Research Article

Climate Change and Sustenance: Assessing Dairy Cattle Farmers' Food Security Resilience in Indonesia

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Abstract | Climate change poses a significant threat to food security, particularly among dairy farmers in Indonesia who rely on climate-sensitive agricultural and livestock systems. This study examines the resilience of dairy cattle farmers in Malang Regency, East Java, focusing on how food accessibility, utilization, and stability influence household food security amidst climate variability. Using a Structural Equation Modeling (SEM) approach, data were collected from 302 dairy farmers in the Pujon and Ngantang subdistricts. The findings indicate that food accessibility, food utilization, and food stability positively contribute to household food security, while climate change has a significantly negative impact. Demographic characteristics such as farming experience, household size, and income also influence food security outcomes. The study underscores the necessity of targeted policy interventions, including climate-resilient livestock farming, improved market infrastructure, and access to financial support to mitigate the adverse effects of climate change. These findings provide empirical evidence to support climate adaptation strategies and enhance food security resilience among dairy farming communities in Indonesia.

Keywords | Climate change, Food security, Dairy farmers, Structural equation modeling (SEM), Livestock farmers, Adaptation strategies

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INTRODUCTION

Climate change has become one of the most critical global challenges, particularly due to its effects on food security and agricultural livelihoods (Muluneh, 2021; Toromade *et al*., 2024; Wiebe *et al*., 2019; Workie *et al*., 2020). Rising global temperatures, changes in climate patterns, and increased variability negatively influence the availability of feed and water, as well as animal health and productivity (Arya *et al*., 2024; Assan, 2022; Pham *et al*., 2024). Additionally, the agricultural sector faces the significant challenge of increasing production by 60% by 2050 to meet the projected global population of 9.3 billion people. This increase is necessary to supplement the current annual supply of 8.5 billion tons of food, feed, and fiber (FAO, 2014). Achieving this goal will require improving productivity while maintaining vital ecosystem functions to ensure long-term sustainability.

Globally, over 844 million people derive part of their income from agriculture, with the livestock industry contributing approximately 40% of the sector's total value-added (FAO, 2016; World Bank, 2005). However, climate change also disrupts the processing, storage, transportation, retail, and consumption of livestock products. One direct consequence is heat stress, which significantly affects cattle productivity by lowering output and increasing susceptibility to disease (Auma and Badr, 2022; Godde *et al*., 2021; Goma and Phillips, 2022; Putri *et al*., 2024; Thornton *et al*., 2022). Although livestock plays a crucial role in food security and broader sustainability efforts, climate change is expected to challenge these contributions, though the full extent of its impact remains uncertain.

Livestock products and services are essential to global food systems and rural economies, particularly in developing countries, as they provide meat, milk, and eggs, major sources of both nutrition and income (FAO, 2021). hese contributions represent approximately 15% of global per capita calorie intake and 31% of protein consumption, although regional variations exist (Nandelenga and Legesse, 2020). Research on livestock and climate change frequently emphasizes the climate mitigation potential of livestock and agriculture while addressing adaptation practices. Studies by Idrissou *et al*. (2020); Nugroho *et al*. (2024); Purwanti *et al*. (2022, 2023); Rojas-Downing *et al*. (2017) highlight that farmers' perceptions, sustainable livelihoods, and psychological factors significantly influence agricultural, dairy, and cattle farmers in adopting strategies to adapt to climate change impacts on agriculture.

Similarly, research by Anderson *et al*. (2020); Asfaw *et al*. (2019) show that smallholder adaptation is influenced by factors such as education, household size, access to training, finance, and extension services. Strengthening adaptive capacity requires addressing financial barriers, improving services, and promoting diversified livelihoods. Other research highlights that climate change reduces crop productivity (Habib-ur-Rahman *et al*., 2022) and adversely affects livestock performance, including growth, reproduction, and feed supply Cheng *et al*. (2022), particularly in developing countries.

Research on the impacts of climate change on food security among smallholder farmers particularly dairy smallholders remains limited, despite their increasing vulnerability to climate-induced disruptions. As climate change continues to affect agricultural production, it is crucial to understand how various dimensions of food security shape the well-being of dairy households, especially given their reliance on climate-sensitive farming systems. Food security is a multidimensional concept that has evolved beyond its initial focus on availability the physical presence of sufficient nutritious food in a region (Alonso *et al*., 2018; Gebre *et al*., 2025; Rahman *et al*., 2025; Squires and Gaur, 2020). However, as demonstrated by Bonuedi *et al*. (2022); Degarege and Lovelock (2021); Denny *et al*. (2018) through an analysis of historical famines, availability alone is not sufficient; households must also possess the economic and physical means to access food, highlighting the significance of accessibility. In addition, utilization plays a crucial role in food security, referring to a household's ability to safely prepare, store, and consume food to maximize its nutritional value (Adem *et al*., 2018; Adjimoti and Kwadzo, 2018; García-Díez *et al*., 2021; Toiba *et al*., 2021). Lastly, which reflects the consistency of access and utilization over time, is also threatened by environmental, economic, and social shocks or chronic food insecurity (Kim-Mozeleski *et al*., 2023; Shinwell and Defeyter, 2021). These interrelated dimensions underscore the complexity of food security, particularly in the context of smallholder farmers who are highly susceptible to climate change impacts.

Given the increasing risks posed by climate variability, it is imperative to conduct research that examines how these pillars of food security are affected in dairy smallholder households. This study aims to investigate the role of food accessibility, utilization, and stability in determining the food security status of dairy farming households. Furthermore, it explores how demographic factors influence food security within these communities and assesses the extent to which climate change shapes their food security outcomes. By addressing these critical issues, this research provides valuable insights that can inform policies and interventions aimed at enhancing the resilience of dairy smallholders in the face of climate change.

MATERIALS AND METHODS

Research location

This study was conducted in the subdistricts of Pujon and Ngantang, located in Malang Regency, East Java. These areas were purposively selected due to Malang Regency's vulnerability to climate change and its economic reliance on dairy farming. According to the BPS (2019), Malang Regency is Indonesia's second-largest dairy-producing region, with a total dairy cattle population of 86,058 and 391,383 farmers engaged in the sector. Within this regency, Pujon and Ngantang house the highest concentrations of dairy cattle, with Pujon accounting for 23,600 head and Ngantang for 15,960 (Health, 2022). To mitigate potential sample bias from purposive sampling, the study further ensured diversity by capturing variation in household demographics, climate experiences, and livelihood characteristics within these two sites. This prominence makes these subdistricts particularly relevant for the study. The majority of dairy farms in Pujon and Ngantang operate on a smallholder scale, characterized by traditional farming practices, serving as a supplementary source of income, relying on simple technologies, and operating at a household level. In contrast, other subdistricts in Malang Regency, such as Jabung and Ngajum, have relatively smaller dairy cattle populations, with 15,960 and 9,612 head, respectively. Given the concentration of dairy farming in Pujon and Ngantang, these subdistricts were deemed the most suitable locations for this research. Nevertheless, the findings from this region may not be generalizable to all dairy-producing areas in Indonesia due to agroecological and socio-economic variations across districts.

