A Model for Estimating the Effect of Climate Change on Subsistence Agricultural Yields Environmental Policy Observatory – OPA

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1 ABSTRACT

This study combines a Ricardian model with micro-simulation techniques to assess the projected impacts of climate change on net agricultural income and the well-being of rural subsistence households. The results reveal a heterogeneous impact across regions and crops, with staples such as rice and corn experiencing significant income declines in areas facing higher temperatures and reduced precipitation. Subsistence agricultural units (UPAs) under two hectares are especially vulnerable due to limited adaptive capacity and economic flexibility. Furthermore, the greatest losses in income and well-being occur among households in the lowest income deciles, underscoring their increased sensitivity to climate shocks. Under pessimistic climate scenarios (SSP3-7.0 and SSP5-8.5), negative impacts are more severe, while mitigation scenarios (SSP1-2.6) show reduced losses and occasional benefits from the effect of CO fertilization. The findings also indicate that spontaneous farmer adaptation is insufficient to counteract climate risks, emphasizing the urgent need for targeted policy interventions and support programs. Overall, subsistence-level UPAs are particularly vulnerable to climate-induced extreme events, such as droughts, frosts, and floods, which threaten agricultural livelihoods and rural well-being.

RESUME Este estudio integra un modelo Ricardiano con técnicas de micro-simulación para evaluar los impactos proyectados del cambio climático sobre el ingreso agrícola neto y el bienestar de los hogares rurales de subsistencia. Los resultados evidencian una afectación heterogénea entre regiones y cultivos, destacándose reducciones significativas en los ingresos derivados de cultivos

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básicos como el arroz y el maíz en aquellas zonas expuestas a mayores incrementos de temperatura y disminución de precipitaciones. Las unidades de producción agropecuaria (UPAs) de subsistencia con menos de dos hectáreas presentan una especial vulnerabilidad atribuible a su limitada capacidad de adaptación y escasa flexibilidad económica. Asimismo, las mayores pérdidas en términos de ingreso y bienestar se concentran en los hogares pertenecientes a los deciles más bajos de ingreso, lo que pone de relieve su elevada sensibilidad frente a los choques climáticos. Bajo escenarios climáticos pesimistas (SSP3-7.0 y SSP5-8.5), los impactos negativos se intensifican, mientras que los escenarios de mitigación (SSP1-2.6) reportan menores pérdidas e incluso beneficios puntuales asociados al efecto de fertilización por CO. Los hallazgos sugieren, además, que las estrategias de adaptación espontáneas implementadas por los agricultores resultan insuficientes para contrarrestar los riesgos climáticos, lo que subraya la necesidad apremiante de políticas públicas específicas y programas de apoyo diferenciados. En términos generales, las UPAs de subsistencia enfrentan una alta vulnerabilidad ante eventos climáticos extremos —como sequías, heladas e inundaciones— que ponen en riesgo la sostenibilidad de los medios de vida agrícolas y el bienestar de las comunidades rurales.

2 Introduction

Ecuador is an Andean country located in the northwest corner of South America, with a total area of 256,370 square kilometers (km^2). Geographically diverse, it is crossed by the Andes mountain range, marked by a double mountain chain that divides the continental territory into three regions, Coast, Sierra, and Amazon. Each of these regions is characterized by unique conditions of climate, soil, landscapes, and biodiversity. Ecuador is one of the 20 most bio diverse countries in the world due to its location in the neotropics, the presence of the Andes mountain range, and the influence of ocean currents, which define 91 ecosystems (65 forested, 14 herbaceous, and 12 shrubland) (**burneo2009megadiversidad**)

In terms socio-economic context, the country had an estimated population of 17.3 million people in 2020, which, according to projections, could reach 23 million by 2050. Approximately 64% of Ecuadorian residents live in urban areas, and this figure is expected to rise to 67% by 2030 and 75% by 2050 (World Bank, 2023).

Ecuador has seen a significant decrease in poverty incidence, especially in rural areas, where it has fallen from 71.3% in 2003 to 57.5% in 2009, and to 25% in 2022. Meanwhile, in urban areas, this proportion decreased from 38.7% in 2003 to 25% in 2009, and 16.7% in 2022. In terms of inequality, a decreasing trend has been recorded in the country, although significant increases have occurred in certain periods.

In June 2022, national income poverty stood at 32.3%, with extreme poverty at 14.7%. In urban areas, income poverty reached 24.2%, and extreme poverty 8.4%. In rural areas, poverty was at 49.2%, and extreme poverty at 28% (**INEC**) (Figures 1 and 2).

