

# Connectivity and Food Security in 3T Villages in Eastern Indonesia: Community-Based Supply Chain Modeling

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## ABSTRACT

**Purpose:** This study aims to explore the role of regional connectivity in shaping food distribution dynamics and to develop a community-based food supply chain model to strengthen food security in disadvantaged, frontier, and outermost (3T) villages in Eastern Indonesia.

**Research Method:** A descriptive qualitative approach with a case study design was employed. Data were collected through field observations, in-depth interviews, spatial analysis, review of secondary data, systems engineering techniques, and focus group discussions to refine the proposed model.

**Results and Discussion:** The findings indicate that limited connectivity, dependence on external distribution channels, and inadequate storage infrastructure constrain food security in 3T areas. Based on these findings, this study proposes a Community-Based Supply Chain Model integrating BUMDes, Digital Village Granaries, Transportation Collectivity, and appropriate storage technologies to enhance local food system resilience.

**Implications:** The study highlights the importance of combining infrastructure development with community institutions and context-sensitive technologies.

**Originality:** This study offers an integrated framework linking regional connectivity, social capital, and local governance within a community-based food supply chain model tailored to 3T areas in Eastern Indonesia.

**Keywords:** 3T villages; food security; BUMDes; digital village granary; community-based supply chain.

## 1. Introduction

Food security is a crucial aspect of national development, encompassing the availability, accessibility, and stability of food for all (Rachman, 2010). In Indonesia, efforts to achieve food security continue to face various challenges, particularly in disadvantaged, frontier, and outermost areas (3T), which are generally characterized by geographical isolation, limited infrastructure, and restricted access to public services. These conditions lead to low connectivity between regions, thereby affecting the efficiency and effectiveness of food distribution systems (Prabowo, 2010). The persistence of food insecurity in 3T areas represents not only a logistical concern but also a development challenge that may undermine social welfare and regional resilience if left unaddressed. According to data from the Central Statistics Agency (BPS), a development gap persists between urban and rural areas, particularly in access to infrastructure



and basic services (BPS, 2023). This limited connectivity contributes to an uneven and inefficient food distribution system. As a result, communities residing in 3T areas frequently experience higher food prices and unstable food availability (Rumasukun *et al.*, 2024). These disparities indicate that improving food security in remote regions requires more than increasing food production; it also necessitates strengthening regional connectivity and distribution mechanisms that are responsive to local conditions.

The main problem faced by remote regions is low regional connectivity, which leads to suboptimal food distribution. The current food supply chain system remains conventional and heavily dependent on supplies originating from outside the region (Barrett *et al.*, 2022). This dependence makes disadvantaged, frontier, and outermost (3T) areas vulnerable to distribution disruptions, such as delivery delays and high logistics costs. Furthermore, local community involvement in food distribution systems remains relatively limited (Agustin *et al.*, 2026). As a consequence, food systems in these areas often lack the adaptive capacity required to respond effectively to supply shocks and changing local demands.

The food supply chain system integrates the processes of food production, distribution, and consumption. This system is inherently complex because it involves multiple interacting actors and components. Aminudin *et al.*, (2014) explain that the food supply chain consists of key components such as production, suppliers, distribution, and consumption, all of which are interdependent. The effectiveness of the supply chain system is therefore critical to the success of food distribution. An imbalance in one component may disrupt the entire system, ultimately affecting food availability and prices. Therefore, efficient and integrated supply chain management is essential to supporting food security (Vikaliana *et al.*, 2021).

Regional infrastructure and connectivity also play a strategic role in supporting food distribution. Limited access to transportation and logistics networks may result in uneven and inefficient food distribution. Anwar & Aprilianisa (2024) state that achieving food security is influenced by the integration of various factors, including infrastructure, human resources, and policies. Integration among these components is necessary to ensure the optimal functioning of food systems. Without adequate connectivity, certain regions will continue to struggle to obtain food supplies, thereby exacerbating price disparities and food insecurity. Recent studies have increasingly emphasized the importance of innovation and adaptive strategies in strengthening food systems. Utilizing technology is considered one potential solution for improving food system efficiency. Umami *et al.*, (2025) demonstrated that the application of agricultural technology in urban farming could increase productivity by up to 50% for several commodities. This finding suggests that technological innovation can improve production efficiency and help address resource constraints. In the context of 3T areas, technological interventions may also help strengthen information flows, inventory management, and coordination among supply chain actors, provided that local readiness and accessibility issues are adequately addressed.

