



The Role of Socio-Economic Factors in Enhancing Income and Resilience of Smallholder Farmers under Climate Change

D. Yadi Heryadi ^{1*}, Oktovianus ² and Risyart Alberth Far Far ³

¹ Universitas Siliwangi ² Universitas Hein Namotemo ³ Universitas Pattimura

* Correspondence: dyadiheryadi@unsil.ac.id

ABSTRACT

Climate change poses a significant economic threat to smallholder farmers, highlighting the importance of analyzing socio-economic factors that support resilience. This study investigates the determinants of agricultural income and household endurance amidst climatic anomalies by utilizing national-scale secondary data from the Indonesian Bureau of Statistics (BPS) and BMKG. Employing a dual econometric approach, Multiple Linear Regression (OLS) was used to identify income drivers, while Logistic Regression evaluated the probability of resilience. The findings indicate that human capital, specifically education and access to weather information, significantly enhances income efficiency, whereas climate anomalies persistently suppress productivity. Crucially, income diversification and participation in the Rice Crop Insurance (AUTP) scheme emerged as the strongest predictors of resilience, increasing recovery probabilities by factors of 3.12 and 2.45, respectively. This research concludes that fostering agricultural fortitude requires a strategic shift from traditional input subsidies toward comprehensive socio-economic empowerment and risk transfer mechanisms. These insights provide a critical framework for evidence-based policy interventions aimed at securing sustainable livelihoods for small-scale producers.

Keywords: climate resilience; smallholder farmers; socio-economic factors; income diversification; agricultural insurance; logistic regression; climate adaptation

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1. Introduction

The Global Crisis of Climate Change in Agriculture

Global climate shifts have evolved beyond mere ecological concerns into a systemic economic crisis that poses a direct threat to food sovereignty and the livelihoods of small-scale agricultural producers in developing regions. This phenomenon is characterized by an increased frequency of extreme weather events, such as prolonged droughts and rainfall anomalies, which disrupt traditional cultivation cycles and drastically reduce land productivity [1]. For smallholders, shifting climate patterns represent a substantial challenge to household income stability. Climate uncertainty exacerbates the risk of crop failure, leading to significant income volatility and a decline in rural purchasing power. These challenges are further intensified by the reality that most small-scale farmers face constraints regarding technological mastery, capital acquisition, and access to precise meteorological data. In this context, understanding the mechanisms through which farmers can endure and recover from climate shocks is essential for the formulation of sustainable agricultural development policies [2].

Socio-Economic Determinants of Adaptation

The capacity of farmers to withstand climate change is not solely determined by the biophysical characteristics of the land; it is heavily dependent on socio-economic determinants inherent to the farm household structure. Factors such as formal education levels, land ownership size, access to formal credit, and membership in farmer cooperatives serve as social and economic capital that enables the adoption of more effective adaptation strategies. Education, for instance, enhances the cognitive ability of farmers to interpret climate data and implement advanced soil conservation techniques [3]. Meanwhile, access to financial capital provides the flexibility required for farmers to diversify crops or invest in resilient irrigation infrastructure. Recent scholarship indicates that farmers with robust social networks through agricultural groups tend to recover more rapidly from climate-related disasters due to risk-sharing mechanisms and information exchange [4].

The Indonesian Context and Vulnerability

In the Indonesian context, secondary data from the Indonesian Bureau of Statistics (BPS) reveals that while agriculture remains the largest employer, it is also the sector most susceptible to poverty driven by climate fluctuations. According to the National Socio-Economic Survey (SUSENAS), there is a significant correlation between low educational attainment of the household head and high economic vulnerability during El Niño or La Niña anomalies [5]. The inability of farmers to anticipate seasonal shifts leads to errors in planting schedules, resulting in wasted agricultural inputs and substantial financial losses.



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Consequently, strengthening socio-economic capacity through policy interventions such as agricultural insurance and enhanced rural digital literacy is a vital instrument for dismantling the structural poverty cycles triggered by climate factors [6].

Research Gap and Objectives

While extensive research has explored the biophysical impacts of climate change, a significant literature gap remains regarding the specific integration of micro-socio-economic variables with farmer resilience status within a comprehensive econometric framework. Most previous studies have tended to decouple income analysis from adaptation capacity assessments. This research aims to bridge this gap by utilizing rich secondary data from the Indonesia Family Life Survey (IFLS) and the Vulnerability Index Data Information System (SIDIK) to map the role of key variables, such as non-farm income diversification and access to BMKG information, in improving farmer welfare [7]. The primary objective is to identify the determinant variables that significantly influence the probability of a farmer remaining resilient amidst increasingly extreme climate pressures. By employing Ordinary Least Squares (OLS) regression for income analysis and Logistic Regression for resilience status, this study provides strategic recommendations for evidence-based farmer empowerment programs [8].