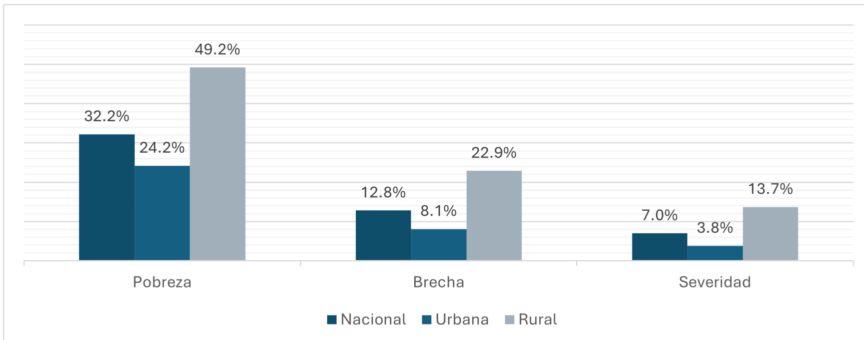

Figure 1: Incom Poverty Ecuador 2022

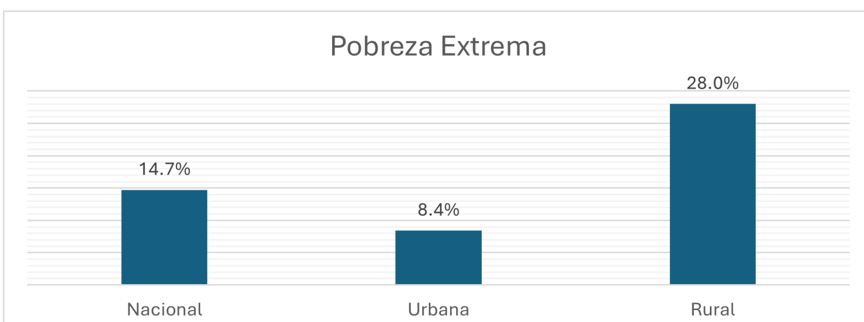

Figure 2: Extrem Poverty

INDICADOR	
Esperanza de vida al nacer, Total (años) (2019)	77.0
Densidad poblacional (personas por km2 (2028)	76.8
% de población con acceso a electricidad (2019)	100%
PIB per cápita (US$ corrientes) (2020)	$5,600.4

Figure 3: Ecuador Development Indicators

The country has a Gross Domestic Product (GDP) of approximately $117.8 billion in 2023. It is considered a middle-income country; however, around one-fifth of the population lives below the national poverty line. Endemic poverty in rural and indigenous communities persists, leading many Ecuadorians to rely on informal businesses as their only means of livelihood. In rural areas, access to land is unequal, with small farmers owning a small percentage of the arable land. (World Bank, 2023)

In 2023, Ecuador's Gross Domestic Product (GDP) grew by 2.4%, lower than the 6.2% growth achieved in 2022. This growth was driven by the dynamism of Government Spending, which increased by 3.7%; Exports by 2.3%; Household Consumption by 1.4%; and Gross Fixed Capital Formation (GFCF) by 0.5%. (BCE, 2024) Other indicators of the country are presented in the Figure 3.

Due to its wide range of climatic zones, Ecuador has an extraordinary variety of geographical systems, ranging from high-altitude glaciers to tropical forests in the upper tributaries of the Amazon and dry tropical forests on the Pacific coast, as well as an insular region in the Pacific, the Galápagos Islands. Many of Ecuador's systems are highly vulnerable and have already shown significant sensitivity to climatic variability and long-term change. (World Bank, 2023)

Regarding temperature, Ecuador has experienced increases in average temperatures, as well as minimum and maximum temperatures, between 1960 and 2020. The observed average temperature increase was 1.4°C (Figure 4), with maximum temperatures rising by 1°C and minimum temperatures by 1.1°C. Maximum temperatures have increased by 1°C per decade in the high mountains and 0.6°C per decade in the moorland regions. The number of warm nights has increased, while the number of cold nights has decreased. (World Bank, 2023)

Regarding precipitation, Ecuador experiences a high degree of variability in precipitation trends. The annual amount of precipitation has varied regions. Between 1960 and 2006, there was an increase in precipitation in the eastern Amazon rain forest, in the Highlands and along the northern coast, particularly in the coastal areas of the provinces of El Oro, Guayas, Santa Elena, and Manabí. Annual precipitation increased by 33% in the Coastal Region and by 8% in the Inter-Andean Region. The retreat of glaciers in the Andean region is significant, around 20 to 30% in the last 30 years. (World Bank, 2023)

These warmer temperatures, with altered precipitation patterns, have changed the start and end of growing seasons for agricultural products, contributed to reductions in regional crop yields, reduced the availability of freshwater, placed

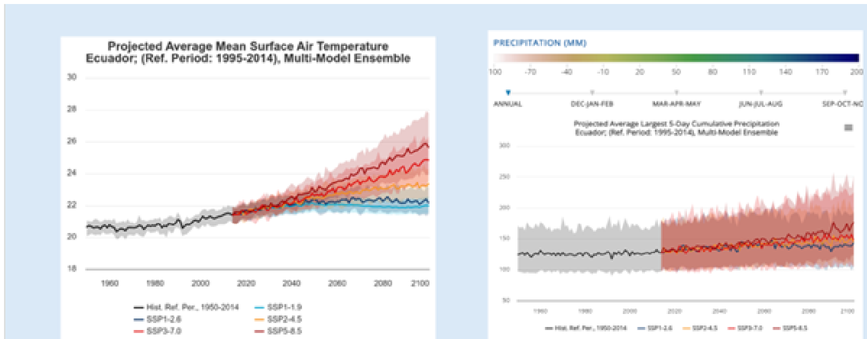

Figure 4: Project Average Mean Surface Air Temperatrue and Precipitacion in Ecuador 1995-2014

biodiversity under greater stress, and increased tree mortality. (IPCC, 2019)

In all emission scenarios, temperatures are projected to continue rising in Ecuador until the end of the century, with warming of up to 1.0 ° C expected in the short term along the eastern border in the Inter-Andean valley by the 2030s. Average temperatures are expected to increasing rapidly after the 2040s. According to these scenarios, the Amazon and Sierra regions will experience the highest temperatures, with increases of up to 5°C and 4°C, respectively, while the coastal region will see a slower increase, reaching temperature rises of up to 3.3 ° C at the end of the century under the RCP8.5 scenario. (Figure 5). The rise in temperatures and extreme heat conditions will have significant implications for human and animal health, agriculture, water resources, and ecosystems.

