activities, which indicates low logistics efficiency due to the many layers of intermediaries and waiting times between distribution stages. In contrast, DTM schemes feature a more even distribution of cost burdens, with significant contributions coming from the digital coordination activities of components not found in conventional schemes. This shows that the digitization of logistics management replaces some of the traditional functions of intermediaries with a more responsive and coordinated information system. This change in structure reflects a shift from a fragmented physical logistics system to an information-based and consolidated logistics model.

Figure 3 | Composition of chili commodity logistics costs in Central Java Province, Indonesia (February to April 2025)

Logistics Cost per Activity in Two Chili Distribution Schemes

These findings support the study of Wang *et al*. (2025)domestic substitution is increasingly crucial to mitigate reliance on foreign suppliers. However, the quality of domestic components is unstable, and the R&D costs are substantial. Recognizing this quandary, the government has intervened through technology subsidies(TS and Dadzoe *et al*. (2024)green building construction is still at its nascent stage in Ghana. Most studies in sub-Saharan Africa point to the lack of knowledge as one of the mitigating factors against its development. However, there is a dearth of studies assessing the level of knowledge of stakeholders. The terms "knowledge" and "awareness" of green building construction are often used interchangeably in the Ghanaian Construction Industry (GCI, which emphasized that digital integration in the horticultural supply chain can reduce distribution costs by up to 15% through a reduction in transit time and food loss. In addition, these results align with the research of Reardon *et al*. (2024)e.g., with rice combine harvesting services in China and Myanmar for domestic and export markets; (2, which shows that the cost structure of horticultural logistics is greatly influenced by the length of the distribution chain and the fragmentation of post-harvest management. However, this study adds a new dimension by using the Activity Based Costing (ABC)

approach, which reveals the details of activities granularly, which has not been widely discussed in the previous literature. This study's methodological advantage is that it can map cost efficiency based on the type of activity, not just on total costs or marketing margins.

In terms of scientific contribution, this study enriches the understanding of the efficiency of the distribution of horticultural products by combining a quantitative approach of cost per activity and a cross-scheme comparative statistical test. This differs from the previous approach, which focused more on output prices and margins between actors. Thus, the results in Table 1 provide concrete evidence that digital cooperative-based distribution cuts total costs and restructures the cost burden towards more value-added and managerially controlled activities.

Table 2 | Proportion of logistics costs to selling price of chili in Central Java Province, Indonesia (February to April 2025)

Distribution Scheme	Average Selling Price (IDR/kg)	Logistics Cost (IDR/kg)	Proportion of Logistics Costs (%)
Conventional	6,251.84	2,575.65	41.45
Direct-to-Market	5,872.51	2,306.81	39.66

Source: Research Data (2025)

The results in Table 2 related to the Proportion of Logistics Costs to Chili Selling Prices show that logistics costs account for almost half of the selling price of chili in both conventional and direct-to-market (DTM) distribution schemes. Although there is a slight decrease in proportion in DTM schemes, the difference indicates significant economic efficiency, especially in the context of horticultural distribution, which tends to be prone to cost fluctuations. This suggests that the reduction of the distribution chain impacts the total logistics costs and can also increase the portion of net income received by farmers. In the DTM system, profit margins can be more evenly distributed due to a controlled and more transparent distribution of logistics costs.

These findings support the research results by Al-Aziz & Suryani (2024), which stated that the price structure of horticultural commodities in Indonesia is greatly influenced by the length of the supply chain and the logistics burden that accumulates at the middle point of distribution. This research is also consistent with a study by Yang *et al*. (2023), which emphasizes the importance of logistics efficiency in controlling national food prices. However, the study expands its contribution by demonstrating the direct relationship between logistics costs and selling prices through a proportion-

based quantitative approach. This distinguishes this study from previous studies, highlighting more price or margin policy aspects between actors.

