IJEMD-SS, 5 (1) (2026) https://doi.org/10.54938/ijemdss.2026.05.1.741

International Journal of Emerging Multidisciplinaries: Social Science

Research Paper
Journal Homepage: www.ojs.ijemd.com
ISSN (Online): 2958-0277

Digital Transformation, Knowledge Based Economy, and Zero Hunger: Evidence from Asian Developing and G-7 Countries

1. Seemab Ahmad, 2. Prof. Dr. Dilawar khan, 3. Dr. Alam Khan

1. Department of Economics, Kohat University of Science & Technology, Kohat 26000, Pakistan,
seemiguli98@gmail.com

2. Department of Economics, Kohat University of Science & Technology, Kohat 26000, Pakistan
dilawar@kust.edu.pk **(corresponding author)**

3. Department of Economics, Kohat University of Science & Technology, Kohat 26000, Pakistan
alamkhan@kust.edu.pk

Abstract

Achieving Sustainable Development Goal 2 (Zero Hunger) necessitates novel approaches that improve food security via knowledge-based economic development. This research examines at the influence of the knowledge-based economy (KBE) on achieving zero hunger in 44 Asian developing nations and the G7 economies between 2000 and 2024. A composite Knowledge Economy Index based on education, innovation, information and communication technology, and the economic and institutional regime is compared to a Zero Hunger Index using second-generation panel econometric approaches. This empirical investigation includes use of cross-sectional dependency and slope homogeneity tests, the Cross-sectionally Augmented IPS (CIPS) unit root test, the Westerlund cointegration test, Cross-Sectional Autoregressive Distributed Lag (CS-ARDL) estimate, and Dumitrescu-Hurlin panel causality analysis. The results reveal a strong long-term link between the knowledge-based economy and zero hunger in groups both of countries. Improvements in the knowledge-based economy greatly reduce hunger, with a greater impact shown in G7 nations than in Asian developing countries. Renewable energy and foreign direct investment improve food security, whereas growing urbanization exacerbates hunger-related issues. The error correction estimates support a quick convergence to long-run equilibrium, whereas bidirectional causation between the KBE and Zero Hunger suggests a mutually supporting connection. The study suggests that enhancing education, innovation, digital infrastructure, and institutional quality is critical for improving food security. It will speed up the progress toward SDG 2, particularly in Asian developing nations and G7.

Key words: Zero hunger, knowledge-Based Economy, SDG-2, Panel Analysis, Asian Developing Nations, G7 Economies.

1. Introduction

A global commitment to promoting equitable society, environmental integrity, and long-term economic development for current and future generations is embodied in the Sustainable Development Goals (SDGs). A comprehensive development framework of 17 objectives, 169 targets, and 234 indicators. World leaders convened at the UN headquarters in New York on September 25, 2015, accepted this agenda, which is to be completed by 2030 (UN, 2015). This systematic agenda was developed to address the underlying inequalities and structural barriers that prohibit large segments of the global population from appropriately exercising their social and economic rights. (Egido et al., 2023). The Millenium Development Goals (MDGs), which spanned from 2000 to 2015 with 67 goals and mostly focused on improvements in aggregate national indicators, are built upon by the SDGs. The SDGs, on contrary, extend beyond average national performance and specifically aim to lessen development inequities both within and between nations, institutionalizing the idea of "leaving no one behind." The SDGs are a more sophisticated and comprehensive framework than the MDGs, although being based on the larger expansion of sustainable development rhetoric. The agenda promotes a balanced development paradigm based on the interconnectedness of environmental sustainability, social inclusion, and economic growth—often referred to as the Triple E aspects. Additionally, the SDGs present a common worldwide vision for 2030 that motivates decision-makers to adopt coordinated international action rather than limited domestic agendas. The SDGs continue to serve as a key strategic blueprint directing the global shift toward a more inclusive, resilient, and environmentally friendly development trend by encouraging innovation, sustainable patterns of production and consumption, energy efficiency, improved public health, and general human well-being (Jednak & Krgulj, 2015; Ivanova Boncheva, 2021; Elavarasan et al., 2022).

In order to accomplish the Sustainable Development Goals (SDGs), local, national, and international governance entities must work together in a coordinated manner. Progress toward these goals is influenced by a number of structural variables, including disparities in income distribution both within and across countries, persistent poverty, and widening socioeconomic inequalities that obstruct inclusive growth patterns. Environmental limitations including damage to ecosystems, climate change, and over use of natural resources make a transition to sustainability more challenging. Inadequate infrastructure, limited access to high-quality education, and unreliable healthcare systems all hinder the development of human capital and the overall welfare of society. Governance-relevant problems that hinder the implementation of policies and the implementation of laws include political instability, armed conflict, and institutional corruption (Singh et al., 2022). Within this broader developmental framework, the Knowledge-Based Economy (KBE) framework emerges as a key enabler of long-term prosperity. It is based on four fundamental pillars: advanced education and skill formation systems, a robust information and communication technology (ICT) infrastructure, a dynamic innovation ecosystem, and a sustaining institutional and economic regime. The KBE endorses long-term growth and structural transformation by enhancing productivity, speeding technology diffusion, and stimulating innovative capability. A knowledge-driven economy's technological advancements directly support improvements in vital industries like healthcare, renewable energy, and sustainable agriculture, strengthening alignment with several SDGs and advancing socially and environmentally sustainable development avenues.

By propelling innovation, information sharing, food security, and data-driven strategies, a knowledge-based economy is essential to attaining SDG2-Zero hunger. It makes it possible to develop sustainable farming methods, increased crop yields, and effective food delivery networks thru research, technology, and teaching. By using data analytics to track food production and consumption, KBE can improve food policy and governance. It recognizes weaknesses and develops well-informed plans to reduce hunger. These economies support the overall objective of eradicating hunger by 2030 and help build a more resilient, food-secure world by encouraging knowledge and innovation (Mensi et al., 2021). In order to achieve Zero

Hunger, sustainable smart agricultural practices must be critically investigated. Hunger remains an overwhelming global issue. These connections, together with the worldwide scope of food systems, account for the impact that world events have had, have had, and will continue to have on the attainment of SDG2 goals. For example, even if agricultural operations were not subject to the COVID-19 pandemic limitations, there were unavoidable interruptions in the efficiency and functionality of global food supply systems during those years, which had an impact on nutrition and food security. The Russian-Ukrainian war has highlighted how vulnerable global agricultural systems and food and nutrition security goals are to geopolitical developments that affect nations regardless of how close they are to one another (Mhlanga & Ndhlovu, 2023).

The repercussions of the many global environmental impacts that food systems continue to create will have a significant impact on them (Singh et al., 2021). Thru a variety of direct and indirect channels and feedback processes, the climate crises and shocks in particular will have a direct detrimental impact on food prices, food insecurity, and malnutrition. In fact, the growing unpredictability of the climate is changing planting patterns, increasing the frequency of pest and disease outbreaks, putting more strain on already limited natural resources, and encouraging local conflicts and migration patterns that negatively impact nutrition and food security (Crippa et al., 2021). After a period of favourable developments between 2018 and 2019, when the total number of undernourished people worldwide (since 2014) also grew, some ascribe the rise in the percentage of undernourished people to climate dynamics. Given the interconnectedness of the three main sources of disruption major risks to global health, geopolitical conflicts, and climate-induced environmental degradation. This predicament may only become worse in the future. Chronic hunger, acute food insecurity, and malnutrition have been made worse by the combined effects of conflict, climate unpredictability, and extreme weather events. This leads to resource degradation, economic hardship, and social and political instability (FAO, 2023).

The concept, features, and incorporation of disruptive technologies of smart agriculture are all covered in this research paper. This covers the widespread impact on the agricultural environment of artificial intelligence, machine learning, big data, precision agriculture, and the internet of things. With an emphasis on resource management, reducing environmental impact, and improving food security, the critical role that technology plays in supporting sustainability is emphasized. This section gives alarming statistics on hunger and malnutrition worldwide and highlights the need of understanding Zero Hunger. The contribution of smart agriculture to reducing hunger is thoroughly examined. Key tactics include managing crops and yields, supervising livestock and fisheries, optimizing the supply chain, reducing food waste, and promoting digital financial inclusion in rural communities (Mishra & Mishra 2024). It can ensure food supply for current and future generations while protecting the natural environment of the planet by implementing ecologically sound farming practices. Governments, organizations, and individuals must work together to advance sustainable agriculture and spur innovation in the direction of a future free from hunger. In order to achieve zero hunger by 2030, urgent coordinated action and policy solutions are required to address structural inequities, reorganize food systems, fund sustainable farming techniques, and mitigate the detrimental impacts of conflict and the pandemic on global nutrition and food security. Protecting natural resources, boosting agricultural output, enhancing farmer livelihoods, fortifying resistance to climate change, and minimizing environmental damage all contribute to the objective of eliminating global food insecurity (Kadomtseva, 2022).

Malnutrition may be lessened, and people can make more nutritiously dietary choices by promoting nutrition-related education and awareness. People can learn about the value of balanced meals and appropriate nutrition thru public campaigns, school nutrition programs, and community workshops. Thru policies that help smallholder farmers and provide access to nutrient-dense food, governments play a critical role in the fight against hunger. Vulnerable populations can achieve their nutritional needs with the use of social protection programs like school feeding programs and food assistance programs (Berchin et al., 2019). Food consumption patterns, nutritional gaps, and hotspots for food poverty may all be better understood by using technology for data collection and analysis. Policymakers may more successfully target interventions and distribute resources where they are needed the most with the use of geographic information systems, remote sensing, and machine learning algorithms (Rejeb et al., 2021).

Establishing sustainable agricultural methods and boosting food security need education and capacity building. Implementing laws that encourage and promote sustainable farming methods, such as those that limit the use of pesticides, support agroecological methods, and offer subsidies for organic farming. Resilient regulatory systems can help achieve zero hunger and ease the shift to sustainable agriculture. Promoting cooperation between governments, corporations, farmers, academics, and non-governmental groups in order to solve issues related to food security and advance sustainable agricultural projects. Partnerships can accomplish shared objectives and have a large-scale impact by utilizing their combined resources and experience. By putting these sustainable agriculture techniques into practice, we can end hunger while maintaining the long-term wellbeing of our people and environment. In order to provide food security for both present and future generations while respecting the planet's scarce reserves, environmentally friendly agriculture is essential.

