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Analysis of Technical and Allocative Efficiency Models for Shallot Farming to Increase Production in Karo Regency

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Abstract

The shallot commodity has a strategic role in national food security, but its production still experiences fluctuations, especially in Karo Regency. The primary challenge faced by farmers is the low level of productivity and efficiency in their production. This study aims to analyze the efficiency model of shallot farms in Karo Regency and identify the factors influencing it, including the complex interaction between external factors (climate change), farmers' adaptive responses, and existing socioeconomic structures. The methods employed are a combination of qualitative and quantitative approaches, including surveys and in-depth interviews. Data analysis will use the Stochastic Frontier Analysis (SFA), Data Envelopment Analysis (DEA), and Tobit regression models. The expected results can provide a comprehensive understanding of the sustainability of shallot farming and offer integrated policy recommendations for local governments, extension workers, and farmers.

Keywords: *Farm Efficiency; Shallot Production; Karo Regency; Stochastic Frontier Analysis; DEA.*

I. INTRODUCTION

Shallot (*Allium ascalonicum* L.) is a superior horticultural commodity that is a target for increasing production in Indonesia. Shallots are not only important as a cooking spice but also have a strategic role in maintaining national inflation and are a significant source of income for farmers (Yusuf, Nursan, & Rahayu, 2023). However, shallot production in Indonesia still faces various problems, including low yields and suboptimal planting techniques (Rauf & Bulkis, 2023). Data from 2021 to 2023 shows a decrease in the national shallot harvest area, although there was a slight increase in production in 2023 (GoodStats Data, 2025). Specifically, in North Sumatra Province, shallot production fluctuates, and Karo Regency is one of the significant production centers known for its high contribution at the provincial level (BPS of North Sumatra Province, 2024). However, despite the increased harvest area in Karo Regency, productivity per unit area remains low (BPS of Karo Regency, 2025), indicating a low level of production efficiency. This problem is caused by various factors, including inappropriate agronomic practices, high production input costs, a lack of access to superior seeds (Rosliani, Hilman, & Kusmana, 2024), and market price fluctuations (Hamzah & Huang, 2023).

The level of farm efficiency is a crucial aspect of enhancing farmer productivity and income (Farrell, 1957; Anang, 2021). Many studies have measured technical and allocative efficiency in various agricultural commodities using parametric approaches such as Stochastic Frontier Analysis (SFA) and non-parametric approaches such as Data Envelopment Analysis (DEA) (Sultana, Rahman, & Hossain, 2023). These studies have identified various factors that influence efficiency, including the use of fertilizer (Guo, Li, & Wu, 2023), pesticides (Mo & Zeng, 2025), labor (Xue et al., 2024), and capital (Wu, Zhou, & Wang, 2025). In Indonesia, research on shallot farming efficiency has also been conducted in various regions (Dasipah, Hariyanto, & Tani, 2023; Asriadi et al., 2024). However, most of these studies tend to focus on internal production factors and analyze the impact of climate separately from socioeconomic dynamics (Yeshiwas, Alemayehu, & Adgo, 2023). This study has novelty with a holistic and integrated approach that has rarely been explored in the context of shallot farming in Karo Regency. This study will reveal the complex interaction between external environmental factors (climate change), farmers' adaptive responses (Kalli, Mandal, & Pal, 2024), and existing socioeconomic structures (Liang, Wang, & Zhou, 2023).

The objectives of this study are:

1. To analyze the level of technical and allocative efficiency of shallot farming in Karo Regency using the SFA and DEA models.
2. To identify socioeconomic and demographic factors that influence the level of shallot farming efficiency.

3. To provide integrated policy recommendations for stakeholders to increase the productivity and sustainability of shallot farming.

The pursuit of farm efficiency is central to enhancing both regional agricultural output and the economic welfare of rural communities. Technical efficiency refers to a farmer's ability to produce the maximum possible output from a given set of inputs, while allocative efficiency relates to the ability to use inputs in optimal proportions given their respective prices. In the dynamic and often volatile agricultural sector, achieving both types of efficiency is challenging, necessitating robust analytical tools.

