Vulnerability to climate change and economic impacts in the agriculture sector in Latin America and the Caribbean

Climate Change Division

Environment, Rural Development and Risk Management Division

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CIAT
International Center for Tropical Agriculture
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IDB Inter-American Development Bank

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CGIAR RESEARCH PROGRAM ON Climate Change, Agriculture and Food Security CCAFS

CGIAR RESEARCH PROGRAM ON Policies, Institutions, and Markets Led by IFPRI

2020

TABLE OF CONTENTS

I. Introduction

Over the last several decades, countries throughout Latin America and the Caribbean (LAC) have been developing rapidly in terms of economic development and incomes. The agriculture sector is fundamental to this development from the economic and social perspectives. However, the agriculture sector is highly sensitive to changes in temperature and precipitation and the increased climate change impacts. For this reason, the **Inter-American Development Bank (IDB)** and the **International Center for Tropical Agriculture (CIAT)**, with the support of the CGIAR Research Programs on Policy, Institutions and Markets (PIM) and on Climate Change, Agriculture and Food Security (CCAFS), have teamed up to understand the potential impacts of climate change in key crops for Latin America and the Caribbean and identify adaptation measures. This report presents the results of this research on the potential impact in productivity and trade at regional and country levels. It also presents key recommendations to reduce their vulnerability in line with the goals of the National Determined Contribution (NDCs) in the context of the Paris Agreement.

II. Executive summary

1. Climate change vulnerability and economic impacts in LAC

In the coming years, agricultural economies in LAC will face increasing challenges posed by climate change and variability, including rising temperatures, changing rainfall patterns, and more intense, more frequent extreme weather events. These changes could affect yields and food security in the region. In order to formulate effective responses to these challenges, it is necessary to examine the economic ramifications of the biophysical impacts associated with changing climates. Biophysical impacts vary not only with climate and crops varieties, but also with the global market. The articulation of the interactions among these three dimensions requires a threefold modeling workflow: 1) climate modeling, 2) crop modeling, and 3) economic modeling (Figure 1).

The biophysical impact assessment focuses primarily on five crops that figure prominently in LAC economies and food security: beans, maize, rice, soybean, and wheat. Regional variation in the economic ramifications of these impacts are modeled by taking into account their relative price movements in the global market, together with those of approximately fifty basic agricultural commodities, using the International Model for Policy Analysis of Trade and Commodities (IMPACT) model, developed at the International Food and Policy Research Institute (IFPRI). Through this analysis, sub-regional variations emerge due to shifting comparative advantages brought about by climate change, in some cases offsetting biophysical impacts, while in other cases aggravating them.

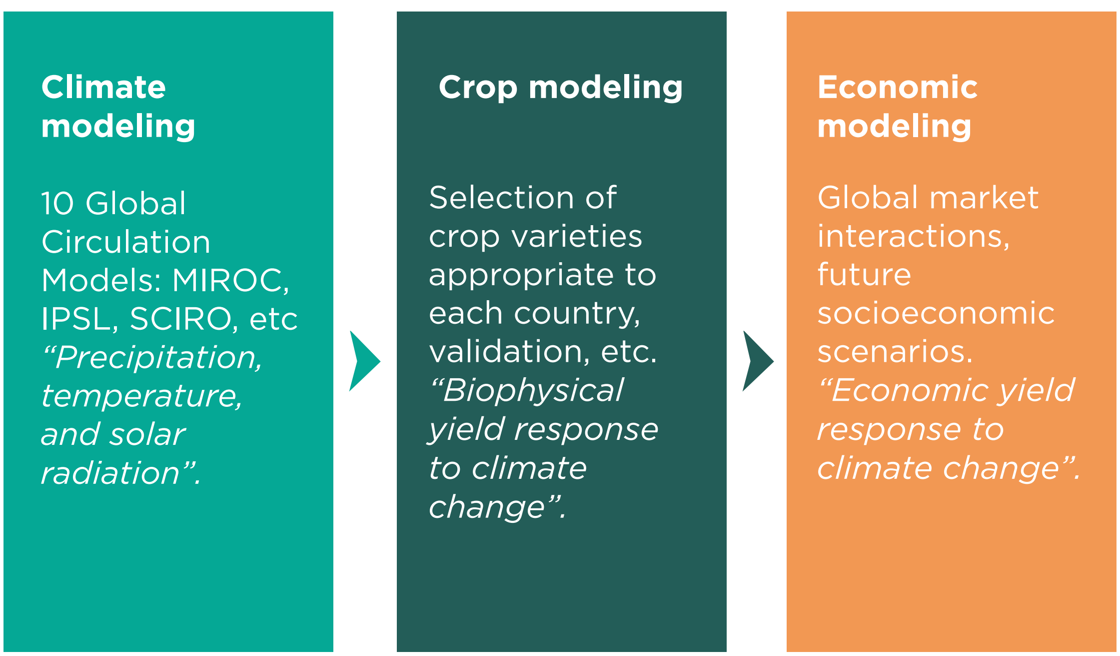


Figure 1. Modeling workflow

2. General region wide results

This analysis present some results at the LAC regional level although it provides more detailed information for thirteen countries analyzed: Bolivia, Colombia, Costa Rica, Dominic Republic, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Peru and Uruguay. At the regional level, the climate models project an average 1C-4C degree increase in maximum temperatures, and a 30% decrease in rainfall (Figure 2).

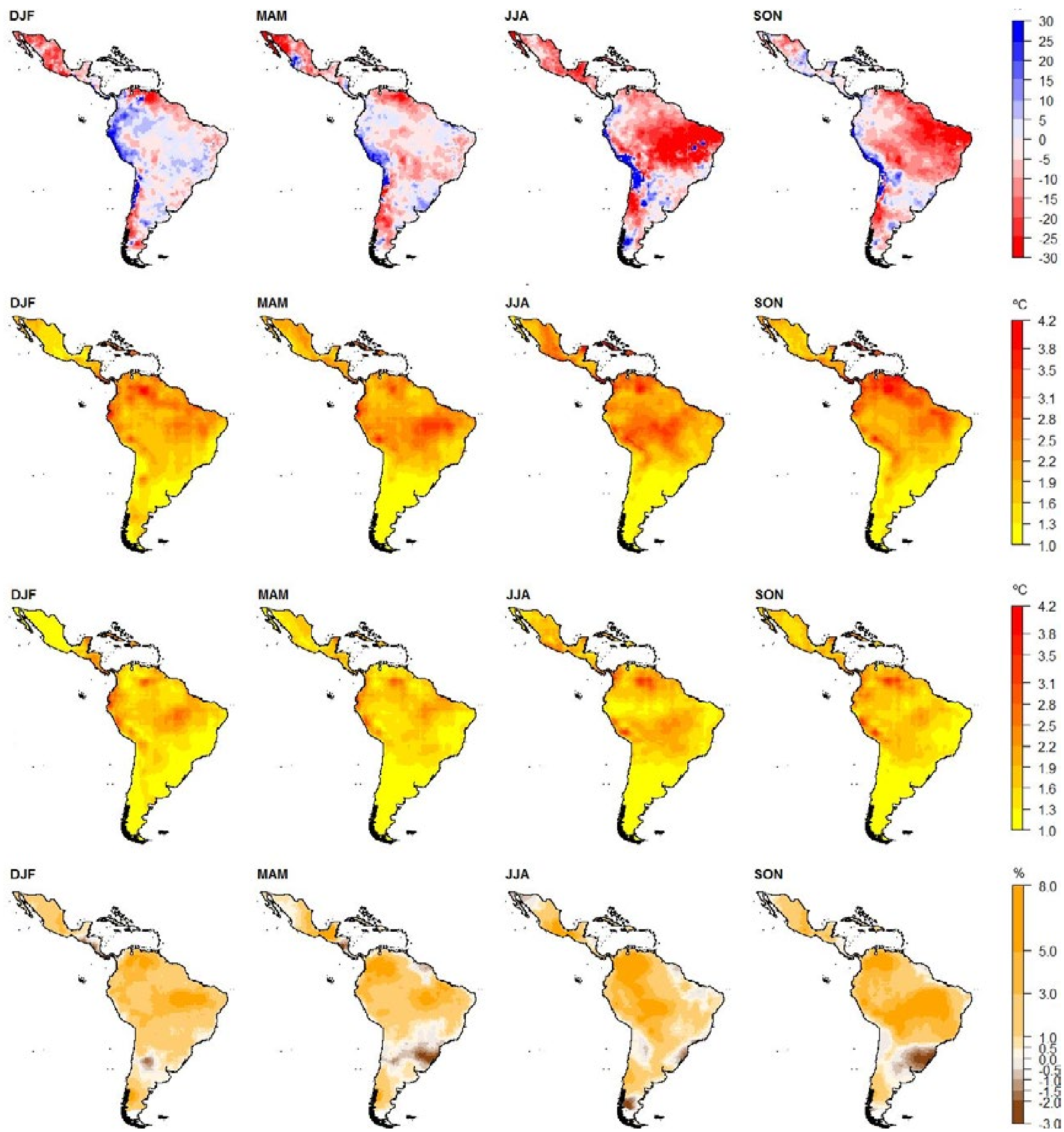


Figure 2. Climate impacts (2020-2050)

Legend: DJF= December - February, MAM= March - May, JJA= June - August, SON= September - November.

Across LAC, in a No-CC scenario, total agricultural production, area, demand, and trade are expected to increase as population and consumption patterns change. However, the introduction of climate change into the modeling lowers the average growth in yields, total area, and production by 7.5 pp, 1.2 pp, and 5.2 pp, respectively, at the LAC level. Globally, in a No-CC scenario, prices for beans, maize, rice, soybean, and wheat are projected to increase out to 2050 by 4.6%, 27.6%, 16.1%, 6.5%, and 11.7% respectively, over their current levels. But the introduction of climate change amplifies this rise by 14.6 pp, 15.4 pp, 10.1 pp, 0.5 pp, and 1.7 pp, respectively (Table 1).

Price increases and trade deficits in several LAC regions, suggest the possibility for increased exposure to food insecurity for most countries, with the Southern Cone serving as a notable exception. Given these circumstances, most regions in Latin America will just meet, or fall below the critical food supply/demand ratio (Figure 3). It is clear that the Andean, Mexico, and Central America and the Caribbean regions will face substantial difficulties. The more temperate SUR region, meanwhile, is projected to have a surplus that could bolster food security.

3. The way forward

The Nationally Determined Contributions (NDCs) of the countries examined in this document expressly include agriculture as a major component of their adaptive strategy. However, some of them also include mitigating measures to reduce emissions generated by this sector. LAC is faced with the challenge of producing enough food to feed a growing population while at the same time conserving its natural resources and ecosystem and adapting to climate change. The adaptation of the agricultural sector to climate impacts is key for its survival. From the recommendations presented in the individual country briefs presented below, five general adaptive themes or imperatives emerge: 1) inclusion of climate change scenarios as a key element in agricultural ministry and research institute decision making processes; 2) support research and adoption of drought and heat tolerant crop varieties; 3) promotion of sustainable irrigation as an effective adaptive strategy; 4) recovery of degraded lands and sustainable intensification to prevent further deforestation, one of the main causes of climate change in the first place; and 5) implementation of climate smart practices and technologies to increase productivity while improving adaptability and decreasing green gas house emissions.

Table 1: Regional trends in net trade by crop

Regional trends in net trade by crop (2050)	
Dry bean	Key crop supporting food security. Stable demand. Climate change related declines in production with the exception of SUR. High potential for trade surplus in BRA and some potential in SUR
Maize	Flex crop with complex demand profile. Downward pressure in demand associated with climate change scenarios. Potential for trade surplus in BRA but with high climate-related uncertainty, as well as in SUR. Substantial trade deficit in AND and CEN. Long-term potential for reduction of trade deficit in MEX.
Rice	Key food crop supporting increased food security. Downward pressure in demand associated with climate change. Increasing trade deficit in AND. Increasing uncertainty in trade for BRA and SUR.
Soybean	Flex crop with complex demand profile. Modest downward pressure in demand associated with climate change, though increasing in MEX. Increasing potential trade in SUR and BRA, with relatively stable trends in trade through the remainder of the sub-regions, albeit towards trade deficit.
Wheat	Flex crop with complex demand profile. Increased demand under climate change, with substantially increasing demand in BRA. Declines in net trade in AND, BRA, MEX and CEN. Increases in trade in SUR.

Legend: AND: Colombia, Ecuador, Peru, Bolivia and Venezuela; BRA: Surinam, Guyana and Brazil; CEN: Centro America and the Caribbean; MEX: Mexico; and SUR: Chile, Paraguay, Uruguay and Argentina.

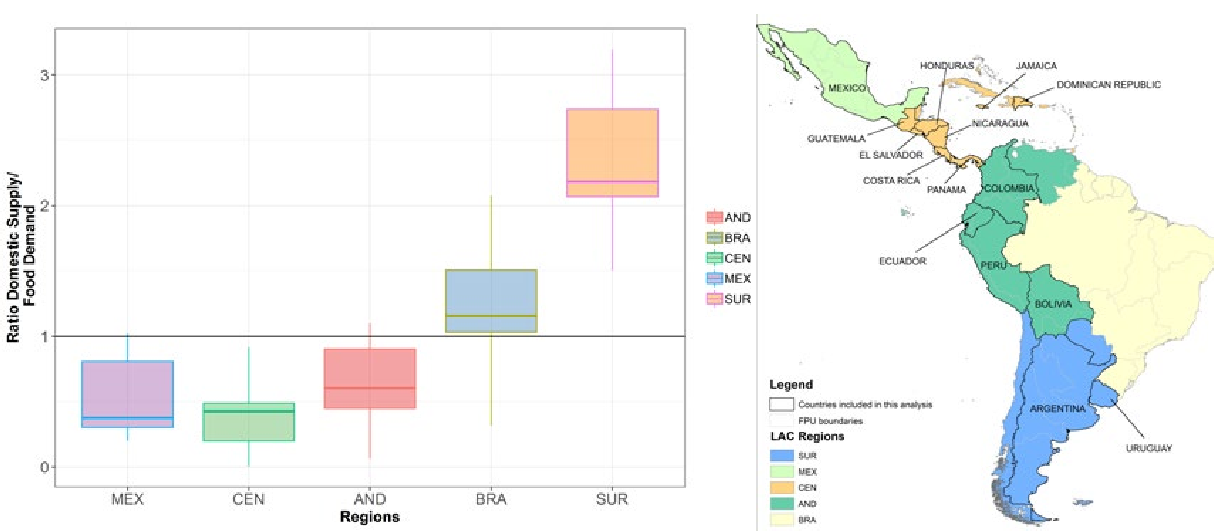


Figure 3: Food supply to demand ratios for the five LAC sub-regions defined in the map

III. Methodological summary

In assessing future climate impacts, this study utilized nine general circulation models (GCMs),[1] selected for their strong performance in the Latin American and Caribbean (LAC) region. Overall, temperatures are predicted to increase by 1-4 °C across the LAC region, with the Caribbean and tropical South America projected to warm at higher rates than Mexico and the Southern Cone.

Based on the projected changes in climate discussed above, 2050 projections of maize, rice, and bean yields were modeled using the Decision Support System for Agrotechnology Transfer (DSSAT v4.5) at 0.5 degree spatial resolution. Model runs for each crop were parameterized using genetic coefficients of varieties carefully selected by experts for their relevance in the region.

Additionally, climate change impacts on agro-ecological suitability for coffee (Robusta and Arabica), banana, yam, and cassava were assessed using niche based models.[2] In these models, "suitability" is defined based on how well local precipitation and temperature match the biophysical requirements of the given crop.

In order to understand the real impacts of climate change on demand, supply, and international trade flows, the purely biophysical impacts addressed in the sections above must be adjusted for the economic agency of farmers who can adapt to yield and suitability loss by switching to alternative cultivars and practices. Ongoing advances in productivity and yield enhancing agricultural research, as well as the mitigating action (or inaction) of governments on emissions policy, must also be taken into consideration. The interplay of these factors was modeled using the International Model for Policy, Agricultural Commodities, and Trade (IMPACT), developed at the International Food Policy Research Institute.[3] In this section, IMPACT projections are presented for the DSSAT modeled crops, accounting for global economic and climate change contexts of these crops as well as their substitutes.

1 The nine GCMs used were BCC-CSM1, BNU_ESM, CCCMA_CANESM2, GFLD_ESM2G, INM-CM4, IPSL-CM5A-LR, MIROC-MIROC5, MPI-ESM-MR, and NCC-NORESM1-M. For full details on all climate, crop, and economic models used in this report, see the **Methodology for Integrating Climate Change, Crop Response, and Economic Impact Climate Change Vulnerability and Economic Impacts in the Agricultural Sector.**

2 Yield impacts could not be assessed for these crops because the available data was insufficient to calibrate the DSSAT module, or because a DSSAT module does not yet exist for the crop. Coffee suitability was assessed using a machine learning ensemble-based approach. Suitability of the other crops was modeled using EcoCrop, based on the FAO EcoCrop database. See Methodology Brief for details.

3 See methodology brief for details. When interpreting the results in this section, it is important to consider that IMPACT output is the result of the complex interplay of many factors over time (climate change, GDP growth, demographics, mitigation policy, comparative advantage in trade, research, etc.) and across all countries. The results shown in this section are thus not attributable to any single one of these factors, but rather the complex interplay of all of them.

IV. Argentina

1. Context

Agriculture plays a declining but important role in Argentina. The sector accounts for 5.6% of GDP, down 4.7 percentage points (pp) from a peak of 10.3% in 2003. Crop products accounted for 25.2% of all exports in 2018, up 3.9 pp from 2009. Jobs in agriculture account for 0.5% of all employment in the country, down 0.7 pp from 8 years ago [1]. Argentina is the world's third largest exporter of soybeans, and the second largest exporter of maize [2]. With 47% of its land used for agriculture, climate change presents a significant risk to the country's agricultural sector. Flooding has already cost an estimated USD $3 billion per year over the past two decades; and desertification is expected to increasingly affect agricultural productivity in some parts of the country in coming years [3]. A better understanding of the climate change impacts on specific crops will hence assist in decision making. For this purpose, climate, crop, and economic modeling results are presented in this brief (averaged over 2020–2050), regarding agricultural production and trade in the country, set in the LAC regional context. Based on these trends, adaptation measures are proposed at the end of the brief.

2. Climate impacts

In assessing future climate impacts, this study utilized nine general circulation models (GCMs),selected for their strong performance in the LAC region. Overall, temperatures are predicted to increase by 1-4°C across the LAC region, with the Caribbean and tropical South America projected to warm at higher rates than Mexico and the Southern Cone.

In Argentina, projected changes in rainfall by 2050 vary from region to region and season to season (Figure 1). Sharp percentage decreases in rainfall are projected at higher elevations in the west and south throughout the year, especially during the winter months; but little to no agriculture occurs in these areas. Decreases in rainfall of 5%-15% are projected across much of the Pampas region during September to November, but increases are also projected in this area during December to February. A substantial increase in rainfall is projected across much of the north and northwest, meanwhile, especially during June to November. Maximum and minimum temperatures are projected to increase by about 1°C across much of the country, although the increase could be as great as 2°C at higher elevations and latitudes.

