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# Provincial-Level Dynamic Modeling of Climate Influence on Agriculture and Consumption: Case Studies in Central Java, East Java, Bali, and North Sumatra

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## Abstract

Indonesia's agricultural sector is increasingly exposed to climate change, as shifts in rainfall, temperature, and humidity disrupt crop yields and farmer livelihoods. These disruptions weaken domestic supply and heighten reliance on external sources. To capture regional differences, this study examines East Java, Central Java, Bali, and North Sumatra, using a Power BI-based interactive dashboard to integrate climate indicators, production data, commodity prices, and consumption patterns from 2018 to 2021. The results highlight distinct provincial dynamics. In Bali, yields respond positively to humidity but decline with rainfall, while Central Java's rice production is strongly shaped by rainfall variability. East Java's horticultural crops are highly sensitive to humidity and temperature, and North Sumatra's diversified systems show inverse effects from all three climate variables. Correlation analyses suggest that higher harvest yields slightly reduce commodity prices, particularly for rice, shallots, and garlic; the coefficients remain weak (−0.1 to −0.4), reflecting the role of transportation, market access, and trade pressures. By visualizing these relationships, the dashboard underscores interconnected vulnerabilities such as dependence on staple crops, reliance on imports, and affordability challenges. It also provides policymakers with a practical tool to monitor climate-related risks and price instability. Overall, the findings emphasize the need for integrated food security policies that combine climate science, crop management, and economic equity to support sustainable outcomes across Indonesia.

**Keywords:** Climate; Dashboard; Consumption; Commodities; Food Security

## INTRODUCTION

Indonesia's agricultural sector has been the backbone of food security for ages. But now, it's increasingly at risk from climate change. Changes in rainfall, temperature, and humidity have upset crop yields and farmer welfare (Rozci, 2023). This has weakened local supplies and ramped up dependency on outside sources (Mariyanto, 2025; BPN, 2024). These challenges highlight how fragile food systems are and the need for stronger strategies in line with global reform demands (BMJ Global Health, 2023).

In Central Java, the irregularity of rainfall deeply impacts rice production, the main crop here. Unpredictable precipitation has caused yield instability, directly hitting farmers hard and showing the risk of a food system that relies on just one crop. East Java relies on strategic crops like shallots and garlic, which can't handle temperature and humidity changes well. Climate variability worsens production inefficiencies. Bad weather means lower output and makes it tougher to keep a stable

supply. It shows how closely climate issues are tied to food security in gardening systems.

Bali, with its diverse local production, isn't safe from brewing troubles. Rice is still the main staple grown through the Subak irrigation system, along with cassava, sweet potatoes, maize, vegetables, fruits, coffee, and cocoa. Livestock, mainly Bali cattle, offer some resilience but struggle with seasonal feed shortages. Even with this variety, limited farmland and rising tourism demands often push consumption beyond local limits, forcing reliance on supplies from other provinces. Looking ahead, climate change, especially shifts in rainfall, could disrupt the yields of rice and other crops. Plus, competition for land from urban growth and tourism might shrink farmland even more. Along with price swings and rising needs for protein-heavy foods, these issues indicate Bali's food supply will stay under threat unless crop management, livestock feeding, and sustainable land use strategies improve.

In North Sumatra, a mix of crops like rice, corn, soybeans, cassava, and protein-rich livestock helps withstand climate shifts. But high temperatures and erratic rainfall still threaten productivity and hike up costs. At the same time, the rising need for meat, milk, and eggs raises affordability issues since climate change also impacts feed and livestock care.

These provinces show distinct but intertwined problems: Central and East Java focus on staple food risks due to rainfall and temperature shifts; Bali faces the dangers of being too dependent on outside supplies; and North Sumatra finds some resilience with crop variety but deals with rising costs. By highlighting staples and supplementary foods like rice, corn, soybeans, peanuts, cassava, sweet potatoes, garlic, shallots, chili, coconut, palm oil, coffee, tea, cocoa, sugar cane, meat, milk, and eggs—while viewing tobacco as a separate economic crop this study emphasizes that Indonesia's food security policy needs to blend climate science (Khoirul Anam, 2023), crop management, and economic fairness to foster sustainable results.

