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Global hunger risk projections and the factors shaping future vulnerabilities

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A R T I C L E I N F O

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A B S T R A C T

Hunger remains one of the most persistent barriers to human development, with progress uneven across regions and increasingly exposed to economic instability, climate pressure and structural vulnerabilities. This study investigates the key drivers of cross-country variation in hunger severity and develops forward looking projections to support evidence based global policy planning. Using a comprehensive global panel dataset covering 146 countries over the period, 1992 to 2024 the analysis identifies the socio-economic and environmental factors more strongly associated with changes in hunger outcomes over time. The results reveal that hunger severity is not shaped by a single pathway but by a combination of development related conditions, demographic pressures, and external shocks with substantial heterogeneity across country groups. Building on the estimated relationships the study generates projections from 2025 to 2029, highlighting regions where hunger risks may remain elevated or worsened in the absence of targeted interventions. The findings underscore that substantial progress in hunger reduction requires integrated methods that extend beyond food supply alone including strengthening resilience, improving social protection and supporting inverse growth by combining long run global evidence with near turn projections. This study contributes to the literature on hunger dynamics and offers timely insights for international organisations and national policymakers working towards the achievement of food security and related Sustainable Development Goals.

1. Introduction

Food security remains one of the most urgent and multidimensional global challenges of the 21st century (FAO, 2003; Mumah et al., 2025; Food Security Information Network, 2025; FAO, 2011; Shreya, 2025). Despite notable progress in areas such as exclusive breastfeeding, 713 million people remain undernourished (World Health Organization, 2024), while 2.33 billion experience moderate to severe food insecurity (Crispian, 2024), including 151 million stunted children under five, 613 million women and girls aged 15 to 49, and 2 billion adults with obesity (Intergovernmental Panel Climate Change, 2025). If unaddressed, global malnutrition could reach 512 million people by 2030 (FAO and UNICEF, 2025).

This ongoing problem stems from a complex web of interrelated factors, with Greenhouse Gas (GHG) emissions being a key driver of climate change, which disrupts global food systems (Environmental Protection Agency, 2025; FAO, 2015; Saleem et al., 2025; Hong et al., 2025; Bibi and Rahman, 2023). GHG emissions indicate a negative association with food security (Rahman et al., 2025; Xiong and Yu, 2025; Gobezie and Boka, 2023) with a percent rise in GHG emissions leading to a 0.2 percentage larger decline in food security (Gobezie and Boka, 2023; Mirzabaev et al., 2023). Climate change and extreme temperatures are major consequences of GHG emissions (The World Bank Group, 2022), thus undermining the affordability, availability, quality of natural resources in food (Yiadom et al., 2023). This is further worsened with long run food production identified as a negative contributor to GHG emissions (Kibria et al., 2023; Gao et al., 2026; Su et al., 2024; UN, 2021; FAO and Greenhouse gas emissions from, 2000; Timesofagriculture.org, 2025). Renewable energy emerges as a critical pathway to mitigate these impacts by promoting sustainable food production and reducing energy poverty (FAO, 2021; WFP, 2025; World Economic Forum, 2023; Irfeey et al., 2024; Atlas, 2023). However, the impact of on food production may vary across long and short run (Rehman et al., 2024; Li et al., 2024; Batool et al., 2024). Higher initial

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costs in the short run and increased opportunity cost of agricultural land in the long run would negatively impact the use of renewable energy on food production (Pulle et al., 2026). Opportunity cost created on institutional investments and the overuse of agricultural resources such as water and land would boost food prices (Ujjayant et al., 2015; Hochman et al., 2012). In response the low-income families would be oppressed more with less affordable food, thus widening the disparity among the rich and the poor. In response it is important that renewable energy is implemented as such, that its benefits are maximised while the negative aspect of it is controlled, especially in the long run. Therefore, it is crucial that fragmented renewable energy systems are brought together for centralised and efficient renewable energy use (Islam et al., 2025a), backed by smart renewable energy storage (Tourang et al., 2026). The trade-off between GHG emission and renewable energy (Islam et al., 2025b), expects countries to boost their food production in the long run.

However, food security outcomes are also shaped by demographic transitions, especially urbanisation (Ikudayisi, 2024; Lee et al., 2024; Abebe, 2024; Macalou et al., 2023), which reshapes food systems by shifting consumption from home-produced staples to market-based and processed foods (de Bruin et al., 2021; Pandey et al., 2020; FAO, 2023; Putra et al., 2020). Today, cities house 56% of the world's population, which is projected to reach 68% by 2050, particularly in Low Income Countries (LICs) and Lower Middle Income Countries (LMICs) (FAO, 2023; UN and 68, 2018; UN and Peace, 2024). Hence, projections are made to free up 52 million hectares of arable land by 2025 in order to meet the rising demand (de Bruin et al., 2021; Wang et al., 2025). Proper urban planning could enhance resilience and sustainable food systems (Kamali et al., 2025; Opoku et al., 2024; Matooane et al., 2025), boost food production, reduce urban sprawl (Tabrez, 2025), boost gross income of urban community (Giyarsih et al., 2024; Gunapala et al., 2025) and assist in crop diversification (Gu et al., 2024). Proper urban planning would likely be backed by government policies that ensure urban and peri-urban food security is maintained in the long term. Additionally, low-income households are more likely to be food secure (Ikudayisi, 2024), supported by direct access to staple food and government subsidies that cushion their income baselines, enabling them to afford basic nutrition. Nevertheless, when combined with population growth, which has already surpassed 8 billion, the pressures on food systems intensify (UN, 2022; Conrad, 2022; Jain et al., 2023). Meeting this demand requires at least a 70% increase in food supply (FA O and 2050, 2009). In addition to raising the demand for food and undernourishment (Molotoks et al., 2021; Miladinov, 2023; Hall et al., 2017), growing populations also compete over limited resources, especially energy, water, and land (Pereira, 1993; Natalia, 2023; Connection, 2025; Daniil, 2025). Additionally, population ageing especially in agriculture sector could lead to increased risks in food security (Liu et al., 2025), thus demanding significant policy reformations (Kinawy and Ahmed, 2024).

However, Gross Domestic Product (GDP) could offset these adversities by facilitating investment; both public and private, in agriculture and infrastructure (Kerrouche and Zehri, 2025; Reuveni, 2024; Fernandes and Samputra, 2022; Agro Momentum, 2025; True, 2024; The World Bank Group, 2018), creating job opportunities and increase disposable income, making staple food more affordable. Rising incomes lead to higher demand in locally produced products (Tinta et al., 2018), boosting food security (He et al., 2024; Abdi et al., 2024; Ceesay and Ben Omar Ndiaye, 2022; Farooq et al., 2024). In addition, improved remittances, human capital and boosted quality of institutions (Gnedeka and Wonyra, 2023), growing access to credit (Opportunity International, 2025; The Independent, 2025; Bank of Ceylon, 2025), followed by improved agricultural infrastructure (Live to Plant, 2025; Edeme et al., 2020), and adaptation of technology assists in raising the food security levels of countries (IWMI, 2025; Raji et al., 2024). Therefore, while the use of financial and technological resources are optimised, it is essential to ensure necessary knowledge is shared to exploit the long-term benefits of economic growth. It is further crucial that all technological and digitalisation investments made as a response to boosted PGDP remains at controlled reach of negative digital footprint (Meinhold et al., 2025), which in the long run may distress food production systems. Along with PGDP, agricultural land also forms the backbone of food production (Arumugam, 2025; Pawlak and Kołodziejczak, 2020; Bonventure et al., 2025). Factors such as farm size, crop diversification index, digital innovation, gender, remittance income, education, land restoration, land use change, land accessibility and secure land increases land access and food security (Ayanwale and Kehinde, 2025; Orou and Guenther, 2025; Egerson et al., 2025). Further, improvements in land use efficiency in one region could encourage neighbouring regions to boost their efficiency (Chen et al., 2024). This indicates that strategic and sustainable farming practices must be utilised to make land usage more efficient and productive, thereby enhancing food security.

Acknowledging the variables identified in association to food security, this study can be anchored with the Amartya Sen's Entitlement Theory (Pulle et al., 2026), which emphasises access to food through entitlements that support access, such as production and trade, rather than just availability (Sohlberg, 2006; Rubin, 2009; Cui and Zhang, 2025). Agricultural land followed by the food production index would be major contributors to production-based entitlements. Income per head boosted further through urbanisation contributes to trade based entitlements and rural population growth being greater than the urban population growth contributes to own labour entitlement. The subsidies and aids received in controlling GHG emissions and boosting controlled renewable energy production falls under transfer entitlement.

While numerous studies have evaluated the determinants of food security as identified above, in country or region-specific scope, there is a lack of empirical evidence examining how these variables jointly influence food production at a global scale. This study aims to investigate the joint impact of renewable energy, GHG emissions, population growth, urbanisation, agricultural land, and GDP on food production globally and across income groups, uncovering both universal patterns and income-specific dynamics. To empirically examine these impacts, this study formulates nine hypotheses across the identified explanatory variables and the dummy variables. Adding to its novelty, this study predicts the likelihood of countries falling into these categories for the period 2025 to 2029, providing data-driven insights for decision-making. Second, the study offers a comprehensive overview of the final model's development using a forward stepwise approach. Across nine steps, it identifies the strongest predictors of FPI and highlights their significance levels throughout the process. Moreover, the inclusion of 146 countries enhances the model's generalisability across global and income group contexts. Third, the polar heatmap illustrates the predicted probabilities of countries falling into low, moderate, and high food security categories for each income group. Fourth, this study aligns

Table 1
Data sources and variables.

Acronym	Variable	Measurement Unit	Source
FPI	Food security	Food Production Index (2014-2016 = 100)	The World Bank Group (2024a)
UB	Urbanisation	Share of the population living in urban areas	Our World in Data (2024a)
RE	Renewable Energy Consumption	Percentage of total final energy consumption	The World Bank Group (2024b)
GHG	Greenhouse Gas Emissions	Tons of CO_2 equivalent	Our World in Data (2024b)
PG	Population Growth	Annual percentage change in population size	The World Bank Group (2024c)
GDP	Gross Domestic Product per Capita	GDP per capita (constant 2015 USD)	The World Bank Group (2024d)
AGRI	Agricultural Land	Land under cereal production (hectares)	The World Bank Group (2024e)

Source: Authors' compilation based on the data sources (The World Bank Group, 2025a) and (Our World in Data, 2025).

Table 2
Variables and supporting articles.

Variables	Supporting Research Articles
FPI	(Kibria et al., 2023; Abdi et al., 2024; Obekpa et al., 2025; Applanaidu et al., 2014; Onwe et al., 2024; Tariq et al., 2023; Gyimah et al., 2023; Segbefia et al., 2023)
UB	Gyimah et al. (2023)
RE	(Li et al., 2024; He et al., 2024; Gyimah et al., 2023)
GHG	Abdi et al. (2024)
PG	(Abdi et al., 2024; Onwe et al., 2024; Gyimah et al., 2023; Devesh and Abdullah, 2020)
GDP	Onwe et al. (2024)
AGRI	Abdi et al. (2024)

Source: Authors' compilation.

with the SDGs, providing insights into achieving SDG-2: Zero Hunger, and other SDGs. This analysis helps identify more vulnerable countries and provides clearer insights into the global distribution of food production levels. These insights are further supported by detailed heatmaps depicting the trends of key variables over the years.

2. Materials and methods

2.1. Data sources and sample selection

This study takes the initiative in providing a detailed analysis from 1992 to 2024, including 33 years' worth of data and covering 146 countries, sourced from data sources such as "Our World in Data" and "World Bank." Table 1 provides an overview of the data and their sources, while Appendix 1 contains the overall dataset. Cubic

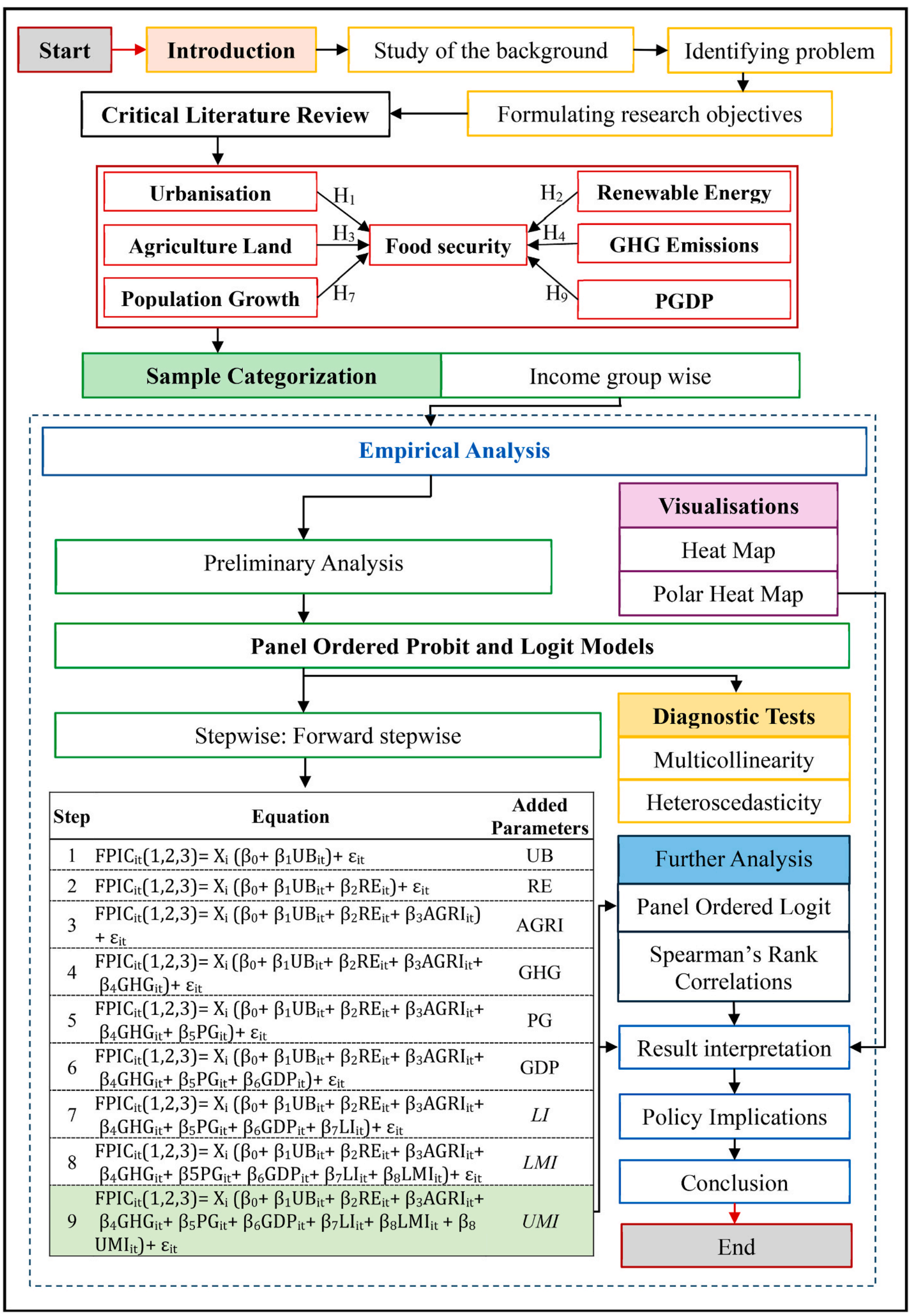

Fig. 1. Data and methodology flow diagram.
Source: Authors' compilation.

polynomial regression was used to fill in missing data up to 2024, which is approximately 4% of the total data available. Extrapolation was used in predictive modelling from 2025 to 2029, thus avoiding spurious trends and biases caused by cubic polynomial imputation. Later, predicted probabilities from 1992 to 2029 were generated to gain a comprehensive understanding of the odds over time. The statistical analysis for the collected panel data was done using the Stata software (StataCorp LLC).