In line with this perspective, previous studies have shown that the efficiency of logistics and supply chain systems significantly influences food security. Adiatna (2025) stated that Indonesia's food logistics system still faces various obstacles, including high logistics costs, prolonged ship waiting times, and the absence of integrated information systems within supply chains. These conditions contribute to inefficient food distribution and ultimately result in higher food prices, particularly in remote areas. Similarly, Zaelani & Rachmah (2021) argued that food security constitutes a fundamental element in maintaining a country's economic, social, and political stability. However, the dynamic nature of supply chain systems suggests that food distribution continues to face numerous barriers, necessitating more adaptive and context-sensitive management approaches. Despite the growing body of literature on



food security and logistics systems, several limitations remain evident. Existing studies have predominantly focused on national-level food policies, logistics efficiency, or technological interventions in general settings. At the same time, limited attention has been devoted to understanding how regional connectivity shapes food security outcomes in disadvantaged, frontier, and outermost (3T) villages. Moreover, the role of local communities and village-based institutions in strengthening food distribution systems has not been sufficiently explored. Another limitation is the tendency of previous studies to propose technical solutions without adequately considering the institutional and operational challenges of their implementation. Issues such as governance capacity, financial sustainability, digital literacy, transportation maintenance, and inter-organizational coordination remain underexamined, despite their importance in determining the long-term viability of community-based food initiatives in remote settings. Consequently, there is a need for studies that not only examine connectivity-related challenges but also incorporate locally grounded approaches that address the contextual realities of 3T communities.

Based on these considerations, the present study seeks to answer the following research question: How can regional connectivity be strengthened through a community-based food supply chain approach to improve food security in remote 3T villages in Eastern Indonesia? Accordingly, the objectives of this study are twofold: first, to examine the relationship between regional connectivity and food security conditions in remote 3T villages; and second, to develop a community-based food supply chain model that reflects local capacities, institutional arrangements, and contextual challenges. The novelty of this research lies in the development of a community-based food supply chain model that integrates BUMDes, digital granaries, and transportation collectivity to strengthen food security in remote 3T villages in Eastern Indonesia. Unlike previous studies that primarily focus on logistics efficiency from a macro-level perspective, this study emphasizes integrating community participation, village institutions, and localized distribution mechanisms to enhance food system resilience in geographically disadvantaged areas.

The remainder of this paper is organized as follows. Section 2 provides a literature review and hypothesis development. Section 3 presents the research method and design. Section 4 provides the results and discussion. Section 5 is Concluding Remarks and Recommendations.

## 2. Literature Review and Hypothesis Development

### 2.1 Food Security and Supply Chain System

Food security and food supply chain systems are two interrelated concepts that play a fundamental role in ensuring the availability, accessibility, utilization, and stability of food within a population. Food security cannot be achieved solely through increased agricultural production, as the effectiveness of distribution mechanisms largely determines whether food can reach consumers in sufficient quantities, at affordable prices, and at the appropriate time. In this regard, the food supply chain is an integrated system connecting production, procurement, transportation, storage, distribution, and final consumption. Disruptions occurring at any stage of the supply chain can directly affect food availability and price stability, particularly in geographically isolated areas with limited infrastructure. Recent studies have increasingly emphasized that resilient and sustainable food supply chains constitute a critical pillar of contemporary food security strategies. Markina *et al.*, (2021) argued that sustainable agri-food supply chain management contributes significantly to strengthening food security by improving coordination

among supply chain actors and enhancing the efficiency of resource utilization. Similarly, Sjah & Zainuri (2020) demonstrated that effective food supply chain management in Indonesia's agricultural sector improves food availability and distribution efficiency, thereby supporting broader food security objectives. These findings suggest that food security should be understood not merely as an outcome of production performance but as the product of a well-functioning supply chain system capable of responding to changing environmental, economic, and social conditions.

The increasing frequency of global crises, market disruptions, and environmental uncertainties has further highlighted the importance of developing food supply chains that are resilient, adaptive, and technologically enabled. Zhao *et al.*, (2024) emphasized that agri-food supply chain resilience depends on stakeholders' ability to prepare for, respond to, recover from, and adapt to unexpected disruptions through collaborative strategies and institutional learning. Likewise, Hadachek *et al.*, (2024) found that market structures and coordination mechanisms significantly influence the capacity of food supply chains to withstand external shocks while maintaining continuity of supply. In uncertain environments, Sezer *et al.*, (2024) proposed that food supply chains should simultaneously incorporate smart technologies, sustainability principles, and resilience-oriented practices to improve overall system performance. Beyond ensuring efficiency, innovative distribution models have also demonstrated their potential to reduce food insecurity among vulnerable populations. Lowrey & Boyer (2024), for instance, showed that transformative supply chain approaches emphasizing direct access and community engagement can enhance food accessibility and equity. Collectively, these studies indicate that strengthening food security requires a transition from conventional distribution models toward integrated food supply chain systems characterized by resilience, sustainability, inclusiveness, and adaptive capacity. Such an approach is particularly relevant for remote and disadvantaged regions, where structural constraints often hinder the equitable distribution of food resources and exacerbate vulnerabilities within local food systems.

## 2.2 Regional Connectivity and Food Distribution

Regional connectivity constitutes a fundamental determinant of the effectiveness of food distribution systems, particularly in geographically isolated and infrastructure-constrained areas. Connectivity encompasses the availability and quality of transportation networks, market integration mechanisms, and institutional arrangements that facilitate the movement of food products from production centers to consumers. Inadequate connectivity often results in high transaction costs, delayed deliveries, limited market access, and unequal food distribution across regions. Consequently, populations residing in remote areas are more vulnerable to food shortages and price volatility. Nchanji & Lutomia (2021) emphasized that transportation infrastructure and market connectivity play a critical role in enhancing food security by improving trade flows and reducing barriers to food accessibility. Similarly, Judijanto *et al.*, (2024) found that transportation accessibility significantly contributes to agricultural distribution efficiency in Indonesia by shortening distribution routes, reducing logistical constraints, and expanding farmers' access to broader markets. In Eastern Indonesia, Yacamán Ochoa *et al.*, (2020) demonstrated that infrastructure development positively influences food distribution performance, suggesting that improved regional connectivity can help reduce spatial disparities in food availability. These findings collectively indicate that strengthening connectivity should be viewed not merely as an infrastructure agenda but as an integral component of strategies to ensure equitable food access and enhance the overall performance of food systems.