## METHODS

This research adopts a quantitative approach with the primary goal of identifying and interpreting relationships between various variables through meticulous statistical analysis of numerical data. This methodology is widely recognized in agricultural and health policy studies because it can provide objective, evidence-based insights into the complex dynamics of food production, distribution, and consumption patterns (Andrews & Bellamy, 2023; Burgaz et al., 2024).

By concentrating on measurable indicators, the study aims to understand how climate variability impacts agricultural output and how these changes, in turn, lead to price fluctuations and shifts in consumption behavior across different regions. Ultimately, these factors affect nutritional outcomes and health equity (Sparling et al., 2024). Additionally, the research employed artificial intelligence (AI) tools to identify relevant references and ensure accurate English translations, which contributed to the creation of grammatically correct, standardized, and formally structured sentences.

The primary dataset for this study combines both climate and economic factors to accurately represent the complexity of Indonesia's food system. It includes climate indicators such as air temperature, rainfall, and humidity, alongside production yields of staple, supplementary, and key commodities. Economic variables comprise average commodity prices by province, regional food consumption statistics, and export volumes and values for leading commodities in Central Java, East Java, Bali, and North Sumatra. The data was sourced from reputable publications by the Central Statistics Agency (BPS) and the Ministry of Agriculture of the Republic of Indonesia, which are available through annual statistical reports and online repositories (https://www.bps.go.id; repository.pertanian.go.id). Additional inputs were gathered from provincial statistics agencies and regional development planning bodies to ensure comprehensive coverage of export data (Central Java Provincial Statistics Agency, 2025; East Java Provincial Statistics Agency, 2024; East Java Regional Development Planning Agency, 2025; Bali Provincial Statistics Agency, 2025; North Sumatra Provincial Statistics Agency, 2025). Together, these sources create a robust foundation for agricultural and economic planning, capturing both climate variability and the critical role of food commodities in maintaining Indonesia's national resilience (Astuti et al., 2026).

To prepare the data for analysis, the research team undertook a meticulous extraction and transformation process. They converted raw documents into spreadsheet format to facilitate structured validation and computational processing. This step included verifying the completeness

of data over multiple years to ensure there were no significant gaps in the time series. Variable types were standardized: continuous data like temperature and rainfall were categorized as numerical, while region names and commodity classifications were labeled as categorical to ensure compatibility across analytical models. The team also conducted consistency checks and resolved discrepancies, such as mismatched units or misaligned regional codes, to maintain data integrity (WHO & World Bank, 2023).

After cleaning and validating the dataset, the researchers conducted a statistical analysis using multivariate regression and correlation techniques to uncover both direct and indirect relationships among variables. The regression models assessed the impact of rainfall variability on rice yields, while correlation matrices highlighted connections between crop yields, commodity prices, and regional consumption levels (Dela Arinda, 2025). These methods established a strong foundation for understanding how climate factors influence agricultural productivity and market behavior in Indonesia, linking food insecurity to broader pressures on the health system (Chavarría-Guzmán et al., 2025).

All statistical analyses and visualizations were performed using Power BI, which facilitated advanced data modeling, interactive filtering, and real-time dashboard creation. Building on these outputs, the study developed an interactive dashboard that translates complex statistical findings into more digestible visual formats (Muh Kevin Adesyahputra, 2025). With dynamic filters by year, region, and commodity type, this dashboard allows stakeholders to monitor changes in harvest yields, prices, and consumption across various areas. Moreover, it identifies anomalies such as provinces where rising temperatures consistently reduce yields and instances of price spikes coinciding with decreased production. These insights are crucial for early warning systems and strategic planning. As Delena (2023) points out, this dashboard serves as a decision-support tool for policymakers by integrating climate, production, price, consumption, and export data in one location. Ultimately, it provides a comprehensive overview of Indonesia's food system and supports the development of more responsive, evidence-based interventions to enhance national food security (BMJ Global Health, 2023; WHO Indonesia, 2025).

## RESULTS AND DISCUSSION

This research resulted in the creation of an interactive Power BI-based dashboard designed to analyze and visualize the relationships between climate variables—such as temperature, precipitation, and humidity—and Indonesia's food system, which includes aspects like production, market prices, consumption, and export dynamics. The dashboard allows users to explore how environmental factors affect agricultural performance and economic indicators across various provinces and over time. The selection of variables and commodities was guided by both data availability and national significance, ensuring the dashboard reflects essential elements of Indonesia's food security landscape (Andrews & Bellamy, 2023).