Dual Methodology: SFA and DEA for Robustness

A key methodological innovation of this study is the combined use of the Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) models. While both are widely accepted for efficiency measurement, their distinct advantages make a dual application crucial for obtaining a comprehensive and robust efficiency score (Sultana, Rahman, & Hossain, 2023). The SFA model, a parametric approach, is favored because it accounts for the stochastic noise inherent in agricultural production, such as weather variability, pests, or measurement errors. By distinguishing between random error and systematic inefficiency, SFA provides a technically sound measure of inefficiency (Skevas, 2025). This is particularly important in the context of Karo Regency, where the volatile climate due to its volcanic location frequently introduces production shocks (BPS of Karo Regency, 2025). Conversely, the DEA model, a non-parametric method, establishes an efficiency frontier based on the best-performing farmers in the sample, without requiring a pre-specified functional form for the production relationship (Kyrgiakos, Anastasopoulos, & Goudelis, 2023). DEA is highly effective in measuring allocative efficiency and scale efficiency, aspects often less explicitly handled by the standard SFA model. By using an input-oriented DEA approach, this research can precisely determine the potential input reductions necessary for inefficient farmers to reach the efficiency benchmark set by their peers. The convergence or divergence of results between these two models will provide a strong foundation for validating the farm efficiency scores before they are used in the second stage of the analysis (Appiah Twumasi, Mckenzie, & Kyei-Baffour, 2022).

Determinants of Inefficiency: Socioeconomic and Technological Factors

Once the efficiency scores are established, the research shifts focus to identifying the determinants of inefficiency using the Tobit regression model. This model is suitable because efficiency scores are bounded between zero and one, which requires a specific censored regression technique (Yeshiwas, Alemayehu, & Adgo, 2023). A range of variables that reflect the human, financial, and institutional capital of the farmer will be explored (Wu, Zhou, & Wang, 2025). Firstly, demographic and human capital variables such as the farmer's age, level of formal education, and years of farming experience are critical. Younger, more educated farmers are often hypothesized to be more technically efficient because they are quicker to adopt new, efficient technologies and management practices (Xue et al., 2024). Conversely, long-term experience, while valuable, can sometimes lead to entrenched, outdated farming methods if not coupled with continuous learning and adaptation.

Secondly, financial and institutional factors play a decisive role. Access to agricultural **credit** is often a prerequisite for timely and adequate input purchase, allowing farmers to operate closer to the optimal frontier (Haryanto, Susilowati, & Suryani, 2023). Similarly, membership and active participation in farmer groups or cooperatives facilitate knowledge exchange, collective bargaining for inputs and outputs, and better access to extension services (Liang, Wang, & Zhou, 2023). These institutional structures represent vital social capital that can directly translate into higher allocative efficiency by securing better prices and reducing transaction costs. Finally, technological and resource management variables are essential. The adoption rate of modern technologies, such as True Shallot Seed (TSS), the precision of fertilizer application (Guo, Li, & Wu, 2023), the efficiency of the irrigation system (Kalli, Mandal, & Pal, 2024), and integrated pest management (Mo & Zeng, 2025) are all expected to significantly influence technical efficiency. These factors directly affect the input-output relationship, pushing the production frontier outwards.

The Role of Climate and Context in Karo Regency

The study is critically grounded in the unique geographical and ecological context of Karo Regency. Situated on the Barisan Mountains, with highly fertile volcanic soil and a distinct high-altitude climate, Karo is one of the primary shallot seed multiplication centers in North Sumatra. This ecological advantage, however, is increasingly threatened by climate change. Erratic rainfall patterns, temperature spikes, and increased pest intensity introduce significant environmental risk factors (Yeshiwas, Alemayehu, & Adgo, 2023). The farmers' capacity for adaptive response to these external shocks becomes a crucial variable in maintaining efficiency. The study will specifically model how farmer adaptations—such as altering planting schedules, utilizing protective measures like simple greenhouses, or switching to drought-resistant techniques—mitigate climate-induced inefficiency. Understanding this complex interplay between environment, adaptation, and efficiency is where the novelty of the research lies, moving beyond simple input-output analysis to a more dynamic model of agricultural sustainability. A regional focus like this is vital, as policy recommendations derived from general national or provincial data often fail to account for the specific needs of local farming systems, such as those in the high-altitude volcanic plains of Karo (BPS of North Sumatra Province, 2024).