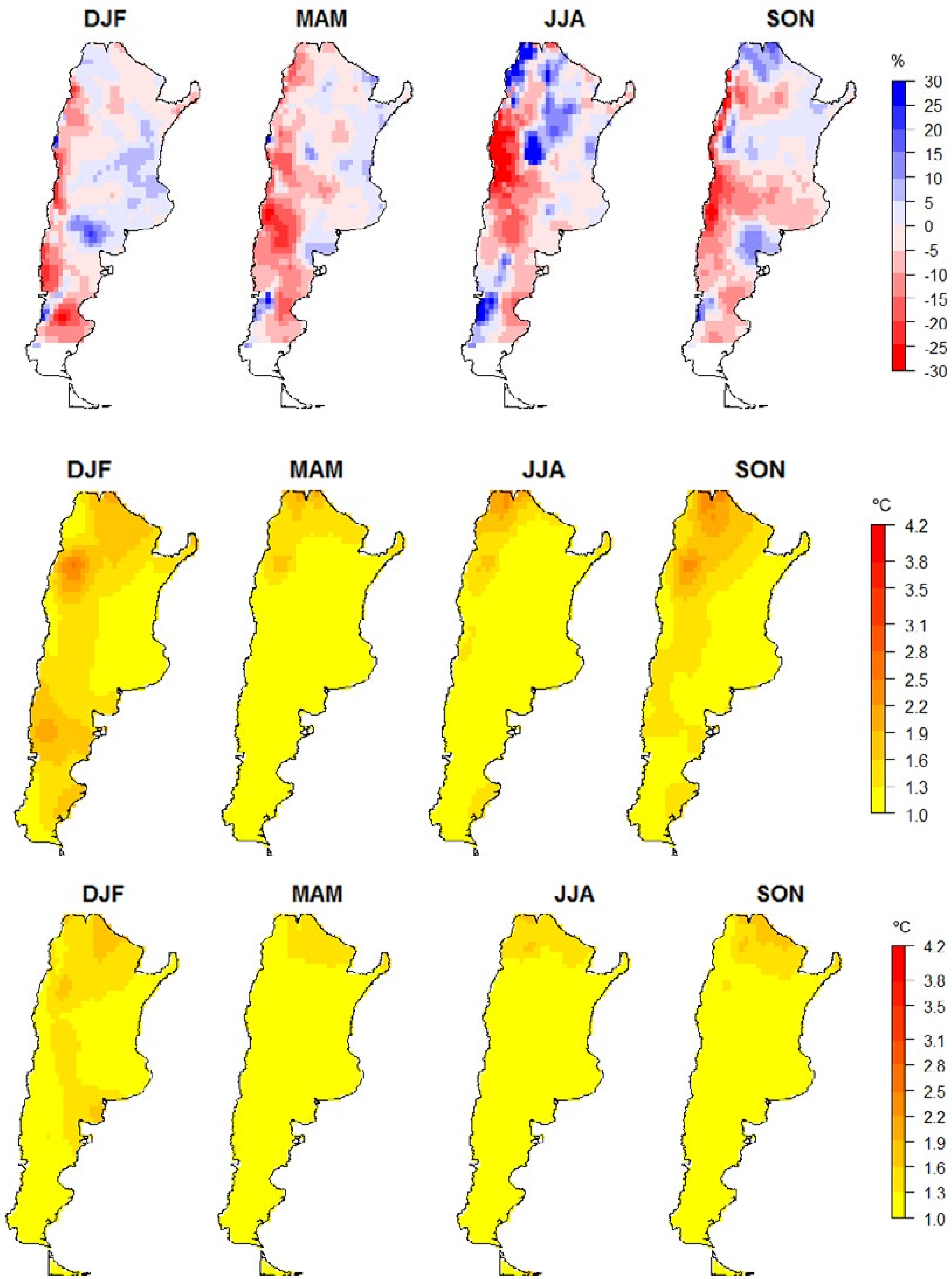


Figure 1: Change in (top to bottom) precipitation, maximum temperature, and minimum temperature averaged across nine GCMs (2020-2050). DJF= December - February, MAM= March - May, JJA= June - August, SON= September - November.

3. Yield impacts

Based on the projected changes in climate discussed above, 2050 projections of maize, wheat, and soybean yields were modeled using the Decision Support System for Agrotechnology Transfer (DSSAT v4.5) at 0.5 degree spatial resolution. Model runs for each crop were parameterized using genetic coefficients of varieties carefully selected by experts for their relevance in the region.

In Argentina, the modelling results shown in Figure 2 suggest that important rainfed crop yields could see substantial declines. Rainfed maize and wheat, in particular, could face decreases of about 11%, and 8%, respectively. Rainfed soybean yield, meanwhile, exhibits relative resilience under climate change, increasing by about 10%. Irrigated systems are projected to fare considerably better. Irrigated bean, soybean and wheat yields are projected to increase by about 19% and 3%, respectively, while irrigated maize yield is projected to decrease by about 3 pp less than its rainfed counterpart.

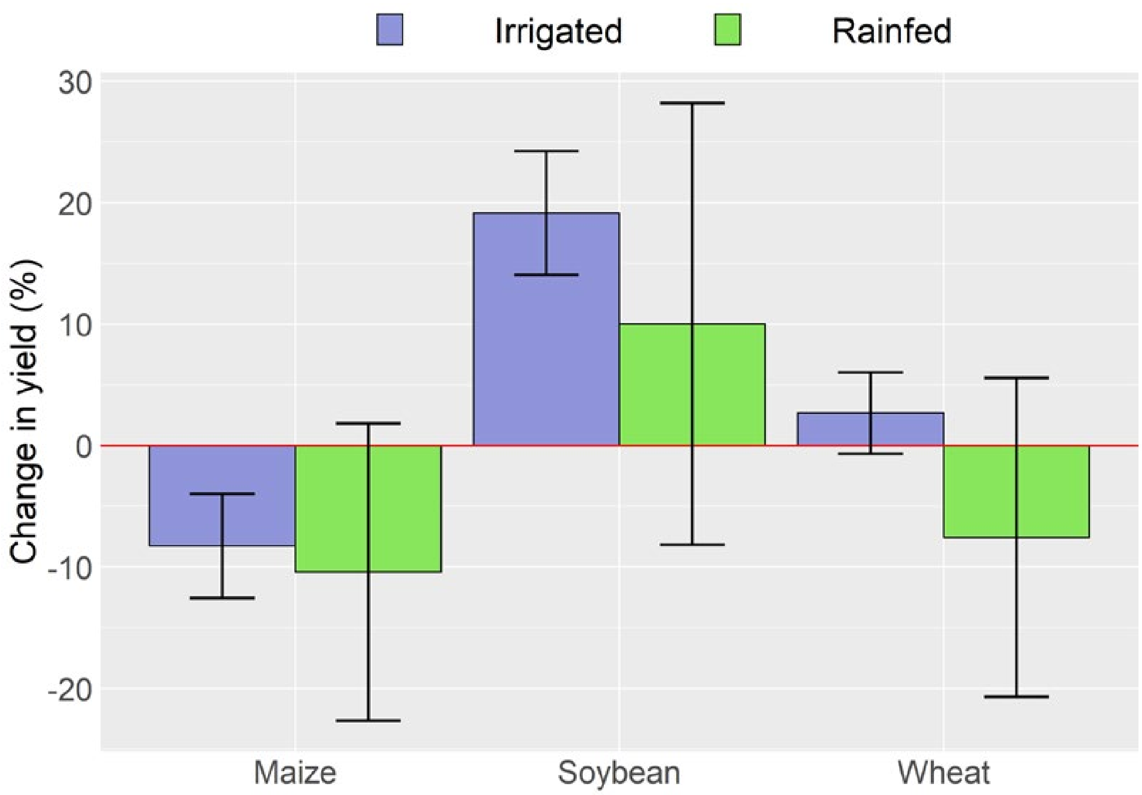


Figure 2: Projected average yield change, key crops (2020–2050). The error bars indicate the range of output across the nine climate models.

The geographically disaggregated view of these yield declines presented in Figure 3 reveals important variation hiding behind these national level averages. Note that maize and wheat yields are projected to decrease across much of the north; but that this general decline is offset by pockets of resilience and even yield increases towards the Pampas region, where increased rainfall is projected for parts of the year (recall Figure 1). Likewise, the projected resilience and/or increase in irrigated and rainfed soybean yields is most pronounced in and around the Pampas region, with less resilience and pockets of yield decreases projected farther north.

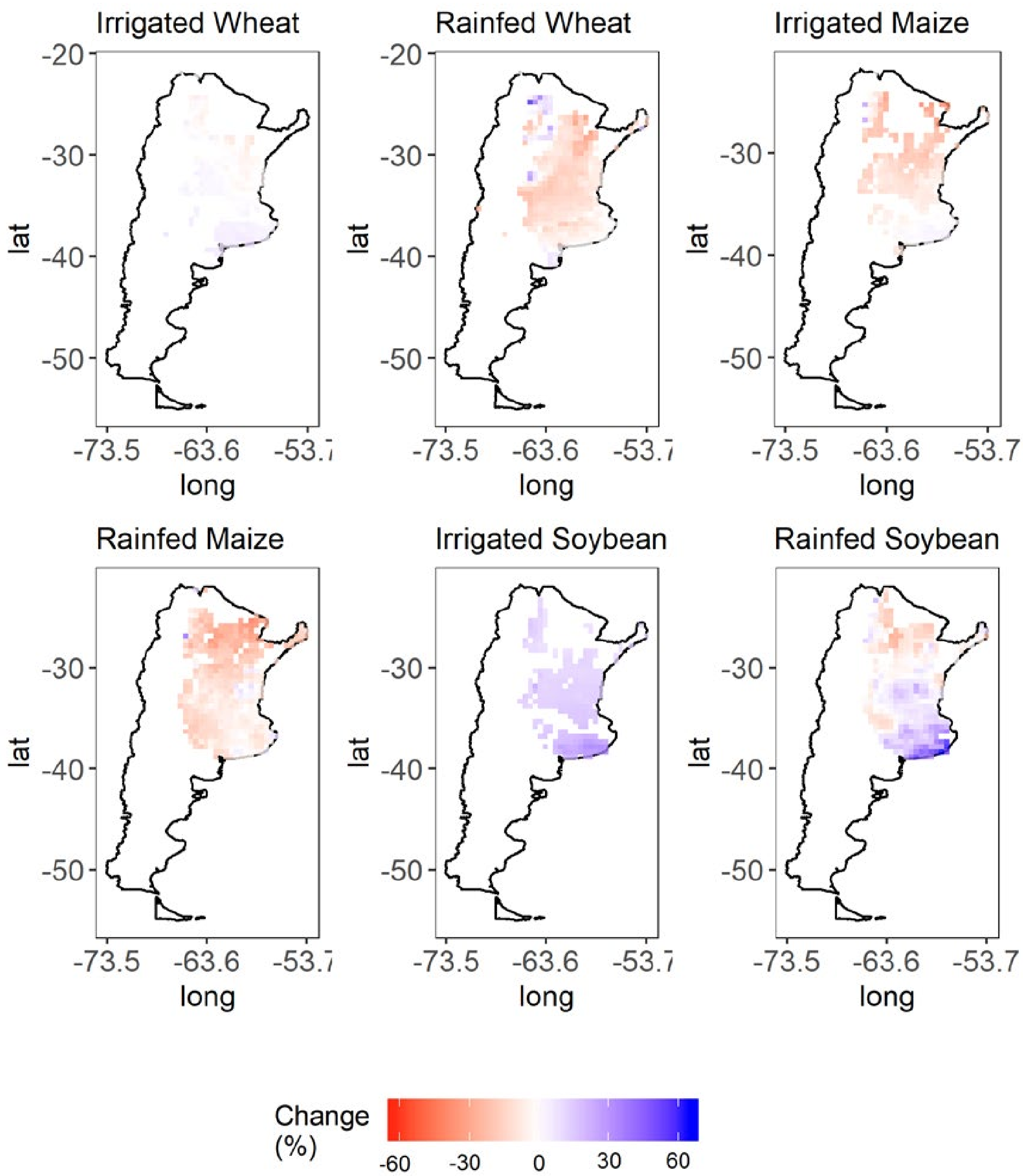


Figure 3: Projected yield impact maps, key crops (2020-2050).

4. Economic impacts

In order to understand the real impacts of climate change on demand, supply, and international trade flows, the purely biophysical impacts addressed in the sections above must be adjusted for the economic agency of farmers who can adapt to yield and suitability loss by switching to alternative cultivars and practices. Ongoing advances in productivity and yield enhancing agricultural research, as well as the mitigating action (or inaction) of governments on emissions policy, must also be taken into consideration. The interplay of these factors was modeled using the International Model for Policy, Agricultural Commodities, and Trade (IMPACT), developed at the International Food Policy Research Institute. In this section, IMPACT projections are presented for the DSSAT modeled crops, accounting for global economic and climate change contexts of these crops as well as their substitutes.

In Argentina, total agricultural production is expected to increase by 2050 under both CC and No-CC scenarios for all modeled crops except rice (Figure 4). Bean production growth is especially pronounced, and is even greater when climate stressors are introduced, surpassing the No-CC benchmark by 20 pp. Climate change is also projected to have a positive impact on rice production, cutting its negative growth trajectory to 10.3 pp above the No-CC benchmark. Meanwhile, the introduction of climate stressors has a comparatively slight impact on soybean (+2.7 pp), maize (+1.5 pp), and wheat (+1.3 pp) production growth. Demand for each of these crops will also rise during the 2020-2050 period, as will area planted, with the notable exception of rice (falling 24% without climate change, and 16.8% with climate change impacts).

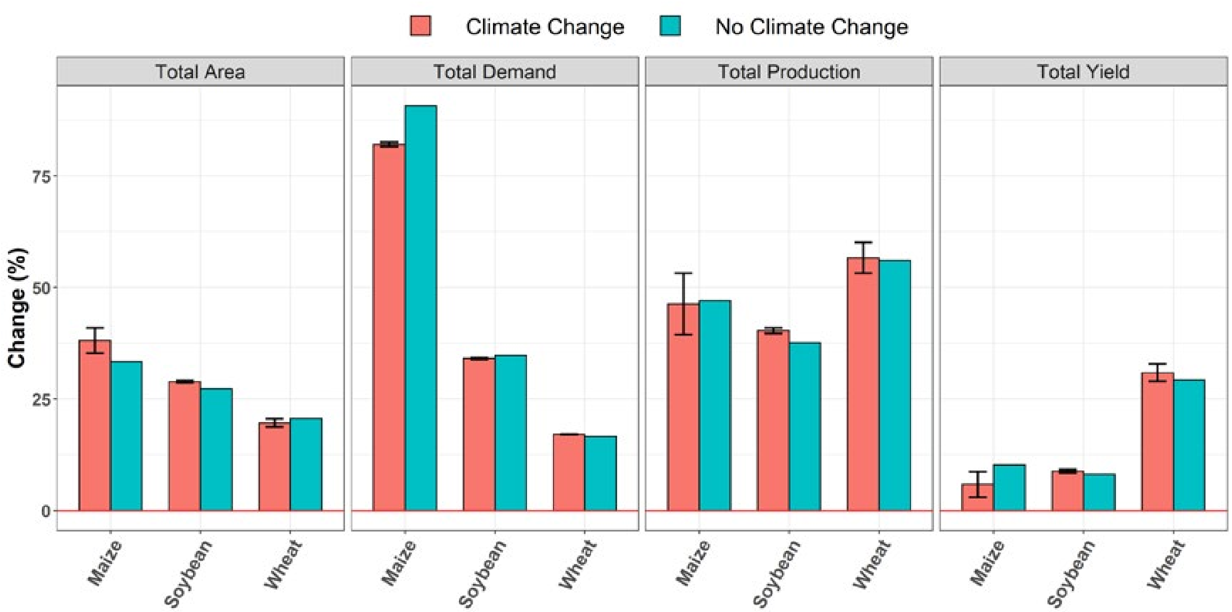


Figure 4: Percentage change in yield, demand, cultivated area, and production (2020–2050), when economic context and agricultural research are taken into account. The error bars indicate the range of output across the nine climate models.

The higher growth trends generally exhibited in Argentina stand in contrast to the anticipated experience of most other countries in LAC, where crop production growth is largely projected to undergo considerable reductions under climate change. This comparative advantage is reflected in sustained and rising trade surpluses for Argentina projected out to 2050. In particular, trade surpluses are expected for soybean, wheat, and maize (Figure 5).

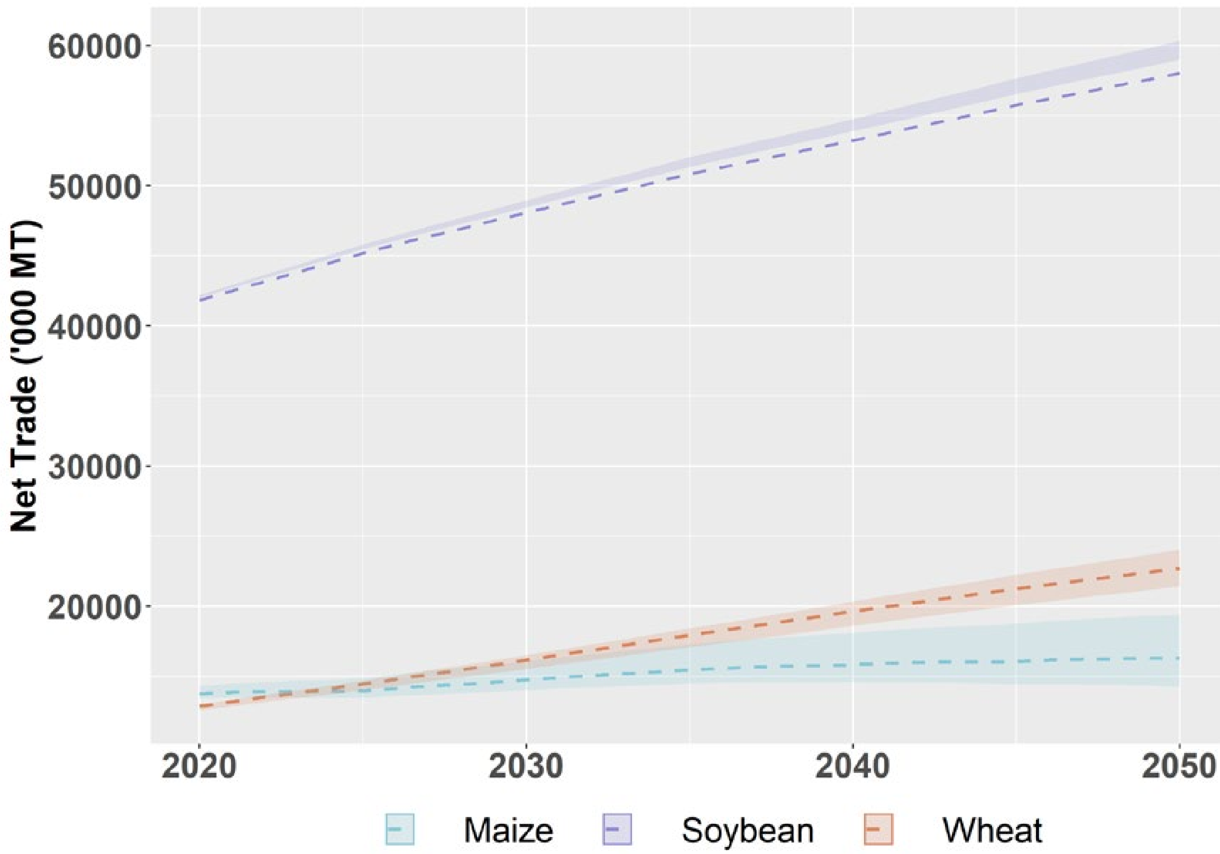


Figure 7: Climate change impact on trade. The dotted lines indicate the no climate change (No-CC) trajectory while the shaded areas correspond to the range of climate change (CC) trajectories given by the nine climate models.

5. The way forward

To limit the rise in global mean temperature below 2°C and ensure food security, most climate change pledges of the United Nations Framework Convention on Climate Change (UNFCCC) cite agriculture and land use as key elements for climate action [4]. In fact, Argentina's Nationally Determined Contribution (NDC) to the 2015 Paris Agreement places considerable emphasis in adaptation and mitigation actions. In this regard, prioritized measures include the generation of climate information, research and development, vulnerability analysis, integral land management, identification and promotion of good practices and tools for adaptation, and institutional strengthening/capacity building [5].

Table 2: Key messages for policy interventions

<table>
<tr><th colspan="2">Key messages for policy interventions</th><th>Way forward</th></tr>
<tr><td>Climate</td><td>• Climate change presents significant risk to crop yields and the broader economic performance of the agricultural sector in Argentina. Flooding, increased temperatures, and glacial retreat will impact production.
• Maximum temperatures projected to increase between 1 and 2°C by 2050, with most pronounced warming in the northwest.
• Decreased rainfall projected across much of the Pampas region during September to November; but increases also projected in this area during December to February. Increased rainfall projected across the north and northwest, especially during June to November.</td><td rowspan="2">Adaptation measures are key, especially those that have the potential to increase productivity while mitigating climate change. Main activities should focus on:
• Sustainable agricultural practices (i.e. CSA)
• Forest, land and water management.
• Increasing the efficiency in water use.
• Plan for a comparative advantage in soybean, wheat, and maize, leading to rising trade surpluses for these crops.
• Conduct ex-ante impact assessment studies to determine the best allocation of resources across the export portfolio, given desired domestic/regional food security and economic goals.
• Robust communication between farmers and markets, responsible land management and planning.
• Develop mechanisms to inform and orient CC adaptation policy at departmental and municipal levels.
Agricultural research:
» Conduct necessary analyses to identify and prioritize CC adaptation research options for the most relevant crops.
» Develop and release new technologies to reduce the impact of climate change shocks on the most vulnerable crops.</td></tr>
<tr><td>Agriculture</td><td>• Rainfed bean, maize, and wheat exhibit vulnerability under CC.
• Rainfed rice and soybean exhibit resilience under CC.
• Irrigated systems generally projected to fare better than their rainfed counterparts.
• Projected decreases in yield are generally most pronounced in the north.
• Trade surplus in soybean and wheat projected to increase out to 2050, while the trade surplus in maize is projected to hold steady.</td></tr>
</table>

Argentina and other LAC countries may be able to reduce the impact of climate change on the agricultural sector by adopting other climate smart agricultural (CSA) practices that increase productivity while reducing greenhouse gas (GHG) emissions and adapting to shifting growing conditions.

