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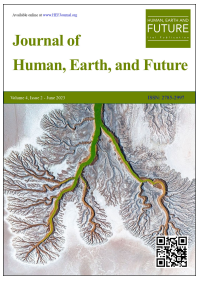

The Nexus between Food Security and Investment, Exports, Infrastructure, and Human Capital Development

Miguel A. Esquivias [1*], Akhmad Jayadi [1], Syahiru Shafiai [2], Intan M. Abd Rashid [2], Amirah H. Borhanordin [2], Kemala Sari Agusti [1], Lutfi Yahwidya [1]

[1] *Department of Economics, Faculty of Economics and Business, Universitas Airlangga, Surabaya, Indonesia.*

[2] *Department of Finance and Economics, Faculty of Business and Management, Universiti Teknologi MARA Cawangan Melaka, Malaysia.*

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Abstract

Objectives: We examine the impact of economic sectors, including agriculture, industry, services, and exports, on Indonesia's food security. Furthermore, we investigate the influence of three types of capital—direct investment, infrastructure, and human capital—and several socioeconomic factors—inequality, unemployment, poverty, and population density. *Methods/Analysis:* Using data on all 34 Indonesian provinces from 2011 to 2019, we employ the generalized method of moments and other panel techniques to assess four food security indicators: a principal component analysis-based food index, daily protein consumption, daily calorie consumption, and agricultural production. *Findings:* investment significantly drives agricultural production and food security. Net exports are positively associated with calorie intake, protein consumption, and food security. Surprisingly, infrastructure expenditure negatively affects calorie and protein consumption. While expanding manufacturing activities threaten food security, growth in agriculture and the service sector supports higher protein and calorie intake. Factors such as income inequality, poverty, and unemployment positively correlate with agricultural production. *Novelty/Improvements:* As societal welfare decreases, agricultural production increases alongside shifts in dietary preferences. Agriculture serves as a source of employment during economic downturns. Conversely, a higher Human Development Index and population density suggest that as Indonesia flourishes economically, the demand for calorie- and protein-rich foods grows, even as agricultural production declines.

Keywords: Food Security; Sustainable Agriculture; Food Products Trade; Foreign Direct Investment; Agricultural Production.

1. Introduction

Food security is a crucial concern not only for every country but also for society as a whole. Therefore, attaining food security should be considered a fundamental objective of global development. Indeed, in 2000, world leaders pledged their commitment to improving living conditions and reducing the prevalence of hunger globally through the Millennium Development Goals (MDG). Similarly, Indonesia's economic development agenda encompasses several objectives, including improving social welfare [1]. A crucial aspect is guaranteeing food security [2]. The social facet of food security can be divided into three parts: human health, demographics, and socio-political factors, including social conflicts and demographic phenomena [3, 4]. Health-related challenges often linked to food security include

* Corresponding author: miguel@feb.unair.ac.id

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malnutrition, obesity, insufficient hygiene and sanitation, limited access to clean drinking water, and essential medications [5, 6]. From a socioeconomic perspective, inadequate food security can threaten social stability, cause price volatility, increase the cost of living, raise dependency on foreign supply, widen the trade deficit, and result in the failure to meet basic needs [7, 8]. Finally, from a demographic perspective, the exodus of people from the agricultural sector can threaten national food security [2, 9].

As Pasaribu et al. [10] noted, Indonesia ranks 102nd on dietary diversity on the 2019 Global Food Security Index (GFSI), 103rd on micronutrient availability, and 97th on protein quality. These relatively low rankings underscore the challenges faced by many disadvantaged Indonesians in accessing affordable, high-quality food [2]. In particular, agriculture in Indonesia faces numerous challenges that hinder farmers' efficient participation in providing necessary food. These challenges include diminishing farmland, rising input costs, limited access to capital and essential resources, unfavorable farm gate prices, and adverse terms of trade for farmers [9, 11–13]. Foreign Direct Investment (FDI) has emerged as a potential avenue through which economic openness can help improve food affordability and quality [14]. FDI can introduce new technologies, managerial expertise, and knowledge while also establishing connections with the global market [15, 16], thereby increasing productivity among firms receiving FDI.

However, between 2015 and 2019, FDI in Indonesia's agriculture sector accounted for only 3–7% of the total FDI inflow. Furthermore, since 2003, FDI in Indonesian agriculture has been predominantly centered on the palm oil sector, driven by the global surge in palm oil commodities [10]. From 2003 to 2018, the FDI in the palm oil sector surged to USD 13.9 billion. By contrast, FDI in broader agricultural categories, such as food crops, horticulture, and plantations, amounted to USD 441 million. Indonesia has maintained a relatively cautious approach to foreign investments, especially in the agricultural sector, compared to its neighboring Asian nations. In 2019, Indonesia's foreign investment regulations were more stringent than those of Australia, China, Malaysia, and Vietnam. These restrictions primarily revolve around equity limitations (setting the maximum proportion of foreign ownership in a company), requirements for crucial foreign personnel, and other related constraints [10].

Nonetheless, research shows the positive impact of FDI on productivity, technological diffusion, and efficiency in Indonesia. Specifically, FDI not only boosts productivity spillover effects in sectors related to those receiving investment but also in the regions where these recipient firms are located [17, 18]. Although these findings predominantly stem from studies in the manufacturing sector, similar effects can reasonably be anticipated in agriculture. Investment, both domestic and FDI, can potentially contribute to the development of Indonesia's agricultural sector and enhance access to high-quality food for the population [2] by increasing agricultural production, efficiency, and higher technological capabilities.

According to Santangelo [19], the positive impact of FDI on food security extends beyond increased capital and technology transfers. FDI can stimulate infrastructure development, such as transportation and irrigation systems, which are essential for efficient agriculture. It also encourages the adoption of sustainable farming practices, ensuring long-term food security by maintaining and improving soil quality, and reducing environmental degradation. Therefore, FDI may bolster food security in developing countries. Focusing on the Belt and Road Initiative (BRI) countries, Yao et al. [20] showed that FDI in the agriculture sector has both direct and indirect positive impacts on food security in these countries. This positive effect is particularly evident when a country consistently attracts agricultural FDIs. Other studies have reported similar results, confirming the potential gains from investments in food security. At the sectoral level, Tondl & Fornero [21] found significant linkages between FDI and productivity in various economic sectors. However, studies are far from reaching a consensus on the impact of investment on food security. Balouza [22] identified an adverse effect of primary and tertiary sector FDI on calorie and protein intake in developing countries and a positive impact of secondary sector FDI.

Dey [23] examined various factors affecting food security in Bangladesh from 1971 to 2017, including the relationships between rice and fishery production, gross domestic product (GDP), and food security. The author identified some crucial agricultural sectors that contributed significantly to GDP growth, job creation, and food security. In Senegal, Van Den Broeck et al. [24] studied the impact of agricultural exports on food security, highlighting that exports can enhance a country's ability to import food without major risks to food availability, thus benefiting household food security. Ashraf & Javed [25] found significant positive effects of human capital and institutional quality on improving food security in developing countries. Similarly, Rashidi Chegini et al. [26] established a direct and significant association between household income levels and food security.

Here, we delve into the influence of various economic variables on food security in Indonesia. Specifically, we investigate how a country's economic composition, encompassing the agricultural, industrial, and service sectors as a share of total regional GDP, impacts food security. In addition, we explore the role of physical investments (both domestic and foreign direct investments), infrastructure investments, and human capital investments in supporting food security nationwide. Next, we examine the impact of various socioeconomic factors, including income inequality, unemployment, poverty rates, population density, farmers' exchange rates, years of schooling, and life expectancy. Finally, we analyze whether an open economy improves food security.

To construct a food security index, we employ principal component analysis (PCA) on various indicators, such as average daily protein consumption, average daily calorie consumption, and agricultural production. Our study uses socioeconomic data from 2011 to 2019, covering all 34 Indonesian provinces. We apply a range of panel techniques, including the generalized method of moments (GMM), to evaluate models with four distinct food security indicators: a PCA-based food index, daily protein consumption, average daily calorie consumption, and agricultural production (specifically, rice production).

