Converging Paths to Resilience: Analyzing Food and Energy Security Dynamics in SULAMPUA

Basri Basri [1*] and Yusri Yusri [2]

[1] *Postgraduate Program, Sunan Kalijaga State Islamic University, Yogyakartay, Indonesia;*
[2] *Postgraduate Program, State Islamic Institute of Bone, Indonesia*

[*]*E-mail:* basribasyir862@gmail.com

Abstract

This study examines the convergence of food and energy security in the Sulawesi, Maluku, and Papua (SULAMPUA) region as a key element of national resilience. Using a dynamic panel model with the Generalized Method of Moments (GMM) on data from 10 provinces (2018–2023), the analysis reveals that food security is strongly supported by agricultural technology assistance, which boosts productivity despite shrinking farmland. Equitable fertilizer subsidies are also critical, while natural disasters require targeted adaptation strategies. On the energy side, declining crude oil production weakens stability, but renewable energy development offers significant potential. However, infrastructure limitations and global oil price fluctuations remain significant challenges. Policy implications underscore the need to integrate food and energy strategies, combining agricultural technology, fertilizer subsidies, and accelerating renewable energy development. Green infrastructure, including clean-energy irrigation systems, can enhance resilience while reducing carbon emissions. Strengthening disaster risk management through early warning systems and local crop diversification is also vital. Additionally, energy price-stabilization policies, such as buffer stocks and fiscal incentives for renewables, are necessary to reduce dependence on global markets. Overall, the findings underscore the importance of a multisectoral, evidence-based approach to building sustainable resilience in the SULAMPUA region.

Keywords: Food Security; Energy Security; Green Infrastructure; SULAMPUA; GMM
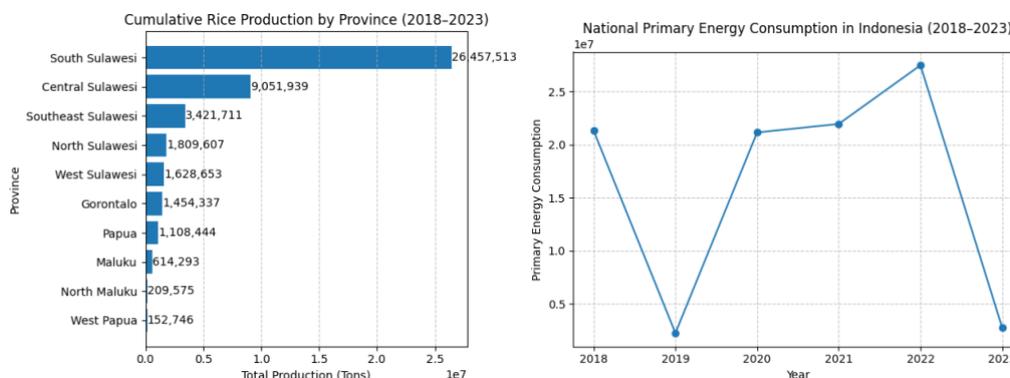
INTRODUCTION

Food and energy security are fundamental to sustainable development and global stability. The projected global population growth of 9.7 billion by 2050 is expected to drive food demand up to 60 percent compared to current levels (FAO, 2023). Simultaneously, energy needs are increasing as industrialization, urbanization, and digitalization accelerate. These two sectors are closely interconnected: energy is a critical input throughout the food production chain, from land cultivation and fertilizer production to transportation and household consumption, while food can also serve as a

source of energy through the use of bioenergy based on food crops and organic waste (He et al., 2024).

The phenomenon of climate change increases vulnerabilities to food and energy availability. The FAO (2023) indicates that changes in rainfall patterns, rising average temperatures, and extreme climate events reduce agricultural productivity, particularly in tropical regions. The (IPCC 2022), report warns that if global temperature increases exceed 2°C, global production of key food crops, such as rice, corn, and wheat, will decline significantly. This indicates that food security no longer depends solely on production, but also on access, distribution, and price stability, which are strongly influenced by the global energy system.

In the Indonesian context, food and energy are highly strategic. As the world's fourth most populous country, demand for these two commodities continues to increase annually. However, despite its strategic position, Indonesia still faces significant challenges, including dependence on imports of several staple food commodities, such as wheat, soybeans, and rice, at certain times (Singh, 2006). In the energy sector, declining national oil reserves are being offset by increasing consumption, making Indonesia a net oil importer since 2004 (IEA, 2021). This situation has the potential to create vulnerability to economic and political turmoil, given that food and energy are commodities sensitive to global dynamics.

Figure 1. Rice production and primary energy consumption in SULAMPUA, 2018–2023

Source: Statistics Indonesia (BPS), processed by the author

Rice production in Eastern Indonesia (Sulawesi, Maluku, and Papua) during the 2018–2023 period highlights structural disparities and their implications for national food security. As shown in Figure 1, South Sulawesi dominates regional rice production, contributing approximately 26.4 million tons over the observation period and thereby serving as the primary production center in the SULAMPUA region. Central Sulawesi and Southeast Sulawesi follow, with cumulative production of about 9.0 million tons and 3.4 million tons, respectively, indicating considerable potential for further agricultural development. Nevertheless, a substantial production gap persists relative to South Sulawesi. Moderate production levels are observed in North Sulawesi (around 1.8 million tons), West Sulawesi (around 1.6 million tons), and Gorontalo (around 1.4 million tons). Although smaller in scale, these provinces remain important contributors to regional food

availability and stability. In contrast, Maluku, North Maluku, Papua, and West Papua record relatively low cumulative production, ranging from approximately 0.15 to 0.61 million tons. These disparities are associated with structural constraints, including geographic conditions, infrastructure limitations, and land suitability. Consequently, food security strategies in these regions should not rely solely on increasing rice production but should also emphasize diversification based on local staple commodities to support more adaptive and sustainable food systems (Central Bureau of Statistics of Indonesia., 2024).

Meanwhile, Indonesia's national energy sector exhibits considerable fluctuations over the 2018–2023 period. Primary energy consumption declined sharply in 2019 to approximately 2.25 million units, compared with 21.31 million units in 2018. A substantial rebound occurred in 2020, when consumption increased to around 21.16 million units, followed by a gradual rise in 2021. Consumption continued to increase and peaked in 2022 at approximately 27.49 million units, the highest level during the observation period. However, in 2023, primary energy consumption declined again significantly, falling to approximately 2.78 million units. These pronounced fluctuations reflect the volatility of national energy demand and its sensitivity to broader economic conditions (Our World in Data, 2024).