2. Literature Review

In this section, we review the literature on the knowledge-based economy and its relevance to achieving the Sustainable Development Goal, namely zero hunger. The review then considers empirical research linking KBE factors with outcomes related to food security, employment and growth, income inequality, and climate action.

3. Sustainable Development Goal 2 (Zero Hunger)

3.1. Theoretical Framework

The theoretical literature explores the relationship between the knowledge-based economy and sustainable development goal 2.Theoretical models indicate that economies that invest in research, talent development, and technical innovation are better positioned to have climate-friendly technology. According to these theories, knowledge is a strategic asset that affects both ecological viability and the competitiveness of the economy.

Recent studies also highlight the role of technology and safety in progressing the Zero Hunger agenda. Mishra et al. (2025) examined how sustainable smart agriculture can minimize hunger on the global scale. They investigated the growing use of the Internet of Things, artificial intelligence, machine learning, big data, and precision agriculture in modern agri-sector. These technologies support better crop and yield management. It enhanced livestock and fisheries monitoring, stronger supply chains, and reduced food waste. Also it fosters greater digital financial inclusion in rural areas. The literature focuses that ZH is closely interlinked with other SDGs, which indicates both synergies and trade-offs that are necessary to be considered. Main challenges along the avenues to zero hunger include the lack of a systemic approach, the multifaceted, global, and nested nature of food networks. To cope with these challenges coordinated action from diverse stakeholders across multiple fronts is required. This will ensure equitable and sustainable progress toward zero hunger (Sporchia et al., 2024).

Utilizing neglected yet nutrient-dense crops that have been cultivated for centuries but are still mostly underused today presents a significant potential in the Asian environment. Cereals, roots, nuts, pulses, fruits, and vegetables are among the crops that are rich in micronutrients, robust to environmental stressors, and well suited to local circumstances. A practical way to bridge Asia's production and nutritional gaps is to switch from near-monoculture farming methods to diverse cropping portfolios that incorporate these neglected crops. This strategy has been supported by the Food and Agriculture Organization's Zero Hunger campaign. This aims to eradicate hunger by 2030. Notwithstanding its promise, obstacles including farmers' reluctance to accept novel crops and the lack of government backing for their implementation still exist. However, nations like Nepal have started embracing neglected crops, offering feasible ways to get over these obstacles and open up new pathways for sustainable agriculture (Siddique et al., 2021).

3.2. Empirical Framework

Empirical literature on the KBE and SDG2 primarily focuses on evaluating the link via real-world data and econometric analysis. Researches generally use panel data models, time-series techniques, and regression frameworks to investigate how knowledge indicators such as education, innovation, and digital advancement impact environmental findings.

An estimated 735 million people worldwide suffer from hunger, which is a persistent problem, especially in portions of the Middle East, South Asia, and sub-Saharan Africa. Despite the size of the problem, scientific objectivity is frequently lacking in its quantification. The most widely used statistic, the Global Hunger Index (GHI), uses participatory weighting of four highly interrelated indicators undernourishment, child stunting, child wasting, and child mortality to produce subjective and perhaps erroneous values. More objective methods are suggested by recent studies, such as sophisticated clustering algorithms to deal with missing data and dimensionality-reduction techniques to provide practical weighting schemes. When compared to the traditional GHI, these updated methods significantly alter country rankings, highlighting the necessity of reevaluating how hunger intensity is measured for policy objectives. While cutting-edge agricultural techniques like high-yield technologies and genetically modified crops may aid in further reducing hunger worldwide, scholars also stress the significance of accurate hunger assessment in resource allocation, progress monitoring, and intervention design (Montero et al., 2025). Building on the need of accurate measurement, researchers have looked at the factors that influence food security in a range of geographical settings. For instance, studies was out in important Asian countries including Bangladesh, Malaysia, China, India, Indonesia, and Pakistan. It highlights that while fertilizer use and investments in agricultural fixed capital boost food supply and stability, rising temperatures and decreasing arable land have a negative effect on food security. These results emphasize how crucial land resources, productivity-boosting inputs, and environmental considerations are for creating the zero-hunger goal (Ashraf et al., 2024). According to parallel study from Nigeria, macroeconomic instability is particularly significant since inflation significantly affects agricultural productivity both in the short and long term, making hunger-related issues worse. According to studies using ARDL projections, stabilizing prices and reducing inflation might help boost agricultural growth and lessen social unrest caused by hunger (Reuveni, 2025).

By examining how institutional, family, and economic factors contribute to undernourishment in developing countries, recent studies have added to the body of knowledge on hunger and food insecurity. Ghosh and Sahu (2023) analyzed 61 developing and least-developed nations between 2004 and 2019 and discovered that increased food production, growing per capita income, and greater financial inclusion considerably reduce undernourishment, although rises in food prices exacerbate the problem in the long run. Their panel cointegration and error-correction results also show that competent governance and political stability help to reduce undernourishment while corruption worsens it in the near term, emphasizing the significance of institutional quality in reaching zero hunger. Ensuring food security while building a self-sufficient food economy is a major challenge in today's globalized world. It is also crucial for sustained social resilience. China still faces challenges in guaranteeing long-term food security and eradicating hunger despite achieving agricultural self-sufficiency. Food consumption has shifted from staple crops to meat, dairy, and premium imported goods due to rapid economic growth and urbanization. Between 1991 and 2018, Djokoto et al. (2022) examined 44 nations, 18 of which were developing and 26 of which were developed. They examine that foreign direct investment (FMFDI) in food production fosters human development in both industrialized and developing countries. To draw FMFDI, developing countries should improve its macroeconomic conditions. International bodies like UNCTAD have endorsed the idea of reallocating FMFDI to developing nations. In order to lessen world hunger, these studies highlight the importance of sustainable food production, investment, and regulatory frameworks.

4. Research Methodology

4.1.Description of Data and Variables

This Research provides a thorough, multifaceted assessment of food security outcomes across Asian developing and G7 countries. The current research utilised panel data from 2000 to 2024. A comparative analysis of why advanced economies have been more successful in reaching the SDGs while developing countries still struggling. The World Bank (WB, 2026), United Nations (UN), International Monetary Fund (IMF), Food and Agriculture Organization (FAO, 2026), World Economic Outlook, International Labor Organization (ILO, 2026), and Our World in Data (2026) are just a few of the reliable sources from which the dataset was assembled.

This study utilizes the World Bank's Zero Hunger Index as a proxy for SDG 2 success because it offers a comprehensive, multidimensional evaluation of food security results across nations. The index includes four core components prevalence of undernourishment, prevalence of wasting among children under five, prevalence of stunting among children under five, and the under-five mortality rate all of which are aligned with internationally recognized indicators for assessing hunger, dietary habits, and the well-being of children. Their integration enables cross country comparisons between Asian emerging economies and the G-7 countries, while also assuring compliance with global SDG monitoring criteria. Using this indicator increases the study’s empirical validity by providing a comprehensive assessment of Zero Hunger.

The main independent variable used in this study is Knowledge-based Economy (KBE). For this analysis, the idea of a knowledge-based economy is based on the World Bank Institute's framework, which divides knowledge into four main areas: (i) The economic and institutional system, (ii) Education and skills, (iii) An effective innovation system, and (iv) Information and communication technology infrastructure. These components together make up a country's knowledge economy (World Bank, 2015). Since this study examines a dependent variables Zero Hunger (ZH). The econometric model is specified for each to evaluate the impact of the Knowledge-Based Economy (KE) on the achievement of the selected Sustainable Development Goals (SDGs). In the first model (Equation 1), Zero Hunger (ZH) serves as the dependent variable, with KE as the primary independent variable. The model includes control variables such as cereal yield (CY), fish production (FP), agriculture, forestry, and fishing value added (AFV), annual temperature (AT), inflation (INF), and population growth (PG) to account for other determinants of food security.

Table 1: Description of Variables

Variable	Abb	Measurement	Source
Knowledge Based Economy:	KBE		
KBE index will be used as proxy and will be computed			
from the following four pillars.			
a-Economic and Institutional Regime			
i. Trade		(% of GDP)	World Bank (2026)
ii. Govt effectiveness		Score	World Bank (2026)
iii. Regulatory quality		Score	World Bank (2026)
b-Education & Skill			
i. Adjusted saving on education expenditure		(Current US$)	World Bank (2026)
ii. Tertiary enrollment		(% of gross	World Bank (2026)
c-Effective Innovation System		enrollment)	
i. Scientific and technical journal articles			World Bank (2026)
d-Information and Communication Technology		Numbers	
infrastructure			
i. Internet users		(% of population)	World Bank (2026)
ii. Mobile cellular subscription		(Per 100 population)	World Bank (2026)
Zero hunger index: Zero hunger index is used as proxy	ZH		
and it is computed from the following four components.			
i. prevalence of undernourishment			
ii. prevalence of wasting in children under 5		(%) of population	FAO (2026)
iii. prevalence of stunting in children under 5		(%) of population	FAO (2026)
iv. Under five mortality rates		(%) of population	FAO (2026)
		(%) of population	FAO (2026)
Control Variables			
Cereal Yield	CY	(Kg per hectare)	World Bank (2026)
Fish Production	FP	(Metric tons)	World Bank (2026)
Agriculture, forestry, and fishing, value added	AFV	(% of GDP)	World Bank (2026)
Annual temperature	AT	Degree Celsius	FAO (2026)
Inflation	INF	(annual %) of Prices	World Bank (2026)
Population	POP	Total	World Bank (2026)

4.2. Econometric models

The use of econometric models in this study is motivated by the need to move beyond descriptive analysis and establish statistically robust relationships among the variables of interest. The complexity of these connections cannot be adequately captured by simple correlations due to the multifaceted character of the knowledge-based economy and its potential impact on Zero Hunger. Econometric approaches provide a rigorous framework for determining the strength, direction, and significance of correlations while accounting for unobserved heterogeneity between countries. Adequate estimation approaches contribute to ensure the coefficients' consistency and dependability. As changes in institutional quality, technological advancement, and macroeconomic structures can distort results in cross-country panel settings if not controlled effectively.