The advantage of this finding lies in the presentation of proportional data that provides a concrete picture to policymakers regarding the magnitude of the contribution of logistics to final price fluctuations in the market. Thus, the results in Table 2 are descriptive and strategic for designing policies to strengthen digital cooperatives and activity-based logistics subsidies. An emphasis on transparency and control of distribution costs through the DTM scheme could be an alternative model for improving the national food distribution system, especially for commodities susceptible to price changes like chili.

Table 3 | Comparison of farmer margin and intermediary share in Central Java Province, Indonesia (February to April 2025)

Distribution Model	Price Received by Farmers (IDR/kg)	Consumer Price (IDR/kg)	Farmer Margin (%)	Intermediary Share (%)
Conventional	3,661.52	6,251.84	58.06%	41.94%
DTM	4,837.41	5,872.51	68.97%	31.03%

Source: Research Data (2025)

Interpretation of Table 3, Farmer Margin Comparison, shows that the direct-to-market (DTM) distribution scheme can increase the portion of income received by farmers compared to conventional schemes. In a conventional scheme, most of the selling value of the product is absorbed by intermediaries who perform distribution functions, such as collectors and wholesalers. In contrast, DTMs that rely on digital cooperatives allow farmers to sell directly to the final market, resulting in higher margins that farmers enjoy. This margin increase is an important indicator that logistics efficiency impacts costs and improves the value-sharing structure in the supply chain.

These findings support the research results by Cao; Guo; Li (2025) and De; Singh (2022)virtual retailing trends, and smart logistics and warehousing services. The post-COVID worldwide growing demand for regional agri-products has increased the competitiveness in logistics outsourcing. Motivated by these changing notions, this paper addresses two major questions—whether the competitiveness in logistics outsourcing allows the supply chain drivers (supplier, retailer, and 3PL,

who stated that direct marketing schemes such as contract farming or e-csommerce tend to increase farmers' bargaining positions in the horticultural market. In addition, the study by Clavijo-Buritica; Triana-Sanchez; Escobar (2023) and Singh; Agrawal; Kumar (2025) also underlined that cooperatives' price transparency and ownership of distribution systems can increase farmers' income share by up to 25 percent. However, this study provides methodological added value by quantifying farmers' margins comparatively between two distribution schemes in chili logistics. This has not been discussed much in the previous literature, which generally onsly captures the difference in margins between market actors without considering the burden of logistics costs borne by farmers.

Thus, the contribution of this research proves that the DTM scheme can reduce costs and strengthen farmers› bargaining power through larger margins. Direct connectivity with end consumers, facilitated by digital cooperatives, makes this model worthy of replication as a national policy strategy to improve farmers› welfare while reducing price disparities. These findings provide an empirical basis for a value fairness-based logistics approach in sustainable food systems.

Table 4 | Identify critical points of inefficiency in Central Java Province, Indonesia (February to April 2025)

Activity	Conventional Cost (IDR/kg)	DTM Cost (IDR/kg)	Difference (IDR/kg)	Information
Transportation	984.24	727.43	256.81	Key efficiency points
Storage	271.83	169.88	101.95	Significant reduction
Digital Coordination	-	152.11	-	DTM system investment

Source: Research Data (2025)

The results in Table 4, Identification of Inefficiency Critical Points, show that transportation activities are the dominant point of inefficiency in the conventional distribution scheme of chili. The high cost of transportation is closely related to the length of distribution lines and the involvement of many intermediaries, which leads to duplication of shipping routes and a lack of logistical coordination. In addition, the high storage costs in conventional schemes reflect the long waiting time between supply chains and the low post-harvest handling capacity at the farmer level. In contrast, in the direct-to-market (DTM) scheme, the two activities experience significant efficiency because they are centered in one digital cooperative entity that functions as a logistics aggregator.