A rigorous screening process focused on staple and supplementary commodities that are central to national food policy and daily consumption. These include rice, corn, soybeans, peanuts, mung beans, cassava, sweet potatoes, garlic, shallots, potatoes, chili peppers, carrots, coconut, palm oil, coffee, tea, cocoa, sugarcane, meat, eggs, and milk. Tobacco was analyzed separately as a non-staple yet economically significant commodity (Astuti et al., 2026). The dataset encompasses the years 2018 to 2021 to capture recent climate trends and their impacts on production, pricing, and consumption. Statistical methods, including multivariate regression and correlation analysis, were employed to examine two primary relationships: the influence of climate variables on production volumes and the subsequent effect of production levels on commodity prices (Dela Arinda, 2025).

The analysis revealed distinct regional dynamics. In Bali, humidity had a positive effect on yields, while rainfall negatively impacted production. In Central Java, precipitation was the most influential factor affecting rice yields. In East Java, humidity positively influenced productivity, whereas rainfall was inversely associated with yields. In North Sumatra, humidity, precipitation, and air temperature all showed negative effects, highlighting the complexity of climate-agriculture interactions across diverse ecological contexts. Crop production in these provinces also affected local commodity prices, with higher yields generally linked to slight price declines, reflected by correlation values between -0.2 and -0.35 (Figure 1). Power BI visualizations further indicated a weak negative relationship between production volumes and prices, particularly evident for rice, shallots, and garlic

(correlation values between -0.1 and -0.4). These results suggest that while increased production slightly lowers prices in line with supply-demand principles, other factors—such as transportation costs, market access, and external trade pressures—also significantly influence price dynamics.

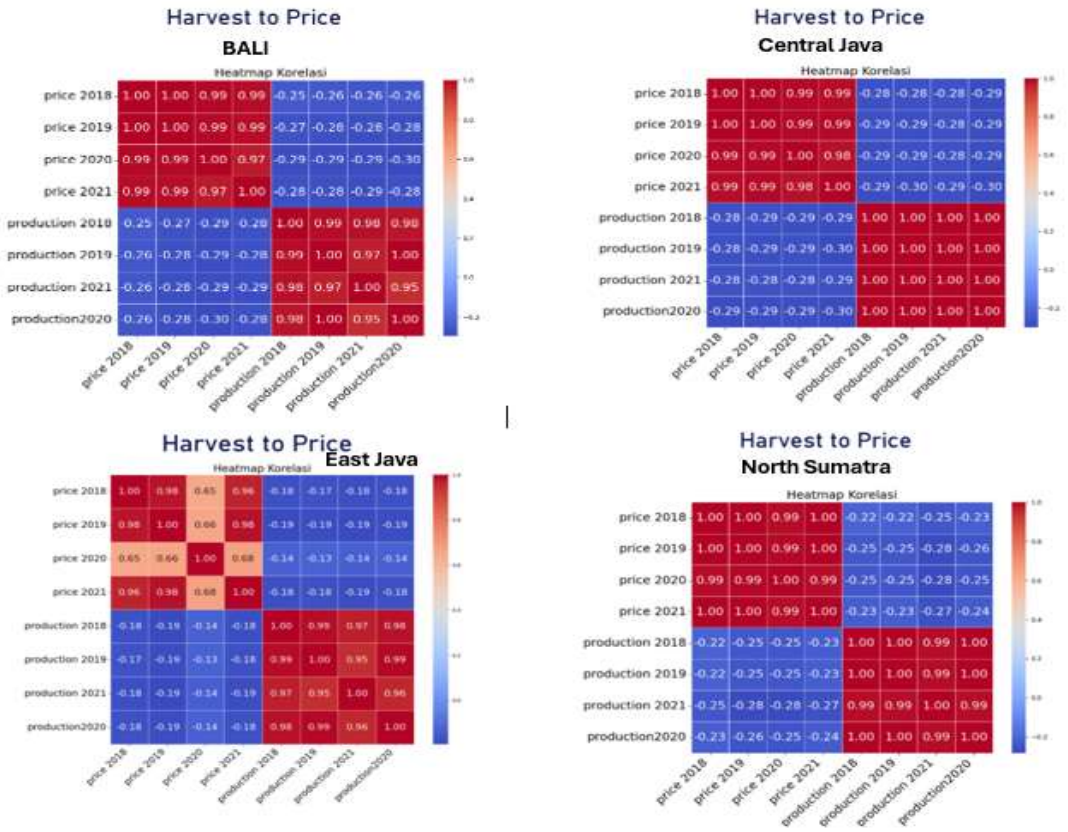


Figure 1. Correlation Dashboard of Harvest Yields and Commodity Prices for Bali, Central Java, East Java, and North Sumatra

