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Food Insecurity and Climate Vulnerability:

Empirical Evidence for Countries in Latin America and the Caribbean

Lina Salazar
Mario González-Flores
Luis Alvarez

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Lina Salazar
Inter-American Development Bank
lsalazar@iadb.org

Mario González-Flores
Inter-American Development Bank
mgonzalez@iadb.org

Luis Alvarez
Inter-American Development Bank
luisalv@iadb.org

Agri-food systems face unprecedented challenges in feeding a growing population while preserving natural resources. Climate variability is a global phenomenon but its impacts on food systems are highly heterogenous. Economic, social, geographical, and environmental factors might increase or reduce a region's vulnerability. This study uses panel data analysis to explore the channels through which climate vulnerability affects food security in Latin America and the Caribbean (LAC), including subregional analysis. The results confirm that climate vulnerability is closely linked to food security and its dimensions, namely: availability, access, use and stability. These findings provide important insights for LAC countries to take action on improving climate resilience for food systems.

Keywords: Climate Vulnerability, Food Security, Latin America and the Caribbean

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I. Introduction

Feeding the world's population is facing unprecedented challenges. Agri-food systems are called to simultaneously produce enough food without threatening natural resources, contribute to poverty reduction, and offer affordable healthy and nutritious diets. And all this, in the context of climate change. Climate change has contributed to the recent increase in food insecurity, and it is magnifying the existing challenges to achieve food security in the medium term (Mbow et al., 2019; FAO et al., 2017; HLPE, 2017; Springmann et al., 2016). Projected changes in temperature, precipitation patterns, glacier retreat and the incidence and magnitude of extreme weather events, among others, will have a negative impact – with some exceptions – on the availability, access, use and stability of food. It is estimated that people at risk of suffering hunger could increase up to 170 million by 2080 due to climate change (Schmidhuber and Tubiello, 2007). Springmann et al. (2016) report that by 2050 climate change will lead to global reductions in food availability (3.2%), consumption of fruits and vegetables (4%), and consumption of red meat (0.7%). This scenario could significantly delay or even reverse progress in achieving the Sustainable Development Goal (SDG) #2: Zero Hunger.

The threats of climate change on food security are eminent. As proof of this, in 2023, one hundred and sixty (160) countries endorsed the COP28 UAE Declaration on Sustainable Agriculture, Resilient Food Systems, and Climate Action, acknowledging that climate impacts are rapidly endangering agrifood systems resilience and committing to work collaboratively to scale-up adaptation and resilience activities, promote food security and nutrition efforts, support workers in agriculture, and strengthen efficient use of water in agriculture, among other initiatives (United Nations, 2023).

Climate vulnerability aggravates food insecurity through an array of channels, it limits the availability of food by reducing agricultural productivity (Ortiz-Bobea et al. 2021; Descheemaeker et al. 2018; Hristov et al. 2018; Myers et al. 2017; CEPAL 2013, 2014; Fernandes et al. 2012), cuts food access by increasing poverty levels (Fanzo et al. 2017; WFP and Met Office Hadley Center 2012), degrades the nutritional quality of foods due to higher concentrations of atmospheric carbon dioxide, and undermines food stability by boosting crop losses and spikes in food prices due to climatic shocks (Mbow et al., 2019).

Latin America and the Caribbean (LAC) is not the exception, food systems in the region have experienced, first-hand, the impact of climate change. This paper aims to provide evidence on the link that exists between vulnerability to climate change and food security in the region. For this purpose, we use a country index to measure the vulnerability to climate change and its evolution in LAC for the period of 2000-2019 and several measures of food security in all its dimensions. In addition to an overall measure of food security (e.g.: undernourishment), we also use proxies to measure the performance of countries on each food security dimension (e.g.: availability, access, use and stability). The results suggests that high levels of climate vulnerability are associated with a higher prevalence of undernourishment and greater food insecurity in its four dimensions. Further, we conduct an assessment on the link between food security and natural disasters, which are expected to increase frequency and intensity due to climate change.

The remainder of the paper is organized as follows: section II discusses the literature on the relationship between climate change vulnerability and food insecurity, including its four dimensions—food availability, food access, food use, and food stability. Section III describes the data and section IV analyzes the descriptive statistics and trends of the main variables of interest. Sections V and VI present the empirical methodology and the results obtained, respectively. Finally, conclusions are stated in Section VII.

II. Climate change and its implications on food security

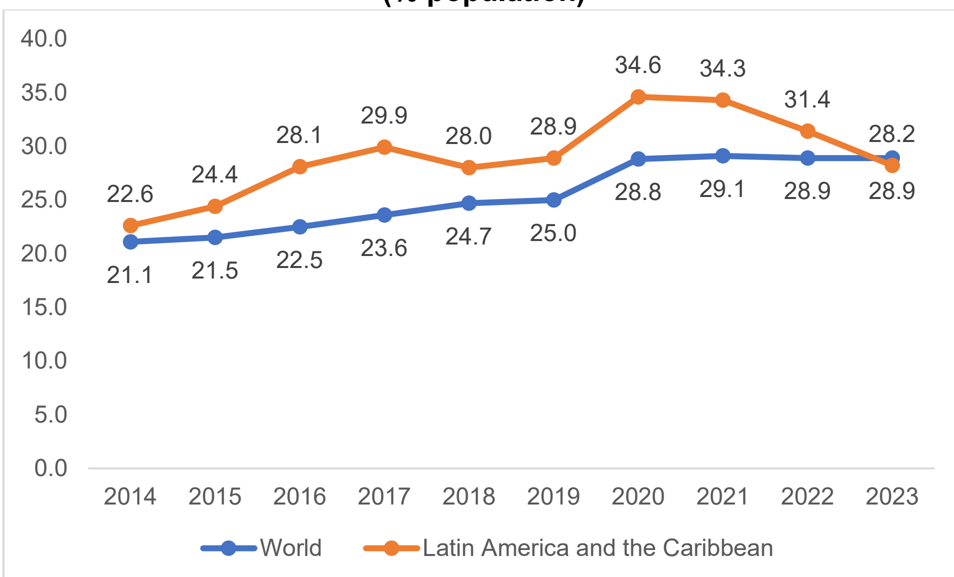
Climate change and natural disasters are key factors contributing to food insecurity in LAC. Recent droughts, hurricanes, floods, and extreme temperatures have exposed the population to reduced food availability and increased instability in the supply and access to food. From 2000-2019, the region experienced 548 floods, 74 droughts, and 50 events of extreme temperature (OCHA, 2020). Climate change is expected to further increase the frequency and intensity of natural disasters. Large areas of the region are expected to experience changes in the precipitation patterns and increased probabilities of extreme droughts and floods (IPCC, 2022; Magrin et al, 2014). From 2000-2019, the region experienced 548 floods, 74 droughts, and 50 events of extreme temperature (OCHA, 2020). On a global level, economic losses linked to natural disasters have averaged around USD$170 billion per year over the past decade (EM-DAT-CRED, cited in FAO, 2021). Data from 71 Post-Disaster Needs Assessments (PDNA) conducted between 2008 and 2018 shows that agriculture accounted for 26% of the overall impact caused by medium- to large-scale disasters in lower to lower-middle-income countries (FAO, 2021). In terms of impacts in LAC, from a total of USD$280 billion losses as a result of declines in crop and livestock production following disasters for the same period across all countries, the LAC region accounted for 10.36% of losses, which amounts to USD$29 billion (FAO, 2021)

Climate change vulnerability is defined as “The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes” (IPCC AR4, 2007, cited in Least Developed Countries Expert Group, 2012). Based on this, the vulnerability of food systems to climate change refers to their ability to maintain an adequate supply and demand of nutritious foods, in terms of frequency and safety, in the face of climate change and adverse weather effects. Consequently, the impact of climate change and natural disasters on food security is related to the degree of vulnerability associated with the food systems.

The impact of disasters on food security depends on the intensity, duration, and type of disaster as well as the nutritional conditions of the population (PAHO/WHO, 2019). Hurricanes, floods, volcanic eruptions, and tsunamis affect food availability by destroying crops and livestock but can also impact food access, use, and stability by damaging infrastructure and supply chains, disrupting communications, affecting means of employment, disarraying economic dynamics, etc. (PAHO/WHO, 2019).