These findings support a study by Yassi; Demmallino; Sultani (2023) and Wang *et al*. (2025) domestic substitution is increasingly crucial to mitigate reliance on foreign suppliers. However, the quality of domestic components is unstable, and the R&D costs are substantial. Recognizing this quandary, the government has intervened through technology subsidies(TS, which found that reducing distribution nodes could cut more than 30% of horticultural transportation costs. In addition, research by Chauhan; Nunes (2025) shows that points of logistics inefficiency in the distribution of fresh food generally occur in uncoordinated storage and non-standard packaging. The novelty of these findings lies in the ability to identify which logistics activities contribute the most to specific cost waste, which has not been widely discussed in studies of horticultural supply chains in Indonesia. This information is important not only for policy-making at the cooperative and local government levels, but also for the design of a more adaptive and cost-effective digital-based logistics system. By presenting data at the activity level, this study fills in the gaps in the literature. It strengthens the argument that the DTM approach can systematically overcome the weak points of conventional logistics that have been the cause of price fluctuations and low farmers' incomes.

C: Comparison of logistics costs: conventional and direct-to-market:

The study results were used to determine the significance of the difference in logistics costs between the two distribution schemes. A nonparametric statistical test was conducted using the Mann–Whitney U test because the data are not generally distributed in Table 5.

Table 5 | Results of the Mann–Whitney U Test on chili logistics costs in Central Java Province, Indonesia (February to April 2025)

Variable	Conventional Distribution	DTM Distribution	Information
Number of Samples (n)	48	32	Farmers/cooperative farmer groups
Average Cost (Mean)	IDR 2,585.76	IDR 2,420.42	Per kg of chili peppers
Standard Deviation (SD)	IDR 195.2	IDR 170.77	Spread of costs among respondents
Minimum Score	IDR 2,242.18	IDR 2,050.31	Lowest cost data
Maximum Value	IDR 2,855.24	IDR 2,533.85	Highest cost data
Average Difference	IDR 165.34		Potential cost efficiency
Statistical Test (U value)	281.0		Mann–Whitney U test results
Sig. (2-tailed)	0.017**		Significant at α = 0.05
Interpretation	There is a significant difference in logistics costs between conventional and DTM schemes.		Statistically supported

Note: ** Signifikan <0.05

Source: Research Data (2025)

Interpretation of Table 5. A comparison of Chili Logistics Costs between Conventional and Direct-to-Market (DTM) Schemes shows a statistically significant difference in logistics costs between the two distribution schemes. The results of the Mann–Whitney U test reinforce this conclusion, with a significance value that is below the threshold of 0.05, which means that the null hypothesis (no difference) can be rejected. This shows that the logistics cost per kilogram of chili peppers in the DTM scheme is consistently lower than the conventional scheme. This difference is economical and can be considered substantial in supporting digital-based logistics efficiency.

These findings align with the study of Shirwa *et al*. (2025) and Liu; Zhang (2023), which found that digitizing horticultural supply chains can reduce logistics costs by up to 20% by trimming the distribution layer. This research also supports the findings of Chauhan; Nunes (2025), who emphasize that cooperative-based marketing schemes can significantly reduce logistics costs by consolidating direct supply to the parent market or modern retail. However, the advantage of this study lies in the quantitative approach used to directly and objectively compare the two systems through activity-based costing and nonparametric statistical tests.

The results of this study underscore a fundamental structural distinction between conventional and Direct-to-Market (DTM) distribution systems in the Indonesian chili supply chain. The conventional model comprises multiple intermediary layers, each contributing to redundant

transportation, repetitive handling, and prolonged storage. These inefficiencies not only escalate logistics costs but also increase the likelihood of product deterioration during transit. In contrast, the DTM model facilitated by digital cooperatives streamlines the distribution path by consolidating logistics functions at the cooperative level. This results in a shorter, more synchronized, and information-enabled supply chain. The structural transformation brought by DTM models translates directly into operational efficiencies, particularly in transportation and storage, the two most cost-intensive activities in the conventional scheme.