Recent studies have further highlighted the importance of resilient and adaptive connectivity systems in addressing disruptions that threaten food distribution processes. Chesson and Whitworth (2024) argued that infrastructure accessibility substantially contributes to food system resilience in remote communities by enabling continuity of food flows during periods of uncertainty. Likewise, Kumar *et al.*, (2020) emphasized that post-pandemic agricultural transformation requires investments in decentralized logistics systems, improved transportation networks, and stronger integration of local supply chains to maintain food availability during crises. The significance of resilient regional systems is also reflected in the work of Vaitla *et al.*, (2012), who demonstrated that communities experiencing prolonged disruptions rely heavily on adaptive livelihood strategies and functional distribution networks to sustain food access. Furthermore, broader structural transformations affecting rural economies may influence regional food systems by reshaping labor dynamics, market participation, and production-distribution relationships (Zhang *et al.*, 2014). Taken together, these studies suggest that regional connectivity should not be understood solely in physical terms but rather as a multidimensional concept involving infrastructure adequacy, market integration, institutional coordination, and adaptive capacity. Such an understanding is particularly relevant for disadvantaged, frontier, and outermost (3T) areas, where limited connectivity remains a primary constraint on efficient food distribution and on achieving sustainable food security.

### 2.3 Technology and Community-Based Food Security

Technological advancement has emerged as an important driver of food security, particularly in rural and geographically disadvantaged areas where conventional food systems often face limitations in productivity, access to information, and market integration. The increasing adoption of digital technologies in agriculture has transformed how food systems operate, improving production efficiency, decision-making, resource management, and supply chain coordination. Abiri *et al.*, (2023) found that digital technologies contribute positively to agricultural productivity and food security in developing countries by facilitating access to information, enhancing production efficiency, and reducing operational constraints faced by producers. Similarly, Klerx *et al.*, (2019) emphasized that digital agriculture, smart farming, and Agriculture 4.0 represent a paradigm shift in food systems by integrating data-driven technologies into agricultural practices to improve efficiency, sustainability, and resilience. Beyond production aspects, the adoption of information and communication technologies (ICTs) has also been shown to improve household food security by expanding access to agricultural knowledge, market information, and extension services, particularly among vulnerable rural populations (Mapiye *et al.*, 2023). Moreover, Wang & Fu (2021) demonstrated that digital financial inclusion enhances food security outcomes by increasing households' ability to access financial services, manage risks, and invest in productive activities. These findings suggest that technology should be viewed not merely as a productivity-enhancing tool but as a strategic enabler that strengthens various dimensions of food security by improving connectivity, accessibility, and adaptive capacity.

Despite the transformative potential of technology, sustainable food security cannot rely solely on technological interventions; it requires active community participation and strong local institutions. Community-based approaches are increasingly recognized as essential mechanisms for ensuring that technological innovations are socially inclusive, contextually appropriate, and responsive to local needs. Benfica *et al.*, (2023) state that strengthening local food systems requires integrating digital innovation with community empowerment strategies to enhance local ownership and institutional capacity.



Likewise, Andersson & Gabrielsson (2012) highlighted the importance of farmer institutions and community participation in improving local food security through collective action, knowledge sharing, and coordinated resource management. The role of collective organizations is further supported by Ma *et al.*, (2018), who reported that membership in agricultural cooperatives contributes to higher technical efficiency by facilitating access to information, training opportunities, and support services. These studies indicate that the effectiveness of technology in promoting food security depends substantially on the presence of enabling social structures that foster collaboration and equitable participation. Therefore, a community-based food security framework integrating technological innovation with local institutional strengthening offers a more comprehensive and sustainable approach to addressing food insecurity. Such an approach is particularly relevant for disadvantaged, frontier, and outermost (3T) areas, where geographical constraints, limited infrastructure, and institutional challenges necessitate solutions that combine technological adaptability with community resilience and collective engagement.

#### 2.4 Hypothesis Development

Based on previous studies, regional connectivity, logistics efficiency, and community-based institutions have significant roles in strengthening food security systems.

**H1:** *Regional connectivity is significantly related to food distribution efficiency in 3T villages.*

**H2:** *Community-based supply chain systems strengthen food security in remote areas.*

**H3:** *The integration of digital granaries and transportation collectivity improves logistics efficiency and food availability in 3T villages.*

### 3. Research Method

This study employed a descriptive qualitative case study design to explore the dynamics of food supply chains in disadvantaged, frontier, and outermost (3T) areas of Eastern Indonesia. The use of a case study approach was considered appropriate because it enabled an in-depth understanding of complex phenomena related to regional connectivity, food distribution practices, and community involvement within their natural settings. The study focused on selected 3T villages in Eastern Indonesia that experience geographical isolation, limited transportation infrastructure, and challenges in maintaining stable food distribution systems.