Table 2 provides supporting research articles for all the variables used in the study.

2.2. Research framework

After critical literature evaluation this study establishes its conceptual framework in such way that the uni-directional impact of the identified independent variables on FPI is evaluated as depicted in Fig. 1. The empirical analysis of the study consists of a preliminary analysis that examines the correlations between the explanatory variables to ensure that perfect multicollinearity is avoided (Studenmund, 2016). In this case, the Variance Inflation Factor (VIF) test is used to assess this. Further heteroscedasticity tests are conducted to determine whether the variance of errors is consistent across the time range. Later the panel ordered probit model was employed using the forward stepwise method whereby the predicted probabilities generated later on were illustrated through heatmaps. The study was concluded with a comprehensive discussion followed by policy implications and limitations.

2.3. Econometric methodology

2.3.1. Panel ordered probit model

The basic probit model estimates equations with dummy variables to avoid the unboundedness problem of the linear probability model, using a variant of the cumulative normal distribution (Studenmund, 2016; Jayathilaka and Keembiyahetti, 2009; Hettiarachchi et al., 2025). Scaling the general probit model to a panel context allows unobserved heterogeneity across individuals to be accounted for (Studenmund, 2016; Suliyanto and Fariz, 2024). Hence, to explain the determinants of FPI, this study utilises a stepwise panel ordered probit model. Inspired by previous studies (Macalou et al., 2023) FPI was categorised into three levels of food security: low, moderate and high. The authors took initiative in determining the thresholds. The study employs a forward stepwise method, setting the "pe" value at 0.15 to derive the final model.

Before delving into the final model Eq. (1) sets out the latent regression model with y^*_{it} representing the latent dependent variable of the i^{th} individual at the t^{th} time, which will later be substituted by $FPIC^*_{it}$. The deterministic part of the model is presented through $\beta' x_{it}$, where β' is the parameter vector and x_{it} is the vector of the predictor variables of the i^{th} individual at the t^{th} time. u_i Represents the random effect of the i^{th} individual and v_{it} represents the random error of the i^{th} individual at the t^{th} time. Where in Eq. (2), ε_{it} represents the generalised error term. In this case, N would equal 146, thus representing the number of countries used in the study, and T would be 33, explaining the number of years utilised in the study.

$$y^*_{it} = \beta' x_{it} + u_i + v_{it}, i = 1, \ldots\ldots, N;\ t = 1, \ldots\ldots, T \tag{1}$$

$$y^*_{it} = \beta' x_{it} + \varepsilon_{it} \tag{2}$$

The decision to adopt a panel ordered probit model was driven by the lack of studies identified in the study areas, thus providing a new contribution. Simultaneously, the ability to predict the likelihood of falling into predetermined categories helps understand how the independent variables have collectively influenced the observed variable over time (Jayathilaka and Keembiyahetti, 2009; Hettiarachchi et al., 2025; Jayathilaka and Udara, 2024; Kalansuriya and Jayathilaka, 2025).

The initial thresholds μ_1 and μ_2 are set at 48 and 112, respectively adapting from (Pulle et al., 2026), to ensure that meaningful heterogeneity across thresholds were defined. This led to the determination of the cut-off points between $FPIC^*_{it}$, with $FPIC^*_{it}$ representing the latent variable as presented through Eq. (3).

$$\mathrm{FPIC}_{it} = \begin{cases} 1 \text{ if } FPIC^*_{it} \le \mu_1 \\ 2 \text{ if } \mu_1 < FPIC^*_{it} \le \mu_2 \\ 3 \text{ if } FPIC^*_{it} > \mu_2 \end{cases} \tag{3}$$

The above equation is further elaborated on, showing how it is built around the cumulative distribution function (Φ), thus representing the probability of each outcome. In the case of probit functions, it is always assumed that ε_{it} follows a normal distribution and is independent of X_{it}. Eqs. (4)–(6) substitutes the latent variable function to $FPIC^*_{it}$ thus deriving the respective functions, with probability of ε_{it} being substituted by Φ.

- Category 1: Low food secure:

$$P(FPIC_{it} = 1|X_{it}) = \Phi(\mu_1 - \beta' X_{it}) \tag{4}$$

- Category 2: Moderate food secure:

$$P(FPIC_{it} = 2 \mid X_{it}) = \Phi(\mu_2 - \beta' X_{it}) - \Phi(\mu_1 - \beta' X_{it}) \tag{5}$$

- Category 3: High food secure:

$$P(FPIC_{it} = 3 \mid X_{it}) = 1 - \Phi(\mu_2 - \beta' X_{it}) \tag{6}$$

The elaborated equation of the model is presented as shown in Eq. (7);

$$FPIC_{it}(1,2,3) = X_i\,(\beta_1 UB_{it} + \beta_2 RE_{it} + \beta_3 GHG_{it} + \beta_4 PG_{it} + \beta_5 AGRI_{it} + \beta_6 GDP_{it} + \beta_7 LI_{it} + \beta_8 LMI_{it} + \beta_9 UMI_{it}) + \varepsilon_{it}, \varepsilon_{it} \sim N(0,1) \tag{7}$$

where.

FPIC_{it} (1,2,3)	The latent dependent variable together with the defined category levels
$\beta_{1,2..6}$	Coefficients of the independent variables
UB	Urbanisation
RE	Renewable Energy
GHG	Greenhouse Gas Emissions
PG	Population Growth
AGRI	Agricultural Land
GDP	Gross Domestic Product per Capita
LI	Low-Income (Dummy variable)
LMI	Lower Middle-Income (Dummy variable)
UMI	Upper Middle-Income (Dummy variable)
ε	Standard error term

2.3.2. Parameter sensitivity

To ensure the parameter sensitivity, a panel ordered logit model is expected to be employed.

Panel ordered logit models follow a variant of the cumulative logistic function (Studenmund, 2016). In the instance of a logit model, acknowledging that the probability may range from 0 to 1, the logit function would range from -∞ to +∞, thus signalling the unboundedness of logit and (STATA 17, 2025; Damodar, 2015). Hence, the logistic cumulative distribution function would be as shown in Eq. (8);

$$\Lambda(z) = \frac{1}{1 + e^{-z}} \tag{8}$$

Here, Λ represents the logistic cumulative distribution function, z represents the log odds, and e represents the natural logarithm, hence, $-z$

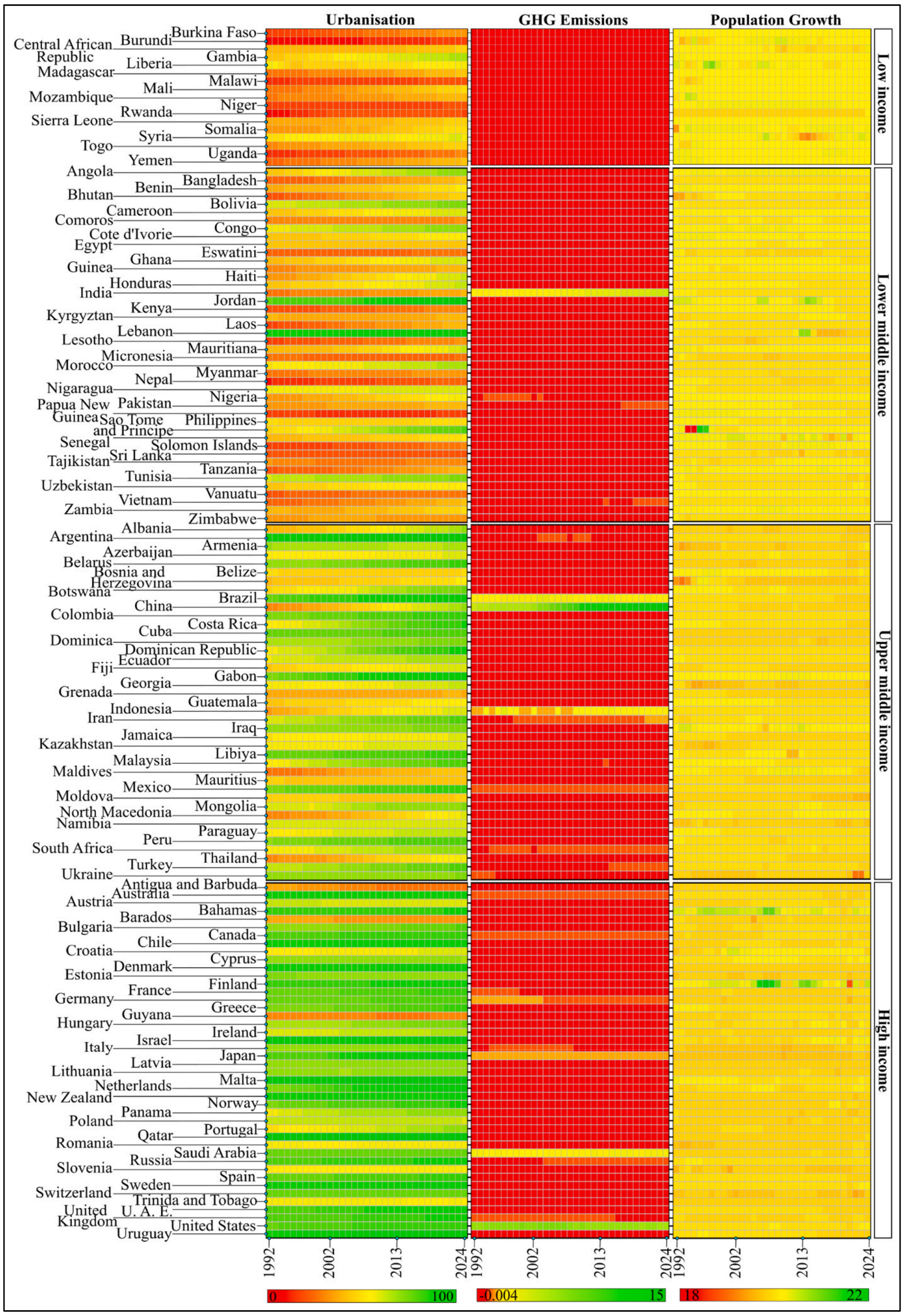

Fig. 2. Urbanisation, GHG emissions, and population growth from 1992 to 2024.
Source: Authors' compilation using (OriginLab Corporation and OriginPro [software], 2024) and (Kosiński et al., 2025).

could be substituted with the basic linear function. Since the study is restricted from running fixed effects, the ordered logit model was employed for further confirmation due to the existence of heterogeneous panels.

A Spearman's rank correlation is further carried out in validating the monotonic relationship between the predicted values of the two models (Samuel et al., 2024; Geeks for Geeks, 2025). The formula for this is set out as shown in Eq. (9);

$$p = 1 - \frac{6\sum d^2}{n(n^2 - 1)} \tag{9}$$

Further, Ranked Probability Sore (RPS) is utilised in evaluating the predictive performance of the model. Lower RPS values indicate better predictive accuracy. Model performance is assed both in-sample and out-of-sample to evaluate generalisation and potential overfitting.

2.3.3. *Hypothesis testing approach*

This study follows a two-tailed hypothesis testing approach, ensuring that the leading hypotheses are set against the variables, resulting in 9 main hypotheses. Hypotheses are tested at a 5% significance level, resulting in the final hypotheses being set as follows.

H1. Urbanisation has a significant impact on the likelihood of being categorised as food secure.

H2. Renewable energy consumption has a significant impact on the likelihood of being categorised as food secure.

H3. Agricultural land has a significant impact on the likelihood of being categorised as food secure.

Fig. 3. Renewable energy, PGDP, and agricultural land from 1992 to 2024.
Source: Authors' compilation using (OriginLab Corporation and OriginPro [software], 2024) and (Kosiński et al., 2025).

H4. GHG emissions have a significant impact on the likelihood of being categorised as food secure.

H5. Being a LIC has a significant impact on being categorised as food secure, compared to a High-Income Country (HIC).

H6. Being a LMIC has a significant impact on being categorised as food secure, compared to a HIC.

H7. Population growth has no significant impact on the likelihood of being categorised as food secure.

H8. Being an Upper Middle-Income Country (UMIC) has a significant impact on being categorised as food secure, compared to a HIC.

