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RESEARCH ARTICLE

Allocation Efficiency of Agricultural Sector Resources in Supporting Food Security, Economic Equity, and Regional Self-Reliance in Bireuen Regency

Hakim Muttaqim [1*], Fauzi [2], Muhammad Rizal [3]

[1*,3] Fakultas Ekonomi, Universitas Almuslim, Matangglumpangdua, Paya Cut, Kec. Peusangan, Kabupaten Bireuen, Aceh, Indonesia.
[2] Fakultas Ilmu Sosial dan Politik, Universitas Almuslim, Matangglumpangdua, Paya Cut, Kec. Peusangan, Kabupaten Bireuen, Aceh, Indonesia.

Email: hakimmuttaqim11@gmail.com [1*], fauzi.s.ip.ma@gmailcom [2], muhammadrizal@umuslim.ac.id [3]

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Abstrak

Penelitian ini mengkaji efisiensi alokasi sumber daya dalam usahatani padi untuk mendukung ketahanan pangan, pemerataan ekonomi, dan kemandirian wilayah di Kabupaten Bireuen. Pendekatan metode campuran (*mixed-methods*) diterapkan dengan mengintegrasikan analisis kuantitatif menggunakan *Data Envelopment Analysis* (DEA) dan *Stochastic Frontier Analysis* (SFA) serta metode kualitatif yang mencakup wawancara mendalam dan *Focus Group Discussion* (FGD). Data yang digunakan meliputi data primer dan sekunder. Hasil penelitian menunjukkan bahwa efisiensi teknis dalam usahatani padi masih relatif rendah, dengan skor rata-rata DEA dan SFA masing-masing sebesar 0,88 dan 0,86, yang mengindikasikan adanya potensi realokasi input sebesar 10–15%. Faktor-faktor penentu utama efisiensi meliputi pendidikan petani, akses terhadap kredit formal, partisipasi dalam kelompok tani, dan kedekatan dengan pasar. Sebaliknya, keterbatasan modal, teknologi yang kurang memadai, dan kepemilikan lahan yang sempit (<0,5 ha) diidentifikasi sebagai penyebab utama ketidakefisienan. Temuan kualitatif memperkuat hasil kuantitatif, yang menunjukkan bahwa petani skala kecil lebih rentan terhadap ketidakefisienan dibandingkan petani berskala lebih besar (>1 ha). Penelitian ini menyimpulkan bahwa peningkatan efisiensi memerlukan intervensi kebijakan yang tepat sasaran, termasuk perluasan akses kredit mikro, promosi mekanisasi, penguatan kelembagaan kelompok tani, dan stabilisasi harga gabah. Langkah-langkah ini sangat penting untuk meningkatkan ketahanan pangan, mengurangi kesenjangan ekonomi, dan mendorong kemandirian wilayah yang berkelanjutan di Kabupaten Bireuen.

Kata Kunci: Efisiensi; Ketahanan Pangan; Pemerataan Ekonomi; Kemandirian Daerah; Ekonomi Berkelanjutan; Distribusi Pendapatan.

Abstract

This study investigates the efficiency of resource allocation in rice farming to support food security, economic equity, and regional self-reliance in Bireuen District. A mixed-methods approach was employed, integrating quantitative analyses using Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) with qualitative methods comprising in-depth interviews and Focus Group Discussions (FGDs). The data used is primary and secondary data. The results indicate that technical efficiency in rice farming remains relatively low, with average DEA and SFA scores of 0.88 and 0.86, respectively, implying a potential input reallocation of 10–15%. Key determinants of efficiency include farmers' education, access to formal credit, participation in farmer groups, and proximity to markets. In contrast, limited capital, insufficient technology, and small landholdings (<0.5 ha) were identified as the primary sources of inefficiency. Qualitative findings corroborate the quantitative results, revealing that smallholder farmers are more vulnerable to inefficiency than larger-scale farmers (>1 ha). The study concludes that improving efficiency necessitates targeted policy interventions, including expanding access to microcredit, promoting mechanization, strengthening farmer group institutions, and stabilizing paddy prices. These measures are critical for enhancing food security, reducing economic disparities, and fostering sustainable regional self-reliance in Bireuen District.

Keyword: Efficiency; Food Security; Equitable Economic Distribution; Regional Self-Reliance; Sustainable Economy; Income Distribution.