Following are the econometric models that reflect the impact of KBE on respective SDGs. In model 1, ZH represents zero hunger which is the dependent variable. KBE is the main independent variable. While CY, FP, AFV, AT, INF, and PG represent cereal yield, fish production, agriculture forestry and fishing value added, annual temperature, inflation and population growth accordingly.

$$\ln ZH_{it} = \beta + \beta_{1it} \ln KBE_{it} + \beta_{2it} \ln CY_{it} + \beta_{3it} \ln FP_{it} + \beta_{4it} \ln AFV_{it} + \beta_{5it} \ln AT_{it} + \beta_{6it} \ln INF_{it} + \beta_{7it} \ln PG_{it} + \epsilon_{it} \quad (1)$$

From each of the model (ln) is the natural log used to express and interpret the coefficients of explanatory variables in percentage. Each of the variables was converted into their natural-log form to improve linearity, reduce skewness, and interpret coefficients in terms of elasticities. The log conversion additionally allows one to stabilize variance, which is critical for removing heterogeneity. β is the intercept term for each of the respective equation, β_1, β_2,β_3,β_4, β_5, are the slopes and $\in_{it}$ is the error term, while i represents the respective cross section at times t.

4.3. Cross-sectional Dependence (CD) Test

The econometric investigation progresses through a few stages. Prior to estimate the long-run and short-run relationships, it is essential to assess whether the panel data exhibit cross-sectional dependence. It is because the sample includes countries that are economically and geographically interconnected. The presence of CSD implies that traditional first-generation panel methods may produce biased and invalid inferences (Pesaran et al., 2004). It necessitates the implication of second-generation econometric procedures that account for such interdependencies. Therefore, conducting the CSD test leads to select appropriate estimation techniques such as CIPS unit root tests, Westerlund cointegration, and the CS-ARDL model. The most common test for cross-sectional dependence is the Pesaran et al., (2004) CD test which can be applied to both balanced and unbalanced panels even with a small-time dimension. The test is based on the average of pairwise correlation coefficients of the residuals from the individual regressions; the test statistic from the CD test is calculated as:

$$CD = \sqrt{\frac{2T}{X(X-1)}}\left(\sum_{i=1}^{X-1}\sum_{j=i+1}^{X}\hat{o}_{ij}\right) \quad (2)$$

Where T signifies the length of the period while N denotes the sample size. Here, $\hat{o}_{ij}$ is the correlation error of entities, which is presented as follows.

$$\hat{o}_{ij} = \frac{\sum_{u=1}^{U} e_{it}e_{jt}}{\left(\sum_{u=1}^{U} e_{it}^{2}\right)^{1/2}\left(\sum_{u=1}^{U} e_{jt}^{2}\right)^{1/2}} \quad (3)$$

From the formula give above, $\hat{o}_{ij}$ is the sample estimate of the pairwise correlation of residuals between cross-sectional units i and j, X is the number of cross-sectional units, and "U" is time dimension. Under the null hypothesis of cross-sectional independence, the test statistic will be approximately standard normal. The rejection of the null hypothesis indicates cross-sectional dependence is present in the data, and this should be considered in the estimation of the model either with robust panel data, or second-generation panel data methods, such as Feasible Generalized Least Square (FGLS), Common Correlated Effects (CCE) or CS-ARDL. Hence, applying for the CD test is an important aspect of meeting their implications for the assumptions of classical panel data model to provide reliable inference.

4.4. Slope Homogeneity Test

An important diagnostic issue in panel-data analysis is determining whether the slope coefficients are homogeneous or heterogeneous across cross-sectional units. Slope homogeneity implies that the coefficients of the explanatory variables remain identical across all countries in the sample. However, imposing such an assumption may fail to capture country-specific responses arising from differences in institutional structures, levels of economic development, and policy environments. This concern is particularly relevant when analyzing a diverse panel comprising Asian developing economies and G-7 countries, as imposing homogeneous slope coefficients may lead to model misspecification and unreliable statistical inferences.

To account for potential differences in the responses of individual countries, this study applies the Delta and adjusted Delta tests. These second-generation tests assess the null hypothesis of slope homogeneity against the alternative hypothesis of slope heterogeneity across cross-sectional units. The corresponding test statistics are specified as follows:

$$\Delta = \sqrt{P} * \left(\frac{\frac{1}{N}\sum_{i=1}^{N} t_i - x}{\sqrt{2x}}\right) \text{ and } \Delta_{adj} = \sqrt{P} * \left(\frac{\frac{1}{N}\sum_{i=1}^{N} t_i - 2x}{\frac{\sqrt{2k(T-x-1)}}{\sqrt{T+1}}}\right) \quad (4)$$

From the above formula x is the number of regressors, t_i is the individual slope coefficient test statistic for i^{th} unit and N is the number of cross-sectional units while T is the time dimension. The adjusted version of this test improves reliability in panels with moderate T by correcting for small-sample bias.

The null and alternative hypothesis for this test are as under.

$$H_0 = Slopes\ are\ homogenous$$
$$H_a = Slopes\ are\ heterogeneous$$

A statistically significant result provides strong evidence for heterogeneous slopes and rejects the null hypothesis of homogeneous slope indicating that variation in regressor varies across the countries which justifies the use of estimators that allows for individual and country specific slope-coefficients such as Cross-Sectional Autoregressive Distributed Lag model (CS-ARDL) proposed by Chudik and Pesaran (2015) while the Pooled Mean Group (PMG) and Mean Group (MG) estimators developed by Pesaran and Smith (1995). Both of these methods accounts for cross-sectional dependencies and structural asymmetries, yielding more robust log-run and short-run estimates.

4.5. Cross-sectionally Augmented Lm-Pesaran-Shin (CIPS) Panel Unit Root Test

Economic time-series variables may exhibit unit-root behaviour, causing their statistical properties, including the mean, variance, and covariance, to change over time. Such characteristics indicate non-stationarity in the underlying series. In econometric analysis, establishing stationarity is important because conventional regression techniques generally require variables with stable statistical properties for reliable parameter estimation and valid hypothesis testing. When non-stationary variables are included in a regression without accounting for their time-series properties, the analysis may generate spurious relationships and misleading statistical inferences, including the incorrect rejection of a true null hypothesis. To determine the order of integration and assess the stationarity properties of the panel variables, this study employs the Cross-sectionally Augmented IPS (CIPS) unit-root test. Identifying the integration properties of the variables is essential because inappropriate treatment of non-stationary data can result in unreliable or inconsistent parameter estimates. The CIPS test is particularly appropriate for the present macro-panel dataset because its test regression incorporates cross-sectional averages, allowing it to account for cross-sectional dependence among the panel units. Consequently, compared with conventional first-generation panel unit-root tests that assume cross-sectional independence, the CIPS approach provides a more suitable framework for examining the stationarity of the variables in this study. The CIPS test equation is specified as follows:

$$\Delta y_{it} = \beta_1 + \beta_2 y_{s-1} + \beta_3 \bar{y}_{s-1} + \beta_4 \Delta \bar{y}_{t-1} + \pounds_{it} \qquad (5)$$

where y_{it} is the variable of interest, $\bar{y}_{s-1}$ denotes the cross-sectional average, and $\pounds_{it}$ represents the error term. The null hypothesis (H_0) assumes the presence of a unit root (non-stationary series), while the alternative hypothesis (H_a) suggests stationarity of the series. CIPS test performs better in the presence of common shocks or spillover effects across countries as compared to first-generation panel unit root tests like Levin, Lin & Chu (LLC) or LM, Pesaran & Shin (IPS). So, in order to assess the stationarity of the variables, the Cross-sectionally Augmented LM Pesaran-Shin (CIPS) test.

4.6. Westerlund Panel Cointegration Test

Conventional panel cointegration tests may produce unreliable or misleading inferences when cross-sectional dependence (CSD) and slope heterogeneity are present. In addition, the Westerlund cointegration test has been shown to perform well and provide reliable results even in relatively small samples (Cojocaru et al., 2022). Therefore, this study employs the error-correction-based panel cointegration approach developed by Westerlund to investigate the existence of a long-run equilibrium relationship among the variables. The test represents a second-generation panel cointegration technique that accommodates cross-sectional dependence, parameter heterogeneity, and non-stationarity, making it appropriate for the characteristics of the present dataset. Prior to its application, panel unit root tests were conducted, which reveal that the variables are either stationary at level I(0) or become stationary after first differencing, indicating integration of order one I(1), with no evidence of I(2) processes. In such circumstances, the use of conventional cointegration techniques remains appropriate, as the existence of a long-run relationship is primarily defined among non-stationary series.

4.7. Cross Sectional Auto Regressive Distributed Lagged Model CS-ARDL

Before the development of CS-ARDL, the conventional ARDL approach was widely employed to examine relationships among variables with either a common or mixed order of integration, subject to the underlying assumptions of the model. However, the Cross-Sectionally Augmented ARDL (CS-ARDL) approach introduced by Chudik and Pesaran (2015) provides a more suitable framework for panel datasets characterized by cross-sectional dependence, slope heterogeneity, and variables integrated at the same or mixed orders. The method addresses these econometric concerns by incorporating cross-sectional averages of the dependent and explanatory variables, thereby capturing the influence of unobserved common factors and reducing the possibility of biased or misleading estimates (Ahmad et al., 2022; Çoban & Topcu, 2013;Yao et al., 2025).

The CS-ARDL framework is more appropriate for panels with cross-sectional dependency and heterogeneous responses than traditional estimators like Dynamic Ordinary Least Squares (DOLS) and Fully Modified Ordinary Least Squares (FMOLS). Similarly, CS-ARDL offers a versatile framework for concurrently accounting for dynamic adjustments, cross-sectional dependence, and heterogeneous slope coefficients when compared to other dynamic and static panel estimators, such as the Augmented Mean Group (AMG), Common Correlated Effects Mean Group (CCEMG), and Mean Group (MG) estimators. These features make it an appropriate and reliable estimator for the present study.