Increased trade and productivity in the face of yield declines and faltering suitability for both domestic food security and export-oriented crops will require continued investment in agricultural research, robust communication between farmers and market intermediaries, and responsible land management and planning. Given the especially severe production losses in tropical Latin America, temperate zones like Argentina will need to step up production, an important responsibility and opportunity. Political and financial market stability will be key to ensuring that these potential opportunities – and responsibilities – are realized. Key messages for policy interventions and a way forward for adaptation measures are shown in table 2.

References:

[1] The World Bank. 2018. World Development Indicators. Washington, D.C., USA. **http://data.worldbank.org/indicator**

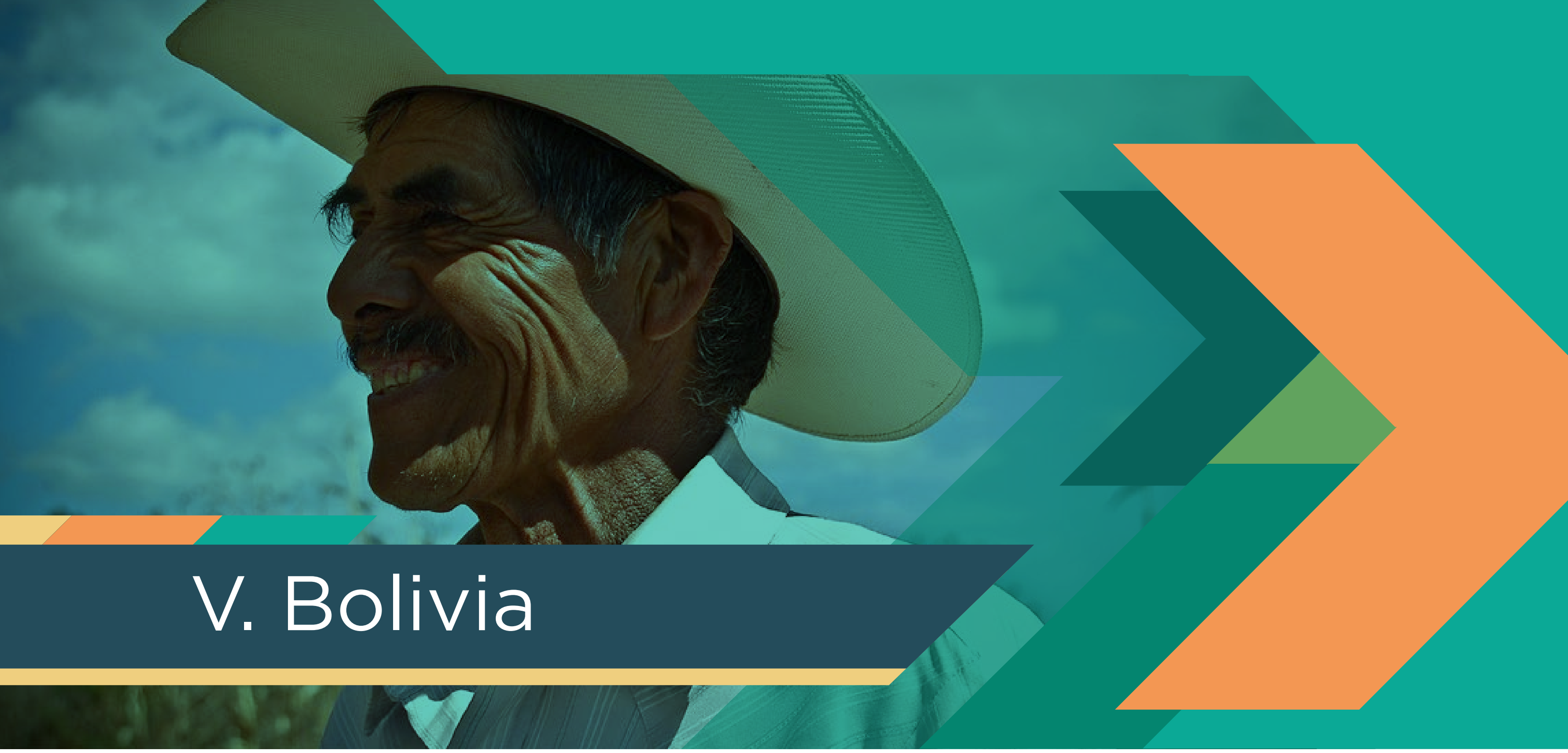
[2] The Food and Agriculture Organization. 2018. Rome, Italy. **http://www.fao.org/faostat/en/#data**

[3] The World Bank. 2019. Climate Change Knowledge Portal: Argentina. **http://bit.ly/2TtmHjb**

[4] CCAFS. 2015. Info Note: Agriculture's prominence in the INDCs. https://cgspace.cgiar.org/rest/bitstreams/62364/retrieve Detailed country information on agriculture in INDCs available at: **https://cgspace.cgiar.org/handle/10568/73255**

[5] Republic of Argentina. 2016. First Revision of its Nationally Determined Contribution. **https://bit.ly/2KqN9oh**

V. Bolivia



1. Context

Agriculture continues to play an important role in Bolivia. The sector accounts for 11.6% of GDP, down 1.8 percentage points (pp) from a peak of 13.4% in 2003. Crop products accounted for 9.1% of all exports in 2015, up 1.1 pp from 2006. Jobs in agriculture account for 27% of all employment in the country, down 3.1 pp from 8 years ago [1]. Climate change presents significant risk to crop yields and the broader economic performance of the agricultural sector given its effects in temperatures, precipitation, intensity and frequency of extreme events, and glacier retreat among others. For instance, Bolivia commonly suffers drought and floods, with increased frequency in the recent years, and reports indicate that 80% of the glaciers are retreating [2]. Climate change will in fact have considerable impacts in the agricultural sector, which has been estimated to be the most affected by this phenomenon [3]. A better understanding of the climate change impacts on specific crops will hence assist in decision making. For this purpose, climate, crop, and economic modeling provide future trends (average for 2020-2050) regarding agricultural production and trade in the country, set in the LAC regional context. Then, based on these trends, adaptation measures are proposed.

2. Climate impacts

In assessing future climate impacts, this study utilized nine general circulation models (see Methodological Summary), selected for their strong performance in the LAC region. Overall, temperatures are predicted to increase by 1-4 °C across the LAC region, with the Caribbean and tropical South America projected to warm at higher rates than Mexico and the Southern Cone.

In Bolivia, reduced rainfall (in some cases a 30% decrease) is expected in the central and eastern lowlands, especially during the June–November dry period (Figure 1). However, this same period is projected to see higher rainfall levels in the elevated Altiplano in Western Bolivia. Generally, in the wetter areas, precipitation is likely to increase in both magnitude and frequency.

Widespread temperature increases are expected in Bolivia, especially in the months of June, July, and August, but continuing through the dry season. These increases in maximum temperatures accompanied by decreases in precipitation are likely to increase the risk of agricultural drought in Bolivia. Temperature increases may be accompanied by increased solar radiation, evident almost everywhere throughout the year, with the strongest increases in the tropical latitudes of South America.

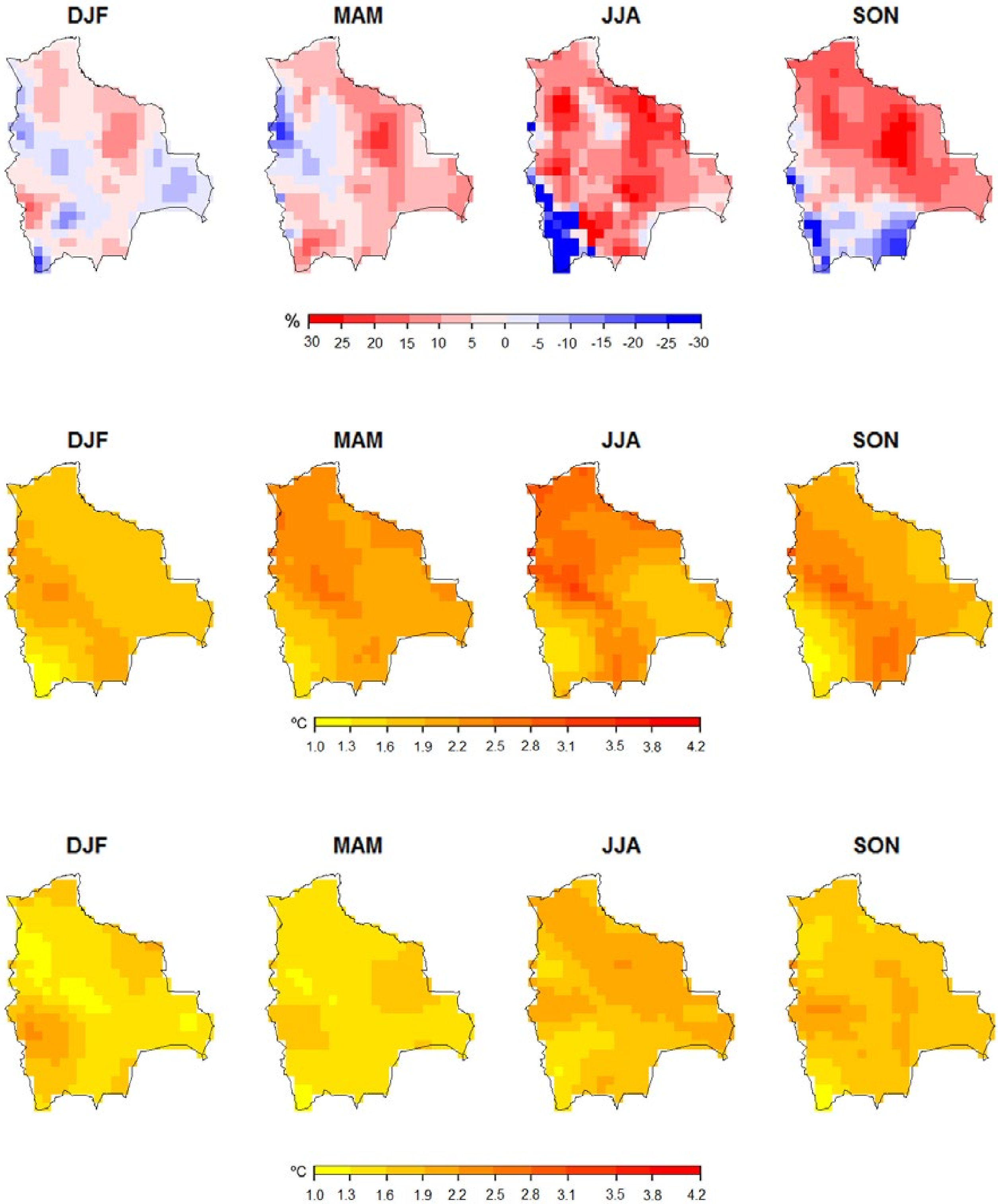


Figure 1: Change in (top to bottom) precipitation, maximum temperature, and minimum temperature averaged across nine GCMs (2020-2050). DJF= December - February, MAM= March - May, JJA= June - August, SON= September - November.

3. Yield and suitability impacts

Yield

Based on the projected changes in climate discussed above, 2050 projections of maize, rice, bean, and soybean yields were modeled using the Decision Support System for Agrotechnology Transfer (DSSAT v4.5) at 0.5 degree spatial resolution. Model runs for each crop were parameterized using genetic coefficients of varieties carefully selected by experts for their relevance in the region.

With the exception of irrigated rice and soybean, simulations show that, in a 'no-adaptation' scenario, the modeled cropping systems in Bolivia are likely to experience yield declines, on average, relative to a no-climate change (No-CC) scenario (Figure 2). Bean systems in the central lowlands may be especially hard hit, followed by rainfed wheat and maize (it should be noted that rainfed maize and wheat yields in Bolivia are already considered low relative to continental averages). Rainfed soybeans, currently planted across more than a million hectares in eastern Bolivia, are projected – although not universally – to see yield declines of at least 10% below the No-CC benchmark, while irrigated soybean will experience some yield increases (Figure 3).

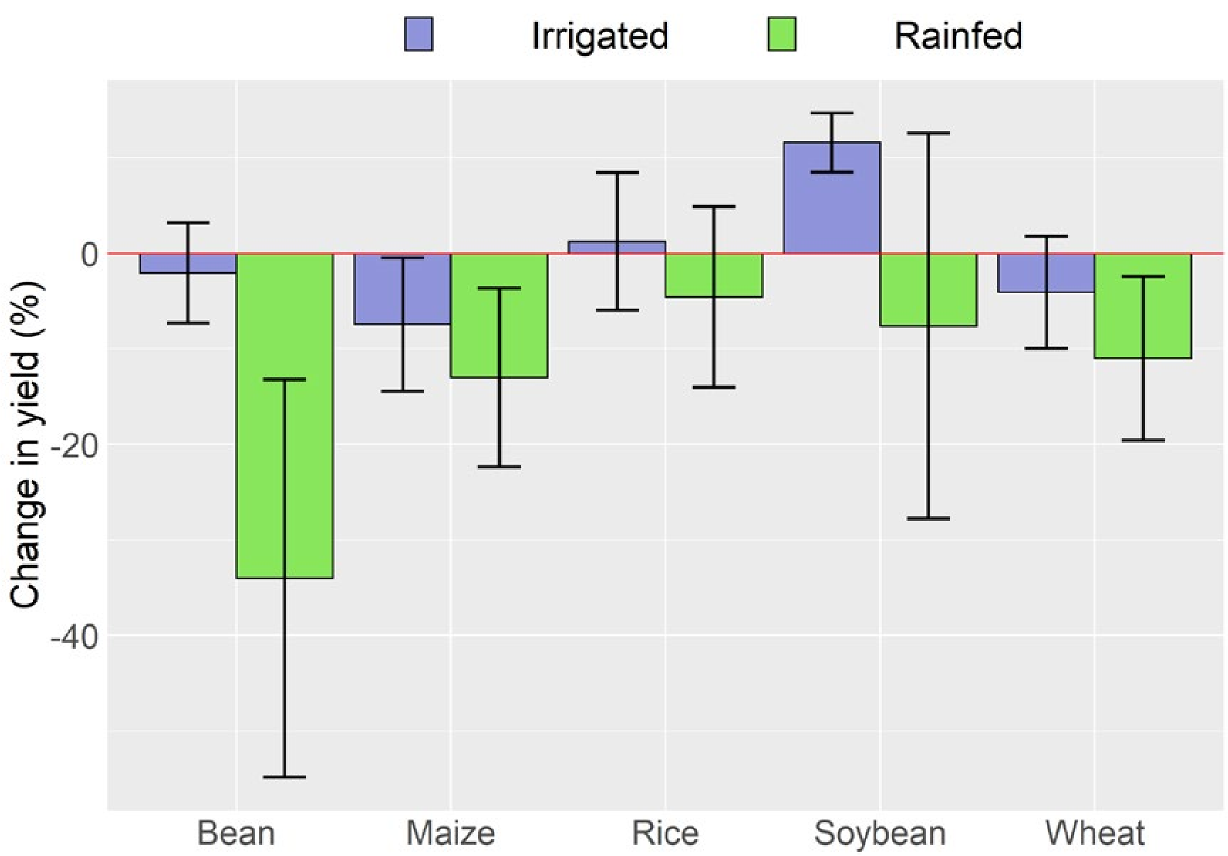


Figure 2: Projected average yield change, key crops (2020–2050). The error bars indicate the range of output across the nine climate models.

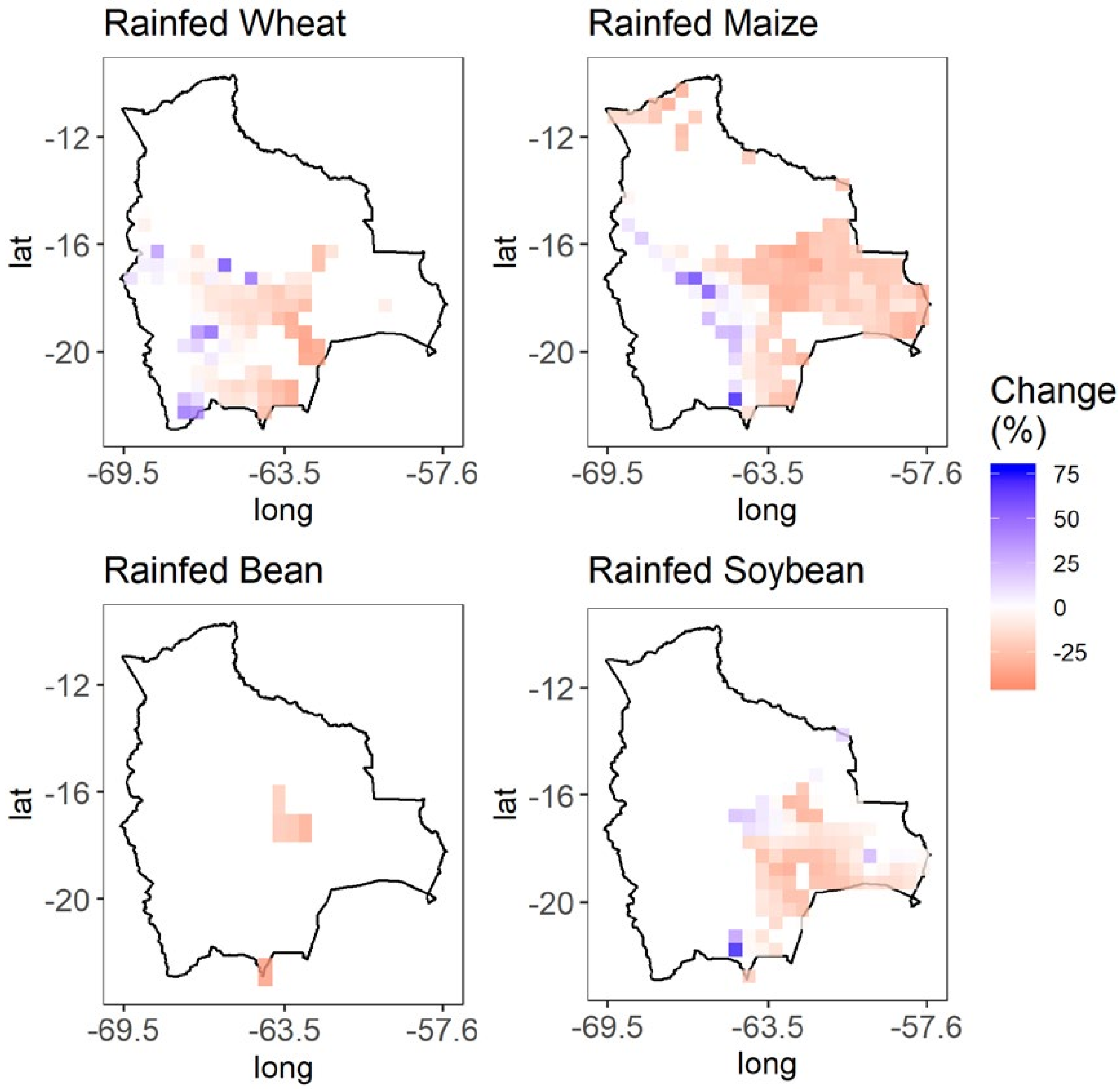


Figure 3: Projected yield impact maps, key crops (2020-2050).

Maize losses in Bolivia are paralleled by severe declines for maize across the entire LAC region, especially in central Mexico, the Yucatan and northern South America. This is true also for wheat, which may generally see yield declines on the continent as temperatures warm. Beans, an important food security crop in Latin America, while losing yield in Bolivia, may see some increases in parts of Argentina and Mexico. All told – with these few exceptions – a 7.5 percentage point (pp) reduction in yield growth is projected averaged across crops, sub-regions, and GCMs in Latin America.

Suitability

Climate change impacts on agro-ecological suitability for coffee (Robusta and Arabica), banana, yam, cassava, potato and sugarcane were assessed using niche based models. In these models, "suitability" is defined based on how well local precipitation and temperature match the biophysical requirements of the given crop.

Suitability modeling suggests that the area suitable for the cultivation of tuber crops, including potato, will largely remain the same under climate change, while the area suitable for banana may decline sharply (Figure 4). However, the spatially explicit suitability impact maps in Figure 5 indicate that banana suitability loss is projected in the northern portion of the country, where it is not currently grown in large quantities. Meanwhile, suitability gains are projected for sugarcane across the north and east of the country. The resilience of cassava and yam is also evident in Figure 5, including some pockets in the Andes where suitability may increase. Cassava production in Bolivia is low compared to potato production, and yams are not currently grown anywhere in the country in significant quantities. However, the projected resilience of these crops may make them an attractive alternative carbohydrate source under climate change.