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1. Introduction

Bireuen District in Aceh Province has a predominantly agricultural sector, which makes a significant contribution to the Regional Gross Domestic Product (RGDP) and employment absorption. The main agricultural commodities include rice, maize, oil palm, and coconut. Data from the Central Bureau of Statistics show that in 2019, the harvested area of rice reached 38,837 hectares, while oil palm and coconut production amounted to 3,990.13 tons and 15,720.87 tons, respectively. The local government has continuously sought to improve agricultural productivity through various initiatives, such as providing water pumps to enhance the cropping index and overall yield productivity (Marlinda *et al*., 2023). In addition, an integration strategy between oil palm cultivation and cattle farming has also been developed to enhance the regional economy (Braun *et al*., 2023). As one of the food barns in Aceh Province, Bireuen possesses substantial agricultural potential, particularly in rice, secondary crops, and horticultural commodities. However, challenges such as climate change, land-use conversion, and limited agricultural technology remain significant obstacles to enhancing productivity (Christyanto & H., 2021). The community is also expected to advance by generating environmentally sustainable products and processes that support rural development (Fauzanna & Indrayati, 2021). The cultivation of food crops such as rice, maize, and soybeans holds considerable prospects for strengthening food security in Bireuen District. Nevertheless, issues concerning the efficiency of resource allocation in the agricultural sector remain a persistent challenge in supporting food security, economic equity, and regional self-reliance (Fetra *et al*., 2021). Although the agricultural sector serves as the backbone of livelihoods for the majority of the population, the utilization of land, water, and labor, as well as access to technology and capital, remains suboptimal (Yuspin *et al*., 2023). This imbalance in resource distribution has resulted in low agricultural productivity, income disparities across regions, and dependence on external food supplies (Wuli, 2024). The lack of integrated planning and sustained policy support exacerbates this condition, thereby hindering efforts to achieve sustainable food security.

Research on the efficiency of resource allocation in the agricultural sector has become a central focus in the pursuit of sustainable development, particularly in the context of food security, economic equity, and regional self-reliance. Previous studies have highlighted that the agricultural sector in developing countries, including Indonesia, holds substantial potential to foster inclusive economic growth and social sustainability. However, this potential is often constrained by suboptimal resource allocation (Tangngisalu *et al*., 2023). Several studies have employed quantitative approaches such as Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) to measure technical and allocative efficiency in agricultural input utilization. Resource allocation efficiency is highly contingent upon farmers' access to information, technology, and capital (Suhela Putri Nasution & Abdurrozzaq Hasibuan, 2023). The unequal distribution of agricultural inputs, such as fertilizers and irrigation, hampers efficiency at the smallholder level (Komendangi *et al*., 2023). Food security depends not only on sufficient production but also on the distribution system and the capacity of regions to achieve self-reliance in meeting their food needs. It must be examined across four dimensions: availability, access, utilization, and stability (First *et al*., 2023). At the national level, the efficiency of agricultural supply chains is critical for maintaining the stability of food supply and prices. Several studies have demonstrated that the agricultural sector plays a pivotal role in reducing economic disparities, particularly in rural areas. Appropriate resource allocation can enhance smallholder productivity and generate employment opportunities (Darojat *et al*., 2025). Growth in the agricultural sector is twice as effective in reducing poverty compared to other sectors. The concept of regional self-reliance has become increasingly relevant in the context of decentralization. Regions with the capacity to manage agricultural resources efficiently tend to be more resilient in facing food and economic crises. Strengthening the synergy between local policies and central government support is essential to foster agricultural innovation and the development of local agribusiness. Advances in information technology provide new opportunities for optimizing agricultural resource allocation. Precision agriculture initiatives, geospatial information systems, and digital platforms for agricultural marketing constitute integral components of modern solutions (Lermating *et al*., 2025). However, adequate infrastructure readiness and improved digital literacy among farmers are still required to achieve the expected efficiency.

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The agricultural sector is highly dependent on the efficient management of key resources such as land, water, labor, capital, and technology. According to Todaro and Smith (Darojat *et al*., 2025), the optimal availability and utilization of agricultural resources are key to improving productivity and farmers' welfare, particularly in developing countries. Inefficient resource allocation is often a major cause of low production yields, unequal access, and economic stagnation in agrarian regions (Yuspin *et al*., 2023). In Indonesia, challenges in the agricultural sector lie not only in the limitation of resources but also in their unequal distribution across regions and stakeholders. According to the Ministry of Agriculture (First *et al*., 2023), efforts toward agricultural modernization and governance reform should be directed at improving input allocation efficiency and enhancing the competitiveness of local farmers. This study investigates the extent to which agricultural resources in Bireuen District have been allocated efficiently and how such allocation influences food security, economic equity, and regional self-reliance. This approach is expected to address the research gap in prior studies, which have predominantly emphasized agricultural output while overlooking the dimensions of efficiency and equity in resource management. This study introduces a novel analytical approach to examining the efficiency of agricultural resource allocation by simultaneously addressing its interlinkages with three strategic dimensions of regional development-food security, economic equity, and regional self-reliance-which have generally been studied in isolation. The key novelty lies in positioning equity in resource distribution (such as access to land, technology, and government support) as an integral component of efficiency, rather than focusing solely on productivity. This perspective offers the potential to generate empirically grounded models or policy recommendations on how agricultural resources should be allocated to achieve sustainable regional self-reliance.