This study aims to fill several gaps in the literature. First, besides FDI, we examine the impact of domestic investment on food security. Other forms of investment, such as human capital, infrastructure, and social programs, are also important drivers of food security; however, few studies have considered all three simultaneously [25]. Second, socioeconomic factors, such as poverty, inequality, and unemployment [27, 28], are often overlooked despite their potential implications for food security [14, 29, 30]. Rapid urban growth, increasing levels of inequality, and high levels of poverty can have severe consequences for food security, especially in emerging countries. Third, the economic structure of countries is often not considered, despite the crucial impact of shifts in resources from the primary to secondary and tertiary sectors on a country's ability to produce food [7, 8, 31]. In addition, large countries, such as Indonesia, that rely on agricultural exports are exposed to domestic food supply problems if global trade leads to more exports and lower production for the home market. Fourth, recent studies only focus on caloric and protein intake or other food consumption indicators [28, 32, 33] without considering more comprehensive food security indices and the agricultural output of main national crops. These factors are crucial for capturing a complete picture of food security.

This study contributes to the existing literature in several ways. First, we estimate the impact of economic activity across the primary, secondary, and tertiary sectors on food security. The rapid transfer of labor from primary to secondary and tertiary activities suggests that labor mobility and structural changes may affect food security in Indonesia [2, 34]. Second, we consider the impact of three sources of capital: direct investment (foreign and domestic), infrastructure investment, and human capital. This helps in recognizing the specific roles played by each type of capital in pursuing food security and formulating policies to bolster their respective contributions to national food security. Third, we consider socioeconomic aspects such as poverty, income inequality, unemployment, and population density. These factors have been studied in the context of developing economies, although often independently [26, 29, 30]. Fourth, we use four measures to capture food security. This strategy helps us obtain robust results, examine changes in dietary and nutritional intake, and assess overall food security.

2. Literature Review

2.1. Understanding Food Security: Definitions and Evaluation

The concept of food security has evolved over the years. In 1986, the World Bank initially defined it as "access by all people at all times to enough food for an active, healthy life." However, in 1996, the World Food Summit provided a more comprehensive definition: "food security exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life." This updated definition considers the quantity of food available and its safety, nutritional value, and accessibility, emphasizing the holistic well-being of individuals and communities [30]. Essentially, the absence of any of these essential factors within a population indicates food insecurity. The United Nations Committee on World Food Security has provided another definition, emphasizing not only physical and economic access but also the social aspect: "the condition in which all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life." This expanded definition recognizes the importance of social factors in ensuring food security and well-being [22].

The Food and Agriculture Organization (FAO) has formulated a comprehensive framework consisting of four pillars that collectively define food security.

- ***Food availability:*** It refers to having sufficient quantities and required quality of food, whether through domestic production or imports. This underscores the importance of having an ample food supply to meet the needs of the population.
- ***Food access:*** It refers to access to the necessary resources to obtain appropriate food that contributes to a nutritious diet. It recognizes that people must have the means and opportunities to acquire the food they need.
- ***Food use:*** It encompasses factors such as access to clean water, sanitation, and healthcare which collectively enable individuals to attain a state of well-rounded nutrition in which all physiological needs are met.
- ***Food stability:*** It refers to having consistent access of populations, households, and individuals to sufficient food. Continuity of access and protection against potential disruptions in the food supply are essential.

These four pillars collectively provide a comprehensive framework for understanding and assessing food security from various perspectives, including availability, access, utilization, and stability [20]. The FAO underscores the

importance of investing in agriculture because such investments are instrumental in enhancing productivity growth in food output. Increased productivity is pivotal for reducing food prices and boosting farm income, thereby improving access to food in impoverished communities. In developing countries, these investments can safeguard the economy and ensure employment during crises [1, 31].

2.2. Investment and Food Security: FDI, Human Capital, and Infrastructure Investments

In the early 1980s, the link between FDI inflows and food security gave rise to two distinct theories: dependency and modernization. These theories offer various perspectives. Dependency theory suggests that depending heavily on foreign investment can negatively affect economic growth and the fair distribution of income [22, 35]. Ullah et al. [35] and Adams [36] argued that foreign investment can foster monopolization and the inefficient use of productive resources in developing countries. This may lead to reduced demand for other sectors and contribute to stagnant economic growth. Conversely, modernization theory emphasizes the significance of both internal and external factors in driving economic development. Domestically, countries should rely on domestic investment, economic growth, and education as catalysts for industrialization, cultural advancement, and improvements in social welfare [37]. Externally, they should leverage FDI to provide technology, organizational expertise, management skills, and marketing knowledge. FDI inflows grant easy access to international markets and facilitate the dissemination of new skills and knowledge in the host economy [38]. The transfer of technology and know-how improves productivity and resource allocation efficiency [39, 40].

Empirically, Wegren & Elvestad [41] and Fitawek & Hendriks [33] underscored the importance of increased investment in the agricultural sector to enhance food security by boosting farm production and income in various countries. Chaudhuri & Banerjee [42] found that agricultural FDI in developing countries improved national welfare and alleviated unemployment, thereby enhancing food security. Amendolagine et al. [43] noted that the positive spillover effects of FDI from developing countries depend on the industry in which the investments are made. In the natural resources sector, for instance, investors from developing countries often rely primarily on their parent companies for inputs in their local production facilities. Meanwhile, with investors from developed countries, they tend to employ advanced technologies that facilitate cropland expansion in host developing countries. The resulting cropland expansion mitigates food supply issues and bolsters food security in developing countries.

Ben Slimane et al. [31] demonstrated that in developing countries, agricultural FDI contributes to food security. The authors also highlighted the noteworthy influence of FDI spillovers on food security, primarily through their impact on agricultural production. By contrast, FDI in the manufacturing and service sectors tends to exacerbate food insecurity. Meanwhile, Pavleska & Kerr [44] found that enhancing FDI to introduce better technologies into a country's crop production processes and fully harnessing agricultural biotechnology will be vital in addressing food security challenges.

Liu [45] argued that in developing countries, one should not assume that the advantages of agricultural FDI will automatically enhance food security. Instead, the author emphasized that the impact of agricultural FDI on food security is contingent on local government policies and legislation. Certain forms of large-scale agricultural investments can even pose risks to host countries. Similarly, Yao et al. [20] explained that agricultural FDI has negative effects in some developing countries, which are often characterized by weak economic systems and do not open their doors to FDI. Some developing countries are concerned that foreign investments in agriculture may hurt local farmers because of the historical experience of foreign investors' monopolistic behavior. To improve food security, these countries should carefully select agricultural investments and focus on strategies that boost local farming productivity. Thus, they can benefit from foreign investments while protecting the interests of local farmers.

Focusing on 56 developing and transitioning economies from 1981 to 2001, Keef & Li [46] also revealed agricultural FDI is associated with decreased food security. The authors argued that FDI in various sectors (primary, manufacturing, and services) influences food security in different ways. Specifically, FDI in the primary sector tends to diminish food security through resource exploitation and misallocation, insignificant spillover effects, adverse labor market impacts, and environmental and demographic externalities.

Nevertheless, Smyth et al. [47] and Warr [48] emphasized the importance of direct private (domestic or foreign), public (infrastructure), and social investments or partnerships in which producers actively participate, as these are critical for optimizing the adoption and application of technologies, particularly for high-value crops. Given the decline in crop productivity, and public sector-funded research and development (R&D), mobilizing all stakeholders to support investments to improve food security and rural development is crucial. Ashraf & Javed [25] found that investments in human capital and institutional quality play a substantial role in bolstering food security in developing countries. Specifically, food security contributes to ecological sustainability through the human capital channel, while institutional quality aids in alleviating the adverse environmental impacts associated with food security. Gnedeka & Wonyra [49] affirmed that improving human capital and institutions can also contribute to improving food security in sub-Saharan Africa. Ardianti et al. [1] highlighted that investments in information and communication technologies, particularly in improving Internet access, positively impacted food security in Indonesia. Mensah et al. [50] revealed that good

governance is instrumental for bolstering food security; well-defined investment guidelines can have a sustained positive impact on economic development and food security.