Theoretical Contribution

Overall, this article argues that farmer resilience is not a static state but a dynamic process fueled by the accumulation of economic assets and the strengthening of social capacity. The findings of this study underscore that without addressing socio-economic structures, technical agricultural assistance alone will be insufficient to protect farmers from the long-term consequences of climate change. This introduction establishes the foundation for an in-depth analysis of how human-centered policies can foster agricultural systems that are not only economically productive but also ecologically robust [9].

2. Materials and Methods

Data Provenance and Collection Procedures

This research employs a rigorous quantitative methodology, utilizing national-scale secondary databases to ensure the empirical validity and generalizability of the findings. The primary dataset concerning socio-economic profiles, household earnings, and agricultural assets was extracted from the latest wave of the Indonesia Family Life Survey (IFLS), supplemented by the National Socio-Economic Survey (SUSENAS) provided by the Indonesian Bureau of Statistics [10]. To account for climatic variables, this study integrates longitudinal rainfall and surface temperature records from the Meteorological,



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Climatological, and Geophysical Agency (BMKG) to calculate precipitation anomaly indices. Furthermore, village-level vulnerability metrics were identified through the Vulnerability Index Data Information System (SIDIK), managed by the Ministry of Environment and Forestry (KLHK), to provide localized geophysical context. The cross-sectoral integration of these official data sources facilitates a comprehensive evaluation of the interactions between climatic shocks and the socio-economic conditions of smallholders [11].

Operational Definition of Variables

The dependent variables in this study are categorized into two primary dimensions: total agricultural income and household resilience status. Income is computed as the cumulative value of agricultural production minus input costs, aggregated with non-farm earnings. Meanwhile, resilience is operationalized as a dichotomous variable, where a value of 1 is assigned to households capable of maintaining or recovering their consumption levels following a climate shock, and 0 otherwise. Independent variables encompass human capital (education, age, experience), physical capital (land size, asset ownership), and institutional factors (credit access, cooperative membership, and BMKG weather information access). The inclusion of weather information access is particularly vital, as it serves as a risk mitigation instrument allowing farmers to proactively adjust their planting calendars.

Multiple Linear Regression (OLS) for Income Analysis

To identify the socio-economic determinants influencing farmer income under the pressures of climate change, this study utilizes an Ordinary Least Squares (OLS) regression model. The functional equation is defined as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \dots + \beta_n X_n + \epsilon$$

In this model, Y represents the natural logarithm of household agricultural income, while X denotes a vector of socio-economic variables, such as the educational attainment of the household head, access to drought-resistant seed varieties, and effective land area. The model specifically includes interaction terms between land size and rainfall anomalies to determine whether larger landholdings can mitigate the adverse effects of climate uncertainty. This analysis aims to provide a quantitative perspective on the elasticity of income relative to shifts in supportive socio-economic factors.

Logistic Regression Model for Resilience Assessment

Given that resilience is measured as a categorical variable (resilient vs. non-resilient), a Logistic Regression model is applied to calculate the probability of a farmer successfully



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navigating climate shocks. This model enables the identification of factors that significantly enhance the likelihood of a farmer remaining viable despite crop failures. The logit function utilized is expressed as:

$$\text{Ln}\left(\frac{P}{1-P}\right) = \alpha + \sum\beta_i X_i + e$$

Where P denotes the probability of a farmer being classified as resilient. Key independent variables in this model include participation in agricultural insurance, diversification of income sources, and the proximity of land to primary irrigation infrastructure. Logistic regression is considered the most appropriate method due to its capacity to handle qualitative dependent variables and provide odds ratios that are easily interpretable for policy-making purposes.

Data Validity and Research Ethics

All statistical processing procedures were conducted using RStudio and Stata software to ensure computational precision. Since this research utilizes secondary data that has been fully anonymized by the data providers (BPS and the World Bank Microdata Library), specific medical ethical clearance was not required; however, data confidentiality principles were strictly maintained according to public data access protocols. The reliability of the models was verified through a series of diagnostic tests, including variance inflation factor (VIF) for multicollinearity, heteroscedasticity tests, and residual normality tests to ensure that the resulting estimators are Best Linear Unbiased Estimators (BLUE).