2. Literature Review

Food security is a condition in which households have sustainable access to sufficient, safe, nutritious, and affordable food (Wuli, 2024). In Indonesia, food security constitutes a strategic component of the national development agenda, particularly in the face of global food crises, climate change, and disparities in the distribution of agricultural outputs (Tangngisalu *et al*., 2023). The efficiency of agricultural resource allocation is closely linked to food security. Optimizing the use of production factors can enhance food availability, strengthen community access, support the utilization of nutritious food, and ensure supply stability. Therefore, agricultural development policies should be directed toward strengthening farmers' capacities, providing appropriate technologies, improving access to capital, and promoting sustainable land and water management. In this regard, efficiency in resource allocation within the agricultural sector will serve as a fundamental pillar for achieving national food security. According to Maxwell and Slater in (Darojat *et al*., 2025), food security is determined not only by production volume but also by the overall efficiency of the food system, encompassing production, distribution, and consumption. The efficient allocation of agricultural resources-such as land, water, labor, and technology-constitutes a critical prerequisite for ensuring food availability at the local level.

Several studies indicate that regions with poor resource allocation systems tend to experience food insecurity, particularly among smallholder farmers (Komendangi *et al*., 2023). Therefore, this study examines the relationship between the efficiency of agricultural resource allocation and food security in Bireuen District, with the aim of formulating more adaptive and sustainable local food development strategies. Regional self-reliance refers to the capacity of a region to optimally manage its local resources in order to meet the economic, social, and cultural needs of its community without dependence on external sources (Yuspin *et al*., 2023). In the context of regional development, self-reliance serves as a key indicator reflecting the resilience and sustainability of local development (First *et al*., 2023). Regional self-reliance is a multidimensional concept encompassing economic, social, cultural, institutional, and environmental aspects. The optimal management of local resources requires a combination of resource availability, institutional capacity, human capital, infrastructure, market access, and social capital. To foster sustainable self-reliance, policies must adopt a holistic approach that strengthens local capacities, facilitates community participation, and ensures the sustainable management of resources. The

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agricultural sector plays a central role in promoting regional self-reliance, particularly in agrarian areas such as Bireuen District. According to Kusnadi and Setiawan (Komendangi *et al*., 2023), the effective management of agricultural resources through efficient allocation can enhance local food production while simultaneously creating broader economic opportunities for local communities. This, in turn, reduces regional dependence on external food supplies. Furthermore, the concept of regional self-reliance emphasizes not only the aspect of production but also the equitable distribution of economic benefits and fair access to resources (Tangngisalu *et al*., 2023). Therefore, this study aims to examine how the efficiency of resource allocation in the agricultural sector can strengthen regional self-reliance in Bireuen District through enhanced food security and economic equity.

3. Research Methodology

This study employs a mixed-methods approach with an explanatory sequential design (Creswell, 2014). The first stage involves quantitative analysis using Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) to measure the efficiency of agricultural resource allocation. The second stage adopts a qualitative approach through in-depth interviews (Key Informant Interviews/KII) and Focus Group Discussions (FGDs) to explore the underlying factors of inefficiency and their implications for food security, economic equity, and regional self-reliance in Bireuen District. This study was conducted in Bireuen District, Aceh Province, which holds a significant contribution to the agricultural sector, particularly rice and secondary crops. The research was carried out over a period of six months, encompassing primary data collection, data processing, analysis, and validation of findings. The population of this study consists of all rice farming households in Bireuen District. The quantitative sample was determined using a multistage sampling technique. First, five sub-districts that serve as rice production centers were selected. Second, from each sub-district, a minimum of 300 farming households were identified. The total sample for this study comprised 150–200 rice farming households. According to (Meilyana & Abdullah, 2019) the criteria for DEA with five inputs and two outputs, as well as 21 observations, are as follows:

$$n \geq \max\{m\ x\ s, 3(m+s)\}$$

The sample in this study was selected using purposive sampling, consisting of the head of the agricultural office, agricultural extension officers, farmer group leaders, agricultural product traders, and representatives of both small- and large-scale farmers in Bireuen District, Aceh Province. This research employed both primary and secondary data. According to (Sugiyono, 2017) primary data are sources that directly provide information to the researcher, such as data obtained from respondents through interviews or questionnaires, whereas secondary data are research data that do not directly provide information to the data collector. In this study, primary data were obtained from respondents through questionnaire distribution, in-depth interviews, and focus group discussions (FGDs). Meanwhile, the secondary data consisted of market prices, production inputs, and agricultural statistics sourced from the Central Bureau of Statistics (BPS) and the Bireuen Agricultural Office. Quantitative data collection was conducted through household surveys of farmers using a structured questionnaire. The questionnaire was developed based on input and output variables relevant to paddy farming efficiency analysis (DEA and SFA), as well as supporting factors such as access to credit, extension services, and infrastructure. The research instrument included: Respondent Profile (age, education, number of dependents, farming experience), Production Inputs (land area, labor, seeds, fertilizers, irrigation costs, use of agricultural machinery, capital/credit), Production Outputs (total production, production value, net income), and Supporting Factors (access to extension services, farmer group participation, market distance, selling price). In addition, in-depth interviews were conducted with key informants, along with FGDs involving farmer groups in three sub-districts of Bireuen. Data collection also involved documenting existing information, particularly historical records concerning individuals, groups, events, and socio-economic contexts.

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The quantitative data analysis in this study employed two approaches: (1) Stochastic Frontier Analysis (SFA) and (2) Data Envelopment Analysis (DEA). In the operationalization of the SFA approach, the production function applied in this study follows the framework proposed by (Aigner, .D.J, 1968). The production function adopted is specified in the form of a Cobb-Douglas function, as follows:

$$I_n\, Y_i = \beta_o + \sum_{j=1}^{4} \beta_j\ LnX_{ij} + v_i - u_i \ldots\ldots\ldots\ldots\ldots (1)$$

Where Y represents the rice production of the *i*, X_{ij} is the input vector of type *j* for farmer *i*, which includes seeds, fertilizers, pesticides, labor. β_j represents the parameters to be estimated. V is a random variable assumed to be *N*~ (0, δ2V) shows the error factor of the stochastic effect that farmers cannot control. U is a non-negative random variable that indicates the technical inefficiency of farming. U is assumed to be independent of V. The parameters σ_2^u and σ_v^2 are presented in the form of parameters:

$$\sigma_2^u + \sigma_v^2 = \sigma^2 ;\ \gamma =: \sigma_2^u \frac{}{\sigma_2^u + \sigma_v^2} ;\ \lambda = \sigma_u \,/\, \sigma_v\ (> 0).$$

The parameter γ lies from 0 to 1. A value of 1 indicates that all deviations are purely attributable to differences in technical efficiency among farmers. Parameter estimation was conducted using the Maximum Likelihood Estimation (MLE) method. In this study, the level of technical efficiency (TE) was measured using the following calculation:

$$TE_i = \frac{y_i}{y_{i^*}} = \frac{\exp(x_i\beta + v_i - u_i)}{\exp(x_i\beta + v_i)} = \exp(-u_i) \ldots\ldots\ldots\ldots\ldots (2)$$

Where y_{i^*} denotes the actual observed production, and y_i represents the estimated frontier production derived from the stochastic frontier production function. Data Envelopment Analysis (DEA) was employed to assess efficiency among farmers as well as overall efficiency across farms. To determine the technical efficiency of the i-th farmer, the following linear programming model was used:

Maximize $\theta_\lambda\ \theta$
$-\theta_{yi} + \mathrm{Y}\lambda \geq 0$
$\mathrm{X}_i - \mathrm{Y}\lambda \geq 0$
$N1'\lambda = 1$
$\lambda \geq 0 \ldots\ldots\ldots\ldots\ldots (3)$

Where θ represents the technical efficiency (TE) score, $y_i$denotes the rice production of the i-th farmer, and xi is an N x 1 vector of production inputs for the i-th farmer. Y is a 1 x M vector of outputs, N is an N x M matrix of the input quantities used, λ is an M x 1 vector of weights, and θ is a scalar. Technical efficiency is determined using the Constant Returns to Scale (CRS) approach, while Variable Returns to Scale (VRS) is used to assess scale efficiency. Overall efficiency (OE) is then obtained from:

$$SU_i = \theta_\mathrm{i}^{\,CRS} / \theta_\mathrm{i}^{\,VRS} \ \ldots\ldots\ldots\ldots\ldots (4)$$

The factors influencing technical efficiency, as obtained through SFA and DEA, were analyzed using regression estimated with a Tobit model.

$$TE_i = u_i = \alpha_0 + \sum_{j=1}^{10} \alpha_J\, Z_{ij} \ldots\ldots\ldots\ldots\ldots (5)$$

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Where TE represents the level of technical efficiency, and Z_{ij} denotes the factors influencing technical efficiency, comprising ten variables: manager's gender, age, farmer's gender, education, family size, land area, land type, land tenure status, crop variety, frequency of extension services, and farm enterprise characteristics. Following the quantitative data analysis, qualitative data analysis was conducted, which is a systematic and complex process of processing data obtained from various sources, such as interviews, observations, field notes, and documentation. This process aims to organize, structure, and interpret the data to provide a deeper and more detailed understanding of the phenomena under study. According to (Sugiyono, 2019), qualitative data analysis involves three main stages: data reduction, data display, and drawing conclusions.