The 1996 World Food Summit defined food security as the condition when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life. The Food Insecurity Experience Scale (FIES) reduce the quality and/ or quantity of food consumed. Population with severe food insecurity measured by the FAO, presents the prevalence of severe or moderate food insecurity. Individuals with moderate food insecurity are uncertain of their ability to obtain food due to lack of resources and, at times, have likely run out of food and experienced hunger for one or more days (FAO et al., 2023). Historical data from 2014 to 2022 shows that food insecurity has been growing since 2015 in LAC, remaining above the world's average since 2014[1] (Figure 1). The COVID19 pandemic and other recent crises have aggravated this trend by exacerbating poverty and inequality through inflationary pressures that increased food prices. In consequence, the population with moderate or acute food insecurity increased from 186 million (28.9%) in 2019 to 224.9 million in 2021 (34.6%) (FAO et al., 2024). Pre-pandemic levels observed until 2023 with 187.6 million people experiencing food insecurity (28.2% of the population).

Figure 1. Food Insecurity in the World and Latin America and the Caribbean (% population)

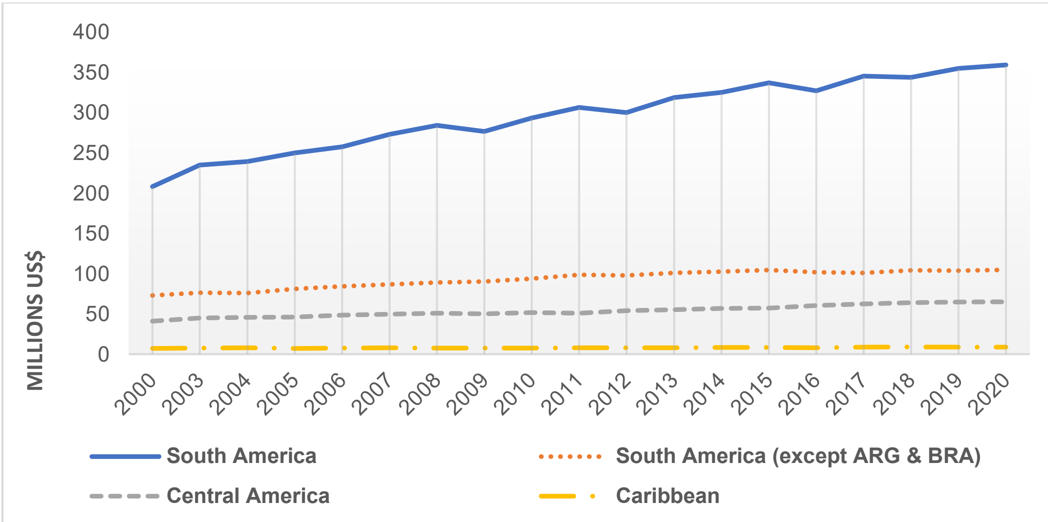


Source: Authors' calculations using FAOSTAT (accessed on 1 October 2024).

The modern concept of food security encompasses the complexity of agrifood systems. This approach considers all the processes and stakeholders that participate in the stages of food production, processing, transportation and consumption. To capture this complexity, food security is conceived in four dimensions that entail food supply, logistics, distribution, consumption and quality. The first dimension, *Food availability*, refers to the supply of food which can be obtained through a country's own agricultural production or international trade. Latin American and Caribbean countries produced 12% of the food in the world in 2021 (FAOSTAT). Of all the food produced by the region, South America produced 83%, Central America 15% and the Caribbean 2%. Furthermore, three countries, Brazil, Argentina and Mexico, produce 70% of the food in LAC (Figure 2).

Figure 2. Food Production in LAC (2000-2020)
Value of food production (constant US$ 2014-2016)

[1] https://www.fao.org/in-action/voices-of-the-hungry/fies/en/



Source: Authors' calculations using FAOSTAT.

Recent estimates suggest that LAC's population will continue to rise until 2058 (UN Department of Economic Affairs Population Divisions, 2019). To sustain a growing population, it is of most importance to boost food availability by increasing food production. The challenge consists of achieving this goal without increasing GHG emissions, threatening natural resources or expanding the agricultural production frontier, causing deforestation and biodiversity losses that might exacerbate the consequences of climate change. Hence, it is crucial to increase agricultural productivity in a sustainable manner and most importantly, to boost sustainable productivity of nutritious food crops.

Climate change poses an enormous challenge to achieving this goal. In LAC, agricultural productivity growth has been decreasing since 2011 and recent evidence suggests a clear association between climate change and lower agricultural productivity, especially in warmer regions (Ortiz-Bobea et al., 2021). In fact, estimates suggest that 25% of agricultural total factor productivity growth was lost, since 1961, due to the cumulative impact of anthropogenic climate change (Ortiz-Bobea et al., 2021). Declining yields of staple production and the deterioration of land suitable for food crops, such as corn and beans, are expected to increase some countries because of temperature rise, high variability in the precipitation patterns and the increase in the magnitude of dry and heat periods (Bouroncle et al., 2015; USAID, 2017).

Changes in temperature and precipitation, shorter production cycles and reduction in water availability, are identified as some of the main causes of agricultural productivity losses (Fernandes et al., 2012). Changes in the amount of precipitation and glacier setbacks are also important impacts of climate change that negatively affect agricultural production (Handmer et al., 2012). Overall, numerous studies report reductions in agricultural productivity due to climate change (Deschemaeker et al. 2018; Hristov et al., 2018; Myers et al, 2017; CEPAL, 2014 and 2013; Fernandes et al., 2012).

Similarly, livestock and fishery productivity are expected to decline due to increasing temperatures. Warmer temperatures affect the amount and quality of forage (e.g., protein content and digestibility), cattle fertility, and animals' energy demand (Hristov et al., 2018). Indeed, heat stress has a negative effect on milk and meat production (Lemes et al., 2021). Climate change also impacts fishing and aquaculture. Fishery resources are affected by ocean acidification, and rising sea temperatures and levels (Pörtner et al., 2022; Ding et al., 2017; Allison et al., 2009). In this context, the availability of fishery resources is projected to increase by more than 30% in high-latitude areas, while it is expected to reduce by up to 40% in the tropics (Cheung et al., 2010). These impacts increase vulnerability to food insecurity, particularly in coastal areas with high dependance on fish for protein intake and other dietary needs (Ding et al., 2017).

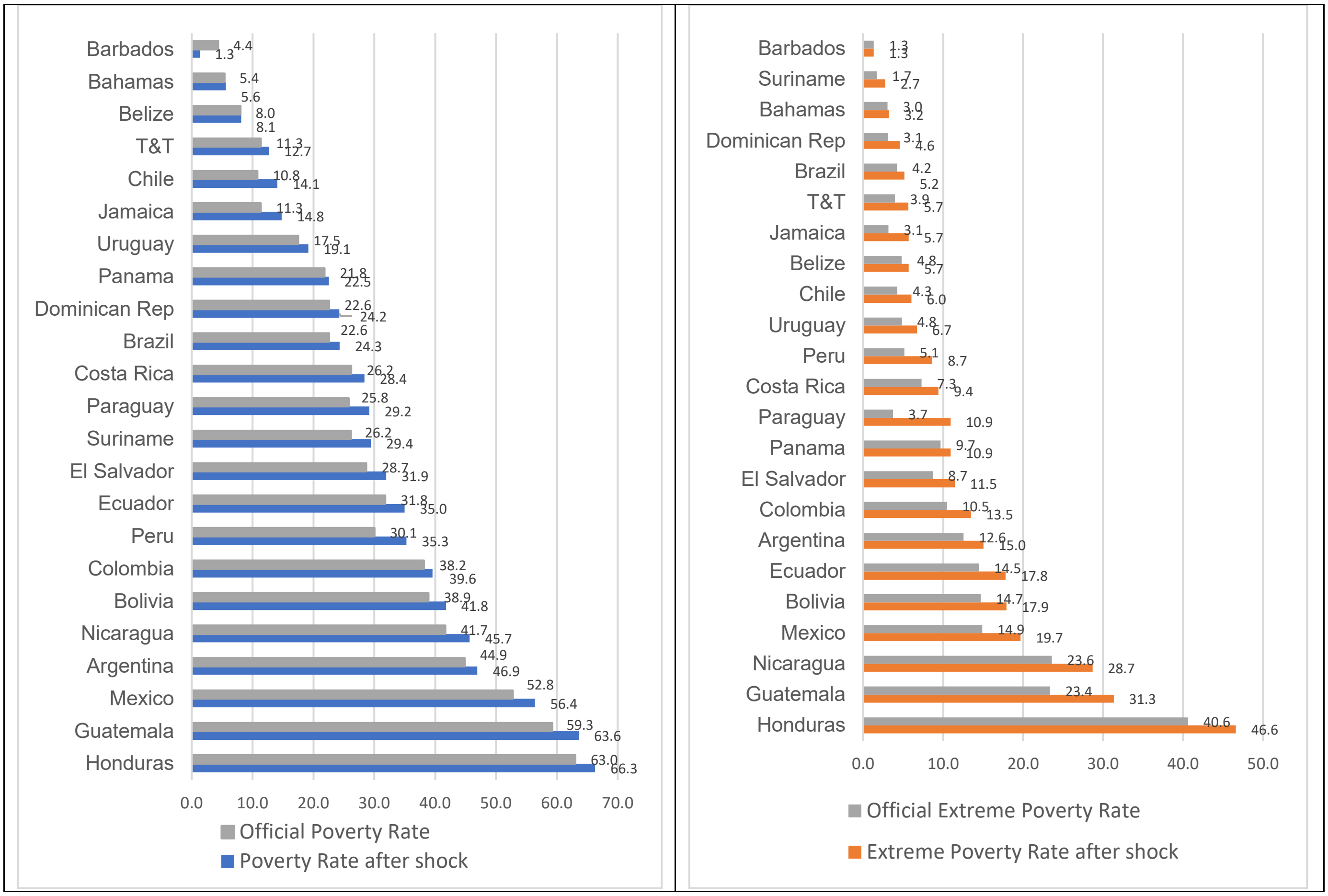
Aside from these direct adverse effects of climate change on food availability, climate change could adversely affect food production by reducing labor productivity (Myers et al., 2017; Dunne et al., 2013). This is of particular importance in countries where agriculture is labor intensive. For instance, in recent decades the increase in relative humidity has led to a 10% reduction in the work capacity during the warmer months and is expected to be reduced by up to 20% by 2050 (Dunne et al., 2013).