On average, areas suitable for Robusta and Arabica coffee cultivation are projected to decline by 30.7% and 60.2%, respectively. However, in Figure 6 it is evident that these national averages hide important sub-regional variation. Steep coffee suitability losses are projected mainly in lowland areas, while suitability gains are projected in the Yungas highlands region, which is home to much of Bolivia's current coffee production.

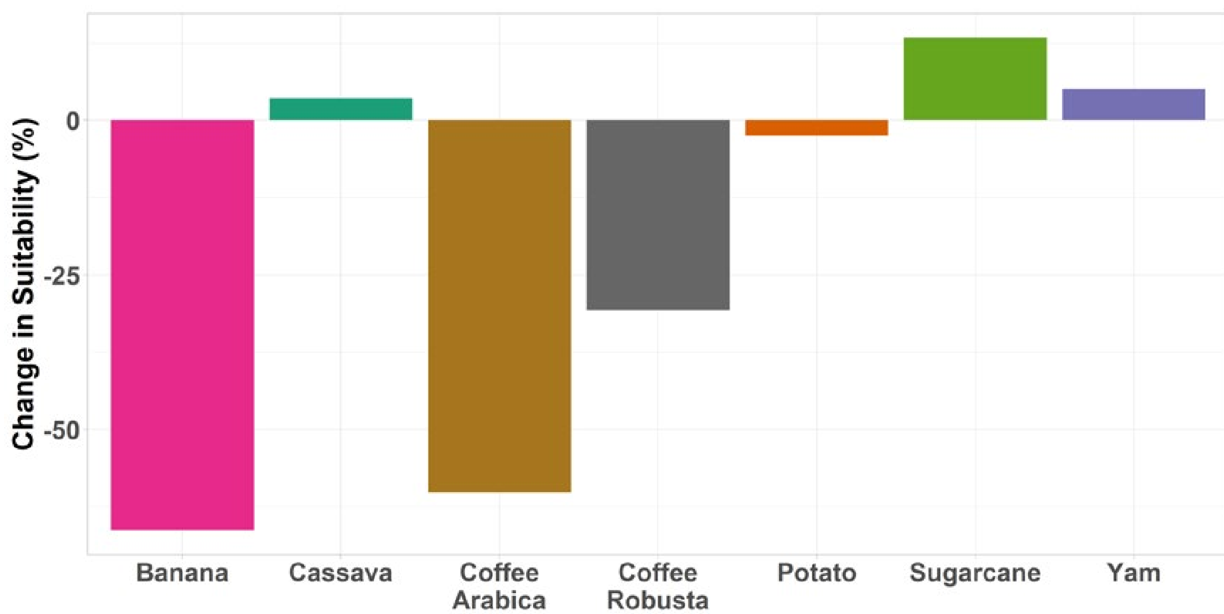


Figure 4: Projected change in suitability for key crops (2020-2050).

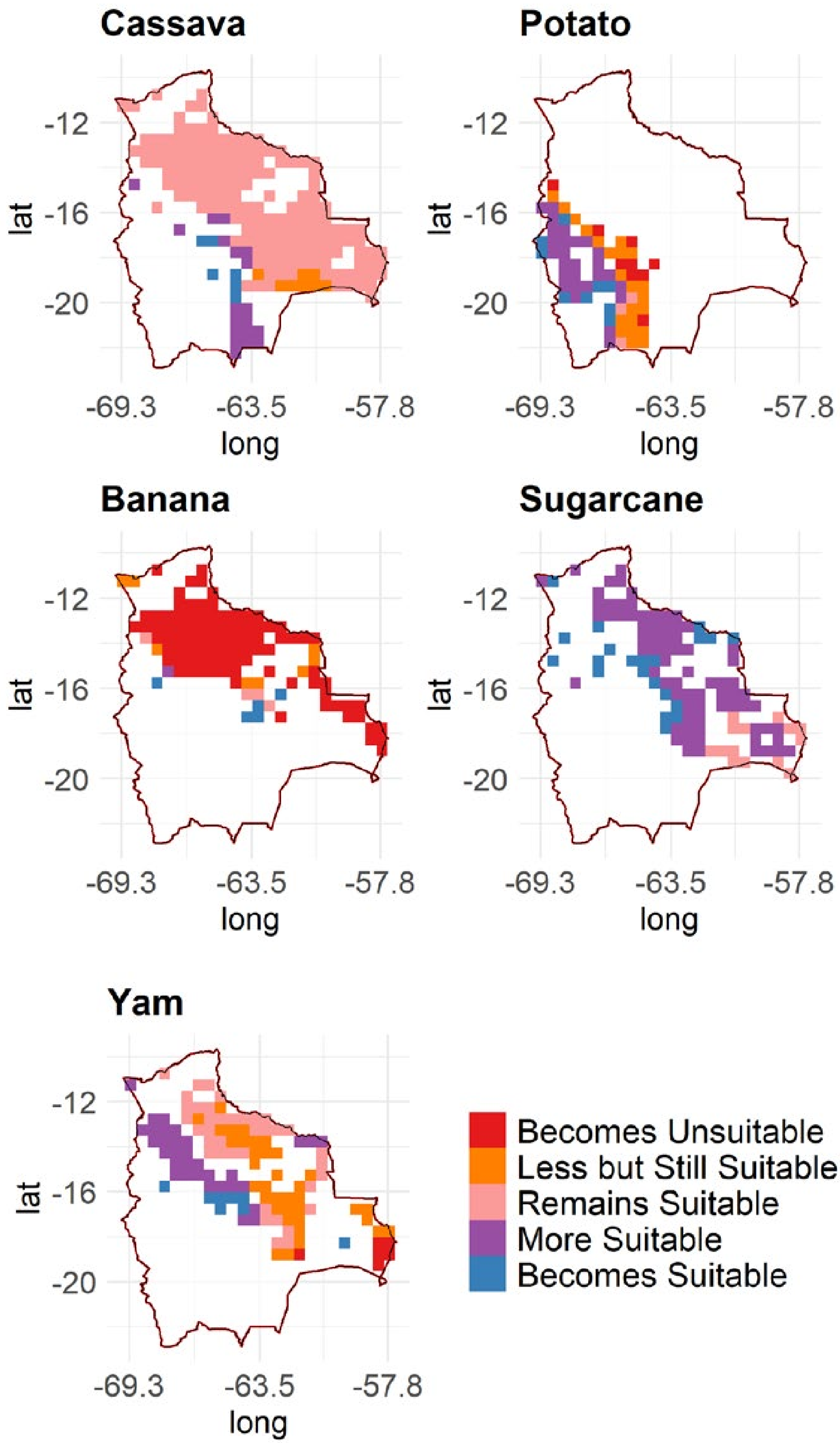


Figure 5: Projected suitability impact maps (2020-2050).

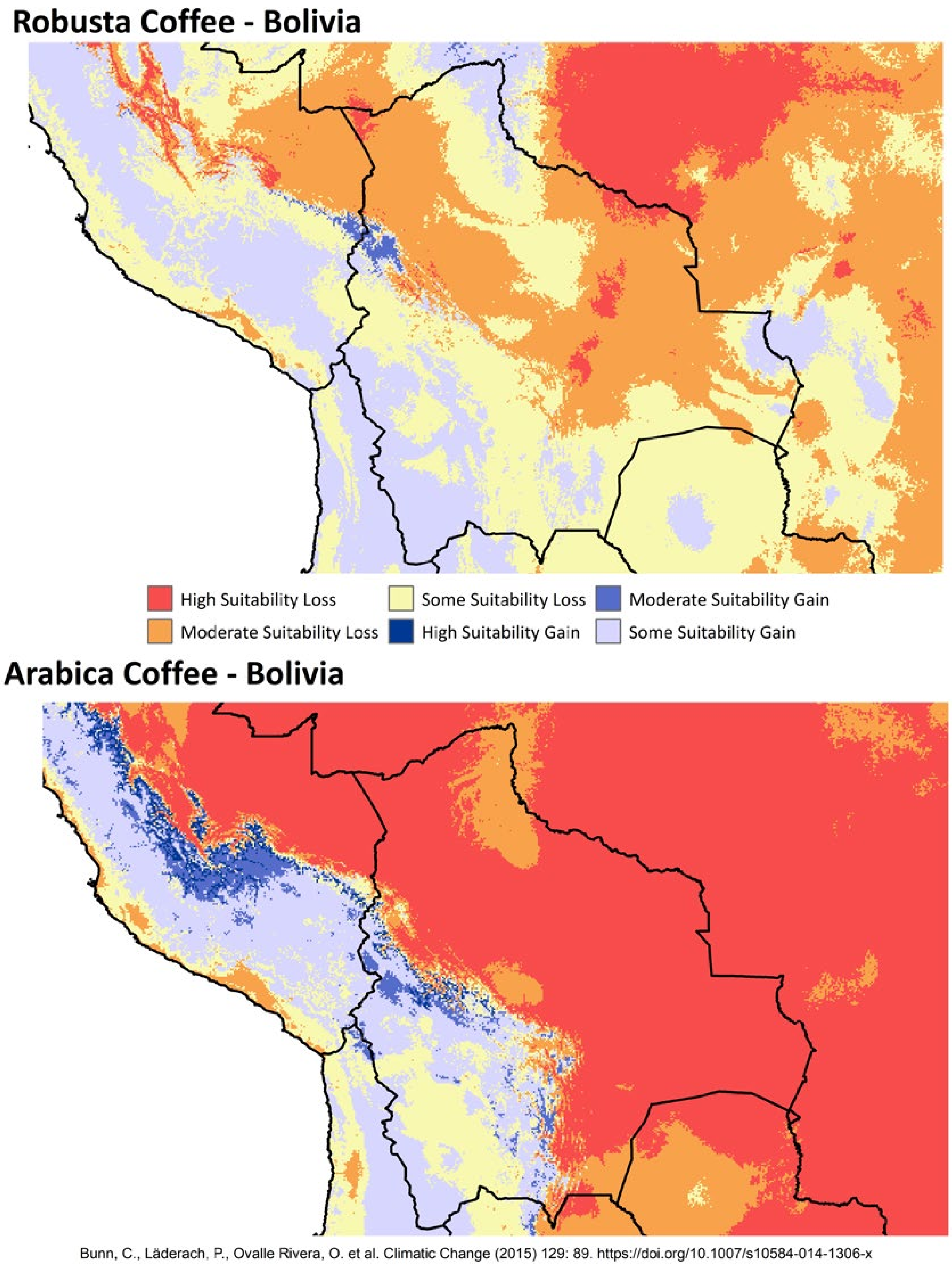


Figure 6: Projected change in suitability for coffee by 2050.

4. Economic impacts

In order to understand the real impacts of climate change on demand, supply, and international trade flows, the purely biophysical impacts addressed in the sections above must be adjusted for the economic agency of farmers who can adapt to yield and suitability loss by switching to alternative cultivars and practices. Ongoing advances in productivity and yield enhancing agricultural research, as well as the mitigating action (or inaction) of governments on emissions policy, must also be taken into consideration. The interplay of these factors was modeled using the International Model for Policy, Agricultural Commodities, and Trade (IMPACT), developed at the International Food Policy Research Institute. In this section, IMPACT projections are presented for the DSSAT modeled crops, accounting for global economic and climate change contexts of these crops as well as their substitutes.

Agricultural production is projected to increase under both CC and No CC scenarios for all of the modeled crops (Figure 7). Bean, maize, and wheat production growth are especially pronounced. However, the introduction of climate stressors may have a considerable negative impact on wheat production, cutting its growth to 12.6 pp below the No-CC benchmark. Climate change may also have a negative impact on soybean (-6.8 pp) and dry bean (-2.1 pp) production, although maize (+10.1 pp) and rice production (+9.7 pp) may increase under such conditions.

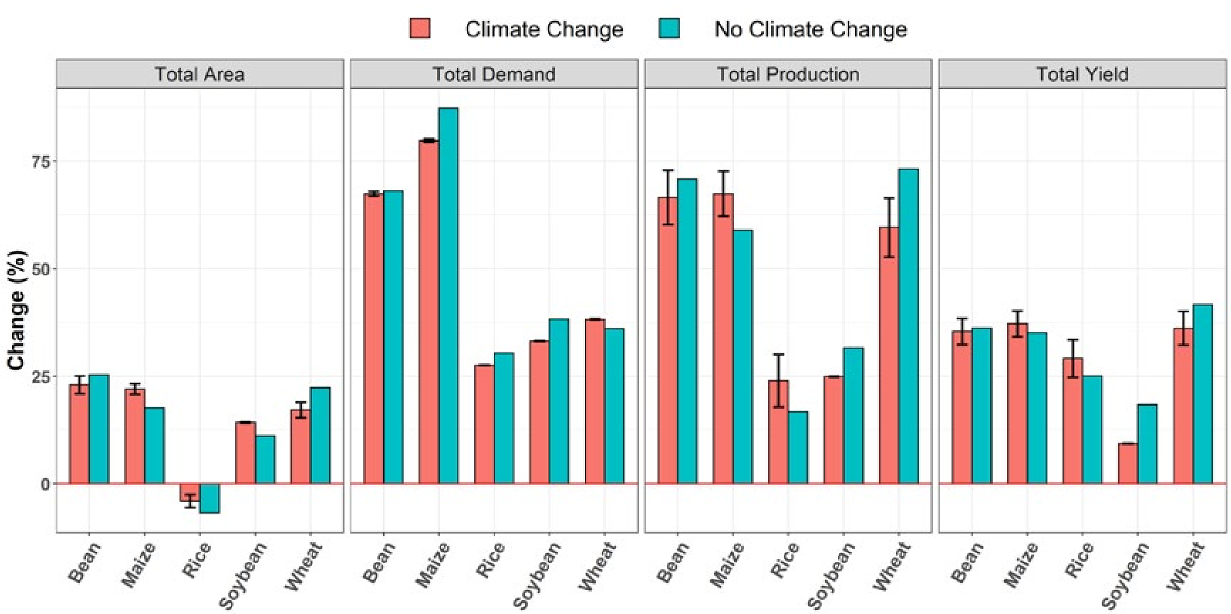


Figure 7: Percentage change in yield, demand, cultivated area, and production (2020–2050), when economic context and agricultural research are taken into account. The error bars indicate the range of output across the nine climate models.

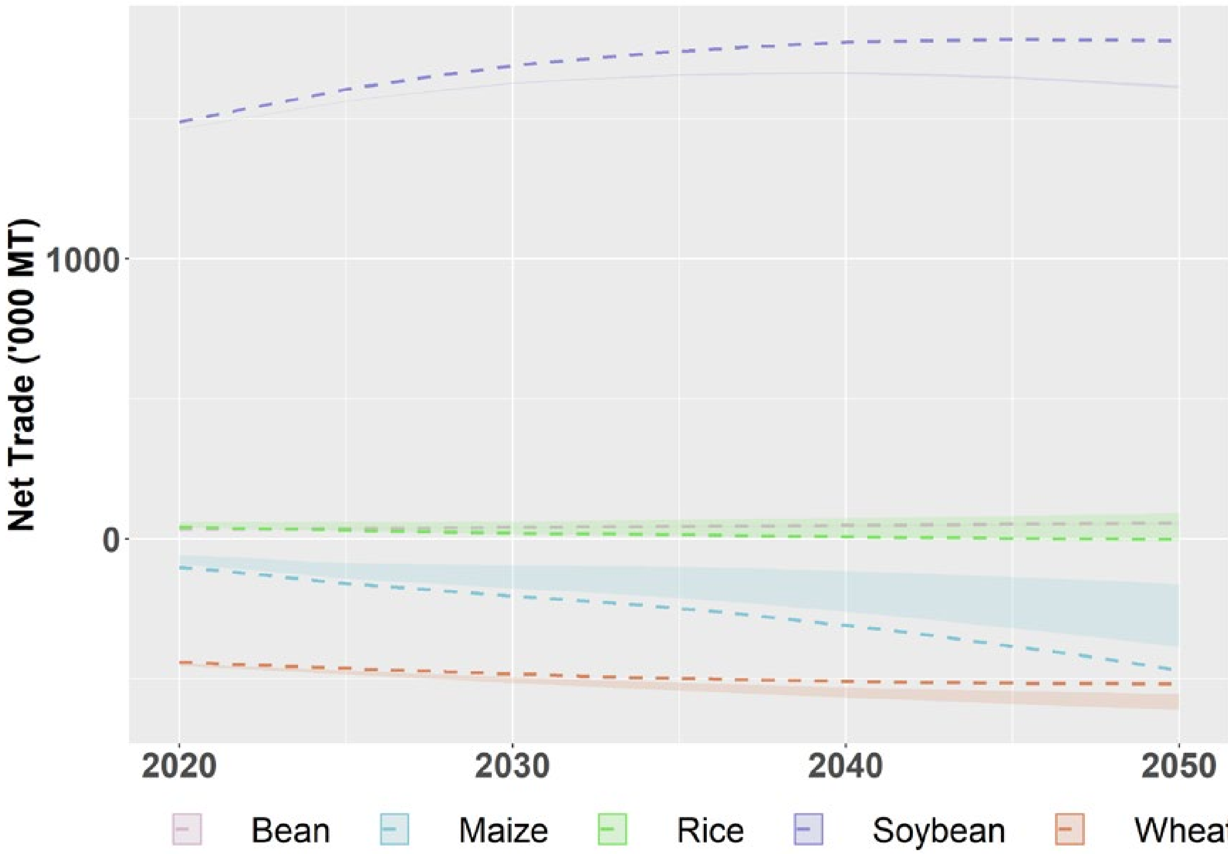


Figure 8: Climate change impact on trade. The dotted lines indicate the no climate change (No-CC) trajectory while the shaded areas correspond to the range of climate change (CC) trajectories given by the nine climate models.

Given these climate-related production trends, continued trade deficits are expected to increase for maize and wheat in Bolivia by 2050 (Figure 8). Minimal trade surpluses are expected for bean and rice and continued surpluses are expected for soybean, increasing slightly with the impact of climate change. In the Andean region more broadly, relative to a No-CC scenario, rice trade may increase slightly, while climate change may further exacerbate trade deficits for maize.

5. The way forward

Bolivia's Nationally Determined Contribution (NDC) to the 2015 Paris Agreement includes integrated agricultural mitigation and adaptation goals that may work to reduce the magnitude of the trends seen here. In an effort to limit the rise in global mean temperature below 2°C and ensure food security, most UNFCCC climate change pledges – 177 of 189 – to the United Nations Framework Convention on Climate Change cite agriculture and land-use as a key source of adaptation and/or mitigation potential [4]. As stated in Bolivia's NDC, in the face of climate change, the country aims to eradicate extreme poverty within the next decade and achieve a 5.4% annual GDP growth rate by 2030. This will necessarily involve productivity improvements from small-scale producers, currently representing 57% of total agricultural lands [2]. These goals will be challenged by the crop yield and suit-

ability changes highlighted here. With potential crop suitability changes, Bolivia's commitments to control, monitoring, and tracking systems for forest management will also be especially important. Meanwhile, the use of local, well-adapted crops to drought and heat will be especially relevant, particularly for dry bean, maize, and wheat. Given the universally negative impacts on rainfed production and a low rate of irrigation infrastructure in the country (combined with reduced glacial mass), expanding irrigation capacity will be critical in Bolivia. Other adaptation strategies identified in Bolivia's First and Second National Communications to the UNFCCC include: improved land and water management, deepened integration of indigenous knowledge, expansion of plant gene banks, agricultural research, improved pasture and livestock varieties and even migration. Bolivia, and other countries in Latin America, may be able to reduce the impact of climate change on the agricultural sector by adopting additional climate-smart agricultural (CSA) practices that increase productivity while reducing greenhouse gas (GHG) emissions and adapting to shifting growing conditions. This may include the expansion of no-till agricultural practices, precision nutrient management (fertilizer), intercropping, and more advanced crop rotations. Overall, crop diversification should increase in Latin America, and integrated crop-livestock and agro-forestry systems become more common.