To ensure comprehensive data collection, fieldwork was conducted over a one-month period from August 1 to August 31, 2024. This timeframe was chosen to allow for systematic data gathering, ensuring the robustness of the study's findings within the prevailing environmental and socio-economic context.

Respondents

The study using multistage random sampling procedure to select the research location, beginning with East Java Province, then narrowing to Malang Regency, and ultimately focusing on the subdistricts of Pujon and Ngantang due to their prominence in dairy farming. Within each subdistrict, 160 dairy farmers were randomly targeted, resulting in a total sample of 320 respondents. After excluding incomplete responses, the final dataset consisted of 302 valid observations. While area selection was random, individual respondents met purposive criteria specifically, farmers had to (i) be members of livestock groups, (ii) own dairy cattle, and (iii) have at least one year of dairy farming experience. These criteria were used to ensure that respondents had the practical knowledge and exposure necessary to provide reliable and relevant insights into food security and the impacts of climate change. To address potential selection bias, we compared the sample's socio-demographic characteristics (e.g., age, education, income, herd size, milk production) with official regional statistics, confirming the sample's representativeness.

Research variable and variable measurement

In this study, both independent and dependent variables are utilized as constructs, with each construct comprising multiple indicators. Table 1 and Figure 1 provides a detailed overview of the construct variables, measurement indicators, and corresponding measurement approaches. The table comprises various independent variables that influence household food security as the dependent variable. The independent variables include food accessibility, food utilization/consumption, food stability, demographic factors, and climate change, each assessed through specific indicators and measured using a Likert scale (1–5). To ensure conceptual distinctiveness and reduce redundancy among constructs, we conducted multicollinearity diagnostics and confirmatory factor analysis (CFA) prior to estimation. Items with high cross-loadings were removed or re-specified, and final constructs retained only indicators with strong discriminant and convergent validity.

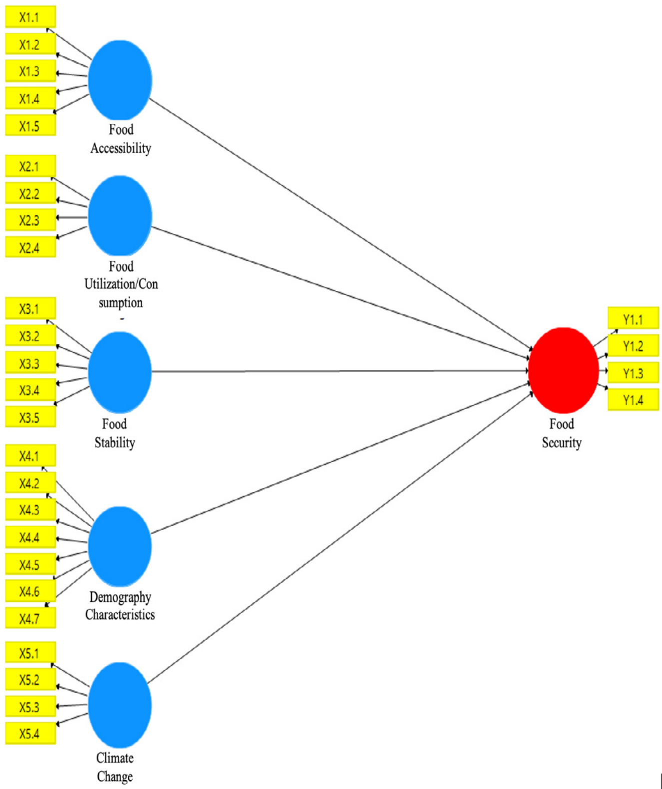

Figure 1: Conceptual model of structural equation modeling (SEM).

Food accessibility (X1) represents an individual's or household's ability to access food through physical, economic, and social means. It is measured through indicators such as the effectiveness of food distribution in businesses (X1.1), the quality of infrastructure supporting food distribution (X1.2), the impact of high food prices on household food shortages (X1.3), and the influence of low income on food shortages (X1.4) and Access to food resource (X1.5). While X1.3 and X1.4 may conceptually overlap with X3.1 (price stability) and X4.5 (household income), factor analysis confirmed they loaded distinctly on the accessibility construct, justifying their inclusion as access-specific items.

Food utilization/consumption (X2) refers to the ability of individuals to properly utilize food to meet their nutritional and energy needs. This is assessed through perceptions of differences in food quality between rural and urban areas (X2.1), household knowledge of nutritious and hygienic food preparation (X2.2), maintenance of a clean kitchen environment (X2.3), and the adequacy of drinking water quality (X2.4).

Table 1: List of dependent and independent variables.

Construct	Code	Indicator (Abbreviated Description)	Measurement
Food accessibility	X1.1	Distribution process is effective	Likert Scale 1–5
	X1.2	Distribution infrastructure is adequate	Likert Scale 1–5
	X1.3	High food prices cause shortages	Likert Scale 1–5
	X1.4	Low income causes shortages	Likert Scale 1–5
	X1.5	Access to food resource is limited	Likert Scale 1–5
Food utilization/ Consumption	X2.1	Perceived food quality varies (urban vs rural)	Likert Scale 1–5
	X2.2	Knowledge of cooking/washing nutritious food	Likert Scale 1–5
	X2.3	Kitchen and dining area hygiene	Likert Scale 1–5
	X2.4	Drinking water quality is sufficient	Likert Scale 1–5
Food stability	X3.1	Food prices tend to be stable	Likert Scale 1–5
	X3.2	Food supply is generally stable	Likert Scale 1–5
	X3.3	Shortages occur when food is unavailable	Likert Scale 1–5
	X3.4	Price differences exist among local stores	Likert Scale 1–5
	X3.5	Institutional support exists for food security	Likert Scale 1–5
Demographic characteristics	X4.1	Age of respondent	Ratio Scale
	X4.2	Gender (1 = Male, 2 = Female)	Nominal Scale
	X4.3	Years of dairy farming experience	Ratio Scale
	X4.4	Household size	Ratio Scale
	X4.5	Monthly household income	Ratio Scale
	X4.6	Number of livestock	Ratio Scale
	X4.7	Milk production	Ratio Scale
Climate change perception	X5.1	Climate shortens shelf life of food	Likert Scale 1–5
	X5.2	Climate increases short-term food prices	Likert Scale 1–5
	X5.3	Climate affects food quality and safety	Likert Scale 1–5
	X5.4	Climate causes store-level price variations	Likert Scale 1–5
Household food security	Y1.1	Income change increases food insecurity risk	Likert Scale 1–5
	Y1.2	Households consume balanced diets	Likert Scale 1–5
	Y1.3	Households worry about running out of food	Likert Scale 1–5
	Y1.4	Households unable to access sufficient food	Likert Scale 1–5