Methodologically, CS-ARDL can be viewed as an extension of the conventional ARDL model because it augments the specification with cross-sectional averages of the dependent variable and the explanatory variables. The inclusion of these averages enables the model to control for unobserved common shocks and cross-sectional dependence while allowing heterogeneous relationships across panel units. The general specification of the CS-ARDL model is presented in Equation (2).

$$Y_{i,t} = \sum_{I=0}^{J_w} \gamma I, iY_{i,t-1} + \sum_{I=0}^{J_z} \beta I, i\mathrm{X}_{i,t-1} + u_{i,t} \quad .. \qquad (2)$$

The ARDL specification presented above can be extended to the Cross-Sectionally Augmented ARDL (CS-ARDL) framework by incorporating the cross-sectional averages of the dependent and explanatory variables. This extension helps address cross-sectional dependence and reduces the risk of biased or misleading estimates arising from unobserved common factors across cross-sectional units. The CS-ARDL model is specified in Equation (3).

$$Y_{i,t} = \sum_{I=0}^{J_w} \gamma I, iY_{i,t-1} + \sum_{I=0}^{J_z} \beta I, i\mathrm{X}_{i,t-1} + \sum_{I=0}^{a_x} \alpha' i, I\overline{X}_{t-1} + u_{i,t} \quad ..... (3)$$

From equation 3, $Y_{i,t}$ and $\mathrm{X}_{i,t-1}$ are the dependent and independent variables respectively, i is the respective cross – sectional unit at times t, J_w, J_z, a_x represents the variable lags, $u_{i,t}$ is the error term and the cross- sectional average presented by $\overline{X}$ in order to tackle the issue of misleading results (Liddle, 2018). This cross – sectional average term incorporates the average of both the dependent and independent variable given as under.

$$\overline{X}_{t-1} = \overline{\mathrm{X}}_{i,t-1}, \overline{Z}_{i,t-1} \quad .... (4)$$

In CS-ARDL test, the long-run coefficients are predicted by short-run coefficients. Further, the mean group estimator (MG) and the long-run coefficients are specified respectively as follows.

$$\widehat{\emptyset}_{MG} = \frac{1}{N} \sum_{i=1}^{N} \widehat{\emptyset}_{\iota} \quad ...... (5)$$

$$\widehat{\emptyset}_{CS-ARDL,i} = \frac{\sum_{I=0}^{P_z} \beta_{I,i}^{pw}}{1 - \sum_{I=0} 1} \widehat{\gamma_{I,1}} \quad ..... (6)$$

After (MG) and long – run coefficients, below are the short run - coefficients presented in equation 3.10.

$$\Delta Y_{i,t} = \emptyset_i [\, Y_{i,t-1} - \vartheta_i X_{i,t}] - \sum_{I=1}^{a_{w-1}} \lambda_{I,i} \Delta_u Y_{i,t-1} + \sum_{I=1}^{a_{ws-1}} \beta_{I,i} \Delta_u X_{i,t} + \sum_{I=0}^{a_x} \alpha'_{i,} I\bar{X}_{t-I} + \varepsilon_{i,t} \quad (7)$$

And were,

$$\Delta_u = u - (u - 1)$$

$$\widehat{\emptyset}_i = -(1 - \sum_{I=1}^{a_w} \hat{\lambda}_{I,t})$$

$$\vartheta_i = \frac{\sum_{I=0}^{a_z} \beta_{I,i}^{aw}}{\hat{\delta}_i}$$

$$\frac{\wedge}{\vartheta_{MG}} = \frac{1}{N}\sum_{i=1}^{N} \hat{\vartheta}$$

Finally, by incorporating the variables used in the study the CS – ARDL model, equation (8) can be specified as follows.

$$\Delta lnZH_{i,t} = \emptyset_i[lnZH_{i,t-1} - \vartheta_1 lnKBE_{i,t-1} - \vartheta_2 lnCY_{i,t-1} - \vartheta_3 lnFP_{i,t-1} - \vartheta_4 lnAFV_{i,t-1} - \vartheta_5 lnAT_{i,t-1} + \vartheta_6 lnINF_{i,t-1} + \vartheta_7 lnPG_{i,t-1}] + \sum_{p=1}^{p} \partial_p \Delta lnZH_{i,t-p} + \sum_{q=0}^{q}\{ \rho 1_q \Delta lnKBE_{i,t-q} + \rho 2_q \Delta lnCY_{i,t-q} + \rho 3_q \Delta lnFP_{i,t-q} + \rho 4_q \Delta lnAFV_{i,t-q} + \rho 5_q \Delta lnAT_{i,t-q} + \rho 6_q \Delta lnINF_{i,t-q} + \rho 7_q \Delta lnPG_{i,t-q}\} + \delta ln\overline{ZH}_{t-I} + \sigma_1 ln\overline{KBE}_{t-I} + \sigma_2 ln\overline{CY}_{t-I} + \sigma_3 ln\overline{FP}_{t-I} + \sigma_4 ln\overline{AFV}_{t-I} + \sigma_5 lnAT_{t-I} + \sigma_6 ln\overline{INF}_{t-I} + \sigma_7 ln\overline{PG}_{t-I} + \varepsilon_{i,t} \quad (8)$$

The specified model represents a Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) framework, designed to capture both dynamic adjustments and cross-sectional interdependencies in panel data. The dependent variable, $\Delta \ln ZH_{i,t}$, denotes the short-run change in Zero Hunger for country i at time t. The expression inside the square brackets constitutes the error correction term (ECT), where $\phi_i$is the speed of adjustment coefficient. This parameter measures how quickly deviations from the long-run equilibrium relationship—defined by the lagged levels of $\ln ZH$, $\ln KBE$, $\ln CY$, $\ln FP$, $\ln AFV$, $\ln AT$, $\ln INF$, and $\ln PG$ are corrected over time. The coefficients ϑ_1 to $\vartheta_7$represent the long-run elasticities, indicating the equilibrium impact of each explanatory variable on Zero Hunger.

The computational CS-ARDL model produces robust and consistent findings in a variety of panel settings by including long-run equilibrium connections, short-run adjustments, and cross-sectional dependencies into a single structure. This idea is especially relevant to the current inquiry, in which nations differ in structural characteristics while being integrated thru global economic and environmental ties.

To facilitate comprehension of the variables, the (ln) function is used to convert them to their natural log form for linearity. It interprets the coefficients in terms of elasticities, which reduces skewness.

4.8. Robustness Check (The Pairwise Dumitrescu Hurlin Causality Test)

The Dumitrescu-Hurlin causality test is a well-known econometric instrument used in panel data analysis to uncover Granger-type causal relationships between variables across heterogeneous units. Since it takes into consideration changes in the dynamics of individual units within the panel as well as differences in intercepts and lag structures between them, this technique is more challenging than standard single-country testing. This test offers a strict framework for figuring out which way variables have an influence. It is highly helpful in macroeconomics and development research since it gathers causality data for every unit while taking cross-sectional fluctuations into consideration. Current investigations have effectively used this method to study a wide range of research issues. It examines the causative linkages between energy consumption and economic growth in several nations, demonstrating both unidirectional and bidirectional causation that changes with context and panel heterogeneity (Ersöz Kaya, 2025; Ahmad et al., 2022).

5. Results and Discussion

This chapter presents the empirical findings of a study that examined the influence of the knowledge-based economy on the Sustainable Development Goal Zero Hunger in Asian developing and G-7 nations.

5.1. Descriptive Statistics for SDG 2 Zero Hunger

This subsection contains descriptive data on the variables used in the study. It gives an overview of the data structure and distributional characteristics across 44 developing countries and the G7 economies. The summary computes the mean, standard deviation, minimum, and maximum values. It provides information on the fundamental patterns and variability of key metrics.

The descriptive data for Asian emerging nations show significant variety in key metrics of knowledge-based economies and zero hunger. Table 2 reveals that the mean values of ZH (3.4) and KBE (5.6) suggest moderate performance, although with somewhat significant standard deviations (1.73 and 2.34, respectively). It shows notable differences in the region's economic potential and knowledge network. The enormous variation in grain yield (CY) from 176.3 to 36,761 indicates notable differences in the accessibility and connectivity of technologies. The institutional diversity among these countries is also shown by the large variation in fish production (FP) and agriculture-related indicators like AFV and AT. While some economies are moving toward service and technology-oriented industries, others are still mostly dependent on agriculture. Macroeconomic conditions and demographic dynamics vary throughout the region, as seen by the fluctuations in inflation (INF) and population growth (PG). All things considered, these numbers demonstrate the diversity of Asian developing countries as well as the differences in institutional capacity and economic growth.

G-7 nations, on the other hand, have far more dependable and consistent data architectures. Smaller standard deviations for almost all variables serve as evidence of it. KBE has a tight range of 11.55 to 13.01, with an average of 12.15. Grain yield (CY) has a moderate spread and an average of 6,132.6, although the volatility is far lower than in impoverished Asian countries. It stands for more equitable access to food. There is limited variation in variables like AFV, AT, and INF. This serves as a reminder that the macroeconomic, institutional, and environmental circumstances of the G-7 countries are essentially similar. The similar low population (POP) and little variance align with the demographic trends observed in developed countries. In a nutshell, these descriptive patterns demonstrate strong structural disparities between the two groups, strengthening the case for comparing their approaches to achieving SDG 2 objectives thru KBE.