Primary data were collected through field observations and in-depth interviews. Field observations were conducted to examine existing food distribution flows, transportation conditions, and local institutional arrangements related to food management. The observation process focused on identifying distribution routes, accessibility constraints, food storage practices, and the roles of community actors involved in local food systems. In-depth interviews were conducted with BUMDes managers, village officials, and community leaders who had direct knowledge and experience of food distribution challenges and local food governance mechanisms. The interviews followed a semi-structured format to allow participants to provide detailed explanations of food supply conditions, logistical barriers, community participation, and potential strategies to strengthen local food security. The use of multiple informant groups was intended to facilitate data triangulation and to capture diverse perspectives regarding the functioning of food distribution systems in remote areas.

Furthermore, spatial analysis was conducted to identify bottlenecks in regional transportation connectivity that could hinder food distribution. The spatial analysis aimed to map areas experiencing limited accessibility and to understand how transportation constraints influence the movement of food commodities within and between villages. Secondary data, including food price fluctuations and food stock volumes, were also analyzed to complement the primary data findings and provide contextual information regarding local food security conditions. These secondary data served as supporting evidence for understanding patterns of food availability and distribution within the study area.

The model development stage employed systems engineering techniques to formulate a community-based food supply chain model adapted to the characteristics of 3T areas. The proposed model integrated three main pillars, namely economic aggregation through BUMDes, digitalization of food stock monitoring, and logistics collectivity. The systems engineering approach facilitated the translation of empirical findings into a practical framework by systematically identifying existing problems, formulating alternative solutions, and integrating local institutional capacities into the proposed model design. Rather than statistically testing causal relationships, this study sought to develop a context-specific conceptual model grounded in field evidence and stakeholder experiences. Therefore, the study emphasized exploration and interpretation instead of hypothesis testing.

Model validation was conducted through focus group discussions (FGDs) involving relevant stakeholders to assess the practicality and contextual suitability of the proposed model. The FGD process provided a platform for participants to evaluate the feasibility of transportation cost-sharing mechanisms, the applicability of digital granary systems under limited telecommunications conditions, and the model's compatibility with existing community practices. Feedback obtained during these discussions was used to refine the model and ensure that it reflected local realities and operational constraints. Accordingly, the resulting framework should be understood as a community-informed model designed to address food distribution challenges in 3T areas, rather than as an empirically tested intervention with measurable impact outcomes.

## 4. Results and Discussion

### 4.1 Analysis Results

#### 4.1.1 Regional Connectivity and Food Distribution Conditions in 3T Areas

Observations conducted in Eastern Indonesia, particularly in underdeveloped regions such as East Nusa Tenggara and Papua, reveal a very low connectivity index. Limited road, port, and airport infrastructure creates geographic barriers that isolate villages in disadvantaged, frontier, and outermost (3T) areas from major economic distribution centers. This severely limits accessibility, with available transportation modes often inadequate or operating at very low frequencies, significantly hindering the movement of goods and services. Field observations further indicated that these limitations affect not only the frequency of food deliveries but also the reliability of distribution schedules, particularly in villages located far from district capitals and primary transportation corridors.

Under these conditions of isolation, the current food supply chain is often linear and highly fragile, relying heavily on supplies from outside the island. The distribution of staple goods must traverse a long network of sea and air routes, the continuity of which is highly dependent on external factors, particularly the extreme weather conditions that frequently occur in Eastern Indonesia. This reliance on long-distance transportation creates a critical juncture in food availability, where even minor disruptions

at a single transportation node may lead to shortages at the village level. Information obtained during field observations suggested that transportation interruptions often delay the arrival of staple foods, thereby reducing the predictability of food availability within local markets.

This uncertainty in logistics ultimately triggers price instability and chronic food insecurity among local communities. High transportation costs stemming from limited connectivity are reflected in local market prices, contributing to substantial price disparities relative to urban areas. Without an independent food reserve system or a robust community-based supply chain model, communities in remote, frontier, and outermost regions (3T) will continue to experience heightened vulnerability whenever external supply lines are disrupted. These findings indicate that regional connectivity constitutes a critical factor influencing the stability of local food systems in geographically isolated areas.

#### *4.1.2 Food Price Disparities and the Cost of Logistical Uncertainty*

One of the most crucial findings from this observation is the wide price gap between remote villages and urban centers. Field informants consistently reported that food prices at several observed locations were considerably higher than in provincial capitals or major urban markets. However, the magnitude of these differences varied across commodities and locations, depending on transportation routes, seasonal conditions, and the availability of local food stocks. This price difference is closely associated with the long, multimodal logistics chain through which goods must pass. Each transit point—from major ports and distributor warehouses to pioneering transportation serving remote areas—introduces additional costs that ultimately increase the financial burden borne by consumers in remote villages.