H9. GDP has no significant impact on the likelihood of being categorised as food secure.

3. Results

3.1. *Temporal and spatial variations of global food production security*

Analysing the explanatory variables as depicted in Fig. 2, urbanisation remains high in HICs and UMICs. At the same time, most LICs and LMICs show rising urbanisation, except for Burundi and Papua New Guinea, which indicate a slight change. Grenada, Mauritius, Antigua, and Barbados present declining levels of urbanisation. GHG emissions show extreme disparity across income groups, with countries such as India, Brazil, China, Indonesia, the United States, and Saudi Arabia making significant contributions over the years. The yearly percentage change of population throughout the world remains moderate. Rwanda signals the lowest percentage change amongst LICs over the years.

Table 3
Panel ordered probit and logit results.

Variables	Panel Ordered Probit Results					Panel Ordered Logit Results				
	Estimate	Robust SE	Marginal Effects			Estimate	Robust SE	Marginal Effects		
			Low Food Secure	Moderate Food Secure	High Food Secure			Low Food Secure	Moderate Food Secure	High Food Secure
UB	0.097***	0.021	−0.010***	−0.003*	0.013***	0.189***	0.039	−0.009***	−0.005	0.014***
RE	−0.425***	0.102	0.046***	0.013*	−0.058***	−0.850***	0.209	0.043***	0.022	−0.064***
AGRI	0.008**	0.004	−0.001**	−0.0002	0.001**	0.016**	0.008	−0.001**	−0.0004	0.001*
GHG	−0.315**	0.142	0.034**	0.009	−0.043**	−0.595**	0.271	0.030***	0.015	−0.045**
LI	7.019***	1.344	−0.755***	−0.210*	0.965***	13.666***	2.607	−0.686***	−0.351	1.037***
LMI	4.805***	0.951	−0.517***	−0.144*	0.661***	9.326***	1.858	−0.468***	−0.240	0.708***
PG	−0.564*	0.319	0.061*	0.017	−0.077*	−1.004*	0.584	0.05	0.026	−0.076*
UMI	1.823***	0.504	−0.196***	−0.055*	0.251***	3.479***	0.973	−0.175***	−0.089	0.264***
GDP	0.023*	0.013	−0.003*	−0.001	0.003*	0.043*	0.026	−0.002*	−0.001	0.003
Ancillary Parameters										
$\widehat{Y}_1$	4.885	1.525				9.508	2.901			
$\widehat{Y}_2$	8.568	1.619				16.374	3.112			
χ^2	63.410					69.48				
ln $\widehat{L}_p$	−2361.107					−2350.03				

Note: $\widehat{Y}_1$ represents cut 1, $\widehat{Y}_2$ represents cut 2, χ^2 represents chi-squared, ln $\widehat{L}_p$ represents log pseudolikelihood, Obs. represents number of observations, Obs. = 5548, the coefficients and marginal effects presented above represent significant levels as follows: * significant at 10%, ** significant at 5%, and *** significant at 1%. SE represents the standard error.
Source: Authors' compilation using StataCorp LLC (2021).
Source: Authors' compilation using (StataCorp LLC).

Angola, Senegal, and Solomon Islands indicate a decline in population growth around the 2020s. The Maldives indicate a rise in population growth around the early 2010s, followed by a decrease later in the decade. Qatar indicates a varying but comparatively high population growth, with the significant impact of COVID-19 being signalled by a steep decline in 2021.

Fig. 3, on the other hand, presents the yearly statistics for renewable energy, PGDP and agricultural land. Syria and Yemen indicate constant low adoption of renewable energy across LICs. Most LMICs show a decline in the adoption of renewable energy, while Zimbabwe shows the opposite trend. Paraguay, Gabon, and Guatemala show the highest adaptation over the years among UMICs, while Uruguay, Sweden, Norway, and Finland demonstrate significantly rising adaptation of renewable energy across HICs. On the contrary, PGDP presents income inequality across the world attractively, showing how LICs to HICs evenly distribute income from red to green, with the latter being the highest. Niger and Mali indicate increasing agricultural land in the case of LICs. While Bangladesh, India, Nigeria, Pakistan, and Vietnam signalled larger agrarian lands, they show a slight decline in these areas over the years. China, Brazil and Argentina indicate the highest amongst UMICs, while the United States and Saudi Arabia take the lead amongst HICs.

3.2. *Driving mechanisms of global food production security*

Prior delving to the probit regression a VIF test conducted revealed, that data was free from multicollinearity. Diagnostic tests on heteroscedasticity revealed the data were heteroscedastic as presented through Appendix 2. The results for the panel ordered probit model is presented through Table 3. Here the three categories of food security simply suggests that any country categorised as low food secure indicates very low food production capacity, followed by higher reliance on food imports and greater vulnerability to external food supply shocks. Moderate food security implies functioning but heterogeneous agricultural systems and high food security exhibiting expanding agricultural capacity backed by advanced technology, better irrigation systems, and potential export capacity. Sensitivity of the adapted thresholds were further evaluated using thresholds 50/110, 45/115, and 55/115 which derived same signs of coefficients, thus indicating insensitiveness as presented through Appendix 3.

In addition, the parameter sensitivity test conducted through panel ordered logit regression revealed that coefficients remained the same with the marginal effects varying only to the second decimal place. This consistency validated that the results are robust to the choice of link function. Extensive results on both models are presented in Appendix 4. Further to address endogeneity, panel ordered probit model was re-run with lagged variables, where it was identified that the signs remained the same with slight variations in coefficients as presented through Appendix 5.

The study summarises the central hypothesis set with respect to each variable over the panel ordered probit model, thus elaborating on nine hypotheses, set as follows:

Hypothesis 1 indicates that urbanisation has a significant positive impact on FPI. A 1% rise in urbanisation reduces the likelihood of a country being categorised as low and moderate food secure by 1.0% and 0.3% respectively, while the likelihood of a country being classified as high food secure rises by 1.3%. This improvement is led by factors such as increased agricultural land availability (Bodirsky et al., 2020; Ramdé et al., 2025), improved infrastructure, encouraged urban and peri-urban farming and increased dietary diversity (Alene and Aga, 2025; Srinivasan and Yadav, 2023; Cockx and Boti, 2025). In addition, most countries focus on planned urbanisation (Wijeya Newspapers Ltd, 2023; UN, 2025), ensuring optimised sustainability, which leads to the achievement of SDG 11: Sustainable Cities and Communities.

Hypothesis 2 suggests that the likelihood of being food secure is significantly impacted by renewable energy consumption. A 1% rise in renewable energy consumption reduces the odds of being categorised as highly food secure by 5.8%, while the odds of being low and moderately food secure increase by 4.6% and 1.3%, respectively. In the long run, agricultural land displacement due to renewable energy installations, increased opportunity costs for hydro power resources (Shivaprakash, 2022; Directory, 2025), and rising costs of crop production (Asamoah, 2020) would raise food prices. This signals unplanned renewable energy consumption, where rather than optimising its vast benefits, excessive usage may counteract food security levels causing hunger. However, it is important to acknowledge that current coefficient depicts average global association of renewable energy, and many vary across countries depending on the country specific contexts.

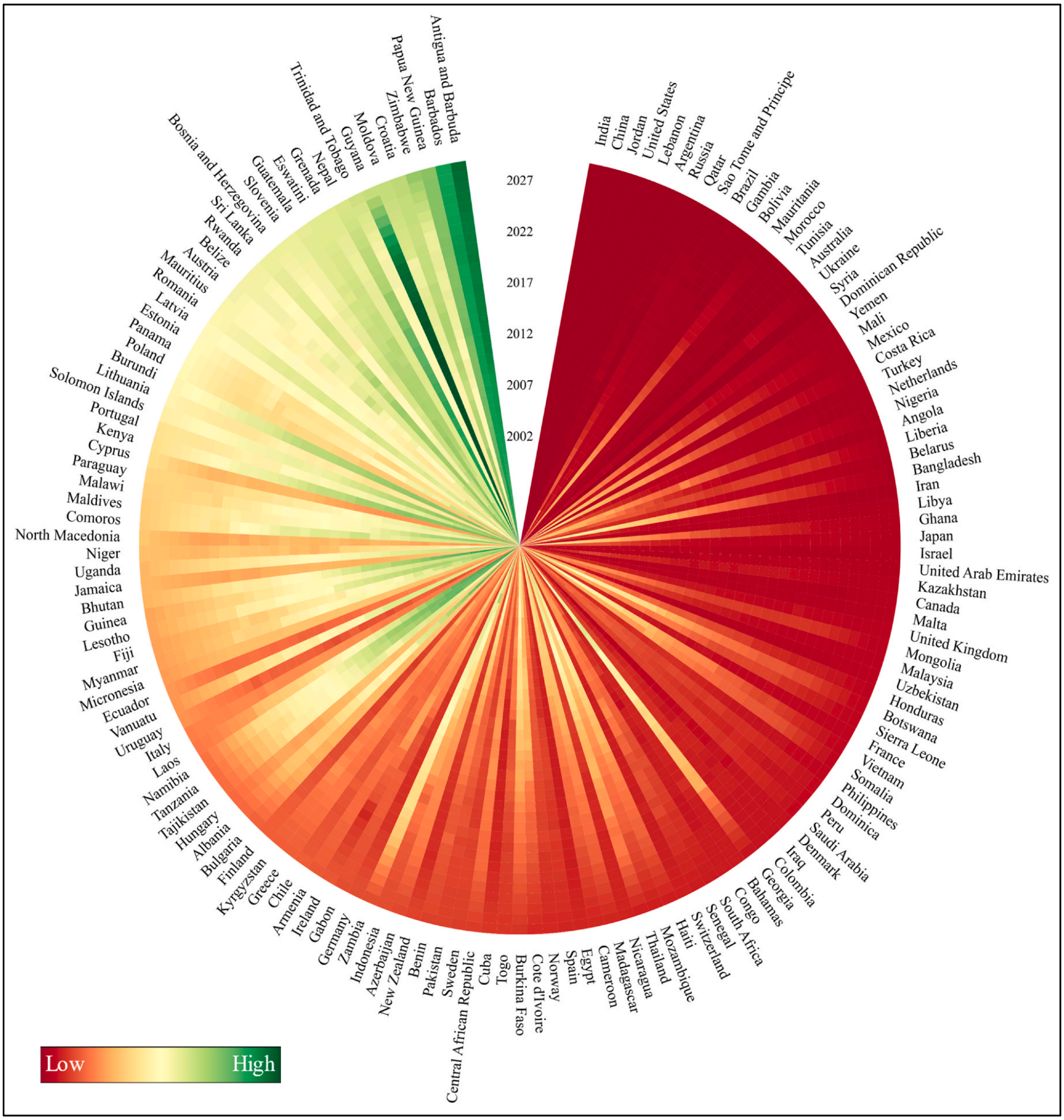

Fig. 4. Predicted probabilities of being low food secure (ordered probit model, 1992-2029).
Source: Authors' compilation using (Python and Python, 2025).

Hypothesis 3 elaborated that agricultural land significantly and positively impacts food security. Rising agricultural efficiency, with greater allocations of Agri-tech investments by governments, growing urban agricultural prospects such as vertical farming, hydroponics, rooftop farming, and concessional loans in encouraging young farming enthusiasts (Economynext, 2025), act as significant boosts in improving the food production levels. Therefore, as agricultural land increases by a percent, the likelihood of a country being categorised as highly food secure rises by 0.1% while the probability of being low food secure falls by 0.1%.

Hypothesis 4 suggests that GHG has a significant and negative impact on FPI, whereby when GHG rises by 1%, the odds of a country being highly food secure fall by 4.3%, and the odds of the same country being low food secure rise by 3.4%. Worsening climatic conditions across the world, with rising unique and unexpected natural catastrophes led by primary GHG emissions, play a key role in deteriorating food security. Parallelly, agricultural production itself acts as a contributor to GHG emissions (Hasan et al., 2025), especially in the long run. Hence, governments and institutions must strengthen their policies and precautions against GHG emissions to optimise these emissions.

Hypothesis 5 elaborates that a country categorised as LIC has 96.5% odds of being classed as high food security, while the same country being classified as low and moderate food security would fall approximately by 76% and 21%, respectively. This can be supported by the fact that the majority of employment in LICs is accounted for in the agriculture sector (The Global Economy, 2025). While women's employment in LICs is gradually increasing, women play a key role in agriculture and food security (Visser and Wangu, 2021), thereby boosting food security. However, these countries may be challenged by improper allocation of resources, which counteract the food security levels.