Regarding vulnerability to extreme events, climate change in Ecuador is closely linked to the El Nio South Oscillation (ENSO), with increased rainfall and flooding along the coast and western Andes, and droughts in the northern and eastern areas. In the medium and long term, the trends of climate change in Ecuador are expected to generate significant impacts for the country. These include the intensification of extreme weather events (e.g., ENSO); rising sea levels; greater glacier retreat; reduced annual runoff and increased vulnerability of water resources; increased vulnerability to flooding and prolonged droughts; greater transmission of dengue and other tropical diseases; the expansion of invasive species populations in the Galápagos and other sensitive ecosystems of mainland Ecuador; and the extinction of some species. (UNDP, 2023)

Ecuador is exposed to a wide range of natural threats that are increasing in magnitude and frequency due to climate change. Approximately 28,000 natural disasters occurred between 1990 and 2015 in Ecuador, 96 of which were considered major events that resulted in USD 3.8 billion in economic damage. Floods account for 30% natural disasters in the country, followed by earthquakes and landslides. (World Bank, 2021)

The annual average of natural phenomena that occurred between 1980 and 2020 shows 26 floods, representing 32% of all natural events, followed by land-

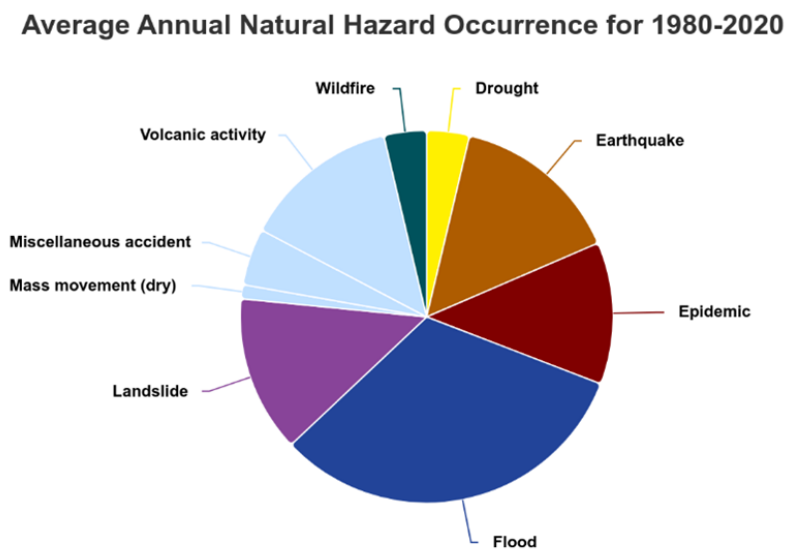

Figure 5: Annual average occurrence of extreme natural events

slides, which account for 13%, equivalent to an average of 11 occurrences per year. Figures 5 and 6 summarize the occurrence of wildfires, floods, mass movements (drought), and other events, as well as the number of people affected on average by each event. (World Bank, 2021)

These floods affected around 40% of the total number of people affected by natural disasters and 35% by volcanic activity. Approximately 4 million people in the country are vulnerable to the climate crisis.

A significant number of landslides occur in the central part of the country due to the geography of the country. In particular, informal settlements in the province of Napo are mostly exposed to landslides due to their geographical location and the poor quality of housing materials. Landslides damage agricultural resources. In 1998, 16,830 hectares of crops were affected, as well as in 2008 when 20,012 hectares of crops were affected by landslides. (Figure 7) **WBGroup**

Agriculture is one of the sectors that suffers the greatest consequences of drought, and is often the most affected, with severe consequences for food supply and the livelihoods of many people (FAO, 2016). In terms of fires, the country experiences the highest number of these events primarily in the regions of the highlands and the coast regions. The provinces most susceptible to forest fires are in the central part of the country, in the Sierra region. In particular, Bolívar and Chimborazo stand out for having a high percentage of vulnerable households living in fragile housing, which are especially prone to damage caused by these fires cite **FAO**