4. Results and Discussion

4.1 Results

4.1.1 Results of Efficiency Analysis With DEA

The Data Envelopment Analysis (DEA) was conducted using an input-oriented model under the assumption of Variable Returns to Scale (BCC). The inputs considered included land area, labor, seeds, fertilizers, machinery services/equipment, fuel costs, irrigation, and credit. The outputs measured were rice production (ton/ha), production value (IDR), and margin per hectare. The analysis revealed that the average technical efficiency of rice farmers in Bireuen was 0.74, indicating that, on average, farmers could reduce input use by 26% without decreasing output. Among the 180 respondents, only 28 households (15.6%) were on the efficiency frontier (score = 1), while the majority had scores ranging from 0.60 to 0.85. Approximately 40% of farmers operated under increasing returns to scale, meaning their output could be proportionally increased by adding more inputs. Only 22% exhibited constant returns to scale, whereas the remaining 38% experienced decreasing returns to scale, suggesting that input use exceeded the optimal capacity of the land. Farmers in Jeunieb and Peusangan sub-districts recorded higher average efficiency scores (0.81), likely due to better access to technical irrigation networks and proximity to rice markets. In contrast, Pandrah and Simpang Mamplam sub-districts recorded lower efficiency (0.67), influenced by limited access to agricultural machinery and reliance on rainfed irrigation systems.

4.1.2 Results of Efficiency Analysis with SFA

The estimated rice production function is presented in Table 1. The Stochastic Frontier Analysis (SFA) was conducted using a Cobb–Douglas production function with primary inputs including land, labor, fertilizer, and credit.

Table 1. Production Function Estimation Cobb-Douglas Frontier

Variable	Coefficient	Standard-error	t-count
Intercept	7.220	0.521	14.248
X_1 (Land)	0.221	0.084	2.654*
X_2 (Labor)	0.098	0.047	1.930
X_3 (Fertilizer)	0.165	0.035	2.345*
X_4 (Credit)	0.170	0.033	2.276*
Sigma-squared	0.065	0.024	3.985
Gamma	0.985	0.051	19.867
Log Likelihood Function			16,4
LR test			3,21
Note * is real at $\alpha = 0.05$			

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The input coefficients indicate that land area has a positive and significant effect on output, with an elasticity of 0.221. Fertilizer use is also significant, with an elasticity of 0.165. Credit has a significant positive impact on output, with an elasticity of 0.170, suggesting that access to capital enhances productivity. Labor has a positive but statistically insignificant effect at the 5% level (elasticity 0.098), indicating potential overuse of labor. Technical efficiency (TE) for each farmer was estimated using a parametric approach through SFA (Equation 2) and a non-parametric approach through DEA (Equation 3), with average results presented in Table 2. The distribution of efficiency levels among farmers is presented in Table 3.

Table 2. Average Efficiency in Farming Business

Model	Efficiency	Minimum	Maximum	Mean	Std. Deviation
DEA	Overall technical efficiency (CRSTE)	0.44	1.00	0.84	0.16
	Pure technical Efficiency (VRSTE)	0.60	1.00	0.88	0.14
	Scale efficiency (SE)	0.047	1.00	0.90	0.12
SFA	Pure technical Efficiency	0.035	0.98	0.86	0.11

The average technical efficiency obtained using the SFA approach was 0.86, while the DEA approach yielded 0.88. Scale efficiency was estimated at 0.90. Based on the DEA results, 71% of farmers achieved technical efficiency, and 85% reached scale efficiency. In contrast, using the SFA approach, only 52% of farmers attained technical efficiency above 0.90.

Table 3. Technical Efficiency Distribution of DEA and SFA Approaches

Efficincy Level	DEA			SFA
	Overall technical efficiency (CRSTE)	Pure technical Efficiency (VRSTE)	Scale efficiency (SE)	Pure technical Efficiency
0 -0.50	2.073	2.073	2.073	2.073
0.51-0.60	4.132	0.000	0.000	0.000
0.61-0.70	25.210	2.041	4.101	6.702
0.71-0.80	21.005	6.310	6.520	14.656
0.81-0.90	16.143	12.581	12.805	34.934
0.90-1.00	34.432	71.110	85.250	52.125

In terms of production scale, which indicates the operational scale of farmers, the results show that only 24.95% of farmers operate under Constant Returns to Scale (CRS), representing the optimal scale. Meanwhile, 27.02% of farmers operate under Decreasing Returns to Scale, and 45.81% under Increasing Returns to Scale.