Table 2: Key messages for policy interventions

Table 2: Key messages for policy interventions		Way forward
Climate	• Maximum temperatures projected to increase by 1-4°C by 2050, with most pronounced warming in the northwestern territory • Changes in precipitation patterns and quantities: drying trend for the central and northern areas, increased rainfall during the growing season in the Altiplano, and precipitation likely to increase (in both magnitude and frequency) in wet areas • A rise in solar radiation accompanied by higher temperatures	Adaptation measures are key and may increase productivity while mitigating climate change. Main activities should focus on: • Agricultural practices (i.e. crop diversification, CSA, use of improved varieties, no-till, intercropping, precision nutrient management, and integration of indigenous knowledge). • Forest, land, and water management. • Increasing efficiency in water use (i.e. expansion and/or rehabilitation of irrigation systems). • Agricultural research.
Agriculture	• Rainfed bean, rice, wheat, maize, and soybean likely to experience yield declines • Yield losses for soybean and maize in Santa Cruz may be especially severe for Bolivia's export economy • Adverse changes in suitability for crop production, particularly arabica coffee and bananas	

Bolivia is known for its immense diversity in both people and geography. Food security is intimately linked to the social well-being of the nation, with agriculture assuming a critical role in Andean culture and providing the engine for the rural and national economy. Increased trade and productivity in the face of yield declines and faltering suitability for both domestic food security and export-oriented crops will require continued investment in agricultural research, robust communication between farmers and market intermediaries, and responsible land management and planning. Given the especially severe production losses in tropical Latin America and in its own eastern Llanos, Bolivia will increasingly rely on trade with more temperate zones of the world, including the Southern Cone, to ensure domestic food security. Political and financial market stability will be key to ensuring that these potential opportunities are realized. Key messages for policy interventions and a way forward for adaptation measures are summarized in Table 2.

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[3] BID and ECLAC. 2014. La Economía del Cambio Climático en el Estado Plurinacional de Bolivia 2014. **https://publications.iadb.org/handle/11319/6817**

[4] CCAFS. 2015. Info Note: Agriculture's prominence in the INDCs. **https://cgspace.cgiar.org/rest/bitstreams/62364/retrieve Detailed country information on agriculture in NDCs available at: https://cgspace.cgiar.org/handle/10568/73255**

VI. Colombia

1. Context

The agricultural sector plays an important but declining role in Colombia, accounting for 6.5% of GDP and 4.9% of exports. Jobs in agriculture account for 16.1% of all employment in the country, down 2.5 percentage points (pp) from 8 years ago [1]. Aside from its famous Arabica coffee, some of Colombia's most important crops in terms of area include palm oil, plantain, rice, maize, sugarcane, banana, cacao, beans and cassava [2]. A wide range of climatic conditions exist across Colombia's varied terrain, from arid dessert in the north-east, to highland Andean páramos, to lowland plains and wet tropical forests in the eastern and coastal regions, giving rise to Colombia's world-renowned biodiversity [3]. Colombia's rainfall patterns are highly influenced by the El Niño Southern Oscillation. Rising temperatures and increasingly erratic extreme rainfall events associated with El Niño/La Niña cycles may lead to increased drought, soil erosion, flooding, landslides, and pest/disease outbreaks in the mountainous and coastal areas where most of the population lives and farms [4]. Climate change impacts on crop yields and suitability – and the resulting impacts on regional trade – are of severe consequence for both farmers and policy makers. Heavy rains due to the 2010/2011 La Niña event resulted in an estimated $6 billion USD in damages to crops and infrastructure, as well as millions of displacements and hundreds of deaths [4].

2. Climate Impacts

In assessing future climate impacts, this study utilized nine general circulation models (see Methodological Summary for detail), selected for their strong performance in the Latin American and Caribbean (LAC) region. Overall, temperatures are predicted to increase by 1-4 °C across the LAC region, with the Caribbean and tropical South America projected to warm at higher rates than Mexico and the Southern Cone.

2050 rainfall is projected to increase across most of the country during December-May, while decreasing during June-November. Decreases are most pronounced in the eastern plains and La Guajira desert in the north. Meanwhile, maximum and minimum temperatures are projected to increase across the country, especially from June to November. These increases are most pronounced in the west and north—including areas that are important for banana and palm production—as well as the eastern extremity of the country (Figure 1).

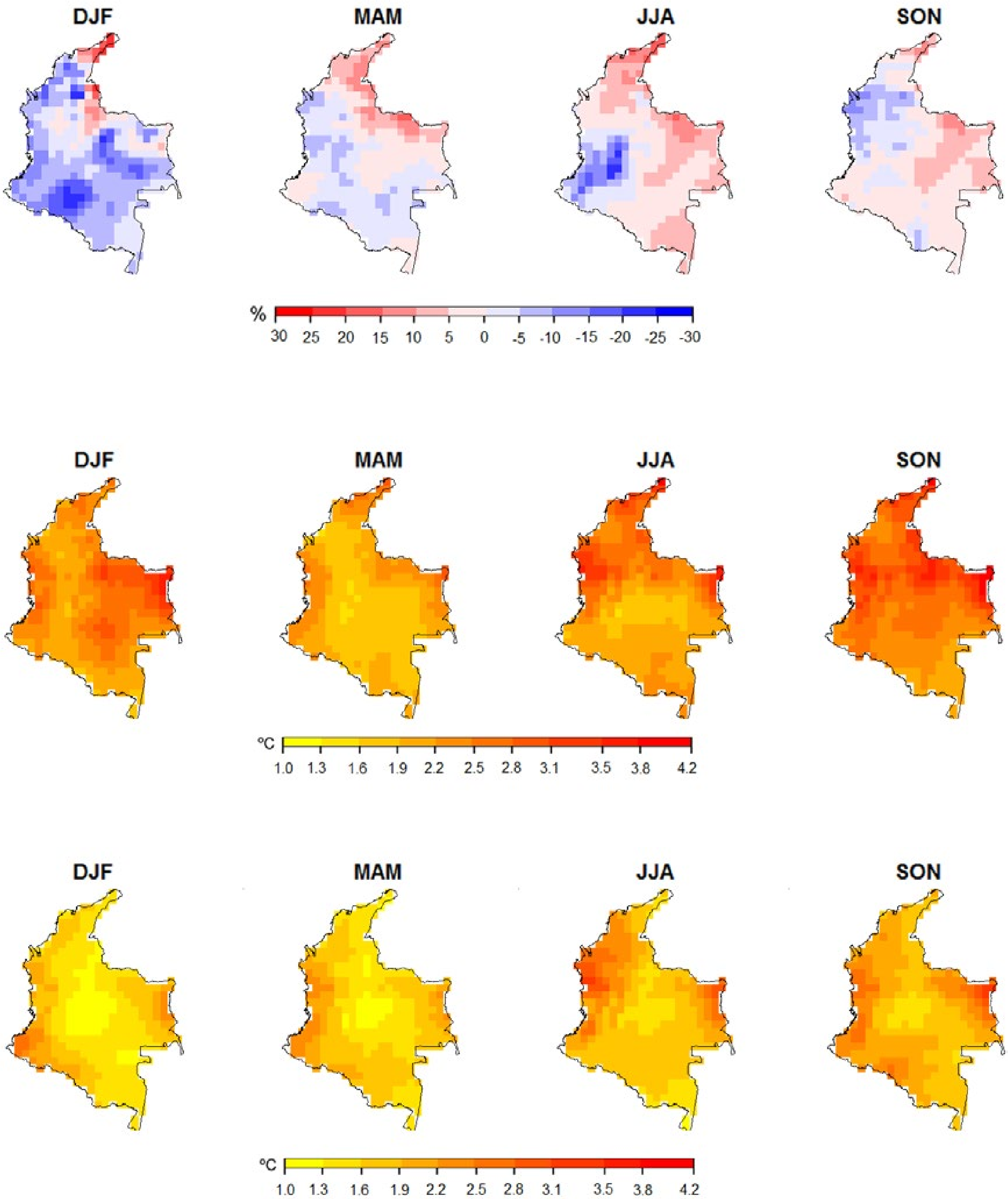

Figure 1: Climate impacts averaged across nine GCMs (2020-2050). DJF= December - February, MAM= March - May, JJA= June - August, SON= September - November.

3. Yield and suitability impacts

Yield

Based on the projected changes in climate discussed above, 2050 projections of maize, rice, bean, and soybean yields were modeled using the Decision Support System for Agrotechnology Transfer (DSSAT v4.5) at 0.5 degree spatial resolution. Model runs for each crop were parameterized using genetic coefficients of varieties carefully selected by experts for their relevance in the region.

Yield impact modeling suggests that in 2050, on average, climate change could result in substantial declines in yields for irrigated and rainfed maize—by 33.2% and 12.8%, respectively—particularly in the north. Significant increases in yields, on the other hand, are projected for rainfed rice and soybean—by 12.1% and 23.7%, respectively (Figure 2). Rainfed bean yield is projected to increase throughout most of the Andean region, although these gains are offset by steep declines in the north. Colombia's residual rainfed wheat production will face yield losses in the southwest, while mixed gains and losses are projected in the central regions (Figure 3). Yield losses generally correspond to areas in Figure 1 where rising temperatures and decreased rainfall are projected to be most severe.

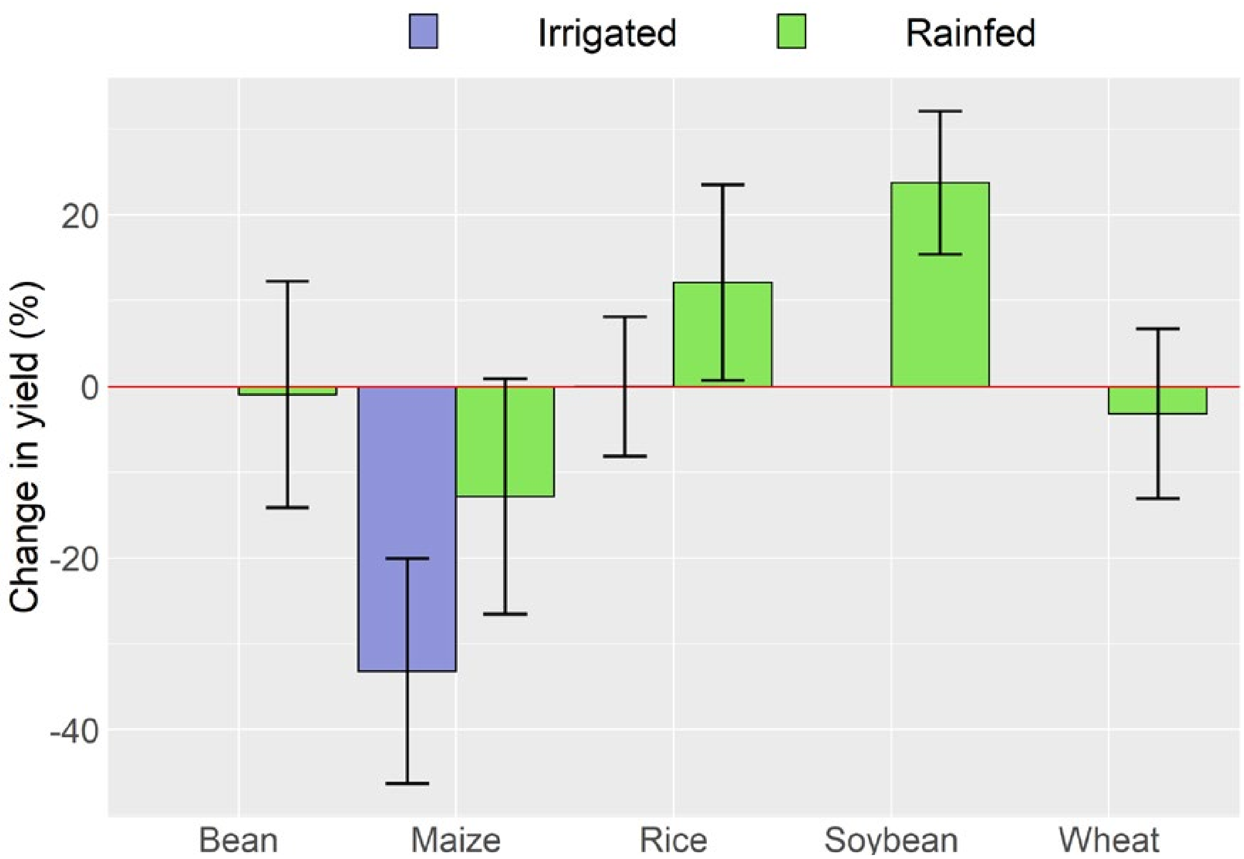

Figure 2: Projected average yield change, key crops (2020–2050). The error bars indicate the range of output across the nine climate models.

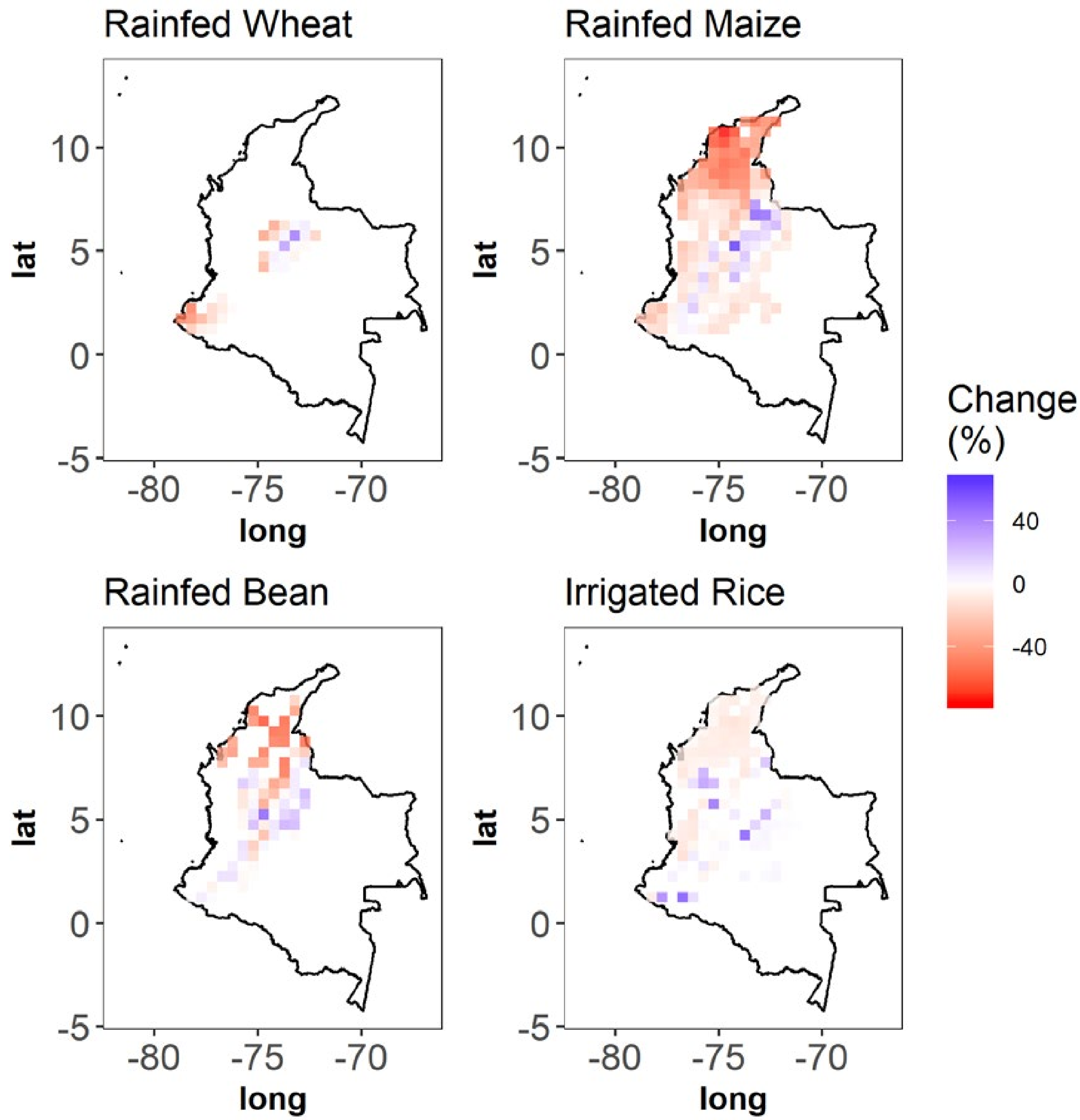

Figure 3: Projected yield impact maps, key crops (2020-2050).

Suitability

Climate change impacts on agro-ecological suitability for coffee (Robusta and Arabica), banana, yam, cassava, potato and sugarcane were assessed using niche based models. In these models, "suitability" is defined based on how well local precipitation and temperature match the biophysical requirements of the given crop.

Suitability modeling suggests that the average suitable area for banana, potato, and wheat cultivation may decrease substantially—by 55.1%, 20.8%, 21.3%, respectively (Figure 4). Projected suitability loss for sugarcane in parts of Valle del Cauca is offset by suitability gains in the northeast. Cassava and yam exhibit considerable resilience, with suitability projected to remain stable or increase across most of the country (Figure 5). Yam is not currently produced in Colombia in any significant quantity, but these results suggest it could play an important role as an alternative source of carbohydrates and nutrients as maize and rice succumb to yield loss.

On average, areas suitable for Arabica and Robusta coffee cultivation are projected to decline by 12.6% and 21.8%, respectively. However, these national averages hide important sub-regional variation. Steep suitability losses projected for Arabica coffee in the areas where it is traditionally grown are counterbalanced by substantial gains at higher elevations across the Andean region, as well as moderate gains across lower lying pockets in the north and southwest (Figure 6).

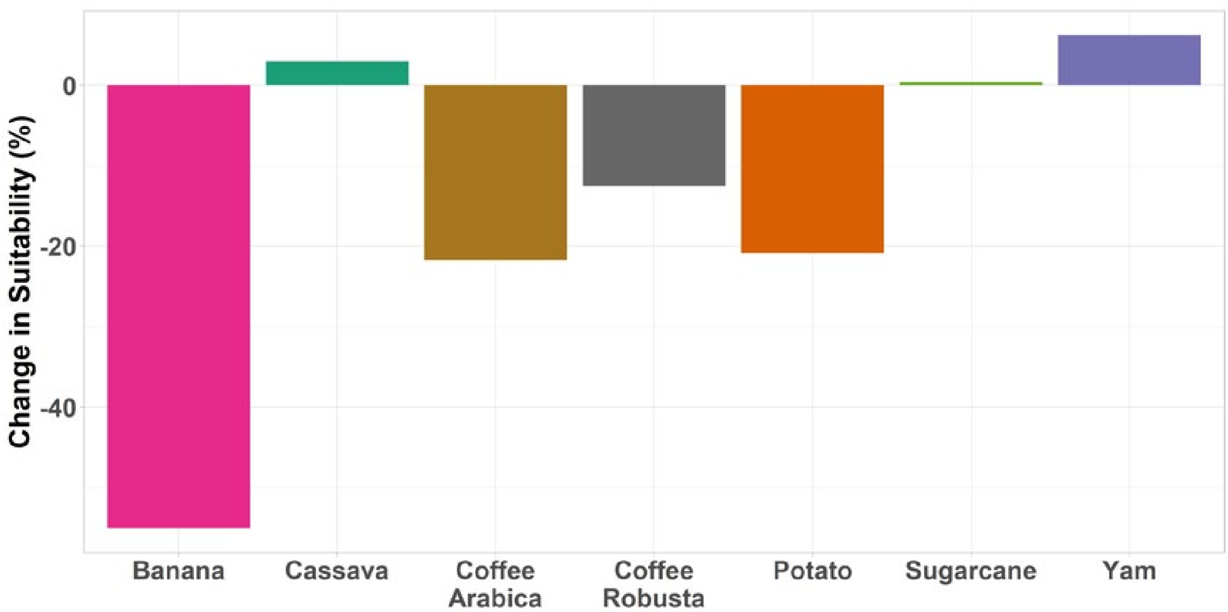

Figure 4: Projected change in suitability for key crops (2020-2050).