The Sulawesi, Maluku, and Papua (SULAMPUA) region occupies a unique and strategic position on the national map of food and energy security. From a food perspective, this region relies not only on rice production from South Sulawesi as its primary food source, but also holds potential for diversification through Maluku's abundant fisheries sector. Meanwhile, in the energy sector, Papua is recognized for its substantial oil and gas reserves and significant renewable energy potential. Despite its substantial resource potential, food and energy security at the local community level still faces various complex challenges. Factors such as limited supporting infrastructure, dependence on external supplies, and high logistics costs due to the region's archipelagic and mountainous geographical configuration are significant obstacles to optimizing its potential (Fatimah et al., 2024).

Furthermore, vulnerability to natural disasters such as earthquakes, tsunamis, floods, and droughts further exacerbates the risks. Each time a disaster occurs, food distribution is hampered, prices soar, and energy supplies are disrupted. Therefore, food and energy security in SULAMPUA is determined not only by availability but also by socio-ecological resilience. The food-energy nexus framework is necessary to understand the relationship between the two in a more integrative manner, so that policies are no longer sectoral and partial (Rachmaningsih & Priyarsono, 2012).

Therefore, the literature on food and energy security in Indonesia has largely concentrated on production systems and policy dynamics in Java and Sumatra, while studies on eastern Indonesia remain relatively limited despite the region's distinct socio-ecological characteristics and structural vulnerabilities (Lisanty et al., 2021; Syuhada et al., 2020; Bilqis et al., 2026). Consequently, empirical research examining the convergence between food and energy security at the sub-national level in eastern Indonesia is still scarce. This study seeks to address this gap by analyzing the dynamic

relationship between food and energy security in the SULAMPUA region. The findings are expected to contribute to the academic literature and provide policy-relevant insights for both central and regional governments. Based on this background, this study aims to answer three main questions: (1) what are the dynamics of food security in the SULAMPUA region; (2) what is the condition of energy security in the region; and (3) to what extent is there a reciprocal relationship between food and energy security and its implications for sustainable development. Methodologically, this research applies a dynamic panel approach using the Generalized Method of Moments (Arellano & Bond, 1991; Blundell & Bond, 1998).

The contributions of this research can be divided into two. First, from an academic perspective, this research enriches the study of the food-energy nexus, which remains relatively underexplored in eastern Indonesia. Second, from a practical perspective, this research supports the formulation of more integrative policies, both within the framework of the National Medium-Term Development Plan (RPJMN) and the strategy for achieving the Sustainable Development Goals (SDGs), especially goal 2 (Zero Hunger), goal 7 (Affordable and Clean Energy), and goal 13 (Climate Action) (Arora & Mishra, 2023; South & Alpay, 2025). Thus, this research is not only theoretically relevant but also has strategic value for sustainable development in Indonesia.

LITERATURE REVIEW

Food and energy security constitute two fundamental pillars of sustainable development that are deeply interconnected. In contemporary economic systems, food production and distribution are highly dependent on energy inputs, ranging from the operation of agricultural machinery and fertilizer production to irrigation systems, cold-chain management, and logistics (Taghizadeh-Hesary et al., 2019). This structural dependency generates systemic vulnerability, whereby fluctuations in energy prices directly affect food production costs and supply stability, particularly for vulnerable populations (To & Grafton, 2015). Conversely, energy development especially bioenergy expansion, may compete with food production for critical resources such as land and water. These dynamics are closely aligned with the Food–Energy–Water (FEW) Nexus framework (Bazilian et al., 2011; D'Odorico et al., 2018), which provides a comprehensive analytical lens to assess sectoral trade-offs and synergies while addressing fragmented policy approaches.

The interconnection between food and energy security becomes more analytically robust when examined through the Social–Ecological Systems (SES) perspective (Folke, 2006; Hodbod & Eakin, 2015). This framework emphasizes system resilience and adaptive capacity in responding to shocks. From this standpoint, food and energy security should not be conceptualized as static outcomes but rather as dynamic capacities to absorb disturbances such as natural disasters or market volatility while maintaining essential functions. Furthermore, to understand the paradoxes frequently observed in resource governance, the Resource Curse hypothesis (Sachs & Warner, 2001) and New

Institutional Economics (North, 1990) offer complementary theoretical insights. The former explains how resource abundance, such as oil wealth, may undermine long-term energy security through economic distortions and institutional fragility, whereas the latter underscores the critical role of institutional quality in facilitating technological adoption and sustainable innovation.

Empirical scholarship increasingly investigates the interdependencies between food and energy systems, particularly in developing economies where agricultural production is highly sensitive to energy availability and price stability. Evidence suggests that improvements in food security are often associated with rising energy intensity and carbon emissions, thereby generating a policy dilemma between agricultural expansion and environmental sustainability (Hasan & Adnan, 2025). Moreover, energy transition policies influence food systems through shifts in land use, changes in agricultural value-added dynamics, and variations in rural energy access (Zhuang et al., 2022). Recent geopolitical disruptions further illustrate the tight coupling between global energy and food markets. The Russia–Ukraine conflict, for instance, triggered substantial increases in wheat, fertilizer, and energy prices, thereby exacerbating food insecurity in import-dependent countries (Zhuang et al., 2022; Hellegers, 2022).

These developments underscore the vulnerability of food systems to energy shocks, particularly in developing economies characterized by high dependence on energy-intensive inputs. At the same time, renewable energy expansion has been widely recognized as a strategic pathway to enhance energy security. Empirical evidence indicates that renewable energy development can mitigate energy security risks and improve system stability, although its magnitude and direction vary across national contexts (Cergibozan, 2022; Khan et al., 2023). Within developing-country settings, infrastructure deficits, institutional quality, and macroeconomic constraints further intensify the linkage between energy and food security (Karunathilake et al., 2022; Wudil et al., 2022).

Overall, the literature demonstrates that the relationship between food and energy security operates through multiple channels, including price transmission mechanisms, infrastructure dependence, land-use competition, and geopolitical risk exposure. Nevertheless, empirical investigations examining the dynamic convergence between food and energy security at the subnational level particularly in archipelagic and disaster-prone regions remain limited.

In Indonesia, discourse surrounding food and energy security has gained increasing scholarly and policy attention. However, integrative empirical analyses bridging these two sectors remain scarce and are largely concentrated in Java and Sumatra (Rachmaningsih & Priyarsono, 2012). In contrast, the Sulawesi, Maluku, and Papua (SULAMPUA) region exhibits distinct and paradoxical characteristics: despite its abundant natural resource endowment spanning agriculture, fisheries, and renewable energy it continues to experience structural vulnerabilities driven by infrastructural limitations, archipelagic geography, and recurrent natural disasters (Fatimah et al., 2024; Alfiandy & Ilahi, 2023).