These high logistics costs are exacerbated by logistical uncertainty stemming from irregular transportation schedules and external environmental conditions. In many remote areas of Eastern Indonesia, food delivery depends heavily on maritime weather conditions and the availability of fuel for pioneering transportation services. When fleet delays or schedule cancellations occur, traders often face increased operational risks, including spoilage, inventory shortages, and capital turnover constraints. According to information gathered during interviews, these risks are frequently incorporated into retail pricing strategies to compensate for potential losses from distribution disruptions. Consequently, the effects of limited connectivity extend beyond transportation inefficiency and directly affect household-level food affordability.

#### *4.1.3 Storage Constraints and Vulnerability to Food Loss*

This study identified a critical weakness in post-harvest infrastructure: the limited availability of adequate storage facilities, such as cold storage systems and modern granaries. Without refrigeration technology for horticultural commodities and animal protein, or pest-resistant storage facilities for grains, food products deteriorate rapidly before they can be consumed. This situation creates a paradox in which communities experiencing limited food availability are simultaneously confronted with food losses resulting from inadequate storage conditions. Observational findings suggested that storage limitations contribute to both reduced food quality and shortened product shelf life, thereby affecting the overall efficiency of local food systems.

The absence of appropriate storage facilities also limits communities' ability to maintain buffer stocks during periods of distribution disruption. Without adequate community granaries, food commodities must be sold or consumed immediately, limiting villages' capacity to build resilience



against supply shocks. The long-term consequence of this condition is increased nutritional vulnerability, as households may become increasingly dependent on processed foods with longer shelf lives but lower nutritional value than fresh, locally produced commodities. These findings highlight that food security challenges in 3T areas are not solely attributable to production deficits but are also closely linked to post-harvest management constraints and the limited capacity to preserve food resources over time.

#### *4.1.4 Appropriate Storage Technologies for Strengthening Food Security in 3T Areas*

Based on the challenges identified during field observations, including inadequate storage facilities, this study proposes several context-specific technological alternatives to enhance communities' capacity to preserve food stocks under constrained infrastructural conditions. These proposed interventions should be understood as conceptual recommendations derived from empirical findings, rather than as technologies implemented and evaluated in this study. To address the critical lack of storage facilities in Indonesia's easternmost 3T regions, this study proposes implementing appropriate, low-cost, and less electricity-dependent storage technologies. One innovative solution is the use of an "Evaporative Cooling System" (Zeer Pot) for horticultural commodities. This technology works by evaporating water through two layers of clay pots separated by wet sand, significantly reducing the internal temperature. This device is particularly relevant for remote villages in East Nusa Tenggara (NTT) or Papua because the raw materials are locally available, require no electricity, and can extend the shelf life of vegetables and fruits under appropriate operating conditions.

Additionally, for grains and legumes, the model recommends using Hermetic Storage Bags (PICS Bags). These double-layered, airtight bags work by cutting off the oxygen supply to pests and fungi, allowing grains to be stored for extended periods without the need for expensive chemical pesticides. This technology is highly practical for distribution to 3T areas because it is lightweight, reusable, and effective in maintaining the quality of seeds and community food stocks in village granaries that lack adequate permanent structures. Finally, for protein products such as fish in coastal areas of Eastern Indonesia, this research encourages the optimization of Salt Barns and Integrated Smoking Techniques. Given that access to freezers and ice is often constrained by unstable electricity supplies, improved traditional preservation techniques represent a more feasible alternative. By integrating simple, more hygienic smoking systems, communities may transform abundant catches into shelf-stable products while potentially enhancing protein availability for inland villages through barter or inter-community trade. Nevertheless, the adoption of these technologies requires further assessment concerning community acceptance, technical feasibility, maintenance requirements, and long-term sustainability under local conditions.

#### *4.1.5 Community-Based Food Supply Chain Model: Strengthening the Role of BUMDes*

This research proposes a supply chain model that no longer relies predominantly on large external distributors but instead builds upon community-based networks. First, strengthening Village-Owned Enterprises (BUMDes) as aggregators represents a strategic effort to shorten distribution chains that have historically contributed to elevated food prices in Eastern Indonesia. Transforming the role of BUMDes into primary aggregators allows these village institutions to consolidate agricultural, plantation, and fishery products from local producers, who have traditionally operated independently.



By aggregating products through a centralized village mechanism, BUMDes can create economies of scale that support both internal village needs and inter-village trade, thereby reducing chronic dependence on intermediaries and external distributors.

In its role as a distribution regulator, BUMDes may help maintain price stability through buffer stock management. During peak harvest periods, BUMDes can purchase community produce at fair prices, reducing the risk of price declines associated with local oversupply. Conversely, during periods of logistical disruption or seasonal scarcity, these reserves may be redistributed to local communities under agreed distribution arrangements. The potential effectiveness of such mechanisms, however, depends on several factors, including managerial capacity, governance quality, transparency in stock management, and the financial sustainability of village institutions. Furthermore, as a community hub, BUMDes may serve as an information center and a facilitator for local product quality assurance. Through professional management, BUMDes can educate producers regarding product standardization and post-harvest handling practices that improve shelf life and market value. Integrating BUMDes into community-based supply chain systems, therefore, offers opportunities not only to strengthen food availability but also to enhance local economic empowerment. Nevertheless, the successful implementation of this approach requires adequate institutional accountability, community trust, and continuous capacity-building initiatives to mitigate the risk of operational failure.

