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Nexus between food insecurity, poverty, and climate change: a cross-regional multifactorial analysis

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Climate change, by exacerbating poverty and food insecurity, creates complex dynamics that threaten global food security. This study aims to examine the complex interactions between these phenomena (climate change, poverty and food security), adopting a multidimensional approach to understand their direct and indirect relationships. The study focused on eight countries representing the African, Asian, American and European continents, selected according to their Human Development Index (HDI). Data is collected for the period 1990–2020 from platforms such as FAO, World Bank, UNDP and Our World in Data, based on indicators of poverty, climate change and food insecurity (qualitative approach). Data analysis is based on time series (temporal evolutions in climate and poverty variables) as well as thematic content analysis. Analysis of evolutions in poverty indicators and the HDI reveals marked disparities between regions, with notable progress in Asia and Europe, but persistent challenges in Africa and Yemen. Similarly, these disparities are also observed for climate evolutions and changes in land, particularly in Africa and Asia. Regarding food insecurity evolutions, there is a considerable increase with marked regional disparities, where Africa and Latin America are the most affected. Direct arable effects include reduced agricultural productivity, crop and livestock yield, increased undernourishment, reduced livelihoods and producer incomes. Indirectly, these changes reduce crop quality, disrupt ecosystem services, exacerbate resource conflicts and increase production costs. These findings provide guidance for policymakers and researchers in developing integrated strategies that address not only food security and poverty, but also climate change.

KEYWORDS

climate change, poverty, food security, effects, HDI

1 Introduction

Climate change is a major challenge for global sustainable development, integrated into the United Nations Sustainable Development Goals (SDGs), with SDG 13 specifically focusing on addressing climate change (Ngarava et al., 2019). Climate change is driven by changes in temperature regimes, precipitation levels, and extreme weather events, thereby increasing food insecurity (El-Sayed and Kamel, 2020; Lee et al., 2023). Indeed, the impacts of climate change, including extreme weather events, global warming, and precipitation variability, exacerbate interconnected issues (increasing aridity, water deficits, desertification, increased evapotranspiration), thereby threatening agricultural production systems (Grigorieva et al., 2023; Onyenekwe et al., 2019).

At the same time, the World Bank estimates that approximately 735 million people worldwide live in extreme poverty (Sachs, 2022). Although climate conditions are never considered the sole cause of poverty, climate variability and change are widely recognized as factors that can exacerbate poverty, particularly in less economically developed countries and regions (Eriksen and O'Brien, 2007; Leichenko and Silva, 2014).

However, the relationship between poverty, climate change and food insecurity is based on complex dynamics. Indeed, analyses of the impacts of climate change on poverty remain very limited and are generally based on the recognition that the poor are already vulnerable to the adverse effects of climate change (Leichenko and Silva, 2014). On the other hand, the links between climate change and food security remain obscure and unexplored (Dewananda et al., 2023). Most often these phenomena are developed independently, either by highlighting the relationship between food security and climate change (El Bilali et al., 2020; Hasegawa et al., 2021; Adesete et al., 2023) or between poverty and climate change (Lankes et al., 2024; Marotzke et al., 2020; Moellendorf, 2024; Pérez-Peña et al., 2021; Rosyadi and Badriah, 2024). This approach does not provide a better understanding of the complex relationships between these phenomena (Toromade et al., 2024). However, in the face of evolving challenges caused by climate change, it is becoming crucial to refer to reliable data to ensure food security in the short and long terms (Cafiero et al., 2022). And the adoption of assessment methods that do not integrate all these phenomena, as demonstrated above, could be perceived as a major constraint for achieving these objectives, both in the short and long term, in a climate context. Gold (2024) attempted to fill these gaps by merging these phenomena, proposing an analysis of food insecurity under the influence of climate change and poverty through a few indicators. However, the latter focused on the West African region in its methodological approach, thus limiting the scope of the conclusions.

Although economic, geographical, and social contexts differ considerably from one region to another, these differences should not be seen only as limitations but also as opportunities for comparative analysis. Indeed, the determinants of food insecurity and poverty vary depending on available resources, the resilience of production systems, and institutional capacities to cope with the effects of climate change (Hasegawa et al., 2021; Cafiero et al., 2022; Dossa et al., 2025). Thus, the inclusion of countries from different regions allows for the identification of not only common vulnerabilities but also regional specificities, providing a robust comparative framework.

Based on these observations, a joint assessment of the three phenomena on a broader regional (transcontinental) scale is crucial for a better understanding of the interactions between them and for proposing appropriate solutions. By highlighting these links, this study seeks to provide a robust analytical framework to guide decision-makers toward appropriate and equitable solutions. It also aims to assess the dynamics of the three situations (poverty, food security and climate change) and through a multidimensional transcontinental analysis, to assess the direct and indirect relationships between poverty, climate change and food insecurity. This assessment is based on two main assumptions: (i) climate change has a negative impact on poverty and food security

by reducing the availability and stability of agricultural resources; (ii) countries with a low Human Development Index (HDI) are most vulnerable to the effects of climate change and food insecurity.

To better situate our contribution, the article is structured as follows. The first part presents the empirical framework, drawing on previous studies and specifying the scientific interest that motivates this research. The second part describes the methodology adopted, including the areas studied, the data collected, and the analytical methods employed. The third part presents the results obtained, followed by a discussion that puts these results into perspective in relation to existing work and public policy issues. Finally, a final section is devoted to the limitations of the study and opens avenues for future research.

2 Empirical framework (previous studies) and scientific interests of the study

Much research has been done on the relationship between climate change, food security or poverty in national, regional and global contexts. Among the most recent, the studies of Adesete et al. (2023) (including 30 countries in sub-Saharan Africa); Ohiomu and Ozor (2021) (including 17 countries in sub-Saharan Africa); Appiah-Otoo et al. (2024) (including 27 countries in sub-Saharan Africa); Sambo and Sule (2024) (Nigeria); Parkhomenko et al. (2024) (Ukraine and Slovakia); Zarei and Azizi (2024) (Iran); Fiorini et al. (2024) (Brazil); Łacka et al. (2024) (including all European Union countries except Belgium, Cyprus, Luxembourg, Malta and Slovenia).

However, these researchers have focused mainly on analyzing the relationship between climate change and food security. This work, although crucial, does not take into consideration the poverty dimension. An aspect that few other studies have tried to explore. These are mainly the works of Rosyadi and Badriah (2024) (Indonesia), Pindiriri et al. (2024) (Zimbabwe); Azzarri and Signorelli (2020) (24 countries in sub-Saharan Africa); Ogbiede-Osaretin et al. (2022) (Nigeria); Gilli et al. (2024) (Sub-Saharan African countries).

However, this work has also focused mainly on bilateral analyses, focusing on the relationship between climate change and poverty, without adopting an integrative approach that simultaneously encompasses the three interdependent dimensions: climate change, poverty and food security.

Furthermore, very few studies (Kalu et al., 2024; Tamasiga et al., 2023) have attempted to deepen the analysis by adopting an integrative approach, thus considering the three dimensions targeted in this study. While Kalu et al. (2024) limited his research to the specific case of Nigeria, Tamasiga et al. (2023) restricted their work to a conceptual literature review, highlighting the need for empirical, multi-regional approaches. These studies nonetheless underline the importance of viewing climate change not as an isolated phenomenon but as a multiplier of vulnerabilities, particularly in developing regions where social safety nets are weak and livelihoods are highly dependent on climate-sensitive sectors.

Recent global analyses have further reinforced these findings. For instance, Samiullah et al. (2024) conducted a comprehensive global review on “The Nexus Between Climate Change and Food Security: A Comprehensive Review of Global Trends and Regional Disparities”, revealing that Africa and South Asia remain the most affected regions due to low adaptive capacity and institutional fragility. Similarly, the FAO (2018) emphasizes that climate change acts as a risk amplifier by deepening poverty, undermining food security, and increasing inequality, particularly among vulnerable populations. These organizations advocate for integrated strategies linking poverty alleviation, climate resilience, and food system transformation as part of the global agenda for sustainable development.

Despite these advancements, empirical research that integrates the threefold relationship between climate change, poverty, and food security across multiple continents remains scarce. Most existing works are limited either by geographical focus or by methodological constraints, often failing to capture cross-regional dynamics and comparative vulnerabilities. The present study fills these limitations by including several regions from different continents including America, Europe, Africa and Asia, with a broader method of analysis (qualitative and quantitative), offering a broader view of these phenomena. This approach provides a more holistic understanding of the direct and indirect linkages among the three phenomena and offers new insights for developing evidence-based, regionally adapted policy responses to address global sustainability challenges.

3 Methodology

3.1 Study areas

To ensure that the generality of climate change impacts is considered at the global level (Ahmed et al., 2023; Ngarava et al., 2019; Sey, 2023), the study was carried out by integrating a total of eight countries, with two countries per continent. The main criterion for selecting countries considered in this study was the Human Development Index (HDI) (country with

the lowest index and the country with the highest index). This is an indicator that several studies (Barnett et al., 2008; De Sherbinin, 2014; Leichenko and Silva, 2014; Romero-Lankao et al., 2012; Preston et al., 2011) have used as an indicator of poverty, food security and social vulnerability in studies focused on climate change. Thus, based on data from the United Nations Development Programme (UNDP) (2024) (<https://hdr.undp.org/data-center/human-development-index#/indicies/HDI>), the countries selected by continent are summarized in Figure 1. The main indicators used in this study, along with their expected outcomes and sources, are presented in Table 1.