To date, empirical research examining the convergence and interrelationship between food and energy security in eastern Indonesia using dynamic panel econometric

techniques remains virtually absent. This research gap constitutes the primary motivation for the present study. Accordingly, this study aims to analyze the convergence of food and energy security in Sulawesi by employing a Generalized Method of Moments (GMM) dynamic panel model. This methodological approach enables the identification of causal and dynamic relationships among key variables while addressing endogeneity concerns and controlling for interregional heterogeneity. The findings are expected to provide robust empirical evidence on the mechanisms underlying food–energy interactions within an archipelagic context and to formulate integrated policy recommendations aimed at strengthening sustainable national resilience.

Hypotesis Development

The literature indicates that food and energy security constitute interdependent systems shaped by technological development, institutional capacity, resource availability, and vulnerability to external shocks. Within the Food–Energy Nexus and Social–Ecological Systems frameworks, the relationship between these domains is non-linear and contingent upon system adaptability, institutional quality, and regional economic structures. Accordingly, this study formulates a set of hypotheses to examine the effects of agricultural technology, farmer capacity, energy sources, infrastructure, and disasters on the dynamics of food and energy security in the SULAMPUA region, as follows:

    1) Determinants of Food Security

H1. Agricultural technology has a positive effect on regional food security.

H2. The positive effect of agricultural technology on food security is strengthened by higher farmer capacity.

H3. Agricultural infrastructure has a positive effect on food security.

H4. Expansion of cultivated land has a positive effect on food security.

H5. Diversification of agricultural and livestock commodities contributes positively to food security.

H6. Natural disasters have a negative effect on food security.

    2) Determinants of Energy Security

H7. Dependence on petroleum production negatively affects regional energy security.

H8. Renewable energy development positively affects energy security.

H9. Energy infrastructure significantly influences the level of regional energy security.

H10. Global energy prices influence the dynamics of regional energy security.

    3) Food–Energy System Linkages

H11. Food security and energy security interact through structural mechanisms, including technology, infrastructure, and resource utilization.

H12. Regional adaptive capacity reflected in institutional quality, infrastructure development, and economic diversification moderates the impact of external shocks on food and energy security.

METHODOLOGY

Research Design and Regional Coverage

This study uses a quantitative approach to analyze the dynamic relationship between food and energy security in the Sulawesi, Maluku, and Papua (SULAMPUA) region. Ten provinces were selected for the study: Gorontalo, Maluku, North Maluku, Papua, West Papua, West Sulawesi, South Sulawesi, Central Sulawesi, Southeast Sulawesi, and North Sulawesi, with an observation period from 2018 to 2023. This region was selected based on its strategic characteristics as a paradoxical duality: on the one hand, it has the potential to become a food barn based on local commodities and the largest renewable energy hub in Eastern Indonesia, but on the other hand, it faces structural vulnerability due to the high risk of natural disasters and limited basic infrastructure. The research period was chosen because it encompasses the implementation phase of the 2020-2024 National Medium-Term Development Plan (RPJMN) and the Sustainable Development Goals (SDGs) agenda, both of which emphasize the convergence of the food, energy, and environmental sectors.

Estimation Method

The analytical method used is the Generalized Method of Moments (GMM) for dynamic panel data with System GMM specifications (Blundell & Bond, 1998). This method was chosen based on three crucial methodological considerations. First, there is the possibility of endogeneity in the relationship between variables such as agricultural technology and food security, which GMM addresses by using lags of the level variables as valid internal instruments. Second, this method captures temporal dynamics by including lags of the dependent variable, enabling convergence analysis (β-convergence) within the food-energy security framework. Third, System GMM is robust to unobserved province-specific heterogeneity, which is particularly relevant given the significant performance disparities between provinces in SULAMPUA.

Model Specifications and Variables

Based on the Food-Energy Nexus framework, this study develops three groups of estimation models:

$$FSI_{it} = \alpha + \delta FSI_{i}, t - 1 + \beta_1 TECH_{it} + \beta_2(TECH \times FARMER)_{it} + \beta_3(TECH \times ROAD)_{it} + yControl + \mu\acute{\imath} + eit \tag{1}$$

$$IEC_{it} = \alpha + \delta IEC_{i}, t - 1 + \beta_1 DE_{it} + \beta_2(DE \times RENEWABLE)_{it} + \beta_3(DE \times POWER)_{it} + yyControl + \mu\acute{\imath} + eit \tag{2}$$

$$FSI_{it} = \alpha + \delta FSI_{i}, t - 1 + \beta_1 DIS_{it} + \beta_2(DIS \times FARMER)_{it} + yControl + \mu\acute{\imath} + eit \tag{3}$$

First, we estimate the effect of agricultural technology (TECH) and its interaction with institutional factors (FARMER) and infrastructure (ROAD) on the Food Security Index (FSI), controlling for planted area (PLANT), harvested area (HARVEST), and other factors. Where FARMER is the number of farmers, ROAD is the length of roads, and X is a vector of control variables such as planted area (PLANT), harvested area (HARVEST), fertilizer subsidies, and agricultural credit. Second, our model focuses on

the determinants of energy security, analyzing the effects of crude oil production (DE) and its interaction with renewable energy and infrastructure on the Energy Security Index (IEC). With RENEWABLE as the proportion of renewable energy, POWER as energy infrastructure, and Z as a vector of control variables, including global oil prices (OILPRICE), per capita GRDP, and population. Third, we focus on the impact of disaster frequency (DIS) and its interaction with technological capacity on food security. To test the hypothesis that technology can moderate the negative impact of disasters on food security, within each group, several variations of the specification were estimated to assess robustness and explore different mechanisms of influence. Complete operational definitions and data sources for all variables are presented in Table 1.

Table 1. Variable Description

Variable	Measurement	Data Source
Agricultural Technology	Use of agricultural tools/machinery (units/ha)	Statistics Indonesia
Natural Disaster	Frequency of disaster events (times/year)	Statistics Indonesia
Number of Farmers	Total active farmers (persons)	Statistics Indonesia
Crude Oil Production	Production volume (barrels/year)	Statistics Indonesia
Harvested Area	Harvest area (hectares)	Statistics Indonesia
Planted Area	Planting area (hectares)	Statistics Indonesia
Food Security Index	Ratio of production/food needs (tons/year)	Statistics Indonesia
Farmer Income	Farmer Terms of Trade (NTP) (%)	Statistics Indonesia
Livestock Commodity Consumption	Consumption volume (kg/capita/year)	Statistics Indonesia
Fertilizer Subsidy	Subsidized fertilizer volume (tons/year)	Statistics Indonesia
Transportation Infrastructure	Road length (km)	Statistics Indonesia
Geographic Coordinates	Latitude of study area (degrees)	Statistics Indonesia
Global Oil Price	Average world oil price (USD/barrel)	Statistics Indonesia
Agricultural Credit	Total agricultural credit (IDR/year)	Statistics Indonesia

Agricultural Sector GDP	Per capita agricultural sector GDP (IDR)	Statistics Indonesia
Energy Infrastructure	Number of power plants (units)	Statistics Indonesia
Electricity Access	Percentage of households with electricity (%)	Statistics Indonesia
Renewable Energy	Proportion of renewable energy in mix (%)	Statistics Indonesia
Population	Total population (persons)	Statistics Indonesia
Energy Consumption Intensity	Ratio of primary energy to GDP (TOE/IDR)	Statistics Indonesia

Source: Created by the Author

RESULTS

In this section, we present the results of statistical tests, including descriptive statistics, Pearson correlation, and dynamic panel estimation using the Generalized Method of Moments (GMM).