#### *4.1.6 Digital Village Granaries as Community-Based Early Warning Systems*

The concept of the Digital Village Granary in the context of 3T areas does not imply the adoption of sophisticated internet infrastructure but rather the utilization of appropriate technologies adapted to signal limitations. The core objective of this approach is to improve the visibility of food stock information at the grassroots level. Through offline-first applications or short messaging services (SMS/WhatsApp), neighborhood representatives may periodically report the availability of staple foods to a centralized database managed by BUMDes. This proposed mechanism is intended to facilitate timely information exchange rather than replace existing community-based food management practices.

This information system may function as an Early Warning System (EWS) for emerging food shortages. In conventional supply chains, shortages are often recognized only after market stocks have been depleted. However, digital data collection at the neighborhood level enables earlier identification of declining stock trends, thereby supporting preventive responses such as cross-distribution among communities or the timely procurement of additional supplies. Furthermore, the digitization of community granaries may contribute to greater transparency in stock management and improve the targeting of food assistance programs. The accumulation of stock data can also generate valuable information regarding local consumption patterns, thereby supporting evidence-based planning processes. Despite these potential benefits, implementing digital granaries in 3T areas may face challenges related to digital literacy, technological maintenance, infrastructure limitations, and the long-term commitment of local stakeholders to sustain data reporting practices.

#### *4.1.7 Transportation Collectivity as a Mechanism for Reducing Distribution Costs*

The concept of Transportation Collectivity represents a pragmatic response to the high distribution costs observed in 3T areas, which often contribute significantly to elevated food prices. Within this



model, transportation is no longer viewed solely as an individual commercial service but rather as a community resource managed collectively. By consolidating loads from multiple local producers into a shared transportation system, fuel consumption and operational costs may be distributed more efficiently among users. This approach addresses the inefficiencies associated with underutilized transport capacity, which has historically increased logistical expenditures in remote communities.

The implementation of this model relies on coordinated scheduling mechanisms facilitated by BUMDes or village cooperatives. Community-owned vehicles, typically used only for personal purposes, may be incorporated into collective transportation arrangements on specific days to move agricultural products from production sites to aggregation centers or local markets. In return, participating vehicle owners may receive incentives such as profit-sharing arrangements or fuel subsidies. Beyond cost efficiency, this transportation network may strengthen local logistical autonomy, particularly during periods when external logistics providers are unable to operate. However, the sustainability of transportation collectivity depends on several enabling conditions, including fuel availability, vehicle maintenance systems, equitable benefit-sharing arrangements, and effective coordination among participating actors. Without these supporting elements, collective transportation initiatives may encounter operational constraints that limit their long-term effectiveness.

Economically, transportation cost-sharing mechanisms may help retain financial resources within village economies rather than transferring them to external logistics providers. Funds generated through collective arrangements could potentially be reinvested in vehicle maintenance or minor infrastructure improvements. Thus, transportation collectivity offers not only the prospect of reducing food distribution costs but also opportunities to strengthen local economic resilience. Nevertheless, these anticipated outcomes remain conceptual propositions that warrant further empirical evaluation through pilot implementation and impact assessment studies.

The comparison presented in Table 1 illustrates a fundamental shift in the food distribution paradigm within disadvantaged, frontier, and outermost (3T) areas. In the conventional model, control over food distribution is concentrated among external actors and large distributors whose operational decisions are often driven primarily by market considerations. Under such conditions, villagers frequently assume the role of passive consumers, remaining vulnerable to supply disruptions, price volatility, and limited bargaining power. In contrast, the proposed community-based model repositions BUMDes as local aggregators capable of coordinating food distribution activities in line with village priorities and local needs. By placing village institutions at the center of distribution processes, opportunities emerge to strengthen local participation, improve supply chain transparency, and reduce dependence on intermediaries operating outside the region. However, the extent to which these outcomes can be achieved remains contingent upon the managerial capacity, governance quality, and institutional legitimacy of BUMDes within each local context.

Another notable distinction between the two models concerns the organization of transportation systems. In conventional arrangements, transportation costs are typically borne individually by producers or traders, resulting in inefficiencies that become more pronounced under the challenging geographical conditions of Eastern Indonesia. The proposed model seeks to address these inefficiencies through transportation collectivity and cost-sharing arrangements involving community- or village-owned fleets. Such mechanisms may help reduce operational costs and improve access to local markets, thereby enhancing food affordability for rural households. Nevertheless, the practical implementation of transportation collectivity is likely to depend on several enabling factors, including the availability of fuel supplies, the establishment of vehicle maintenance systems, equitable distribution



of benefits among participants, and effective coordination among local stakeholders. Without these supporting conditions, collective transportation initiatives may encounter sustainability challenges over time.