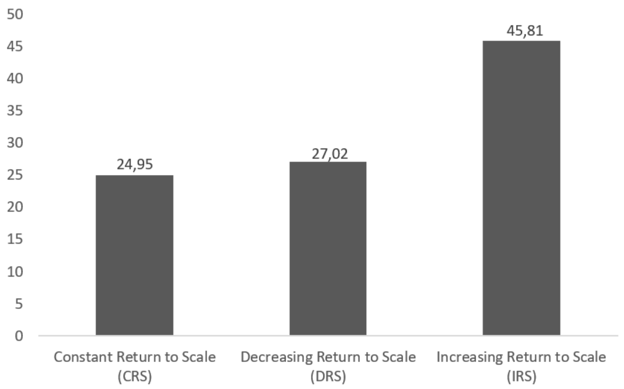

Figure 1. Distribution of Scale Operation

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In general, rice farmers who are technically inefficient tend to overuse inputs. The DEA analysis revealed that zero slack values were not achieved for all variables for a portion of the farmers. Land, labor, fertilizer, and credit are generally overutilized by farmers (Table 2).

Table 4. Slack Value of Farm Business Production Input

Production Facilities	Slack Average	Over-Farming Frequency
Land (m)	7.020	14.350
Fertilizer (kg)	18.450	19.023
Labor (day)	82.566	41.830
Credit (rp)	12.034	8.440

The factors influencing technical efficiency in this study were compared between the SFA and DEA approaches. The TE values derived from the SFA approach exhibited greater variability that could be explained by changes in the independent variables compared to DEA. Furthermore, the SFA model identified three variables with significant effects, whereas the DEA model showed no significant determinants. Therefore, the interpretation of results in this study relies on the SFA approach (Table 5). The findings indicate that no farmer-specific characteristics significantly affect TE. The factors influencing technical efficiency are land use and the frequency of extension services. Consequently, efforts to enhance the technical efficiency of rice farming can be effectively guided using these instruments.

Table 5. Factors Affecting Technical Efficiency (TE) of Farming Businesses

Variables	SFA				DEA			
	Coef.	Std. Err.	t	P>t	Coef.	Std. Err.	t	P>t
Intercept	0.7122	0.0619	13.05	0.000	0.7607	0.1301	7.67	0.000
Age	0.0009	0.0009	0.96	0.402	0.0034	0.0034	1.20	0.407
Gender	0.0005	0.0305	0.01	0.879	0.0051	0.0511	0.07	0.879
Education	-0.0006	0.0030	-0.21	0.626	*0.0080	0.0042	1.97	0.091
Employment	0.0030	0.0098	0.45	0.690	0.0281	0.0205	1.88	0.198
Art	0.0070	0.0086	0.79	0.549	0.0003	0.0213	0.02	0.981
Area Size	*0.0185	0.0186	1.72	0.153	0.0291	0.0282	0.87	0.390
Ownership	-0.0080	0.0168	-0.40	0.620	-0.0598	0.0450	-1.37	0.178
Variations	***0.0916	0.0406	3.97	0.001	-0.0204	0.0729	-0.46	0.781
Counseling	***0.0354	0.0073	4.76	0.000	-0.0083	0.0189	-0.49	0.801
Sigma Squared	0.0632	0.0067			0.1421	0.0238		
Log likelihood				73.287				35.1409
LR chi2(10)				62.09				14.88
Prob > chi2				0.000				0.2065

* = 90 percent confidence level
** = 95 percent confidence level
*** = 99 percent confidence level

4.1.3 Interview and FGD Results

Interviews with Agricultural Office officials, extension agents, and focus group discussions (FGDs) with farmers revealed several key findings as follows:

1) Farmers often apply fertilizers in ways that do not conform to recommended guidelines, driven both by limited capital and the perception that "more fertilizer leads to higher yields." As a result, production costs are high without a proportional increase in output. The practice of applying fertilizers beyond technical recommendations is widespread among rice farmers in rural areas, including Bireuen District. In practice, farmers frequently use higher fertilizer doses than advised, believing that greater input will result in higher harvests. This perception is reinforced by empirical trial-and-error experiences and

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limited access to research-based agricultural extension and information. However, field findings indicate that excessive fertilizer use does not always correspond to proportional yield increases. According to production theory, inputs above the optimal level encounter the law of diminishing returns, where each additional unit of fertilizer contributes progressively smaller yield increments. At certain points, over-application can reduce soil quality, increase production costs, and create chemical residues that undermine the sustainability of the agricultural ecosystem. Capital constraints are also a critical factor. Some farmers apply fertilizer below recommended levels due to financial limitations, resulting in nutrient deficiencies and reduced productivity. Consequently, both over-application and under-application of fertilizers decrease the technical and economic efficiency of farming operations. This phenomenon is also reflected in DEA and SFA efficiency analyses, where the fertilizer variable often shows a positive but statistically insignificant contribution for most farmers, indicating usage above the optimal requirement. The impact is high production costs and low per-hectare profit margins, which diminishes farmers' competitiveness and has implications for regional economic equity.