Having adequate food availability does not guarantee that households are able to obtain the food to meet their dietary requirements. The next dimension, *Food access*, refers to the availability of household resources (e.g., financial, physical) for acquiring an adequate amount of food. Climate change and disasters can reduce food access by: (i) reducing rural income from agricultural activities (due to declining productivity); and (ii) increasing food prices (due to reduced food availability) (Fanzo et al., 2017; WFP and Met Office Hadley Center, 2012). Considering the effect of climate change, Nelson et al. (2010) report significant increases in real international prices of key staples: maize (87-106%), rice (31-78%) and wheat (44-59%) by 2050. Increases in food prices, in turn, can lead to a rise in poverty and food insecurity in developing countries (Myers et al., 2017; Anderson et al., 2014; Ivanic and Martin, 2014). For example, simulations indicate that a 10% increase in food prices leads to an increase in poverty of 0.8 percentage points (Hallegate et al., 2016; Ivanic and Martin, 2014).

Along the same lines, simulations for LAC suggest that a 20% increase in food prices would increase poverty in the LAC region by 2.6 percentage points on average, causing 63.5 million people to transition into poverty. Rural areas would be the most affected, with a 3.9 percentage point increase in poverty compared to 2.3 increase in urban areas.[2] Except for Barbados, an increase of this magnitude would increase the percentage of people under poverty and extreme poverty for all countries in the region (Figure 3). The countries that could be most affected by an increase in food prices could be Nicaragua, Guatemala and Peru, where poverty rates would increase by more than 4 percentage points.

Figure 3 Food prices and Poverty Rate Changes
(Poverty and Extreme Poverty after 20% increase in food prices)

[2] Based on the SCL Policy Simulator developed by the IDB: https://bid-data.shinyapps.io/scl_policy_simulation/



Source: Author's calculations based on SCL Policy Simulator of the IDB

Impoverish populations are more vulnerable to climate change (Leichenko and Silva, 2014) as they might be more dependent on climate-sensitive sectors, such as agriculture, particularly in rural areas, and since poor households allocate a greater share of their income to purchase food (Ritchie, 2023). In general, income reduction or price increases due to extreme climate events reduce poor households' ability to obtain nutrients and access food. Poverty leads to financial constraints that force poor households to consume less food, and to substitute consumption of healthy foods towards cheap, high-energy staple foods, mainly carbohydrates, and fats, compromising nutritional quality (Siddiqui, Salam, Lassi, et al., 2020).

Food utilization refers to the quality of food in terms of nutrient composition, and overall state of health. Sufficient energy and appropriate nutrient intake by individuals are the result of good food quality, good feeding practices, appropriate food preparation, diet diversity, and intra-household distribution of food (FAO, 2008a).

There are several pathways through which climate change affects nutrition. First, nutritional quality of diets tends to decline in response to climatic shocks (Hallegate et al., 2017; Baez et al., 2010). Empirical evidence shows that children born in areas affected by natural disasters are more likely to suffer malnutrition and stunting (WFP and Met Office Handley Center, 2012). Second, climate change affects food safety by increasing the incidence, persistence, and intensity of foodborne and waterborne diseases (Fanzo et al., 2017; Schmidhuber and Tubiello, 2007; Duchenne-Moutien and Neetoo, 2021; Tirado et al., 2010). For instance, the incidence of aflatoxin contamination of corn and wheat increases with high temperatures (Fanzo et al., 2017), the likelihood of contamination of leafy green vegetables increases with heavy rainfall (Ge, Lee and Lee, 2012), the risk of intoxication by marine biotoxins rises with ocean temperatures (Unnevehr, 2022), waterborne diseases occur more often with droughts when potable water is scarce, or extreme floods when water for irrigation is contaminated (Duchenne-Moutien and Neetoo, 2021). Consequently, affected populations cannot attain an optimal assimilation of food and therefore, experience lower nutritional outcomes. Third, elevated CO_2 levels result in a decrease in protein, iron, and zinc from various crops, therefore, increasing the number of people at risk of macro and micronutrient deficiency (Myers et al., 2017; Medek et al., 2017; Smith et al., 2017; Myers et al., 2015). For instance, due to climate change, Medek et al. (2017), report a possible increase of 148 million people with protein intake deficiency by 2050 due to reduced protein content in rice (7.6%), wheat (7.8%), barley (14.1%) and potato (6.4%).

The final dimension, *Food Stability*, refers to the need for populations to maintain consistent access to food without disruption from sudden shocks or seasonal events, including those caused by climate change (FAO, 2015). Climate change threatens food stability through various mechanisms, such as increased frequency and severity of extreme weather events, rising and volatile food prices, and income instability—especially in agriculture-dependent regions (Mbow et al., 2019). According to IPCC projections (2018), the frequency, duration, and intensity of extreme events will continue to increase in the coming decades, further disrupting food stability (FAO, 2015; IPCC, 2022).

Additionally, food supply stability may be compromised by the rising incidence of pests and diseases, which are more likely to proliferate under changing climate conditions. Climate change could lead to declines in both the production and quality of agricultural products by: (i) altering the incidence and geographic spread of pests and diseases in plants and animals (Mbow et al., 2019; Adedayo et al., 2014), (ii) encouraging the proliferation of certain pests (Huot et al., 2017; Evans et al., 2007), and (iii) contributing to the emergence or re-emergence of infectious diseases (Van den Bossche and Coetzer, 2008). These factors collectively heighten food supply instability and price volatility.

In summary, extensive research highlights the significant threat climate change poses to food security across all dimensions. This study seeks to analyze this challenge in the LAC region and its subregions (e.g., Central America, the Andean Region, the Southern Cone, and the Caribbean) by assessing various indicators that capture the four dimensions of food security.

III. Empirical methodology

To explore the link between climate change vulnerability and food security, we propose an empirical estimation using panel data methods applied to annual data for 25 countries and 20 years (2000-2019)[3] . The analysis excludes years affected by Covid-19 (2020-2023) to eliminate the bias that could emerge due to the extreme levels of food insecurity experienced during the pandemic. Our empirical analysis implements a fixed-effects model to obtain estimates of the

[3] Countries included in the analysis are grouped as follows: (i) Central America includes Belize, Costa Rica, Dominican Republic, Nicaragua, El Salvador, Guatemala, Honduras, Mexico, and Panama; (ii) Andes includes Bolivia, Colombia, Ecuador and Peru; (iii) Caribbean includes Bahamas, Barbados, Guyana, Haiti, Jamaica, Suriname and Trinidad and Tobago; and (iv) Southern Cone includes Argentina, Brazil, Chile, Paraguay and Uruguay.

relationship between the ND-GAIN climate vulnerability index[4] -our climate vulnerability measure- and food security, controlling for time invariant and country specific characteristics. To measure food security, we use the prevalence of undernourishment as well as proxy variables to capture its four dimensions (e.g.).