These findings resonate with global evidence. Research by Chauhan; Nunes (2025) observed similar challenges in India, where fragmented logistics networks in the agri-food sector contributed to significant inefficiencies. Clavijo-Buritica; Triana-Sanchez; Escobar (2023) reported that coordination failures in Latin America's coffee supply chains imposed excessive transaction costs. The Indonesian case contributes new empirical insights to this global discourse by quantifying the impact of logistics resstructuring at the activity level, specifically through digital cooperative intervention.

Using the Activity-Based Costing (ABC) method, this study reveals a transparent reallocation of cost components in the DTM scheme. The reduced reliance on transportation and temporary storage is accompanied by the emergence of digital coordination as a significant but productive cost component. This cost reallocation signals a shift from physical to informational efficiency, where technology replaces intermediaries, and coordination is achieved through data-driven mechanisms rather than redundant processes. Such transformation has been largely overlooked in traditional agri-supply chain literature, which often focuses on aggregate costs or producer-retailer margins. This study, therefore, advances the field by showing how digitalization not only lowers total cost but also reshapes the internal structure of logistics expenditure toward higher-value and managerial activities.

The significance of this transformation is validated statistically. Results from the Mann–Whitney U test confirm that the logistics cost difference between DTM and conventional schemes is not only meaningful in practical terms but statistically significant (p = 0.017). Additionally, the analysis of farmer-level outcomes reveals that DTM farmers capture a larger share of the consumer price (68.97% vs. 58.06%), demonstrating the dual benefit of increased cost efficiency and improved value distribution. These findings construct a logical and empirical chain linking logistics structure → cost

per activity → farmer income share, and thus reinforce theories of transaction cost economics (Yin *et al.*, 2025)but the related research ignores the influence of digital innovation of construction projects on the cooperative behavior of all participants. Therefore, this study discusses the comprehensive influence of digital innovation on cooperative behavior in construction projects and provides references for formulating reasonable digital innovation strategies. Design/methodology/approach: This study constructs a theoretical model according to the logical thread of "digital innovation → capital → cooperative behavior," and discusses how construction project participants can improve their cooperative performance through digital innovation. And bring the institutional environment into the research framework as a regulating variable. Subsequently, this study uses the survey data of 276 construction employees from China to verify and analyze the theoretical model by structural equation model (SEM and supply chain disintermediation (Reardon *et al.*, 2024)e.g., with rice combine harvesting services in China and Myanmar for domestic and export markets; (2.

This study also offers several key theoretical contributions to the agri-logistics literature, particularly within the context of developing economies. First, it introduces the ABC approach to a horticultural logistics setting, where micro-level cost tracking has been largely absent. The ability of ABC to reveal granular inefficiencies adds precision to the measurement of logistics performance. Second, the study moves beyond focusing on cost reduction by demonstrating how digitalization actively restructures logistics costs, substituting fragmented manual processes with centralized digital coordination. Third, integrating microeconomic cost mapping with nonparametric statistical validation offers a replicable empirical framework for analyzing distribution reforms. Collectively, these contributions position the study at the intersection of logistics efficiency measurement and broader theoretical discourses on supply chain governance, transaction efficiency, and digital coordination in rural markets.

From a policy perspective, the findings provide robust evidence to support the scaling of DTM models through strategic interventions. Investments in digital infrastructure, cooperative strengthening, and integrated logistics management systems will likely yield significant cost savings and improve price stability for perishable commodities. The ABC-based cost structure presented in this study can also serve as a diagnostic tool for policymakers and agri-cooperatives to identify

specific inefficiency points within their value chains. These insights align with Indonesia's national priorities on agri-digitalization and global efforts toward resilient, inclusive food systems (FAO, 2024; Reardon *et al*., 2024). Furthermore, the study reinforces the importance of shifting policy orientation away from subsidy-heavy, infrastructure-dominated approaches toward more innovative, digital coordination strategies.