Food stability (X3) reflects the ability to sustain continuous access to food without significant fluctuations. Indicators include the stability of food prices in local markets (X3.1), the reliability of the food supply (X3.2), the occurrence of food shortages due to unavailability in markets (X3.3), price variations among different stores (X3.4), and the existence of institutional support for food security (X3.5). Although some overlap was identified between X3.1, X3.4 and price-related indicators in other constructs (e.g., X1.3, X5.2), these were retained following discriminant validity tests confirming distinct dimensions of temporal versus economic food risk.

Demographic factors (X4) encompass key population characteristics that may affect food security. These include age (X4.1), gender (X4.2), dairy farming experience (X4.3), household size (X4.4), household income (X4.5), number of livestock (X4.6), and milk production (X4.7). Variables were selected based on established literature linking household characteristics to adaptive capacity and food access. Tests for multicollinearity were conducted and VIF values were below the accepted threshold (VIF < 5).

Climate change (X5) is another critical variable influencing food security. It is assessed through the impact of climate issues on food shelf life (X5.1), short-term food price increases (X5.2), changes in food quality affecting food safety (X5.3), and price variations caused by climate conditions (X5.4). This construct reflects farmers' perceptions, which serve as a proxy for localized climate impact data. However, further validation with objective meteorological records is recommended for future studies.

The dependent variable, household food security (Y), represents the household's ability to sustainably meet its food needs, considering aspects of food availability, accessibility, and stability. It is measured through indicators such as income fluctuations leading to food insecurity (Y1.1), the ability of well-functioning households to consume a balanced diet (Y1.2), household concerns about food shortages (Y1.3), and the inability of households to access sufficient food (Y1.4). These indicators were adapted from validated food insecurity scales, ensuring comparability and content validity.

Data analysis

Statistic descriptive

Quantitative descriptive analysis refers to a statistical method used to summarize, describe, and present data quantitatively from a selected sample. The primary goal of quantitative descriptive analysis is to gain a clear understanding of the data's characteristics, such as central tendencies and distributions. This method is applied to evaluate the predefined sample comprehensively. Descriptive statistics were calculated for all constructs and indicators, including mean, standard deviation, minimum and maximum values, and distribution shape to check for normality assumptions and outliers prior to SEM analysis.

SEM-PLS (structural equation modeling-partial least squares)

PLS-SEM has experienced significant development as a statistical modeling approach. In recent decades, numerous introductory articles have been published on this methodology (Chin, 1999; Hair Jr *et al*., 2021; Hwang *et al*., 2020; Khan *et al*., 2019; Purwanti *et al*., 2023). Structural Equation Modeling (SEM) is a statistical method employed to test and evaluate the relationships among various conceptual variables within a model. Meanwhile, Partial Least Squares (PLS) is a statistical approach used to analyze and model the relationship between dependent and independent variables, especially in cases involving multiple interrelated independent variables. The SMART-PLS 4.0 software was used to estimate the model. Model evaluation consisted of measurement model assessment (validity and reliability) and structural model assessment (path coefficients, R^2, and predictive relevance) (Sarstedt *et al*., 2021).

Additionally, model specification entails converting the path diagram into a series of structural equations and measurement model equations. The structural equations detail was presented in Supplementary File 1.

One potential concern is the possibility of reverse causality namely, that food insecurity may influence farmers' perceptions of climate change rather than the other way around. However, we argue that this concern is minimal in the present study for two reasons. First, the climate change variable was constructed from farmers' assessments of long-term and external phenomena (e.g., rising food prices, shortened food shelf life, and climate-induced food quality degradation), which are more likely to be influenced by observable environmental changes than by household-level food insecurity. Second, our conceptual model follows a theoretically grounded direction of causality, consistent with previous empirical literature e.g., (Anderson *et al*., 2020; Purwanti *et al*., 2023; Rojas-Downing *et al*., 2017), which posits that climate variability and perceptions thereof are critical antecedents to food security outcomes. Nonetheless, we acknowledge that future studies using panel data or instrumental variable approaches may further strengthen the causal interpretation of the results.

RESULTS AND DISCUSSION

Descriptive analysis socio-demography characterteristics

Table 2 presents the socio-demographic characteristics of the respondents, who are dairy farmers residing in Pujon and Ngantang Subdistricts, Malang Regency. The descriptive analysis reveals several key findings:

- The majority of respondents are aged between 31 and 60 years, indicating a dominance of farmers in the productive age group with adequate physical capacity and work experience. However, the low participation of younger farmers suggests a potential generational gap within the dairy farming sector.
- In terms of gender, most respondents are male, reflecting traditional gender roles in rural areas. The limited involvement of women highlights the need for gender-inclusive strategies that enhance women's access to resources, training, and cooperative membership.
- The respondents' educational attainment is relatively low, with most having completed only elementary school. This limited educational background may hinder technology adoption, farm record-keeping, and the application of modern livestock practices, underscoring the importance of extension services tailored to low-literacy farmer populations.
- Household sizes tend to be small, with the majority comprising fewer than five members. This may affect the availability of household labor while simultaneously reducing food requirements, which could influence food security dynamics.
- Farming experience is relatively high, with 50% of respondents having more than 20 years of experience and 41% between 10 and 20 years. This indicates that most farmers are long-time practitioners with strong local knowledge.
- Daily milk production ranges from 10 to 15 liters per household. Although this uniformity may appear

unusual, it results from standardized cooperative practices related to herd size (typically 2–3 cows per household), feeding systems, and milking schedules.