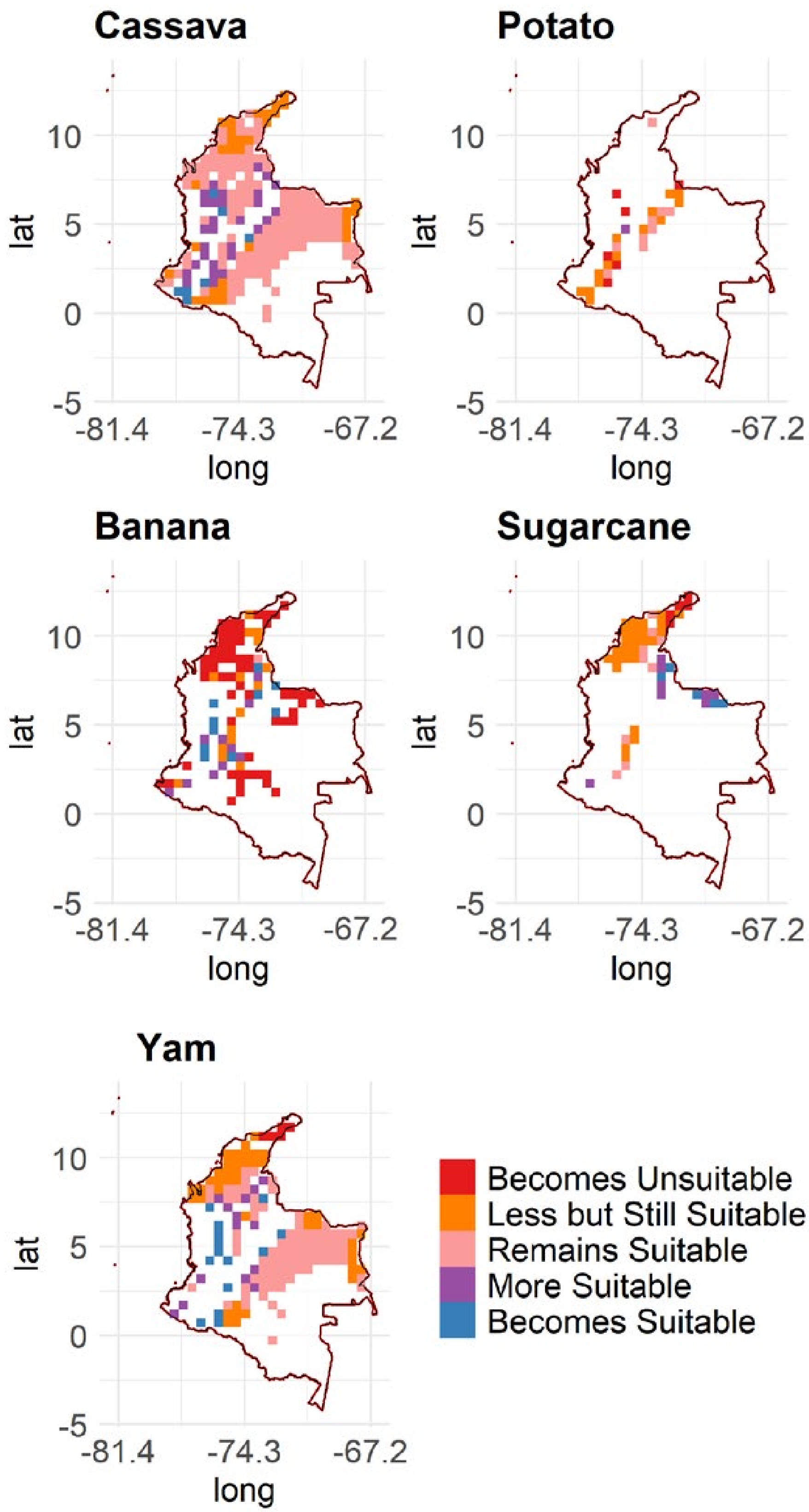

Figure 5: Projected suitability impact maps (2020-2050).

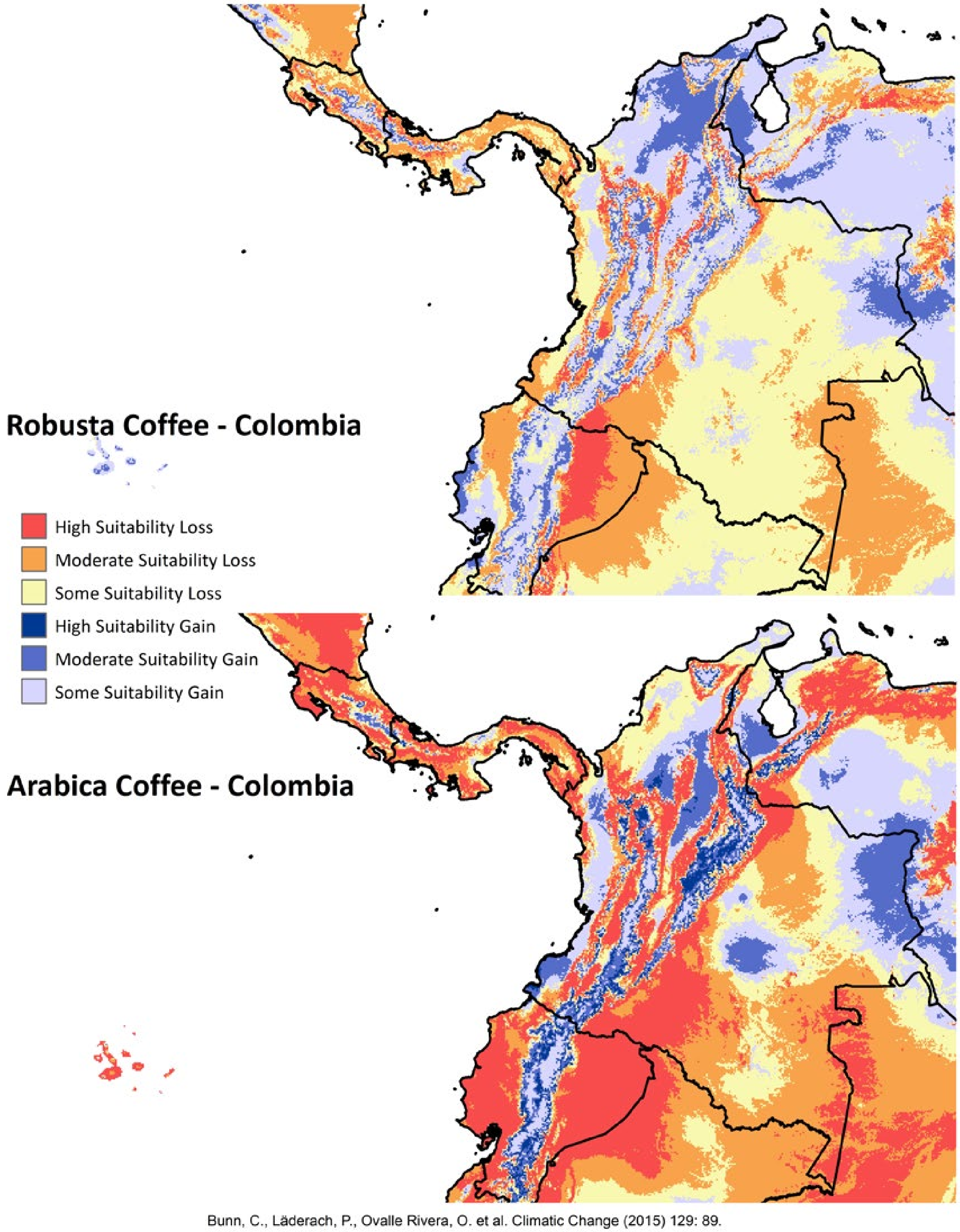

Figure 6: Projected change in suitability for Arabica Coffea by 2050.

4. Economic impacts

In order to understand the real impacts of climate change on demand, supply, and international trade flows, the purely biophysical impacts addressed in the sections above must be adjusted for the economic agency of farmers who can adapt to yield and suitability loss by switching to alternative cultivars and practices. Ongoing advances in productivity and yield enhancing agricultural research, as well as the mitigating action (or inaction) of governments on emissions policy, must also be taken into consideration. The interplay of these factors was modeled using the International Model for Policy, Agricultural Commodities, and Trade (IMPACT), developed at the International Food Policy Research Institute. In this section, IMPACT projections are presented for the DSSAT modeled crops, accounting for global economic and climate change contexts of these crops as well as their substitutes.

Agricultural production is projected to increase out to 2050 under both climate change (CC) and no-climate change (No-CC) scenarios for beans and soybean, reflecting the biophysical resilience of these crops observed in the yield modeling section above. A large percentage increase in production is also projected for wheat, although this may be largely attributable the small quantities of this crop currently grown in the country (Figure 7). Maize production, on the other hand, is projected to fall steeply under climate change—about 40 percentage points below the No-CC benchmark—reflecting the biophysical vulnerability observed in the yield modeling section. Rice production is projected to fall under both CC and No-CC scenarios, but considerably less so under climate change, suggesting that the biophysical resilience observed in the yield modeling section above may result in a comparative advantage in this crop. In Figure 7 it is also evident that demand is projected to outpace production, the result of which is reflected in Figure 8, where negative trade balances in rice, soybean, wheat, and especially maize are projected to grow out to 2050 under both CC and No-CC scenarios. Note that the maize trade deficit trajectory is aggravated by climate change, while the rice trade deficit trajectory is somewhat offset by climate change. Little or no trade is projected for beans, meaning that the increased production will be consumed domestically.

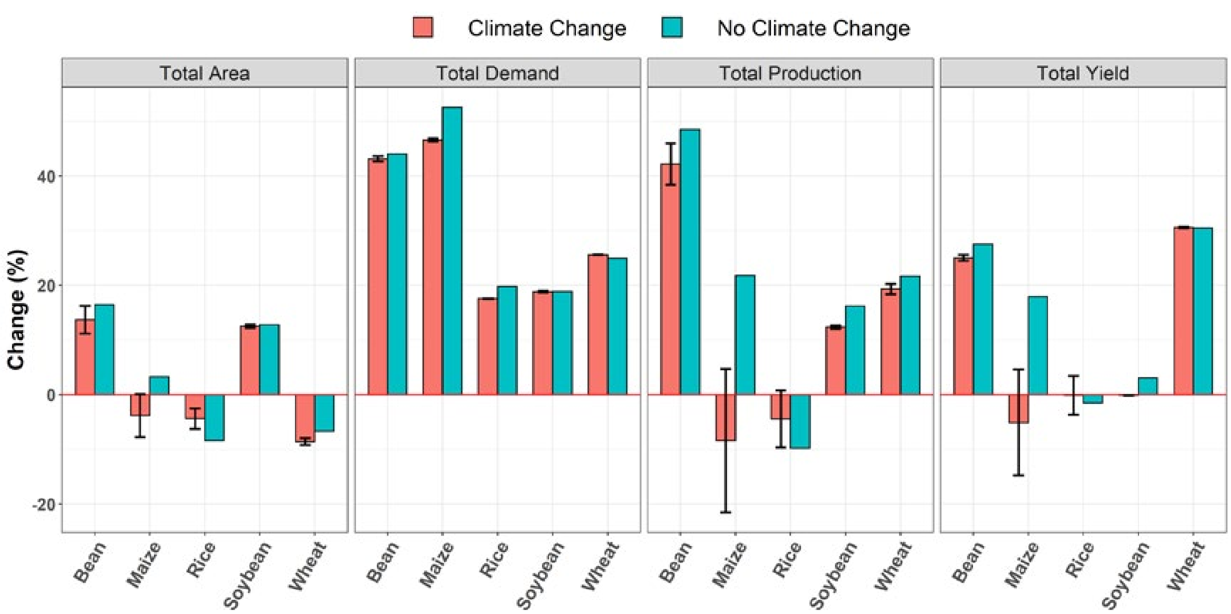

Figure 7: Percentage change in yield, demand, cultivated area, and production (2020–2050), when economic context and agricultural research are taken into account. The error bars indicate the range of output across the nine climate models.

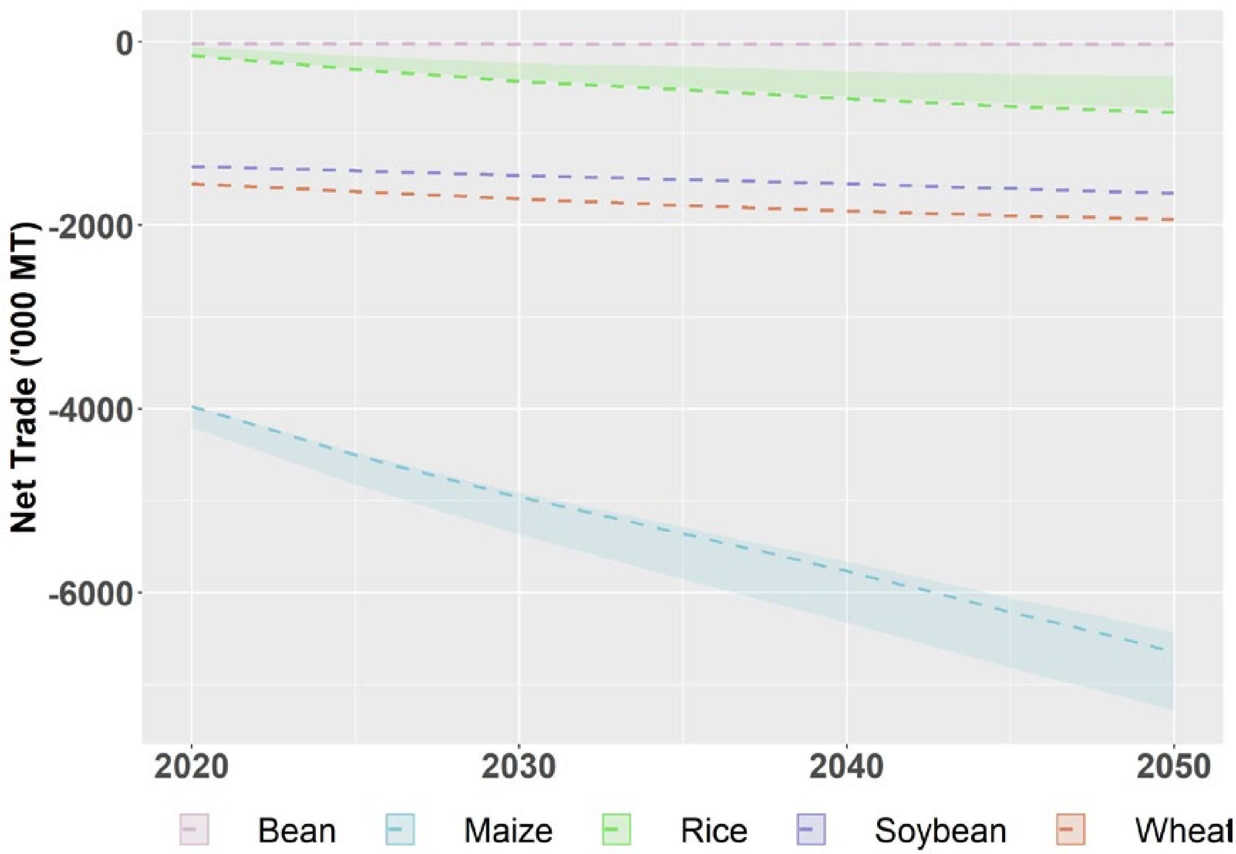

Figure 8: Climate change impact on trade. The dotted lines indicate the no climate change (No-CC) trajectory while the shaded areas correspond to the range of climate change (CC) trajectories given by the nine climate models.

5. The way forward

Colombia's Nationally Determined Contribution (NDC) to the 2015 Paris Agreement includes integrated agricultural adaptation goals that may work to reduce the magnitude of the trends seen here.. Colombia has taken important steps in the creation of a national climate change mitigation policy framework. In 2009, Colombia became the fifth Latin American country, and twelfth in the world, to implement Kyoto Protocol Clean Development Mechanism projects. The Interagency Environmental Agenda, jointly managed by the Ministry of Environment, Housing, and Territorial Development, and the Ministry of Agriculture and Rural Development, has been established to guide agricultural mitigation interventions. Efforts have focused on emergent pest and plague research [5]. Colombia and other countries in Latin American may be able to reduce the impact of climate change on the agricultural sector by adopting climate-smart agricultural (CSA) practices that increase productivity while reducing greenhouse gas (GHG) emissions and adapting to shifting growing conditions. Some specific adaptation measures are presented in (Table 2).

Table 2: Key messages for policy interventions

Table 2. Key messages for policy interventions		Way forward
Climate	Key Climate Observations • Minimum and maximum temperatures are projected to increase substantially, especially in the north. • -Rainfall is projected to increase in the west but decrease in the north and east.	Main activities should focus on: • Strengthening of research capacity, technology transfer, and public extension services oriented towards smallholder farming, especially in the most vulnerable areas such coastal and high elevation regions, as well as water basins. • Strengthening of agroclimatic information and market intelligence services, especially in areas of greatest vulnerability. • Strengthening of monitoring and evaluation of progress towards mitigation/adaptation goals. • Assessment of cassava and yam as climate change resilient alternatives to cereal carbohydrate sources.
Agriculture	Key Agriculture Observations • Suitability for banana projected to decline sharply across the country. • Suitability for Arabica coffee projected to decline substantially in areas where it is currently cultivated, but higher elevation regions and some lower lying pockets could become suitable. • Valle del Cauca projected to become largely unsuitable for sugarcane cultivation in 2050, but parts of the northeast could become suitable. • Yield modeling indicates considerable biophysical vulnerability for maize; and this may be aggravated by international trade. • On the other hand, yield modeling indicates relative biophysical resilience for soybean and rice. • Rainfed bean yield potential projected to decline in the north but increase in the mountainous regions. • Rainfed potato yield projected to decline, while rainfed cassava and yam yields exhibit resilience out to 2050	

References:

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VII. Costa Rica

1. Context

Agriculture plays an important but declining role in Costa Rica. The sector accounts for 5.2% of GDP, down 4.1 percentage points (pp) from 9.3% in 2000. Crop products accounted for 27.4% of all exports in 2015, up 2.6 pp from 2006. Jobs in agriculture account for 12% of all employment in the country, down 2.1 pp from 8 years ago [1]. Though Costa Rica exports many different agricultural products, tropical fruits, banana and coffee account for over 50% of agricultural export value [2]. Costa Rica is the largest supplier of dried cassava to the United States [3]. Roughly 6.7% of the land is under permanent cropping, while 25.5% is used as pasture; and 51.5% consists of the forests that are home to Costa Rica's famous biodiversity [4]. The government provides a strong social safety net compared to other Central American nations, with food security a national priority enshrined in the Costa Rican constitution. Over the past two decades, access to food has steadily increased, and undernourishment has held steady [5]. However, such gains are increasingly threatened by climate change and increased climate variability. Rainfall patterns are highly coupled with the El Niño Southern Oscillation, which has gradually intensified the hydrological cycle over the past 40 years, resulting in increased drought along the Pacific slope and increased flooding along the central Caribbean slope [6]. This has placed considerable stress on the yields of staple crops such as maize, rice, beans, and tomatoes, among others.

Costa Rica is also vulnerable to increased incidence of extreme weather events resulting from climate change, such as Hurricane Otto, which cost 10 lives and USD $200 million in damages in 2016.

2. Climate Impacts

In assessing future climate impacts, this study utilized nine general circulation models (see Methodological Summary for detail), selected for their strong performance in the Latin American and Caribbean (LAC) region. Overall, temperatures are predicted to increase by 1-4 °C across the LAC region by 2050, with the Caribbean and tropical South America projected to warm at higher rates than Mexico and the Southern Cone.

Climate modeling for Costa Rica suggests a considerable increase in minimum and maximum temperatures across the country, but especially in the critically important northwest region where most agricultural production takes place. December-February rainfall is projected to increase substantially along the Pacific slope and central range, while decreasing slightly along the northern Caribbean slope. During March-May this pattern is reversed, with rainfall decreasing along the Pacific slope and increasing along the northern Caribbean slope. Across most of the country rainfall is projected to decrease during June-August, and to increase slightly during September-November (Figure 1).