Nevertheless, several limitations should be acknowledged. First, the geographical scope of the study is limited to two regencies in Central Java. While both are key horticultural centers, the findings may not fully represent the diversity of chili supply chains across Indonesia's broader agroecological landscape. Second, the study's timeframe was confined to the peak post-harvest season, excluding potential seasonal variations in logistics performance and cost structures. Third, the analysis is focused exclusively on economic costs, omitting environmental dimensions such as greenhouse gas emissions, packaging waste, and spoilage rates, factors increasingly relevant to sustainable food system discussions.

To address these gaps, future research should consider expanding the scope to include multi-season, cross-regional data and incorporate environmental assessments using frameworks such as Life Cycle Costing (LCC) or Life Cycle Assessment (LCA). Longitudinal studies could also capture dynamic impacts of DTM adoption over time, including shifts in farmer profitability, consumer access, and technology diffusion within rural supply chains.

CONCLUSIONS

This study demonstrates that the Direct-to-Market (DTM) distribution model offers significant logistical and economic advantages over conventional chili distribution systems in Indonesia when implemented through digital cooperatives. By applying the Activity-Based Costing (ABC) approach, the research identifies that conventional models' transportation and temporary storage are the most cost-intensive activities. In contrast, DTM schemes reallocate logistics functions toward digital coordination, resulting in a more efficient and synchronized cost structure. The Mann–Whitney U test confirms that the logistics cost differential between the two systems is statistically significant, while farmer-level analysis shows improved income share under the DTM model.

These findings provide empirical evidence that logistics digitization reduces total distribution cost and restructures cost components to enhance value capture for farmers. This contributes theoretically by linking micro-level cost efficiency with broader supply chain governance and transaction cost economics, particularly in underexplored contexts like perishable horticultural logistics in developing countries.

This study also contributes to the literature on management and regional development by demonstrating how digital cooperative governance can transform traditional supply chain structures into more coordinated, transparent, and cost-efficient systems. The DTM model showcases a management innovation that reduces transaction costs, enhances operational integration, and improves value distribution throughout the supply chain. In the context of regional development, digitalisation of logistics can enhance rural economic structures, promote equitable value sharing, and support more stable and resilient regional food distribution systems. These contributions provide evidence that strengthening cooperative-based digital logistics can serve as a strategic policy instrument for advancing sustainable regional economic development.

ACKNOWLEDGMENT

CONFLICT OF INTEREST

There are no conflicts to declare.

REFERENCES

AL-AZIZ, F. N.; SURYANI, E. System dynamics modeling to increase the productivity of chili pepper through good agricultural practices in east java. **Procedia Computer Science**, v.234, p.733–740, 2024. https://doi.org/10.1016/j. procs.2024.03.094. Accessed on: Jan. 20, 2025.

ANDANI, A.; NUSRIL,; WARDOYO, H. Investigating the market's behavior of curly red chili in bengkulu indonesia using price formation and transmission elasticity model. **International Journal on Advanced Science, Engineering and Information Technology,** v. 14, n. 2, p. 683–690, 2024. https://doi.org/10.18517/ijaseit.14.2.7187. Accessed on: Des. 2, 2024.

CAO, A.; GUO, L.; LI, H. Understanding farmer cooperatives' intention to adopt digital technology: mediating effect of perceived ease of use and moderating effects of internet usage and training. **International Journal of Agricultural Sustainability.** v. 23, n. 1, p. 1–21, 2025. https://doi.org/10.1080/14735903.2025.2464523. Accessed on: Jan. 18, 2025.

CHAUHAN, A.; NUNES, W. Assessing the role of kisan rail on agri-supply chain in india: insights from mixed-method. **Research. Research on World Agricultural Economy.** v. 6, n. 2, p. 629–651, 2025. https://doi.org/10.36956/rwae. v6i2.1726. Accessed on: Nov. 12, 2024.

CLAVIJO-BURITICA, N.; TRIANA-SANCHEZ, L.; ESCOBAR, J. W. A hybrid modeling approach for resilient agri-supply network design in emerging countries: colombian coffee supply chain. **Socio-Economic Planning Sciences**. v. 85, 2023. https://doi.org/10.1016/j.seps.2022.101431. Accessed on: Jan. 22, 2025.