Hypothesis 6 claims that being an LMIC strongly and significantly impacts the likelihood of it being categorised as food secure. When a country is classified as LMIC, the possibility of it being categorised as highly food secure rises by 66%, while the probability of being low and

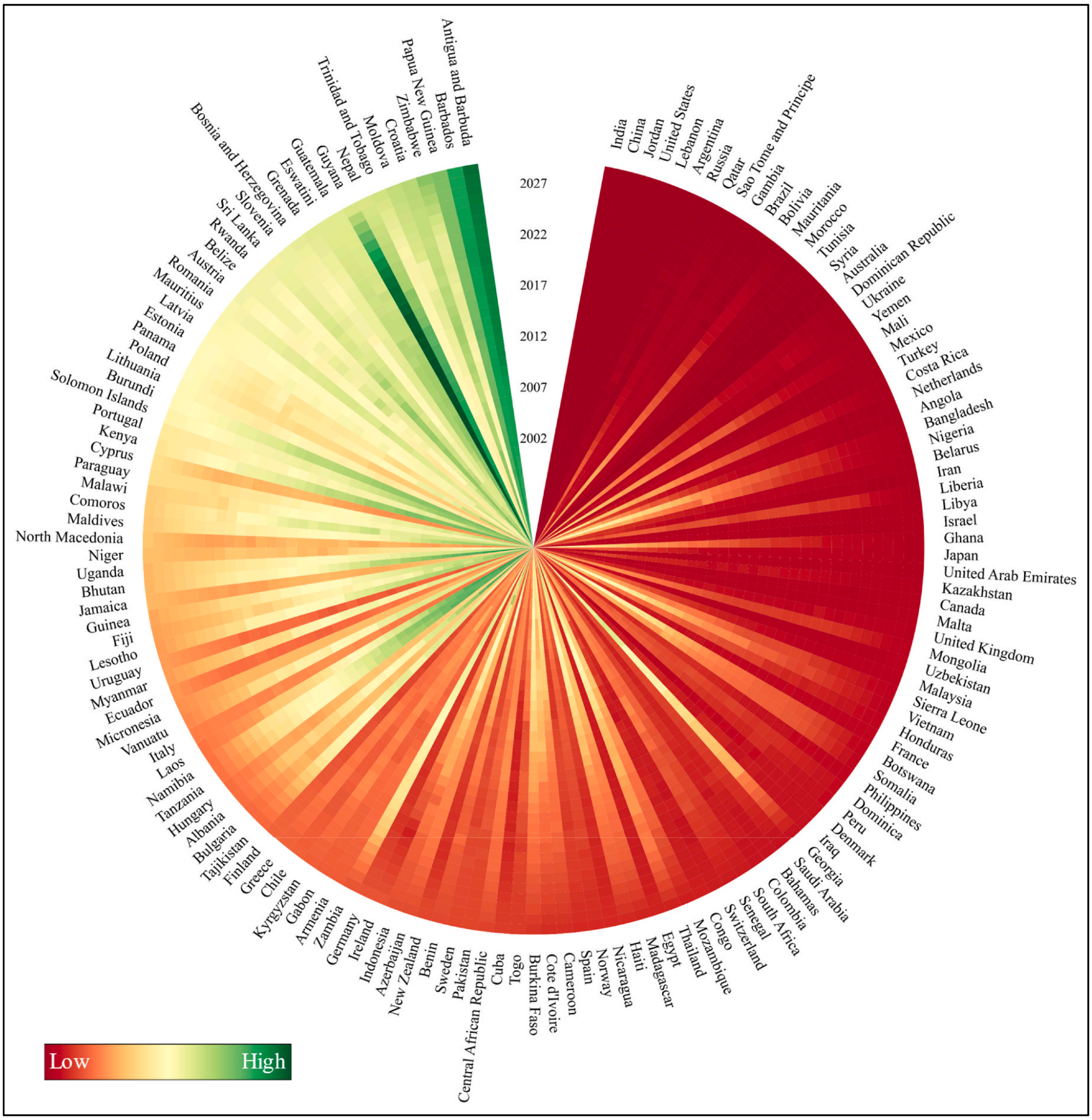

Fig. 5. Predicted probabilities of being low food secure (ordered logit model, 1992-2029).
Source: Authors' compilation using (Python and Python, 2025).

moderate food secure falls by 52% and 14%, respectively. These countries consist of faster-growing economies, leading to improved standards of living. However, they may be challenged by increasing food price inflation (The World Bank Group, 2025b), leading to hunger. However, consistent support from governments and institutions in strengthening food security has led to an increase in overall food production levels and security.

Hypothesis 7 highlights that population growth negatively but significantly impacts food security. Increasing pressure on food systems, rising pollution levels, growing households encroaching on agricultural lands, rising prices, and higher vulnerability to economic and environmental shocks may lead to a fall in food security levels. As results suggest, when population growth increases by a percentage, the likelihood of a country being categorised as low food secure increases by approximately 6%, while the possibility of being moderately food secure rises by about 2%. Complementing this, the odds of being highly food secure would fall by approximately 8%.

Hypothesis 8 indicates that UMICs have a significant impact on food security. Hence, when a country is categorised as UMIC, the probability of being highly food secure rises by 25.1%, while the probabilities of being low and moderate food secure fall by 19.6% and 5.5%, respectively. This is because these countries might experience rapid but controlled urbanisation, improved food systems and policies, quicker adaptations to new Agri-technologies, and optimised government spending, thus complementing food security levels.

Hypothesis 9 elaborates on the significance of GDP, highlighting its impact on food security at a 10% significance level. Thus, as the probability of a country being categorised as highly food secure rises by 3% the likelihood of being classified as low food secure would fall by the same percentage. Rising GDP signals, higher purchasing power, better economic conditions, improved infrastructure, greater agricultural investments and research (Rabbi et al., 2025) would boost food security levels.

3.3. Future projections of global food production security

The predicted probabilities from 1992 to 2029 across both models are visualised below for further comparison. Green indicates a higher

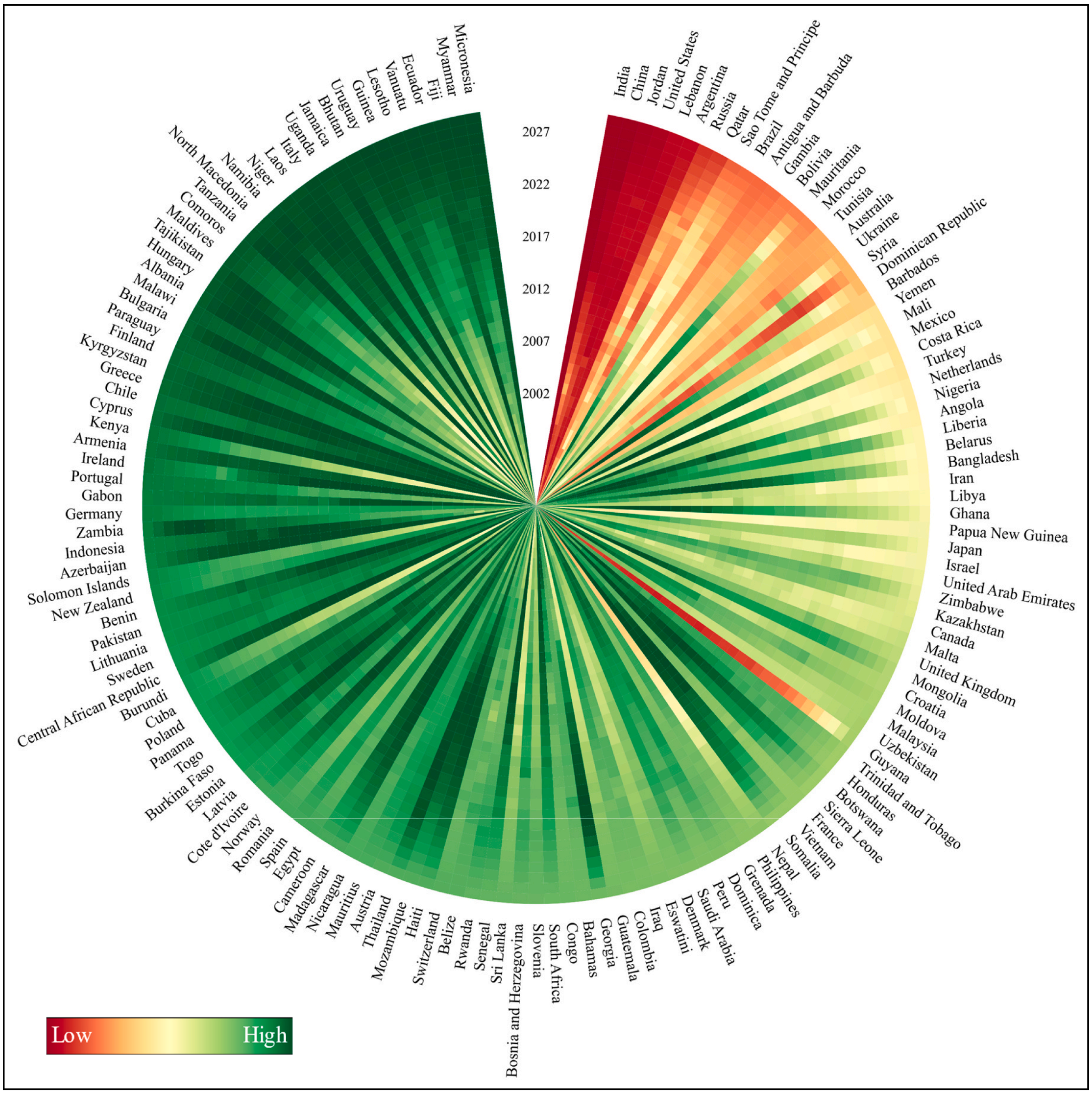

Fig. 6. Predicted probabilities of being moderate food secure (ordered probit model, 1992-2029).
Source: Authors' compilation using (Python and Python, 2025).

likelihood, while red indicates lower odds, with detailed statistics provided in Appendix 6. Figs. 4 and 5 present the odds of being low food secure, generated for all 146 countries through the ordered probit model and ordered logit model, respectively.

The country rankings remain mostly consistent across the two models. Countries such as Antigua and Barbuda, Barbados, Papua New Guinea, Zimbabwe, Croatia and Moldova rank the highest in both models. However, minor shifts occur among the remaining countries; for instance, Guyana drops from 7th to 9th place, and Grenada falls from 10th to 12th place, as they move from the panel ordered probit model to the panel ordered logit model.

Figs. 6 and 7 display that the majority of the countries fall into the moderate food secure category. In 2029, Micronesia indicates the highest likelihood of being categorised as moderately food secure under both the panel ordered probit model and the panel ordered logit model, while Myanmar shows the highest likelihood under the panel ordered logit model. Micronesia, when presented at the panel, instructed the logit model to drop to 6th in the rankings.

When considering the odds of belonging to the highly food secure category, India, China, and Jordan rank at the top, amongst both models. This is elaborately depicted through Figs. 8 and 9.

The Spearman's rank correlation run on the predicted probabilities for further validation indicated a 99.9% powerful monotonic relationship, reasoning the small to no variations in the country rankings and further validating that country-specific heterogeneity has no profound impact on the model variation. In addition, Table 4 depicts the predictive accuracy under the panel ordered probit model, where the in-sample indicates an RPS score of 2.78 and out-of-sample RPS score of 2.48. The in-sample scores were predicted by fitting years, 1992 to 2019, while predictions were made for the next five years ending 2024. The slightly improved out-of-sample performance indicates stable predictive ability and limited overfitting. The difference is consistent with heterogeneity across panels and with the utilisation of population-mean predictive probabilities obtained by integrating over the random effects distribution. Despite RPS indicating a strong predictive performance, it is important to understand that long term projections carry major uncertainties mainly driven by unforeseen external shocks, structural and technological shifts and policy changes.

Further analysing into the geographic maps presented through Appendix 7, it could be identified that the likelihoods of being categorised

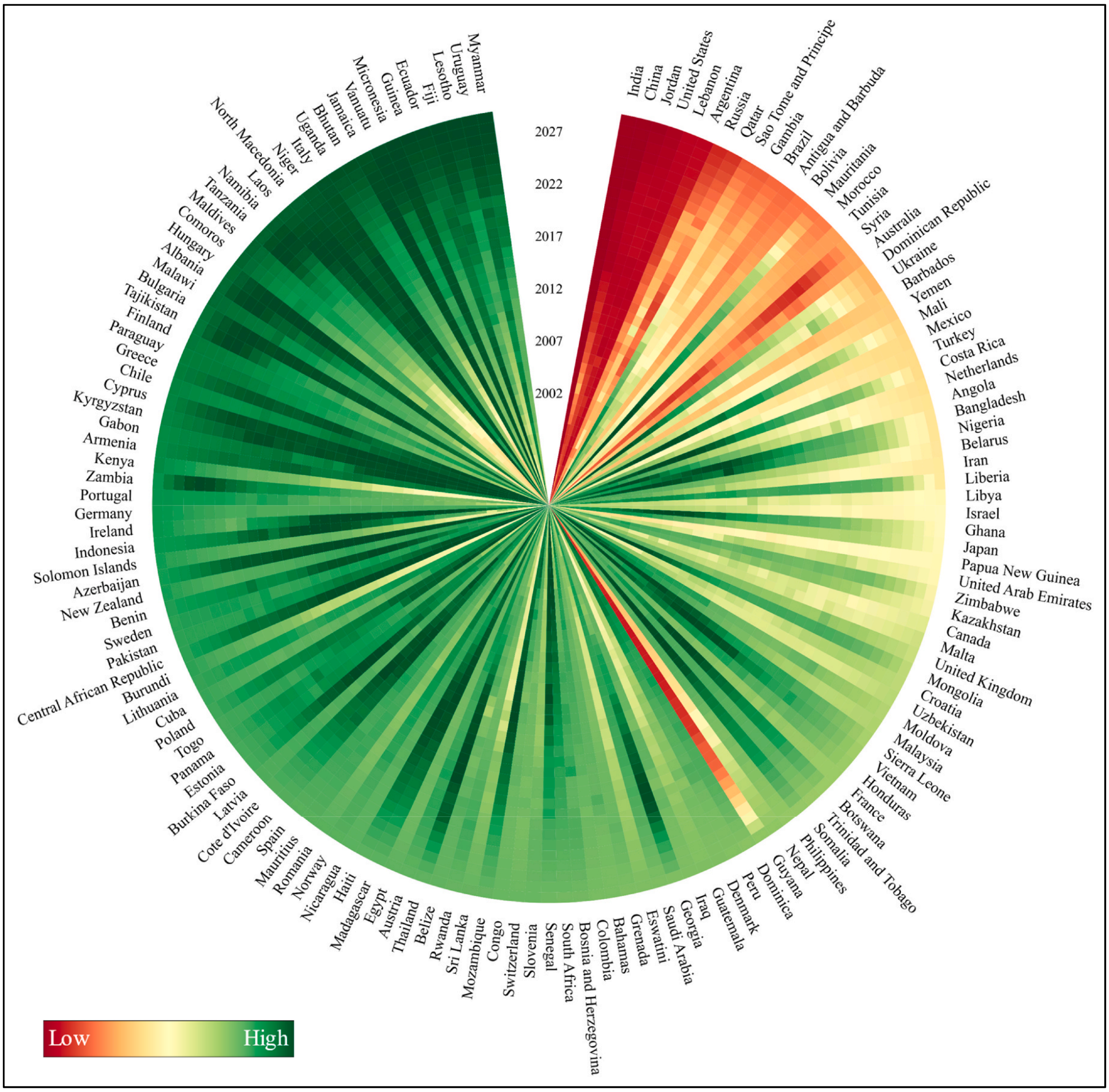

Fig. 7. Predicted probabilities of being moderate food secure (ordered logit model, 1992-2029).
Source: Authors' compilation using (Python and Python, 2025).

as low food secure has reduced slightly over the years. This could be as a response to the initiatives taken by governments and institutions to reduce it. However, it can be significantly noticed that many countries in the Sub-Saharan Africa and Southeast Aisa, indicates higher likelihood of being low food secure throughout the years, thus hinting the concerned parties to take actions in avoiding hunger.