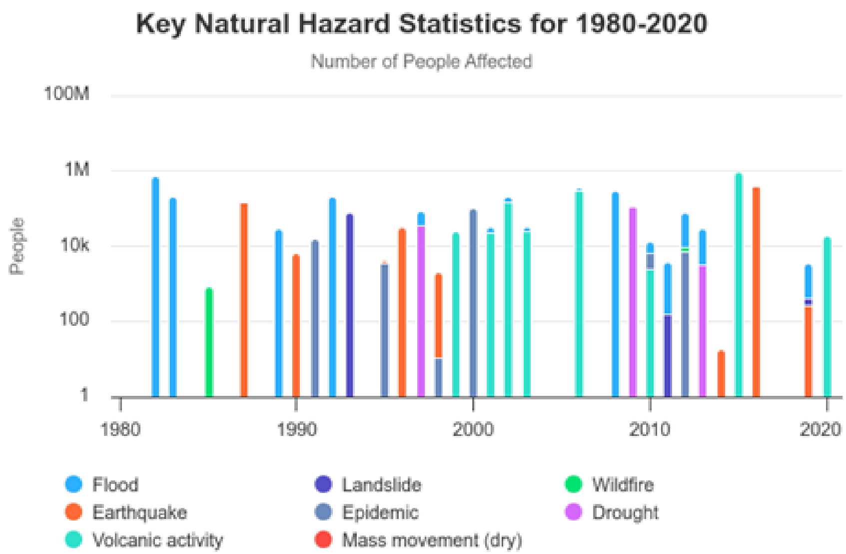

Figure 6: Number of People Affected by Natural Extreme Events

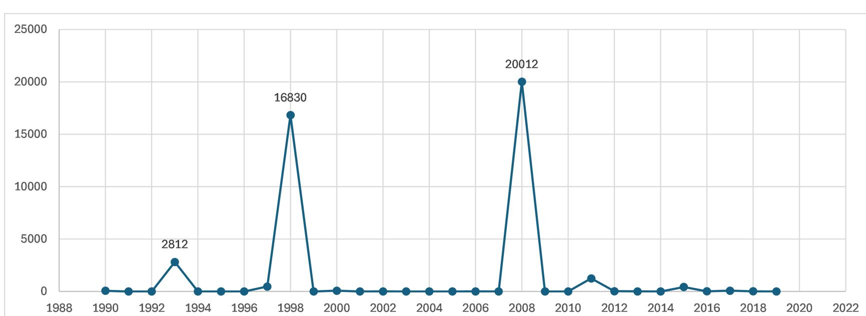

Figure 7: Crops affected by landslides (Ha)

2.1 Methological Framework

2.1.1 Climate change and its impact on agricultural yields

It is possible to discern an irrefutable and logical global behavior of the effects of climate change on crop productivity, which could have consequences for farmers' incomes. The stability of all food systems is at risk due to climate change and short-term supply variability.

Climate change has a significant effect on the rural landscape and the balance of agricultural and forest ecosystems; it affects various agricultural sectors, causing productivity losses, profitability problems, and job losses. **sanchez2000**

However, the potential effect of climate change is less clear on a regional scale, but it is likely that climate change will affect access to and consumption of food through collateral effects on household incomes, particularly those that depend on and are engaged in agriculture. **sobre2001tercer**

The reduction in crop yields has been identified as a direct way in which climate change affects the income of people who depend on agriculture. This paper uses crop production estimates and economic models to explore how climate change and associated conditions, including rising average temperatures, changes in precipitation patterns, and increased variability, affect agricultural productivity and crop yields, directly influencing farmers' incomes.

Several studies in the scientific literature have sought to model the effect of climate change on agriculture using laboratory or field experiments and agronomic models.

The so-called structural approach has been used, linking complex natural processes soil, phenological, and climatic systems with crop yields, combining the biophysical responses of crops with the economic responses of farmers **conde2000estudio**

One of the main features of these models is that they are based on an empirical production function that predicts the effects of climate on agriculture **adams1998effects** , **deschenes2011economic** .

The "Monte Carlo" method has also been used to approximate the probability distribution of agricultural production and the effect on the average producer's net profits, under baseline and climate change conditions, taking into account the observed variability in climate series. This method has the advantage of including uncertainty in economic variables, allowing for probabilistic solutions for models where, due to uncertainty and variability in the components, a deterministic solution would not make sense.

On the other hand, there are also agricultural vulnerability models using the spatial or Ricardian approach, which aim to estimate the effects of climate change on agriculture based on observed differences in land values, agricultural production, and other climate-related impacts between regions, using statistical or programming methods to analyze changes in spatial patterns of production (Molua E. L., 2008) (Molua & Lambi, 2007), establishing the analysis in Ricardian economic models, Computable General Equilibrium (CGE) models,

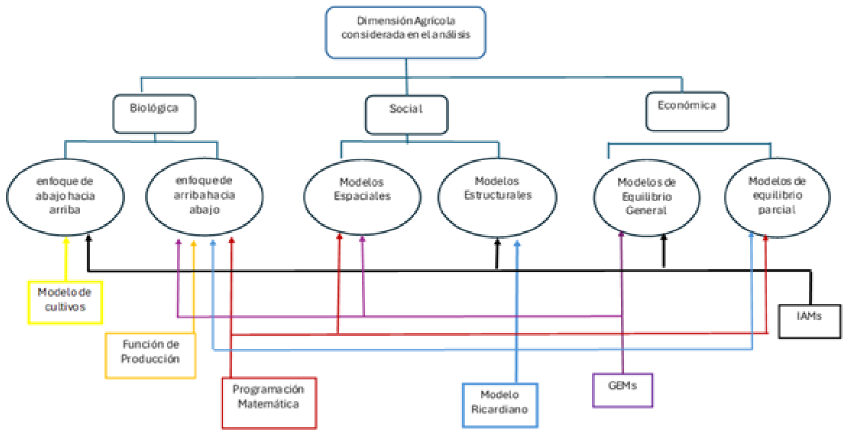

Figure 8: Classification of Models Assessing the Impact of Climate Change on Agriculture

Geographic Information Systems models, among others.

Figure 8 shows the main models used to estimate the impact of climate change on agriculture."

2.2 Analytical framework.

2.2.1 Double Exposure: Combined Impacts of Ecosystem Degradation and Climate Change on Subsistence Agriculture .

Double exposure emphasizes the interactions between two processes affecting agricultural crops and, consequently, the vulnerable population that depends on income from this activity. Through this double exposure framework, the interactions between the two processes that are contributing to increasing vulnerabilities in the population in the bottom quintile of poverty in the social registry in Ecuador are highlighted.

One is unquestionably the degradation of ecosystems and the loss of the environmental services provided by these ecosystems to support agriculture. The second is the biological effect of climate change on crop yields, and therefore its effect on the income of the population whose main source of income comes from agriculture, influencing poverty levels.