The main model is estimated as follows:

$$Y_{i,t} = \alpha + \rho VC_{i,t} + \delta DIS_{i,t} + X_{i,t}\beta + C_i + Year_t + \mu_{i,t} \qquad (1)$$

Where $VC_{i,t}$ represents the vulnerability component of ND-GAIN index for country i on year t and X is a vector that includes time-varying control variables at the country-level, such as Gross Domestic Product (GDP) and the contribution of the agricultural sector to the economy (Agricultural GDP). Vector $DIS_{i,t}$ includes a set of dichotomous variables that indicate whether country i experienced drought, storm or flood events in year t. Variables C_i and $Year_t$ account for country and year fixed effects, respectively. An alternative specification includes interaction terms to shed light on the heterogenous effects among LAC subregions (e.g.: Caribbean, Central America, Andean Region and Southern Cone):

$$Y_{i,t} = \rho VC_{i,t} + \sum_{j=1}^{3} \rho^j sr_i^j VC_{i,t} + \delta DIS_{i,t} + \sum_{j=1}^{3} \delta^j sr_i^j DIS_{i,t} + X_{i,t}\beta + Year_t + \sum_{j=1}^{3} \tau^j sr_i^j Year_t + C_i + \mu_{i,t} \qquad (2)$$

Where sr_j are set of dummy variables that indicates whether country i is located in a subregion j[5], using Southern Cone as the base category. The coefficients of the interaction terms, ρ^j and δ^j provide the estimations of the impact of climate vulnerability and disasters events in each subregion, relative to the Southern Cone. In this specification, interaction terms between year-fixed effects and subregional dummy variables are included to control for time-varying unobserved factors that affect countries within a subregion.

The vulnerability component of the ND-GAIN is composed of six sectors that capture the biophysical impacts of climate change on a country's society, and the socio-economic factors that either amplify or reduce such impacts (Chen, Noble, Hellmann, et al., 2023). These sectors are food, water, health, ecosystem services, human habitat, and infrastructure. In other words, this measurement implies that a country's vulnerability to climate change can be measured by the level of vulnerability in each sector. These sectors and their corresponding indicators are presented on Appendix A. The results from the estimations will provide insights for countries to prioritize investments to increase resilience in the specific sectors that are most vulnerable to climate change and therefore, threaten food security.

IV. Data

The data used for the empirical analysis combines variables obtained from several sources including the FAO to measure food insecurity and its dimensions, the Notre Dame Global Adaptation Initiative (ND-GAIN) to capture climate change vulnerability, and the International

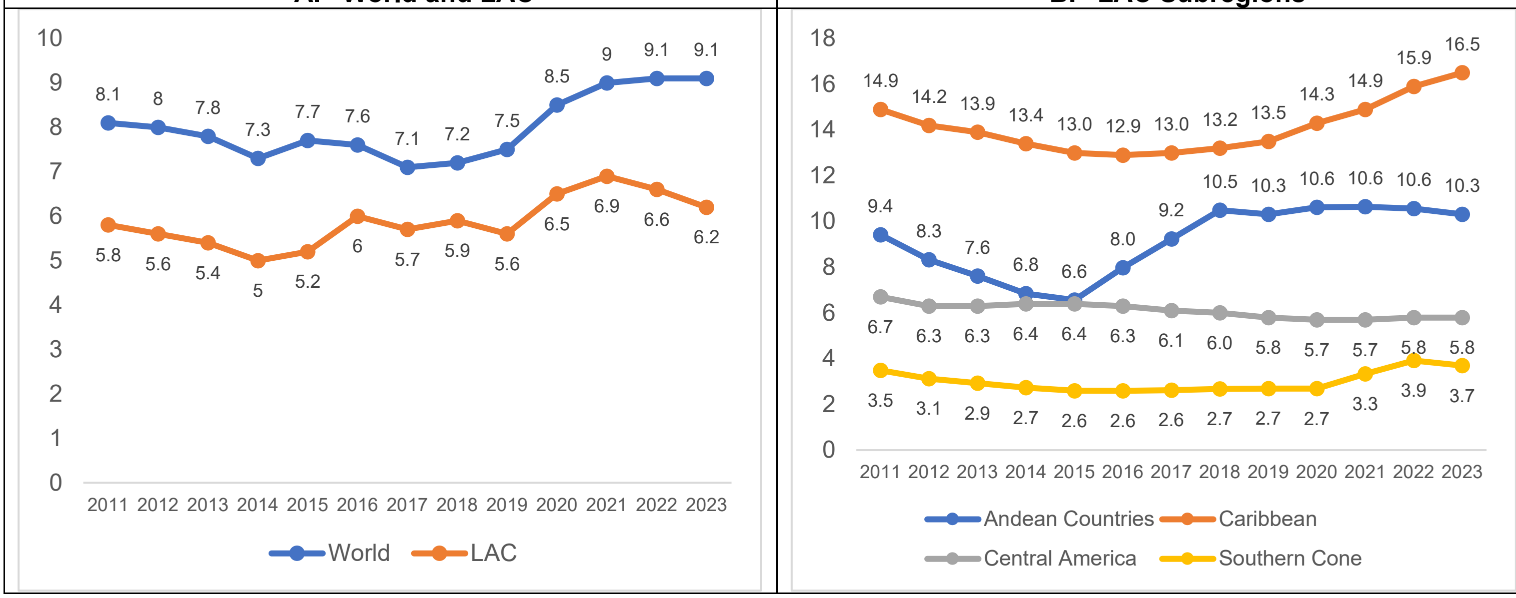
[4] ND-GAIN captures vulnerability to climate change (this index has a value of 0 to 1 (or 0 to 100) where a higher score represents higher vulnerability to climate change, i.e., "worse off"). We do not use the *readiness* component of the ND-GAIN as part of the analysis, as it might be endogenous in our model.

[5] Superscript j takes the value of 1 for the Caribbean subregion, 2 for Central America and 3 for Andean Region.

Disaster Database (EM-DAT) to analyze natural disasters. To assess chronic food insecurity at the national level, we use the prevalence of undernourishment. This variable refers to the proportion of the population with insufficient caloric intake to maintain a healthy life or people who experience hunger (FAO et al., 2023). LAC achieved the Millennium Development Goal (MDG) of halving the proportion of people with undernourishment from 1990 to 2015 (UN, 2015). Since then, trends have been reversed. In fact, even before the COVID-19 pandemic, undernourishment increased from 5.2% in 2014 to 5.9% in 2018 (Figure 4.A). From 2021 to 2023, the region exhibited a decline in the prevalence of undernourishment (from 6.9% in 2021 to 6.2% 2023) (FAO et al., 2024). However, this improvement was driven by South America, while the Caribbean and the Central America presented higher prevalence of undernourishment (Figure 4.B).

Figure 4. Undernourishment in Latin America and the Caribbean (% population)

A. World and LAC | **B. LAC Subregions**



Source: Authors' calculations using FAOSTAT. Notes: Values for Central America and the Caribbean are reported by FAOSTAT. For the Andean countries and the Southern Cone, we report aggregates based on country values reported by FAOSTAT (accessed 1 October 2024), using weighted-population averages.