2) Many farmers are reluctant to access formal credit because the procedures are perceived as complicated. They tend to rely on informal loans despite higher interest rates. Capital availability is a key factor in enhancing farm efficiency, particularly for purchasing inputs such as high-quality seeds, fertilizers, pesticides, and for renting agricultural machinery and equipment. In practice, however, many farmers in rural areas, including Bireuen District, remain hesitant to obtain formal credit from banks or cooperatives. The main factors contributing to low formal credit uptake include complex administrative procedures, limited accessibility, lack of financial literacy, and concerns about repayment risks. As an alternative, farmers often utilize informal credit sources, such as moneylenders, local traders, or nonformal financial institutions in villages. Informal credit offers advantages such as quick access, no collateral requirements, and trust-based arrangements. However, its drawbacks include higher interest rates and often disadvantageous conditions, such as obligations to sell harvests at lower prices to the lender. This phenomenon highlights a capital access dilemma for farmers: informal credit provides immediate liquidity but reduces long-term profit margins due to high financing costs, whereas formal credit is cheaper but constrained by burdensome procedures and requirements. In Bireuen District, limited access to formal credit helps explain why some farmers cannot purchase inputs according to technical recommendations. This situation results in lower productivity and inefficient allocation of resources, as identified in DEA and SFA analyses. Therefore, policies aimed at simplifying formal credit procedures, improving farmers' financial literacy, and strengthening agrarian microfinance institutions are critically important.
3) Farmer groups that received assistance with tractors and combine harvesters were found to be more efficient, particularly in reducing harvesting costs. The study shows that tractor use decreases reliance on manual labor for land preparation. While traditional methods require 15-20 man-days per hectare, tractor operation requires only 4-6 machine hours. This reduces labor costs and accelerates land preparation, enabling earlier or simultaneous planting, which in turn enhances productivity and land-use efficiency. Meanwhile, the use of combine harvesters is highly effective during the harvesting stage. These machines simultaneously cut, thresh, and package rice grains, thereby reducing harvest losses typically associated with manual harvesting. Whereas manual harvesting can result in losses of 10-12% of rice, the use of a combine harvester can reduce losses to approximately 3-4%. In addition, harvesting costs decrease substantially: manual harvesting averages IDR 4-5 million per hectare, compared to IDR 2.5-3 million per hectare with a combine harvester. These findings are consistent with DEA and SFA analyses, which indicate that the use of machinery or agricultural services contributes positively to technical efficiency scores. Farmer groups with access to mechanization assistance programs generally exhibit higher efficiency scores compared to non-recipient farmers.
4) Most farmers report that their rice production is sufficient to meet household consumption needs throughout the year; however, fluctuations in selling prices undermine food security from an economic access perspective. The majority of farmers in Bireuen District indicate that the quantity of their rice harvest generally meets their household consumption needs over the year. This suggests that the food availability dimension at the household level is adequately secured. With an average paddy field size

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of 0.5-1 hectare and productivity of 4.5–5.5 tons/ha, many households can reserve a portion of their harvest for family consumption, extending even to the next planting season. Nevertheless, food security is not determined solely by availability; it also encompasses economic access. It is in this aspect that Bireuen farmers face significant challenges. Farm-gate rice prices fluctuate sharply: during peak harvest seasons, prices can drop below IDR 5,000/kg, whereas in lean seasons, prices can rise above IDR 6,500/kg. Smallholder farmers, who typically sell their harvest immediately to cover living expenses and repay input loans, are particularly affected by low selling prices, which reduce their net income. Consequently, even when household rice stocks are sufficient, purchasing power for non-food items and additional nutritious food (e.g., protein, vegetables, and health-related goods) becomes constrained. This situation diminishes the quality of food security in terms of utilization (nutritional use) and stability (long-term access). This phenomenon aligns with the FAO (2008) conceptualization of food security, which emphasizes that food must be available, physically and economically accessible, nutritionally utilized, and stable over time. In the case of Bireuen, the availability dimension is met, but economic access remains fragile due to price instability. Weak economic access in Bireuen is therefore a key factor explaining why food security is not yet fully robust, despite relatively adequate rice production for household consumption. Strategic interventions such as strengthening marketing institutions (e.g., farmers' cooperatives and Bulog), establishing village-level food reserves, and implementing price stabilization policies by local government are crucial measures to mitigate this vulnerability.