Following the food security literature, we hypothesize that increasing investments can influence food security by providing resources for increasing food production capacity, enhancing food related technology, increasing the scale of production, improving efficiency, and enabling the diversification of food production [3, 20, 48]. Moreover, human capital investments can increase workers' skills, raise technological absorption capability, and improve managerial capabilities to produce food [44, 49]. However, a higher Human Development Index (HDI) can lead to fewer workers in food-based activities and increase the labor supply in non-agricultural sectors [25]. Infrastructure investments which are food-related can enhance connectivity, reduce coordination complexity, reduce the cost of supplying food, and increase efficiency in markets [1, 47]. However, non-food-related infrastructure investments may lead to a decrease in food security or boost the redistribution of resources to other economic activities [51, 52].

2.3. Economic Structure and Food Security

A country's economic structure can also influence food security. The economic structure indicates how resources are allocated and the orientation of economic activities. Empirical evidence indicates that an increasing share of agriculture in the GDP is positively correlated with increased rice production, particularly when the government allocates additional subsidies to the agricultural sector [53]. This allocation boosts the agricultural GDP, subsequently leading to enhanced crop availability, improved efficiency of farming methods, and the implementation of various programs aimed at promoting rice production [23]. By contrast, neglecting agriculture can leave a country vulnerable to external food supply disruptions, exacerbating food insecurity [23, 54]. Studies focusing on developing countries [55, 56], South Asia [57], and Sub-Saharan Africa [49] consistently highlight the substantial positive effects of boosting agricultural production. This increase in agricultural output plays a crucial role in alleviating undernourishment and enhancing food security [58]. Thus, stimulating agricultural productivity can be an effective strategy for reducing food insecurity. However, reducing or eliminating government intervention through trade barriers is equally critical since they can distort prices, leading to unintended and adverse outcomes [56].

Meanwhile, the share of GDP in manufacturing and services can influence food security in various ways. A strong manufacturing sector can create jobs and increase income, thereby improving people's access to food. A thriving service sector can enhance infrastructure, transportation, and market access, thereby facilitating food distribution. The rise of both sectors can contribute to economic dynamism. This can positively affect food availability and affordability, and thus, enhance food security. However, an overemphasis on manufacturing may divert resources away from agriculture, thereby reducing food production [8, 31]. A disproportionate service sector may also lead to income inequality, thereby limiting vulnerable populations' access to food.

Next, the literature examining the relationship between trade openness and food security presents diverse findings. Some authors contend that international trade adversely affects food security by increasing dependence on food imports or diminishing the domestic food supply, as exemplified in the case of China [59]. However, greater trade openness is also associated with improved food security due better access to food, improved food quality, and more efficient allocation of resources towards higher-yielding crops [49].

Specifically, the volume of exports can impact food security both positively and negatively [28]. On the positive side, a diversified export base can foster the relocation of agricultural resources to the most competitive food-related sectors, increasing the food supply [24]. Higher exports can generate foreign income, potentially improving the country's ability to import food during food shortages [49, 60]. Indeed, Van Den Broeck et al. [24] underscored the positive impact of exports on food security as they can strengthen a nation's capacity to import food without jeopardizing food availability. Alhussam et al. [60] also observed that expanding trade connections and deepening food exports within the BRI improved food security in the 46 participating countries. This positively affects household food security at the microeconomic level, including a reduced likelihood of food insecurity, improved food consumption quality, and shorter periods of widespread hunger. However, excessive reliance on exports may lead to the neglect of the domestic agricultural sector, reducing food self-sufficiency and making the country vulnerable to global food price fluctuations [56]. This can negatively affecting food security. Furthermore, agricultural goods exports can shift production away from essential food items, exacerbating limited availability of domestic food and agricultural products [58].

2.4. Socio-economic Aspects and Food Security

Finally, the socioeconomic conditions of a country's inhabitants, such as poverty, unemployment, population density, and income inequality, can be related to food security. In developing countries, household income levels and food security are often related, suggesting the need to examine whether socioeconomic factors are positively or negatively related to food security [26, 29, 30, 53]. Further, food insecurity and hunger are intricately tied to poverty [26, 32], with limited access to food representing the gravest deprivation experienced by those enduring extreme poverty [29]. However, poverty and other forms of temporary destitution (i.e., unemployment) can also have implications for

agricultural workers (a rise in the number of farmers), as rural jobs often provide the safety of employment for unemployed individuals [61, 62]. In developing countries, both urban and rural areas (typically larger than urban ones) have implications for food consumption [63, 64] and food security [28].

Another socioeconomic phenomenon in developing countries with implications for food security is rising population density fueled by urbanization and an increase in GDP. Both urban development and increased income levels are associated with better jobs in cities, which can affect food consumption habits (variety, quality, and volume of food) [55]. Similarly, as more people move to urban areas, it may affect agricultural labor supply. This can affect the availability and quality of food in increasingly populated urban areas [30, 63]. Moreover, income inequality may be related to food insecurity because it can influence households' ability to access essential food items [4, 63]. Indeed, Savari et al. [4] found that income inequality contributes to food insecurity. Increasing income levels can empower households to secure essential food items and enhance their access to food; however, an unequal income distribution can lead to an imbalance in the distribution and availability of food for less-well-off households [65]. Hosseini et al. [53] and Rashidi Chegini et al. [26] also established a direct and significant link between household income levels and food security.

In summary, the relationship between food security and factors such as investment, socioeconomic conditions, and economic structure of a country is complex and multifaceted. Furthermore, the outcomes can vary depending on factors such as the type of investment, local policies, and economic conditions. Further research is needed to comprehensively understand how these factors together contribute to global or a country's food security. Here, we examine this in the context of Indonesia. The economic transformations witnessed in Indonesia over the past two decades, marked by substantial service sector growth, expansion of industrial activities, greater openness to trade and investment, and improved individual welfare, necessitate a re-evaluation of the sustainability of food production in the country. To evaluate this multifaceted situation, we first examine food security using a composite index built from several food-related indicators, including average protein consumption per capita per day, average calorie consumption per capita per day, and total rice production (a proxy for agricultural output). We also compare the index-based results with those of individual indicators. Based on this index, we create a framework to examine the nexus between food security and a set of investment, socioeconomic, and economic structure-related variables (Figure 1).