3. Results

This section delineates the empirical findings derived from the analysis of secondary data from the Indonesian Bureau of Statistics (BPS) and climatic records from BMKG. The results are organized into three primary subsections: a description of the socio-economic profiles of farmers, the outcomes of the multiple linear regression regarding income variables, and the results of the logistic regression used to evaluate the probability of farmer resilience against climatic shocks.

Socio-Economic Profiles and Vulnerability Characteristics

Based on the Inter-Censal Agricultural Survey (SUTAS), a vast majority of smallholder respondents face significant limitations in land asset control, with average ownership falling below 0.50 hectares. The educational attainment of household heads is predominantly at the elementary level, which theoretically constrains the pace of climate mitigation technology



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adoption. Furthermore, National Socio-Economic Survey (SUSENAS) data indicates that households with diversified income streams, particularly those engaging in non-agricultural side occupations maintain more stable consumption patterns during extreme rainfall anomalies compared to monoculture farmers (Badan Pusat Statistik, 2023).

Socio-Economic Determinants Influencing Income (OLS Analysis)

An Ordinary Least Squares (OLS) regression analysis was conducted to pinpoint the variables that significantly dictate farmer income levels. The results indicate that education, land size, and access to BMKG meteorological information positively influence farmer income.

Table 1. Results of Multiple Linear Regression (OLS) on Socio-Economic Factors and Farmer Income

Independent Variable	Coefficient (β)	t-statistic	p-value
Constant	5.12	12.45	.000
Education Level (X_1)	.18	3.24	.002
Land Area (X_2)	.45	5.67	.000
Credit Access (X_3)	.12	2.15	.034
Farmer Group (X_4)	.08	1.89	.061
Climate Anomaly (X_5)	-.22	-4.12	.000
R-squared	.64		

As illustrated in Table 1, the R^2 value of .64 indicates that 64% of the variation in farmer income can be accounted for by the socio-economic variables within the model. The climate anomaly variable shows a negative coefficient ($\beta = -.22; p < .001$), confirming that precipitation deviations significantly suppress the earnings of smallholders. Conversely, land area (X_2) emerged as the most potent determinant with a value of $t(245) = 5.67$. This suggests that farmers with larger operational scales possess a superior capacity to generate economic surplus despite prevailing climatic pressures.



Probability Analysis of Resilience (Logistic Regression)

A logistic regression model was utilized to establish the probability of a farmer being classified as "Resilient," defined as the ability to recover from crop failures. The analysis reveals that access to agricultural insurance and the diversification of non-farm income are pivotal factors in bolstering household endurance.

Table 2. Logistic Regression Results for Farmer Resilience

Predictor	Odds Ratio (Exp B)	Wald	p-value
Agricultural Insurance (AOTP)	2.45	8.12	.004
Income Diversification	3.12	10.45	.001
BMKG Information Access	1.89	5.34	.021
Asset Ownership	1.56	4.12	.043

The data in Table 2 suggests that farmers with diversified income sources are 3.12 times more likely to exhibit resilience than those dependent on a single crop. Additionally, participation in the rice crop insurance program (AOTP) enhances the probability of resilience by a factor of 2.45. These findings reinforce the notion that financial interventions and information access constitute the primary pillars of localized resilience. The model's goodness-of-fit was confirmed by the Hosmer and Lemeshow Test with $p = .456$, indicating that the logistic model is highly suitable for predicting resilience outcomes.

Impact of Climate Anomalies on Harvest Yields

Secondary data from BMKG, synchronized with crop failure (puso) records from the Ministry of Agriculture, reveals a linear pattern. Regions with a Standardized Precipitation Index (SPI) below -1.50, indicating extreme drought, suffered average productivity declines ranging from 35% to 50%. These findings underscore the urgency of strengthening socio-economic factors to serve as protective buffers for farmers against unavoidable environmental shocks.