Agriculture is extremely vulnerable to climate change. The rise in temperatures ultimately reduces the production of desired crops, while also causing the proliferation of weeds and pests. Changes in rainfall patterns increase the likelihood of crop failure in the short term and reduced production in the long term. **nelson2009cambio**

Most climate change models predict that the damages will be disproportionately borne by small farmers in the developing world and particularly by farmers who depend on unpredictable rainfall patterns. These production losses will intensify increasing temperatures and differences in precipitation. Climate change will reduce crop production, and thus the effects on the well-being of thousands of smallholder farmers will be very severe, especially if the subsistence productivity component is reduced, affecting farmers' labor productivity and even impacting their health. (Altieri / Nichols, 2009)

As a result of various processes related to climate change and land misuse, desertification occurs. The degradation of a particular area of fertile land due to climatic phenomena or human activity is a determining factor in crop yields. This transformation is closely linked to drought. The use of marginal land increases the risk of soil degradation. **metz2007climate**

On the other hand, as already mentioned, the biological effect of climate change on crop yields, and therefore its effect on the income of the population whose main source comes from agriculture, impacts poverty levels.

These effects of climate change on human well-being and income are related to 'calorie availability' and 'the number of malnourished children.' By 2050, calorie availability will not only be lower than in a scenario without climate change, but will actually decrease worldwide in developing countries, compared to the levels reached in 2000. By 2050, the reduction in calorie availability will increase childhood malnutrition by 20 percent, compared to what would be expected in a world without climate change. Climate change will eliminate many of the improvements in childhood malnutrition that would occur in the absence of it **nelson2009cambio** becoming a direct channel for worsening poverty.

The daily availability of calories per capita for developing countries, without climate change, would reach 2886 by 2050 (it was 2696 in 2000), whereas in climate change scenarios for that year, a 15.7% reduction is projected, reaching only 2432, with the consequence of increased childhood malnutrition.

2.3 Ecosystem degradation is a factor that increases vulnerability to climate change

Climate change represents a significant additional pressure on terrestrial ecosystems, which are already seriously affected by pollution, over exploitation, and fragmentation of the land.

When a community depends on natural resources and primary agricultural systems, the effects of climate change have a profound impact. The increase in CO2 concentration and air temperature, as well as changes in precipitation patterns — in intensity, distribution, and timing — combined with the greater frequency and severity of extreme events, severely affect the sensitivity of ecosystems. These already degraded ecosystems are further harmed by socioeconomic factors. In this context, there is a mutually determining relationship between climate change and environmental degradation, exacerbating the challenges for communities that rely on these resources.

The consequences of climate change on biological systems not only affect variables associated with the configuration of ecosystems, but these systems also experience a reorientation of their functions. Several ecological processes are affected by climate change: productivity, population dynamics of wildlife, species abundance and distribution, among others.

In this mutually determining relationship, the factors of vulnerability to climate change for people engaged in agriculture are highlighted. Agriculture is one of the activities with the greatest negative impact on soil resources due to the pressure exerted on the resource to meet food production needs (overexploitation), as well as inadequate practices such as excessive use of agrochemicals and intensive tilling, causing loss of organic matter, greenhouse gas emissions, pollution, erosion, desertification, salinization, acidification, and loss of genetic diversity, all of which directly affect soil quality. **kopittke2019soil**

2.4 Effect of Climate Change on Agricultural Crop Yields

The effect of climate change on agricultural crop yields is complex and can vary significantly depending on the region, crop type, and agricultural practices. In some temperate regions, a rise in temperature extends the growing season, allowing for more crop cycles per year. However, in warmer regions, an increase in temperature may reduce yields due to heat stress on plants, affecting photosynthesis and fruit production. Additionally, high temperatures accelerate evapotranspiration, increasing water demand. *(UNDP, 2023)*

Regarding changes in precipitation patterns, some regions experience an increase in rainfall, which could benefit crop growth if excess water is properly managed. Erratic rains and prolonged droughts damage crops, reduce yields, and increase the need for irrigation. Floods destroy fields and erode soil, reducing its fertility.

Furthermore, extreme weather events such as storms, floods, and hurricanes cause direct damage to crops, agricultural infrastructure, and soil. Prolonged droughts drastically reduce the availability of water for irrigation, decreasing yields and crop quality.

Changes in the distribution of pests and diseases alter pest and pathogen habitats, allowing them to establish in new areas and affect crops that were previously not exposed to them.

The rise in mean sea level (MSL) causes saltwater intrusion into agricultural fields, affecting soil quality and freshwater availability, thereby reducing agricultural productivity in coastal areas.

Changes in temperature and humidity recorded in climate change scenarios impact soil fertility by affecting soil microorganisms and decomposition processes, which in turn influence soil fertility and thus crop yields.

An increase in carbon dioxide concentrations enhances photosynthesis and the growth of some plants through the carbon dioxide fertilization effect, especially in (C^3) crops like wheat and rice. However, this benefit may be offset by negative factors associated with climate change, such as heat stress and reduced water availability.

In summary, climate change has the potential to affect agricultural crop yields in various ways, with predominantly negative impacts. Adaptation and the implementation of resilient agricultural practices will be key to mitigating negative effects and seizing any potential opportunities that may arise. These effects of climate change on agriculture are estimated using an agricultural vulnerability model based on the **spatial or Ricardian approach**, which aims to assess the impact of climate change on agriculture by analyzing observed differences in land values, agricultural production, and other related climatic impacts across regions, using statistical or programming methods. *(Mendelsohn, Nordhaus, & Shaw, 1994)* This study is based on a combination of **Ricardian models of agricultural income** and **microsimulation models**. The model examines the net income per hectare of the crops with the greatest contribution to the agricultural GDP (banana, coffee, cocoa, sugarcane, soft corn, hard corn, and rice). The limited range of temperature variation allows only a basic test of temperature impacts, but the broader range of precipitation across the country enables a more complex analysis of precipitation effects. [1]

The Ricardian model of agricultural income is based on the understanding that agricultural rent arises from the difference between the market price of an agricultural product and its production cost. This production cost, in turn, is determined by the amount of labor required to produce the product on land of decreasing fertility.[2]

On the other hand, the **microsimulation model** [3] is used to analyze the effects of climate change on household income and well-being. This model accounts for household heterogeneity due to differences in their socioeconomic characteristics, production strategies, and access to other income sources. The model is implemented for **agricultural production units (UPAs)** that do not exceed 2 hectares in size and for representative households in **deciles 1, 2, and 3**, at the **parish-level geographic scale**.