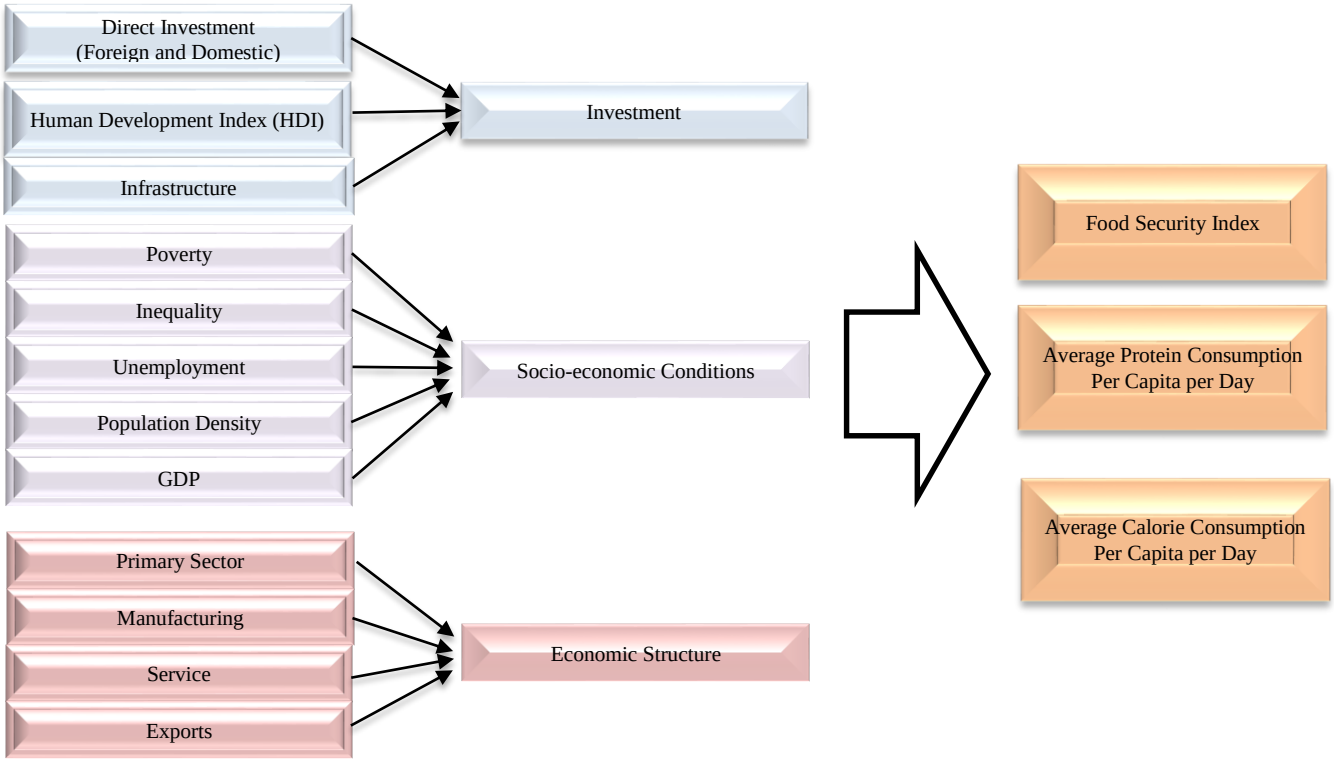


Figure 1. Empirical framework

3. Research Methodology

We first construct our food security index using through PCA. This involves the careful selection of components. We employ various essential tests and estimation approaches, including Bartlett and Kaiser-Meyer-Olkin (KMO); assess the total variance of principal components; and examine the eigenvectors for each component. After obtaining the food security index and other food security indicators, we gather secondary data to measure investment (direct, human, and infrastructure) and socioeconomic factors (income inequality, poverty, unemployment, and population density) across

all Indonesian provinces. Subsequently, we test our empirical framework by employing four proxies for food security: agricultural production, calorie intake, protein intake, and the food security index. This testing is carried out using a range of panel data regression techniques, including GMM, two-step GMM, fixed effects model (FEM), random effects, and partial least squares (PLS). The empirical strategy and estimation techniques are detailed in Figure 2.

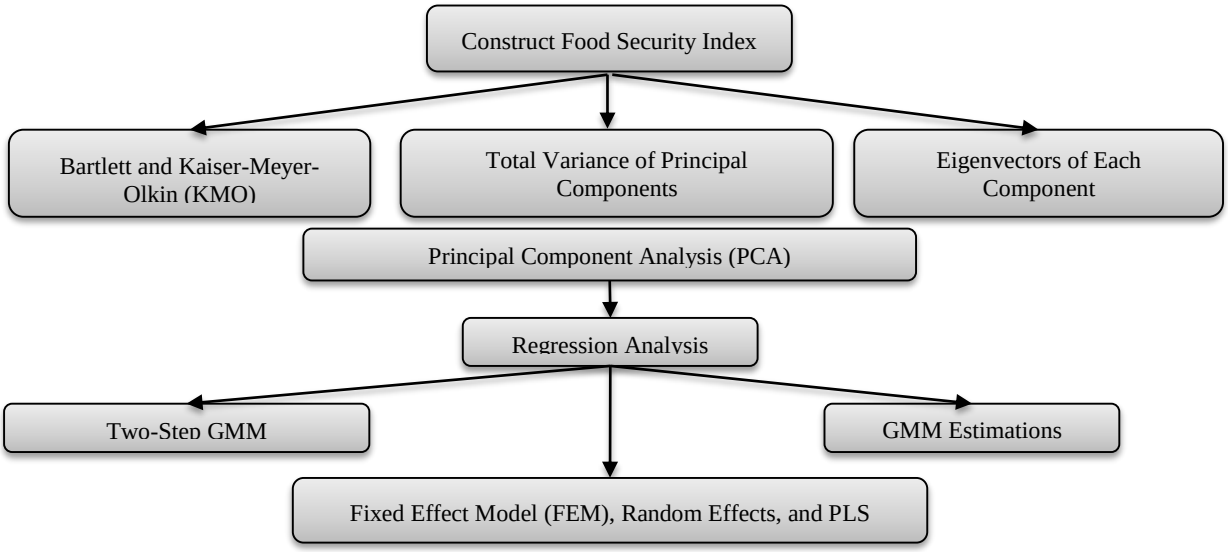


Figure 2. Empirical approach and estimation techniques

3.1. Constructing a Composite Food Security Index

We use PCA to construct the index. PCA is a multivariate technique used to analyze the relationships among variables and express these variables in terms of their components [66]. Through PCA, correlated variables are transformed into a new set of uncorrelated variables referred to as principal components [31]. As outlined in Table 1, we use seven food security indicators to create the food security index. We use the min-max normalization method to normalize these indicators for comparability.

Table 1. Indicators for constructing the food security index

Variables	Impact	Description	Unit
(1) navgprotein	+	Average protein consumption per capita per day	Gram
(2) ncalorie	+	Average calorie consumption per capita per day	Kkal
(3) nfoodexp	+	Percentage of average monthly expenditure per capita on food in rural areas	Percentage
(4) nlandsize	+	Size of rice harvested area	Ha
(5) nagrproduction	+	Total rice production	Ton
(6) nlifexpc	+	Life expectancy after birth	Year
(7) nyos	+	Number of years of schooling	Year

Prior to conducting PCA, we evaluate the dataset using the Bartlett and KMO tests to assess its suitability for factor analysis. Bartlett's Test of Sphericity assesses the null hypothesis that the population correlation matrix variables are uncorrelated or identical to the identity matrix [66, 67]. The KMO value ranges from 0 to 1, with a value exceeding 0.5 indicating the appropriateness of the dataset for PCA computations. The selection of the number of components to retain adheres to Kaiser's criteria, which involves preserving principal components with eigenvalues greater than one [68]. Furthermore, the determination of the number of principal components considers the cumulative variance, typically capturing at least 60-70% of the total information [31]. The results of both the KMO and Bartlett's tests, shown in Table 2, confirm the suitability of the dataset for PCA.

Table 2. KMO and Barlett's test results

KMO and Bartlett's Test			
Kaiser-Meyer-Olkin Measure of Sampling Adequacy	**KMO**	**=**	**0.595**
Bartlett test of sphericity	Chi-square	=	1712.476
	Degrees of freedom	=	21
	p-value	=	0.000
	H0: Variables are not inter-correlated		

Table 3 illustrates that components 1 through 3 are the most appropriate choices, as they collectively account for 86.3% of the total information and their eigenvalues, reported in Table 4, are greater than one. As we select these three components, we opt for the largest eigenvalue among them to calculate the contribution value. This allows us to assess the contribution of each indicator to the construction of the index, with nlandsize and nagrproduct~n making the most significant contributions at 18% each. We apply a consistent standard weight across all years and provinces, and multiply it by the predicted principal component values, resulting in the following formula, where PC_n represents the nth principal component:

Food security index (fsindex) = (0.4438007 × PC_1) + (0.3673233 × PC_2) + (0.1900347 × PC_3)

Table 3. Total variance of principal components

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	2.680	0.465	0.383	0.383
Comp2	2.215	1.070	0.317	0.699
Comp3	1.145	0.607	0.164	0.863
Comp4	0.538	0.236	0.077	0.940
Comp5	0.302	0.207	0.043	0.983
Comp6	0.094	0.069	0.014	0.996
Comp7	0.026	.	0.004	1.000
Number of obs	293			
Number of comps.	7			
Trace	7			
Rho	1.000			

Table 4. Eigenvalues of each component

Variable	Comp1	Comp2	Comp3	Weight	Contribution
navgprotein	0.54	0.027	0.375	0.001456479	0.168573944
ncalorie	0.435	0.069	0.619	0.000932195	0.107892902
nfoodexp	-0.359	0.192	0.47	0.000707805	0.081921913
nlandsize	0.035	0.657	-0.081	0.001591054	0.184149796
nagrproduc~n	0.046	0.652	-0.118	0.001578946	0.182748352
nlifexpc	0.422	0.2	-0.402	0.001138211	0.131737415
nyos	0.458	-0.247	-0.272	0.00123531	0.142975678
Total	1.42	1.309	1.089	0.00864	1
Proportion	0.383	0.317	0.164		
Cumulative Proportion		0.863			
Standard weight	0.443801	0.367323	0.190035		