Table 2. Descriptive Statistics

Variable	Mean	STD. Dev	Maximum	Minimum	Obs
Agricultural Technology	94,23	123,5	65,00	1,00	59
Natural Disaster	45,00	53,37	267,	5	60
Number of Active Farmers	24,03	13,62	99,38	81,81	60
Crude Oil	4,30	1,768	292.373	221.088	60
Harvested Area	30,05	17,46	1.185,	579,8	60
Planted Area	30,03	17,03	53,23	31,48	60
Food Security Index	30,50	17,46	5.952,5	2.396	60
Farmer Terms of Trade	23,10	12,99	38.265	1.111	50
Livestock Commodity	30,50	17,46	6.474,8	701	60
Fertilizer Subsidy	30,50	17,46	38.265	0,04	60
Infrastructure/Road Length	7,53	4,26	2.361	1.009	60
Latitude	24,50	14,42	3,6693	-4,14491	60
Global Oil	3,76	2,028	9,98	-0,97	60
Credit	30,50	17,46	7.598,1	22,17	60
GDP_Capita	30,50	17,46	64,499	16,60	60
Energy Infrastructure	29,46	16,71	9.239	44,25	60
Electricity Access	29,31	16,71	3.020,37	33,27	60
Renewable Energy	3,50	1,722	25,22	13,09	59
Population	30,00	1,17	9.463.400	941.400	60
Energy Security Index (Primary)	3,50	1,722	27.492,4	22.539.	60

Source: Data Processed

Table 2 above displays descriptive statistics for each variable investigated in this study. However, to save space, we only display the Mean, Standard Deviation, Minimum, and Maximum values. For the agricultural resources and production variables, the highest number of technological assistance or agricultural machinery was recorded in South Sulawesi Province in 2022 at 65 units, while the lowest was in North Sulawesi at 1 unit. The percentage of the workforce in the agricultural sector reached its highest level in Papua in 2023 at 99.38%, while the lowest was recorded in North Sulawesi in 2021 at 81.81%. The largest harvested area occurred in South Sulawesi in 2019, at approximately 1,185.4 hectares, while the smallest occurred in West Sulawesi in 2018, at 579.83 hectares. In terms of planted area, the most significant achievement occurred in West Sulawesi in 2021 with 53.23 hectares, while the lowest was in Papua in 2020 with 31.48 hectares. The highest rice production was recorded in South Sulawesi in 2019, at 5,952.6 tons, while the lowest production was in West Sulawesi in 2018, at 2,396 tons.

Meanwhile, the highest meat production from animal commodities was recorded in Southeast Sulawesi in 2018 at 6,474.8 kilograms, while the lowest was recorded in North Maluku at 701 kilograms. In terms of agricultural input support, Central Sulawesi received the highest fertilizer subsidy assistance in 2023, totaling 38,265 tons, while Papua received the lowest, at 1,111 tons. The farmer welfare indicator, measured by the farmer exchange rate (NTP), reached its highest value in Gorontalo in 2019 at 99.91, while the lowest was recorded in Central Sulawesi in 2020 at 95.27. In terms of road infrastructure, the longest was recorded in Papua in 2018 at 2,361 kilometers, while the shortest was in Southeast Sulawesi in 2019 at 1,009 kilometers.

In terms of energy units, Central Sulawesi had the highest number in 2018, at 9,239 units, while West Sulawesi recorded the lowest in 2019, at 44.25 units. The highest electricity flow was recorded in South Sulawesi in 2020, at 3,020.37 gigawatt-hours (estimated), while the lowest was in Gorontalo in the same year, at 33.27 gigawatt-hours. The highest national renewable energy consumption was recorded in 2018, while the lowest consumption was observed in 2023. Meanwhile, the highest energy security index (primary energy) value was recorded in 2022 at 27,492.4, while the lowest was in 2019 at 22,539. For other variables, the highest crude oil production was recorded in 2018 at an estimated 292,373 barrels, while the lowest was recorded in 2023 at 221,088 barrels. Gorontalo had the highest number of financial aid recipients in 2022, with 7,598.1 recipients, while West Papua had the lowest number of recipients in 2019, with 22.17 recipients. Demographically, South Sulawesi had the largest population in 2019 with 9,463,400 people, while Papua had the smallest population in 2023 with 941,400. Geographically, South Sulawesi is located at a latitude of 3.6693, while Southeast Sulawesi is at a latitude of -4.14491. The highest number of disasters was recorded in South Sulawesi in 2023, with 267 incidents, while the lowest was in Gorontalo. In 2019, there were only 5 incidents. Meanwhile, West Papua recorded the highest Gross Regional Domestic Product (GRDP) per capita in 2019 at IDR 64,499 million, while Maluku Province recorded the lowest at IDR 16.60 million.

After conducting descriptive statistics, we proceeded to the Pearson correlation test (Tables 3, 4, and 5) for each model to assess the strength and direction of the linear relationship among the variables. This test is used to determine the extent to which

variables are simultaneously related, whether the relationship is positive, negative, or absent. This allows us to determine whether these variables influence each other within the context of the model being analyzed and to identify potential multicollinearity that could affect the model's validity.