To measure climate vulnerability, we use the Notre Dame Global Adaptation Initiative's (ND-GAIN[6]) Country Index, which is a free, open-source index that captures a country's level of *vulnerability* to climate disruptions (Chen, Noble, Hellmann, et al., 2023).[7] This index is comprised of three components: exposure, sensitivity, and adaptive capacity. Exposure captures the physical factors that contribute to a country's vulnerability, and it is based on projected changes on key variables (to 2040-2060 or 2070). Sensitivity captures the degree of dependency of a country on sectors that are climate sensitive as well as the proportion of populations that are sensitive to climate hazards due to factors such as topography or demography. Lastly, adaptive capacity captures the ability of countries to reduce potential damage and to respond to the impacts of climate events. In turn, each component includes key indicators for the sectors of food,

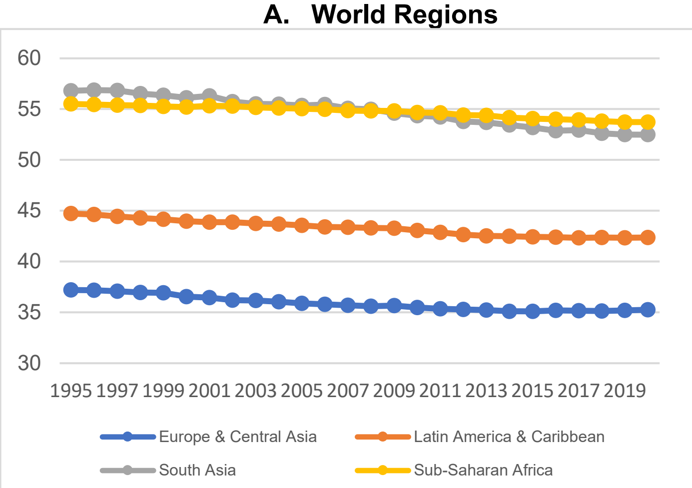
[6] The technical aspects of the ND-GAIN presented here are from Chen, Noble, Hellman, et al., 2023).
[7] The ND-GAIN also captures the *readiness* component which refers to the ability of a country to leverage investments for climate change resilience. Under this framework, the *vulnerability* component measures the propensity or predisposition of countries to be negatively affected by climate change, while the *readiness* component measures a country's ability to make effective use of investments for adaptation actions due to a safe and efficient business environment (Chen, Noble, Hellmann, et al., 2023).

population, water, health, ecosystem services, human habitat, and infrastructure. In total, the vulnerability part of the ND-GAIN is composed of 36 indicators, which yields an index with values from 0 to 1 (or 0 to 100), a higher score representing greater vulnerability to climate change, i.e., “worse off” (Ibid.).[8] [9] [10] Appendix A presents a summary of the six life-supporting sectors and their respective cross-cutting components and indicators, including a detailed description of each indicator and data sources.

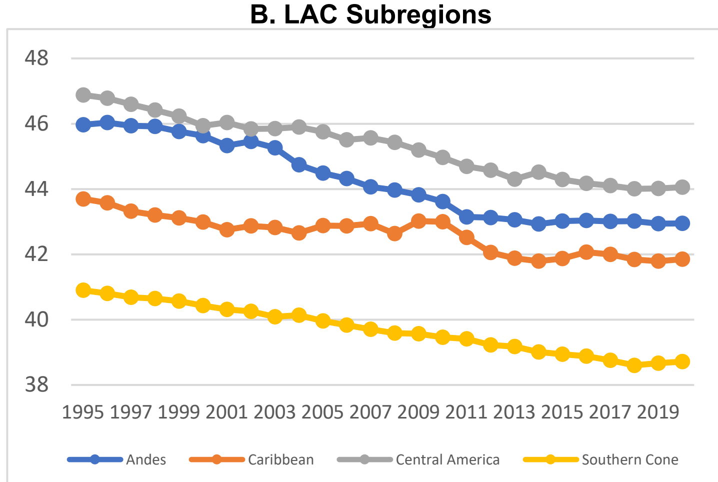
Historical data shows that LAC’s vulnerability to climate change has been slightly decreasing since 1995, presenting higher vulnerability to climate change (42.4) in relation to Europe and Central Asia (35.3), but lower vulnerability than South Asia (52.5) and Sub-Saharan Africa (53.7) (Figure 5.A). At subregional levels, the vulnerability scores of the ND-GAIN are highest for Central America (44.1) and lowest for the Southern Cone (38.7) (Figure 5.B). However, vulnerability to climate change varies by country.[11] For instance, Chile, Ecuador, Bolivia, and Peru have reduced their vulnerability to climate change while other countries, such as Colombia and Venezuela, have increased their vulnerability. Caribbean countries have been relatively stable without major changes in their vulnerability to climate change.

Figure 5 Climate vulnerability (1995-2020)

A. World Regions



B. LAC Subregions



Source: Authors’ calculations using ND-GAIN.

Droughts and floods or storms are the most prevalent hazards affecting LAC. Using data from the Emergency Events Database (EM-DAT)[12], that provides information on catastrophic events associated with a formal declaration of national emergency, LAC registered 69 droughts during

[8] For a detailed description of the indicators please see Chen, Noble, Hellman, et al.,2023).

[9] For complementary information, including a detailed description of the indicators considered in the six life-supporting sectors and their respective cross-cutting components and indicators please refer to from Chen, Noble, Hellman, et al., 2023).

[10] Under this and the other regression models, the *readiness* component of the ND-GAIN is not included as part of the analysis, as it might be endogenous. In fact, it is expected that countries with high readiness scores, related to economic, governance and social aspects, are also able to experience less food insecurity even in the absence of climate change. Hence, there is a bidirectional relationship between readiness score and food security.

[11] Subregions in LAC are defined as follows: (i) Central America includes Belize, Costa Rica, Dominican Republic, Nicaragua, El Salvador, Guatemala, Honduras, Mexico, and Panama; (ii) Andes includes Bolivia, Colombia, Ecuador and Peru; (iii) Caribbean includes Bahamas, Barbados, Guyana, Haiti, Jamaica, Suriname and Trinidad and Tobago; and (iv) Southern Cone includes Argentina, Brazil, Chile, Paraguay and Uruguay.

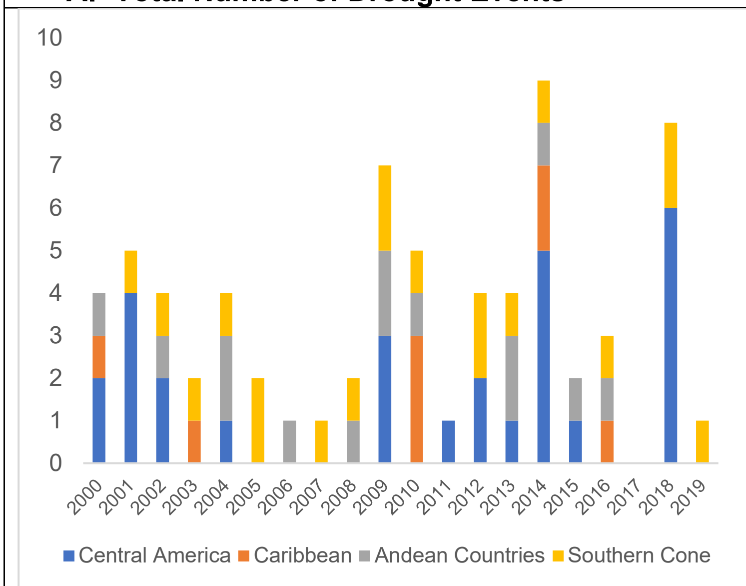
[12] The EM-DAT database was created as a joint initiative between the Centre for Research on the Epidemiology of Disasters (CRED) and the World Health Organization (WHO). It records the occurrence of disasters globally at the country level from 1900 to present dat. Disasters included in the database must fulfill at least one of the following criteria: i) 10 fatalities, ii) 100 affected people, iii) a declaration of state of emergency, iv) a call for international assistance.

the period 2000-2019. The fluctuation in the number of droughts registered increased since 2009, with 2014 being the single year that registered the largest number of droughts (9), followed by 2018 (8 droughts). Central America is the subregion most affected by droughts, registering a total of 28 events during this period. On the other hand, the Southern Cone and the Andean countries presented a stable cyclical pattern of droughts, with one or two events per year. The subregion least affected by this hazard is the Caribbean, where droughts occurred in 5 years of the 20 years included in the analysis (Figure 6A).

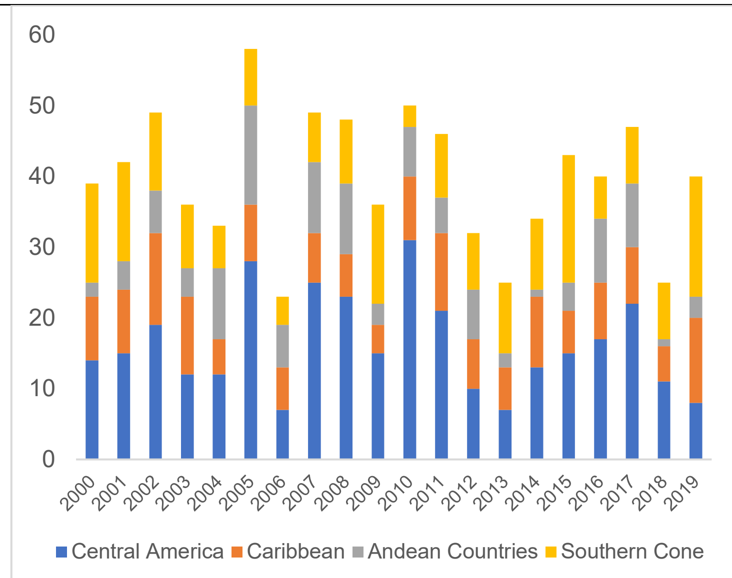
For the same period, LAC experienced 759 floods, averaging a total of 40 events per year, that exhibit cyclical pattern fluctuation with peaks in 2005 and 2010 (58 and 50 events recorded, respectively). As with droughts, Central America is the region most affected by floods, registering 325 of the 795 flood events recorded, nearly twice the number recorded in the other subregions (with an average of 16 floods per year). The second most affected subregion is the Southern Cone, registering a total of 193 floods (with an average of 10 storms or floods per year). Finally, the Caribbean and the Andean countries registered a total of 160 and 117 floods (with an annual average of 8 and 6), respectively (Figure 6B).