These findings align with Burgaz et al. (2024), who emphasize that food affordability is influenced by global trade and policy environments. They also highlight the importance of integrated nutrition and health governance within universal health coverage frameworks (WHO & World Bank, 2023). By consolidating climate, production, price, consumption, and export data into a single platform, the dashboard offers policymakers a comprehensive view of Indonesia's food system and supports evidence-based strategies to enhance national food security (BMJ Global Health, 2023; WHO Indonesia, 2025).

In East Java, shallot production increased by 15% in 2019, yet average prices fell by only 4%, demonstrating that local gains are undermined by inefficiencies in logistics and market integration. Studies confirm that optimizing import volumes and improving supply chain communication are essential for stabilizing rice prices (Muhammad Shobur et al., 2025). Price volatility in shallots and garlic has been shown to directly drive inflation (Ayu Wulandari Priyambodoi, 2022). Additionally, food insecurity has increased demand for health services, with local clinics reporting spikes in malnutrition. Fiscal pressures on BPJS and uneven subsidy distribution raise concerns about the sustainability of universal health coverage (UHC).

In Central Java, rainfall variability was strongly correlated with rice yields, with regression coefficients ranging from 0.35 to 0.45. A 10% decline in rainfall in 2020 corresponded to a 9% decrease in yields, directly affecting food availability. Comparative spatial-temporal analyses confirm that rainfall is the most critical determinant of rice productivity, with regional differences impacting vulnerability (Rachmawati et al., 2025). These fluctuations highlight the need for climate adaptation policies that integrate food and health systems to mitigate malnutrition risks.

In Bali, weaker correlations between production and price reflect a reliance on imports and consumption driven by tourism, which leaves the province highly vulnerable to global market volatility. Garlic consumption per capita was 20% higher than the national average despite limited

local production, revealing systemic inequities, as global price shocks disproportionately affect low-income households. Recent studies advocate for sustainable food security strategies within provincial development planning (Widhianthini et al., 2025). While rice cultivated through the subak irrigation system remains central, yields are increasingly sensitive to changes in rainfall, and horticultural crops such as garlic and vegetables face similar challenges. Heavy reliance on imports enhances vulnerability, as global price fluctuations significantly impact local households. Climate-driven challenges and limited agricultural land emphasize the need for adaptive crop management and resilient production strategies (Muhammad Satrio et al., 2025).

In North Sumatra, diversified cropping systems have helped reduce vulnerability to climate shocks. The correlation coefficients for rice and maize yields are below –0.1, which indicates resilience through diversification. However, ongoing dietary shifts towards protein-rich foods have created new challenges related to affordability and increased health risks. The rising demand for these foods has been associated with an increase in diet-related non-communicable diseases (NCDs) and has raised concerns about health equity (Mulia Nurhasan et al., 2024).

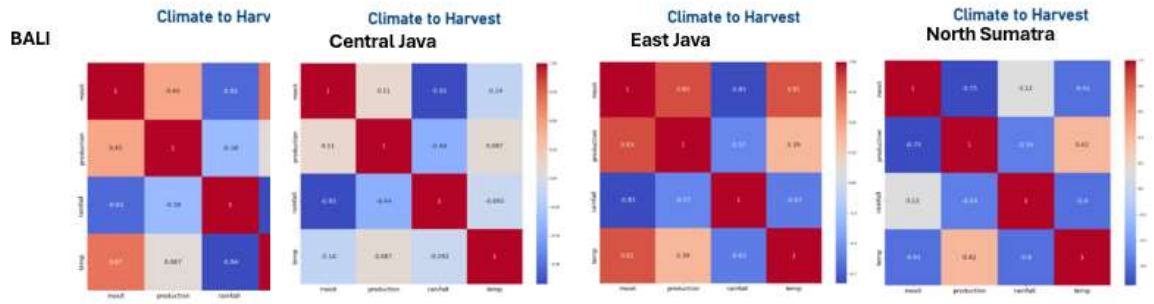


Figure 2. Dashboard of Climate Correlation to Crop Yields for Bali, Central Java, East Java, and North Sumatra