Table 3. Pearson Correlation Estimation Results

Food Security	1,0										
Technology	0,26*	1,0									
Number of Farmers	0,04*	-0,03*	1,0								
Technology*Number of Farmers	0,29*	0,88*	0,28*								
Road	-0,32*	0,04*	-0,30*	1,0							
Technology*Road	-0,40*	0,91*	-0,13*	-0,07*	1,0						
Harvested Area	0,16*	0,02*	-0,09*	0,70*	0,33*	1,0					
Planted Area	-0,06*	0,44*	-0,12*	-0,00*	0,40*	0,44*	1,0				
Farmer Income (NTP)	0,30*	0,07*	0,20*	0,42*	0,35*	0,12*	-0,00*	1,0			
Animal Commodities	-0,08*	-0,14*	0,05*	0,09*	-0,01*	-0,21*	-0,50	0,10*	1,0		
Latitude	0,02*	0,40*	-0,20*	-0,12*	-0,26*	0,46*	0,11*	-0,15*	0,01*	1,0	
Farmer Credit	0,05*	0,11*	0,00*	0,27*	0,19*	0,11*	0,05*	0,17*	0,11*	-0,12*	
Capital GRDP	0,05*	0,10*	0,01*	0,08*	0,07*	0,07*	0,08*	0,11*	-0,42	0,00*	1,0

Source: Data Processed

Table 4. Pearson Correlation Estimation Results

Energy Security Index	1,0								
Crude Oil	-0,19*	1,0							
Renewable Energy	0,08*	0,89*	1,0						
Crude Oil*RE	-0,11*	0,91*	0,94*						
Energy Infrastructure	0,04*	-0,28*	0,22*	1,0					
Crude Oil*INF. Energy	-0,04*	0,42*	0,32*	-0,25*	1,0				
Global Oil	-0,01*	0,66*	0,64*	0,36*	0,68*	1,0			
Per Capita GRDP	-0,04*	0,03*	0,17*	0,59*	0,16*	0,15*	1,0		
Population	-0,02	0,12*	0,03*	0,11*	0,19*	0,06*	0,06*	1,0	
Electricity Supply	0,13*	-0,07*	0,03*	0,09*	0,11*	-0,21*	0,33*	0,01*	1,0

Source: Data Processed

Tabel 5. Pearson Correlation Estimation Results

Disaster	0,34*	1,0						
Technology	0,26*	0,65*	1,0					
Disaster*Technology	0,22*	0,85*	0,87*					
Per Capita GRDP	0,05*	0,15*	0,10*	1,0				
Fertilizer Subsidies	0,17*	0,12*	0,10*	0,17*	1,0			
Farm Credit	-0,02*	-0,04*	0,11*	0,02*	-0,09*	1,0		
Infrastructure (Roads)	0,32*	-0,06*	0,04*	0,12*	-0,79*	-0,10*	1,0	
Global Oil	0,02*	0,06*	0,01*	0,42*	0,35*	0,13*	-0,03*	1,0

Source: Data Processed

4.1 Dynamic Panel Estimation (GMM) Results

Table 6. Regional Food Security Estimation Results

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Food security (L.1)	-0,019 (0,789)	-0,882 (0,313)	-0,059 (0,658)	0,142 (0,463)	-0,494 (0,284)
Agricultural technology	0,059 (0,220)	-0,292 (0,271)	0,017 (0,868)	0,118** (0,020)	-0,934 (0,308)
Number of active farmers		-0,259 (0,471)			1,023** (0,050)

Technology*number of farmers	0,006** (0,043)			0,006** (0,011)	
Road		0,474 (0,687)		1,841 (0,276)	
Technology*Road		0,008 (0,389)		0,002 (0,819)	
Harvested area			0,261 (0,288)	0,024 (0,852)	
Planted area			0,261 (0,360)	0,641*** (0,004)	
Farmer exchange rate/farmer income	-0,358 (0,321)	-0,357 (0,213)	-0,361 (0,198)	-0,503** (0,032)	0,048 (0,852)
Animal commodities	0,090 (0,436)	0,136* (0,099)	0,184** (0,047)	0,089 (0,688)	-0,135 (0,299)
Fertilizer substitute	-0,249 (0,394)	-0,217 (0,402)	0,324 (0,228)	-0,352 (0,304)	0,665* (0,097)
Agricultural credit	-0,012 (0,903)	0,042 (0,533)	0,006 (0,995)	0,067 (0,636)	0,665* (0,076)
GRDP_Capita	-0,392 (0,191)	-0,232 (0,430)	-0,013 (0,876)	-0,109 (0,796)	0,657 (0,153)
Latitude	0,158 (0,895)	-0,759 (0,629)	0,239 (0,591)	0,027 (0,970)	0,832 (0,390)
Number Of Provinces	10	10	10	10	10
Sargan T	18,53 (0,294)	17,23 0,451	26,95 (0,126)	21,53 (0,629)	13,42 (0,308)
AR 1	-1,787 (0,073)	-1,918 (0,055)	-2,370 (0,178)	-1,718 (0,085)	-1,376 (0,168)
AR 2	-1,069 (0,287)	-1,107 (0,268)	-1,087 (0,278)	-1,188 (0,234)	-1,081 (0,308)

Source: Data Processed

The estimation results presented in Table 6 reveal complex and context-dependent dynamics of food security in the SULAMPUA region. Agricultural technology, when treated as an isolated input, does not consistently demonstrate a significant effect on food security across model specifications. This suggests that technological adoption alone is insufficient to strengthen food system resilience. However, when technology is interacted with the number of active farmers (Technology × Number of Farmers), the effect becomes positive and statistically significant (Model 2: $\beta = 0.006$, $p < 0.05$; Model 5: $\beta = 0.006$, $p < 0.05$). This finding supports Hypothesis 2 and indicates that the effectiveness of agricultural technology is closely associated with collective production capacity and farmer-based institutional arrangements. From the perspective of New Institutional Economics (North, 1990), technological outcomes are shaped not only by the availability

of innovation but also by the institutional environment that enables its diffusion and utilization. In the SULAMPUA context, the number of active farmers may be interpreted as a proxy for collective production networks, knowledge-sharing mechanisms, and informal institutional capacity that facilitate technology adoption. This helps explain why technology transfer programs often generate limited and uneven impacts when not accompanied by institutional strengthening and farmer coordination. In this regard, farmer organizations function as mediating structures that translate technological inputs into tangible productivity and resilience outcomes through collective learning and risk-sharing processes, consistent with the concept of social capital (Putnam, 1993).

The role of infrastructure also reveals important nuances. The road variable exhibits inconsistent effects across model specifications, and the interaction between technology and road infrastructure is not statistically significant. These results indicate that physical infrastructure investment alone does not automatically translate into improved food security outcomes, providing only partial support for Hypothesis 3. Within the Social–Ecological Systems (SES) framework (Folke, 2006), infrastructure must be understood as part of an integrated system involving institutional coordination, market access, and distribution efficiency. In SULAMPUA, road availability becomes less effective without complementary factors such as affordable transportation services, reliable market information, and connectivity to distribution centers. Similar patterns have been observed in other developing regions, where infrastructure benefits depend heavily on supportive institutional and economic conditions (Dercon et al., 2009).