Table 2: The Results of Descriptive Statistics of SDG-2 (Zero Hunger)

Asian Developing Nations								
Variable	**ZH**	**KEI**	**CY**	**FP**	**AFV**	**AT**	**INF**	**POP**
Mean	3.4	5.6	3876.9	2861166	11.58	1.10	7.95	0.096
Minimum	0.17	0.154	176.3	27	0.028	0.32	0.24	282507
Maximum	8.17	10.19	36761	0.08	57.14	2.85	154.75	1.42
S. Deviation	1.73	2.34	3847	0.01	10.16	0.53	14.99	0.27
G7 Advanced Nations								
Mean	2.04	12.15	6132.6	1230428	1.31	1.25	1.91	0.01

Minimum	1.87	11.55	2375.4	61996	0.54	0.19	0.37	0.03
Maximum	2.30	13.01	8614.2	6483310	2.56	2.92	8.02	0.33
S. Deviation	0.15	0.33	1384.6	1645663	0.51	0.56	1.45	0.08

5.2. Cross Sectional Dependence Test for SDG-2 (Zero Hunger)

The variable based Cross-Sectional Dependence (CSD) results indicate considerable and statistically significant interdependence in both the Asian developing and G-7 panels. For Asian emerging countries, all variables had extremely high CD-test values, each with a p-value of 0.01. These findings indicate significant cross-country spillovers. It suggests that economic developments, technology diffusion, agricultural shocks, and demographic trends in one emerging nation have a significant influence on others. Such high levels of reliance imply shared regional vulnerabilities, interconnected markets, and structural restrictions that influence their growth routes. Similarly, the G-7 countries also exhibit statistically significant CD across all variables with p-value 0.01. Advanced economies exhibit strong interconnectedness through their linked financial systems, extensive technological and trade integrations, despite lower magnitudes compared to developing nations.

Table 3: The Results of Cross-Sectional Dependence Test for SDG-2 (Zero Hunger)

Asian Developing Nations								
	ZH	**KBE**	**CY**	**FP**	**AFV**	**AT**	**INF**	**POP**
CD-test	113.75*	131.85*	55.30*	18.28*	38.63*	65.59*	27.05*	103.11*
P-value	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
G7 Advanced Nations								
CD-test	16.48*	15.40*	7.52*	10.83*	12.41*	6.96*	9.95*	6.78*
P-value	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Note(s): (*) shows 1% significance and (**) shows 5% significance level

5.3. The Slope Homogeneity test for SDG-2 (Zero Hunger)

The results of the slope homogeneity test shows that the assumption of homogeneous slope coefficients is strongly rejected for both Asian developing countries and the G7 group. In case of developing nations, the Δ statistic is 15.09 and the adjusted Δ statistic is (20.07). Both having p-value of 0.00. It indicates significant heterogeneity in the relationships among variables across countries. Similarly, the G7 countries also show statistically significant slope heterogeneity, with Δ (4.58) and adjusted Δ (5.67) having p-values of 0.00.The heterogeneity is less pronounced in G7 than in developing countries. This lack of slope homogeneity suggests that advanced economies exhibit varying strengths and directions in their relationships. These are influenced by differing innovation systems, policy frameworks, and societal priorities. These results validate the use of heterogeneous panel estimators such as the CS-ARDL model which accommodate cross-country differences and produce more reliable long-run and short-run estimates.

Table 4: The Results of Slope Homogeneity test for model 1 SDG-2 (Zero Hunger)

	Developing Nations		G7 Countries	
Δ	15.09*	0.00	4.58*	0.00
$\tilde{}$ Δ adjusted	20.07*	0.00	5.67*	0.00

Note(s): (*) shows 1% significance and (**) shows 5% significance level

5.4.The CIPS Unit Root Test for Model 1 SDG-2 (Zero Hunger)

The presence of cross-sectional dependence led us to employ second-generation panel unit root tests such as CIPS. Table 4.2.4.1 and 4.2.4.2 represent the CIPS test results of the Asian developing and advanced G7 nations. It is evident from Table 5 and table 6 that the study variables are integrated at first difference, which leads us to employ the CS-ARDL technique to analyze the long run and short run relationships in the data.

Table 5: The results of CIPS tests for developing nations Model 1

	At Level		At First Difference			At Level		At First Difference		
	Constant		Constant		Result	Trend & Constant		Trend & Constant		Result
Variables	CIPS Value	C-Value	CIPS Value	C-Value		CIPS Value	C-Value	CIPS Value	C-Value	
lZH	-1.90	-2.11	-4.50	-2.11	I (1)	-2.28	-2.61	-4.99	-2.61	I (1)
lKBE	-2.05	-2.11	-4.97	-2.11	I (1)	-2.33	-2.61	-4.37	-2.61	I (1)
lCY	-1.89	-2.11	-5.14	-2.11	I (1)	-2.78	-2.61	-4.43	-2.61	I (1)
lFP	-1.70	-2.11	-3.69	-2.11	I (0)	-2.17	-2.61	-3.97	-2.61	I (0)
lAFV	-1.79	-2.11	-4.16	-2.11	I (1)	-2.45	-2.61	-3.23	-2.61	I (1)
lAT	-2.01	-2.11	-6.14	-2.11	I (0)	-2.16	-2.61	-5.73	-2.61	I (0)
lINF	-0.86	-2.11	-5.06	-2.11	I (1)	-1.75	-2.61	-4.35	-2.61	I (1)
lPOP	-1.99	-2.11	-2.30	-2.11	I (1)	-1.49	-2.61	-2.99	-2.61	I (1)

Table 6: The results of CIPS tests for G7 countries Model 1.

	At Level		At First Difference			At Level		At First Difference		
	Constant		Constant		Result	Trend & Constant		Trend & Constant		Result
Variables	CIPS Value	C-Value	CIPS Value	C-Value		CIPS Value	C-Value	CIPS Value	C-Value	
lZH	-2.10	-2.11	-4.70	-2.11	I(1)	-3.03	-2.61	-4.86	-2.61	I(1)
lKBE	-1.08	-2.11	-4.97	-2.11	I(1)	-3.37	-2.61	-5.16	-2.61	I(1)
lCY	-1.72	-2.11	-5.14	-2.11	I(1)	-2.96	-2.61	-5.37	-2.61	I(1)
lFP	-1.02	-2.11	-3.69	-2.11	I(0)	-2.68	-2.61	-3.89	-2.61	I(0)
lAFV	-1.33	-2.11	-4.16	-2.11	I(1)	-2.88	-2.61	-4.24	-2.61	I(1)
lAT	-1.91	-2.11	-6.14	-2.11	I(0)	-4.73	-2.61	-6.31	-2.61	I(0)
lINF	-2.09	-2.11	-5.06	-2.11	I(1)	-3.82	-2.61	-5.08	-2.61	I(1)
lPOP	-0.31	-2.11	-2.82	-2.11	I(1)	-2.85	-2.61	-2.85	-2.61	I(1)

5.5. Penal Cointegration (Westerlund Test) for SDG-2 (Zero Hunger)

Testing the long run cointegrated link among dependent and independent variables is important because of the potential for the feedback via Westerlund cointegration. The results of Westerlund test for both Asian developing and G7 nations can be seen in table 7.The null hypothesis of no cointegration is rejected as indicated by significance of variance ratios. The results suggests that improvement in KBE dimensions systematically contribute to progress in SDGs outcomes overtime. So the findings of Westerlund cointegration test support a long term cointegrated relationship between knowledge based economy and selected SDGs across both Asian developing and advanced G7 economies.

Table 7: The Results Westerlund Cointegration Test for SDG-2

	Asian developing nations		G-7 Advanced Nation	
	Statistics	P-value	Statistics	P-value
Variance Ratio	2.73*	0.01	1.78*	0.01

Note(s): (*) shows 1% significance and (**) shows 5% significance level

5.6. The Cross-Sectional ARDL Model-1 SDG-2 (Zero Hunger)

We estimate one basic model. This model uses KE as primary variable of interest and alternately assesses its effects on Zero hunger. Furthermore we estimate the long run and short run relationship of the model. The results of the long-run CS-ARDL cointegration model for zero hunger, as reported in Table 8, suggest that the impact of knowledge based economy on zero hunger varies depending on the type of structural changes within the economies.

The long-run CS-ARDL findings provide important insights into how knowledge-based economy factors and key agricultural, environmental, and macroeconomic variables influence SDG-2 zero hunger outcomes across Asian developing and G-7 countries. The short-run CS-ARDL estimates highlight important dynamic adjustments in how knowledge-based economy indicators and control variables influence SDG outcomes across Asian developing nations and G-7 countries. For Asian developing economies, the short-run coefficient of the Knowledge Economy Index (ΔlKBE)) is negative and significant (–0.56), indicating that immediate improvements in education, innovation, and technological readiness quickly contribute to better SDG performance. A stronger short-run negative effect is also observed in G-7 countries (–1.20), suggesting that the initial gains from knowledge-based interventions are more rapidly translated into sustainable development outcomes in advanced economies with established institutional frameworks. In the long run, the (lKBE) shows a negative and significant relationship with ZH in both Asian developing (–0.66) and G-7 countries (–1.30). This suggests that improvements in education, innovation capacity, and digital infrastructure contribute to long-run decline in hunger. Table 8 demonstrates stronger negative effect in G-7 nations. This indicates that mature knowledge systems have a more direct and substantial long-term impact on achieving SDG-2.The results of the study are consistent with (Anser et al., 2021), who found that institutional reforms are vital for ensuring a stable food supply. Therefore, improved long-term food security has been affected by governance and socioeconomic conditions.

Cereal yield (ΔlCY)) shows a negative and significant short-run impact in both regions, with a greater magnitude in developing countries (–0.29). This implies that improvements in cereal yield quickly reduce zero hunger and support early progress in related SDGs. Fish production (ΔlFP)) is positive and significant in both panels (0.54 for developing nations and 0.03 for G-7), indicating that fluctuations in fish output do not generate immediate SDG improvements; instead, the benefits appear over the long run, consistent with the long-run negative coefficients reported earlier. Agricultural productivity, represented by cereal yield (lCY), also shows a negative and significant effect in both panels, with a much larger magnitude for developing countries (–1.16) compared to G-7 nations (–0.06). This indicates that increases in agricultural productivity play a more critical role in improving SDG-2 outcomes in developing regions, where food systems are more vulnerable and dependent on primary crop output. Similarly, fish production (lFP) demonstrates a significant negative effect in both groups, again stronger in developing Asia (–1.22). This indicates the high reliance of developing countries on fisheries for nutrition, employment, and rural livelihoods. Making improvements in fish production highly influential for hunger reduction and inclusive growth. The results of the current study are in support with the findings of (Mmila& Myeki, 2025).