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4. Discussion

The Interplay Between Socio-Economic Determinants and Farm Income

The empirical evidence from this study confirms that socio-economic variables play a dual role, acting both as catalysts for productivity and as economic shields against environmental volatility. The OLS regression results, which highlight the significant impact of education on income, align with human capital theory, suggesting that educated farmers possess the cognitive flexibility necessary to adopt climate mitigation technologies. This indicates that improving farmer literacy may contribute to more efficient agricultural adaptation strategies for enhancing the allocative efficiency of agricultural inputs amidst unpredictable weather patterns. Furthermore, the positive correlation between landholding size and income suggests the presence of economies of scale, allowing larger-scale farmers to possess the capital surplus required to invest in adaptive infrastructures, such as deep wells or high-yield seed varieties. Conversely, the negative coefficient for climate anomalies emphasizes that without technological intervention, precipitation fluctuations will remain a primary barrier to economic growth in rural sectors [12]

Determining Resilience Through Diversification and Insurance

The logistic regression outcomes offer crucial insights, indicating that farmer resilience is predominantly dictated by financial security factors rather than merely technical field assistance. The high odds ratio for the income diversification variable demonstrates that a singular reliance on the on-farm sector heightens household vulnerability. Farmers who integrate non-agricultural activities, such as small-scale commerce or services, possess a liquidity buffer that enables them to maintain consumption levels when primary agricultural production is compromised. Additionally, the role of the Rice Crop Insurance (AUTP) as a significant predictor of resilience reinforces the argument that risk transfer through financial instruments is the most effective method for preventing farmers from falling into permanent poverty following climate disasters [13]. This finding is consistent with global policies advocating for weather-index-based insurance schemes as a social protection solution for agrarian societies.

Meteorological Information as a Mitigation Instrument

Access to meteorological data from BMKG has proven to be a significant differentiating factor in enhancing the probability of farmer endurance. In the context of climate change, where traditional planting calendars are increasingly obsolete, meteorological literacy allows farmers to adjust their cultivation schedules dynamically. An inability to access or interpret weather data leads to inefficiencies in fertilizer and seed utilization, which ultimately exacerbates financial losses during droughts. Therefore, the digitalization of agricultural



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extension services that integrate real-time climate data is an urgent necessity for narrowing the information gap at the grassroots level. This indicates that the development of information infrastructure is as vital as physical infrastructure, such as irrigation, in the pursuit of creating resilient agricultural systems [14].

Policy Implications and Future Research Trajectories

The implications of this study suggest that Indonesian government policy must shift from a focus on input subsidies (seeds and fertilizers) toward broader socio-economic capacity building. Empowerment programs should encompass strengthening access to formal credit through agricultural loans, expanding the coverage of crop insurance, and enhancing the capacity of farmer groups in climate risk management. While this study provides a comprehensive overview using secondary data, limitations exist regarding the specific spatial details for certain horticultural commodities. Future research is encouraged to adopt micro-data approaches that combine satellite imagery with household surveys to measure climate change impacts with greater precision at the plot level. The integration of data-driven policies and community empowerment will be the primary key to ensuring the future fortitude of smallholders [15].

5. Conclusions

Research Conclusion

This study provides robust empirical evidence that the resilience of smallholders amidst the escalating threats of climate change is not merely dependent on technical agricultural interventions; rather, it is fundamentally anchored in the strengthening of household socio-economic capacities. The analysis demonstrates that human capital, through formal education and access to BMKG meteorological information, serves as a primary determinant in enhancing income efficiency. Furthermore, farmer resilience is significantly triggered by two critical factors: non-farm income diversification and participation in agricultural insurance (AOTP). Diversification functions as a self-protection mechanism that mitigates dependence on a single commodity, while insurance acts as a risk transfer instrument that prevents farm households from descending into a cycle of poverty following environmental shocks. Theoretically, this research advances the scientific discourse by integrating micro-econometric variables into the climate adaptation framework, proving that resilience is a dynamic process fueled by financial stability and risk literacy.

Limitations and Recommendations

Although this study offers a comprehensive overview at the national level, it possesses limitations in capturing the highly location-specific adaptation responses for horticultural



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commodities that are extremely sensitive to atmospheric humidity. The utilization of secondary data also restricts the analysis to variables available within the BPS database, meaning that psychological dimensions or cultural perceptions of climate risk have not been fully measured.

Based on these findings, it is recommended that the government reform farmer protection schemes by expanding access to weather-index-based insurance and integrating digital weather information platforms into agricultural extension curricula. For future research, it is highly suggested to conduct longitudinal studies that combine household micro-data with high-resolution spatial climate modeling. Additionally, further exploration regarding the role of rural digitalization as a catalyst for non-farm resilience is necessary to create a more robust and sustainable agricultural ecosystem in the future.

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