The Climate-Crop Yield Dashboard by Province (Figure 2) highlights significant localized impacts of climate change on agriculture. In Central Java, variability in rainfall negatively affects rice yields. Meanwhile, in Bali, rising temperatures lead to a decline in overall productivity. In West Java, fluctuations in humidity have resulted in lower shallot output. Conversely, in North Sumatra, diversified cropping systems have provided resilience and helped mitigate climate-related risks. These findings emphasize the urgent need for region-specific adaptation strategies that are tailored to the varying ecological and socio-economic contexts (Chavarría-Guzmán et al., 2025; InterAcademy Partnership, 2023).

The comparative analysis of Bali, East Java, Central Java, and North Sumatra reveals how climate conditions, production volumes, and demographic pressures collectively influence agricultural and economic outcomes. Bali exhibits relatively modest harvest totals despite experiencing high moisture and rainfall levels, indicating that climate variability significantly impacts its production stability. In contrast, East Java, which has the largest population, consistently records high harvest volumes; however, its rainfall is lower than Bali's. This suggests that humidity may be a more crucial factor in sustaining crop yields than precipitation.

Central Java experiences notable fluctuations in harvest output, with rainfall playing a vital role in crop performance. The increasing population and consumption levels in this region further strain food supply chains. Meanwhile, North Sumatra combines high moisture and rainfall with moderate harvest totals. The opposing effects of climate variables on yields highlight structural challenges in balancing agricultural production with rising consumption and population growth.

Across all provinces, the "harvest to price" tables indicate that higher yields typically correspond to slight declines in commodity prices, which aligns with basic supply and demand principles. However, the extent of these effects varies by region. This finding emphasizes the necessity of localized climate agriculture analysis to inform food security strategies that consider both ecological diversity and socio-economic dynamics.