3.2 Data Collected

3.2.1 Poverty indicators

Three indicators were identified and included in this study as poverty indicators. These include the poverty rate, the HDI, and the gross national income (GNI). The choice of these continents is based on the fact that they, in particular the HDI, are considered to be a determining factor in assessing countries’ economic growth, the availability of livelihoods, the level of education, access to healthcare, and community income (Aminda et al., 2024; Biggeri and Mauro, 2018; Ladi et al., 2021; Martínez-Guido et al., 2019). HDI and GNI are also the most widely used indicators in studies on climate change and its influence on poverty (Leichenko and Silva, 2014).

3.2.2 Climate change indicators

Regarding climate change, the study also relied on three fundamental indicators. These include average annual temperature and precipitation, as well as the area of arable land. These climate indicators are considered key parameters for understanding long-term climate variations in several other studies (Dahan, 2018; Faye et al., 2018; Grami and Ben Rejeb, 2015).

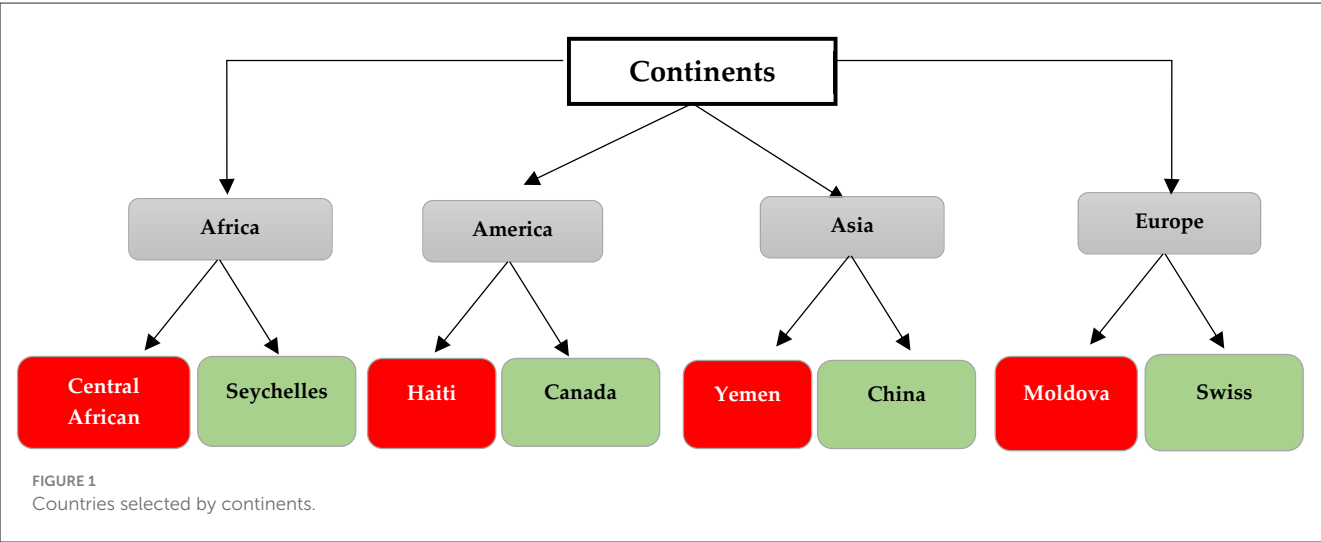


TABLE 1 Key indicators of poverty and climate change exploited.

Variables	Description	Expectation	Sources	Year
Poverty indicators				
Poverty	Average annual poverty rate at the societal poverty line (% of population)	Expected to increase with rising temperature and decrease with higher HDI and GNI	OWD	1990–2020
HDI	The average annual Human Development Index (HDI)	Expected to decrease with climate stress (temperature rise, lower rainfall) and increase with improved food security	UNDP	1990–2020
RNB	Gross national income (GNI) per capita (average)	Expected to decline under severe climate variability and improve with agricultural productivity and food stability	FAO	1990–2020
Climate change indicators				
Precipitation	Average annual precipitation (mm)	A decline in precipitation is expected to increase poverty and food insecurity	BM	1990–2020
Temperature	Average monthly temperature (°C)	A rise in temperature is expected to reduce food production and worsen poverty	BM	1990–2020
Arable land	Proportion of arable land	A higher proportion is expected to enhance food availability and reduce poverty	BM	1990–2020
Food security				
Multidimensional	There is no single, specific indicator for the phenomenon of food insecurity.	Expected to worsen under conditions of poverty, high temperature, and low rainfall	Based on review	

BM, World Bank; OWD, Our World in Data <https://ourworldindata.org/poverty#explore-data-on-poverty>.

3.2.3 Indicators of famine (food insecurity)

Food insecurity is considered a multidimensional problem that is difficult to adequately capture through an indicator (Ayalew et al., 2024). For example, the FAO uses several parameters (prevalence of moderate and severe food insecurity, prevalence of malnutrition, obesity, stunting, and many others) to assess this phenomenon (Ayalew et al., 2024).

Furthermore, given this multiplicity of indicators and the unavailability of information at the national level for all the countries considered, this research drew on the literature to analyze the level of food insecurity at the country level, as have several other authors (Adhikari et al., 2023; Azmi et al., 2023; Righettini and Bordin, 2023).

3.3 Method of analysis

Time series have been used to assess the dynamics or evolutions of different indicators over time (Sakli, 2016). This approach is often used in studies addressing mainly climate change issues (Busker et al., 2024; Espinosa et al., 2022; Rahman and Lateh, 2017). Regarding the data collected through the literature, thematic content analysis is used to explore evolutions in food insecurity, the effects of climate change on food security and poverty from primary texts.

Three main hypotheses underpin this study: (i) Climate change has a negative impact on poverty and food security by reducing the availability and stability of agricultural resources; (ii) countries with a low Human Development Index (HDI) are most vulnerable to the effects of climate change and food insecurity; and finally (iii) poverty exacerbates the effects of climate change on food insecurity by limiting adaptive capacities. Therefore, correlation

matrices were generated using the GGally package and the ggpairs function, allowing us to explore the relationships between indicators (poverty and climate change) for which quantitative data is available. Figure 2 shows the conceptual framework illustrating the interactions between poverty, climate, and food insecurity.

The open and axial coding methods were used to code the information gathered through literature reviews, and to understand how the resulting codes are related to each other.

The analyses were carried out using Python language version 3.9.

4 Results

4.1 Exploring global evolutions and regional country specificities

4.1.1 Evolutions in poverty indicators

4.1.1.1 Poverty rate

The evolution of poverty rates (population living on less than \$1.9 per day) over time in the different selected countries highlights contrasting evolutions across the continents studied, revealing distinct dynamics in poverty reduction (Figure 3). Indeed, the time series shows that in Africa, although progress has been made, instability is still a prevalent factor. First, in the case of Seychelles (a), the evolution of this indicator is characterized by a decreasing dynamic, ranging from 76% (1990) to around 50% (2020), despite some variations. Then, a similar observation is observed in the Central African Republic (b), where the poverty rate decreased from 80% to 50% during this period.

As for the countries of America, notably Canada (c) and Haiti (d), the general evolution in the poverty rate also shows a gradual improvement. However, while Haiti has continued to

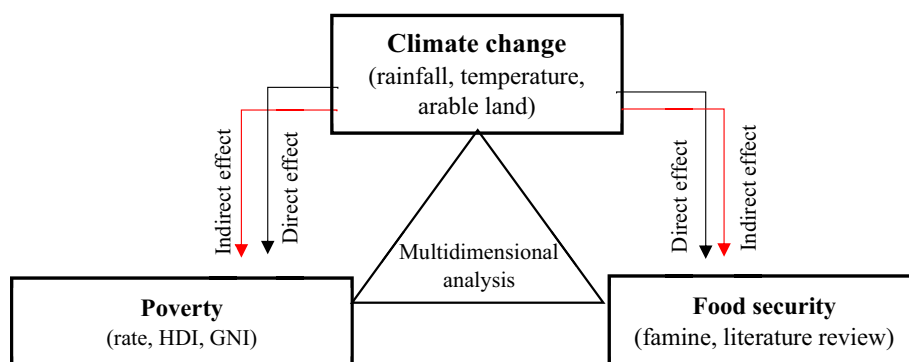


FIGURE 2
Conceptual framework diagram.