5) Economic equity, as revealed through Focus Group Discussions (FGDs), highlights a significant gap between smallholder farmers with less than 0.5 hectares and larger-scale farmers with more than 1 hectare. Smallholder farmers are more vulnerable to inefficiency due to capital constraints. The FGDs conducted with farmers in Bireuen District revealed that this gap extends beyond differences in production capacity, also affecting farm efficiency and contributions to rural economic equity. According to (Fauzan *et al*., 2025), smallholders with limited land typically face several structural constraints: 1) Limited capital-Small farm size restricts income, preventing reinvestment in quality inputs such as improved seeds, balanced fertilizers, or modern technology. 2) Restricted access to formal credit-Smallholders often struggle to meet credit requirements, relying instead on informal financing with higher interest rates. 3) Limited mechanization-Use of tractors or combine harvesters is often uneconomical on small plots, increasing labor costs per unit area. 4) Low economies of scale-Fixed costs per hectare, such as land rent, transportation, and equipment depreciation, are proportionally higher for smallholders. In contrast, larger-scale farmers (>1 ha) benefit from better economies of scale. They have greater access to formal credit, can utilize mechanization technologies, and implement more efficient cropping patterns. This is reflected in DEA and SFA analyses, where average technical efficiency scores of large farmers are higher than those of smallholders. From an economic equity perspective, the efficiency gap between small and large farmers has serious implications. Persistent underperformance of smallholders can exacerbate income inequality among rural households. Moreover, the vulnerability of small farmers undermines the foundation of food security, as they constitute a significant proportion of rice-producing households.

4.2 Discussion

The analysis indicates that the technical efficiency of rice farming in Bireuen District remains relatively low. This finding aligns with the studies of (Nana Trisna *et al*., 2024) and (Riska Rianty *et al*., 2024) which emphasize that technical inefficiency often arises from suboptimal input allocation combined with limitations in farm scale. The difference in scores between DEA (0.86) and SFA (0.88) is reasonable, as DEA measures efficiency relative to the best-performing frontier within the sample, whereas SFA accounts for stochastic errors. The consistent patterns observed across both approaches confirm the validity of the findings. Regarding determinants, farmer education, market access, and participation in farmer groups significantly influence efficiency. These results are consistent with the literature (Purnamasari *et al*., 2023); (Nurhanifa & Budiasih, 2023), which highlights the importance of socio-economic factors in production efficiency. Qualitative findings reinforce the quantitative results, indicating that limited capital and access

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to technology are primary sources of inefficiency. FGDs reveal that collective access to agricultural machinery can substantially reduce production costs, consistent with the concept of economies of scale. However, disparities between smallholders and large-scale farmers continue to pose challenges for equitable economic distribution. From a food security perspective, improving efficiency has the potential to enhance availability (higher production with constant inputs) and strengthen access (greater income for farmers). Nevertheless, without supportive policies for food diversification and price stabilization, the dimensions of utilization and stability remain vulnerable. Overall, this study demonstrates that enhancing the efficiency of agricultural resource allocation impacts not only productivity but also food security, economic equity, and regional self-reliance.

5. Conclusion

This study underscores that the agricultural sector, particularly rice farming, continues to play a vital role in supporting food security, economic equity, and regional self-reliance in Bireuen District. The DEA analysis indicates an average technical efficiency of 0.88 among farmers, while the SFA approach yields an average of 0.86. Both methods consistently suggest that the majority of farmers have not yet achieved full efficiency, with potential improvements in input allocation of approximately 10-15%. The factors found to significantly influence efficiency include farmers' education, access to formal credit, and participation in farmer groups. Conversely, advanced age and greater distance to markets increase the risk of inefficiency. These findings indicate that limited capital, technological literacy, and market access constitute the primary constraints suppressing the performance of smallholder farmers. From a socio-economic perspective, this study also identified disparities between smallholder farmers (<0.5 ha) and large-scale farmers (>1 ha). Smallholders are more vulnerable to inefficiency due to limited capital and low economies of scale. This gap adversely affects the equitable distribution of rural income, even though aggregate rice production in Bireuen is sufficient to ensure food availability. However, food security in terms of economic access remains weak due to fluctuations in farm-gate rice prices. Farmers often sell their harvest immediately after the planting season at low prices, resulting in suboptimal net income. Consequently, households' ability to meet diverse nutritional needs and maintain long-term economic stability is reduced. Overall, the study concludes that enhancing the efficiency of agricultural resource allocation in Bireuen requires not only technical improvements at the farm level but also structural reforms, including improved access to credit, mechanization, strengthened farmer group institutions, and policies for stabilizing rice prices. These measures are critical for achieving an efficient, resilient, equitable, and sustainable agricultural sector.

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