- Household income levels indicate economic vulnerability: 66% of respondents earn less than IDR 1 million per month, 23% earn between IDR 1–5 million, and only 11% earn more than IDR 5 million per month.

Table 2: Results of descriptive statistics on respondent characteristics.

Description	Percentage (%)
Age (Year)	
21-40	53
41-60	42
>60	5
Gender	
Male	71
Female	29
Education	
Primary School	47
Junior High School	28
Senior High School	22
Bachelor	3
Household Size (persons)	
<5	97
>5	3
Farming experience (year)	
<10	9
10-20	41
>20	50
Total livestock (head)	
<5	64
5-10	22
>10	14
Milk production (liters)	
>10	0
10-15	100
<15	0
Income (IDR)	
<1 million	66
1-5 million	23
>5 million	11

Descriptive analysis of research variables

Table 3 presents the results for various indicators related to both dependent and independent variables. A detailed explanation is provided below:

Food accessibility

Respondents generally held positive views on food accessibility. The food distribution process scored highly (Mean = 4.02), indicating efficient logistics. Infrastructure was rated as adequate (Mean = 3.91), though still open to improvement. Economic barriers remain prominent, as high food prices (Mean = 2.88) and low income (Mean = 2.89) scored lower, suggesting reduced affordability. Food access is also competitive, with a high score (Mean = 3.98), indicating frequent competition among households.

Food utilization/consumption

Utilization indicators reflect good household practices in nutrition and hygiene. Respondents moderately agreed that food quality varies between rural and urban areas (Mean = 3.86). Most households reported maintaining proper cooking practices (Mean = 3.97) and clean kitchen areas (Mean = 3.78). Drinking water quality was considered sufficient (Mean = 3.82), supporting safe food preparation and consumption.

Food stability

Perceptions of stability varied. Price stability had the lowest score (Mean = 2.69), highlighting concerns over fluctuating costs. However, food supply was seen as reliable (Mean = 3.90). Market shortages were moderately acknowledged (Mean = 3.60), while price variation across stores (Mean = 3.92) and institutional support (Mean = 3.71) suggest moderate confidence in local systems.

Climate change

Climate change was widely seen as disruptive to food systems. Respondents strongly agreed that it reduces food shelf life (Mean = 4.08) and raises short-term food prices (Mean = 4.27). It also affects food quality (Mean = 4.10) and contributes to price differences across stores (Mean = 4.17), reflecting broad recognition of climate impacts.

Household food security

Indicators showed both resilience and vulnerability. Income-related threats to food security were strongly acknowledged (Mean = 4.10). Balanced diet practices received positive responses (Mean = 4.04). However, concern about food shortages (Mean = 3.61) and difficulty accessing sufficient food (Mean = 4.07) point to ongoing challenges.

Measurement model evaluation

Composite validity test, evaluation of outer model

The initial phase of Partial Least Squares Structural Equation Modeling (PLS-SEM) analysis is crucial as it involves assessing the outer (or measurement) model. This step is essential for determining the extent to which the items (questions) appropriately load onto their respective

Table 3: Descriptive analysis research variables.

Indicators	Mean
Food accessibility (X1)	
The distribution process in my business tends to be effective (X1.1)	4.02
The infrastructure for the food distribution process in my business is generally good (X1.2)	3.91
High food prices cause households to experience food shortages (X1.3)	2.88
Low income levels lead to household food shortages (X1.4)	2.89
I compete to access food resources (X1.5)	3.98
Food utilization/consumption (X2)	
I assume there is a difference between rural and urban food quality (X2.1)	3.86
A good household is knowledgeable about maintaining nutritious and hygienic cooking and washing methods (X2.2)	3.97
A good household has a neat and clean kitchen and dining area (X2.3)	3.78
The quality of drinking water in my neighborhood is sufficiently good (X2.4)	3.82
Food stability (X3)	
Food prices in my neighborhood tend to remain stable (X3.1).	2.69
The food supply in my neighborhood tends to remain stable (X3.2).	3.90
A lack of food availability in the market leads to food shortages (X3.3).	3.60
There is price variation among stores in the local market (X3.4).	3.92
There is institutional support for household food security (X3.5).	3.71
Climate change (X4)	
Climate issues reduce the shelf life of food (X5.1)	4.08
Climate issues increase food prices in the short term (X5.2)	4.27
Changes in food quality affect food safety in local markets due to climate issues (X5.3)	4.10
Climate issues cause price variations among stores in local markets (X5.4)	4.17
Household food security (Y)	
Changes in income levels threaten households with food insecurity (Y1.1)	4.10
Well-functioning households consume a balanced diet (Y1.2)	4.04
Households that are concerned about running out of food supplies (Y1.3)	3.61
Households unable to access sufficient food (Y1.4)	4.07

constructs. The examination of the outer model includes evaluating the unidirectional predictive associations between each latent construct and its observed indicators, which is fundamental in ensuring that the measurement model is valid and reliable (Hair *et al*., 2019, 2021). The measurement model's quality significantly impacts the outcomes of the analysis, as it captures the relationships between latent and observable variables (Dehgani and Jafari, 2019; Hair *et al*., 2021).

In PLS-SEM, reliability is typically assessed using indices such as Cronbach's alpha and composite reliability. These indices evaluate internal consistency by examining the interrelationships among observed items. Specifically, the values for Cronbach's alpha and composite reliability should ideally be above 0.70, indicating acceptable reliability (Ratasuk and Charoensukmongkol, 2020; Wang *et al*., 2022).

Based on the Table 4, all constructs exhibit factor loadings surpassing the 0.7 threshold, which indicates statistically significant relationships between individual items and their respective constructs. This reinforces the validity of the measurement model, as each item reliably represents its associated construct (Adda *et al*., 2021; Ratasuk and Charoensukmongkol, 2020). The assessment of the outer model, including the evaluation of factor loadings and reliability indices, is essential to confirm that the measurement model is robust and suitable for further analysis (Lobo *et al*., 2022; Purwanti *et al*., 2023; Wang *et al*., 2022).

Discriminant validity and convergent validity

Discriminant validity refers to the extent to which a construct is empirically distinct from other constructs, thereby measuring the degree of differences between overlapping concepts. This validity was assessed using two widely accepted methods: The Fornell-Larcker criterion and the Heterotrait-Monotrait (HTMT) ratio (Appiah-Twumasi *et al*., 2022; Azizi and Khatony, 2019; Wu *et al*., 2023).

Table 4: Construct reliability, validity, and multicollinearity diagnostics.