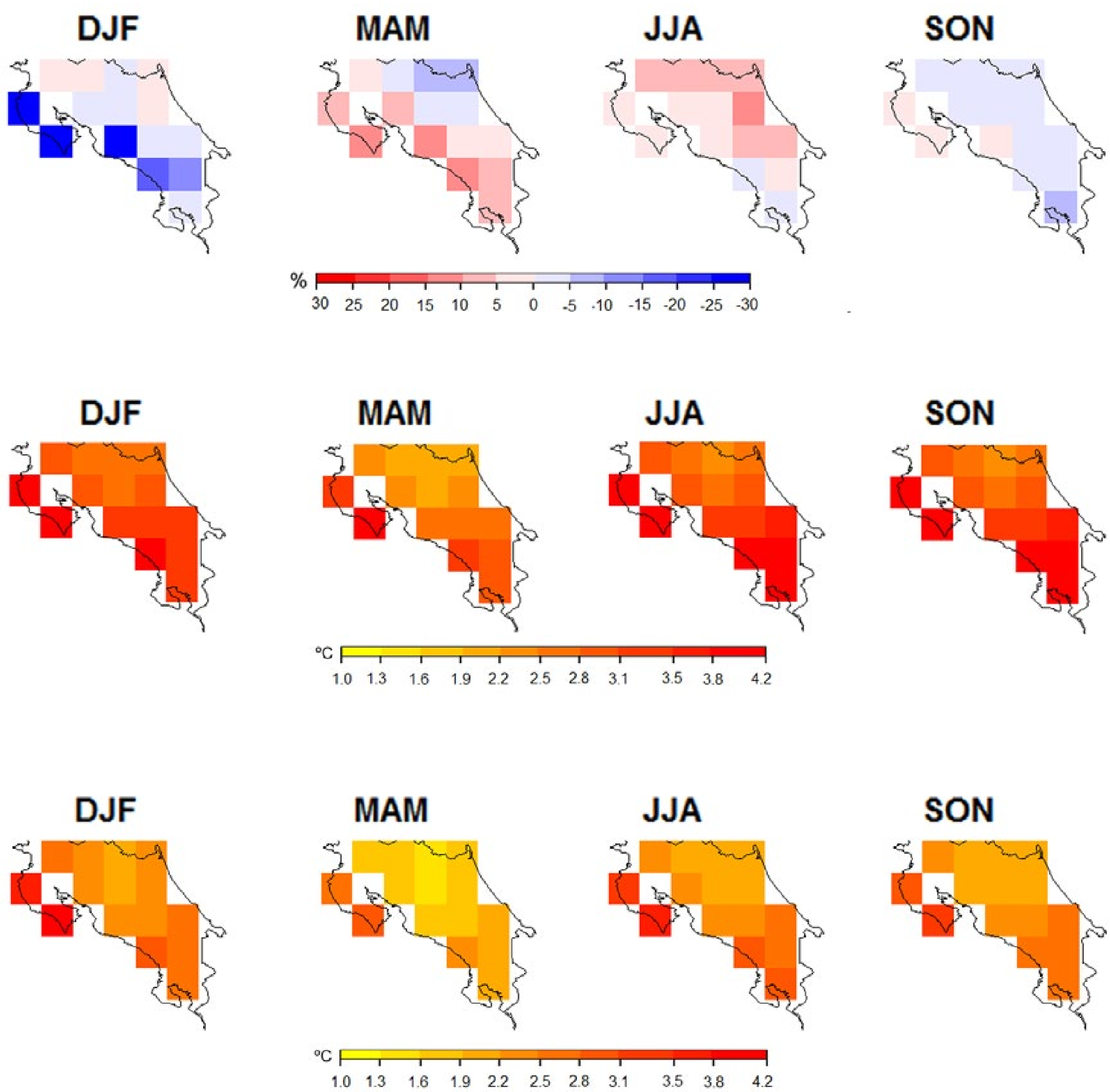

Figure 1: Climate impacts averaged across nine GCMs (2020-2050). DJF= December - February, MAM= March - May, JJA= June - August, SON= September - November.

3. Yield and suitability impacts

Yield

Based on the projected changes in climate discussed above, 2050 projections of maize, rice, and bean yields were modeled using the Decision Support System for Agrotechnology Transfer (DSSAT v4.5) at 0.5 degree spatial resolution. Model runs for each crop were parameterized using genetic coefficients of varieties carefully selected by experts for their relevance in the region.

Yield impact modeling suggests that in 2050, on average, climate change could result in substantial declines for rainfed bean, irrigated and rainfed maize, and irrigated rice by 31.6%, 31.5%, 30.4%, and 19.9%, respectively (Figure 2). The impact maps in Figure 3 indicate that these projected declines generally correspond to the areas in Figure 1 where 2050 temperature increases are most severe. However, irrigated rice yield may actually increase in one pocket of the northern highlands, possibly due to the higher precipitation projected for that area.

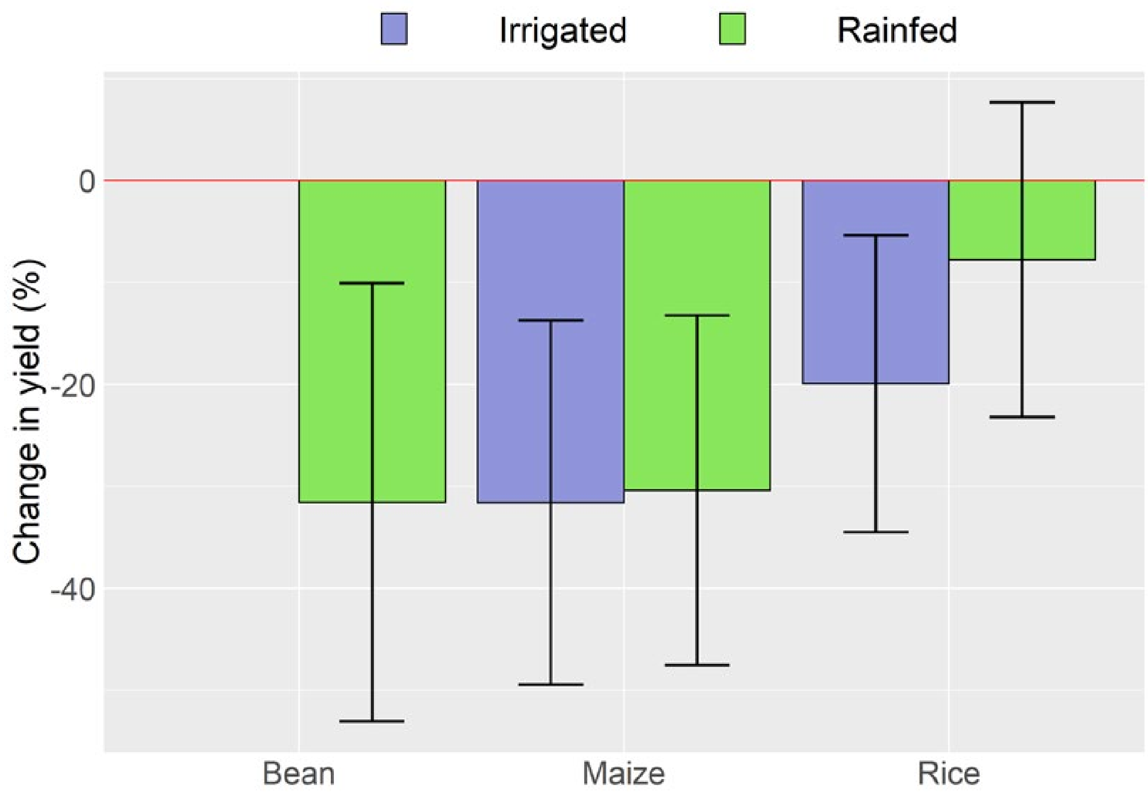

Figure 2: Projected average yield change, key crops (2020–2050). The error bars indicate the range of output across the nine climate models.

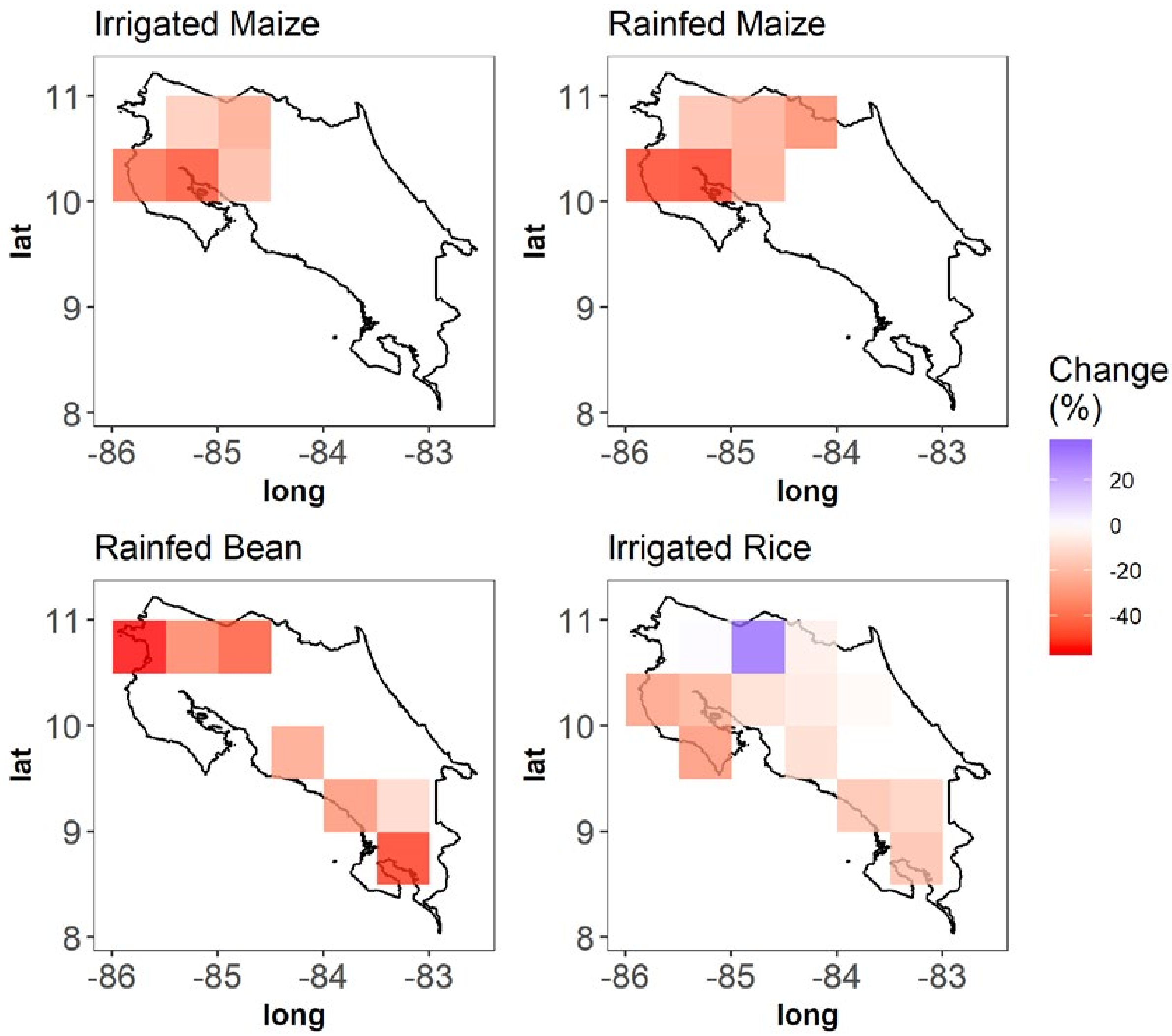

Figure 3: Projected yield impact maps, key crops (2020-2050).

Suitability

Climate change impacts on agro-ecological suitability for coffee (Robusta and Arabica), banana, yam, and cassava were assessed using niche based models. In these models, "suitability" is defined based on how well local precipitation and temperature match the biophysical requirements of the given crop.

Suitability modeling suggests that the average suitable area for banana cultivation may decrease substantially—by 84.7%—while cassava and yam exhibit relative resilience (Figure 4). In the spatially explicit impact maps (Figure 5), we see that declines in banana suitability are concentrated in the northwest, where increasing temperatures are projected to be severe. Meanwhile, much of the country will remain suitable for yam and cassava; and suitability for these crops may even increase in the currently less cultivated south and east.

The average suitable area for Arabica and Robusta coffee cultivation is projected to decrease steeply—by 44.2%, and 25.1%, respectively. However, the spatially explicit impact map in Figure 6 shows important variation hiding behind this national average. While severe declines in Arabica suitability are projected across the northwestern region where coffee production is currently concentrated, this is offset to a considerable degree by projected increases in suitability across a large swath of the central-southern range.

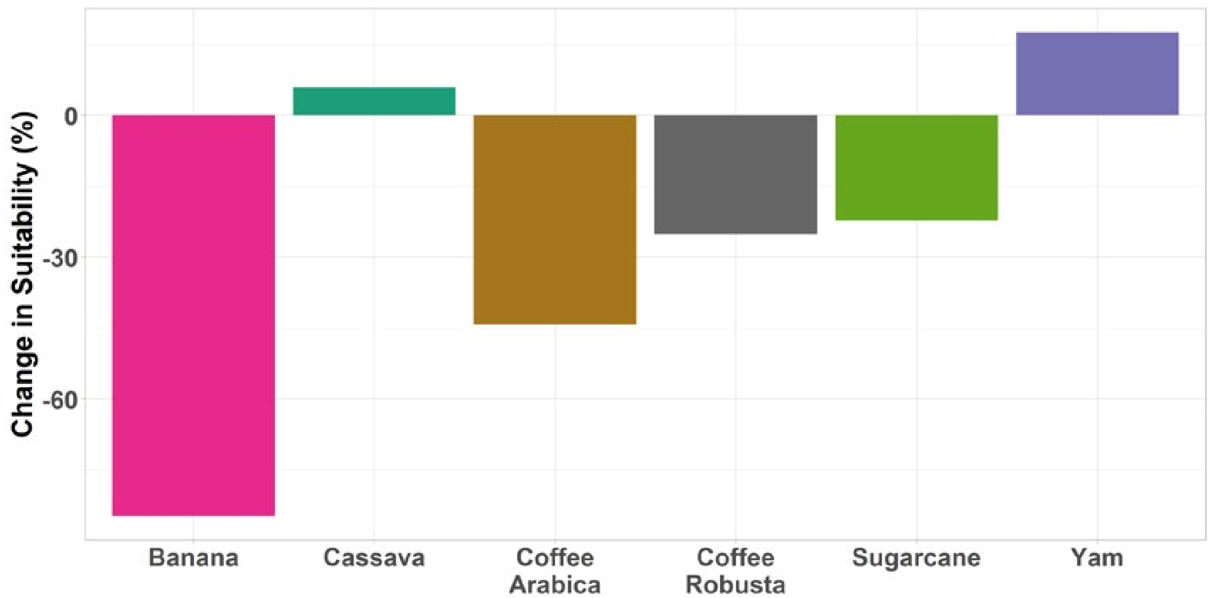

Figure 4: Projected change in suitability for key crops (2020-2050), national average.

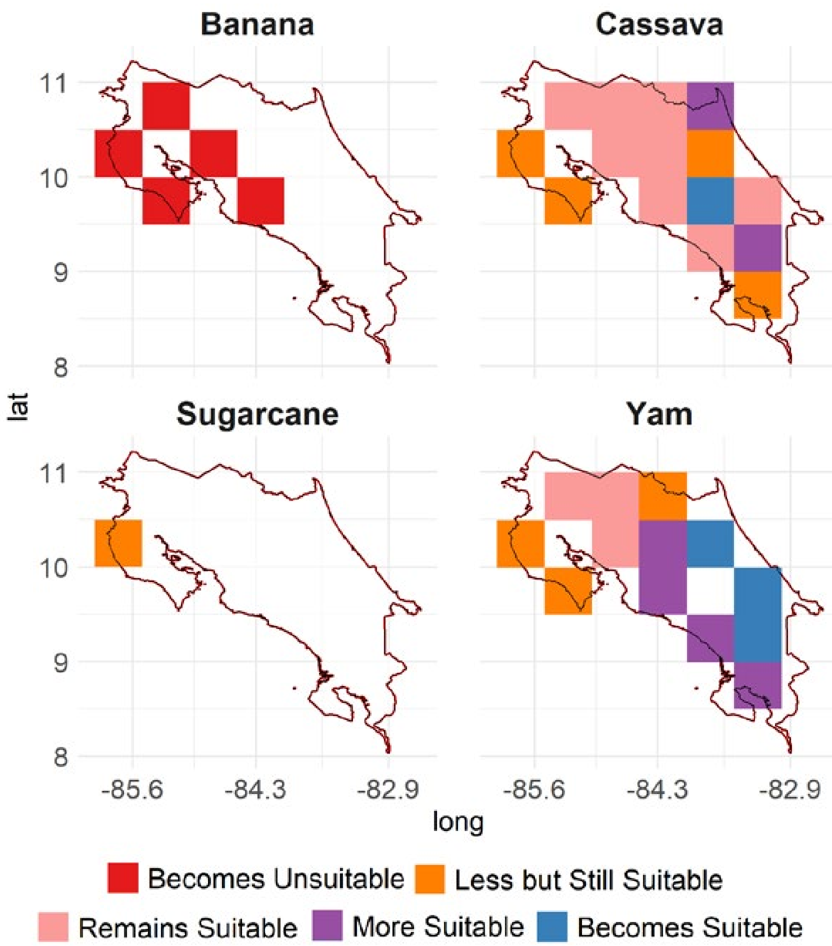

Figure 5: Projected suitability impact maps (2020-2050).

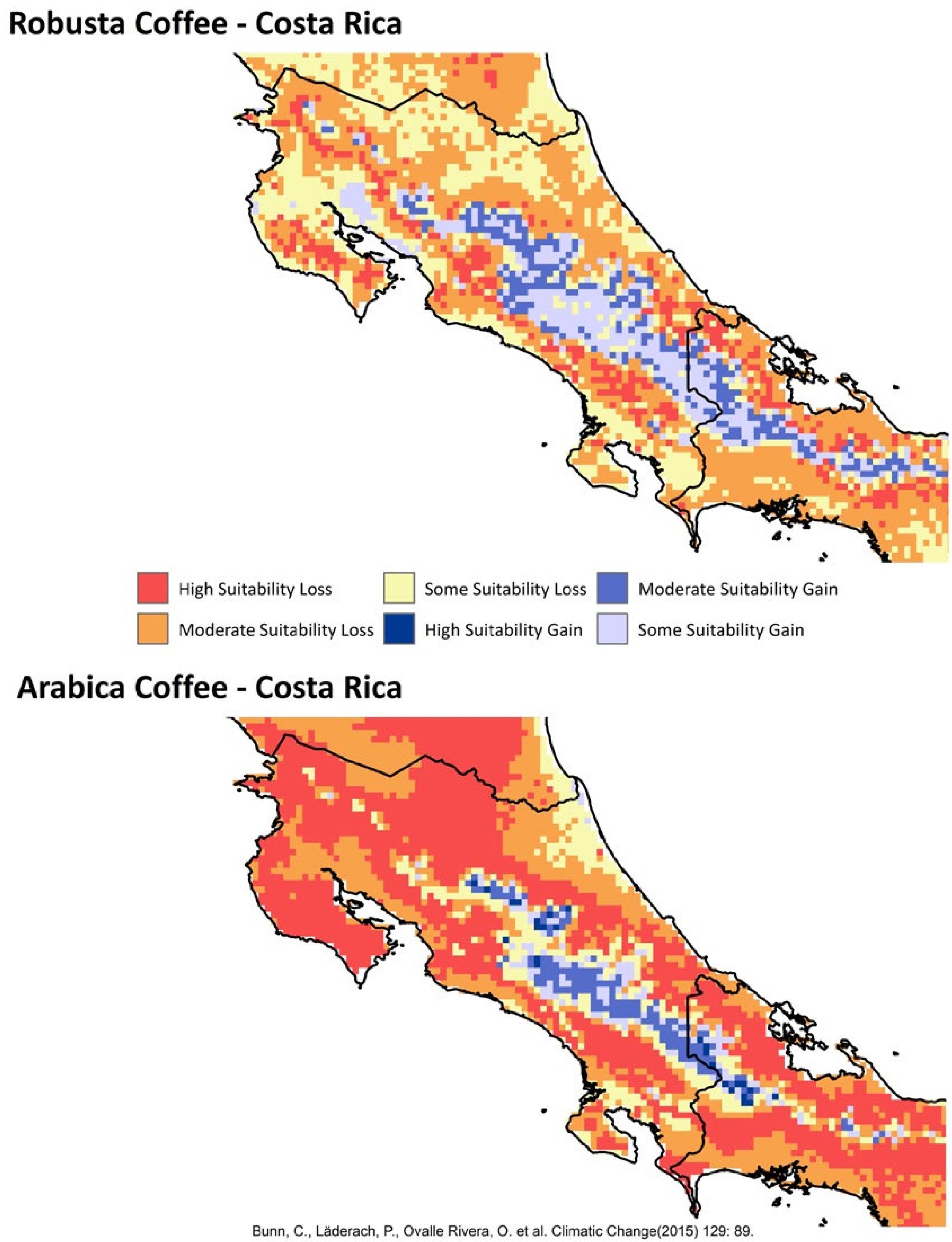

Figure 6: Projected change in suitability for Coffea arabica by 2050.

4. Economic impacts

In order to understand the real impacts of climate change on demand, supply, and international trade flows, the purely biophysical impacts addressed in the sections above must be adjusted for the economic agency of farmers who can adapt to yield and suitability loss by switching to alternative cultivars and practices. Ongoing advances in productivity and yield enhancing agricultural research, as well as the mitigating action (or inaction) of governments on emissions policy, must also be taken into consideration.

The interplay of these factors was modeled using the International Model for Policy, Agricultural Commodities, and Trade (IMPACT), developed at the International Food Policy Research Institute. In this section, IMPACT projections are presented for the DSSAT modeled crops, accounting for global economic and climate change contexts of these crops as well as their substitutes.