4. Discussion

4.1. Cross country comparison

The cross-country comparison reveals that food self-reliance varies from country to country, regardless of the income group. However, the results indicate that LICs and LMICs are the most vulnerable due to economic and social instability, driven by weaker and outdated policies.

Antigua and Barbuda, Barbados, and Croatia, despite being HICs, indicate a higher likelihood of hunger. This is primarily due to over-reliance on imports, declining urbanisation rates, shifting economic focuses, fragmented arable land, and increased climate vulnerability, all of which put overall negative pressure on food production. Papua New Guinea and Zimbabwe face fewer urban developments and investments, followed by weakening agricultural modernisation. Hence, the policymakers in these countries must delve deeper into their self-reliance on food, ensuring that the policies set are aligned with long-term food availability. On the contrary, HICs' and UMICs' such as China and United States, driven by appropriate investments in technology and agricultural mechanisms, backed by larger and diverse land resources and continuous research has assisted them in maintaining their food productivity in the long run. Policymakers in countries such as Antigua and Barbuda, Barbados and Croatia could adapt from the contexts of China and United States to develop their long run agricultural productivity and maintain their food self-reliance and food availability.

Micronesia and Myanmar are countries with small land areas; agriculture is a key part of their economy. For context, Micronesia mainly produces breadfruit, bananas, taro, and yams (The Borgen Project and Farmer training promoting sustainable agriculture in Micronesia, 2025), while relying on rice in the long run (Sandeep and Emihner, 2025). Myanmar mainly depends on rice (FAO, 2025), while pulses, beans, and groundnuts also play a role. However, both these countries face challenges from unprecedented climatic shocks, social factors like income

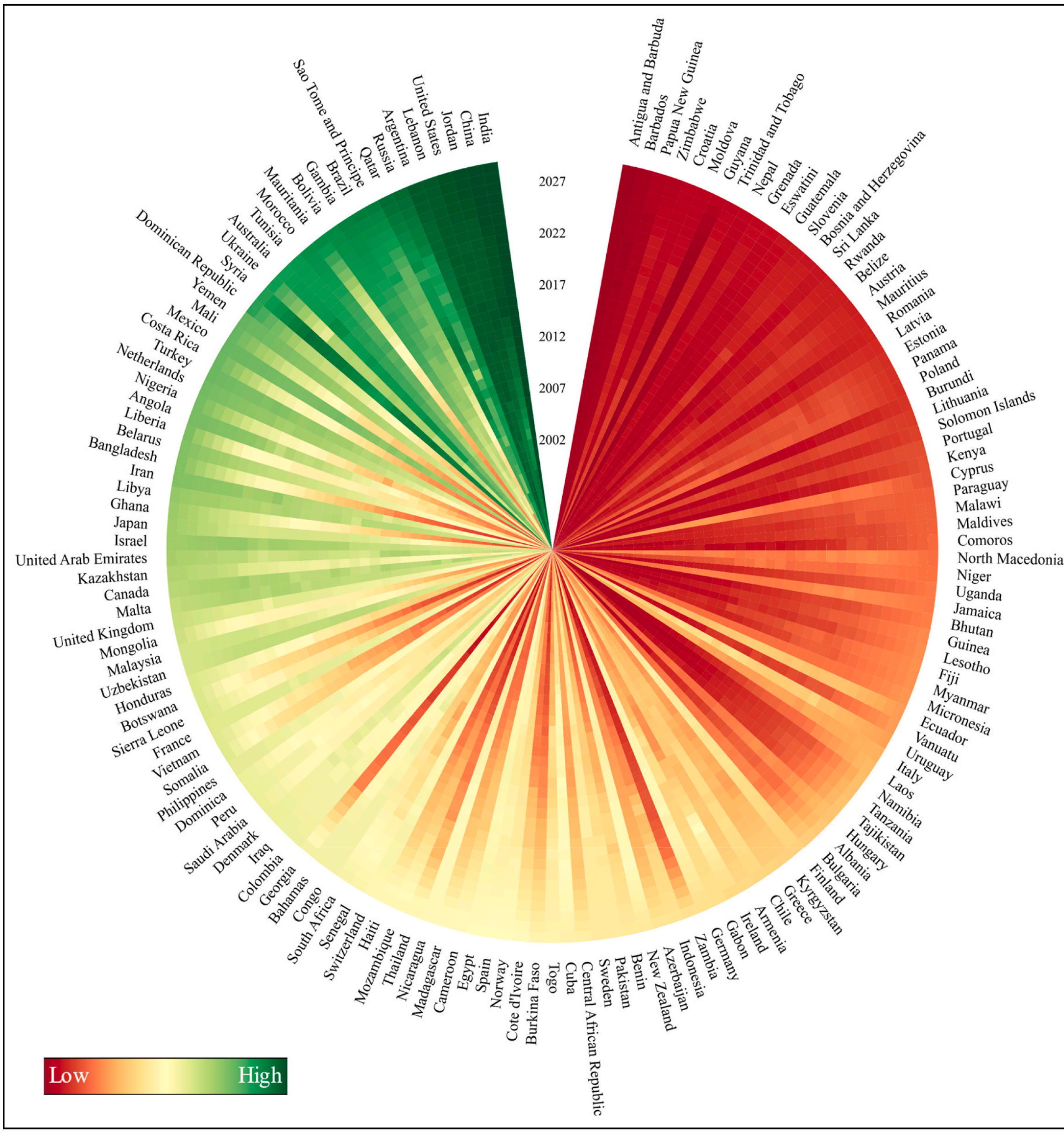

Fig. 8. Predicted probabilities of being high food secure (ordered probit model, 1992-2029).
Source: Authors' compilation using (Python and Python, 2025).

and gender inequality, and political instability, all of which undermine their food productivity. Conversely, India's reduced dependency on imports and standardised food distribution systems, along with China's grain reserves and technological investments, further supported by international aid in the context of Jordan, rank them at the top. While policy makers in LICs' and LMICs' would be constrained in following the current strategies devised by these top-ranking countries, due to lack of resources to invest, they indefinitely can strategize their long-term food availability by referring to the past of top-ranking countries and making sure the use of existing resources such as land and labour are optimised.

4.2. Policy implications

Globally, addressing food availability requires coordinated action to bridge disparities among nations and income groups. Establishing a global food-energy-climate alliance could promote joint investments and technology transfer across borders. Moreover, expanding access to climate finance mechanisms, promoting open data sharing, and resilient trade frameworks would support global coordination and advance towards sustainable improvement in food systems.

In LICs, such as Papua New Guinea and Zimbabwe, hunger is expected to persist through 2029 due to continued dependency on rain-fed agriculture, weak infrastructure, and climatic shocks. Hence it is advisable to prioritise low-cost safety nets like food-for-work programs in the short term. Given the negative impact of GHG on FPI, it is recommended to implement donor-backed initiatives focusing on climate-smart agriculture and to invest in long-term small-scale irrigation, as demonstrated in Ethiopia and Myanmar. Such measures directly advance SDG 2 by enhancing food access, SDG 6 by increasing water supply, and SDG 13 via climate-adaptive agricultural practices. When it comes to LMICs, Nepal and Sri Lanka are seen as highly exposed, with their vulnerability worsened by their reliance on imports, inadequate storage capacities, and fragile rural economies. Short term actions such as seed and fertiliser access programmes backed by microfinance, and investments in affordable solar-powered cold storages ensuring land efficiency and food sensitivity, are recommended in the long run

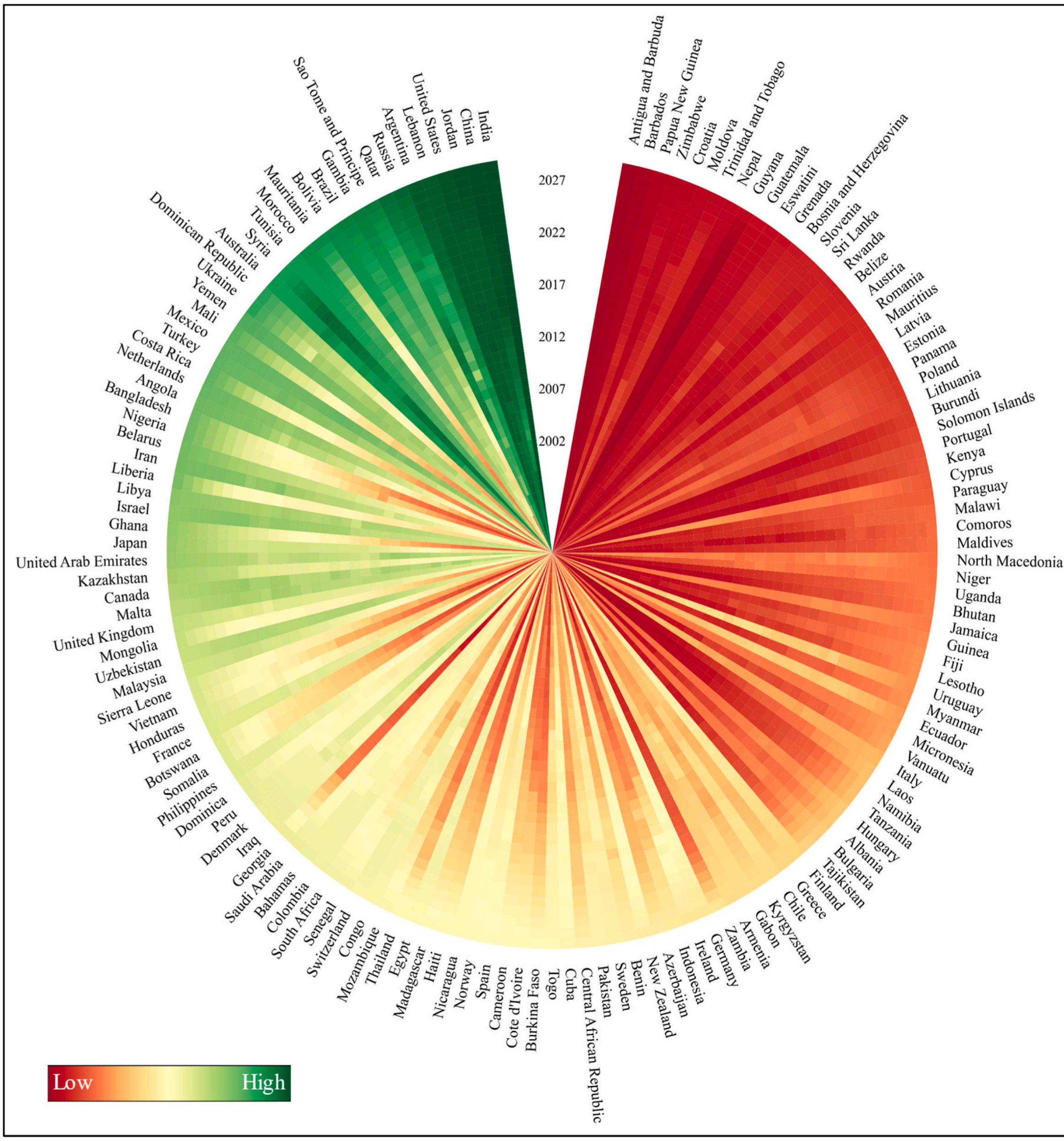

Fig. 9. Predicted probabilities of being high food secure (ordered logit model, 1992-2029).
Source: Authors' compilation using (Python and Python, 2025).

Table 4
Model predictive accuracy.

RPS	Obs.	Mean	SD.	Min.	Max.
Out-of-sample	5548	2.480	1.279	0	4.905
In-sample	4818	2.781	1.167	0.004	4.835

Note: Obs. Represents number of observations, SD. Represents standard deviation, Min represents minimum value, while Max. represents maximum value.

adapting from the best practices from Senegal, Kenya and Benin. These actions align with SDG 1 by improving livelihoods, SDG 7 through renewable-powered storage, and SDG 12 by reducing the reliance on imports.

In the case of UMICs, Moldova and Grenada were noted to face vulnerabilities due to smallholder-dominated agriculture, climate variability and declining rural development. In response, strengthening women-led cooperatives for rural development and given the positive association of urbanisation and FPI, expanding peri-urban farming, such as rooftop gardening, which India, Mexico, and Brazil often adopt as best practices are recommended. In the long term, they should foster regional cooperation for cross-border food supply. These strategies advance SDG 5 by empowering female workers, SDG 11 by integrating urban agriculture and SDG 17 through regional collaboration.

Shifting to HICs, Antigua and Barbuda, Barbados, and Croatia rank the highest among other food-insecure countries, due to their over-reliance on imports, declining agricultural modernisation, and sensitivity to external shocks. It is crucial that these countries diversify into niche industries like horticulture in the short term for improved domestic food production, while digitalising food supply chains to reduce vulnerability to external disruptions in the long term, as adapted in Mexico and Malaysia. These initiatives would contribute towards SDG 9 by modernising supply chains and SDG 12 by reducing reliance on imports.