Theoretical and Policy Implications

The findings of this research are expected to yield substantial theoretical and practical contributions. Theoretically, the integrated SFA-DEA-Tobit framework, applied to the unique socioeconomic-environmental nexus of shallot farming in Karo, will contribute to the specialized literature on efficiency economics by offering a nuanced approach to modeling inefficiency in developing country agriculture. Practically, the identification of the specific factors driving inefficiency will allow policymakers to move beyond generic interventions. If the study reveals that the lack of access to credit is the most significant source of allocative inefficiency, the government can specifically target financial instruments to increase capital availability (Haryanto, Susilowati, & Suryani, 2023). If low education levels are found to limit technical efficiency, resources can be redirected to focused agricultural extension programs. Ultimately, by pinpointing the areas of greatest inefficiency, this research offers a clear, evidence-based roadmap for stakeholders to formulate targeted and integrated policies, thereby maximizing the return on investment in the shallot sector and strengthening its role in national food security (Dirjen Hortikultura, 2023). This targeted approach is the cornerstone of moving shallot farming in Karo Regency from merely productive to sustainably efficient, ensuring long-term profitability for the local farmers.

II. RESEARCH METHODOLOGY

This research uses a mixed-methods approach that integrates qualitative and quantitative methods. The study will be carried out in Karo Regency, North Sumatra Province, which was chosen through purposive sampling because it is a significant shallot production and seed breeding center. The sample will be determined using the snowball sampling technique to obtain representative data from a varied population of shallot farmers.

2.1. Research Design and Data Collection

The research will begin with a preliminary study to identify key variables that influence efficiency, as well as to collect secondary data from relevant agencies such as the Central Statistics Agency (BPS), the Department of Agriculture, and literature. Primary data will be collected through structured surveys and in-depth interviews with farmers. The survey will include data on production inputs (seeds, fertilizers, pesticides, labor), production output, prices, farmer characteristics (age, education, experience), and information related to adaptation to climate change.

2.2. Data Analysis Model

Data analysis will be carried out in two stages:

1. First Stage: Efficiency Measurement.
   - Stochastic Frontier Analysis (SFA): The SFA model will be used to measure technical efficiency and identify factors causing inefficiency. This approach is chosen because it can separate the inefficiency component from random errors or noise that commonly occur in agricultural data (Skevas, 2025; Xue et al., 2024). The production function to be used is Cobb-Douglas, which has been widely applied in agricultural efficiency studies (Appiah Twumasi, Mckenzie, & Kyei-Baffour, 2022).

     • The stochastic frontier production function is defined as:
     $ln(Yi) = Xi\beta + Vi - Ui$ where I = 1, 2, ….., n…………………….............(1)

   - Data Envelopment Analysis (DEA): The DEA method will be used as a complement to measure allocative and scale efficiency. As a non-parametric method, DEA does not require specific functional assumptions, making it suitable for validating findings from SFA (Kyrgiakos, Anastasopoulos, & Goudelis, 2023). DEA will be input-oriented to determine the extent to which farmers can reduce production inputs without reducing output.

• Output-oriented DEA model:

$\sum_{j=1}^{n} \lambda j \, \gamma rj \geq \theta Yri, \quad r = 1, \ldots, s$...(2)

$\sum_{j=1}^{n} \lambda j \, Xmj \leq Xmi, \; m = 1, \ldots, k$..(3)

$\lambda j \; \geq 0, j = 1, \ldots\ldots, n$ ....(4)

Symbol Description:

i =DMU being evaluated (farmer/land).
n = Number of DMUs
s = Number of outputs
k = Number of inputs
γrj = R-th output of the j-th DMU
Xmj = M-th input of the j-th DMU
θ = Output increase factor (relative efficiency)
λj = Weight of the DMUs forming the frontier

Interpretation of DEA scores:

- Score = 1 →AND is on the frontier →(efficient)
- Score < 1→ (output-oriented) or > 1 (input-oriented) →(inefficient)

2. Second Stage: Analysis of Factors Affecting Efficiency.
   - Tobit Regression: The efficiency scores obtained from the First Stage (both from SFA and DEA) will be used as the dependent variable in the Tobit regression model. This model is suitable because efficiency scores are in the range of 0-1 (Yeshiwas, Alemayehu, & Adgo, 2023).

o Tobit model formula (0-1 sensor)

$TEi{*}{=}\alpha\Sigma\beta pZpi{+}$

$\varepsilon iPp = 1$ ....(5)

$$TE_i = \begin{cases} 0, & \text{jika } TE_i^* \leq 0 \\ TE_i^* & \text{jika } 0 < TE_i^* < 1 \\ 1, & \text{jika } TE_i^* \geq 1 \end{cases}$$ ....(6)