3.2. Estimated Model

This study employs two models: a two-step GMM and FEM. The former is chosen for its superior model specifications and robust estimation compared to other panel data models. We also use the Arellano–Bond serial correlation test to address autocorrelation issues. The AR(1) and AR(2) tests serve as diagnostic tools for assessing the accuracy of the generated estimates [69], while the Sargan test is employed to test the validity of the instruments used to over identify restrictions. The equation for the two-step system GMM is as follows:

$$Y_{ijt} = \beta_0 + \beta_1 Y_{i,t-1} + \beta_2 lngdpagri_{it} + \beta_3 lngdpmanuf_{it} + \beta_4 lngdpserv_{it} + \beta_5 ntp_{it} + \beta_6 lnfdi_{it} + \beta_7 lnfdi_{it} + \beta_8 lninfrastructure_{it} + \beta_9 lnnetexport_{it} + \beta_{10} X_{it} + \varepsilon_{it} \quad (1)$$

In Equation 1, *Y* represents the dependent variable, which includes the food security index, average daily protein consumption, average daily calorie consumption, and agricultural production. To address violations of normality and classical regression assumptions, we transform the variables using the natural logarithm (ln). The subscript *i* denotes cross-sectional provinces in a given year *t*. ε_{it} is the error correction term, and X represents other control variables explained in Table 5.

Table 5. Description of variables

Variable		Description
fsindex	Food security index	Obtained from PCA calculation (index)
avgprotein	Average protein consumption	Average protein consumption per day (gram)
calorie	Average calorie consumption	Average calorie consumption per day (kkal)
lnproduk~i	Agriculture production	Total rice production (ton)
lnfdi	Foreign direct investment	Annual foreign direct investment realization.
lnddi	Domestic direct investment	Annual domestic direct investment realization.
lninfrastr~e	Infrastructure expenditure	Regional government infrastructure spending originating from the annual regional revenue and expenditure budget
hdi	Human Development Index	HDI has a range of 0–100, with 0 lowest and 100 highest
lngdpagri	Regional GDP of agriculture	Gross regional domestic product (GRDP) of the agriculture sector with current price (billion rupiahs)
lngdpmanuf	Regional GDP of the manufacturing sector	GRDP of the manufacturing sector with current price (billion rupiahs)
lngdpserv	Regional GDP of service sectors	GRDP of service sectors with a current price (billion rupiahs)
lnnetxport	Net exports	Export-import
Gini	Gini coefficient	The Gini coefficient ranges from 0 to 1. If the Gini coefficient is 0, it means perfect equality; 1 indicates perfect inequality
unmploy	Unemployment rate	The annual open unemployment rate—a percentage of the total unemployed against the entire labor force.
poverty	Poverty	Number of poor people (urban+rural)
popdensity	Population density	Number of people per square kilometer
yos	Number of years of schooling	Average number of years of schooling
productivity	Agricultural productivity	Rice productivity (ku/ha)
lifexpc	Life expectancy	Life expectancy after birth (year)

FEM is employed to confirm the results of the GMM estimations and assess their robustness. Comparisons among the FEM, random effects, and PLS are provided in the Appendix. The FEM is selected based on the specifications outlined by Hausman [70]. The Hausman test assesses the null hypothesis that the preferred model is a random effect, whereas the alternative model is a fixed effect. The test results favour the use of FEM.

3.3. Data

We use data on all 34 provinces in Indonesia from 2011 to 2019. We also include a set of economic and development variables as independent variables (see Table 6 for details). Annual data are obtained from the Central Bureau of Statistics, Indonesia. The dataset covers all provinces in Indonesia (34 regions) from 2011 to 2019, except Bengkulu (2012–2019), North Kalimantan (2018–2019), and Maluku (2016–2019) because of data limitations.

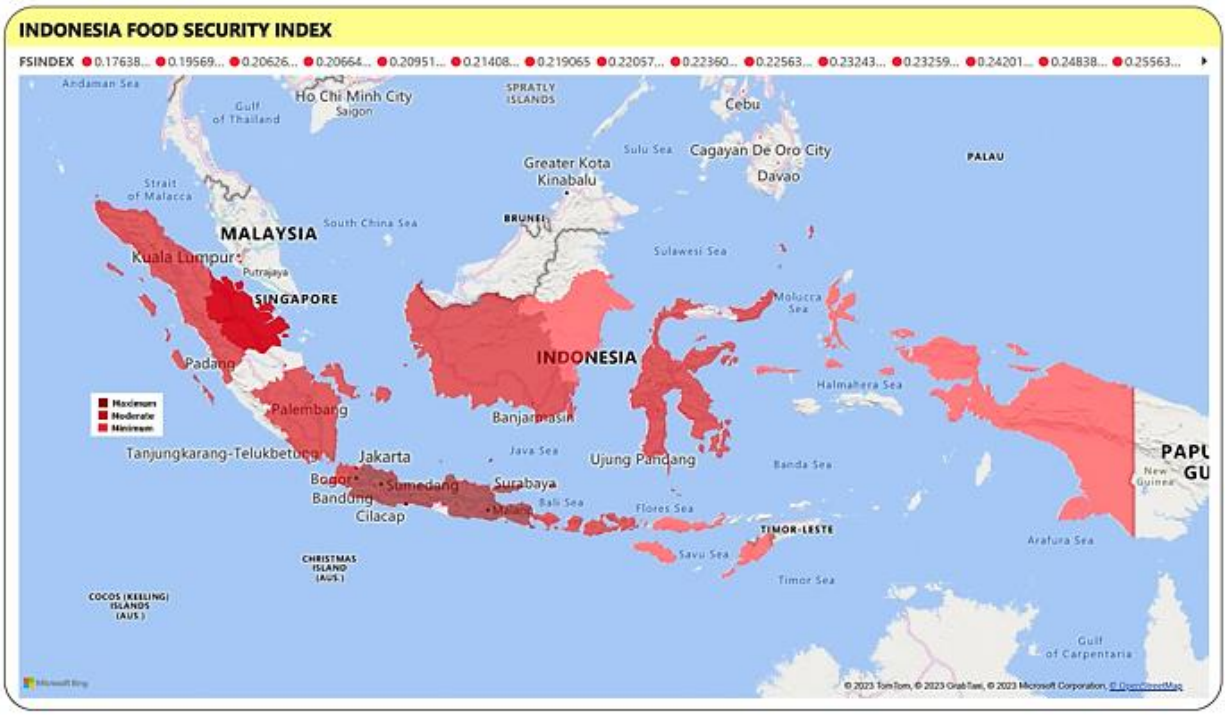
Table 6. Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
fsindex	293	0.419	0.104	0.176	0.755
avgprotein	293	56.413	6.012	38.4	74.29
calorie	293	1981.423	152.635	1617	2452
agrproduction	293	2036576.1	3186678.1	627	13633701
gdpagri	293	46393.282	53179.549	1391.24	268772
gdpmanuf	293	31233.81	58136.664	264.42	297377
gdpserv	293	42376.514	104926.68	1541.83	875166
ntp	290	125.298	15	96.08	174.49
fdi	293	847.357	1255.271	0.2	7124.9
ddi	293	6210.996	9967.839	1	62094.801
expinfra	293	1415.22	2553.951	135.3	29036.301
netxport	293	3909953.5	89719397	-4.556e+08	3.311e+08
Gini	293	0.376	0.042	0.272	0.475
hdi	293	68.657	4.442	55.01	80.76
unmploy	293	5.293	2.047	1.4	13.74
productivity	293	46.072	9.453	19.499	72.34
poverty	293	839.155	1200.001	48.61	5356.21
popdensity	281	772.592	2683.533	8.5	15900
yos	293	8.037	1	5.6	11.06
lifexpc	293	69.263	2.615	62.78	74.92

Note: Not all variables are in3 the displayed results, but are included in the extended results.