4.3. Limitations and future research

The limitation of this study revolves around the variables and methodology. While FPI is used as a proxy to measure food security, it does not capture all four of its pillars, despite prior research supporting its use hence providing future researchers the possibility to construct a more complex secondary use variable. Moreover, the analysis does not explore the components of GHG emissions and renewable energy leaving potential for in-depth analysis. Computational constraints in estimating ordered probit and logit models with fixed effects limit the ability to capture country-specific effects. To cushion this drawback's impacts, income groups were introduced as dummy variables, though these may not represent all qualitative factors influencing FPI. Additionally, the study focuses only on the unidirectional impacts of explanatory variables on FPI, though previous literature had identified possible bidirectional relationships.

5. Conclusion

This study employed a panel ordered probit model to examine the determinants of food security across 146 countries from 1992 to 2029. The results reveal that urbanisation, agricultural land, and GDP have a positive and significant impact on food security, while renewable energy, GHG emissions, and population growth have an adverse effect. The panel ordered a logit model to validate the above results, which indicated the same. This research adds to the existing literature by presenting a global assessment of food security across income groups. By considering environmental, demographic and economic variables into a single empirical framework, it bridges the gap between sector-specific and macro-level analysis. Methodology-wise, this study introduces a predictive analysis for 2025 – 2029, offering a forward-looking approach for policy design.

From a policy perspective, the findings inform both policymakers and development agencies on how tailored interventions, such as renewable energy integration, land-use optimisation, and urban planning, can jointly enhance food system resilience. The results directly support progress toward multiple SDGs.

CRediT authorship contribution statement

Nirmani Pulle: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Prasad Sampath:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation. **Dinuli Wijayaweera:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation. **Sarah Perera:** Writing – review & editing, Writing – original draft, Visualization, Software, Data curation. **Ruwan Jayathilaka:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Consent to participate

Not Applicable.

Statements and declarations

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Clinical trial number

Not applicable.

Ethical approval

Not applicable. This study used publicly available secondary data, and no direct involvement of human participants, human tissue, or identifiable personal data was required.

Consent for publication

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.indic.2026.101216.

Data availability

All data generated or analysed during this study are included in this published article and its supplementary information files.

References

Abdi, A.H., Mohamed, A.A., Mohamed, F.H., 2024. Enhancing food security in Sub-Saharan Africa: investigating the role of environmental degradation, food prices, and institutional quality. J. Agric. Food Res. 17, e101241. https://doi.org/10.1016/j.jafr.2024.101241.

Abebe, M.G., 2024. Impacts of urbanization on food security in Ethiopia. A review with empirical evidence. J. Agric. Food Res. 15, e100997. https://doi.org/10.1016/j.jafr.2024.100997.

Agro Momentum, 2025. Cultivating prosperity: sustainable returns for a greener future. Agro Momentum. https://agromomentum.lk/. (Accessed 7 September 2025).

Alene, F.D., Aga, M.A., 2025. The roles of urban agriculture to household food security: a case study in Kirkos sub-city, Addis Ababa city, Ethiopia. Front. Sustain. Food Syst. 9, e1444320. https://doi.org/10.3389/fsufs.2025.1444320.

Applanaidu, S.D., Bakar, N.A.A., Baharudin, A.H., 2014. An econometric analysis of food security and related macroeconomic variables in Malaysia: a vector autoregressive approach (var). UMK Procedia 1, 93–102. https://doi.org/10.1016/j.umkpro.2014.07.012.

Arumugam, R., 2025. Assessing the impact of agricultural land reduction on future global food security: challenges and sustainable solutions. Indian J. Nat. Sci. 15, 89066–89083. https://www.researchgate.net/publication/389502541_Assessing_the_Impact_of_Agricultural_Land_Reduction_on_Future_Global_Food_Security_Challenges_and_Sustainable_Solutions.

Asamoah, E., 2020. Food security and renewable energy : insights. Int. J. Sci. Res. Sci. Eng. Technol. 7, 18–23. https://doi.org/10.32628/IJSRSET207625.

Atlas, 2023. How renewable energy sources can contribute to the food industries sustainability journey Atlas. https://www.atlasrenewableenergy.com/how-renewable-energy-sources-can-contribute-to-the-food-industrys-sustainability-journey. (Accessed 4 September 2025).

Ayanwale, A., Kehinde, A.D., 2025. Determinants of use of digital innovation and its impact on land acquisition and food security among farming households in Nigeria. World Dev. Perspect. 39, e100702. https://doi.org/10.1016/j.wdp.2025.100702.

Bank of Ceylon, 2025. New Comprehensive Rural Credit Scheme (NCRCS), Bank of Ceylon. https://www.boc.lk/business-banking/development-banking/agriculture/ncrcs. (Accessed 7 September 2025).

Batool, Z., Ain, Q.u., Rehman, A., 2024. Exploring the effects of farm mechanization, financial development, and renewable energy on China's food production. Environ. Dev. Sustain. 26, 18883–18902. https://doi.org/10.1007/s10668-023-03419-2.

Bibi, F., Rahman, A., 2023. An overview of climate change impacts on agriculture and their mitigation strategies. Agric. For. 13, e1508. https://doi.org/10.3390/agriculture13081508.

Bodirsky, B.L., Dietrich, J.P., Martinelli, E., Stenstad, A., Pradhan, P., Gabrysch, S., Mishra, A., Weindl, I., Le Mouël, C., Rolinski, S., Baumstark, L., Wang, X., Waid, J.L., Lotze-Campen, H., Popp, A., 2020. The ongoing nutrition transition thwarts long-term targets for food security, public health and environmental protection. Sci. Rep. 10, e19778. https://doi.org/10.1038/s41598-020-75213-3.

Bonventure, O.M., Wacker, E., Shauri, H., de Vries, W.T., 2025. Impact of agricultural land use changes on food access in Mwatate Sub-county, Taita Taveta County, Kenya. Front. Sustain. Food Syst. 9, e1546943. https://doi.org/10.3389/fsufs.2025.1546943.

Ceesay, E.K., Ben Omar Ndiaye, M., 2022. Climate change, food security and economic growth nexus in the Gambia: evidence from an econometrics analysis. Res. Glob 5, e100089. https://doi.org/10.1016/j.resglo.2022.100089.

Chen, W., Wang, J., Ai, W., 2024. Do urbanization, environmental regulation and GDP affect agricultural land use efficiency? Implications for just transition. Environ. Impact Assess. Rev. 105, e107421. https://doi.org/10.1016/j.eiar.2024.107421.

Cockx, L., Boti, B.B.D., 2025. Urbanization shapes West African diets throughout the rural-urban continuum. Global Food Secur. 45, e100858. https://doi.org/10.1016/j.gfs.2025.100858.

Connection, Population, 2025. Ten ways population growth impacts the environment. Population Connection. https://populationconnection.org/blog/world-environment-day-2025/. (Accessed 4 September 2025).

Conrad, H., 2022. Global Population Projected to Exceed 8 Billion in 2022; Half Live in Just Seven Countries. Pew Research Center. https://www.pewresearch.org/short-reads/2022/07/21/global-population-projected-to-exceed-8-billion-in-2022-half-live-in-just-seven-countries/. (Accessed 4 September 2025).

Crispian, B., 2024. Drive to End Global Hunger has Stalled. United Nations warns, Reuters. https://www.reuters.com/world/drive-end-global-hunger-has-stalled-united-nations-warns-2024-07-24/. (Accessed 4 September 2025).

Cui, S., Zhang, Y., 2025. A comparison between thomas malthus's and amartya sen's views on famine: natural constraints or political pathologies?, J. US-Chin. Public Adm. 22, 37–43. https://doi.org/10.17265/1548-6591/2025.01.003.

Damodar, G., 2015. Econometrics by Example. Bloomsbury Publishing Plc.

Daniil, F., 2025. The Impact of Population Growth on Sustainable Development. DevelopmentAid. https://www.developmentaid.org/news-stream/post/163665/population-growth-and-sustainable-development. (Accessed 4 September 2025).

de Bruin, S., Dengerink, J., van Vliet, J., 2021. Urbanisation as driver of food system transformation and opportunities for rural livelihoods. Food Secur. 13, 781–798. https://doi.org/10.1007/s12571-021-01182-8.

Devesh, S., Abdullah, M.A.A., 2020. Affendi, the linkage between population growth, gdp and food security in Oman: vector error correction model analysis. Int. J. Sci. Technol. Res. 9, 5345–5351. https://www.researchgate.net/publication/340515804_The_Linkage_Between_Population_Growth_Gdp_And_Food_Security_In_Oman_Vector_Error_Correction_Model_Analysis.

Directory, Sustainability, 2025. What are the long-term impacts of renewable energy on food security? Sustainability Directory. https://sustainability-directory.com/question/what-are-the-long-term-impacts-of-renewable-energy-on-food-security/. (Accessed 4 September 2025).

Economynext, 2025. Sri Lanka to offer concessional loans to draw youth to agriculture, industry. Economy. https://economynext.com/sri-lanka-to-offer-concessional-loans-to-draw-youth-to-agriculture-industry-237304/. (Accessed 4 September 2025).

Edeme, R.K., Nkalu, N.C., Idenyi, J.C., Arazu, W.O., 2020. Infrastructural development, sustainable agricultural output and employment in ecowas countries. Sustain. Futures 2, e100010. https://doi.org/10.1016/j.sftr.2020.100010.

Egerson, D., Kpegba-Fiaboe, E.E., Christian, A.K., 2025. Understanding food (In) security through land and livelihoods: evidence from longitudinal household data. J. Rural Stud. 119, e103750. https://doi.org/10.1016/j.jrurstud.2025.103750.

Environmental Protection Agency, 2025. Climate Change Impacts on Agriculture and Food Supply. Environmental Protection Agency. https://www.epa.gov/climateimpacts/climate-change-impacts-sector. (Accessed 21 April 2025).

FAO, 2050, 2009. A third more mouths to feed. Food Agricultural Organization. https://www.fao.org/newsroom/detail/2050-A-third-more-mouths-to-feed/it. (Accessed 4 September 2025).

FAO, 2003. Chapter 2. Food security: concepts and measurement. In: Trade Reforms and Food Security. Food and Agriculture Organization, pp. 25–34.

FAO, 2011. Major Challenges to Food Security in the 21st Century. Food and Agriculture Organization.

FAO, 2015. Climate Change and Food Security: Risks and Responses. Food And Agriculture Organization.

FAO, 2021. Three sustainable energy solutions for food production and places where they are used. Food and Agricultural Organization. https://www.fao.org/newsroom/story/Three-sustainable-energy-solutions-for-food-production-and-places-where-they-are-used/en. (Accessed 4 September 2025).

FAO, 2023. Chapter 3: urbanization is transforming agrifood systems and affecting access to affordable healthy diets across the rural–urban continuum. In: The State of Food Security and Nutrition in the World 2023, Food and Agricultural Organization, pp. 24–38.

FAO, 2025. Global information and early warning system - myanmar. Food and Agricultural Organization. https://www.fao.org/giews/countrybrief/country.jsp?code=MMR. (Accessed 30 September 2025).

FAO, Greenhouse gas emissions from agrifood systems. Global, regional and country trends, 2000. https://www.fao.org/statistics/highlights-archive/highlights-detail/greenhouse-gas-emissions-from-agrifood-systems.-global–regional-and-country-trends–2000-2022/en. (Accessed 18 August 2025), 2024.

FAO, IFAD, UNICEF, WFP, WHO, 2025. The State of Food Security and Nutrition in the World 2025. UNICEF. https://data.unicef.org/resources/sofi-2025/. (Accessed 4 September 2025).

Farooq, U., Chandio, A.A., Guan, Z., 2024. Can board funds, bank credit, and economic development improve food production? Evidence from South Asia, Agricult. Financ. Rev. 84, 143–164. https://doi.org/10.1108/AFR-10-2023-0131.

Fernandes, M., Samputra, P.L., 2022. Exploring linkages between food security and economic growth: a systematic mapping literature review, Potravinarstvo Slovak. J. Food Sci. 16, 206–218. https://doi.org/10.5219/1734.

Food Security Information Network, 2025. Global report on food crises. https://www.fsinplatform.org/report/global-report-food-crises-2025/. (Accessed 4 September 2025), 2025.

Gao, Y., Han, Z., Li, Z., Deng, X., 2026. Global grain crops non-CO2 greenhouse gas emissions and mitigation potential integrating food security and climate change scenarios. Resour. Conserv. Recycl. 224, e108543. https://doi.org/10.1016/j.resconrec.2025.108543.

Geeks for Geeks, 2025. Spearman's Rank Correlation, Geeks for Geeks. https://www.geeksforgeeks.org/data-science/spearmans-rank-correlation/. (Accessed 11 October 2025).

Giyarsih, S.R., Armansyah, Zaelany, A.A., Latifa, A., Setiawan, B., Saputra, D., Haqi, M., Fathurohman, A., 2024. Lamijo, the contribution of urban farming to urban food security: the case of "Buruan SAE". Int. J. Urban Sustain. Dev. 16, 262–281. https://doi.org/10.1080/19463138.2024.2384876.

Gnedeka, K.T., Wonyra, K.O., 2023. New evidence in the relationship between trade openness and food security in Sub-Saharan Africa. Agric. Food Secur. 12, e31. https://doi.org/10.1186/s40066-023-00439-z.

Gobezie, Y. Mebrie, Boka, J. Bane, 2023. The nexus between greenhouse gas emissions and food security in Sub-Saharan Africa: a system GMM analysis. Cogent Econ. Finance 11, e2273590. https://doi.org/10.1080/23322039.2023.2273590.

Gu, Z., Jin, X., Liang, X., Liu, J., Han, B., Zhou, Y., 2024. Diversification of food production in rapidly urbanizing areas of China, evidence from southern Jiangsu. Sustain. Cities Soc. 101, e105121. https://doi.org/10.1016/j.scs.2023.105121.

Gunapala, R., Gangahagedara, R., Wanasinghe, W.C.S., Samaraweera, A.U., Gamage, A., Rathnayaka, C., Hameed, Z., Baki, Z.A., Madhujith, T., Merah, O., 2025. Urban Agriculture: a Strategic Pathway to Building Resilience and Ensuring Sustainable Food Security in Cities, Farm. Syst., e100150 https://doi.org/10.1016/j.farsys.2025.100150

Gyimah, J., Saalidong, B.M., Nibonmua, L.K.M., 2023. The battle to achieve sustainable development goal two: the role of environmental sustainability and government institutions. PLoS One 18, e0291310. https://doi.org/10.1371/journal.pone.0291310.