DADZOE, F.; *et al*. Towards a circular economy: a knowledge-attitude gap between demand and supply-side operators on green building construction in Ghana. **Smart and Sustainable Built Environment.** v. 13, n. 4, p. 763–779, 2024. https://doi.org/10.1108/SASBE-03-2022-0048. Accessed on: Feb. 4, 2025.

DE, A.; SINGH, S. P. Analysis of competitiveness in agri-supply chain logistics outsourcing: a b2b contractual framework. **Sustainability (Switzerland)**. v. 14, n. 11, 2022. https://doi.org/10.3390/su14116866. Accessed on: Oct. 18, 2024.

DENG, C.; *et al*. Potential suitable habitats of chili pepper in china under climate change. **Plants**. v. 13, n. 7, 2024. https://doi.org/10.3390/plants13071027. Accessed on: Jan. 18, 2025.

HANSIKA, S.; WIJERATHNA, M. Evaluation of short organic food supply chains with special reference to climate smartness-the case of direct farmers' market, kurunegala, Sri Lanka. **Journal of Agricultural Sciences - Sri Lanka**. v. 16, n. 2, p. 352–368, 2021. https://doi.org/10.4038/jas.v16i2.9340. Accessed on: Feb. 12, 2025.

KAMAU, J. N.; MATHUVA, D. M.; NDIRITU, S. W. Unlocking sustainable savings through digital financial services: A cooperative lens from Kenya. **Sustainable Futures**, v. 9, n. April. p. 100677, 2025. https://doi.org/10.1016/j. sftr.2025.100677. Accessed on: Feb. 12, 2025.

KUSMIATI, A.; *et al*. Enhancing supply chain resilience through risk mitigation strategies: Evidence from smallholder red chili supply chains in east java indonesia. **Journal of Infrastructure, Policy and Development.** v. 8, n. 10, p. 1–26, 2024. https://doi.org/10.24294/jipd.v8i10.6470. Accessed on: Jan. 22, 2025.

LESTARI, E. P.; *et al*. Assessing production and marketing efficiency of organic horticultural commodities: a stochastic frontier analysis. **Economies**. v. 12, n. 4, p. 1–13, 2024. https://doi.org/10.3390/economies12040090. Accessed on: March. 2, 2025.

LIU, X.; ZHANG, X. The impact of the digital economy on high-quality development of specialized farmers' cooperatives: evidence from china. **Sustainability (Switzerland)**. v. 15, n. 10, 2023. https://doi.org/10.3390/su15107958. Accessed on: Jan. 20, 2025.

MA, D.; *et al*. An evolutionary game theory-based study examining the relationship between fiscal policy, stability of farmers' cooperatives, and environmentally friendly digital management. **Environmental Science and Pollution**

Research International. v. 31, n. 1, p. 909–930, 2024. https://doi.org/10.1007/s11356-023-31092-5. Accessed on: Jan. 14, 2025.

MARCEL,. *et al*. The role of communities of practice in increasing organizational maturity levels towards digital transformation: case study of employee cooperative. **Journal of Applied Engineering and Technological Science**. v. 6, n. 2, p. 1377–1396, 2025. https://doi.org/10.37385/jaets.v6i2.5539. Accessed on: Des. 5, 2024.

MEI, L.; *et al*. Driven by the policy or bent by the market? Cracking the digital transformation code of farmer cooperatives. **Technological Forecasting and Social Change**. v. 208, n. August, 2024. https://doi.org/10.1016/j.techfore.2024.123659. Accessed on: Jan. 25, 2025.

POUDYAL, D.; *et al*. A review of the diversity, distribution, and uses of Akabare chili landraces (Capsicum spp.) in Nepal. **Scientia Horticulturae**. v. 311, n. November 2022, p. 111799, 2023. https://doi.org/10.1016/j.scienta.2022.111799. Accessed on: Feb. 17, 2025.