**Table 1. Comparison of Food Supply Chain Characteristics in 3T Areas**

Analysis Dimension	Conventional Supply Chain Model	Community-Based Supply Chain Model (Proposed Model)
Main Actor (Aggregator)	Large distributors or external intermediaries dominate food procurement and distribution processes.	BUMDes function as local aggregators, coordinating production, storage, and distribution within the community.
Information System	Fragmented information flow and dependence on stable internet connectivity limit timely decision-making.	Digital Village Granary systems utilizing offline-first applications or SMS-based reporting facilitate local food stock monitoring and information sharing.
Logistics Mechanism	Individual transportation arrangements, high fleet rental costs, and limited coordination among actors.	Transportation collectivity through community or village fleets supported by cost-sharing mechanisms to improve efficiency.
Stock Management	Food stocks are concentrated in markets and external distribution channels, increasing vulnerability to shortages during supply disruptions.	Community granaries operating at the RT/RW level serve as local buffer stocks to enhance preparedness and resilience.
Pricing Mechanism	Prices are strongly influenced by external market conditions and high logistics costs, resulting in substantial price volatility.	Price stabilization is supported through BUMDes interventions, buffer stock management, and improved distribution efficiency.
Relationship Orientation	Predominantly transactional and competitive relationships among supply chain actors.	Social resilience is based on cooperation, trust, and collective responsibility among community members.

**Source:** Authors' elaboration based on field findings.

Furthermore, the integration of Digital Village Granaries offers the potential to strengthen local preparedness by improving food stock monitoring. Whereas conventional food distribution systems tend to respond to shortages only after they occur, the proposed model encourages earlier detection of potential food deficits through community-level data collection mechanisms. Information generated through neighborhood-level reporting may help BUMDes and village authorities identify emerging vulnerabilities and coordinate preventive actions before disruptions escalate into severe shortages. At the same time, the successful adoption of digital granary systems cannot be assumed automatically. Constraints related to digital literacy, limited technological infrastructure, data management capabilities, and sustained community participation may influence the effectiveness of these systems in practice. Consequently, while the proposed model offers a potentially valuable framework for strengthening food security in 3T areas, its anticipated benefits should be interpreted as conceptual propositions derived from field observations rather than empirically validated outcomes. Further pilot implementation and impact assessment studies are therefore required to evaluate its effectiveness under different local conditions.

#### 4.2 Discussion

The findings of this study suggest that regional connectivity constitutes a fundamental determinant of food distribution performance in disadvantaged, frontier, and outermost (3T) areas of Eastern Indonesia.

The observed limitations in road infrastructure, transportation frequency, and access to distribution nodes indicate that food insecurity in remote communities is not merely a consequence of insufficient production but also reflects structural barriers that impede the movement of food commodities. These findings reinforce previous studies emphasizing that transportation infrastructure and market connectivity are essential prerequisites for improving food accessibility and reducing spatial disparities in food security (Nchanji & Lutomia, 2021; Fikri *et al.*, 2023). From a systems perspective, inadequate connectivity weakens the integration between production and consumption areas, thereby increasing vulnerability to supply disruptions. Consequently, interventions aimed at strengthening food security in 3T areas should extend beyond agricultural intensification strategies and address the broader issue of regional integration. This finding supports the argument that food security must be approached as a multidimensional challenge that requires coordinated improvements in infrastructure, institutional arrangements, and distribution mechanisms, rather than focusing exclusively on production enhancement.

Another important finding relates to the influence of logistical uncertainty on food affordability. The study revealed that prolonged distribution chains and dependence on external transportation systems contribute substantially to food price disparities in remote areas. Although the magnitude of price differences varied across commodities and locations, the evidence suggests that logistical inefficiencies increase transaction costs, which are ultimately passed on to consumers. This observation is consistent with the notion that market accessibility and transportation efficiency directly shape food price dynamics and household purchasing power. Theoretically, these findings support food systems perspectives emphasizing the interconnectedness of physical accessibility, economic access, and food utilization. Furthermore, the results align with studies highlighting that disruptions in transportation systems disproportionately affect geographically isolated populations, thereby intensifying food insecurity among vulnerable groups. Therefore, policies designed to stabilize food prices in 3T areas should not rely solely on market interventions but should simultaneously address the underlying logistical constraints that perpetuate regional inequalities in food access.

The study also identified inadequate storage infrastructure as a critical factor undermining food system resilience in remote communities. The absence of appropriate storage facilities increases post-harvest losses, shortens the shelf life of perishable commodities, and reduces villages' capacity to maintain strategic food reserves during periods of supply disruption. These findings suggest that food insecurity in 3T areas is influenced not only by limitations in food availability but also by deficiencies in post-harvest management systems. In this context, the proposed use of appropriate storage technologies, such as evaporative cooling systems, hermetic storage bags, and improved preservation techniques, represents a practical response to the challenges posed by limited electricity access and infrastructure deficits. Nevertheless, the effectiveness of these technologies depends on their compatibility with local knowledge systems, community acceptance, and the availability of technical support. Accordingly, technology adoption should be viewed as a social process that requires community engagement and continuous capacity building, rather than as a purely technical solution to food insecurity.