Latent variables	Indicators	Loading factor	Loading factor	CA	CR	AVE	Sqrt AVE	VIF
Food accessibility (X1)	X1.1	0.945	0,924	0,958	0,967	0,855	0.967	2.340
	X1.2	0.921						
	X1.3	0.897						
	X1.4	0.911						
	X1.5	0.949						
Food utilization/ Consumption (X2)	X2.1	0.957	0,947	0,962	0,972	0,898	0.877	1.890
	X2.2	0.931						
	X2.3	0.933						
	X2.4	0.968						
Food stability (X3)	X3.1	0.881	0,934	0,964	0,972	0,874	0.924	2.410
	X3.2	0.944						
	X3.3	0.933						
	X3.4	0.942						
	X3.5	0.971						
Demographic characteristics (X4)	X4.1	0.871	0,876	0,950	0,959	0,770	0.921	1.760
	X4.2	0.907						
	X4.3	0.899						
	X4.4	0.791						
	X4.5	0.889						
	X4.6	0.879						
	X4.7	0.899						
Climate change (X5)	X5.1	0.963	0,967	0,977	0,983	0,936	0.935	2.570
	X5.2	0.953						
	X5.3	0.982						
	X5.4	0.972						
Food security (Y)	Y1.1	0.952	0,920	0,939	0,957	0,848	0.947	1.910
	Y1.2	0.962						
	Y1.3	0.877						
	Y1.4	0.889						

According to the Fornell-Larcker criterion, the square root of the Average Variance Extracted (AVE) for each construct must be greater than its correlations with any other construct. Meanwhile, the HTMT ratio evaluates the degree of similarity between constructs, and values below 0.90 are considered acceptable thresholds indicating satisfactory discriminant validity (Almazrouei *et al*., 2024; Azizi and Khatony, 2019).

Although food accessibility, food utilization, and food stability are conceptually interrelated components of the broader food security framework, this study treated them as independent latent constructs in order to isolate and understand their unique effects on household food security resilience. Theoretically, while food stability (e.g., consistent availability and prices) can influence accessibility (e.g., affordability), modeling them as separate constructs enables a more precise diagnosis of which dimension poses the greatest challenge or leverage point for policy interventions.

To validate their statistical distinctiveness, we conducted discriminant validity tests using the Fornell-Larcker criterion and HTMT ratio. As shown in Table 4, each construct's square root of AVE exceeded its inter-construct correlations, confirming the constructs discriminant validity. Furthermore, all HTMT values were below 0.90, indicating that multicollinearity and conceptual overlap were within acceptable bounds. This validation supports the robustness of the measurement model and confirms that food accessibility, food utilization, and food stability, while conceptually related, function as empirically distinct constructs in the SEM framework.

In addition to discriminant validity, convergent validity was evaluated to ensure that the indicators of each construct are sufficiently correlated. This was assessed through factor loadings, composite reliability (CR), Cronbach's alpha (CA), and AVE. All factor loadings exceeded the recommended threshold of 0.70, and values for CR and CA were above 0.70, indicating good internal consistency (Uysal *et al*., 2024; Zhang *et al*., 2018). The AVE values for all constructs surpassed the 0.50 threshold, confirming that the latent constructs explain more than half of the variance in their indicators. These results collectively indicate that the measurement model possesses adequate convergent and discriminant validity, justifying the use of each construct in the structural model analysis.

To assess potential multicollinearity among the latent constructs in the inner model, we conducted a Variance Inflation Factor (VIF) analysis (Table 4). As presented in Table 4, all VIF values for the constructs-food accessibility (2.34), food utilization (1.89), food stability (2.41), demographic characteristics (1.76), and climate change (2.57) are below the commonly accepted threshold of 5.0. These results indicate that multicollinearity is not a concern in the structural model, and each construct contributes independently to the estimation of household food security (Hair *et al*., 2021). The absence of multicollinearity strengthens the reliability of the regression coefficients and the overall model validity.

Structural model evaluation

R-square (R^2) and model fit evaluation

The structural model produced a high coefficient of determination (R^2) of 0.959, indicating that the combined influence of food accessibility, food utilization, food stability, demographic characteristics, and climate change perception explains 95.9% of the variance in the household food security construct. This exceptionally strong explanatory power reflects the relevance of the selected latent constructs and suggests a robust model. The adjusted R^2 value of 0.957, which accounts for model complexity, further confirms that the model is not overfitted.

To ensure that the high R^2 does not result from multicollinearity among predictor constructs, a multicollinearity diagnostic was conducted using the Variance Inflation Factor (VIF). As presented in Table 4, all constructs had VIF values ranging from 1.76 to 2.57, which are well below the commonly accepted threshold of 5.0. These results confirm the absence of multicollinearity and support the stability of the parameter estimates in the structural model.

In addition, several model fit indices were assessed to validate the model's adequacy. Based on the Smart PLS 4.0 output, the Standardized Root Mean Square Residual (SRMR) was found to be 0.042, which falls within the acceptable limit of 0.08 and indicates a good fit between the predicted and observed data. The Normed Fit Index (NFI) was 0.938, surpassing the minimum threshold of 0.90 and demonstrating substantial improvement over the null model. These values demonstrate that the structural model provides a good overall fit and support the theoretical plausibility of the hypothesized relationships. These findings are supported by the validity and reliability results presented earlier in Table 4, which confirm that all constructs meet the required thresholds for composite reliability, average variance extracted (AVE), and discriminant validity.

Taken together, the strong R^2 (Table 5), acceptable VIF values (Table 4), and satisfactory model fit indices confirm that the SEM-PLS model used in this study is both statistically robust and conceptually valid for analyzing the determinants of food security under climate change pressure among dairy farming households.

Hypothesis test

Table 5 and Figure 2 presents the statistical tests conducted to examine the influence of independent variables on the dependent variable. The statistical tests performed involved hypothesis testing to determine the T-statistic values and p-values, which indicate whether a hypothesis is accepted or rejected. Based on the statistical tests conducted, all hypotheses were accepted, as they exhibited T-statistic values greater than 2.0 and p-values less than 0.05, confirming the significant effect of the independent variables on household food security.

Table 5: Hypotheis test.

	Coefficient (O)	Sample mean (M)	Standard deviation	T statistics	P values
Food accessibility	0,385	0,385	0,128	3,022	0,003**
Food utilization/consumption	0,216	0,216	0,088	2,454	0,014**
Food stability	0,377	0,377	0,130	2,901	0,004**
Demographic characteristics	0,321	0,321	0,102	3,136	0,002**
Climate change	-0,327	-0,327	0,080	4,089	0,000**
R-square	0.959				
Adjusted R-square	0.957				
Sig. F	0.000				

Note: **significant at 5%, Source: This Study, 2024.