In both panels, agricultural value added (ΔlAFV) has a moderate but significant short-term beneficial impact (0.09 and 0.11). This shows that short-term advances in agricultural sector production initially constrain SDG performance, most likely because such expansions occur in response to shocks, supply deficiencies, or price fluctuations rather than structural improvements. These short-term benefits, however, are not the same as the long-term trends, which show that AFV enhances SDG results in developing nations. Value added from forestry, fisheries, and agriculture indicates the primary sector's net economic value to a nation's GDP. After deducting the cost of intermediate inputs like seeds, fertilizer, and electricity, it calculates the output from forestry, fisheries, livestock, and agriculture. This statistic, which is reported in both national and international databases, shows the sector's actual productivity as well as its contribution to food security, economic growth, and other development outcomes. Value added from agriculture, forestry, and fisheries (lAFV) shows different outcomes for the two groups. The coefficient is negative (–0.84) in Asian emerging nations, suggesting that long-term food security, job possibilities, and inequality reduction are all favourably impacted by increase in the value of the agricultural sector. However, AFV exhibits a small positive coefficient (0.11) in G-7 nations, indicating that additional primary sector growth does not directly result in SDG improvements. This is probably because these economies are already highly industrialized and depend less on agriculture for development gains (McConnell, 2023).

In every area, annual temperature (ΔlAT) shows a negative and substantial impact, suggesting that even brief temperature rises cause immediate losses in SDG achievement, particularly by lower agricultural yields and vulnerabilities connected to climate change. Both areas exhibit favourable long-term impacts from annual temperature (lAT), with emerging nations being more sensitive (0.26 vs. 0.02). This implies that rising temperatures deteriorate SDG-2 performance, particularly by impacting food security, agricultural production, and climate-related vulnerabilities. Due to their reliance on climate-sensitive industries and low ability for adaptation, developing countries are more vulnerable. Conversely, higher temperatures have a negative effect on food availability in the short run, although this relationship is generally statistically insignificant. The adverse effects of rising temperatures on cereal yields and overall food availability in Africa are consistent with the findings of previous research (Affoh et al., 2022). Increasing global temperatures can undermine food availability by reducing cereal crop yields, particularly in Africa, where tropical and seasonally dry climatic conditions make agricultural production more vulnerable to temperature changes.

Inflation (ΔlINF)) shows a short-term positive effect in developing countries (0.059) but a negative effect in G-7 economies (–0.03). This suggests that in developing nations, inflationary shocks worsen SDG outcomes in the short run by reducing purchasing power and increasing food prices, whereas G-7 countries may respond more effectively to inflation through stabilizing monetary and fiscal policies. Inflation (lINF) also exerts a positive and significant long-run effect in both groups, with a greater impact in Asian developing countries (0.40). This demonstrates that rising prices undermine progress toward SDG targets especially those related to hunger, inequality, and economic well-being by eroding purchasing power and increasing the cost of basic necessities. Inflation distorts the price system and makes it difficult for farmers to access farming materials and tools, adversely affecting crop yields and the general food availability in Africa. However, the effect of inflation on the other food security dimensions is insignificant (Mumuni et al.,2023).

In developing nations, population (ΔlPOP) has a substantial negative short-run effect (-7.54), which exacerbates the burden that abrupt demographic pressures impose on food supplies, jobs, and welfare systems. The G-7 nations' population growth, on the other hand, has a positive short-term impact (2.64), which may be due to regulated demographic trends, increased per capita productivity, and advanced economies' superior capacity to handle population shifts. With a far higher coefficient for developing nations (20.5) than for G-7 economies (2.79), population (lPOP) shows a robust and favorable long-term influence on SDG outcomes in both categories. This suggests that increased population growth puts strain on employment markets, food systems, and climate sustainability, impeding the attainment of SDG 2.

The negative and highly significant error correction term (ECT) for both groups (-0.87 for developing nations and -0.91 for the G-7) shows that the deviations from long-run equilibrium are rectified over time. A steady long-term correlation between the variables is indicated by the statistically significant estimated error correction coefficient of -0.91. Nearly 91% of any short-run divergence from equilibrium is eradicated after a year, according to the coefficient's value.

Table 8: The Results of CS-ARDL (Zero Hunger)

	Asian developing nations			**Advanced G-7 countries**		
Long run						
Variables	**Parameters**	**Std.Error**	**P-value**	**Parameters**	**Std.Error**	**P-value**
lKBE	-0.66*	0.31	<0.01	-1.30*	0.59	<0.01
lCY	-1.16*	0.57	<0.01	-0.06*	0.02	<0.01
lFP	-1.22*	0.62	<0.01	-0.87*	0.43	<0.01
lAFV	-2.4*	1.10	<0.01	-0.11*	0.07	<0.01
lAT	0.26*	0.12	<0.01	0.02*	0.06	<0.01
lINF	0.40*	0.20	<0.01	0.05*	0.03	<0.01
lPOP	1.58*	0.89	<0.01	2.79*	1.58	<0.01
Short Run						
Δ (lKBE)	-0.56*	0.09	<0.01	-1.20*	0.58	<0.01
Δ (lCY)	-0.29*	0.18	<0.01	-0.10*	0.03	<0.01
Δ (lFP)	-0.54	0.26	2.02	0.31*	0.10	<0.01
Δ (lAFV)	0.09*	2.80	<0.01	0.11*	0.06	<0.01
Δ (lAT)	0.03*	1.5	<0.01	-0.13*	0.05	<0.01
Δ (lINF)	0.05*	0.02	<0.01	-1.03*	0.49	<0.01
Δ (lPOP)	7.54	-4.82	0.15	2.64*	1.61	<0.01
ECT Term	-0.87*	0.09	<0.01	-0.91*	0.09	<0.01

Note(s): (*) shows 1% significance and (**) shows 5% significance level

5.7. The Results of Pairwise Dumitrescu Hurlin Causality Test for SDG2

Detecting potential flaws such as causal linkages and compensating for heterogeneity, this diagnostic test ensures the CS-ARDL model's resilience. As a robustness check, the study applied the Dumitrescu-Hurlin causality test to the initial inconsistencies between the variables.

Statistically significant Z-bar values of 1.98 and 2.45 (p-values < 0.01) show a bidirectional causal link between Knowledge-Based Economy (KBE) and ZH, indicating mutual reinforcement between knowledge-driven economic development and food security results. On the other hand, there is no feedback effect from ZH to CY, and cereal yield (CY) has a unidirectional causal impact on ZH with a Z-bar value of 1.99 (p-value < 0.01), suggesting that increases in cereal production help to reduce hunger. Similarly, there is a one-way causal relationship between ZH and fish production (FP) (Z-bar = 2.11, p-value < 0.01), suggesting that ZH has a beneficial role in improving food security; however, ZH has no significant effect on FP (Z-bar = 1.83, p-value = 0.22).

Additionally, there is a bidirectional causal relationship between ZH and agriculture, fisheries, and value-added (AFV) (Z-bar = 2.09, p-value < 0.01). With a high Z-bar value of 3.98 (p-value < 0.01), annual temperature (AT) shows a strong unidirectional causal relationship with ZH. Additionally, ZH has a unidirectional causal relationship with inflation (INF) (Z-bar = 1.98, p-value < 0.01). Finally, a bidirectional relationship between ZH and population growth (PG) is discovered (Z-bar = 2.54, p-value < 0.01).

There are important connections between Zero Hunger (ZH) and its major causes in advanced economies, according to the causality study for G-7 countries. With statistically significant Z-bar values of 3.54 (ZH → KBE) and 2.34 (KBE → ZH), a bidirectional causal relationship between Knowledge-Based Economy (KBE) and ZH is found, suggesting a mutually reinforcing relationship between knowledge-driven economic advancement and improvements in food security. In the case of cereal yield (CY), a unidirectional causal effect on ZH is observed (Z-bar = 2.13, p-value < 0.01). Similarly, fish production (FP) exhibits a one-way causal relationship towards ZH, with a Z-bar value of 3.23 (p-value < 0.01).

Moreover, agriculture, fisheries, and value-added (AFV) show a unidirectional causal impact on ZH (Z-bar = 3.21, p-value < 0.01). Inflation (INF) is found to have a unidirectional causal effect on ZH (Z-bar = 2.01, p-value < 0.01). Finally, population growth (PG) and ZH exhibit bidirectional causality, with a statistically significant Z-bar value of 2.9.

Table 9: The Results of Pairwise Dumitrescu Hurlin causality test for SDG-2.

Asian developing nations	**G7 Advanced Nations**

Causal Direction	Zbar-Stat.	P value	Zbar-Stat.	P value
ZH----->KBE	1.98*	<0.01	3.54*	<0.01
KBE----->ZH	2.45*	<0.01	2.34*	<0.01
ZH----->CY	0.97	0.33	1.35	<0.11
CY------>ZH	1.99*	<0.01	2.13*	<0.01
ZH----->FP	1.83	0.22	1.69	0.21
FP----->ZH	2.11*	<0.01	3.23*	<0.01
ZH----->AFV	1.75	0.23	1.56	0.43
AFV----->ZH	2.09*	<0.01	3.21*	<0.01
ZH----->AT	1.65	0.23	1.05	0.31
AT----->ZH	3.98*	<0.01	1.94*	<0.01
ZH------>INF	1.32	0.12	0.76	0.31
INF------>ZH	1.98*	<0.01	2.01*	<0.01
ZH------>POP	1.91*	<0.01	3.54*	<0.01
POP------>ZH	2.54*	<0.01	2.99*	<0.01

Note(s): (*) shows 1% significance and (**) shows 5% significance level

6. Conclusion & Recommendations

6.1. Conclusions

This study examines at the short- and long-term association between the knowledge-based economy (KBE) and progress toward SDG 2 (Zero Hunger) in Asian developing countries and G-7 nations. The study employs the Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) method. The findings show that the variables have a stable long-run connection, and the error-correction process indicates that departures from the long-run equilibrium are rectified over time in both nation groups. Overall, the data indicate that advances in knowledge-related qualities, notably education, creativity, and technology preparedness, are strongly correlated with progress toward hunger reduction. The association is obvious in both the short and long run, with the G-7 nations seeing larger adjustment and impacts. This disparity might be attributed to their superior institutional frameworks, technological capabilities, and established innovation systems. The findings suggest that human capital growth and efficient information transfer are essential structural determinants supporting long-term food security.