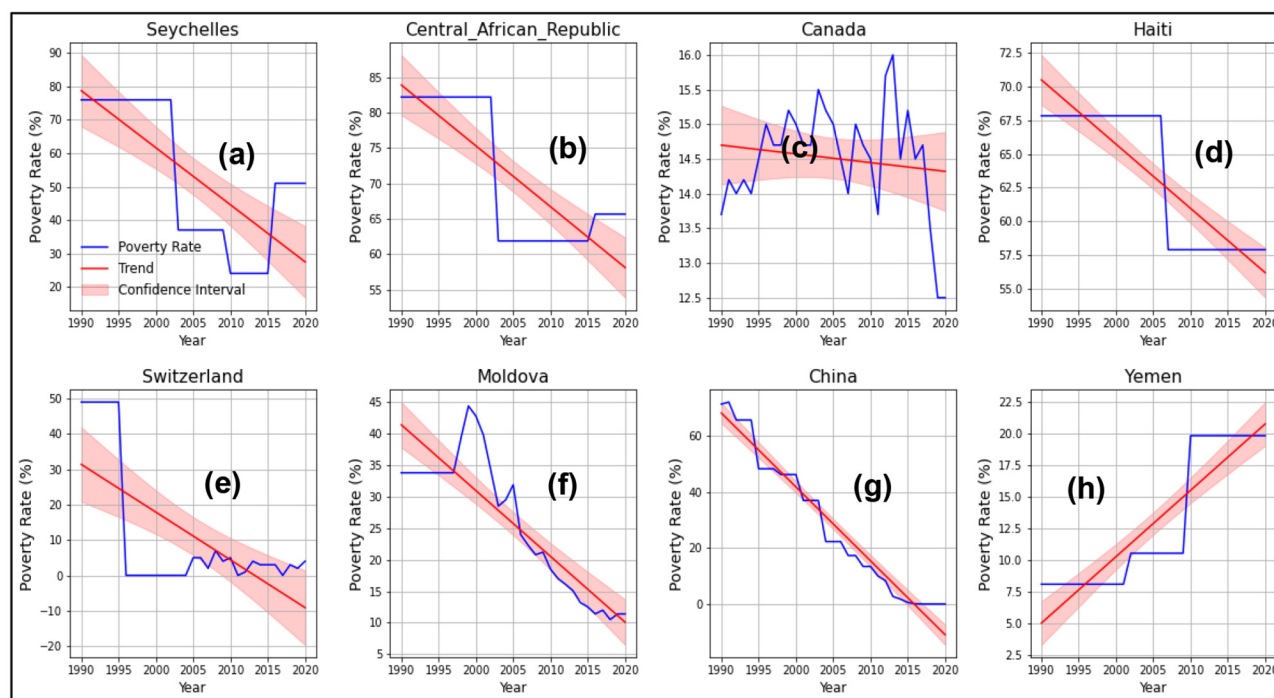


FIGURE 3
Dynamics of poverty rate between 1990 and 2020 in selected countries by continent.

reduce its poverty rates, with a marked downward evolution, Canada is experiencing significant variations, with peaks in poverty, particularly in the period 2012–2013 when the rates were around 16% of the Canadian population. Nevertheless, the American evolutions observed across the two countries show a certain resilience of the economies, but also the existence of pockets of vulnerability marked by temporary oscillations.

In Europe, the figures also reveal a contrasting trajectory with significant improvements but stagnation points for some countries. Switzerland (e), for example, shows a strong reduction in the poverty rate, from 49% in 1990 to around 1% in 2020, illustrating a marked shift toward prosperity and effective management of social policies. In contrast, Moldova (f), although improving (from 35%

in 1990 to around 10% in 2020), has a poverty rate that remains relatively high.

Finally, in Asia, changes in poverty rates reveal even more mixed evolutions, with countries such as China showing rapid and remarkable progress. The poverty rate there fell from 70% in 1990 to almost 0% in 2020 (g), the result of inclusive economic policies and rapid urbanization that facilitated national income growth. In contrast, Yemen (h) shows an increasing evolution, where the poverty rate has continued to increase mainly due to persistent conflicts, political instability and environmental constraints, exposing a significant part of its population to extreme conditions of poverty. In conclusion, in general, there is a gradual decrease in poverty rates within different countries, except Yemen.

Thus, during the 1990s, Africa and Asia were the most affected by poverty, as evidenced by the cases of the Central African Republic and China. These two continents had some of the highest poverty rates in the world. Today, although progress has been made, Africa still lags far behind other regions, showing a persistent evolution toward stagnation in the fight against poverty.

These results partly confirm the first hypothesis, which postulates that climate change negatively affects poverty levels through its impact on agricultural productivity and income stability. The persistent poverty observed in countries such as Yemen and the Central African Republic may be linked to high climate variability and environmental degradation that reduce agricultural output.

4.1.1.2 Human Development Index (HDI)

Figure 4 shows the evolution of the HDI between 1990 and 2020, with a general improvement across the different countries considered, but with significant disparity at the continental level. Indeed, Africa, particularly the Central African Republic, stands out for the lowest HDI levels, with a peak of around 40% (2020). Meanwhile, the Seychelles shows increasing momentum, reaching around 80% over the same period. Regarding the Asian region, analysis of the figure shows a gradual evolution of this index in China, ranging between 60% (1990) and 85% (2020), while Yemen also displays relatively low scores. The improvement observed in China suggests a positive influence of political decisions through economic reforms and investments in several areas (health, education).

However, America and Europe stand out with the highest indices, reaching around 97% in 2020 in Switzerland and 90% in Canada. It primarily reflects the combination of robust social policies, efficient education systems, and dynamic economies promoting inclusive human development.

The observed disparities in HDI across continents clearly support the second hypothesis. Countries with high HDIs, such as Canada and Switzerland, display greater resilience to climate shocks, while those with lower HDIs, such as the Central African Republic and Yemen, remain more exposed to the cumulative effects of poverty and food insecurity. A low HDI amplifies exposure and reduces adaptive capacity, thus perpetuating cycles of poverty.

4.1.1.3 Gross national income per capita

Gross National Income (GNI) is a fundamental economic measure that encompasses all income generated by a country's citizens and businesses, including income from abroad. This indicator provides an important perspective for analyzing a nation's wealth in monetary terms. Despite the inclusion of other indices such as the poverty rate and the HDI, GNI remains relevant for the purposes of this study. This development highlights the importance of GNI analysis for understanding structural inequalities at both the aggregate and national levels. To do this, the analysis of the results in Figure 5 indicates a general upward evolution in GNI per capita in most of the countries studied over the last decades. However, this progression is marked by strong disparities between regions and countries.

In Africa, the Central African Republic (Figure 4a) has the lowest GNIs, ranging from \$150 in 1990 to \$550 in 2020, revealing

slow economic improvement despite a slight increase over time. Asia reflects contrasting dynamics, notably in Yemen, where after a notable increase reaching around \$1,200 per capita between 2010 and 2015, GNI falls dramatically to around \$300 in 2020;

In Europe, the gaps between countries are striking. While Moldova shows slowing dynamics with per capita income increasing from \$1,000 to \$4,000, Switzerland stands out with the highest indices, increasing from \$40,000 per capita in 1990 to around \$80,000 in 2020, testifying to a stable and prosperous economy. On the American continent, high levels of gross national income (GNI) are observed in Canada, which increased from \$20,000 in 1990 to \$40,000 in 2020. In contrast, Haiti, facing economic fragility, experienced a much slower evolution from \$500 in 1990 to \$1,400 in 2020. These gaps illustrate both socio-economic inequalities and divergences in national economic strategies. These observations clearly show that economic growth, as measured by GNI, remains unevenly distributed not only between continents, but also within them.

When summarizing the results of poverty indicators (poverty rate, HDI, and GNI), a complex picture of global poverty emerges. The joint analysis of these indices highlights the importance of integrating several dimensions to assess socio-economic dynamics, as each of these indicators provides unique perspectives. However, an analysis of the possible relationships between these indicators and climate change would be relevant. In this context, a visual exploration of the dynamics around these climate drivers could provide additional insights into current and future challenges related to poverty and equity.

The trends observed in GNI reinforce the third hypothesis, suggesting that poverty exacerbates the effects of climate change on food security by limiting adaptive capacities. In low-income contexts, such as Haiti or the Central African Republic, limited financial and institutional resources restrict investments in climate adaptation and sustainable agriculture. This finding corroborates the integrative approach developed in the conceptual framework (Figure 2), which posits a bidirectional relationship: climate change intensifies poverty, and poverty, in turn, weakens societies' ability to cope with climatic stressors.

4.1.2 Dynamics of climate indicators or factors

4.1.2.1 Temperature

Figure 6 reveals a chronological evolution of temperature characterized by irregular fluctuations across all the countries studied. However, the evolution of temperature highlights clearly marked upward evolutions, regardless of the country or continent considered. However, the annual averages of this parameter also reflect a spatial variability similar to that observed for poverty indicators. Indeed, the two African countries stand out as the hottest with an annual average temperature varying between 25°C (Central African Republic) and 27°C (Seychelles).

However, in America and Asia, the evolution analysis also shows strong differences between countries, with very high temperatures in Haiti and Yemen where temperatures range between 24°C and 25°C, although Canada is the least hot country (negative temperature between 1990 and 2020). Meanwhile, the European zone shows moderately low temperatures between 4 °C