Hall, C., Dawson, T.P., Macdiarmid, J.I., Matthews, R.B., Smith, P., 2017. The impact of population growth and climate change on food security in Africa: looking ahead to 2050. Int. J. Agric. Sustain. 15, 124–135. https://doi.org/10.1080/14735903.2017.1293929.

Hasan, S.S., Li, Z., Zhang, F., 2025. Exploring regional variations in agricultural greenhouse gas emissions: insights from Bangladesh's districts. Geogr. Sustain. 6, e100298. https://doi.org/10.1016/j.geosus.2025.100298.

He, J., Osabohien, R., Yin, W., Adeleke, O., Uduma, K., Agene, D., Su, F., 2024. Green economic growth, renewable energy and food security in Sub-Saharan Africa. Energy Strategy Rev. 55, e101503. https://doi.org/10.1016/j.esr.2024.101503.

Hettiarachchi, S., Kasthuriarachchi, U., Kokilakumar, S., Himaanthri, S., Jayathilaka, R., Peiris, S., 2025. Determinants of firm value in frontier markets: evidence from a panel oprobit analysis in Sri Lanka. Asia Pac. Financ. Mark. 32. https://doi.org/10.1007/s10690-025-09568-w e09568-w.

Hochman, G., Kaplan, S., Rajagopal, D., Zilberman, D., 2012. Biofuel and food-commodity prices. Agriculture 2, 272–281. https://doi.org/10.3390/agriculture2030272.

Hong, C., Zhong, R., Xu, M., He, P., Mo, H., Qin, Y., Shi, D., Chen, X., He, K., Zhang, Q., 2025. Interactions among food systems, climate change, and air pollution: a review. Eng. 44, 215–233. https://doi.org/10.1016/j.eng.2024.12.021.

Ikudayisi, A.A., 2024. Urban food security and socioeconomic sustainability: a multidimensional perspective. Green Technol. Sustain 2, e100080. https://doi.org/10.1016/j.grets.2024.100080.

Intergovernmental Panel Climate Change, 2025. Special report on climate change and land. Intergovernmental Panel Climate Change. https://www.ipcc.ch/srccl/chapter/chapter-5/. (Accessed 4 September 2025).

Irfeey, A.M.M., Musthafa, M.M., Najim, M.M.M., Baig, M.B., 2024. Contribution of renewable energy resources for food production and food security. In: Climate-Smart and Resilient Food Systems and Security. Springer Nature Switzerland, pp. 491–522.

Islam, S., Roshid, M.M., Chandra Bhowmik, R., Dhar, B.K., Raihan, A., Karim, R., 2025a. Policy pathways for renewable energy, health, and sustainability in Sub-Saharan Africa: an empirical assessment of energy access and life expectancy. Energy Policy 206, e114801. https://doi.org/10.1016/j.enpol.2025.114801.

Islam, S., Yousuf, M., Dhar, B.K., Bhowmik, R.C., Roshid, M.M., Sumon, S.A., 2025b. Environmental sustainability and CO2 emissions in Mexico: unveiling the roles of fiscal policy, digital innovation, and renewable energy transitions. Sustain. Dev. 33, 1310–1327. https://doi.org/10.1002/sd.70049.

IWMI, 2025. Smart Farming Transforms Agriculture in Sri Lanka. International Water Management Institute. https://www.iwmi.org/blogs/smart-farming-transforms-agriculture-in-sri-lanka/. (Accessed 7 September 2025).

Jain, N., Kourampi, I., Umar, T.P., Almansoor, Z.R., Anand, A., Ur Rehman, M.E., Jain, S., Reinis, A., 2023. Global population surpasses eight billion: are we ready for the next billion? AIMS Public Health 10, 849–866. https://doi.org/10.3934/publichealth.2023056.

Jayathilaka, R., Keembiyahetti, N., 2009. Adverse selection effect for South Asian countries in fta formation:an empirical study on the determinants of fta among the bilateral trading partners. South Asia Econ. J. 10, 1–30. https://doi.org/10.1177/139156140901000101.
Jayathilaka, R., Udara, I., 2024. Security matters: empowering e-commerce in Sri Lanka through customer insights. Hum. Soc. Sci. Commun. 11, e1054. https://doi.org/10.1057/s41599-024-03585-2.
Kalansuriya, N., Jayathilaka, R., 2025. Comparative determinants of global competitiveness: governance, social progress, and economic trade-offs. Sustain. Dev. 33, 6659–6679. https://doi.org/10.1002/sd.3479.
Kamali, M.I., Nazari, R., Karimi, M., Nikoo, M.R., 2025. Enhancing urban food production: a framework for optimal site selection and policy development. Sustain. Cities Soc. 126, e106375. https://doi.org/10.1016/j.scs.2025.106375.
Kerrouche, N., Zehri, C., 2025. Economic growth, welfare, and sustainability outcomes of integrated water, energy, and food investments in Saudi Arabia. Sustain. Futures 10, e100932. https://doi.org/10.1016/j.sftr.2025.100932.
Kibria, M.G., Aspy, N.N., Ullah, E., Dewan, M.F., Hasan, M.A., Hossain, M.A., Haseeb, M., Hossain, M.E., 2023. Quantifying the effect of agricultural greenhouse gas emissions, food production index, and land use on cereal production in South Asia. J. Clean. Prod. 432, e139764. https://doi.org/10.1016/j.jclepro.2023.139764.
Kinawy, A.A., Ahmed, R.S., 2024. Implications of population growth on food security in Saudi Arabia. In: Food and Nutrition Security in the Kingdom of Saudi Arabia, Vol. 1: National Analysis of Agricultural and Food Security. Springer International Publishing, Cham, pp. 383–403.
Kosiński, K., Jurema, F.L.B., Byak, B., Schwerdtner, T.v., Lipatov, V., Clausen, A., Louette, I., Wybrow, M., Kitaev, N., Bruno, L., Barbry-Blot, P., Fitzsimon, A., Biro, A., Stephan, R., Brubaker, M., Montagne, V., Baxter, B., Cook, K., Remizov, A., Faubel, S., Fred, Sridharan, K., Boldewyn, Moulder, P., Grosberg, M., Verona, J., Harrington, B., Dufour, N., Beard, J., Tebby, H., Barraud, J.-F., Matiphas, Morgan, C., McDermott, P., Shivaken, Cruz, J., Sharma, A., Hughes, R., Hufthammer, K.O., Horkan, A., Hochreiner, H., Mastrukov, D.G., Ceuppens, J., Brown, C., Snan, S., Gussem, K.D., Knoth, A., ~suv, P.B.S., Hetherington, C., Leone, A., jEsuSdA, Caldwell, I., Nick, Boles, D., Wagenaar, D., Neumair, C., Schwienbacher, M., Sheridan, T., Kiirala, N., Monnier, A., Bouclet, B., Moore, D.P., Schaller, C., Flick, E., Albert, M., Smith, J., Floryan, M., Vieites, L., Oka, M., Giannini, S., Holder, T., Xg, G., Doolittle, L., Neuhauser, J., Eberl, M., Jamison, B., Mena, F., Caclin, P., Blocher, J.L., Barton, C., Bintz, J., S, A.A., Andler, J.A., Navez, V., Ingham, T., Kovar, P., Lindgren, N., Hesselle, R.d., Yacob, D., White, L.P., Siejakowski, R., Dziumanenko, M.V., Wüst, S., Sloan, M., Yip, D., Suwalski, P., Marmion, A.-A., Kao, W.-W., Jeanmougin, M., Petroff, M., Spike, A., Penner, A., Levien, R., Kowalski, M., Taraben, A., inductiveload, Valavanis, A., Derezynski, M., Storz, P., Masár, I., Scholten, M., Rodrigues, H., Mooney, T., Twupack, A., Nakai, Y., Chyla, Z., Leray, J., De-Cooman, A., Bishop, N., Urošević, A., Boczkowski, T., Heckert, Brynn, A.A., Marquardt, C., Erikson, U., Rudsatz, J., Breuer, H., Bohre, H., Mathog, D., Hurst, N., Sucha, M., Podobny, Z., Cromwell, B., Reinhard, J.-R., Felfe, F., MenTaLguY, Celorio, C., Gondouin, O., Catmur, E., Owens, M., Cenoz, J.A., Termeau, J., Janeczko, T., Prokoudine, A., Holdsworth, J., Holmstedt, C., Buculei, N., Turner, D., Borgmann, D., Marshall, C., Rodrigo, F., Broberg, G., Lavorata, B., Carmichael, G., Fowler, B., Šegan, D., Kerby, L., Stojek, D., Kilfiger, J., Sanches, F.C.d.S., Yamato, M., Boguszewski, A., Oliveira, V.d.S., Špetič, B., Lierop, D. v., Dwyer, T., Müller, J., Greef, T.d., Gemy, C., Irisson, J.-O., Taxel, P., Phillips, J., Hirth, J., Engelen, J., Dilly, B., Marc, P.-A., Rueda, X.C., Cliff, J., Meeks, M., Falzon, N., Erdelyi, M., Harvey, D., Nilsson, A., Díaz, D., Rodríguez, J.F.A., Kaplinski, L., Kivlighn, J., Gould, T., Bah, T., Böck, H., 2025. Inkscape v1.4.3. Inkscape Developers [software]. https://inkscape.org/.
Lee, C.-C., Zeng, M., Luo, K., 2024. The impact of urbanization on food security in China. Int. Rev. Econ. Finance 93, 1159–1175. https://doi.org/10.1016/j.iref.2024.05.037.
Li, N., Agene, D., Gu, L., Osabohien, R., Jaaffar, A.H., 2024. Promoting clean energy adoption for enhanced food security in Africa. Front. Sustain. Food Syst. 8, e1269160. https://doi.org/10.3389/fsufs.2024.1269160.
Liu, W., Zhang, G., Zheng, X., 2025. Future foodscape: impact of population decline and aging on China's dietary carbon footprint and food security. Global Food Secur. 46, e100875. https://doi.org/10.1016/j.gfs.2025.100875.
Live to Plant, 2025. Essential infrastructure for agricultural development, live to plant. https://livetoplant.com/essential-infrastructure-for-agricultural-development/#article. (Accessed 7 September 2025).
Macalou, M., Keita, S.I., Coulibaly, A.B., Diamoutene, A.K., 2023. Urbanization and food security: evidence from Mali. Front. Sustain. Food Syst. 7, e1168181. https://doi.org/10.3389/fsufs.2023.1168181.
Matooane, L.S., Matamanda, A., Bhanye, J., Nel, V., 2025. The role of urban planning in strengthening urban food security in Africa: insights from Lesotho, Zimbabwe and South Africa. Urban Forum 36, 209–237. https://doi.org/10.1007/s12132-024-09530-5.
Meinhold, R., Wagner, C., Dhar, B.K., 2025. Digital sustainability and eco-environmental sustainability: a review of emerging technologies, resource challenges, and policy implications. Sustain. Dev. 33, 2323–2338. https://doi.org/10.1002/sd.3240.
Miladinov, G., 2023. Impacts of population growth and economic development on food security in low-income and middle-income countries. Front. Hum. Dyn. 5, 1–17. https://doi.org/10.3389/fhumd.2023.1121662.
Mirzabaev, A., Bezner Kerr, R., Hasegawa, T., Pradhan, P., Wreford, A., Cristina Tirado von der Pahlen, M., Gurney-Smith, H., 2023. Severe climate change risks to food security and nutrition. Clim. Risk Manag. 39, e100473. https://doi.org/10.1016/j.crm.2022.100473.
Molotoks, A., Smith, P., Dawson, T.P., 2021. Impacts of land use, population, and climate change on global food security. Food Energy Secur. 10, e261. https://doi.org/10.1002/fes3.261.
Mumah, E., Hong, Y., Chen, Y., 2025. Exploring the reality of global food insecurity and policy gaps. Hum. Soc. Sci. Commun. 12, e1241. https://doi.org/10.1057/s41599-025-05315-8.
Natalia, K., 2023. How does overpopulation affect sustainability? Challenges and solutions. Earth org. https://earth.org/overpopulation-sustainability/. (Accessed 4 September 2025).
Obekpa, H.O., Alola, A.A., Adejo, A.M., Echebiri, C., 2025. Examining the drivers of ecological footprint components: is pursuing food security environmentally costly for Nigeria? Ecol. Indic. 170, e113009. https://doi.org/10.1016/j.ecolind.2024.113009.
Onwe, J.C., Ojide, M.G., Subhan, M., Forgenie, D., 2024. Food security in Nigeria amidst globalization, economic expansion, and population growth: a wavelet coherence and QARDL analysis. J. Agric. Food Res. 18, e101413. https://doi.org/10.1016/j.jafr.2024.101413.
Opoku, A., Duff, A., Yahia, M.W., Ekung, S., 2024. Utilisation of green urban space for food sufficiency and the realisation of the sustainable development goals – UK stakeholders perspective. Geogr. Sustain. 5, 13–18. https://doi.org/10.1016/j.geosus.2023.10.001.
Opportunity International, 2025. Agriculture Finance, Opportunity International. https://opportunity.org/what-we-do/agriculture-finance. (Accessed 7 September 2025).
OriginLab Corporation, OriginPro [software], 2024. Originlab. Northampton, MA, USA. https://www.originlab.com/.
Orou, S.R., Guenther, E., 2025. Exploring the resource nexus between forest-based land restoration and food security: the case of the African great green wall initiative countries. Land Use Policy 151, e107499. https://doi.org/10.1016/j.landusepol.2025.107499.
Our World in Data, 2024a. Share of the population living in urban areas. Our World in Data [data set]. https://ourworldindata.org/grapher/share-of-population-urban.
Our world in data, annual greenhouse gas emissions including land use. Our World in Data, 2024 [data set]. https://ourworldindata.org/grapher/total-ghg-emissions?tab=chart&country=~OWID_WRL.
Our world in data, research and data to make progress against the world's largest problems, our world in data. http://ourworldindata.org/, 2025–. (Accessed 10 June 2025).
Pandey, B., Reba, M., Joshi, P.K., Seto, K.C., 2020. Urbanization and food consumption in India. Sci. Rep. 10, e17241. https://doi.org/10.1038/s41598-020-73313-8.
Pawlak, K., Kołodziejczak, M., 2020. The role of agriculture in ensuring food security in developing countries: considerations in the context of the problem of sustainable food production. Sustainability 12, e5488. https://doi.org/10.3390/su12135488.
Pereira, H.C., 1993. Food production and population growth. Land Use Policy 10, 187–190. https://doi.org/10.1016/0264-8377(93)90013-Z.
Pulle, N., Sampath, P., Perera, S., Wijayaweera, D., Jayathilaka, R., 2026. Achieving zero hunger: a global policy lens on food security drivers and income group disparities. Environ. Chall. 22, e101409. https://doi.org/10.1016/j.envc.2026.101409.
Putra, A.S., Tong, G., Pribadi, D.O., 2020. Food security challenges in rapidly urbanizing developing countries: insight from Indonesia. Sustain. Times 12, e9550. https://doi.org/10.3390/su12229550.
Python, Python, 2025. Python software foundation. https://www.python.org/about/. (Accessed 30 September 2025).
Rabbi, M.F., Kovács, S., Popp, J., Fenyves, V., 2025. Assessing positive and negative factors as catalysts for enhancing European food security amidst threats to SDG 2, sustain. Futures 10, e101000. https://doi.org/10.1016/j.sftr.2025.101000.
Rahman, T.U., Shah, S., Hassan, S., Fahad, S., 2025. Food Security Challenges and Adaptation Strategies in China Amidst Global Climate Change. J. Umm Al-Qura Univ. Appl. Sci., pp. 1–14. https://doi.org/10.1007/s43994-025-00226-5
Raji, E., Ijomah, T., Eyieyien, O., 2024. Improving agricultural practices and productivity through extension services and innovative training programs. Int. J. Appl. Res. Soc. Sci. 6, 1297–1309. https://doi.org/10.51594/ijarss.v6i7.1267.
Ramdé, S.J.C., Ganamé, M., Bayen, P., Lykke, A.M., Thiombiano, A., 2025. Impact of urbanization on uses and conservation of Indigenous leafy vegetable species in Burkina Faso, West Africa. J. Agric. Food Res. 23, e102246. https://doi.org/10.1016/j.jafr.2025.102246.
Rehman, A., Batool, Z., Ma, H., Alvarado, R., Oláh, J., 2024. Climate change and food security in South Asia: the importance of renewable energy and agricultural credit, Humanit. Soc. Sci. Commun 11, e342. https://doi.org/10.1057/s41599-024-02847-3.
Reuveni, S., 2024. A comprehensive analysis of the relationship between gdp and the global hunger index over the last 20 years. Technium Soc. Sci. J. 63, 98–112. https://doi.org/10.47577/tssj.v63i1.11868.
Rubin, O., 2009. The entitlement approach: a case for framework development rather than demolition: a comment on ‘entitlement failure and deprivation: a critique of sen's famine philosophy'. J. Dev. Stud. 45, 621–640. https://doi.org/10.1080/00220380802649947.
Saleem, A., Anwar, S., Nawaz, T., Fahad, S., Saud, S., Ur Rahman, T., Khan, M.N.R., Nawaz, T., 2025. Securing a sustainable future: the climate change threat to agriculture, food security, and sustainable development goals. J. Umm Al-Qura Univ. Appl. Sci. 11, 595–611. https://doi.org/10.1007/s43994-024-00177-3.
Samuel, J., Wisniewski, D., Grace, Brannan, 2024. Correlation (Coefficient, Partial, and Spearman Rank) and Regression Analysis. National Library of Medicine. https://www.ncbi.nlm.nih.gov/books/NBK606101/. (Accessed 11 October 2025).
Sandeep, K., Emihner, J., 2025. Climate and food (in)security in Micronesia: do traditional food crops hold answers? East W. Cent. https://pireport.org/202