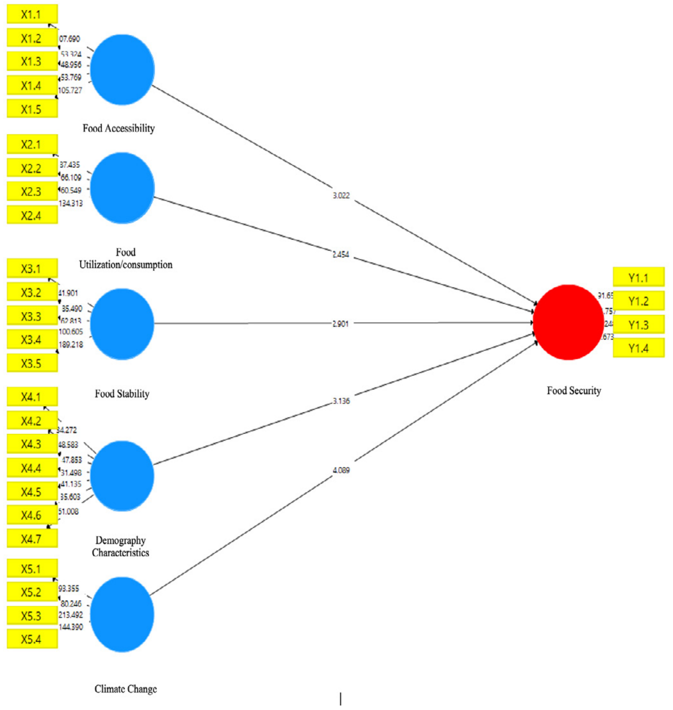

Figure 2: Structural model evaluation with path coefficients.

The influence of food accessibility, utilization, and stability on food security

The findings indicate that food accessibility has a significant and positive influence on household food security among dairy farmers in Malang Regency. Defined as the ability to acquire sufficient food through physical, economic, and social means (Simelane and Worth, 2020), this dimension is statistically supported by a path coefficient of β = 0.385, T = 3.022, and $p < 0.05$. Households with better access to food report higher food security, as supported by Sekaran *et al.* (2021) and Akukwe (2020), who emphasize the role of income and purchasing power in food procurement. High-income households can afford diverse and nutritious foods, while lower-income ones face limited, often inferior, options. Moreover, price volatility limits access to essential foods (Davis *et al.*, 2021; Herforth *et al.*, 2020), compelling households to reduce food quality. Accessibility also depends on market and infrastructure access, as highlighted by Muthuraman and Kasianantham (2023), especially in rural settings. Households with better market linkages and social networks are more likely to secure adequate food (Dinku *et al.*, 2023; Hossfeld *et al.*, 2023), reinforcing that food access involves both economic and spatial dimensions critical to food security.

Similarly, food utilization and consumption were found to significantly influence food security, with β = 0.216, T = 2.454, and $p < 0.05$. This dimension refers to a household's ability to process and consume food in ways that meet nutritional and energy needs (Kleve and Barons, 2021; Paştiu *et al.*, 2024). The results show that households maximize available food resources to maintain adequate intake even amid constraints. As Thomson *et al.* (2024) argue, dietary choices are shaped by financial limitations, making utilization a vital aspect of nutrition security. The ability to use food efficiently through minimizing waste and adopting proper cooking practices is crucial (Barrera and Hertel, 2021; Vågsholm *et al.*, 2020). Respondents confirmed that nutritional adequacy depends not only on availability but also on food management skills. This is supported by Obayelu and Chime (2020), who found that households with better food knowledge tend to maintain better nutrition. The study underscores the importance of food literacy and education as key levers to strengthen food utilization and thus improve food security among dairy farmers.

The results also confirm that food stability significantly affects food security (β = 0.377; T = 2.901; $p < 0.05$). Food stability reflects the consistency with which households can access safe and nutritious food over time (Neuwelt-Kearns *et al.*, 2022; Wahbeh *et al.*, 2022). Respondents reported that local markets play a central role in maintaining food security, especially through steady food supply and price stability. This aligns with Eshetu and Guye (2021), who stress the market's role in consistent food access, and with Savage *et al.* (2020) and Manikas *et al.* (2023), who highlight the disruptive effects of price volatility. In addition, the availability of key food items is essential for households to follow planned and balanced diets, as discussed by Kabisch *et al.* (2021) and Sitaker *et al.* (2020). Supply disruptions can lead to compromises in diet quality. Given their exposure to market fluctuations, smallholder dairy farmers are particularly vulnerable to food instability. As Li and Song (2022) suggest, food security now encompasses not only quantity but also quality, safety, and supply-demand balance. During times of crisis, such as supply chain disruptions, the importance of stability becomes even more pronounced (Ghalibaf *et al.*, 2022; Wahbeh *et al.*, 2022), underscoring the need for systemic resilience in the food system to sustain dairy farmers' food security.

The influence of demographic characteristics on food security

The findings of this study indicate that demographic characteristics positively influence food security among dairy farmers in Malang Regency, East Java. This is statistically supported by a path coefficient of β = 0.321, with a T-value of 3,136 and a p-value less than 0.05, confirming a significant and positive influence of demographic factors on household food security. Demographic attributes serve as key informational sources about individuals, encompassing factors such as age, gender, education, marital status, and other relevant aspects (Benkhelifa and

Laallam, 2020). Previous studies have also highlighted the significance of demographic factors in achieving food security. For instance, Ogundari *et al.* (2022) report that married, educated, and older household heads have a higher probability of attaining food sufficiency, underscoring the importance of these factors in enhancing food security. In this study, the demographic characteristics under examination include age, gender, farming experience, the total number of livestock owned, milk production levels, income, education, and household size.

Furthermore, education plays a crucial role in improving food security. Multiple studies emphasize its impact, with findings indicating that higher educational attainment correlates positively with food security status (Kortei *et al.*, 2022). Education equips individuals with better knowledge and skills for effective resource management, ultimately enhancing their ability to secure sufficient food for their households. Additionally, the study findings demonstrate that households with higher income levels are less likely to experience food insecurity, reinforcing the notion that economic stability is closely linked to demographic factors.