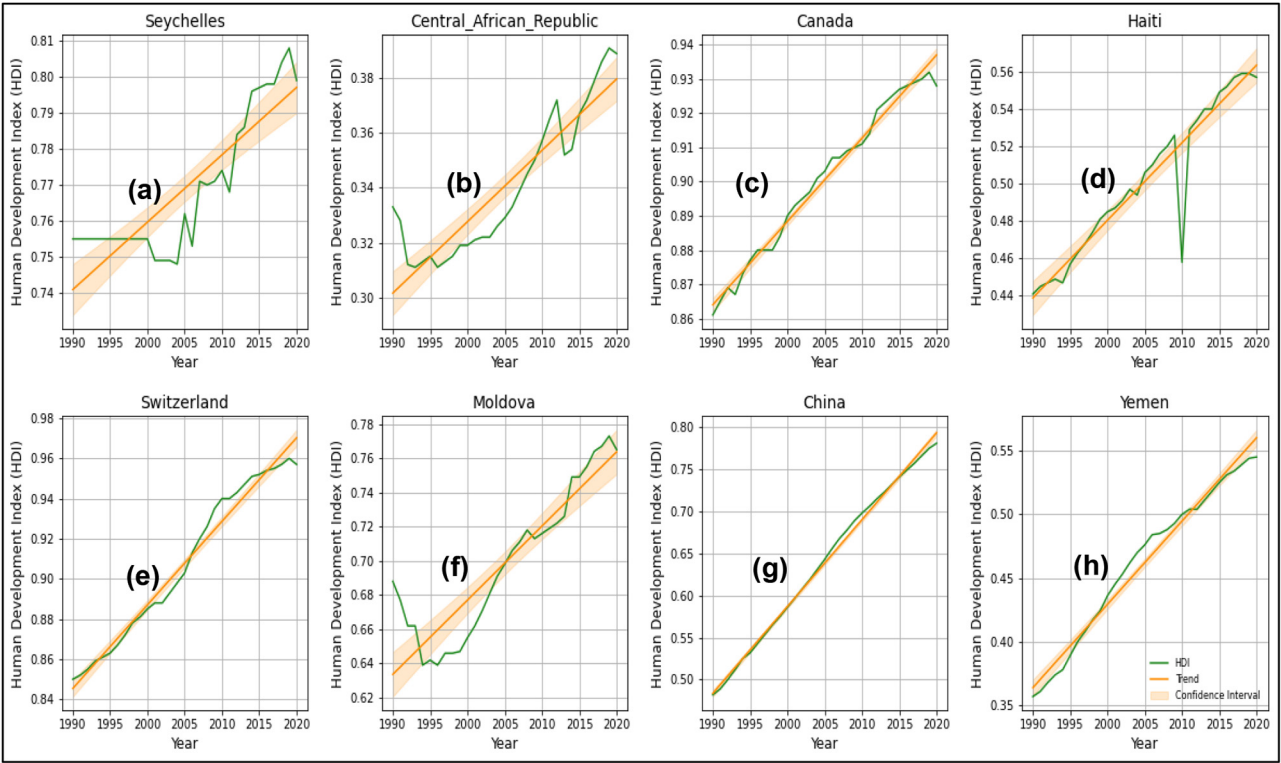


FIGURE 4
HDI dynamics between 1990 and 2020 in selected countries by continent.

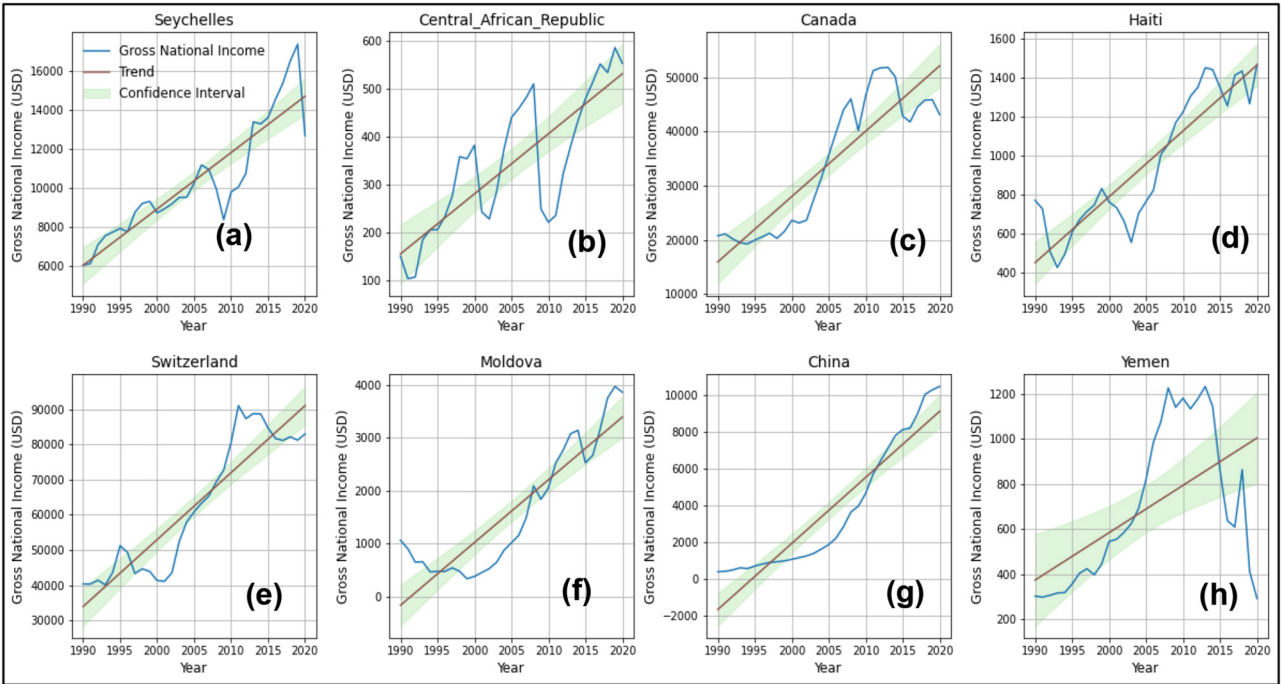


FIGURE 5
Dynamics of gross national income per capita between 1990 and 2020.

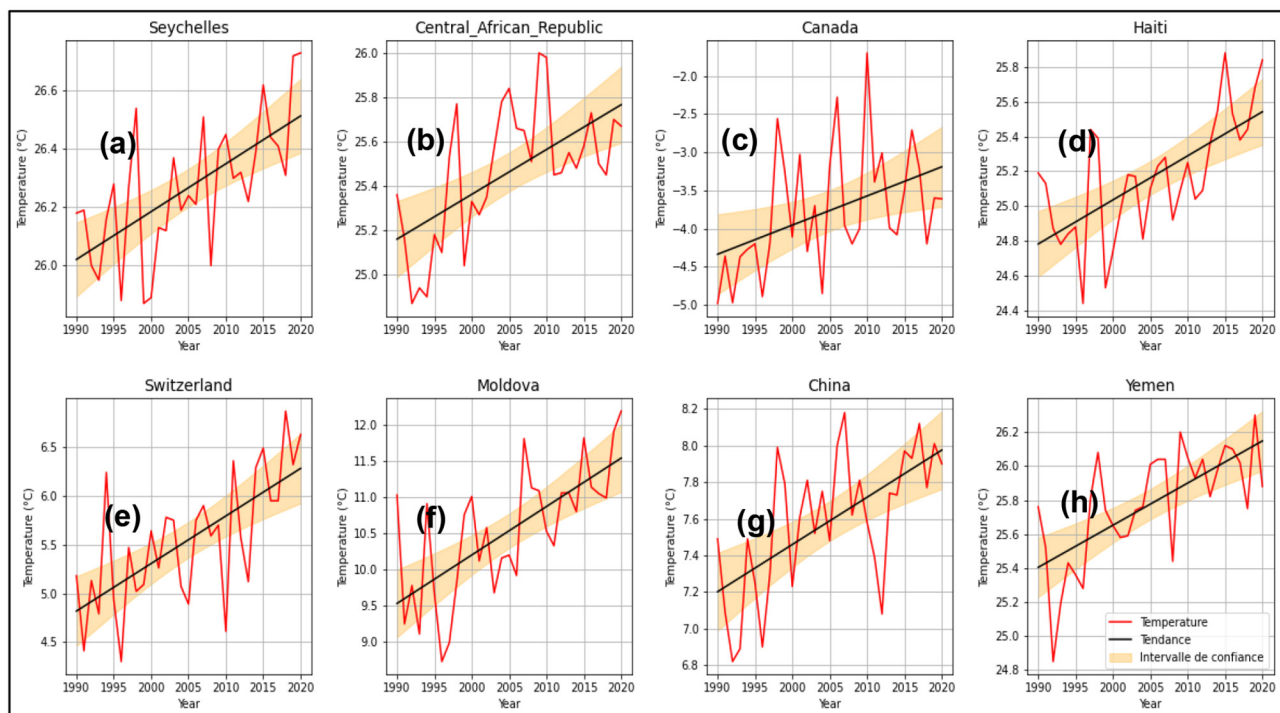


FIGURE 6
Dynamics of average annual temperature between 1990 and 2020.

(Switzerland) and 12°C (Moldova). These results confirm once again a very noticeable regional disparity in terms of climate between countries including those belonging to the same continent.

From a theoretical standpoint, such patterns directly connect to the first hypothesis of this study, which states that climate change negatively impacts poverty and food security by altering agricultural productivity and environmental stability.

4.1.2.2 Precipitation

Figure 7 shows the chronological evolution of rainfall by country (Seychelles, Central African Republic, Canada, Haiti, Switzerland, Moldova, China and Yemen). Analysis of the graphs indicates strong fluctuations at the level of the different countries during the period from 1990 to 2020. However, although the fluctuations are irregular and similar in these countries, there are nevertheless general evolutions that are different from one country to another.

First, the evolution of the average annual rainfall in the two African countries shows generally increasing evolutions. As an illustration, it evolves from 1,200 mm (1990) to around 2,000 mm (2020) in the Seychelles against values oscillating between 1200 mm (1990) and 1360 mm (2020) in the Central African Republic.

Secondly, in America, the analysis of the results shows significant variability between the two countries. Indeed, while in Canada, an upward evolution is observed with precipitation increasing from 660 mm (1990) to around 720 mm (2020), the rainfall values in Haiti show a form of stability oscillating around 900 mm throughout the period. In Europe, rainfall variability is also manifested through divergent evolutions between countries.

Although Switzerland is wetter when observing rainfall values, it experiences relative stability with around 1600 mm between 1990 and 2020. On the other hand, Moldova, less humid, experiences a marked decline with values ranging from 600 mm to less than 500 mm, highlighting a phenomenon of progressive drought. A similar situation prevails in Asia, where China shows a notable decrease in its average rainfall, from 900 mm in 1990 to less than 800 mm in 2019, while Yemen maintains stability around less than 150 mm, reflecting a persistent arid climate.