The proposed approach allows for consideration of the heterogeneity among households and **subsistence-level UPAs**. It enables the simulation of different climate change scenarios and adaptation strategies. The model provides detailed information on the **impacts of climate change on the agricultural production** of these small-scale agricultural units, **household income**, and **levels of well-being**. It also allows for the inclusion of various income sources and multiple household characteristics, and supports the execution of **multiple simulations**.

Among the advantages of this approach is the ability to estimate the **direct**

[1] Climate projections are examined based on historical data from 1961–2014 as a baseline for climate change scenarios in Ecuador. These were generated by NASA through the **NEX-GDDP project (NASA Earth eXchange - Global Daily Downscaled Projections)**, which downscaled data on precipitation, average, maximum, and minimum temperatures to a daily scale and a spatial resolution of 25x25 km. This includes both the historical period (1961–2014) and the future period (2011–2100), across 4 of the 5 SSP scenarios from the IPCC's Sixth Assessment Report (AR6): **SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5**. *(MAATE, 2023)*

[2] By directly measuring net income, the Ricardian method takes into account both the **direct impacts of climate on crop yields**, as well as the **indirect effects** such as substitution between inputs, the introduction of different agricultural activities, and other potential adaptations farmers may adopt in response to changing climatic conitions.

[3] This section was prepared with the collaboration of Luis Castro Abril.

impact of climate change at a highly disaggregated level (farm-level), while also considering other highly relevant variables such as **land quality**.

It is assumed that farmers aim to **maximize net income per hectare (NR)**.

$$MaxNR = P_i \cdot Q_i(R, E) - C_i(Q_i, R, E) \tag{1}$$

$\mathbf{P}_i$ and $\mathbf{Q}_i$ are respectively the **price** and **quantity** of good i; $\mathbf{C}_i\mathbf{(.)}$ is the **relevant cost function** with its corresponding price levels; **R** is a **vector of inputs**, and **E** represents a **vector of environmental characteristics** of the farmer's land, including climate.

In this context, the farmer chooses the **optimal production level** of agricultural good i by solving the following **optimization problem**:

$$Max_\pi \sum_i (P_i Q_i(L_i, K_i, X_i, T_i, Pl_i, E_i) - C(L_i, K_i, X_i)) \tag{2}$$

π_i is the **annual net profit** of the farm.
P_i is the **producer price** of good i.
Q_i is the **quantity produced** of good i, which depends on:

- $\mathbf{L}_i$: the level of **labor** allocated
- $\mathbf{K}_i$: the level of **capital** allocated
- $\mathbf{X}_i$: the **inputs** used
- $\mathbf{T}_i$: the **temperature**
- $\mathbf{Pl}_i$: the **precipitation (rainfall)**
- $\mathbf{E}_i$: the level of **soil erosion**

$\mathbf{C}_i$ is the **cost function** associated with production factors and inputs, which incorporate their respective price levels.

Equation (2) is developed for estimation using a **second-order Taylor expansion**, in order to account for **non-linear responses** and to solve the farmer optimization problem.

Among the main **limitations**, it is noted that the model **underestimates adaptive responses to climate change**, and secondly, there is a **lack of sufficient experimental data** to accurately determine farmers' agronomic responses.

The Ricardian model of agricultural income assumes that households engage in an optimization process when making production decisions. However, this assumption may not always hold true for the type of subsistence-level agricultural production units (UPAs) analyzed, as their production is often driven—at least in part—by poverty alleviation strategies and/or subsistence needs, suggesting that the actual solution to the household's production problem may be at a suboptimal level

Another limitation relates to the **simplifying assumptions of the microsimulation model**, which assumes **linear household behavior** and does **not account for complex interactions** between different factors.

Model Results

The results obtained from the combined Ricardian and micro-simulation model, allow the identification of the projected impact of climate change on net agricultural income and the well-being of rural subsistence households.

The main findings are as follow:

1. **Heterogeneous impact by region and crop**:

   The effects of climate change on the analyzed crops (banana, coffee, cocoa, sugarcane, soft corn, hard corn, and rice) vary according to their geographical distribution and projected climatic conditions. In regions where higher temperature increases and reduced precipitation are expected, crops such as rice and corn, exhibit a substantial decrease in net income per hectare.

2. **Negative effects on subsistence-level UPAs**:

   Agricultural production units less than 2 hectares are especially vulnerable, showing reductions in both productivity and net income. This is mainly due to limited adaptive capacity, low access to technology, and limited economic flexibility.

3. **Variation in household well-being by income decile**:

   Households in the lowest income deciles (1, 2, and 3) experience the greatest losses in terms of income and well-being, reflecting high sensitivity to climate change and low coping capacity in the face of extreme events.

4. **Climate scenarios (SSP)**:

   Under more pessimistic scenarios (SSP3-7.0 and SSP5-8.5), negative impacts are more pronounced. In contrast, under mitigation scenarios (SSP1-2.6), losses are smaller and, in some specific regions, slight benefits are observed, mainly due to the effect of CO2 fertilization on C3 crops such as (if applicable) wheat and rice.