The findings further emphasize the relevance of agricultural output in achieving Zero Hunger goals. Cereal yield and fish output are very important variables, particularly in Asian emerging nations where a large portion of food supply is still dependent on agricultural and primary-sector activities. Improvements in these areas can increase food availability and nutritional security. At the same time, the short-run results suggest that emerging economies are more vulnerable to transitory interruptions in food supplies. The impacts of agriculture, forestry, and fisheries value added varies across the two countries, implying that the contribution of primary-sector activities is influenced by the overall economic structure and stage of development.

Environmental and financial situations have significant consequences for attaining SDG 2. Higher temperatures are connected with poorer food-security results, with the negative long-term effects being especially prominent in Asian emerging nations. This finding is consistent with these economies' higher vulnerability to climate-sensitive agriculture industries and their comparatively restricted ability to absorb environmental shocks. Inflation also slows progress toward Zero Hunger by diminishing family buying power and raising food prices. Similarly, continuous population increase can put further strain on food systems, especially if agricultural resources and productive capability are already limited.

To sum up, the data show that achieving Zero Hunger cannot be accomplished by isolated agricultural methods alone. A more sustainable strategy calls for simultaneous focus to knowledge and human capital development, agricultural production, climatic resilience, and macroeconomic stability. Strengthening these sectors within an effective institutional framework will assist nations in increasing food availability and building more resilient food systems. The comparative results also show that policy goals should be based on the structural characteristics of each nation group, rather than a single strategy for Asian emerging and G-7 countries.

6.2. Policy Recommendations

The policy recommendations described below are based on empirical evidence gained by the Zero Hunger model. Given the disparity in estimated impacts between the two nation groups, the suggestions are offered separately for Asian developing countries and G-7 countries, followed by a comparative policy viewpoint.

6.3. Policy Recommendations for Asian developing countries SDG 2: Zero Hunger

The research findings suggest that the Knowledge-Based Economy (KBE) contributes favourably to progress toward Zero Hunger in Asian developing nations, however its estimated influence is smaller than that of the G-7 economies. This discrepancy indicates that the advantages of knowledge-based development are not yet entirely translating into gains in food-system performance. Limited institutional capability, low levels of technical adoption, and flaws in innovation processes may all impede the translation of knowledge into agricultural production and food security. Policy initiatives should thus begin by improving the KBE's core foundations. Increased public and private investment in agricultural research, technical and vocational education, digital connection, extension services, and institutional capacity can all contribute to a more effective use of knowledge in agriculture. Providing farmers with fast digital information, weather predictions, market information, and technology-based farming solutions will further increase their capacity to make productive decisions.

The positive association between cereal yield and Zero Hunger demonstrates the importance of raising agricultural productivity. Governments should therefore place greater emphasis on improving access to high-yielding and climate-resilient seed varieties, modern irrigation facilities, agricultural machinery, and improved input-delivery systems. Public expenditure on agricultural research and development should also be strengthened, particularly in areas where productivity remains relatively low. Since agriculture continues to provide employment and livelihoods for a large proportion of the population in many Asian developing economies, productivity-enhancing measures can simultaneously support food availability, rural incomes, and progress toward zero hunger.

The findings also show that fish farming contributes favourably to food security outcomes. Fisheries and aquaculture should thus be more clearly included in national food security policy. Governments may help this sector by strengthening fisheries governance, encouraging ecologically sustainable aquaculture, expanding cold storage and transportation facilities, and eliminating losses between production and consumption. Such initiatives would not only enhance the availability of low-cost protein sources, but they might also offer new job and income possibilities in rural and coastal areas.

The negative link between yearly temperature and Zero Hunger emphasizes the vulnerability of food systems to climate-related stresses. Climate adaptation should so be factored into agriculture and food security plans. Farmers may manage growing climatic unpredictability by investing in heat and drought-tolerant crops, efficient irrigation, climate-smart farming techniques, agricultural insurance, and dependable early-warning systems. Small-scale producers should get special attention, as they frequently have fewer financial and technological means to adapt to climate-related shocks.

Inflation is also seen as a significant impediment for food security development. Persistent price rises might lower households' real purchasing power and make healthy food less accessible, especially for disadvantaged groups. Maintaining macroeconomic stability should thus remain a critical component of the Zero Hunger Strategy. Along with smart fiscal and monetary management, governments should increase targeted social protection, improve food distribution systems, keep adequate emergency food stocks, and resolve bottlenecks in agricultural supply chains. These methods can assist to mitigate the consequences of transitory food price shocks while avoiding long-term distortions in agricultural markets.

Growing populations have become additional difficulty for countries with fast expanding food consumption. Growing demands can put additional strain on agricultural land, water, and other productive resources if food production growth does not keep up. Governments should consequently prioritize agricultural modernization with rural infrastructure development, effective land and water management, enhanced storage facilities, and improved transportation networks. Increasing productivity and lowering post-harvest losses would enable food systems to adapt to demographic demands more efficiently than just expanding farmed acreage.

6.4. Policy Recommendations for G-7 Countries SDG 2: Zero Hunger

As per empirical estimations, the Knowledge-Based Economy contributes much more to Zero Hunger in the G-7 nations. This conclusion implies that these economies have greater institutional, technological, and innovation capacity, allowing information to be translated into improvements in food-system performance. The G-7's policy issue is thus less about developing fundamental knowledge infrastructure and more about sustaining technical leadership and ensuring that innovation contributes to resilient and sustainable food systems. Artificial intelligence, biotechnology, precision agriculture, robots, digital supply-chain systems, and resource-efficient manufacturing technologies should all receive more investment. Continued investment for research and innovation can help these countries boost productivity while addressing increasing environmental and food-security issues.

The positive influence of grain output suggests that agricultural production is still significant in industrialized economies. However, future increases are anticipated to be based mostly on enhancing the efficiency and sustainability of existing production methods rather than significantly expanding cultivated area. Policies should thus promote precision farming, automated agricultural machinery, satellite-based crop monitoring, data-driven farm management, and improved breeding methods. These advances can boost production per unit of land and input while minimizing wasteful use of water, fertilizers, energy, and other resources.

Fish production also contributes to food security outcomes, demonstrating that fisheries and aquaculture should remain part of the larger Zero Hunger policy framework. G-7 nations should enhance marine resource management by strengthening ecosystem-based fisheries management, promoting sustainable aquaculture, and using sophisticated monitoring and traceability technology. Such measures can assist to provide a steady supply of healthy food while safeguarding aquatic ecosystems and marine species.

The detrimental effect of yearly temperature illustrates that technical improvement does not diminish food systems' sensitivity to climate change. As a result, G-7 nations' agriculture policy should incorporate both climate reduction and adaptation strategies. Priority topics include climate-resilient production technologies, low-emission agricultural practices, increased resource efficiency, and crop and production system research capable of operating under changing climatic circumstances. Technological innovation has the potential to significantly reduce agriculture's environmental impact while retaining food-system resilience.

The negative effect of inflation illustrates that food affordability is still essential even in industrialized economies. Price stability should consequently remain a component of food security strategy. At the same time, local and international food-supply networks should be strengthened to lessen vulnerability to rising energy prices, geopolitical disruptions, climate-related production losses, and other external shocks. Diversifying the supply chain and enhancing strategic risk management can help to mitigate the impact of such shocks on food prices.

Most G-7 nations' relatively steady demographic dynamics mean that boosting food production volume should not be the primary policy goal. Instead, focus on enhancing the efficiency and sustainability of existing food systems. lowering food waste, enhancing distribution networks, improving storage and logistics, supporting circular-economy ideas, and encouraging sustainable consumption can all assist to increase food system efficiency while lowering demand on natural resources.

6.5. Comparative Policy Perspective: SDG2 Zero Hunger

Comparative research shows that the same policy approach is unlikely to provide equal results in Asian poor and G-7 nations due to significant differences in institutional capacity, technical development, agricultural institutions, and innovative capacities. The comparatively low KBE coefficient for Asian emerging nations shows that greater effort should be focused on improving the necessary conditions for knowledge to contribute to food security. These include institutional quality, digital infrastructure, human resources, agricultural research, extension services, and access to the latest production technology.

For G-7 nations with a significantly larger expected KBE effect, policy priorities should shift to preserving technical leadership and driving innovation toward resilient and ecologically sustainable agricultural systems. Artificial intelligence, biotechnology, precision agriculture, automation, and sophisticated supply-chain technologies can assist emerging economies increase output while lowering resource consumption and environmental concerns.

6.6. Limitations of the study

Due to non-availability of data, the current study assessed data from 2000 to 2024. Certain nations were removed from the analysis, which may restrict the generalizability of the results. Israel and North Korea were removed from the Asian developing nations panel in response to a lack of data availability. These exclusions represent a research constraint as they diminish the comprehensiveness of the regional study and may slightly affect the assessment of the effect of knowledge-based economies on sustainable development outcomes in developing Asia. Future work combining larger datasets could offer a more accurate evaluation.

6.7. Future Research Recommendation

This study encompasses the period from 2000 to 2024. The impact of KBE on SDG 2: Zero Hunger is investigated in this study. Future research may examine other SDGs, offering a more comprehensive perspective on sustainable development. The CS-ARDL econometric method is employed in this investigation. Other specialists could look at various econometric approaches, which could provide different outcomes. Additionally, different SDG 2 proxies and control variables may be employed in subsequent studies to confirm the validity of the results. It would make the results more broadly applicable and enable cross-scenario comparisons. Additionally, expanding the geographical scope to encompass other regions—like ASEAN, SAARC, BRICS, or the European Union will provide distinctive comparative insights into how different regions fulfil the SDGs and their particular challenges and opportunities for sustainable development. Future studies may also focus on the impact of SDG activities on specific industries. It would offer a more in-depth examination of how certain businesses or nations are performing in respect to these objectives.