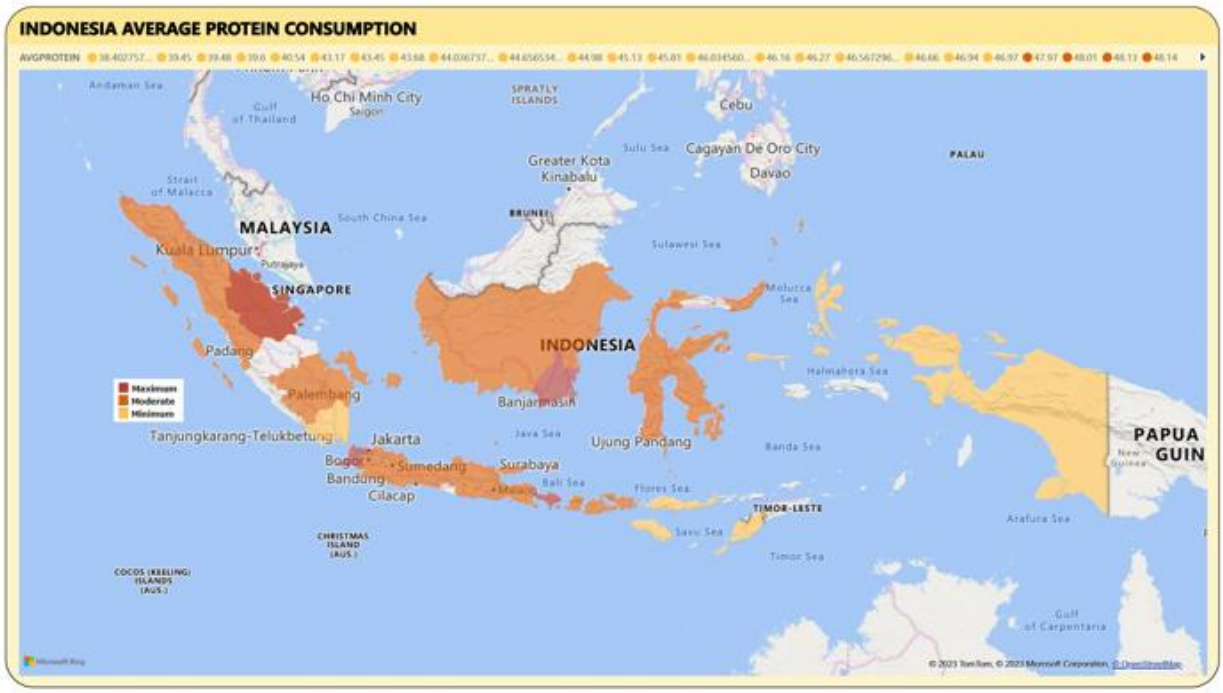
4. Results

Figure 3 illustrates the indicators of food security across Indonesia, including the food security index, average protein consumption, average calorie consumption, and agriculture production. Agricultural output varies among provinces, with larger provinces like Sumatera Utara, Jawa Barat, and Jawa Timur showing higher production compared to smaller provinces like Gorontalo or DKI Jakarta. This disparity may be due to differences in land use, climate, and agricultural practices. Additionally, dietary intake varies across provinces, with no consistent correlation between higher agricultural production and better dietary indicators. Provinces with larger rice harvested areas tend to have higher average protein and calorie consumption, but this correlation is not consistent across all provinces. The Food Security Index considers multiple factors affecting food security, including agricultural productivity, and it shows that some provinces with high agricultural production have lower food security and vice versa, indicating that factors beyond productivity contribute to overall food security.



(a) Food Security Index

(b) Agricultural Production (Total rice production)



(c) Average protein consumption per day (gram)

(d) Average calorie consumption per day (kkal)

Figure 3. Food security indicators across Indonesia (average 2011-2019); Note: From highest levels (dark) to lowest levels (light)

Table 7 presents the GMM estimation results for the four dependent variables: agricultural production, average calories, average protein, and food security index. We compare two models: one includes the Gini coefficient, HDI, and poverty variables, while the other substitutes these variables with population density and unemployment. Several additional models are tested to assess the robustness of the results by adding or removing specific control variables. For simplicity, we present only two models (the other results are available upon request). Overall, the results remain consistent, although the significance of some variables changes when certain control variables are introduced. We first present the results concerning the relationship between food security and economic structure, followed by an exploration of the connection with investment factors, and culminating with an examination of socioeconomic aspects.

Table 7. GMM estimations

	Agriculture production		Average calorie consumption per capita per day		Average protein consumption per capita per day		Food security index	
lnY-1	0.600***	0.904***	0.192**	0.525***	0.222***	0.262***	0.285***	0.458***
	(0.0959)	(0.0867)	(0.0961)	(0.121)	(0.0657)	(0.0931)	(0.0890)	(0.0708)
lnGDPAGRI	0.582*	1.116	147.0	-72.86	-1.779	-3.495*	0.00308	0.0106
	(0.303)	(0.808)	(98.21)	(65.04)	(2.437)	(1.843)	(0.0773)	(0.0404)
lnGDPMANUF	-0.117	0.175	-75.69	-110.8**	-1.558*	-1.769	-0.0516***	-0.0535***
	(0.134)	(0.139)	(57.46)	(52.40)	(0.905)	(1.214)	(0.0166)	(0.0115)
lnGDPSERV	0.287	-1.112	-47.02	446.3***	4.400	12.92***	0.0837	0.0621
	(0.470)	(0.765)	(93.12)	(83.46)	(2.765)	(2.346)	(0.0700)	(0.0402)
lnNETEXPORT	0.0242	-0.0592	5.795	61.78**	1.304	2.360***	0.0149**	0.0181***
	(0.0256)	(0.0400)	(33.32)	(25.48)	(1.696)	(0.907)	(0.00583)	(0.00443)
lnINVESTMENT	0.0524*	0.0324	18.31	3.805	-0.00173	0.187	0.0141***	0.0137***
	(0.0313)	(0.0325)	(24.62)	(21.50)	(0.226)	(0.530)	(0.00524)	(0.00517)
lnINFRAS	-0.0597	-0.0988	-109.0**	-120.5***	-1.314	-3.016***	-0.0278***	-0.0316***
	(0.0926)	(0.0802)	(48.19)	(29.66)	(0.856)	(0.879)	(0.00844)	(0.00779)
hdi	-0.143**	-	78.69***	-	1.807***	-	0.00420	-
	(0.0673)	-	(24.74)	-	(0.537)	-	(0.0114)	-
Gini	3.553***	-	-288.2	-	-14.08	-	-0.149	-
	(1.371)	-	(549.7)	-	(14.90)	-	(0.293)	-
poverty	0.0570*	-	40.53**	-	0.870***	-	0.00587	-
	(0.0298)	-	(19.87)	-	(0.333)	-	(0.00524)	-
popdensity	-	0.00170**	-	-0.926***	-	-0.0220***	-	-0.0000484
	-	(0.00072)	-	(0.139)	-	(0.00552)	-	(0.0000710)
Unmploy	-	0.0138	-	91.84***	-	0.275	-	0.0109***
	-	(0.0120)	-	(29.33)	-	(0.227)	-	(0.00396)
_cons	5.004*	-0.495	-3981.5***	-2025.8***	-106.3***	-44.74**	-0.499	-0.196
	(2.613)	(1.679)	(1341.2)	(551.3)	(20.62)	(21.34)	(0.772)	(0.204)
chi2	777.9	44139.9	2221.9	15659.9	420.6	44682.4	767.2	9937.4
Sargan Test	0.9999	0.9972	0.9989	1.0000	0.9979	1.0000	0.9998	0.9999
AR(1)	0.0140	0.0059	0.0153	0.0055	0.0147	0.0167	0.0137	0.0070
AR(2)	0.3819	0.3339	0.2759	0.9510	0.5519	0.9586	0.0989	0.0796

Note. Standard errors are indicated in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The results obtained using the fixed effects models (FEM), random effects models (REM), and partial least squares (PLS) can in the Appendix (Tables A1, A2, and A3, respectively).