Figure 6. Disaster Events in Latin America and the Caribbean (2000-2019)

A. Total Number of Drought Events



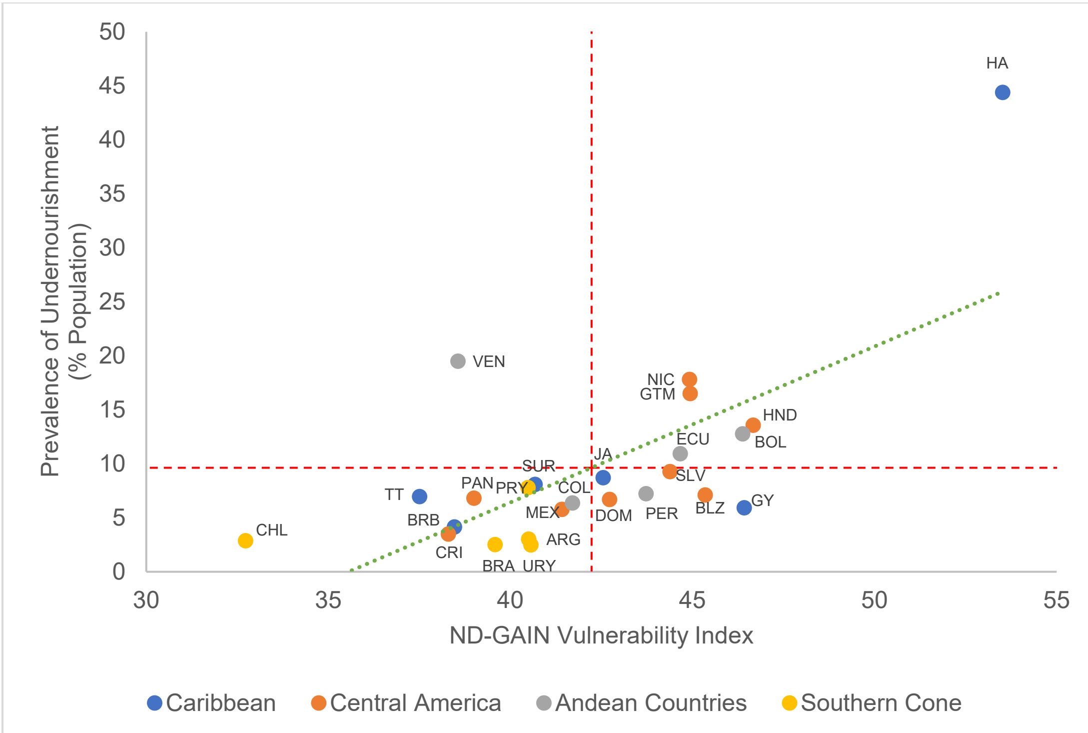
B. Total Number of Storm and Flood Events



Source: Authors' calculations using EM-DAT data**.**

A graphical assessment confirms that food insecurity in LAC is closely associated to climate vulnerability (Figure 7). While graphic correlations do not imply causality, these can be informative to identify countries in riskier situations; namely those with a high degree of climate vulnerability and high levels of food insecurity. For instance, countries with higher food insecurity and higher climate vulnerability, could be at most risk of experiencing acute food crisis if faced with unexpected catastrophic events caused by climatic conditions (i.e., Honduras, Guatemala, El Salvador, Haiti, Jamaica, Nicaragua, Peru, Ecuador and Bolivia). Hence, to reduce the risk of increasing food insecurity in the context of climate change, it is crucial to develop a conscious effort to strengthen agri-food systems' resilience.

Figure 4. Correlation between Undernourishment and Climate Vulnerability in LAC



Notes: Correlation coefficient = 0.69. Source: Authors' calculations using FAOSTAT.

Four variables are used to measure the performance of countries in each food dimension. First, for food availability, we use FAO's food production index (FPI), an annual index that measures the production of edible food crops that contain nutrients, with respect to the base period 2014-2016. For food access, we use the prevalence of monetary poverty, defined as the percentage of the population living with less than US$6.85 per day (World Development Indicators), that captures the ability of households to obtain enough food to satisfy their needs.[13] Poverty and food insecurity are intrinsically linked as poor households usually lack the resources needed to access sufficient nutritious food to live an active and healthy life (Hjelm, Mathiassen, and Wadhwa, 2016). Regarding food use, choosing the prevalence of children who are stunted (FAOSTAT) allows to capture the nutritional outcome of the food eaten by one of the most vulnerable population groups. Stunting is a common measure of food use as it captures the long-term effects of chronic undernutrition at infant stages, when nutritious foods are crucial for healthy long-term development (Caulfield et al., 2006). Stunting is one of the measures most widely used to assess childhood malnutrition as it indicates that a child has failed to reach their growth potential (de Onis and Branca, 2016). There are several factors that contribute to stunting; however, the most direct causes are inadequate nutrition (not eating enough or eating foods lacking in growth-promoting nutrients) (WHO, 2015). A child is classified as stunted if his/her height for their age is below average, based on an internationally agreed measure from the World Health Organization (WHO) (Bukari, Danaa, Mubarak, et al., 2022). Finally, for measuring food stability we use the fluctuations in food prices using the volatility in the FAO Price Index (FFPI). Following Tothova (2011), the volatility in a specific year is measured by the coefficient of variation of monthly prices, which is defined as the ratio of the annualized standard deviation over the mean. Higher values in the

[13] Unfortunately, the prevalence of monetary poverty is not available for Caribbean countries and therefore, these were excluded from the analysis of food access.

coefficient of variation imply a larger dispersion in monthly data, and thus a higher price and food volatility.

Additional variables were included to control for country's income and the level of economic development (e.g. real GDP per capita) and the contribution of the agricultural sector to the country's economy (e.g. GDP of the agriculture, forestry and fishing sectors). Also, the occurrence of natural disasters is included by using data from the Emergency Events Database (EM-DAT)[14]. For this, the regressions include dummy variables to indicate whether a storm, flood or drought occurred in a country for a specific year.

Tables 1 and 2 below presents descriptive statistics of the outcome variables, namely food security and its dimensions, as well as the variables of interest namely, ND-GAIN vulnerability indicators associated and disasters caused by climate related events (e.g. droughts and floods). Regarding food security, the average prevalence of undernourishment for LAC is 11.4% for the period analyzed with compelling differences across subregions. Southern Cone countries report an average prevalence of undernourishment of 4.5%, while the Caribbean and Andean countries the average is higher than 14% (Table 2). Similar results are found for the dimensions of access and utilization. Specifically, the percentage of the population living below the poverty line of $6.85 a day is considerably lower in the Southern Cone (24%) than in Central America and the Andes (38% and 41%, respectively). Likewise, the prevalence of stunting in children under five years old is 8% in the Southern Cone, significantly below the averages reported in the Caribbean (12%), Central America (20%) and Andean Countries (21%).

Table 1 Summary Statistics for Outcome and Explanatory Variables

	(1) Mean	(2) SD	(3) N
Food Security Outcomes			
Undernourishment (Prevalence of, % population)	11.4	9.8	456
Food production index (2014-2016=100)	88.6	16.2	500
Poverty (% Population Living with Less than $6.85 a Day, 2017 PPP)	34.9	15.6	269
Prevalence of stunting, height for age (% of children under 5)	15.8	10.4	480
Food price index volatility (annual coeff. of variation)	2.5	2.6	480
CC Vulnerability (ND-GAIN) and Disasters			
ND-GAIN Vulnerability Score	43.4	4.3	500
Droughts (1,0)	0.1	0.3	500
Storm/Floods (1,0)	0.7	0.5	500
Control Variables			
Agriculture, forestry, and fishing, value added (% of GDP)	8.4	6.0	500
GDP per capita (constant 2015 US$, thousands)	8.2	6.5	500

Source: Author's calculations using ND-GAIN database, FAOSTAT, WDI.