The analysis of land variables provides stronger empirical support for Hypothesis 4. The planted area shows a positive and significant effect on food security (Model 5: β = 0.641, $p < 0.01$), indicating that expansion of cultivated land contributes directly to increased food availability. In contrast, the harvested area does not exhibit a significant effect, suggesting the presence of post-harvest constraints such as yield losses, storage limitations, and distribution inefficiencies. These findings highlight that improvements in production capacity must be accompanied by value-chain efficiency to translate into sustained food security outcomes. Diversification dynamics further reinforce the resilience perspective embedded in Hypothesis 5. The livestock commodity variable demonstrates a positive and significant effect in several model specifications, indicating that diversification of agricultural activities contributes to household-level and regional food stability.

Within the SES framework, diversification functions as a buffering mechanism that enhances adaptive capacity by providing alternative income sources and nutritional support. Small-scale livestock in SULAMPUA, for instance, plays a dual role as both a food source and a financial safety net that can be mobilized during periods of economic stress or climatic shocks. Meanwhile, the negative coefficient of the Farmer Exchange Rate (FAR), which appears significant in certain model specifications, indicates a potential trade-off between commercialization and subsistence-oriented production systems. This suggests that increased market orientation does not necessarily translate into improved food security, particularly when farmers become highly dependent on volatile commodity prices. Such dynamics illustrate the structural vulnerability embedded

in agricultural commercialization and underscore the importance of balancing market integration with local food system resilience.

Table 7. Energy Resilience Estimation Results

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Energy Security (L-1)	-0,467**	0,318***	-0,385***	-423***	0,318***
	(0,021)	(0,000)	(0,000)	(0,000)	(0,000)
Crude Oil Production	-1,070***	1,704***	-2,154***	1,159***	1,704***
	(0,000)	(0,000)	(0,000)	(0,000)	(0,000)
Renewable Energy		-3,961***			-3,961***
		(0,000)			(0,000)
Crude Oil*Renewable		-0,853***			-0,853***
		(0,000)			(0,000)
Energy Infrastructure			-0,169***		
			(0,001)		
Crude Oil*Energy Infrastructure			-0,358***		
			(0,001)		
Global Oil Price				0,147	
				(0,279)	
GDP_Capita	0,150**	0,152	0,160*	0,173	0,015
	(0,052)	(0,293)	(0,095)	(0,151)	(0,293)
POP	0,043	0,13	0,047	-0,061	0,013
	(0,458)	(0,449)	(0,517)	(0,358)	(0,499)
Electric	0,039	0,001	0,045**	0,064***	0,001
	(0,218)	(0,853)	(0,022)	(0,000)	(0,853)
Number of Provinces	10	10	10	10	10
Sargan T	29,77	4659	49,11	47,05	25,35
	(0,067)	(0,073)	(0,228)	(0,345)	(0,097)
AR 1	-2,316	-1,624	-1,713	-2,443	-1,624
	(0,205)	(0,104)	(0,866)	(0,145)	(0,104)
AR 2	-2,531	-0,411	-2,075	-1,336	-0,411
	(0,114)	(0,680)	(0,380)	(0,182)	(0,153)

Source: Data Processed

The estimation results presented in Table 7 reveal structural and non-linear dynamics in regional energy security in SULAMPUA. These findings provide empirical insights into the determinants of energy resilience as articulated in Hypotheses 7–10.

First, the results strongly support Hypothesis 7, which posits that dependence on petroleum production negatively affects regional energy security. Crude oil production exhibits a negative and statistically significant effect across several model specifications (Model 1: $\beta = -1.070$, $p < 0.01$; Model 3: $\beta = -2.154$, $p < 0.01$). This finding reflects the structural vulnerability associated with fossil resource dependence, whereby regional energy systems become increasingly exposed to price volatility, resource depletion risks, and investment distortions. From the perspective of the Resource Curse literature, reliance on extractive sectors may undermine long-term resilience by discouraging economic diversification and delaying the transition toward more sustainable energy systems.

Second, Hypothesis 8, which posits that renewable energy development strengthens energy security, is not supported in its direct form. Renewable energy capacity displays a statistically significant negative coefficient in the estimated models, indicating that expansion of renewable energy does not automatically translate into improved regional energy resilience. This apparent paradox may be interpreted as a transition-friction effect, in which institutional, infrastructural, and technological misalignments constrain the effectiveness of renewable energy deployment. In SULAMPUA, renewable development may continue to face structural barriers, including limited grid integration, high investment costs, and uneven inter-island distribution, thereby reducing its short-term contribution to system stability. Third, the findings provide support for Hypothesis 9, which asserts that energy infrastructure significantly influences regional energy security. However, the estimated effect is negative, and the interaction between crude oil production and energy infrastructure is also significantly negative. These results suggest the presence of infrastructural lock-in, whereby existing energy systems largely designed around fossil fuel distribution, reinforce dependence rather than facilitate diversification. This pattern is consistent with the concept of carbon lock-in in the energy transition literature, which posits that infrastructure developed under fossil-based pathways can constrain adaptive transformation toward cleaner and more resilient energy systems. Fourth, Hypothesis 10, concerning the influence of global oil prices, is not empirically supported.

The coefficient for global oil prices is statistically insignificant, indicating that regional energy security in SULAMPUA is shaped more by internal structural factors than by external price fluctuations. This finding suggests a partial decoupling dynamic, in which vulnerabilities stem primarily from limited diversification, infrastructural rigidity, and institutional constraints rather than global market shocks. Taken together, these results indicate that energy security in SULAMPUA is not determined solely by the availability of energy resources, but rather by the structural configuration of the regional energy system. Fossil fuel dependence, uneven renewable integration, and infrastructural rigidity interact to produce a path-dependent system that constrains adaptive capacity.

Within the Social–Ecological Systems framework, these findings imply that strengthening energy resilience requires systemic transformation rather than incremental resource expansion, particularly in archipelagic regions characterized by spatial fragmentation and logistical constraints. These dynamics further underscore the importance of conceptualizing energy resilience as an integral component of a broader

food–energy system, in which energy availability, infrastructure, and resource governance shape agricultural productivity, distribution networks, and overall regional stability.