5. **Limited spontaneous adaptation**:

   The model shows that, under current conditions, spontaneous adaptive responses by farmers are not sufficient to offset the negative impacts of climate change. This highlights the need for policy interventions and support programs that provide technical and financial assistance.

The results of the estimates show that **subsistence-level agricultural production units (UPAs)** are highly vulnerable to variables associated with external climatic factors that may be modified due to global warming. In this regard, extreme phenomena such as droughts, frosts, and floods caused by extreme variations in temperature and precipitation are the primary threats to all these crops, regardless of their growth cycle. The most relevant production

PROVINCIAL						
Provincia	**Cacao**	**Café**	**Platano**	**Arroz**	**Maiz duro**	**Maiz suave**
AZUAY	-49.00%	-100.00%	-100.00%		-99.50%	-99.90%
BOLÍVAR	-30.60%	-100.00%	-90.20%	-100.00%	-97.50%	-99.80%
CARCHI	-100.00%	-99.80%	-78.00%		-98.40%	-99.90%
CAÑAR	-50.00%	-100.00%	-79.60%	-100.00%	-100.00%	-100.00%
CHIMBORAZO	-40.70%	-100.00%	-98.40%	-100.00%	-97.40%	-99.90%
COTOPAXI	-36.40%	-100.00%	-77.10%		-100.00%	-99.90%
El ORO	-52.30%	-100.00%	-76.40%		-91.90%	-100.00%
ESMERALDAS	-39.10%	-100.00%	-78.70%		-96.50%	
GUAYAS	-20.40%	-100.00%	-65.80%	-99.00%	-64.80%	
IMBABURA	-36.90%	-100.00%	-94.30%		-95.70%	-99.90%
LOJA	-100.00%	-100.00%	-72.80%	-100.00%	-92.00%	-100.00%
LOS RIOS	-21.20%	-100.00%	-66.80%	-99.10%	-63.20%	
MANABÍ	-30.20%	-100.00%	-73.40%	-100.00%	-70.50%	
MORONA SANTIA	-57.00%	-100.00%	-67.40%		-98.90%	-100.00%
NAPO	-51.60%	-100.00%	-88.90%	-100.00%	-98.50%	
ORELLANA	-39.50%	-100.00%	-90.10%	-100.00%	-96.80%	
PASTAZA	-58.20%	-100.00%	-82.40%		-98.70%	
PICHINCHA	-29.20%	-100.00%	-81.50%		-100.00%	-99.70%
SANTA ELENA	-16.00%	-100.00%	-69.30%		-76.90%	
SANTO DOMING(	-30.70%		-76.10%		-91.00%	-100.00%
SUCUMBIOS	-45.50%	-100.00%	-93.60%	-100.00%	-93.90%	
TUNGURAHUA					-100.00%	-98.80%
ZAMORA CHINCH	-51.00%	-100.00%	-96.00%		-100.00%	-100.00%

Figure 9: Crops Yield Looses due to increased temperature and drough

factors for these units are labor, irrigation and the use of chemical fertilizers, indicating that there would be no mitigation mechanisms in place to address the upcoming climatic events.

To identify the possible impacts of climate change on the productivity of subsistence-level agricultural production units (UPAs), simulations were conducted associated with changes in temperature and precipitation that could lead to extreme phenomena such as droughts and floods events that, in climate change scenarios, show significant increases.

The results obtained for the combined **temperature and drought** show that, at the national level, **cacao** would be the product with the least impact, with its productivity reduced by approximately 31%. **Rice** and **soft corn** would be the products most affected, and this phenomenon would nearly destroy the planted hectares. (Figure 9)

When differentiating the effect by province, it is observed that for **cacao**, the greatest impact is in the **Pastaza** province. For **coffee**, the average effect is widespread and the devastation would be nearly total in the provinces. In the case of **banana**, the **Chimborazo** province has the greatest impact. For **rice** and **soft corn**, as with **coffee**, the effect is total and overwhelming in all provinces. For **hard corn**, the most significant impact, equivalent to total devastation, is recorded in **Azuay**.

It should be noted that these results were obtained under the **maximum impact scenario**, which means that the modeled event occurs uniformly in

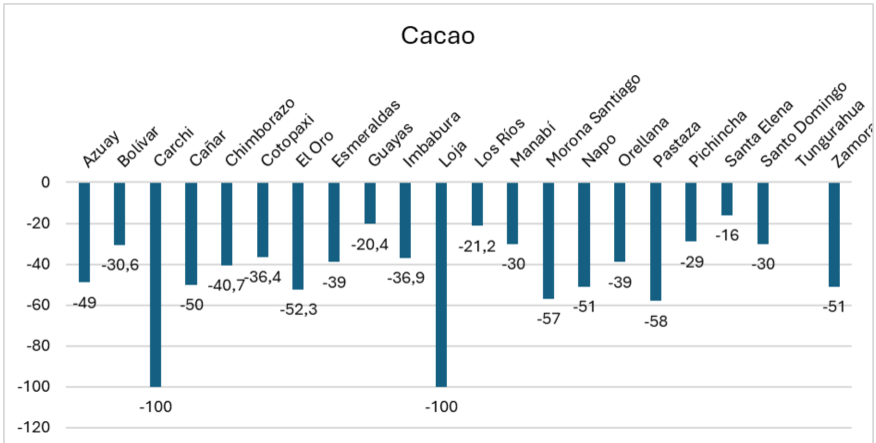

Figure 10: Looses in Cacao Crops Due to Increased Precipitation and Flooding

Ecuador. The results for a national-level results by province, shows in figure 10.