These regional differences confirm the complex climatic, influenced by the geographical, economic and environmental specificities of the countries. An analysis also focusing on available and cultivated arable land will make it possible to further appreciate the extent of the manifestations of climate change in each country. This assessment can provide a valuable perspective on the capacity of populations to maintain their food security and adapt to environmental pressures, while highlighting the structural difference around agricultural resources in these continents.

These heterogeneous rainfall patterns highlight the importance of climatic variability in shaping vulnerability profiles. In the context of our conceptual model, precipitation instability interacts with poverty levels to produce region-specific exposure patterns.

4.1.2.3 Dynamics of arable land available at national scale

Data analysis reveals an overall evolution of decreasing available arable land over time, marked in almost all countries, with the notable exception of Haiti (Figure 8). This country shows a slight increase, from 780,000 hectares in 1990 to approximately 1,000,000 hectares in 2020. In contrast, other countries such

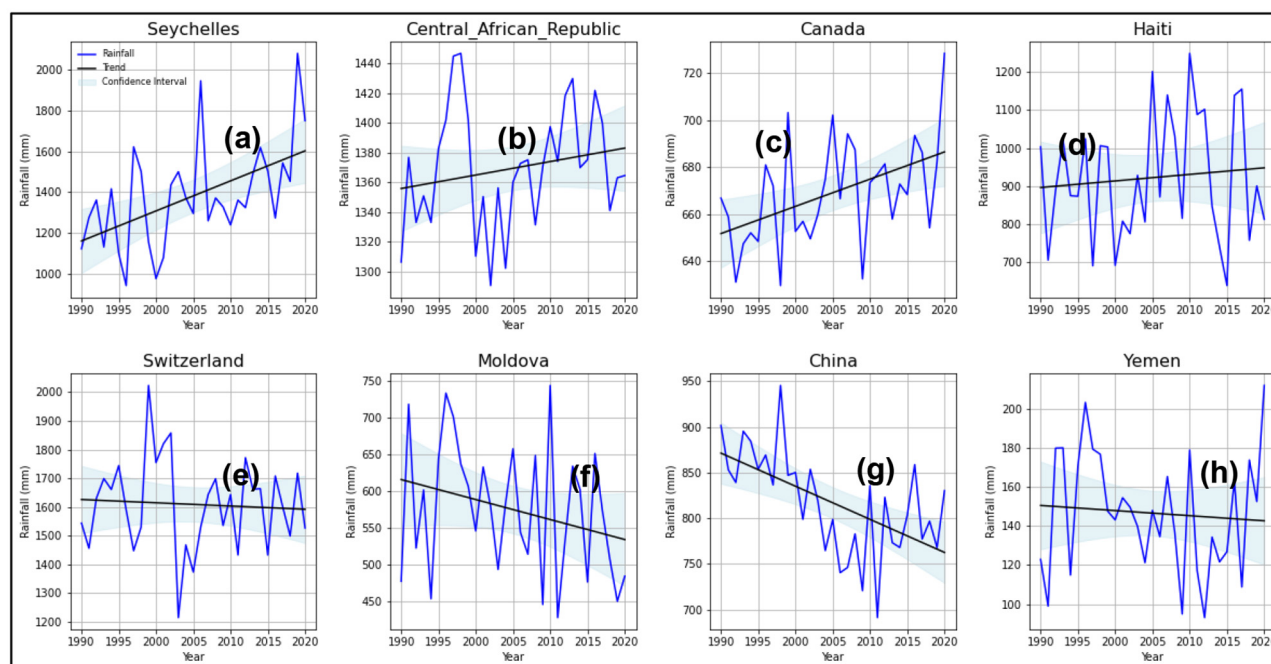


FIGURE 7
Dynamics of average annual rainfall between 1990 and 2020.

as Canada experience a gradual and notable decrease, from 41,420,000 hectares in 1990 to 38,648,000 hectares in 2020. On average, the reduction is particularly significant in countries with a high agricultural dependence, highlighting the impacts of climate variability on agricultural land use.

However, the difference between countries on the same continent are striking. In Africa, the Central African Republic (1,870,000 hectares) has more land throughout the period, while the Seychelles presents a marginal situation with arable land of less than 1,000 hectares. These gaps reflect structural differences between extensive agricultural systems and countries where the available agricultural areas are very small. In Asia, China shows a marked decline in arable land, from 123,800,000 hectares in 1990 to 108,962,000 hectares in 2020, while Yemen presents a more limited variability, with areas fluctuating around 1,500,000 hectares.

Comparative evolutions between continents show a marked heterogeneity in the evolution of available arable land. America illustrates opposing dynamics: Canada is experiencing a steady reduction in available land but maintains one of the largest areas in the world in absolute value, while Haiti shows an atypical increase in arable land, reaching 1,000,000 hectares in 2020. This contrasting dynamic is also observed in the two European countries, with Switzerland maintaining relative stability at around 400,000 hectares, while Moldova recorded a significant reduction from 1,736,000 hectares in 1990 to 1,699,800 hectares in 2020.

The decline in available arable land reinforces the link between environmental degradation and livelihood vulnerability established in the theoretical framework. This confirms that climate-related land pressure acts as both a driver and a consequence of poverty in developing economies.

4.1.2.4 Correlation between climate and poverty indicators

After this assessment of the dynamics of these two groups of factors (poverty and climate change), Figure 9 offers a simpler overview through the evaluation of the correlation between the six indicators. Indeed, the correlation analysis shows that temperature and precipitation have a significant influence on poverty indicators. First, the positive correlation observed between temperature and the poverty rate (0.558) suggests that rising temperatures tend to exacerbate the vulnerability of populations. Similarly, the positive relationship between precipitation and the poverty rate (0.33) may reflect the effect of heavy rainfall, which, when excessive or unevenly distributed, disrupts agricultural yields and exacerbates poverty. However, the positive correlations between precipitation, the HDI (0.208) and average income (0.421) indicate that in certain contexts, better water availability can stimulate and strengthen socio-economic growth.

Conversely, the negative correlations reveal critical dynamics. The negative relationship between arable land and the poverty rate (-0.177) confirms that access to arable land reduces poverty, by improving food security and economic opportunities for rural households. On the other hand, the strongly negative correlations between temperature and the HDI (-0.717) and between temperature and average income (-0.579) show that rising temperatures, manifested as prolonged heat waves, directly compromise human well-being and economic growth. These results thus emphasize that climate conditions, particularly rising temperatures, are a key factor in vulnerability, while the availability of land and water resources plays a central role in poverty alleviation and in improving human development.

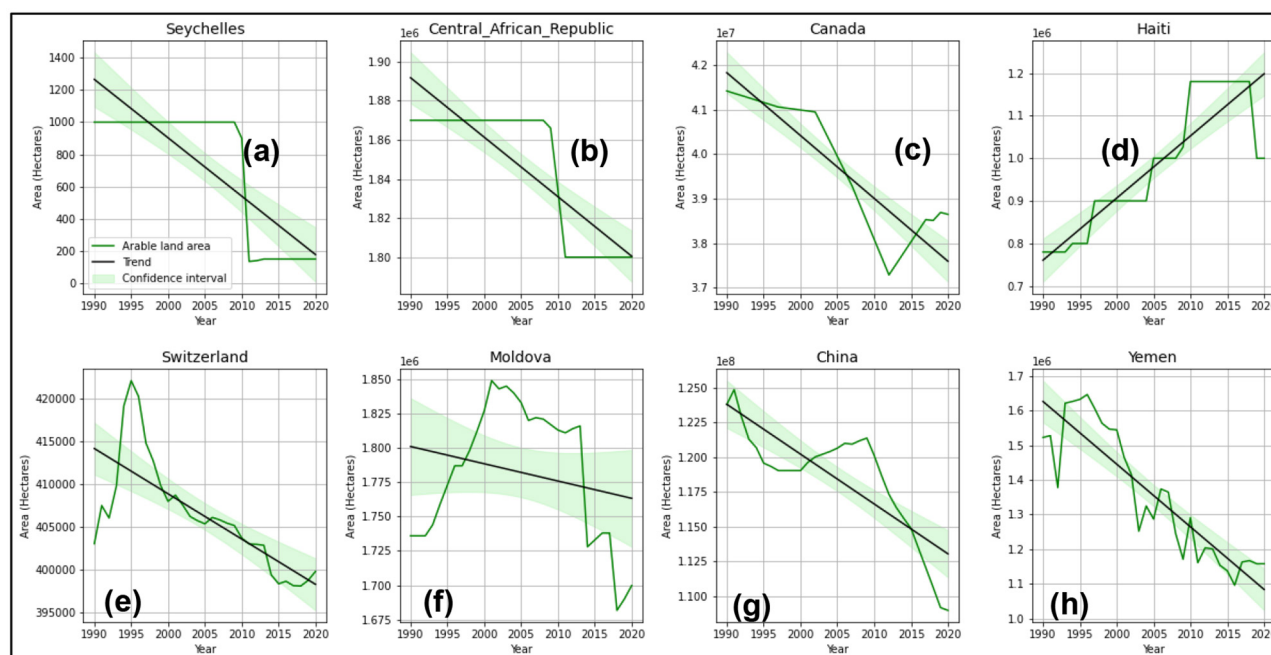


FIGURE 8

Evolution of available arable land in hectares by country.