Symbol description:

TE_i^* = Latent efficiency score which can be <0 or >1 before censoring.
TE_i = Technical efficiency score of SFA or DEA results (0-1).
Zpi = Explanatory variables (education, experience, organization, etc.)
α = Intercept
βp = The coefficient of influence of the p-th variable.
Ei = $Error\ term, \varepsilon i \sim N(0, \sigma^2)$

The independent variables to be tested include:

- Demographic and Social Factors: Age, education level, farming experience, number of family dependents.
- Economic Factors: Land ownership, access to agricultural credit (Haryanto, Susilowati, & Suryani, 2023), membership in farmer groups.
- Environmental and Technological Factors: Cropping patterns, pest management practices, irrigation systems (Kalli, Mandal, & Pal, 2024).

3. Research Framework

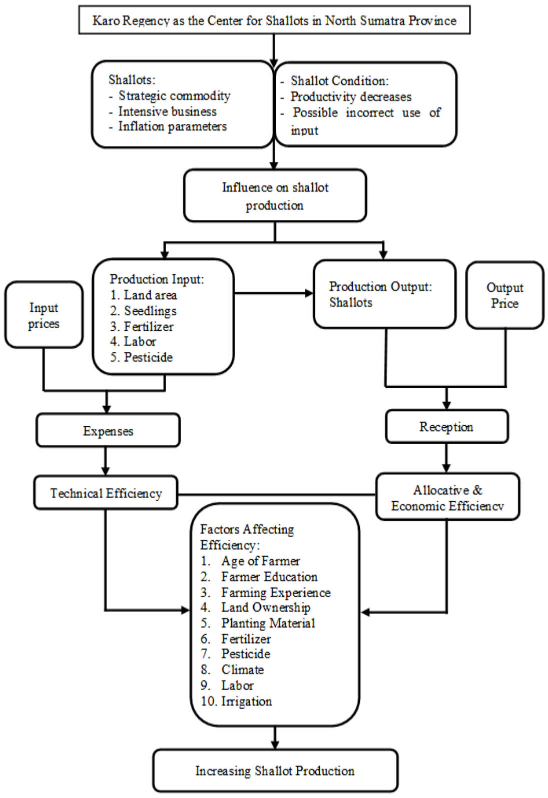

Figure 1. Research Framework

III. RESULTS AND DISCUSSION

3.1. Research Design and Limitations

This proceeding presents the research design for "Farm Efficiency Model in Increasing Shallot Production in Karo Regency," which is still in the data collection and analysis stage. This research aims to provide a comprehensive view of the dynamics of shallot farm efficiency and the factors that influence it. We recognize that every research design has limitations. We plan to address several challenges, such as potential bias in the data collected and the complexity of modeling the interactions between socioeconomic and environmental variables.

3.2. Discussion and Request for Audience Input

We open this session for discussion and welcome input from the esteemed audience, especially those with expertise in agricultural efficiency, econometric models, or horticultural farming. Some specific questions we would like to pose are:

1. Methodology: Is the combination of SFA and DEA models sufficient to measure efficiency in this context, or are there other more relevant approaches to consider?
2. Variables: Are there other variables, besides those we have identified, that you believe are crucial to include in our model to provide more accurate insights?
3. Policy Implications: Based on your experience and knowledge, how can the results of this efficiency analysis be translated into practical and effective policy recommendations for local governments and farmers?

We highly appreciate any constructive suggestions, critiques, or input that will help us refine this research.

IV. CONCLUSION

This research is expected to prove that the efficiency of shallot farming in Karo Regency is influenced by various factors, not only the allocation of physical inputs but also managerial capacity, adaptation to climate, and support from social capital and marketing networks. By using the SFA, DEA, and Tobit regression models, this study will provide a comprehensive understanding of the level of efficiency and the factors causing inefficiency.

V. RECOMMENDATIONS

Based on the expected research results, some recommendations that can be considered are:

1. For Local Governments: Implementing policies that support farmers' access to quality and affordable production inputs, such as superior seeds and subsidized fertilizers.
2. For Agricultural Extension Workers: Providing more intensive education and training to farmers on efficient and sustainable farm management practices, as well as adaptation strategies to climate change.
3. For Farmers: Encouraging the formation and strengthening of farmer groups to increase social capital, facilitate knowledge exchange, and improve bargaining power in product marketing.

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