Table 8. Food Vulnerability Due to Disasters Estimation Results

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
FSI (L.1)	-0,019	6,150*	0,080	-0,487**	-0,145
	(0,789)	(0,067)	(0,687)	(0,049)	(0,566)
Disaster	-2,760***	2,700*	-0,052	-0,124	-0,100
	(0,002)	(0,083)	(0,549)	(0,386)	(0,310)
Tech_Ag		6,520		0,109*	
		(0,361)		(0,079)	
Disaster*Tech		-1,270		-0,000	
		(0,818)		(0,927)	
Gdp_Cap	-1,240***	1,780***	0,267	-0,376	0,086
	(0,008)	(0,003)	(0,935)	(0,233)	(0,852)
Fer_Sub	8,190	-2,080	0,135	0,291	0,340
	(0,198)	(0,617)	(0,633)	(0,157)	(0,409)
Loan_Ag	1,890	1,060	0,102	0,161	0,123
	(0,164)	(0,538)	(0,484)	(0,233)	(0,424)
Road	1,850	-5,900	1,764**	0,973**	1,643*
	(0,105)	(0,681)	(0,047)	(0,011)	(0,061)
Oil_Price					-0,777
					(0,597)
Number Of Provinces	10	10	10	10	10
Sargan T	1574	188	4,120	4,953	22,40
	(0,294)	(0,452)	(0,765)	(0,066)	(0,494)
AR 1	-1,859	-1,828	-2,370	-1,818	-1,983
	(0,062)	(0,055)	(-1,818)	(0,069)	(0,047)
AR 2	-2,449	-1,073	-0,737	-0,737	-0,692
	(0,143)	(0,282)	(0,460)	(0,460)	(0,488)

Source: Data Processed

The estimation results in Table 8 provide important insights into the dynamics of food vulnerability under disaster conditions and offer empirical support for the systemic linkages proposed in Hypotheses 11 and 12. The findings indicate that the impact of natural disasters on food security in SULAMPUA is neither linear nor uniform, but instead depends on the adaptive capacity embedded within the regional food system. The baseline model shows that disasters exert a significant negative effect on food security (β = −2.760, p < 0.01), confirming the disruptive role of external shocks as emphasized in vulnerability theory within the Social-Ecological Systems (SES) framework. However,

the variability in coefficient signs across model specifications suggests that the net impact of disasters is mediated by response capacity and adaptation mechanisms. In some contexts, disaster events trigger emergency redistribution, logistical adjustments, and institutional responses that may temporarily stabilize food availability, reflecting the adaptive nature of regional food systems. This pattern provides empirical support for Hypothesis 12, which posits that regional adaptive capacity moderates the impact of external shocks on food security. Infrastructure, particularly road connectivity, emerges as a key adaptive mechanism.

The road variable shows a consistent positive and statistically significant effect across several models (Model 3: $\beta = 1.764$, $p < 0.05$; Model 4: $\beta = 0.973$, $p < 0.05$; Model 5: $\beta = 1.643$, $p < 0.10$), indicating that spatial connectivity strengthens logistical resilience during crisis periods. Within the SES perspective, infrastructure functions not only as a physical asset but as a systemic component that enhances coordination, distribution efficiency, and emergency response capacity. In contrast, the interaction between disasters and agricultural technology does not exhibit statistical significance, suggesting that technology alone does not automatically translate into resilience. This finding highlights the limitations of technology-centered approaches when not integrated with adaptive institutional and infrastructural support. In disaster-prone environments such as SULAMPUA, agricultural systems that rely heavily on external inputs or centralized infrastructure may face heightened vulnerability when supply chains are disrupted. Similarly, conventional agricultural policy instruments such as fertilizer subsidies and agricultural credit, do not show significant effects in most specifications.

These results indicate that production-oriented policy inputs may be less effective in strengthening systemic resilience to shocks. Rather than functioning as stabilizing mechanisms, such instruments may create dependencies that reduce adaptive flexibility during crisis periods. Taken together, these findings reinforce Hypothesis 11, which emphasizes the structural interdependence between food and energy systems. Food system vulnerability in SULAMPUA cannot be separated from energy availability, given the dependence of irrigation, storage, and distribution on electricity and fuel-based logistics. Disasters disrupt not only agricultural production but also the energy-dependent infrastructure that supports food circulation, illustrating the integrated nature of food–energy resilience. Within the broader Food–Energy Nexus framework, the results suggest that strengthening food security in disaster-prone regions requires systemic approaches that integrate infrastructure, institutional coordination, and energy accessibility. The resilience of the food system is therefore determined not only by production capacity but also by the ability of interconnected systems to absorb, adapt to, and recover from external shocks.

CONCLUSION

This study elucidates the complex dynamics underlying the convergence of food and energy security in the Sulawesi, Maluku, and Papua (SULAMPUA) region, which is characterized by a paradox of abundant resource potential alongside significant structural

vulnerability. The findings indicate that the effectiveness of agricultural technology is strongly conditioned by farmers' institutional capacity, while reliance on crude oil production is associated with weaker regional energy security. These results underscore that strengthening food and energy resilience in SULAMPUA cannot be achieved through fragmented sectoral approaches; rather, it requires integrated strategies that incorporate institutional, infrastructural, and socio-economic dimensions.

Several limitations should be acknowledged. First, the relatively short observation period (2018–2023) constrains the ability to capture long-term structural transformations, including climate-related impacts and global energy transitions. Second, unobserved factors such as socio-cultural dynamics and local agricultural practices were not fully incorporated into the econometric framework. Third, data limitations, particularly regarding renewable energy development and global commodity dynamics, restrict a more in-depth examination of localized energy–food interactions. These constraints present opportunities for future research employing mixed-method approaches, dynamic systems modeling, and comparative regional analyses to better understand adaptive mechanisms in archipelagic contexts. The policy implications derived from these findings are multidimensional. At the strategic level, enhancing resilience in SULAMPUA requires a shift from fragmented policies toward an integrated framework linking food security, energy transition, and climate adaptation. At the operational level, this may involve integrating agricultural technology support with decentralized renewable energy systems, improving energy-based irrigation and cold-chain infrastructure, and strengthening disaster-responsive food distribution mechanisms. In parallel, institutional strengthening and community-based adaptation are essential to ensure that technological interventions translate into sustainable outcomes.

Overall, the findings emphasize that SULAMPUA should not be viewed merely as a peripheral and vulnerable region, but as a strategic arena for developing adaptive and integrated resilience models. By aligning food, energy, and climate agendas within a coherent policy framework, regional vulnerabilities can be transformed into opportunities for advancing sustainable and inclusive development pathways.

REFERENCE

Alfiandy, S., & Ilahi, A. F. (2023). Pendidikan Mengatasi Perubahan Iklim berdasarkan Literasi Iklim untuk Pertanian Berkelanjutan di Provinsi Sulawesi Tengah. Buletin GAW Bariri (BGB), 4(2), 31–39.

Arellano, M., & Bond, S. (1991). Some Test of Spesification for Data Panel: Monte Carlo Evidence and an Aplication of Employment Equations. Source: The Review of Economic Studies, 58(2), 277–297.

Arora, N. K., & Mishra, I. (2023). Sustainable development goal 13: recent progress and challenges to climate action. Environmental Sustainability, 6(3), 297–301.