These empirical relationships align with the theoretical framework developed in the methodology section, particularly the climate–poverty nexus model, which posits that climate variability acts as both a direct and indirect determinant of socioeconomic vulnerability. The strong correlations observed between temperature, precipitation, and poverty indicators empirically validate this theoretical linkage, highlighting how environmental stressors translate into economic deprivation. These findings confirm the theoretical assumption that climate change affects poverty not only through reduced natural capital (land, water) but also through its systemic effects on livelihoods, consistent with the multidimensional poverty and vulnerability framework.

4.1.3 Exploring global evolutions in famine

4.1.3.1 Global evolutions in food insecurity in the world

A literature review indicates that in 2017, approximately 1.9 billion people worldwide did not have a balanced diet, with a higher proportion in South Asia and Africa (Frank et al., 2017; Wudil et al., 2022). Although there will be improvements in 2022 (more than 345 million people facing hunger), the situation remains worrying, with more than 2 billion living in a situation of moderate or severe food insecurity (UNICEF, 2022).

Estimates point to an escalation of the situation by 2030, with approximately 670 million people, or 8% of the global population, who could be threatened by hunger (Clapp and Moseley, 2020). Meanwhile, the World Food Programme (WFP) in its estimates adds that 50 million people in 45 countries will be threatened with extreme hunger (UNICEF, 2022), with a progressive influence of climatic factors (drought and natural disasters) (Wudil et al., 2022).

This situation highlights the urgent need for action to achieve the Sustainable Development Goals aimed at eradicating hunger and ensuring food security by 2030.

Moreover, progress toward this SDG goal is monitored through indicator 2.1.2. on the prevalence of moderate or severe food insecurity in each population. Indeed, a recent assessment of this progress by the Committee on World Food Security (CFS) through this indicator indicates that since 2014, the prevalence of moderate or severe food insecurity in the world has continued to increase, reaching 29.3% of the world population of 2.3 billion people in 2021 (Committee on World Food Security, 2022). Of these people, 40% were facing severe food insecurity (total lack of food), representing 11.7% of the world population (923.7 million), a figure that has been steadily increasing since 2019 (Committee on World Food Security, 2022). This deterioration highlights the worsening conditions for the most vulnerable, despite relative stability between 2020 and 2021.

These global patterns are consistent with the theoretical premise that food insecurity results from structural inequalities exacerbated by climatic stress. This supports the conceptual link established in the methodology between climate variability, agricultural productivity, and human well-being.

4.1.3.2 Global evolutions in food insecurity in Africa

Variability observed in food insecurity are striking, particularly in Africa, where the situation has deteriorated sharply between 2020 and 2021. Indeed, according to the CFS, in Africa, the prevalence of moderate or severe food insecurity increased by 1.9 percentage points, reaching 57.9%, while severe food insecurity affected nearly one in four people (322 million people), an increase of 21.5 million compared to 2020 (Committee on World Food Security, 2022).

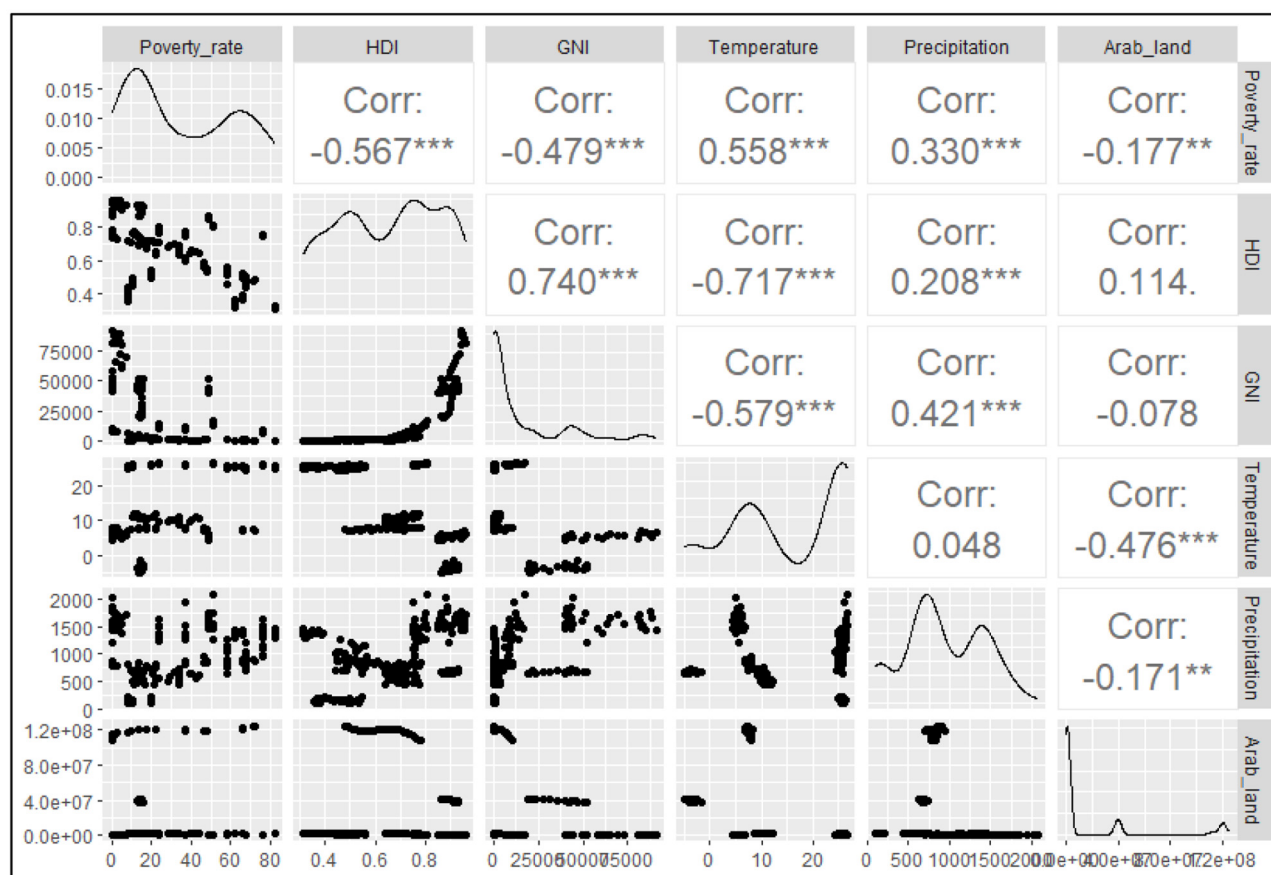


FIGURE 9

Correlations between poverty and climate change. Significant at the following levels: 0.1% "****"; 1% "***"; 5% "**".

Moreover, globally, it is recognized that more than a third of severely food insecure people live in Africa and is the only continent where agricultural productivity per capita has been declining for 30 years (De Carvalho et al., 2021). This rather critical situation in Africa is mainly associated with Africa's strong dependence on other continents on food. For some, such as Wudil et al. (2022), Africa could achieve food self-sufficiency if it ceased to depend on food imports. Thus, Africa has considerable untapped potential, as shown by the region's relatively low yields compared to other regions with similar agro-ecological zones such as South Asia (Wudil et al., 2022). Yet, Farsund et al. (2015) concluded that Africa's land resources could quickly produce an additional 100 million tons of grain equivalent per year if intensively cultivated. This suggests that Africa has a considerable amount of arable land that, if improved, could ensure the region's long-term food security. For others, this situation is compounded primarily by increasingly recurring drought conditions, leading to water shortages for both livestock and crop production, below-average harvests, higher prices for grains and other staple foods, and reduced purchasing power for residents (Devi, 2022; Wudil et al., 2022).

4.1.3.3 Global evolutions in food insecurity in America

In Latin America and the Caribbean, although the deterioration has slowed after a rapid increase in 2020, 40.6% of the population

was moderately or severely food insecure in 2021, an increase of 1.1 percentage points compared to 2020 (Committee on World Food Security, 2022). According to the latest FAO report, Latin America and the Caribbean (LAC) countries were the second most food insecure region in the world, after Africa, with prevalences of 37.5% and 60.9% respectively (Basurko et al., 2024). Moreover, in these countries, the prevalence of moderate to severe food insecurity was higher than the global average (29.6% globally in 2022) (FAO, 2023). This situation has been accentuated by the Covid-19 health crisis. As an illustration, another study conducted in 13 LAC countries, based on World Bank data, estimated that approximately 4 out of 10 households surveyed had experienced food insecurity during the COVID-19 pandemic (Hernández-Vásquez et al., 2022). Further, according to the CSA, this serious food insecurity has crossed a new threshold of 14.2%, with almost 10 million additional people affected compared to 2020, and a total increase of 30 million since 2019 (Committee on World Food Security, 2022).

4.1.3.4 Global evolutions in food insecurity in Asia

For Asia and the Pacific, the prevalence of food insecurity, at both levels of severity (moderate and severe), has been lower than global levels since 2015, with an overall prevalence rate of 23.5% for moderate or severe food insecurity, compared to 29.9% for the

world (FAO, 2024). Compared to sub-Saharan Africa, where the prevalence was much higher at 40.5% in 2020, Asia shows a less severe situation, although South Asia (40.3%) remains particularly affected, accounting for one third of the world's severely food insecure people (FAO, 2024). Indeed, the critical level observed in South Asia seems logical in the context where this region is widely recognized as one of the regions in the world most sensitive to the effects of climate change (Sundram, 2023). This region is highly vulnerable to the adverse impacts of climate change, including rising temperatures, changing precipitation patterns, and extreme weather events such as droughts and floods (United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), 2024). These climate-related challenges directly affect agricultural productivity, leading to yield losses, crop failures, and livestock deaths (Lacetera, 2019). Smallholder farmers, who constitute a significant portion of ASEAN's agricultural workforce, are particularly vulnerable to these climate risks due to limited access to resources and their adaptive capacities (Sundram, 2023).