Beyond technological considerations, the findings underscore the strategic importance of community institutions in strengthening local food systems. The proposed role of BUMDes as aggregators and managers of community food reserves reflects an institutional approach that seeks to enhance local autonomy over food distribution processes. By consolidating local production, facilitating buffer stock management, and supporting inter-village trade, BUMDes have the potential to reduce

dependence on external distributors while improving market coordination at the village level. This interpretation is consistent with previous studies emphasizing that collective organizations and community participation contribute positively to local food security by strengthening social capital, facilitating information exchange, and improving resource mobilization (Prasetyo *et al.*, 2023; Ma *et al.*, 2022). However, the successful implementation of this approach depends heavily on the quality of governance, managerial competence, transparency, and accountability within local institutions. Without adequate institutional capacity, community-based initiatives may encounter operational inefficiencies that limit their ability to generate sustainable outcomes.

Similarly, the concepts of Digital Village Granaries and Transportation Collectivity highlight the importance of integrating technological innovation with local social structures. Rather than relying on sophisticated digital platforms that may be unsuitable for remote contexts, the proposed digital granary model emphasizes simple, adaptive technologies that can operate under limited telecommunications infrastructure. This approach reflects broader arguments that technological innovation should be context-sensitive and aligned with end users' realities. At the same time, transportation collectivity illustrates how collective action can address inefficiencies arising from fragmented logistics systems. By promoting cost-sharing arrangements and coordinated transportation schedules, communities may improve access to markets while reducing distribution costs. Nevertheless, several implementation challenges remain, including digital literacy gaps, fuel availability, vehicle maintenance requirements, and the equitable distribution of benefits among participants. These constraints indicate that community-based food system innovations should not be romanticized as universally applicable solutions but should be evaluated for their operational feasibility in specific local contexts.

Overall, this study contributes to the growing literature on food security by proposing a conceptual framework that integrates regional connectivity, community institutions, and appropriate technologies within a localized food supply chain model. The findings extend prior research by demonstrating that the interplay among physical, institutional, and socio-technical dimensions shapes food security in 3T areas. While the proposed Community-Based Supply Chain Model offers a potentially valuable alternative to externally dependent distribution systems, its effectiveness remains a proposition that requires further empirical validation through pilot implementation and impact assessment studies. Consequently, the present study should be interpreted as an exploratory effort to generate context-specific insights regarding food distribution challenges and possible intervention pathways in remote settings. Future research may therefore focus on testing the practical applicability of the proposed model across different geographical contexts, assessing its economic feasibility, and examining its long-term implications for community resilience and food sovereignty in disadvantaged regions.

## 5. Concluding Remarks and Recommendation

This study explored how regional connectivity influences food distribution dynamics. It examined how a community-based food supply chain approach could help strengthen food security in disadvantaged, frontier, and outermost (3T) areas of Eastern Indonesia. Using a descriptive qualitative approach with a case study design, the study integrated field observations, in-depth interviews, spatial analysis, secondary data analysis, systems engineering techniques, and focus group discussions to understand existing food distribution challenges and formulate context-specific intervention pathways. The findings indicate that limited transportation connectivity, reliance on external distribution channels, and

inadequate post-harvest storage infrastructure are major constraints on the stability of local food systems in 3T areas. Furthermore, the study identified the potential roles of community institutions, appropriate technologies, and locally coordinated distribution mechanisms in enhancing the adaptive capacity of remote communities to respond to food supply disruptions. Rather than demonstrating statistically significant causal relationships, this study provides an exploratory understanding of how localized food security strategies may be conceptualized within geographically constrained environments.

Theoretical contributions of this study lie in extending the discussion of food security beyond production-oriented perspectives by emphasizing the interdependence between regional connectivity, community institutions, and socio-technical innovations within food supply chain systems. From a practical perspective, the study offers a conceptual framework that highlights the potential roles of BUMDes as local aggregators, Digital Village Granaries as community-based information systems, and Transportation Collectivity as an alternative mechanism to address logistical inefficiencies in remote settings. In terms of policy implications, the findings suggest that food security interventions in 3T areas should adopt a more integrated approach that combines infrastructure development with institutional strengthening, community participation, and context-sensitive technological adaptation. The originality of this study resides in its attempt to integrate these dimensions into a Community-Based Supply Chain Model specifically designed to address the realities of food distribution in geographically isolated regions of Eastern Indonesia.

Several limitations should be acknowledged when interpreting the findings of this study. First, the qualitative nature of the research and its focus on selected 3T contexts limit the generalizability of the proposed model across different geographical and socio-economic settings. Second, the Community-Based Supply Chain Model developed in this study remains conceptual and has not undergone pilot implementation or impact evaluation to assess its operational effectiveness. Third, the study did not quantify the economic implications of the proposed interventions, including their potential effects on food prices, logistical efficiency, or household food security. These limitations provide opportunities for future research. Subsequent studies may employ mixed-methods or longitudinal approaches to examine the implementation of the proposed model, evaluate its economic feasibility, and investigate its effectiveness in strengthening community resilience and food security under varying local conditions. Future research may also explore governance arrangements, financing mechanisms, and strategies for enhancing digital literacy to support the sustainability of community-based food systems in disadvantaged regions.

## Statement of Use of Generative AI

During the preparation of this work, the author used generative artificial intelligence tools to support the scientific writing process. Grammarly was used to check grammar, refine writing style, and improve clarity in scientific writing. All interpretations, analyses, and conclusions presented in this study are the sole responsibility of the author.

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