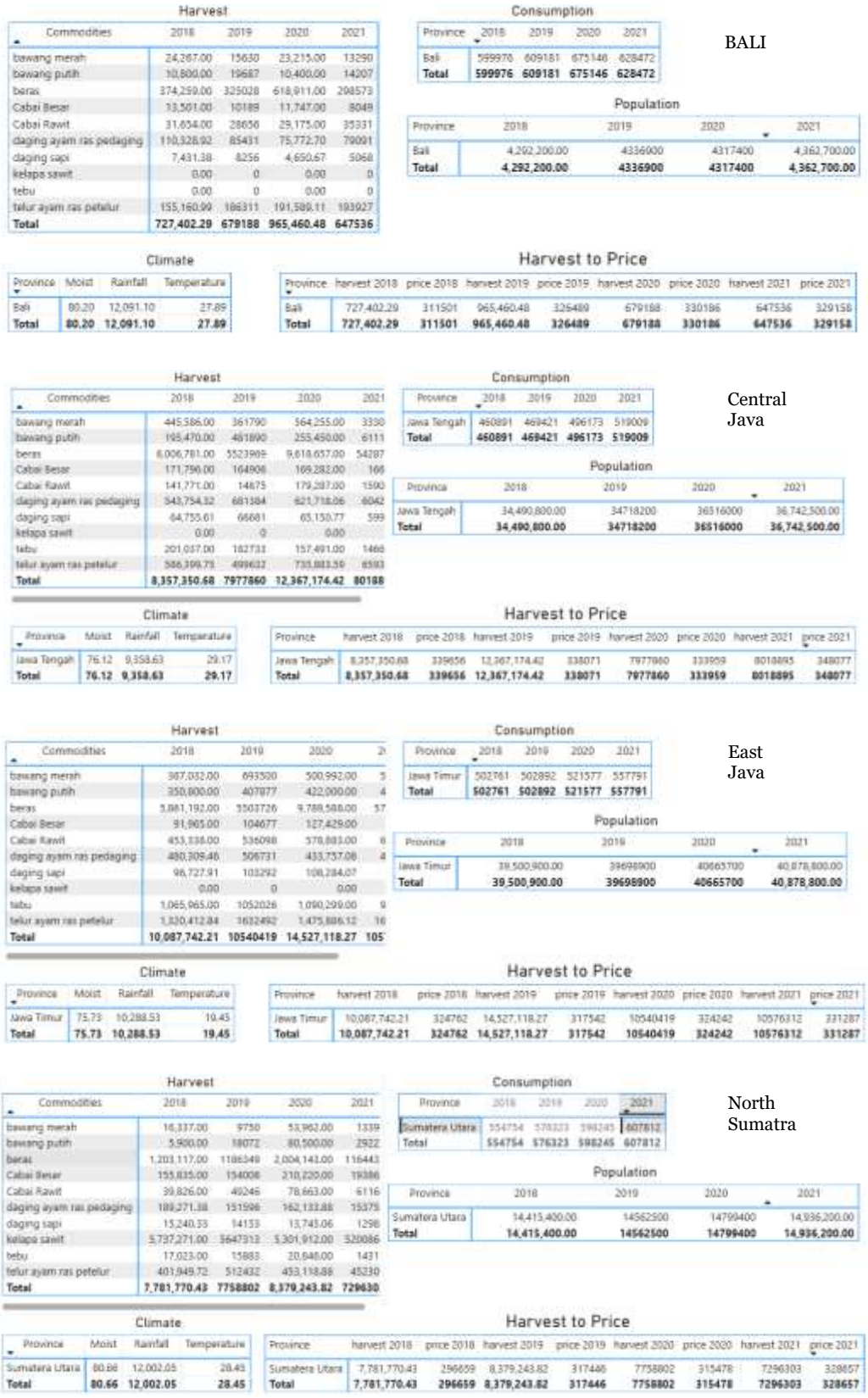


Figure 3. Dashboard Overview of Population, Food Production, Consumption, and Climate in Central Java, East Java, Bali, and North Sumatra

This comprehensive perspective underscores the complex nature of food security, connecting demographic pressures, climate variability, and consumption behavior to health equity outcomes (Sparling et al., 2024).

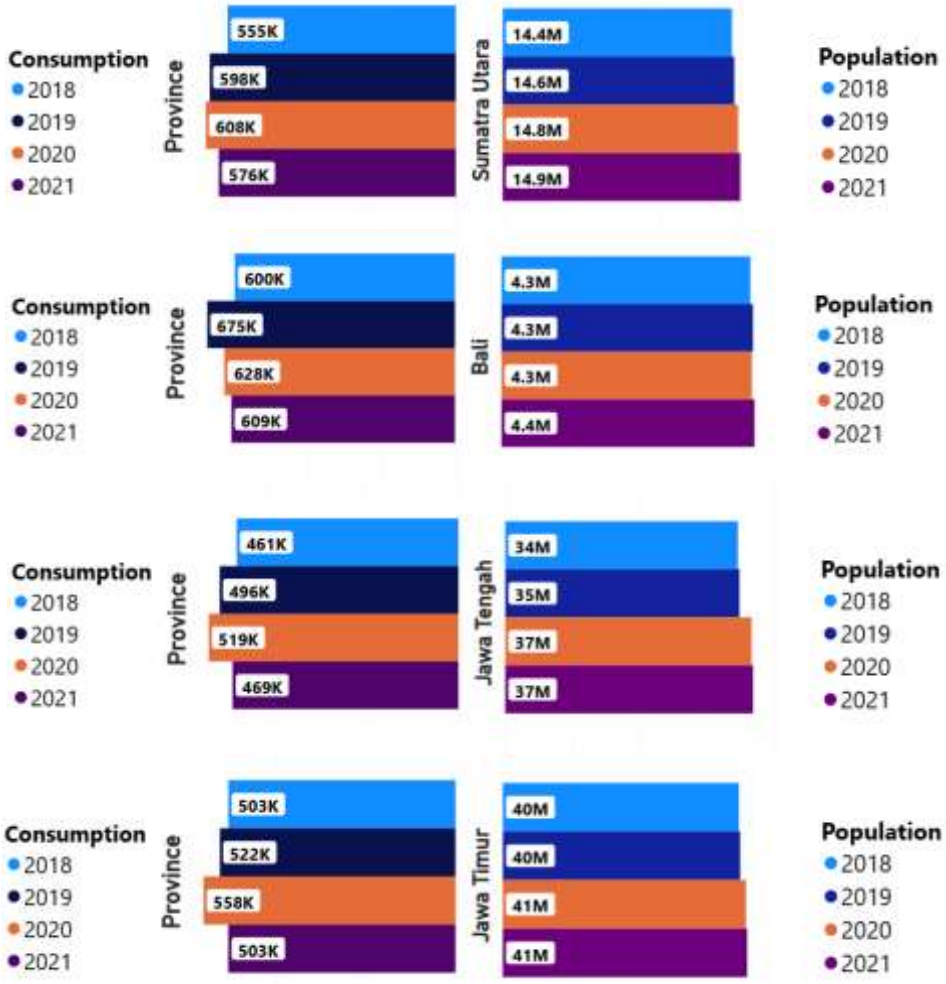


Figure 4. Population and Consumption Dashboard for Central Java, East Java, Bali, and North Sumatra