The lag coefficients (*lnY-1*) consistently showed a positive and statistically significant relationship in all models. This suggests that an increase in agricultural production, average calorie index, average protein index, and food security index is associated with an improvement in the food security index in the current period. This temporal relationship emphasizes the significance of ongoing initiatives to bolster agricultural productivity and facilitate nutritional access, as their enduring influence will contribute to improved food security over time. Furthermore, it underscores the imperative of implementing policy measures that not only cater to increasing nutritional demands within the nation but also address the growing need for food security, ensuring its long-term sustainability.

Similarly, the coefficient of the regional agricultural GDP (lngdpagri) is positively significant for the agricultural production index, suggesting that an increase in the regional agricultural GDP is positively associated with an increase in rice production (agricultural production). Providing additional government support to the agricultural sector (i.e., subsidies) can increase its GDP. This can enhance crop availability, the efficiency of farming methods, and the implementation of various programs to boost agricultural production [23]. However, the coefficient of agricultural GDP is negatively associated with average protein consumption, suggesting that protein consumption decreases as agricultural output increases. Whitton et al. [54] also found that an increase in a country's GDP did not necessarily result in higher meat consumption. This is because environmental concerns are likely to drive a shift in the food production model towards more sustainable methods of protein provision for the growing global population. These innovative approaches to food production are expected to be less harmful to nature and the animal kingdom, as humanity seeks to establish healthier connections with the biophysical world upon which it relies.

The coefficient of the regional GDP of the manufacturing sector (lngdpmanuf) is negative and significant in all models for all dependent variables except agricultural production. This suggests that an increase in manufacturing output adversely affects average calorie consumption, protein intake, and the food security index. This effect can be attributed to the redirection of resources towards industrial activities rather than agriculture. As Indonesia undergoes industrialization [15, 18], the country must ensure food security by providing the necessary support for the agriculture and food sector. The government must aim for industrialization together with advancements in agricultural practices. These findings align with those of studies conducted in West Africa, which revealed the detrimental effects of industrialization on food security [8]. Promoting a dual focus on industrialization and agricultural advancement may require additional infrastructure investment, research, and innovation. Other actions include improving agriculture-specific education and training, financial support for agribusiness, more strategic diversification in agriculture, and support for small-scale producers. Achieving this balance may help ensure industrial growth while enhancing food security in a sustainable and inclusive manner.

Conversely, service GDP has the opposite effects. An increase in service output is linked to higher average calorie and protein consumption. Thus, expanding the service sector could potentially bolster calorie and protein intakes. However, the impact of service GDP on agricultural production and the food security index is positive but not significant. The findings can be linked to the income effect stemming from the rapid growth of service activities in Indonesia and their impact on productivity [71]. Services constitute more than 45% of Indonesia's gross domestic product and are a major source of employment. The sector's expansion has spurred infrastructure development, particularly in information and telecommunications technologies, distribution, finance, and retail [72]. By enhancing employment, the sector has broadened market access and helped diversity the economy [73]. Research also show a positive association between services and access to quality food in Africa [7], indicating that improved services contribute to better food access.

The coefficient for net exports (lnnetexport) is significantly positive for average calories, average protein, and food security indices, but not for agricultural production. This suggests that export growth (net exports) is likely to drive a shift towards more productive sectors, resulting in increased calorie intake, protein consumption, and an improved food security index. This finding aligns with trade theory, implying that specialization in productive activities may lead to consumption benefits, such as improved access to nutritious food and a more secure food supply. These findings are consistent with prior research [24], which suggests that exports can enhance a country's ability to import food without threatening food availability. At the microeconomic level, this positively affects household food security by reducing the likelihood of food insecurity, improving food consumption quality, and shortening the duration of periods characterized by prevalent hunger. Further, our results align with the literature on sub-Saharan Africa and other developing nations [49, 60], indicating that open markets can alleviate food insecurity, and enhance both access to and quality of food. Nonetheless, as Indonesia's agricultural exports continue to grow [74], the country should prioritize that it has a consistent and robust agricultural stock supply by improving agricultural production. This is a crucial challenge, particularly with its growing population and rising income, akin to the challenges faced by China [59].

Investments have a positive and significant impact on agricultural production and the food security index. Thus, increasing foreign and domestic investments can contribute to higher rice production (which is critical for Indonesia) and an improved food security index. However, the results are not significant for average protein and calorie consumption. Overall, the positive relationship between investments and food security supports the hypothesis that more significant investment is necessary to strengthen a country's overall food security, and is particular area of focus for policymakers. Similarly, Ben Slimane et al. [31] found that in developing countries, agricultural FDI supports food security, whereas FDI in the manufacturing and services sectors increases food insecurity. The authors also identified the significant influence of FDI spillover on food security through its impact on agricultural production. Chaudhuri and Banerjee [42], Amendolagine et al. [43], Smyth et al. [47], Pavleska & Kerr [44], and Aloui & Maktouf [3] reported similar findings in Sub-Saharan Africa, where FDI contributed to improved crop production, advanced technology, and enhanced national welfare, thereby increasing the capacity to manage food security.

These results further corroborate the Ardianti et al.'s [1] findings, who demonstrated that investments in Internet infrastructure positively contributed to food security in Indonesia. Likewise, the necessity for investments aligns with Warr's [48] conclusions, who highlighted that agricultural productivity in Indonesia between the 1970s and early 2000s was primarily attributed to agricultural research and development investments. Nyiwul & Koirala [75] stressed that investment in the agricultural sector is pivotal in driving technological improvements, advancing technical expertise, introducing up-to-date practices, and transferring superior managerial skills.

Contrary to expectations, the coefficient of infrastructure expenditure (lninfrastr–e) is significantly negative for the food security index, average calorie consumption, and average protein consumption, but not for agricultural output. This suggests that despite the rapid expansion of the country's infrastructure, it has not contributed significantly to bolstering food security. Instead, these efforts may have diverted resources towards manufacturing and services. These results are noteworthy given the extensive government endeavors in recent years to enhance communication infrastructure throughout the nation, including ports, roads, airports, and energy, as highlighted by Muryani et al. [52]. Indeed, studies

suggest that infrastructure development in Indonesia may have primarily contributed to expanding the manufacturing and service sectors rather than benefiting agriculture [76]. Interestingly, similar findings have been observed in different geographic contexts as well, such as ECOWAS [51], where increased public expenditure on infrastructure in recent years is negatively associated with food security.

Next, when the HDI increases, it corresponds to lower rice production but a higher intake of calories and proteins. Interestingly, while a higher HDI does not directly result in improved food security, it indicates that as Indonesia prospers and human capital improves (as reflected in a higher HDI), the demand for calorie- and protein-rich foods rises, even as agricultural production declines. This shift in dietary preferences occurs even as the agricultural production of staples, such as rice, declines. As people enjoy higher living standards and greater access to education and economic opportunities, they tend to diversify their diets and seek a more varied and nutritious range of foods. This underscores the evolving dynamics between human development and food consumption in Indonesia. Nonetheless, the absence of a substantial connection between human capital investments, and both the food security index and agricultural production implies that increasing levels of human development in Indonesia must be coupled with secure access to quality food and sustained food production. Thus, as the nation grows, it may have to confront food insecurity in the future even with its economic prosperity.

Socioeconomic aspects exhibit distinct correlations with the food security index, average calorie consumption, average protein consumption, and agricultural production. The Gini index is significantly and positively correlated with agricultural production, suggesting that rice production tends to increase as societal inequality increases. Similarly, Rashidi Chegini et al. [26] highlighted a direct and significant association between household income level and food security. Other studies also have similar findings [26, 29, 30, 53, 55]. Essentially, income inequality is linked to food insecurity; still, increasing income levels may enhance households' ability to access essential food items, which is a critical aspect of food security [4].

Next, the poverty rate has significant positive correlations with agricultural production, calorie intake, and protein consumption. However, no significant relationship is observed between poverty and food security. This suggests a connection between poverty and agricultural employment as well as an influence on the dietary preferences of impoverished individuals. Although we do not find a significant link between poverty and the overall food security index, nutritional adjustments due to poverty may cause a reduction in dietary nutrition, consistent with Andrianarison's [29] observations. Alternately, as the poverty rate increases, the labor supply in rural areas also rises. This results in increased agricultural production, and thus, higher overall food production in the country. Our findings differ from those of Montolalu et al. [28], who found that the poverty rate in Indonesia is linked to a decrease in calorie and protein intake after controlling for import tariffs. We argue that Montolalu et al. [28] did not consider that key agricultural imports in Indonesia are mostly controlled through quotas rather than tariffs, leading to possibly biased results and an increase in food prices; this may explain the negative impacts in their results.