4.1.3.5 Global evolutions in food insecurity in Europe

Compared to other regions, Europe has the lowest rates of food insecurity (FAO, 2021a). However, despite having better indices, EU member states are far from having eradicated food insecurity: moderate or severe food insecurity affected 15% of Bulgarians, 11.5% of Portuguese, 10% of Hungarians and 9% of Spaniards (and 6% of French) in 2020 (Laurent, 2023). Overall, the moderate or severe prevalence in the European area was estimated at 10.6% in 2019, while severe food insecurity affects only 1.7% of the total population, rates significantly lower than previous statistics highlighted for other regions.

However, like the global situation, hunger reduction has slowed in recent years and the number of undernourished people in 2019 remained virtually unchanged compared to 2014 (FAO, 2021b). This situation highlights common challenges with other regions such as Africa, Asia and the Americas. This variability observed on a global scale show the intensity and diversity of the challenges that regions must face to ensure the food security of their populations.

In terms of forecasts, nearly 670 million people are projected to still be undernourished in 2030, or 8% of the world population, the same proportion as in 2015 (Committee on World Food Security, 2022). The projected gradual reduction in global hunger by 2030 is largely due to significant improvements in Asia, where the number of undernourished people is projected to fall from the current 425 million to about 295 million (about 6% of the population), and a simultaneous worsening in Africa, where the number of undernourished people is projected to rise from nearly 280 million to over 310 million (just over 18% of the population) (Committee on World Food Security, 2022). In Latin America and the Caribbean, the number of people affected by undernourishment is expected to remain stable until 2030, at around 56 million (or about 8% of the population) (Committee on World Food Security, 2022).

4.2 Influences of climatic factors on the level of famine and poverty

4.2.1 Analysis of direct effects

4.2.1.1 Decrease in agricultural productivity and food availability

Climate change is leading to increased loss of arable land, particularly in drylands of developing countries where desertification and land degradation are rapidly progressing (Nellemann, 2009). This situation is significantly reducing agricultural production capacity. Furthermore, the world's main cereal crops (corn, wheat and soybeans) are influenced by fluctuations in rainfall and rising temperatures, marked by a significant decrease in yields (Hochman et al., 2017; Jha and Tripathi, 2017; Iizumi et al., 2018; Liu et al., 2018). For several authors (Iizumi et al., 2018; Gómez-Zavaglia et al., 2020), small producers, particularly in the African and Asian regions, who are heavily dependent on seasonal agricultural activities, are the most exposed to this situation. This is confirmed by the considerable 34% drop in African agricultural productivity between 1961 and 2021, under the influence of climate change, a decrease well above any other region in the world (Ault et al., 2021; Overland et al., 2022).

4.2.1.2 Reduced yields of fruits, vegetables and animal products

The negative influence of climate change on crops, particularly on productivity and yield, extends to fruits and vegetables (Durán-Sandoval et al., 2023). In addition, environmental constraints (heat waves and aridity) directly impact essential resources for livestock, including access to water and fodder (Egeru, 2016; López-i-Gelats et al., 2016; Rojas-Downing et al., 2017). Specifically, heat stress slows the fruit set of fruit vegetables and accelerates the growth cycle of annual vegetables, thus reducing the duration of their photosynthesis phase and, consequently, altering their quality (Bisbis et al., 2018). As an illustration, in Africa, the yield of crops, fruits and vegetables has decreased significantly in recent years, mainly due to its adverse effects on smallholder farmers and the increase in the duration of dry seasons (Durán-Sandoval et al., 2023). Regarding livestock production, heat stress reduces milk production, animal growth and fertility, leading to significant losses for livestock producers (Rojas-Downing et al., 2017). The availability of water and fodder for herds also decreases, creating strong competition between communities for natural resources (Durán-Sandoval et al., 2023). These also create strong competition between communities for natural resources. These combined factors not only compromise access to animal-source foods but also increase production costs in these fragile regions (Rojas-Downing et al., 2017).

4.2.1.3 Increase in undernourishment and food insecurity

The combination of a general decline in agricultural productivity and a decrease in food supply is worsening undernourishment, particularly in the most vulnerable regions. Indeed, according to the IPCC, countries facing recurrent extreme climatic events such as those in Africa have a prevalence of undernourishment 9.8 points higher than less exposed countries (Durán-Sandoval et al., 2023; FAO, 2018). These factors compromise populations' access to a balanced diet, exacerbating

nutritional disparities and increasing the risk of famine in contexts already weakened by limited income.

4.2.1.4 Loss of farmers' livelihoods and reduction in farm income

The decline in productivity and yields in both agriculture and livestock farming due to climate change directly impacts farmers' livelihoods through a gradual decline in income, thus limiting the purchasing power of rural communities (Durán-Sandoval et al., 2023; Rosegrant et al., 2018). Small producers, already limited in their approaches, are most affected by these impacts, thus accentuating their economic fragility in the face of climate hazards (Durán-Sandoval et al., 2023). This leads to the intensification of other phenomena such as migration and social insecurity through conflicts (Nellemann, 2009). These results thus summarize the direct impacts of climate change on both poverty and food security (Table 2). Taken together, these results confirm the hypothesis that climate change has a negative impact on poverty and food security by reducing the availability and stability of agricultural resources.

These observations empirically validate the theoretical model of vulnerability and resilience, which emphasizes that exposure and sensitivity to climate risks, combined with limited adaptive capacity, amplify poverty dynamics.

4.2.2 Analysis of indirect effects

4.2.2.1 Impact on crop quality and productivity

The literature analysis allows us to identify several elements as indirect impacts of climate change, including the modification of crop growth cycles and the reduction of their capacity for survival or adaptation (Jha and Tripathi, 2017; Hochman et al., 2017; Liu et al., 2018). For example, it has been shown that a reduction in the fruit set rate and the modification of the growth cycle (maturity) of vegetables influence their yield and nutritional value (Bisbis et al., 2018). Similarly, the increase in CO₂ concentration levels is a dimension of climate change that impacts the nutritional quality of foods and their nutrient content (Ishigooka et al., 2017; Zhu et al., 2018).

4.2.2.2 Degradation of agricultural ecosystem services

Firstly, indirect impacts are characterized at this level by the degradation of alterations in biodiversity linked to climate change, leading to threats to pollination services including agricultural production. On the other hand, the activities of these pollinating insects are reduced due to the deterioration of their habitats and extreme weather events, also causing a knock-on effect on the reproduction and productivity of agricultural ecosystems (Klein et al., 2007; Winfree, 2013). Another indirect effect at this level is the decrease in the quantity and quality of crops due to the increased proliferation of pests and diseases, favored by rising temperatures and changes in seasonal cycles (Jha and Tripathi, 2017; Hochman et al., 2017; Liu et al., 2018; Moses et al., 2015; Paterson and Lima, 2010).

4.2.2.3 Pressures on pastoral systems and water supplies

At this level, several authors (Egeru, 2016; López-i-Gelats et al., 2016; Njiru, 2012; Rojas-Downing et al., 2017) highlight that animal health and reproduction are affected by environmental constraints,

thus reducing livestock productivity and worsening food insecurity. Added to this is the contamination of water resources intended for irrigation by pathogens because of rising temperatures, increasing health risks in arid areas (Durán-Sandoval et al., 2023).

4.2.2.4 Rising food costs and disruptions to the agricultural calendar

The decrease in productivity and yields due to climate change leads to an increase in agricultural commodity prices and a restriction of access to adequate food, especially for the most disadvantaged households (Hasegawa et al., 2018; Stehfest et al., 2019; Valin et al., 2014). Also, the irregularity of the seasons causes changes in the agricultural calendar, with a significant disruption of traditional cropping systems and a complication in predicting food availability. These upheavals amplify food insecurity, particularly in areas where adaptive capacity remains limited.

4.2.2.5 Resource conflicts and socio-economic disparities

Multiple conflicts (rivalries for access to water, pastures and land) are intensifying as a result of soil degradation and the refraction of natural resources. Indirectly, these disagreements particularly affect the actors directly involved, pastoralists who are facing a progressive reduction in their livestock, thus compromising their economic and financial stability (Egeru, 2016; López-i-Gelats et al., 2016; Njiru, 2012). Specifically, these conflicts particularly affect women due to their marginalization in resource management bodies (López-i-Gelats et al., 2016; Rojas-Downing et al., 2017; Rosegrant et al., 2018).

4.2.2.6 Increased production costs and increased economic vulnerability

As highlighted above, the influence of climate change on agricultural productivity and yields is leading to an increase in expenditure on basic inputs (water, livestock feed, adapted irrigation systems) among agricultural households (Rivera-Ferre et al., 2016). This limits their ability to invest in sustainable adaptation strategies. These impacts, summarized in Table 2, highlight the extent of the indirect repercussions of global warming which, by accentuating structural constraints, compromise global food security, while widening socio-economic inequalities within the most vulnerable communities.

These indirect effects confirm the theoretical assumption that climate impacts propagate through both ecological and socio-economic systems, reinforcing the multidimensional and systemic nature of vulnerability.