Moreover, the age distribution of respondents in this study reveals that the majority fall within the productive age range of 21–60 years (Ayodele *et al.*, 2020). Being in this age group enables individuals to generate relatively high income levels, ensuring that both the respondents and their family members have access to nutritious and safe food resources. Furthermore, the study indicates that most respondents are male. In Indonesia, men predominantly serve as primary earners responsible for securing household livelihoods and ensuring their families' access to food resources derived from their earnings (Brannen and Wilson, 2023). The study population primarily consists of dairy farmers whose main occupation revolves around livestock farming. Farming experience is another determinant of food security, as a longer duration in dairy farming enhances individuals' understanding of market dynamics, including price fluctuations. This experience enables farmers to make informed financial decisions that contribute to food security (Wachter, 2020). Additionally, the number of livestock owned significantly impacts food security. Studies such as those by Tuholske *et al.* (2020) highlight that households with more livestock tend to be more food secure, as livestock provides both food and income. Similarly, higher milk production levels contribute to food security by ensuring a steady supply of nutritious food for the household.

Additionally, the study findings reveal that respondents produce an average of 10–15 liters of milk per day, with the price per liter ranging between IDR 10,000 and IDR 15,000, depending on the location of the dairy farms (Aulia *et al.*, 2021). Given these prices, respondents can plan their daily food consumption based on their earnings from milk sales. Regarding income levels, most respondents earn below IDR 1,000,000 per month. Although this income is relatively low, respondents reported that they are still able to meet their daily food needs. This can be attributed to the fundamental nature of food as a primary necessity, compelling respondents to prioritize securing food resources despite their limited monthly income (Tuomala and Grant, 2022). Finally, household size also influences food security. The majority of respondents in this study have household size of fewer than five members, which contributes to the perception that their income is adequate for meeting their family's nutritional needs. Smaller household size allow for a more manageable distribution of resources, ensuring access to nutritious food despite financial constraints. The research by Hermawati *et al.* (2022) suggests that understanding the dynamics of household size is essential for addressing food security effectively.

One notable limitation of the study is the underrepresentation of female respondents, who comprised only 29% of the sample. This reflects the gender structure of formal dairy cooperative membership in the study area, where men are often listed as the primary farmers or household heads. However, it is important to recognize that women frequently play a central role in managing household food procurement, preparation, and allocation, making their perspectives critical in food security research.

The limited female sample size constrained the ability to conduct robust gender-disaggregated analysis, which could have revealed important differences in how men and women perceive climate impacts or manage food security. Future research should prioritize more inclusive sampling strategies and explicitly investigate gendered pathways to food security and climate resilience. Integrating gender-sensitive indicators and qualitative data could help capture women's lived experiences and decision-making roles more effectively, particularly in rural livestock-based systems.

The impact of climate change on food security

Research findings indicate that climate change has a significantly negative impact on households food security, with dairy farming households being particularly vulnerable (Aboye *et al.*, 2023). This relationship is statistically confirmed by the model, with a path coefficient of $\beta = -0.327$, a T-value of 4.089, and a p-value less than 0.05, indicating a negative and significant effect of climate change on food security. As climate change worsens, household food security is expected to decline further, especially for those whose livelihoods depend on agriculture and livestock (Mihiretu *et al.*, 2021). Adverse weather conditions, such as prolonged rainfall and extended droughts, directly disrupt agricultural productivity and the stability of farming households (Shahzad *et al*., 2021). These disruptions lead to cascading effects on food availability, accessibility, affordability and utilization.

One of the primary ways climate change threatens the food security of dairy farmers is through its impact on feed availability and production costs. Dairy farming in Malang Regency heavily depends on a stable supply of forage and feed crops, which are highly sensitive to climatic variations. Extreme weather events, such as droughts and floods, reduce the availability of natural pasture, increase feed scarcity, and lower forage quality (Ahmad *et al*., 2022). As a result, dairy farmers are forced to purchase more expensive supplementary feed, increasing their production costs. Rising feed costs lead to lower profit margins, reducing household income and limiting their ability to afford a nutritionally adequate diet. This aligns with findings from Sabola (2024), who highlights that climate-induced fluctuations in market conditions and increased production costs pose significant economic challenges for farmers. Moreover, climate-related challenges extend beyond feed availability. High temperatures, for example, can negatively affect dairy cows health and milk production. Heat stress reduces milk yield and quality, further compromising dairy farmers income and financial stability (Mekonnen *et al*., 2021).

On the other hand, Climate change also influences market dynamics, further exacerbating food insecurity among dairy farmers. Respondents report that climate variability causes short-term fluctuations in food prices, making it difficult for households to afford staple foods consistently (Muluneh, 2021). Extreme weather conditions disrupt supply chains, reduce agricultural output, and cause price volatility in local markets (Mbuli *et al*., 2021). As dairy farmers experience higher production costs and lower income due to climate-induced disruptions, their purchasing power decreases, limiting their ability to buy diverse and nutritious foods. This aligns with findings from Din *et al*. (2022) who state that climate change significantly threatens food security, particularly in local marketplaces where price fluctuations directly impact household affordability.

Interestingly, despite the adverse effects of climate change on household food security, many respondents reported autonomous adaptation strategies developed independently of formal extension systems. Farmers described adjusting milking or breeding schedules during hotter months, modifying sheds to improve ventilation, and substituting conventional feed with locally available alternatives such as banana stems, tofu dregs, or rice straw. Although not directly quantified in this model, these responses reflect practical, low-cost coping mechanisms shaped by environmental stress and resource limitations. These grassroots innovations highlight the importance of designing policy support that builds on existing farmer-led adaptations rather than introducing top-down interventions that may not align with local realities (Meijer *et al*., 2022).

This study contributes to the academic discourse on food security under climate stress by empirically validating the multidimensional framework of food security access, utilization, and stability within the context of smallholder dairy farming. Rather than analyzing these pillars in isolation, the study employs a SEM-PLS approach to demonstrate how each dimension distinctly, yet interdependently, influences food security outcomes amid changing climatic conditions. Focusing on dairy farming a sector both climate-sensitive and critical for rural nutrition this study reveals how climate shocks affect not only agricultural output but also household well-being and livelihood resilience (Rahman *et al*., 2022, 2023; Toiba *et al*., 2024).