5/01/13/climate-and-food-insecurity-in-micronesia-do-traditional-food-crops-hold-answers/. (Accessed 30 September 2025).
Segbefia, E., Dai, B., Adotey, P., Sampene, A.K., 2023. A step towards food security: the effect of carbon emission and the moderating influence of human capital. Evidence from Anglophone countries. Heliyon 9, e22171. https://doi.org/10.1016/j.heliyon.2023.e22171.
Shivaprakash, K., 2022. Unplanned renewable energy drive threatens food security, biodiversity, policy circle. https://www.policycircle.org/environment/renewable-energy-food-security/. (Accessed 4 September 2025).
Shreya, G., 2025. Why Food Insecurity is a Global Problem: a Critical Challenge for the Future. Frost & Sullivan Institute. https://frostandsullivaninstitute.org/why-food-insecurity-is-a-global-problem-a-critical-challenge-for-the-future/. (Accessed 4 September 2025).
Sohlberg, P., 2006. Amartya Sen's entitlement approach: empirical statement or conceptual framework? Int. J. Soc. Welfare 15, 357–362. https://doi.org/10.1111/j.1468-2397.2006.00462.x.
Srinivasan, K., Yadav, V.K., 2023. An integrated literature review on Urban and peri-urban farming: exploring research themes and future directions. Sustain. Cities Soc. 99, e104878. https://doi.org/10.1016/j.scs.2023.104878.
STATA 17, Xtologit, 2025. StataCorp LLC. https://www.stata.com/search/?q=xtologit&restrict=Default&btnG=Search&client=stata&num=&output=xml_no_dtd&site=stata&ie=&oe=UTF-8&sort=&proxystylesheet=stata. (Accessed 30 September 2025).
StataCorp LLC, 2021. STATA 17. StataCorp LLC, College Station, TX, USA [software]. https://www.stata.com/.
Studenmund, A.H., 2016. Using Econometrics: a Practical Guide, seventh ed. Pearson.
Su, Z.e., Zhao, J., Zhuang, M., Liu, Z., Zhao, C., Pullens, J.W.M., Liu, K., Harrison, M.T., Yang, X., 2024. Climate-adaptive crop distribution can feed food demand, improve water scarcity, and reduce greenhouse gas emissions. Sci. Total Environ. 944, e173819. https://doi.org/10.1016/j.scitotenv.2024.173819.
Suliyanto, P.A.P.W.S., Fariz, M., 2024. Fadillah Mardianto parameter estimation of binary probit regression for panel data with random effect using newton-raphson iteration method. Int. J. Acad. Appl. Res. 1, 197–202. http://ijeais.org/wp-content/uploads/2024/11/IJAAR241123.pdf.
Tabrez, Z., 2025. Sustainable cities: enhancing food systems with urban agriculture. Discover Food 5, e173. https://doi.org/10.1007/s44187-025-00439-x.
Tariq, G., Sun, H., Ali, I., Ali, S., Shah, Q., 2023. Influence of access to clean fuels and technology, food production index, consumer price index, and income on greenhouse gas emissions from food system: evidence from developed countries. Environ. Sci. Pollut. Res. 30, 59528–59539. https://doi.org/10.1007/s11356-023-26628-8.
The Borgen Project, Farmer training promoting sustainable agriculture in Micronesia, 2025. The Borgen Project. https://borgenproject.org/sustainable-agriculture-in-micronesia/#:~:text=Agriculture%20is%20a%20very%20large%20part%20of%20the,exports%20being%20fish%2C%20black%20pepper%20and%20betel%20nut. (Accessed 30 September 2025).
The Global Economy, 2025. GDP share of agriculture - country rankings. The Global Economy. https://www.theglobaleconomy.com/rankings/Share_of_agriculture/&lang=en/. (Accessed 17 July 2025).
The Independent, 2025. New digitized credit plans put farmers first. Independent. https://www.independent.co.ug/new-digitized-credit-plans-put-farmers-first/. (Accessed 7 September 2025).
The World Bank Group, 2018. Responsible Agricultural Investment (Rai): Knowledge into Action Notes Series. The World Bank Group. https://www.worldbank.org/en/topic/agriculture/publication/responsible-agricultural-investment. (Accessed 7 September 2025).
The World Bank Group, 2022. What you Need to Know About Food Security and Climate Change. World Bank Group. https://www.worldbank.org/en/news/feature/2022/10/17/what-you-need-to-know-about-food-security-and-climate-change. (Accessed 20 April 2025).
The World Bank Group, 2024a. Food Production Index (2014-2016 = 100) [data set], World Bank Group. https://data.worldbank.org/indicator/AG.PRD.FOOD.XD.
The World Bank Group, 2024b. Renewable Energy Consumption (% of Total Final Energy Consumption). The World Bank Group. https://data.worldbank.org/indicator/EG.FEC.RNEW.ZS. (Accessed 20 April 2025).
The World Bank Group, 2024c. Annual Percentage Change in Population Size [data set], World Bank Group. https://databank.worldbank.org/source/health-nutrition-and-population-statistics/Series/SP.POP.GROW.
The World Bank Group, 2024d. GDP per Capita (Constant 2015 US$). The World Bank Group. https://data.worldbank.org/indicator/ny.gdp.pcap.kd. (Accessed 20 April 2025).
The World Bank Group, 2024e. Land Under Cereal Production (Hectares). World Bank Group. https://data.worldbank.org/indicator/AG.LND.CREL.HA?view=map. (Accessed 20 April 2025).
The World Bank Group, 2025a. Data for Development. The World Bank Group. https://www.worldbank.org/ext/en/home. (Accessed 10 June 2025).
The World Bank Group, 2025b. Food Security Update | World Bank Solutions to Food Insecurity. World Bank Group. https://www.worldbank.org/en/topic/agriculture/brief/food-security-update. (Accessed 13 July 2025).
Timesofagriculture.org, 2025. The impact of agriculture on greenhouse gas emissions? Timesofagriculture.org. https://timesofagriculture.org/the-impact-of-agriculture-on-greenhouse-gas.html. (Accessed 4 September 2025).
Tinta, A.A., Sarpong, D.B., Ouedraogo, I.M., Al Hassan, R., Mensah-Bonsu, A., Ebo Onumah, E., 2018. The effect of integration, global value chains and international trade on economic growth and food security in ECOWAS. Cogent Food Agric. 4, e1465327. https://doi.org/10.1080/23311932.2018.1465327.
Tourang, S.K., Toufighi, S.P., Masoomi, B., Sahebi, I.G., Alizadeh, R., Vang, J., 2026. Blockchain-enabled framework for decision-making in renewable energy storage and sustainable supply chains. J. Energy Storage 148, e120014. https://doi.org/10.1016/j.est.2025.120014.
True, T., 2024. Farmland investments, finance strategists. https://www.financestrategists.com/wealth-management/alternative-investment/farmland-investments/. (Accessed 7 September 2025).
Ujjayant, C., Marie-Hélène, H., Michel, M., Linda, N., 2015. The long-run Impact of Biofuels on Food Prices, Resources for the Future.
UN, 2021. Food Systems Account for over one-third of Global Greenhouse Gas Emissions. United Nations. https://news.un.org/en/story/2021/03/1086822. (Accessed 7 October 2025).
UN, 2022. World Population Prospects 2022. United Nations Department of Economic and Social Affairs, Population Division.
UN, 2025. Applying the Fundamentals of Planned Urbanization for Prosperous Cities. United Nations Human Settlements Programme. https://unhabitat.org/project/applying-the-fundamentals-of-planned-urbanization-for-prosperous-cities. (Accessed 4 September 2025).
UN, 68% of the world population projected to live in urban areas by 2050, says UN, UN. https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html, 2018–. (Accessed 19 July 2025).
UN, Peace, Dignity and Equality on a Healthy Planet, 2024. United Nations. https://www.un.org/en/. (Accessed 10 November 2024).
Visser, J., Wangu, J., 2021. Women's dual centrality in food security solutions: the need for a stronger gender lens in food systems' transformation. Curr. Res. Environ. Sustain. 3, e100094. https://doi.org/10.1016/j.crsust.2021.100094.
Wang, S., Deng, O., Reis, S., Zhu, Y.-G., Xu, J., Gu, B., 2025. Global urbanization benefits food security and nature restoration. Resour. Conserv. Recycl. 216, e108174. https://doi.org/10.1016/j.resconrec.2025.108174.
WFP, 2025. Energy for food security, world food programme. https://www.wfp.org/energy-for-food-security. (Accessed 4 September 2025).
Wijeya Newspapers Ltd, 2023. Govt. must Ensure Sustainable Urbanisation. Wijeya Newspapers Ltd. https://www.ft.lk/FT-View-Editorial/Govt-must-ensure-sustainable-urbanisation/58-747720. (Accessed 4 September 2025).
World Economic Forum, 2023. 3 unusual ways renewable energy is giving farming a boost, world economic forum. https://www.weforum.org/stories/2023/10/agriculture-farmers-renewable-energy/. (Accessed 20 April 2025).
World Health Organization, 2024. Hunger Numbers Stubbornly High for Three Consecutive Years as Global Crises Deepen: UN Report. World Health Organization. https://www.who.int/news/item/24-07-2024-hunger-numbers-stubbornly-high-for-three-consecutive-years-as-global-crises-deepen–un-report. (Accessed 27 July 2025).
Xiong, J., Yu, Z., 2025. Assessing food consumption GHG emissions in China and the impact of alternative proteins on emissions reduction. Ecol. Front. 45, 1210–1217. https://doi.org/10.1016/j.ecofro.2025.03.007.
Yiadom, E.B., Dziwornu, R.K., Mawutor, J.K.M., Amankwah, R.F., 2023. Exploring the relationship between extreme weather events, urbanization, and food insecurity: institutional quality perspective. Environ. Chall. 13, e100775. https://doi.org/10.1016/j.envc.2023.100775.