5 Discussion

This study highlights worrying evolutions around the various indicators analyzed, marked by strong inequalities between continents and nations, thus highlighting the determining role of socio-economic, political and environmental contexts in poverty reduction efforts. In Africa, although progress is being recorded, instability and structural limitations slow the pace, highlighting the crucial role of inclusive policies to avoid an amplification of poverty in regions such as sub-Saharan Africa (Ferreira et al., 2023; Beegle and Christiaensen, 2019). Asia, on the contrary, illustrates the benefits of rapid economic growth, as in China

TABLE 2 Direct and indirect effects of climate change on food security and poverty.

No.	Effects of climate change		References
	Directs	Indirect	
Effects on food security			
1	Decrease in agricultural productivity in drylands	Reduction in fruit setting of fruiting vegetables and acceleration of growth of annual vegetables, reducing their quality.	Bisbis et al., 2018; Nellemann, 2009
2	Decrease in crop yields (corn, wheat and soybeans) worldwide	Changes in the agricultural calendar	Hochman et al., 2017; Jha and Tripathi, 2017; Iizumi et al., 2018; Liu et al., 2018; Nellemann, 2009
3	Reduction in fruit and vegetable yields mainly due to longer dry seasons	Increased pest and disease infestations, affecting crop production and quality	Egeru, 2016; López-i-Gelats et al., 2016; Rojas-Downing et al., 2017
4	Decrease in food availability due to lower productivity in livestock	Decrease in viability of crop varieties, also affecting production and quality of harvests	Jha and Tripathi, 2017; Hochman et al., 2017; Liu et al., 2018; Rojas-Downing et al., 2017
5	Significant drop in food supply	Degradation of pollination services	Klein et al., 2007; Winfree, 2013
6	Increase in undernourishment in countries most vulnerable to extreme weather events	Reduced animal health and reproduction, affecting pastoral systems in developing countries	Durán-Sandoval et al., 2023; FAO, 2018
7		Increase in the price of agricultural products, limiting access to food.	Hasegawa et al., 2018; Stehfest et al., 2019; Valin et al., 2014
8		Increase in pathogens in irrigation water supplies in arid areas.	Jha and Tripathi, 2017; Hochman et al., 2017; Liu et al., 2018; Moses et al., 2015; Paterson and Lima, 2010
9		Modification of photosynthesis and metabolism	Ishigooka et al., 2017; Zhu et al., 2018
Effects on poverty			
1	Loss of livelihoods for farmers in drylands	Increased conflicts over access to natural resources	Durán-Sandoval et al., 2023
2	Reduction in agricultural income	Reduction in livestock numbers for pastoralists, limiting their economic capacities and financial security.	Durán-Sandoval et al., 2023; Rosegrant et al., 2018
3	Socio-economic instability	Increased costs of agricultural inputs (water, feed) and infrastructure	Durán-Sandoval et al., 2023; Nellemann, 2009
4	Increased dependence of small farmers and rural communities on local resources	Exacerbation of social variability in rural areas, particularly among women	Durán-Sandoval et al., 2023

where proactive policies have enabled a dramatic reduction in extreme poverty, reinforcing the idea that a favorable political and economic framework can transform development trajectories (Sumner et al., 2022). On the other hand, the influence of an unfavorable political framework marked by conflicts, exerts opposite effects by accentuating the level of poverty and the prospects for economic recovery as in the case of Yemen (Ferreira et al., 2023). This situation seems to be limitless with an extension to the European and American zone where internal inequalities in terms of economic vulnerability, favor certain regions to socio-economic variations. This reinforces the conclusions of several other authors (Ferreira, 2010; Fosu, 2017) who did not fail to emphasize that even the most developed economies (such as Europe and America in the context of this study), are not immune to a slowdown in progress in poverty reduction. Thus, based on these observations, achieving the Sustainable Development Goals (SDGs) by 2030 must involve adopting a global approach that integrates beyond economic growth, political stability, social inclusion and social justice.

Furthermore, the study also highlights spatio-temporal disparities in the analyzed climate parameters (temperature and

precipitation), reflecting the complexity of climate variations at the global level. Indeed, the instability of precipitation associated with the generalized rise in temperatures underlines the growing influence of human activities on global warming. This situation is even more critical in Africa, corroborating the remarks of several authors (Busby et al., 2014; Overland et al., 2022) highlighting this area as one of the most exposed areas due to high annual averages. These results confirm the second hypothesis, which states that regions with lower HDI scores are most vulnerable to the effects of climate change.

At the same time, significant variations are observed from one area to another. In some areas (Seychelles and Canada), there is an increase in precipitation, while in others (Moldova and China) there is a decrease and intensification of drought phenomena (European Environment Agency, 2021; United Nations, 2019). These variations directly impact agricultural systems by altering essential resources, particularly arable land (Dupar, 2020; Ellouy, 2023).

Regarding the assessment of food security, the results also reveal significant variability resulting from several factors, including not only immediate factors such as recent conflicts

or economic shocks, but also deep-rooted constraints such as dependence on food imports, the low resilience of national agricultural systems, and the uneven impact of climate change (United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), 2024; Onwujekwe and Ezemba, 2021; Wudil et al., 2022). Thus, responses must go beyond ad hoc actions and move toward transformative strategies, with a particular focus on rural communities, particularly smallholder farmers, who are often marginalized despite their central role in food production, to strengthen food security and limit inequalities (Sundram, 2023).

In general, the study outlines the major issues caused by the direct effects of climate change on the two related phenomena, namely food security and poverty. Specifically, the reduction in arable land, falling yields, and the increased vulnerability of livestock farmers expose millions of individuals to persistent food insecurity while exacerbating socioeconomic disparities (Ketiem et al., 2017; Rivera-Ferre et al., 2016). Similarly, the study also identified several interdependent indirect impacts of these climate constraints. The most mitigating are alterations in crop development cycles and increases in the prices of agricultural inputs and infrastructure. These constraints, also highlighted in several other previous works (Durán-Sandoval et al., 2023; Klein et al., 2007; Rivera-Ferre et al., 2016; Winfree, 2013), are positioned as factors that intensify the decline in productivity and quality of agricultural production, particularly among small producers in rural areas.

However, competition for the use of natural resources (water and grazing areas) intensifies tensions and accentuates social inequalities, especially among vulnerable populations and women (López-i-Gelats et al., 2016; Rojas-Downing et al., 2017). Faced with these challenges, it is essential to promote integrated approaches, combining optimized management of natural resources, the development of agricultural varieties adapted to changing climatic conditions and the adoption of sustainable agroecological practices (Jha and Tripathi, 2017; Bisbis et al., 2018).

Overall, the empirical results confirm the interactions described in the conceptual framework used. Combining the approaches of sustainability (Chambers and Conway, 1992), resilience (Folke, 2006), and the climate food security nexus (Ericksen, 2008) made it possible to interpret the complexity of the observed dynamics. The correlations identified between poverty, climate variability, and food security reflect a systemic interdependence, consistent with the principles of these frameworks. However, certain divergences, notably the low effectiveness of certain local adaptation strategies, call for a revisiting of the assumptions of endogenous resilience in contexts of severe economic constraint.

6 Limitations

Despite the relevance of the results obtained, the study has some shortcomings that should be highlighted. Firstly, the methodological approach of selecting the most and least vulnerable countries on each continent based on HDI does not necessarily reflect the average situation across all countries. Secondly, the lack of quantitative data on food insecurity for all the countries studied prevented us from conducting robust statistical analyses,

such as regression analysis, thus limiting the depth of the empirical analysis. Finally, this research, which focused on the analysis of secondary data, would benefit from being complemented by field research in order to obtain results that better reflect the realities of these countries.

7 Conclusion and recommendations

This study highlights the complexity and scale of the problems surrounding poverty and food insecurity, under the influence of climate change, with pronounced gaps between different regions. The study identifies Africa, particularly the sub-Saharan zone, as one of the most fragile regions, due to persistent socio-political instability and the aggravated effects of climate change. At the same time, although having recorded significant progress thanks to solid economic policies, the Asian region considered (Yemen) also continues to face difficulties linked to climatic hazards, social inequalities and certain geopolitical tensions. Therefore, for both continents, investing in climate-smart agriculture and resilience strategies is crucial. For countries affected by conflict (including Yemen), strengthening humanitarian food systems and implementing appropriate social protection mechanisms is essential. Europe and America are also affected by all these concerns. For these predominantly resource-rich regions, improving governance and using resource revenues to strengthen food and climate resilience are fundamental. These results thus underline the need to develop multidimensional strategies combining economic development, political stability and sustainable management of natural resources, while integrating all the direct and indirect impacts of climate change into policies to combat poverty and food insecurity.

In light of these findings, several policy recommendations emerge. Governments and regional institutions should prioritize the integration of climate adaptation and resilience into national development frameworks. Investing in climate-smart agriculture, water management, and rural infrastructure can significantly improve productivity and reduce vulnerability. Social protection mechanisms must be strengthened to support the most vulnerable populations during crises, ensuring food availability and accessibility. Efforts should also focus on promoting inclusive governance, transparency, and regional cooperation to enhance stability and economic integration. For conflict-affected countries, rebuilding institutional capacity and establishing efficient humanitarian food systems are key steps toward recovery. Finally, resource-rich countries must allocate revenues from natural resources to finance climate adaptation, innovation, and sustainable development initiatives.

Overall, addressing poverty and food insecurity in a changing climate requires coherent, multi-sectoral, and inclusive policies that link economic growth with social equity and environmental sustainability.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

KD: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. YM: Data curation, Formal analysis, Investigation, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships

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