Regarding climate vulnerability variables, lower values of the ND-GAIN and lower recurrence of disasters caused by weather related events are also found among Southern Cone countries in comparison to the other subregions. LAC countries reported the occurrence of droughts in 10% of the years included in the period of analysis, while for storms and floods an event was reported

[14] The EM-DAT database was created as a joint initiative between the Centre for Research on the Epidemiology of Disasters (CRED) and the World Health Organization (WHO). It records the occurrence of disasters globally at the country level from 1900 to present dat. Disasters included in the database must fulfill at least one of the following criteria: i) 10 fatalities, ii) 100 affected people, iii) a declaration of state of emergency, iv) a call for international assistance.

for 70% of the years analyzed, being the Andean countries the subregion with the highest recurrence period (90% of the years).

Table 2 Summary Statistics by LAC subregions

	Caribbean			Central America			Andean Countries			Southern Cone		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Food Security Outcomes												
Undernourishment (Prevalence of, % population)	14.2	15.1	114	12.0	6.6	171	14.3	6.7	76	4.5	2.4	95
Food production index (2014-2016=100)	93.2	16.4	140	88.6	15.2	180	85.3	15.5	80	84.9	17.0	100
Poverty (% Population Living with Less than $6.85 a Day, 2017 PPP)				38.1	14.7	117	41.0	13.6	74	24.3	13.5	78
Prevalence of stunting, height for age (% of children under 5)	12.0	6.8	120	20.4	12.3	180	21.3	6.6	80	8.0	4.2	100
Food price index volatility (annual coeff. of variation)	3.5	3.3	120	1.9	1.5	180	2.0	2.6	80	2.9	2.6	100
CC Vulnerability (ND-GAIN) and Disasters												
ND-GAIN Vulnerability Score	44.2	5.5	140	44.0	3.1	180	45.3	2.7	80	39.5	2.6	100
Droughts (1,0)	0.1	0.2	140	0.2	0.4	180	0.2	0.4	80	0.2	0.4	100
Storm/Floods (1,0)	0.4	0.5	140	0.7	0.4	180	0.9	0.3	80	0.7	0.5	100
Control Variables												
Agriculture, forestry, and fishing, value added (% of GDP)	9.0	9.6	140	8.5	4.3	180	8.8	2.2	80	6.9	3.1	100
GDP per capita (constant 2015 US$, in thousands)	12.0	9.8	140	5.9	3.5	180	4.5	1.4	80	10.0	3.5	100

Source: Author's calculations using ND-GAIN database, FAOSTAT, WDI.

V. Results

Overall, the trends for the LAC region confirm that food insecurity has worsened overtime, climate vulnerability has decreased (at a diminishing rate) and the prevalence of disasters (caused by weather related events) has increased, particularly in the case of droughts. However, high heterogeneity is found among subregions and countries in LAC. Therefore, to assess the relationship between climate vulnerability and food insecurity, a panel data regression with fixed effects for country and year is estimated (Section III). This model is calculated for the region as a whole and disaggregated results are obtained for each subregion –Central America, the Caribbean, Andean Countries, and the Southern Cone— through interaction terms.

The results confirm that higher climate vulnerability is associated with an increased prevalence of undernourishment in LAC. Specifically, a one-point increase in the vulnerability score is associated with a 1.14 percentage point increase in the prevalence of undernourishment (Table 3; Column 1). Furthermore, the interaction terms by subregions (Column 2 in Table 3) confirm this link for countries in the Andean region, the Caribbean and Central America[15]. Overall, this finding

[15] We find a positive coefficient for Southern Cone countries significant at the 10%.

implies that investments that aim at reducing vulnerability to climate change could improve food security across LAC.

To prioritize policies that strengthen food security through climate resilience, it is key to recognize the food security dimensions that are most affected by climate change vulnerability. For food availability, the empirical analysis confirms an inverse relation between climate vulnerability and food availability in LAC. Specifically, one-point increase in climate change vulnerability, is associated with a 4.1 percentage points reduction of food production (Table 3, Column 3). The analysis by subregions suggest that climate vulnerability reduces food availability in all subregions except for Southern Cone countries. The magnitude of this relationship is larger in the Caribbean, followed by Andean and Central American countries, respectively (Table 3, Column 4). In terms of disasters caused by natural hazards, droughts are associated with lower food production in Southern Cone countries, with not statistical significance in the relative effect for other subregions, except for the Caribbean where a counterintuitive result is found. This finding could be attributed to the low variability in the number of droughts that occurred in Caribbean countries during the period analyzed, which could reduce the ability of the model to accurately estimate its effects on food availability and other food security variables. On the other hand, the results show some evidence of an increase of food production in the presence of storms or floods, but this result is not confirmed at the level of subregions where the relation is not statistically significant[16]. These results suggest that to maintain food availability it is key to prioritize investments and policies that increase climate resilience, particularly in Andean, Caribbean, and Central American countries. In the case of Southern Cone countries, investments that reduce the impacts of droughts on agricultural production could be the most effective to increase food availability.

Regarding food access, an increase in climate change vulnerability is related to increases in monetary poverty, one percentage point in the ND-GAIN is associated with 3.3 percentage points increase in poverty in LAC[17]. On the other hand, the analysis does not provide evidence of a statistical association between droughts or floods with food access. In general, these findings suggest that investments to strengthen climate resilience could improve food access by reducing poverty in LAC (Table 3, Columns 5 and 6).

As for food use, an increase of one point in climate vulnerability is associated with an increase of 1.3 percentage points in children's stunting (less than 5 years old), for the whole region. Furthermore, the link between food use and climate vulnerability is stronger for Andean and Caribbean countries where one point increase in climate change vulnerability could translate to nearly 3.2 and 1.8 percentage points increase in children's stunting, respectively. Regarding disasters, floods are linked to higher prevalence of children's stunting for Central American and Andean countries. Similarly, in years in which a drought was reported in Central America, a higher prevalence of stunting growth is observed. These findings imply that investments and policies that aim at reducing climate vulnerability have high potential to improve nutritional outcomes in LAC. Additionally, for Central American countries is also key to promote interventions that reduce the effects of natural disasters on food use as these could be highly beneficial in terms of nutritional outcomes (Table 3, Columns 7 and 8).

[16] Although we report positive coefficients significant at the 10% for the whole region, when do not find significant effects disaggregated by subregion.

[17] The two-way fixed effects model with interactions terms does not provide statistically significant results for the coefficient of climate vulnerability on food access. However, when the samples for each subregion are estimated separately, the ND-GAIN coefficient is significant for the Andean and Southern Cone countries.

Table 3. Effects of climate vulnerability and disaster events on food security indicators.