Bazilian, M., Rogner, H., Howells, M., Hermann, S., Arent, D., Gielen, D., Steduto, P., Mueller, A., Komor, P., & Tol, R. S. J. (2011). Considering the energy, water and

food nexus: Towards an integrated modelling approach. Energy Policy, 39(12), 7896–7906.

Bilqis, M., Hendrarini, H., & Atasa, D. (2026). Analisis ketahanan pangan rumah tangga petani berdasarkan proporsi pengeluaran pangan dan kecukupan energi di Kecamatan Mantup Kabupaten Lamongan. Journal of Tropical AgriFood, 7(2), 100–109.

Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. Journal of Econometrics, 87(1), 115–143. https://doi.org/https://doi.org/10.1016/S0304-4076(98)00009-8

BPS. (2023). Produksi Padi dan Beras Menurut Provinsi, 2023. Central Bureau of Statistics of Indonesia. https://www.bps.go.id/id/statistics-table/3/ZDNaak0yODBUVTlGYW5sa2REUkVUVVVVY1YVZkbmR6MDkjMw==/produksi-padi-sup-1--sup--dan-beras-menurut-provinsi--2023.html?year=2023

Cergibozan, R. (2022). Renewable energy sources as a solution for energy security risk: Empirical evidence from OECD countries. Renewable Energy, 183, 617–626.

D'Odorico, P., Davis, K. F., Rosa, L., Carr, J. A., Chiarelli, D., Dell'Angelo, J., Gephart, J., MacDonald, G. K., Seekell, D. A., & Suweis, S. (2018). The global food-energy-water nexus. Reviews of Geophysics, 56(3), 456–531.

Data, O. W. in. (2024). Primary energy consumption, 2024. Energy Institute - Statistical Review of World Energy. https://ourworldindata.org/grapher/primary-energy-cons

Dercon, S., Gilligan, D. O., Hoddinott, J., & Woldehanna, T. (2009). The impact of agricultural extension and roads on poverty and consumption growth in fifteen Ethiopian villages. American Journal of Agricultural Economics, 91(4), 1007–1021.

FAO. (2023). GREENING THE ECONOMY WITH AGRICULTURE (GEA). Food and Agriculture Organization of the United Nations. https://www.fao.org/fileadmin/user_upload/suistainability/docs/GEA__concept_note_3March_references_01.pdf

Fatimah, S., Rasyid, A., Anirwan, A., Qamal, Q., & Arwakon, H. O. (2024). Kebijakan Makan Bergizi Gratis di Indonesia Timur: Tantangan, Implementasi, dan Solusi untuk Ketahanan Pangan. Journal of Governance and Policy Innovation, 4(1), 14–21.

Folke, C. (2006). Resilience: The emergence of a perspective for social–ecological systems analyses. Global Environmental Change, 16(3), 253–267. https://doi.org/https://doi.org/10.1016/j.gloenvcha.2006.04.002

Hasan, M. M., & Adnan, A. T. M. (2025). Nexus between environmental sustainability, energy intensity and food security: evidence from emerging economies. Journal of Business and Socio-Economic Development, 5(2), 139–154.

He, J., Osabohien, R., Yin, W., Adeleke, O. K., Uduma, K., Agene, D., & Su, F. (2024). Green economic growth, renewable energy and food security in Sub-Saharan Africa. Energy Strategy Reviews, 55, 101503.

Hellegers, P. (2022). Food security vulnerability due to trade dependencies on Russia and Ukraine. Food Security, 14(6), 1503–1510.

Hodbod, J., & Eakin, H. (2015). Adapting a social-ecological resilience framework for food systems. Journal of Environmental Studies and Sciences, 5(3), 474–484.

IEA. (2021). Achieving Net Zero Heavy Industry Sectors in G7 Members. IEA Publications. https://www.iea.org/reports/achieving-net-zero-heavy-industry-sectors-in-g7-members/executive-summary?utm_source=chatgpt.com

IPCC. (2022). Climate Change 2022 - Mitigation of Climate Change - Full Report. In Cambridge University Press (Issue 1).

Karunathilake, H., Prabatha, T., Sadiq, R., & Hewage, K. (2022). Overcoming the energy security challenges in developing countries. In Handbook of Energy and Environmental Security (pp. 61–88). Elsevier.

Khan, K., Su, C. W., Khurshid, A., & Qin, M. (2023). Does energy security improve renewable energy? A geopolitical perspective. Energy, 282, 128824.

Lisanty, N., Andajani, W., Pamudjiati, A. D., & Artini, W. (2021). Regional overview of food security from two dimensions: Availability and access to food, East Java Province. Journal of Physics: Conference Series, 1899(1), 12067.

North, D. C. (1990). Institutions, institutional change and economic performance. Cambridge university press. https://doi.org/https://doi.org/10.1017/CBO9780511808678

Putnam, R. D. (1993). The prosperous community. The American Prospect, 4(13), 35–42.

Rachmaningsih, T., & Priyarsono, D. S. (2012). Ketahanan pangan di kawasan timur Indonesia. Jurnal Ekonomi Dan Pembangunan Indonesia, 13(1), 1.

Sachs, J. D., & Warner, A. M. (2001). The curse of natural resources. European Economic Review, 45(4–6), 827–838.

Singh, P. (2006). Hunger amidst plenty: Reflections on law, poverty and governance. Journal of the Indian Law Institute, 48(1), 57–77.

South, D. W., & Alpay, S. (2025). Analyzing Global Progress on United Nations Sustainable Development Goals 7 and 13—Clean Energy and Climate Action. Climate and Energy, 41(9), 23–32.

Syuhada, A., Armanto, M. E., Siswanto, A., Yazid, M., & Wildayana, E. (2020). Food security and environmental sustainability on the South Sumatra Wetlands, Indonesia. Systematic Reviews in Pharmacy, 11(3), 457–464.

Taghizadeh-Hesary, F., Rasoulinezhad, E., & Yoshino, N. (2019). Energy and food security: Linkages through price volatility. Energy Policy, 128, 796–806.

To, H., & Grafton, R. Q. (2015). Oil prices, biofuels production and food security: past trends and future challenges. Food Security, 7(2), 323–336.

Wudil, A. H., Usman, M., Rosak-Szyrocka, J., Pilař, L., & Boye, M. (2022). Reversing years for global food security: A review of the food security situation in Sub-Saharan Africa (SSA). International Journal of Environmental Research and Public Health, 19(22), 14836.

Zhuang, D., Abbas, J., Al-Sulaiti, K., Fahlevi, M., Aljuaid, M., & Saniuk, S. (2022). Land-use and food security in energy transition: Role of food supply. Frontiers in Sustainable Food Systems, 6, 1053031.