Moreover, this research advances the conversation on perception-based climate risk assessment. It shows that perceived climate disturbances significantly compromise food security, reinforcing the utility of experiential and locally observed data in contexts where meteorological datasets are limited. Importantly, the findings also underscore the role of demographic factors such as income and education in shaping adaptive capacity. These insights support the need for integrated policy responses that combine climate-smart agriculture with targeted social protection and capacity building (Ariom *et al*., 2022; Bazzana *et al*., 2022). By capturing both the structural and behavioral dimensions of food insecurity, the study offers a comprehensive lens for designing inclusive, context-aware climate resilience strategies.

CONCLUSION AND RECOMMENDATIONS

Climate change poses a substantial threat to the food security and livelihoods of smallholder dairy farmers, as increasing climate variability undermines food accessibility, utilization, and stability. This study finds that all three pillars significantly and positively influence household food security, while perceived climate change impacts reduce it. Demographic factors such as income, education, and farming experience also play a role in enhancing resilience. Policy efforts should focus on promoting climate-resilient livestock practices (e.g., drought-tolerant forages, low-cost feed alternatives, and water-saving infrastructure), expanding financial support mechanisms (such as microcredit and weather-indexed insurance), strengthening cooperative-based price and input systems, and embedding localized climate adaptation into livestock extension services. Although this study is based on East Java, the findings have broader relevance for other smallholder dairy systems facing similar climate-induced challenges. Limitations include the use of perception-based climate data and the need for future research to integrate objective climate metrics and assess gender-specific impacts.

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NOVELTY STATEMENT

This study makes several novel contributions to the literature on climate change, livestock farming, and food security.

- First, unlike most prior research that primarily focuses on crop farmers, this paper specifically examines dairy smallholders, a group highly vulnerable to climate variability yet underrepresented in food security research.
- Second, the study employs a multidimensional food security framework encompassing accessibility, utilization, and stability within a SEM-PLS modeling approach, thereby empirically validating the distinct yet interdependent effects of these dimensions on household food security. Third, by incorporating perception-based measures of climate change alongside demographic and livelihood characteristics, the study highlights the importance of farmer-experienced climate risk in shaping food security outcomes, offering methodological innovation where meteorological data are scarce.
- Finally, the research advances policy discourse by linking structural determinants with farmer-led adaptation strategies, thereby providing context-specific, evidencebased recommendations for enhancing resilience in livestock-based rural economies of Indonesia and similar developing contexts.

AUTHOR'S CONTRIBUTION

Tina Sri Purwanti: Conceptualization, research design, supervision, methodology, data validation, writing original draft, and final manuscript revision.
Jaisy Aghniarahim Putritamara: Data collection, field survey coordination, data curation, and preliminary data analysis.
Daranrat Jaitiang: Methodology support, statistical modeling guidance, and critical review of results.
Awang Tri Satria: Data analysis, preparation of tables and figures, and writing-results and discussion.
Mochammad Syamsul Hadi: Validation of agricultural context, literature review support, and technical inputs on livestock and plant interactions.
Nisrina Dita Agustina: Data entry, descriptive statistics, visualization, and formatting of references.
Hanifatus Sahro: Policy analysis, interpretation of findings, and writing—implications and conclusion.

Generative AI or AI-assisted Technology Statement

The author(s) declare that no Genrative AI was used in the creation of this manuscript.

Conflict of interest

The author have declared no conflict of interest.

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Supplementary File 1: Structural equations.

$$\eta = \gamma_1\xi_1 + \gamma_2\xi_2 + \gamma_3\xi_3 + \gamma_4\xi_4 + \zeta$$

Measurement Model X (Independent Variables $\xi_1, \xi_2, \xi_3, \xi_4$ and ξ_5)

Food accessibility (X1)

X1.1 = $\lambda_{X1.1}\xi1 + \delta_1$ (Distribution Process)
X1.2 = $\lambda_{X1.2}\xi1 + \delta_2$ (Distribution Infrastructure)
X1.3 = $\lambda_{X1.3}\xi1 + \delta_3$ (Food Price)
X1.4 = $\lambda_{X1.4}\xi1 + \delta_4$ (Income Levels)
X1.5 = $\lambda_{X1.5}\xi1 + \delta_5$ (Food Resources)

Food utilization/consumption (X2)
X2.1 = $\lambda_{X2.1}\xi1 + \delta_1$ (Drinking Water Quality Variation)
X2.2 = $\lambda_{X2.2}\xi1 + \delta_2$ (Drinking Water Quality)
X2.3 = $\lambda_{X2.3}\xi1 + \delta_3$ (Hygienic Kitchen and Dining Area)
X2.4 = $\lambda_{X2.4}\xi1 + \delta_4$ (Hygienic Food Preparation)

Food stability (X3)
X3.1 = $\lambda_{X3.1}\xi1 + \delta_1$ (Food Price Stability)
X3.2 = $\lambda_{X3.2}\xi1 + \delta_2$ (Stability of Food Supply Levels)
X3.3 = $\lambda_{X3.3}\xi1 + \delta_3$ (Level of Food Shortages)
X3.4 = $\lambda_{X3.4}\xi1 + \delta_4$ (Food Price Variations)
X3.5 = $\lambda_{X3.5}\xi1 + \delta_5$ (Institutional Support)

Demographic characteristics (X4)
X4.1 = $\lambda_{X1.1}\xi1 + \delta_1$ (Age)
X4.2 = $\lambda_{X1.2}\xi1 + \delta_2$ (Gender)
X4.3 = $\lambda_{X1.3}\xi1 + \delta_3$ (Education Level)
X4.4 = $\lambda_{X1.4}\xi1 + \delta_4$ (Household size)
X4.5 = $\lambda_{X1.5}\xi1 + \delta_5$ (Household Income)
X4.6 = $\lambda_{X1.6}\xi1 + \delta_6$ (Number of Livestock)
X4.7 = $\lambda_{X1.7}\xi1 + \delta_7$ (Milk Production)

Climate change (X5)
X5.1 = $\lambda_{X5.1}\xi1 + \delta_1$ (Food Shelf Life)
X5.2 = $\lambda_{X5.2}\xi1 + \delta_2$ (Increase of Food Price)
X5.3 = $\lambda_{X5.3}\xi1 + \delta_3$ (Food Quality)
X5.4 = $\lambda_{X5.4}\xi1 + \delta_4$ (Food Price Variations)

Measurement model Y (Dependent Variable η)
1. Household food security

$$Y = \lambda_{Y1.1\eta} + \varepsilon_1$$
$$Y = \lambda_{Y1.2\eta} + \varepsilon_2$$
$$Y = \lambda_{Y1.3\eta} + \varepsilon_3$$
$$Y = \lambda_{Y1.4\eta} + \varepsilon_4$$