The Population and Consumption Dashboard per Province (Figures 3 and 4) reveals interesting insights into consumption patterns that do not always align with population sizes. The comparative chart of consumption and population across North Sumatra, Bali, Central Java, and East Java from 2018 to 2021 highlights important demographic dynamics and demand-side variables.

In North Sumatra, the population grew steadily from 14.4 million to nearly 15 million, while consumption fluctuated, peaking in 2020 and declining slightly in 2021. This suggests potential supply constraints or shifts in household demand. Bali, with its smaller population of around 4.3 to 4.4 million, exhibited high consumption levels, particularly in 2019, reflecting the province's strong reliance on food commodities relative to its population size.

Central Java experienced significant population growth, increasing from 34 million to 37 million, yet consumption did not rise proportionally. This indicates either efficiency gains or pressures on household purchasing power. East Java, the most populous province with over 40 million residents, showed stable consumption patterns, peaking in 2020 before returning to previous levels. This stability highlights resilience but also suggests potential saturation in demand.

Overall, the data illustrate that while population growth is consistent across these provinces, consumption trends are more volatile, influenced by local economic conditions, climate impacts, and production variability. This divergence emphasizes the need for region-specific food security strategies that address demographic pressures alongside agricultural and market realities. These findings highlight the policy challenge of ensuring equitable access to nutritious food across

provinces with varying demographic and economic profiles.

Comparative evidence from Burgaz et al. (2024) indicates that government policies must integrate nutrition, non-communicable disease prevention, and climate adaptation to build resilient food systems. For Universal Health Coverage (UHC), provinces with high consumption but limited production capacity face a greater risk of malnutrition and increased demand for health services (United Nations, 2023).

Ultimately, the dashboard is expected to serve as a strategic resource for evidence-based decision-making, allowing users to respond more effectively to climate variability, supply chain disruptions, and market instability. By integrating climate, production, price, and consumption data into a comprehensive analytical framework, this research contributes to a nuanced understanding of Indonesia's food system and supports the development of targeted, region-specific policies (Delena, 2023). Importantly, the dashboard situates food security within the broader context of UHC, demonstrating how nutritional risks directly impact health equity and service demand. The integration of Street-Level Bureaucracy (SLB) theory further enriches the analysis, illustrating how frontline bureaucrats adapt their decisions under changing institutional and political conditions. This combined empirical and theoretical approach enhances both the academic significance and practical relevance of the study, offering valuable insights.

## CONCLUSION

At the national level, the connection between climate factors—such as temperature, rainfall, and humidity—and crop yields or food prices appears weak and inconsistent. However, when examined at a provincial level, the situation becomes clearer. In East Java, shallot production increased by 15% in 2019, yet prices only dropped by 4%. This indicates that local gains are often hindered by poor logistics and fragmented markets. In Central Java, rainfall played a crucial role; a 10% decrease in rainfall in 2020 resulted in a 9% decline in rice yields, demonstrating that rainfall is a key driver of agricultural productivity.

Bali, on the other hand, relies heavily on imports, which weakens the relationship between local production and prices and exposes the province to fluctuations in the global market. In North Sumatra, diversified cropping systems have reduced sensitivity to climate changes. However, the rising demand for protein-rich foods has created pressure on affordability and raised health concerns.

Looking at the broader picture, air temperature shows a weak negative correlation with yields nationwide (around -0.2), but its effects vary by region. Rainfall variability significantly impacts rice yields in Central Java, while humidity negatively affects shallot productivity in East Java, and rising temperatures reduce yields in Bali. These findings, as illustrated in the Power BI dashboard, emphasize the need for locally tailored adaptation strategies that integrate climate science, crop management, and food security policies to enhance resilience and ensure sustainable outcomes throughout Indonesia.

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