Notably, increased population density is associated with higher agricultural production but reduced intake of calories and proteins. This may be because as the population grows, and agglomerates in rural and urban areas, the available agricultural land remains constant but is used more efficiently for cultivation. This increases crop yields. Furthermore, higher population density may indicate greater availability of labor and capital that can be directed towards agricultural activities. These findings align with those of Kaneva & Untura [77], who found a correlation between the number of rural inhabitants and size of agricultural areas. Although various reasons may explain this, agricultural expansion and rural population growth often move similarly in multiple provinces. Meanwhile, the inverse relationship between population density and protein and calorie consumption suggests a potential shift in dietary preferences. Consequently, individuals may choose low-calorie and low-protein diets. This intricate interplay underscores the multifaceted nature of how population density affects both agricultural output and dietary choices.

Surprisingly, the unemployment rate, food security index, and average protein consumption are positively correlated. One plausible interpretation is that agriculture continues to serve as an alternative avenue of employment for the unemployed. This dynamic prompts unemployed individuals to return to rural areas, thereby fostering increased agricultural production. Labor transfers between rural and urban areas during an economic downturn, when the demand for labor decreases, often lead to systemic barriers. Many migrant workers are compelled to return to rural areas, where they may opt to resume farming. Moreover, being unemployed may lead individuals to adopt different dietary habits, resulting in higher protein consumption. Soy-based products, for instance, often serve as protein-rich alternatives for those facing nutritional adjustments owing to financial constraints in Indonesia. This may account for the elevated protein intake among unemployed individuals. Similar findings have been reported by Kristo et al. [61] and Smed et al. [62], who found that unemployment led to a short-term shift towards a diet composed of more protein, fat, and saturated fat.

The results on the nexus between poverty, unemployment, inequality, and population density imply that the food security narrative in Indonesia should extend beyond merely meeting national production targets, in line with McCarthy & Obidzinski [27]. National food security must consider the significant implications of inequality, unemployment, poverty, and urban demographics on the well-being of less privileged Indonesians. Rising income inequality, a

substantial portion of the population (10%) still in poverty, and ongoing rapid urbanization [78] indicate that agricultural production, nutrition, and Indonesia's ability to achieve food security will undergo substantial dynamic changes. These changes require proactive anticipation and policy intervention. While impoverished individuals in rural areas may have specific coping mechanisms to access food, those living in urban areas may encounter distinct challenges, including food access, quality, and affordability issues. These urban-specific challenges must be addressed in the country's food security agenda, as Dwiartama et al. [63] argued.

Regarding model performance, note that we do conduct appropriate tests to assess its validity. The chi-square (chi2) values show the overall significance of the model and help us gauge its reliability. Furthermore, the results of the Sargan test confirm the credibility of the instruments used in the GMM estimation process. Finally, we use the AR(1) and AR(2) values to examine the autocorrelation, shedding light on potential interdependencies among the variables. Together, this helps us ensure the robustness and reliability of the performance evaluation of the model.

5. Conclusion

Using data on 34 Indonesian provinces from 2011 to 2019, this study investigates the relationship between economic variables and food security in Indonesia. We examine how a country's economic composition, spanning the agricultural, industrial, and service sectors, influences its food security. Furthermore, we explore the roles of physical (domestic and foreign) infrastructure and human capital investments in supporting food security. Finally, we assess the impact of various socioeconomic factors and whether an open economy contributes to food security.

We employ PCA to construct our food security index utilizing diverse indicators, such as average daily protein and calorie consumption and agricultural production. Then, by applying a range of panel techniques, including GMM, we evaluate four distinct food security indicators: a PCA-based food index, average daily protein consumption, average daily calorie consumption, and agricultural production (specifically, rice production).

Our findings provide several insights. Foreign and domestic investments have positive and significant impacts on agricultural production and the food security index. This suggests that increasing investments can contribute to higher rice production and improved food security. Surprisingly, infrastructure expenditure has a significantly negative impact on the food security index, average calorie consumption, and average protein consumption, but not on agricultural production. This implies that, despite substantial infrastructure development, it may not significantly bolster food security but could divert resources towards other economic activities (i.e., manufacturing and services).

Furthermore, an increase in net exports has a significantly positive relationship with higher calorie intake, protein consumption, and the food security index. This indicates that export growth drives a shift towards more productive sectors, thereby improving food security. Our analysis also emphasizes the significance of socioeconomic factors. Income inequality is positively correlated with agricultural production, suggesting that rice production tends to increase as societal inequality increases. Conversely, a higher HDI is associated with lower rice production but higher calorie and protein intake. This suggests that as Indonesia prospers, the demand for calorie- and protein-rich foods increases, even as agricultural production declines. Population density is positively linked to agricultural production but negatively associated with calorie and protein consumption. Lastly, an unexpected positive correlation is observed between the unemployment rate, food security index, and average protein consumption. This may be because agriculture serves as an alternative employment avenue during economic downturns, leading to increased agricultural production and a shift in the dietary habits of the unemployed.

5.1. Policy Implications

With societal prosperity rising and urbanization increasing in Indonesia, agricultural output might decrease. Therefore, adopting modern agricultural methods becomes essential to sustain and enhance production levels. While agricultural production plays a crucial role, other aspects like distribution, economic factors, and access to diverse food sources also significantly impact dietary patterns and food security. Therefore, strategies need to encompass not only increased agricultural productivity but also better distribution systems, nutritional education, and economic policies that ensure access to a diverse and nutritious diet for all provinces in Indonesia.

As average calorie and protein intake increases over time, there is a necessity to enhance the food sector's dynamism to meet the growing demand for more nutritious foods. With the expansion of non-agricultural activities (i.e., manufacturing) and infrastructure development consuming resources, there's a need for the government to direct infrastructure investments towards a more advanced food sector. Focusing on high-value and productive crops will likely boost the ability to produce higher calorie-protein foods.

The evolving socio-economic landscape in Indonesia, marked by reduced poverty, increased inequality, extensive urban development, and rising unemployment, may limit the capacity to satisfy the demands for adequate calorie and protein intake, concurrently altering the dietary preferences of the population. It's imperative for the government to focus on ensuring people have access to nutritious food and can effectively meet their dietary requirements.

Encouraging increased investment in agriculture and the food sector, along with enhancing education and skills, is crucial for maintaining food security. Creating a more conducive investment environment is essential for both domestic and foreign investments in advanced agricultural businesses. It's important to align infrastructure investments with the needs of the agricultural sector, as current projects have adversely affected food security.

The government must anticipate the impact of changing economic activities on food security. Prioritizing and strengthening both the agricultural and service sectors will help ensure food security. Simultaneously, efforts should be made to ensure that the expanding manufacturing activity supports the food industry. Promoting the export of higher-value crops through strengthening the production of highly demanded crops can contribute to food security.

6. Declarations

6.1. Author Contributions

Conceptualization, M.A.E. and A.J.; methodology, M.A.E. and S.S.; software, K.S.A.; validation, K.S.A., S.S., and I.M.A.R.; formal analysis, I.M.A.R. and A.H.B.B.; investigation, A.H.B.B. and K.S.A.; data curation, K.S.A. and L.Y.; writing—original draft preparation, M.A.E., L.Y., and K.S.A.; writing—review and editing, M.A.E. and I.M.A.R.; visualization, A.J. and L.Y.; supervision, A.J. and S.S.; funding acquisition, M.A.E. and S.S. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

Restrictions apply to the availability of these data. Data was obtained from Statistics Indonesia and are available at *https://www.bps.go.id* with the permission of Statistics Indonesia.

6.3. Funding

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6.5. Institutional Review Board Statement

Not applicable.

6.6. Informed Consent Statement

Not applicable.

6.7. Declaration of Competing Interest

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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