The results obtained from analyzing the **combined effects of precipitation and flooding**indicate that, at the national level, hard corn would be the least affected crop on average, with a reduction in productivity of approximately 68%. Cocoa, banana, and rice would experience production losses of at least 80%. Coffee and soft corn would be the most severely impacted crops, with this phenomenon resulting in near-total devastation of cultivated hectares. (figure 12)

When disaggregating the effects by province, it is observed that the greatest impact on cocoa occurs in the provinces of Carchi and Loja. For coffee, the average effect suggests total devastation in the provinces of Cañar, Chimborazo, and Pastaza. In the case of bananas, the coastal area of Azuay province presents the highest level of impact. For rice, total losses are observed in the provinces of Cañar, Napo, and Sucumbíos. In the case of hard corn, total devastation is recorded in Zamora Chinchipe. Finally, for soft corn, the province of Cañar shows the highest average level of impact. (Table 1)

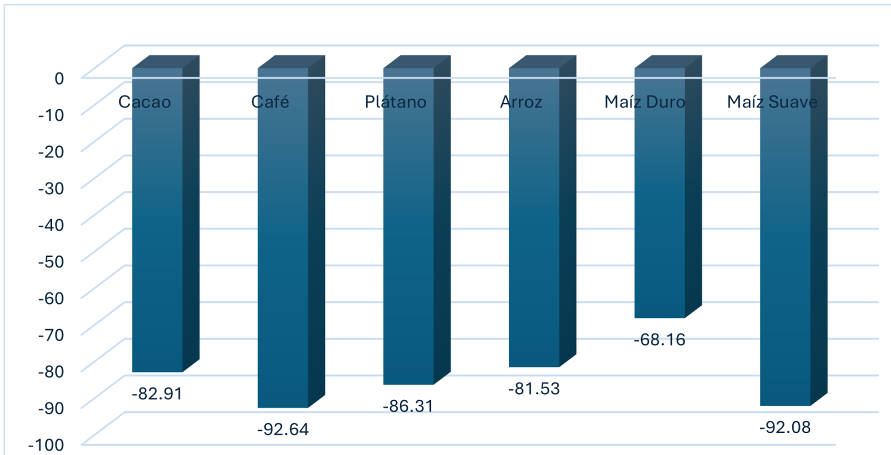

Figure 11:

Figure 12: Crop yield losses due to increased precipitation and flooding

Province	**Cacao**	**Café**	**Plátano**	**Arroz**	**Maíz Duro**	**Maíz Suave**
Azuay	-89	-95.3	-100		-92.2	-89.9
Bolívar	-78	-82.9	-94.7	-83.3	-86.8	-87.8
Carchi	-100	-53.2	-80.6		-80.8	-83.8
Cañar	-95	-100	-95.1	-100	-99.3	-97.2
Chimborazo	-77	-100	-98.4	-53.4	-84.8	-91
Cotopaxi	-86	-98.9	-81.2		-88.8	-94
El Oro	-94	-84	-84.3		-86.7	-93.7
Esmeraldas	-89	-100	-85.3		-91.1	
Guayas	-79	-99.3	-81	-79.8	-58.3	
Imbabura	-80	-93.4	-94.9		-85.1	-96
Loja	-100	-90.1	-75.2	-57.2	-74.5	-96
Los Ríos	-75	-94.1	-79	-81.2	-55.9	
Manabí	-84	-92.3	-84.8	-89.3	-58.5	
Morona Santiago	-80	-99.9	-76.9		-94	-87.8
Napo	-89	-97.7	-94	-100	-99.2	
Orellana	-84	-90.9	-96.3	-97.1	-96.9	
Pastaza	-100	-100	-92.3		-99.3	
Pichincha	-74	-78	-84.7		-97.6	-84.5
Santa Elena	-62		-80.3		-57.9	
Santo Domingo	-85	-88.3	-85.2		-86.3	-62
Sucumbíos	-91	-95.8	-97.2	-100	-93.5	
Tungurahua					-66.5	-84
Zamora	-82	-95.4	-97.1		-99.9	87

Table 1: Loss percentages by crop and province due to precipitation and flooding

3 Conclusions

The agricultural regions most threatened by rising temperatures and increased precipitation due to climate change are the provinces of Azuay, Bolvar, Carchind Chimborazo, where 53% of the population ofof first and second quintiles of poverty, who depedependn income from cococoa, coffee, banana and hard corn cultivation,rience total losses of their crops and, consequently, their livelihood and flooding associated with climate change.

Similarly, 53% of the population from the first and second poverty deciles, who depend on income from coffee cultivation, will suffer total crop losses—and thus loss of livelihood—due to rising temperatures and the occurrence of droughts across all provinces of the country, except Santo Domingo and Tungurahua.

In the case of soft corn producers, 53% of the population depending on income from this crop within the first and second poverty deciles will experience total crop losses in the provinces of Azuay, Bolívar, Carchi, Cañar, Chimborazo, Cotopaxi, El Oro, Esmeraldas, Guayas, Imbabura, Pichincha, Tungurahua, Zamora, and Loja.

The devastating effects of climate change on populations whose livelihoods depend on agricultural income highlight the need to shift from top-down vertical planning mechanisms toward more inclusive and adaptive approaches.

Policy measures to address agricultural disasters under climate change scenarios increasingly involve the development of strategies focused on ecosystem restoration, the maintenance of ecological balance, watershed protection, and reforestation, all through mechanisms of collective action.