Lastly, in order to better understand the trade-offs and synergies between the SDGs, researchers may look at how they are connected. It will offer a more thorough approach to sustainable development, influencing the formulation and execution of international policies.

References

[1] Affoh, R., Zheng, H., Dangui, K., & Dissani, B. M. (2022). The impact of climate variability and change on food security in Sub-Saharan Africa: Perspective from panel data analysis. *Sustainability*, *14*(2), 759. https://doi.org/10.3390/su14020759

[2] Ahmad, S., Khan, D., & Magda, R. (2022). Assessing the influence of financial inclusion on environmental degradation in the ASEAN region through the panel PMG-ARDL approach. *Sustainability*, *14*(12), 7058. https://doi.org/10.3390/su14127058

[3] Anser, M. K., Osabohien, R., Olonade, O., Karakara, A. A., Olalekan, I. B., Ashraf, J., & Igbinoba, A. (2021). Impact of ICT adoption and governance interaction on food security in West Africa. *Sustainability*, *13*(10), 5570. https://doi.org/10.3390/su13105570

[4] Ashraf, J., Jun, M., Ali, S., Ghufran, M., & Xiaobao, P. (2024). Zero-hunger through the lens of food security in populous Asia: Pre and post-pandemic. *Frontiers in Sustainable Food Systems*, *8*, 1210385. https://doi.org/10.3389/fsufs.2024.1210385

[5] Berchin, I. I., Nunes, N. A., de Amorim, W. S., Alves Zimmer, G. A., da Silva, F. R., Fornasari, V. H., Sima, M., & de Andrade Guerra, J. B. S. O. (2019). The contributions of public policies for strengthening family farming and increasing food security: The case of Brazil. *Land Use Policy*, *82*, 573–584. https://doi.org/10.1016/j.landusepol.2018.12.043

[6] Chudik, A., & Pesaran, M. H. (2015). Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors. *Journal of Econometrics*, *188*(2), 393–420. https://doi.org/10.1016/j.jeconom.2015.03.007

[7] Çoban, S., & Topcu, M. (2013). The nexus between financial development and energy consumption in the EU: A dynamic panel data analysis. *Energy Economics*, *39*, 81–88. https://doi.org/10.1016/j.eneco.2013.04.001

[8] Cojocaru, T. M., Ionescu, G. H., Firoiu, D., Cismaș, L. M., Oțil, M. D., & Toma, O. (2022). Reducing inequalities within and among EU countries—Assessing the achievement of the 2030 Agenda for Sustainable Development targets (SDG 10). *Sustainability*, *14*(13), 7706. https://doi.org/10.3390/su14137706

[9] Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F. N., & Leip, A. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food*, *2*(3), 198–209. https://doi.org/10.1038/s43016-021-00225-9

[10] Djokoto, J. G., Gidiglo, F. K., Srofenyo, F. Y., & Agyeiwaa-Afrane, A. (2022). Human development effects of food manufacturing foreign direct investment. *International Journal of Food and Agricultural Economics*, *10*(1), 23–39. https://doi.org/10.22004/ag.econ.319341

[11] Elavarasan, R. M., Pugazhendhi, R., Irfan, M., Mihet-Popa, L., Campana, P. E., & Khan, I. A. (2022). A novel Sustainable Development Goal 7 composite index as the paradigm for energy sustainability assessment: A case study from Europe. *Applied Energy*, *307*, 118173. https://doi.org/10.1016/j.apenergy.2021.118173

[12] Ersöz Kaya, I., & Korkmaz, S. (2025). Empirical analysis of the energy–growth nexus with machine learning and panel causality: Evidence from disaggregated energy sources. *Sustainability*, *17*(19), 8627. https://doi.org/10.3390/su17198627

[13] Food and Agriculture Organization of the United Nations. (2023). *Global food security challenges and its drivers: Conflicts and wars in Ukraine and other countries, slowdowns and downturns, and climate change* (CL 172/5). https://www.fao.org/governing-bodies/council/cl-172/en

[14] Ghosh, S., & Sahu, T. N. (2023). Targeting zero hunger to ensure sustainable development: Insights from a panel structure. *Sustainable Development*, *31*(4), 2814–2825. https://doi.org/10.1002/sd.2549
[15] Ivanova Boncheva, A. (2021). The knowledge-based economy in Asia and the Pacific: Links to the Sustainable Development Goals. In J. E. Rangel Delgado & A. Ivanova Boncheva (Eds.), *Knowledge society and education in the Asia-Pacific: Recent trends and future challenges* (pp. 9–24). Springer. https://doi.org/10.1007/978-981-16-2333-2_2
[16] Jednak, S., & Kragulj, D. (2015). Achieving sustainable development and knowledge-based economy in Serbia. *Management: Journal of Sustainable Business and Management Solutions in Emerging Economies*, *20*(75), 1–12. https://doi.org/10.7595/management.fon.2015.0015
[17] Kadomtseva, M. Ye. (2022). Theoretical and methodological aspects of ensuring the sustainable development of agro-food systems. *Izvestiya of Saratov University. Economics. Management. Law*, *22*(3), 277–286. https://doi.org/10.18500/1994-2540-2022-22-3-277-286
[18] McConnell, L. L., Osorio, C., & Hofmann, T. (2023). The future of agriculture and food: Sustainable approaches to achieve zero hunger. *Journal of Agricultural and Food Chemistry*, *71*(36), 13165–13167. https://doi.org/10.1021/acs.jafc.3c05433
[19] Mensi, A., & Udenigwe, C. C. (2021). Emerging and practical food innovations for achieving the Sustainable Development Goals (SDG) target 2.2. *Trends in Food Science & Technology*, *111*, 783–789. https://doi.org/10.1016/j.tifs.2021.01.079
[20] Mhlanga, D., & Ndhlovu, E. (2023). The implications of the Russia–Ukraine war on sustainable development goals in Africa. *Fudan Journal of the Humanities and Social Sciences*, *16*(4), 435–454. https://doi.org/10.1007/s40647-023-00383-z
[21] Mishra, H., & Mishra, D. (2024). Sustainable smart agriculture to ensure zero hunger. In S. Krishnan, A. J. Anand, & R. Kumar (Eds.), *Sustainable development goals: Technologies and opportunities* (pp. 16–37). CRC Press. https://doi.org/10.1201/9781003468257-2
[22] Mishra, H., Mishra, R., Olayinka, O. T., Ghaib, A. A., Raza, M. Y., & Maroof, K. (2025). The role of digital agriculture in mitigating climate change and ensuring food security: An overview. In M. Ahmed (Ed.), *Climate resilient and sustainable agriculture: Volume 2: Social and transformative strategies* (pp. 287–312). Springer. https://doi.org/10.1007/978-3-032-04141-8_11
[23] Mmila, G., & Myeki, L. W. (2025). The dynamics of broiler meat supply in South Africa and its implications for achieving SDG 2: Zero hunger. *Agriculture*, *15*(12), 1236. https://doi.org/10.3390/agriculture15121236
[24] Montero, J.-M., Roberts, R. J., & Naimy, V. (2025). Revisiting zero hunger from a multidisciplinary perspective: How to measure hunger and reduce it? *Equilibrium. Quarterly Journal of Economics and Economic Policy*, *20*(1), 49–145. https://doi.org/10.24136/eq.3511
[25] Mumuni, S., & Aleer, M. J. (2023). Zero hunger by 2030—Are we on track? Climate variability and change impacts on food security in Africa. *Cogent Food & Agriculture*, *9*(1), 2171830. https://doi.org/10.1080/23311932.2023.2171830
[26] Pesaran, M. H., Schuermann, T., & Weiner, S. M. (2004). Modeling regional interdependencies using a global error-correcting macroeconometric model. *Journal of Business & Economic Statistics*, *22*(2), 129–162. https://doi.org/10.1198/073500104000000019
[27] Prieto-Egido, I., Sanchez-Chaparro, T., & Urquijo-Reguera, J. (2023). Impacts of information and communication technologies on the SDGs: The case of Mayu

Telecomunicaciones in rural areas of Peru. *Information Technology for Development*, *29*(1), 103–127. https://doi.org/10.1080/02681102.2022.2073581

[28] Rejeb, A., Rejeb, K., Abdollahi, A., Zailani, S., Iranmanesh, M., & Ghobakhloo, M. (2022). Digitalization in food supply chains: A bibliometric review and key-route main path analysis. *Sustainability*, *14*(1), 83. https://doi.org/10.3390/su14010083

[29] Reuveni, S. (2025). The role of food prices and market access in contributing to hunger in low-income populations. *Eximia*, *14*(1), 69–96. https://doi.org/10.47577/eximia.v14i1.531

[30] Siddique, K. H. M., Li, X., & Gruber, K. (2021). Rediscovering Asia's forgotten crops to fight chronic and hidden hunger. *Nature Plants*, *7*(2), 116–122. https://doi.org/10.1038/s41477-021-00850-z

[31] Singh, H. P., Singh, A., Alam, F., & Agrawal, V. (2022). Impact of sustainable development goals on economic growth in Saudi Arabia: Role of education and training. *Sustainability*, *14*(21), 14119. https://doi.org/10.3390/su142114119

[32] Sporchia, F., Antonelli, M., Aguilar-Martínez, A., Bach-Faig, A., Caro, D., Davis, K. F., Sonnino, R., & Galli, A. (2024). Zero hunger: Future challenges and the way forward towards the achievement of Sustainable Development Goal 2. *Sustainable Earth Reviews*, *7*, 10. https://doi.org/10.1186/s42055-024-00078-7

[33] Yao, X., Durani, F., Syed, Q. R., Lean, H. H., & Tabash, M. I. (2025). Does tourism promote green growth? A panel data analysis. *Environment, Development and Sustainability*, *27*(1), 2411–2422. https://doi.org/10.1007/s10668-023-03972-w