	Undernourishment		Food Production		Poverty		Stunting Growth		Food Price Variability	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
ND-GAIN	1.143***	-0.945*	-4.131***	2.057	3.330***	1.684	1.303***	-0.456	0.471**	0.731*
	(0.218)	(0.500)	(0.640)	(1.592)	(0.518)	(1.106)	(0.164)	(0.357)	(0.183)	(0.439)
ND-GAIN*Central America		1.278*		-4.570**		-1.551		-0.059		-0.788
		(0.654)		(2.067)		(1.580)		(0.465)		(0.577)
ND-GAIN*Andean		2.696***		-7.677***		-0.133		3.710***		-1.227*
		(0.715)		(2.287)		(1.363)		(0.513)		(0.629)
ND-GAIN*Caribbean		1.380**		-9.397***				2.287***		1.378**
		(0.654)		(1.969)				(0.452)		(0.614)
Droughts	0.429	0.934	-2.219*	-4.561**	0.883	0.563	0.467	-0.407	0.677**	1.177*
	(0.385)	(0.684)	(1.202)	(2.273)	(0.760)	(1.108)	(0.300)	(0.509)	(0.329)	(0.623)
Droughts*Central America		-0.804		4.198		0.795		1.140*		-0.571
		(0.940)		(3.075)		(1.663)		(0.690)		(0.843)
Droughts*CAN		0.095		1.639		-0.485		1.602**		-1.022
		(1.095)		(3.585)		(1.744)		(0.804)		(0.983)
Droughts*Caribbean		-0.953		6.866*				-0.218		-0.630
		(1.315)		(4.023)				(0.920)		(1.144)
Flood/Storms	-0.298	-0.764	1.921*	0.398	-0.365	-0.188	-0.215	-0.632	0.036	-0.581
	(0.324)	(0.666)	(0.986)	(2.174)	(0.712)	(1.221)	(0.253)	(0.488)	(0.273)	(0.597)
Flood/Storms*Central America		1.266		2.265		0.597		1.117*		0.717
		(0.870)		(2.792)		(1.647)		(0.626)		(0.767)
Flood/Storms*Andean		-0.896		1.352		0.248		-0.152		1.795
		(1.296)		(4.282)		(2.128)		(0.960)		(1.175)
Flood/Storms*CAR		-0.103		3.568				0.284		-0.397
		(0.937)		(2.881)				(0.690)		(0.825)
Agric.(%GDP)	-0.230**	-0.312***	-0.210	-0.144	-0.157	0.051	-0.015	-0.045	0.068	0.301***
	(0.098)	(0.100)	(0.285)	(0.295)	(0.267)	(0.269)	(0.071)	(0.067)	(0.094)	(0.115)
GDP	-0.568***	-0.911***	0.258	-1.219***	-1.654***	-1.632***	0.655***	0.838***	-0.097	-0.011
	(0.141)	(0.149)	(0.382)	(0.419)	(0.353)	(0.326)	(0.106)	(0.103)	(0.104)	(0.117)
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects (2000-2019)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R2	0.374	0.493	0.649	0.695	0.805	0.862	0.604	0.720	0.052	0.152
No. Countries	24	24	25	25	17	17	24	24	24	24
No. Observations	456	456	500	500	269	269	480	480	480	480

Notes: *** p-value<0.01, ** p-value<0.05, * p-value<0.1. Columns 1, 3, 5, 7 and 9 report the estimates for the coefficients obtained from the model run on the full sample in Eq. (1). Columns 2, 4, 6, 8 and 10 present the estimated coefficients of the model with interaction terms in Eq. (2).

Lastly, as for food stability, the estimations confirm a correlation between food price volatility and climate vulnerability. Specifically, a one-point increase in climate vulnerability is related with a 0.47 percentage point increase in the coefficient of variation of food prices in LAC. The empirical analysis suggests that, concerning food stability, Caribbean countries are the most affected by climate change vulnerability. Regarding disasters, drought adaptation strategies could be most favorable to increase food stability in the Southern Cone (Table 3, Columns 9 and 10). Finally, there is not compelling evidence of a relationship between floods or storm events and volatility in food prices.

VI. Conclusions

In 2023, a group of 160 nations endorsed the COP28 UAE Declaration on Sustainable Agriculture, Resilient Food Systems and Climate Action, under which they commit to expand climate change adaptation and resilience initiatives while strengthening food security and nutrition (United Nations, 2023). This declaration conveys the urgency to act under the evident threat that climate change poses on food systems endangering food security worldwide. This study confirms that LAC countries are not the exception and demonstrates that vulnerability to climate change threatens regional food security in all its dimensions.

Agri-food systems play a fundamental role in contributing to food security and reaching the SDG#2 of Zero hunger. And while agri-food systems are called upon to simultaneously produce enough food without threatening natural resources, contribute to poverty reduction, and offer affordable healthy and nutritious diets, climate change and disasters are magnifying many of the existing challenges for achieving food security worldwide. Historical data from droughts, hurricanes, floods, and extreme temperatures have revealed the vulnerability of food systems to climate change and disasters, which translate into reduced food availability, access and high variability in the supply and access to food.

This study confirms the strong link between climate vulnerability, disasters, and food security in LAC countries, considering its four dimensions: availability, access, use, and stability. The results, derived from panel data econometric techniques using a unique data set that combines several sources of climate-related variables, food security indicators and socio-economic characteristics for the entire region, provide compelling evidence that higher levels of climate vulnerability are strongly associated with: increased undernourishment (i.e. greater food insecurity), a lower food production index (i.e. reduced food availability), higher poverty rates (i.e. diminished food access), higher prevalence of stunting in children under 5 years old (i.e. impaired food use), and greater food price variability (i.e. reduced food stability). Regarding disasters triggered by natural hazards, the analysis reveals that droughts are highly correlated with lower food availability and increased food instability, especially in the Southern Cone. On the other hand, storms and floods are linked to a higher prevalence of children's stunting, particularly in Central America. While these results confirm the heterogeneous effects of climate vulnerability and climate-related disasters across subregions, they also highlight the threat that climate change poses to food security throughout the region.

The evidence presented in this paper serves as a critical call to action for governments, international organizations, and donors to bolster the climate resilience of agri-food systems across LAC countries, with the ultimate goal of achieving Zero Hunger and eliminating food insecurity. To realize this vision, investments must be prioritized to scale and strengthen climate adaptation and resilience strategies at regional, subregional, national, and subnational levels, alongside ongoing climate mitigation efforts. Currently, climate finance in LAC is highly concentrated in a few countries, with a predominant focus on mitigation. In fact, multilateral climate funds for mitigation activities are allocated more than five times the amount for adaptation, hindering climate resilience of agrifood systems (Watson, Schlatek, and Evéquoz, 2022) . Finally, investment efforts must adopt a multidisciplinary, multisectoral approach that fully integrates the complex functioning of agri-food systems to ensure sustainability and inclusion.

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Appendix A. Components of ND-GAIN

		Cross-cutting components		
		Exposure (non-actionable because they do not change since they are based on projections to mid- or end of century): extent to which human society and its supporting sectors are stressed by the future changing CC conditions. It captures the physical factors that are external to the system that contribute to vulnerability.	**Sensitivity (Actionable)**: degree to which people and the sectors they depend on are affected by climate related perturbations	**Adaptive Capacity (Actionable)**: ability of society and its supporting sectors to adjust to reduce potential damage and to respond to the negative consequences of climate events.
Life-supporting sectors	**Food**	• Projected change of cereal yields by 2050 (Earth System Grid Federation). • Projected population change by 2050 (HNPStats).	• Food import dependency (cereal imports dependency ratio, FAOSTAT). • Share of rural population, as a proxy for subsistence farming	• Agricultural capacity: fertilizer, irrigation, pesticide, tractor use (FAOSTAT) • Child malnutrition (prevalence of wasting in children under 5,
	Water	• Projected change of annual runoff 2040-2060 (Aqueduct at World Resource Institute). • Projected change of annual groundwater recharge (Goethe University Frankfurt).	• Fresh water withdrawal rate (AQUASTAT). • Water dependency ratio (AQUASTAT).	• Access to reliable drinking water: dam capacity per capita (AQUASTAT). • Dam capacity: % population with access to improved water sources (WDI).
	Health	• Projected change of deaths from climate change induced diseases to 2030 (Ebi, 2008). • Projected change in vector borne disease to mid-century (Caminade et al 2014; WHO).	• Slum population as % of urban population (MDGs). • Dependency on external resource for health services (WDI).	• Medical staff: physicians, nurses, and midwives per 1000 people (WDI). • Improved sanitation facilities: % population with access (WDI).
	Ecosystem services	• Projected change of biome distribution to 2070-2100 (Gonzalez et al, 2010). • Projected change of marine biodiversity to mid-century (Cheung et al, 2009).	• Dependency on natural capital: indicator based on the deployment of natural capital in national accounting (World Bank, 2011) • Ecological footprint: has of land and water needed to meet the demand on ecosystems' services based on population's lifestyle (National Footprints Accounts).	• Protected biomes: Environmental Performance Index (Yale Center for Environmental Law & Policy). • Engagement in international environmental conventions
	Human Habitat	• Projected change of warm period to 2040-2070: days in year in which the daily maximum temperature exceeded a threshold	• Urban concentration: % urban population (WDI). • Age dependency ratio: % population under 14 and above 65 (WDI).	• Quality of trade and transport-related infrastructure: perception of logistic professionals (WDI).

		for at least 6 consecutive days (Warm Spell Duration Index). • Projected change of flood hazard to 2040-2070: monthly maximum precipitation in 5 consecutive days (rx5day indicator).		• Paved roads as a % of total roads (WDI). •
	Infrastructure	• Projected change of hydropower generation capacity to mid-century • Projected change of sea level rise impacts to end of century	• Dependency on imported energy • Population living under 5m above sea level	• Electricity access • Disaster preparedness

Source: Chen, Noble, Hellman, et al., 2023