PURNAMA, A. W.; PRADONO, P.; YUDOKO, G. Coffee beans special handling: analysis the cost of hinterland freight transport. **Acta Logistica**. v. 12, n. 1, p. 199–211, 2025. https://doi.org/10.22306/al.v12i1.616. Accessed on: Jan. 13, 2025.

REARDON, T.; *et al*. Emerging outsource agricultural services enable farmer adaptation in agrifood value chains: A product cycle perspective. **Food Policy**. v. 127, n. August, p. 102711, 2024. https://doi.org/10.1016/j.foodpol.2024.102711. Accessed on: Des. 18, 2024.

SHIRWA, A. M.; *et al*. A cooperative governance framework for sustainable digital transformation in construction: The role of digital enablement and digital strategy. **Results in Engineering**. v. 25, n. October 2024, p. 104139, 2025. https://doi.org/10.1016/j.rineng.2025.104139. Accessed on: Jan. 20, 2025.

SINGH, V.; AGRAWAL, S.; KUMAR, S. Is effective coordination the key to sustainable performance? A probe into integrated e-agri supply chains in India. **International Journal of Productivity and Performance Management**. v. 74, n. 5, p. 1766–1795, 2025. https://doi.org/10.1108/IJPPM-08-2023-0437. Accessed on: Jan. 13, 2025.

SUSANAWATI, S.; NOVIYANTI, N. Supply chain efficiency of red chilies in the production center of Sleman Indonesia based on performance measurement system. **Open Agriculture**. v. 9, n. 1, 2024. https://doi.org/10.1515/opag-2022-0294. Accessed on: Jan. 22, 2025.

TZIOLAS, E.; *et al*. Economic and environmental assessment of olive agroforestry practices in Northern Greece. **Agriculture (Switzerland)**. v. 12, n. 6, 2024. https://doi.org/10.3390/agriculture12060851. Accessed on: Des. 19, 2024.

WANG, J.; *et al*. Domestic substitution and supply chain performance: The impact of technology and price subsidies. **Transportation Research Part E: Logistics and Transportation Review**. v. 201, n. February, p. 104218, 2025. https://doi.org/10.1016/j.tre.2025.104218. Accessed on: Jan. 20, 2025.

YANG, Y.; *et al*. Study on the Application of Activity-Based Costing in Cold Chain Logistics Enterprises under Low Carbon Environment. **Sustainability (Switzerland)**. v. 15, n. 18, 2023. https://doi.org/10.3390/su151813808. Accessed on: Feb. 13, 2025.

YASSI, A.; DEMMALLINO, E. B.; SULTANI, H. R. Tropical climate change and its impact on horticultural plants in Enrekang District, South Sulawesi, Indonesia. **Biodiversitas**. v. 24, n. 6, p. 3073–3079, 2023. https://doi.org/10.13057/biodiv/d240601. Accessed on: Feb. 16, 2025.

YIN, Y.; *et al*. How digital innovation affects the cooperative behavior?. **International Journal of Managing Projects in Business**. v. 18. n. 2. p. 291–311, 2025. https://doi.org/10.1108/IJMPB-09-2024-0212. Accessed on: Jan. 4, 2025.

ZHANG, L.; *et al*. Improving agricultural commodity allocation and market regulation: a novel hybrid model based on dual decomposition and enhanced BiLSTM for price prediction. F**rontiers in Sustainable Food Systems**. v. 9, n. April, p. 1–18, 2025. https://doi.org/10.3389/fsufs.2025.1568041. Accessed on: March. 12, 2025.

ZUHRI, N. M.; NURCAHYONO, N.; PUSPITA, N. The sustainable agriculture supply chains: a bibliometric analysis approach. **Agrisocionomics: Jurnal Sosial Ekonomi Dan Kebijakan Pertanian**. v. 9, n. 1, p. 250–272, 2025. https://doi.org/10.14710/agrisocionomics.v9i1.22691. Accessed on: Feb. 14, 2025.