In a No-CC scenario, substantial percentage increases are projected for beans and maize production. Under climate change, the bean production outlook falls below its No-CC benchmark by just 5.8 percentage points (pp), while the maize production outlook falls considerably farther below its No-CC benchmark—by 34.1 pp (Figure 7). Both maize and beans exhibited biophysical vulnerability to climate change in the yield modeling section above. The IMPACT results here thus suggest that international trade dynamics evolve out to 2050 in such a way as to largely offset the biophysical vulnerability for beans while exacerbating it for maize. International trade incentives also appear to exacerbate the biophysical vulnerability observed for rice, with a CC production outlook falling 10.7 pp below its No-CC benchmark.

The production outlooks in Figure 7 generally fall short of their respective demand outlooks; and the result of this can be seen in Figure 8, where the current negative balance of trade in beans, maize, rice, soybean, and wheat is projected to continue out to 2050 under both CC and No-CC scenarios.

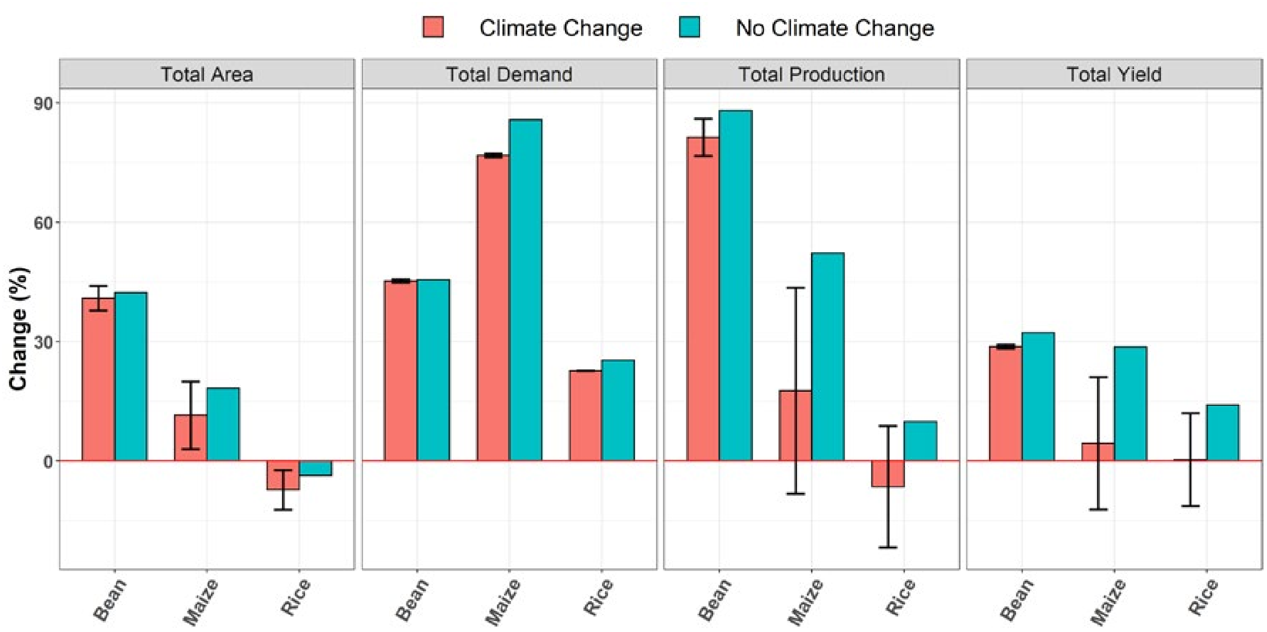

Figure 7: Percentage change in yield, demand, cultivated area, and production (2020–2050), when economic context and agricultural research are taken into account. The error bars indicate the range of output across the nine climate models.

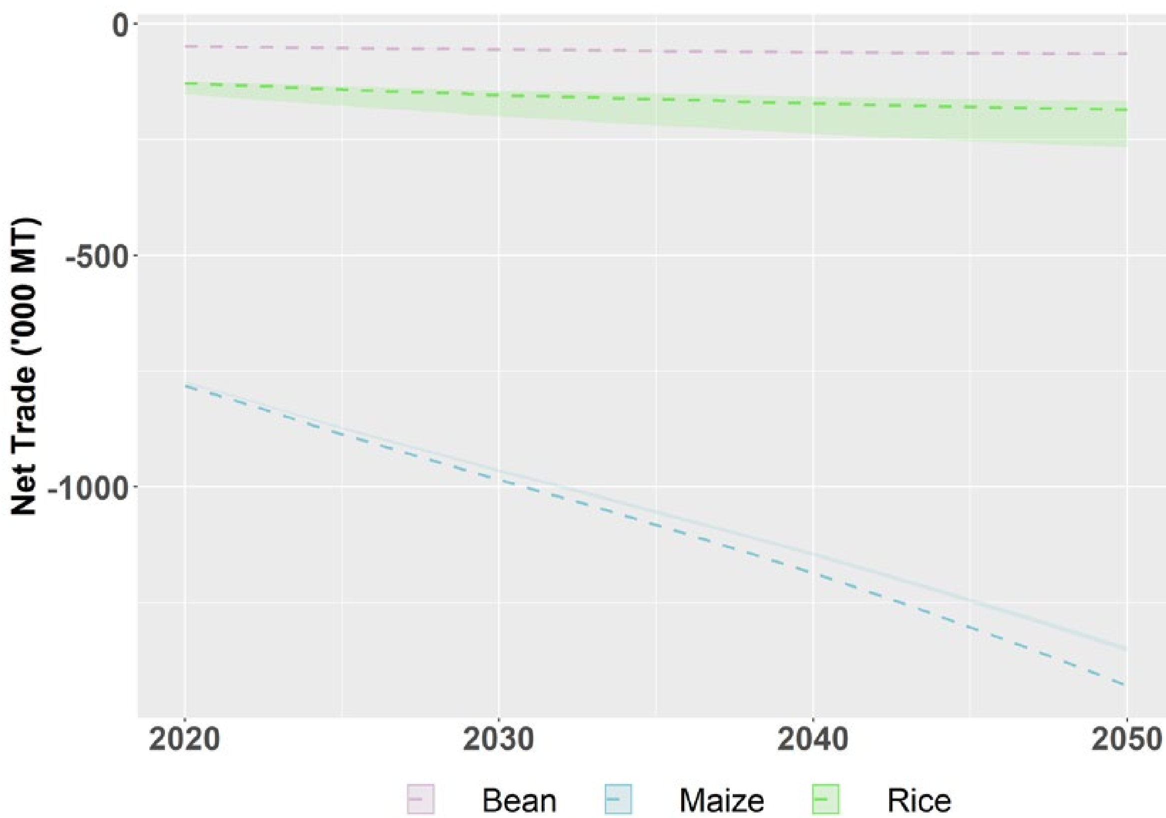

Figure 8: Climate change impact on trade. The dotted lines indicate the no climate change (No-CC) trajectory while the shaded areas correspond to the range of climate change (CC) trajectories given by the nine climate models.

5. The way forward

Costa Rica's Nationally Determined Contribution (NDC) to the 2015 Paris Agreement includes integrated agricultural adaptation goals that may work to reduce the magnitude of the trends seen here [7]. In particular, substantive strides have been made in the creation of a national climate change mitigation policy framework that has generally set a high standard for further mitigation and adaptive work in the region. The National Climate Change Strategy and Plan of Action has been established to reach the goal of becoming a carbon neutral country by 2021, laying the groundwork for a voluntary carbon market, the REDD+ mechanism, and numerous multisectorial interventions—including agriculture [7]. Costa Rica and other countries in Latin American may be able to reduce the impact of climate change on the agricultural sector by adopting climate-smart agricultural (CSA) practices that increase productivity while reducing greenhouse gas (GHG) emissions and adapting to shifting growing conditions. Some specific adaptation measures are presented in Table 2.

Table 2: Key messages for policy interventions

Table 2. Key messages for policy interventions		Way forward
Climate	Key Climate Observations • Along the Pacific slope, rainfall projected to increase during December-February, and to decrease during March-May. • Along the Caribbean slope, a slight increase in rainfall projected for the north during March-May, with a more substantial increase along the entirety of the region during September-November, and a decrease during June-August. • Higher minimum and maximum temperatures projected across the country, especially along the Pacific coast.	Main activities should focus on: • Strengthening of research capacity, technology transfer, and public extension services oriented towards smallholder farming. • Strengthening of agro-climatic information and market intelligence services, especially in areas of greatest vulnerability. • Promotion of the research, release, and adoption of flood and drought tolerant varieties of key staple crops. • Assessment of potential adaptive measures and/or alternatives to maize, beans, banana and sugarcane, which exhibit high vulnerability to climate change. • Assessment and exploitation of the climate change resilient properties of yam and cassava.
Agriculture	Key Agriculture Observations • Parts of the agriculturally important northwest will see the highest increases in temperature. • A steep decline in areas suitable for banana and sugarcane cultivation are projected in 2050. • Steep declines in suitable area for coffee also projected, although this may be offset by new areas of suitability at higher elevations along the central range. • Areas suitable for cassava and yam cultivation are projected to increase or remain stable in 2050, exhibiting resilience in the face of climate change. • Steep declines in yield projected for maize, beans, and rice, which could affect food sovereignty if adaptive measures not taken. • International trade incentives may offset biophysical vulnerability of beans while exacerbating it for maize and rice.	

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[1] The World Bank. 2018. World Development Indicators. Washington, D.C., USA. **http://data.worldbank.org/indicator**

[2] Massachusetts Institute of Technology. 2018. Observatory of Economic Complexity. **http://bit.ly/2UUTxvt**

[3] FAOSTAT. 2018. Detailed Trade Matrix. **http://www.fao.org/faostat/en/#data/TM**

[4] CIA Factbook. 2018. **http://bit.ly/2GF37tM**

[5] FAOSTAT. 2018. The Right to Food around the Globe. **http://bit.ly/2DxCncR**

[6] The World Bank. 2011. Vulnerability, Risk Reduction, and Adaptation to Climate Change, Costa Rica. **https://bit.ly/2GhhLt8**

[7] Ministerio de Ambiente y Energia, Instituto Meterealogico Nacional. 2014. Tercera Comunicación Nacional, Convención Marco de las Naciones Unidas sobre Cambio Climático. **https://unfccc.int/resource/docs/natc/crinc3.pdf**

VIII. Dominican Republic

1. Context

Agriculture plays an important but declining role in the Dominican Republic. The sector accounts for 5.7% of GDP, down 1.5 percentage points (pp) from a peak of 7.2% in 2005. Jobs in agriculture account for 12.4% of all employment in the country, down 2.5 pp from 8 years ago [1]. While representing a relatively small share of GDP, agricultural products contribute nearly 40% of all DR exports in value [2]. Climate change presents significant challenges to both domestic food security and export crop yields as well as the broader economic performance of the agricultural sector in the Dominican Republic (DR). Two especially relevant impacts to the agricultural sector include flooding and increased extreme events from tropical storms and other hydro-meteorological hazards producing high winds and landslides. National estimates suggest that extreme events have caused nearly US$10 billion in economic losses on the island over the last decades, disproportionately impacting the agricultural sector [3]. The impact of long-term progressive climate change on crop yields and suitability – and the resulting impacts on regional trade – are of severe consequence for both farmers and policy makers in DR. A better understanding of the climate change impacts on specific crops will hence assist in decision making. For this purpose, climate, crop, and economic modeling provide future trends (average for 2020-2050) regarding agricultural production and trade in the country, set in the LAC regional context.

2. Climate impacts

In assessing future climate impacts, this study utilized nine general circulation models (see Methodological Summary for detail), selected for their strong performance in the LAC region. Overall, temperatures are predicted to increase by 1-4°C across the LAC region, with the Caribbean and tropical South America projected to warm at higher rates than Mexico and the Southern Cone.

On average, the DR is projected to become drier between March and August, with rainfall reductions as high as 20% in the June to August period (Figure 1). The northern December to February rainy season and the southern March to May rainy season may both see increased rainfall. Generally, in the wetter areas, precipitation is likely to increase in both magnitude and frequency. Maximum temperatures are projected to increase substantially throughout the country—by as much as 4°C in the eastern provinces. Minimum temperatures are projected to increase by about 2°C, with the highest increases again occurring in the east.

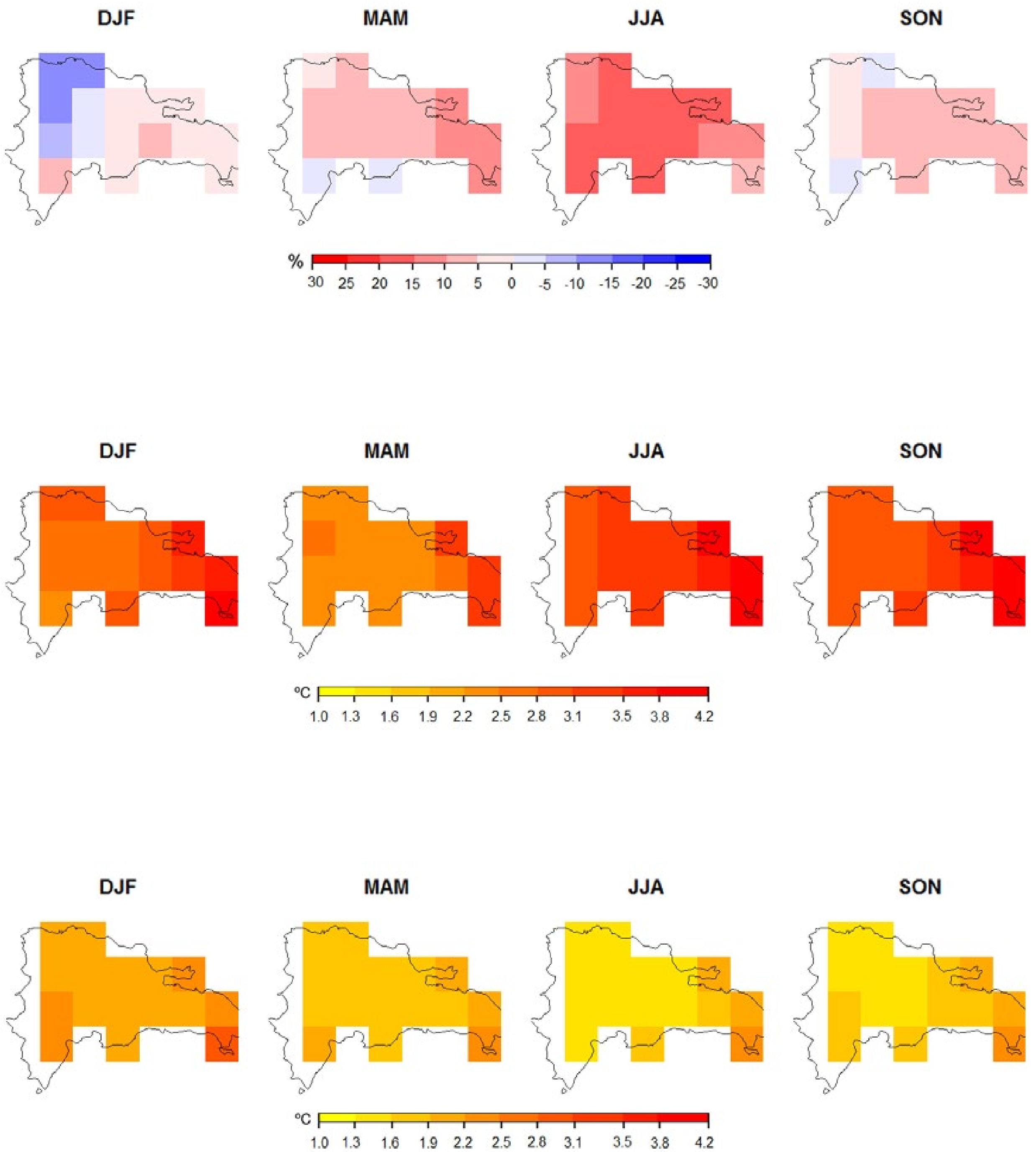

Figure 1: Change in (top to bottom) precipitation, maximum temperature, and minimum temperature averaged across nine GCMs (2020-2050). DJF= December - February, MAM= March - May, JJA= June - August, SON= September - November.

3. Yield and suitability impacts

Yield

Based on the projected changes in climate discussed above, 2050 projections of maize, rice, bean, and soybean yields were modeled using the Decision Support System for Agrotechnology Transfer (DSSAT v4.5) at 0.5 degree spatial resolution. Model runs for each crop were parameterized using genetic coefficients of varieties carefully selected by experts for their relevance in the region.

Maize, bean, and rice are particularly relevant in the DR context. Modeling suggests that rainfed bean and maize yield may decline considerably by 35% and 37%, respectively. This is more severe than the average for the Central American and Caribbean region as a whole, at 22% and 27%, respectively. Irrigated maize and rice, meanwhile, and rainfed maize yields, exhibit relative resilience, meanwhile, projected to decline by 21% and 3%, respectively (Figure 2).

The geographically explicit yield impact maps in Figure 3 show that these projected declines in yield are more pronounced in some places than in others. The projected decline in rainfed bean yield is particularly steep in El Seibo, La Altagracia, La Romana, and Hato Mayor provinces in the southeast of the country; while projected declines in maize yields (both irrigated and rainfed) are most pronounced in Monte Cristi province, in the northwest. The relatively small projected decline in irrigated rice yield is concentrated in La Altagracia and El Seibo provinces in the southeast, with only slight losses—and one pocket of slight gains in Azua province—projected for the rest of the country.

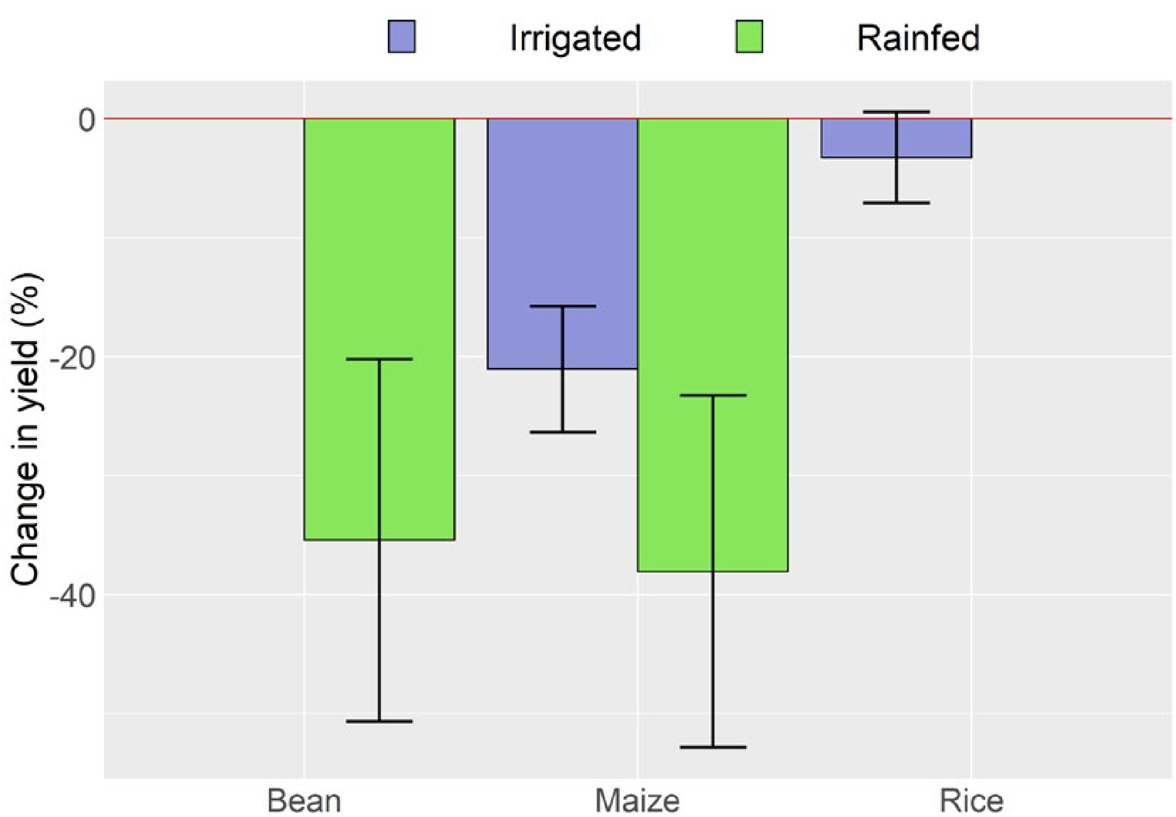

Figure 2: Projected average yield change, key crops (2020–2050). The error bars indicate the range of output across the nine climate models.

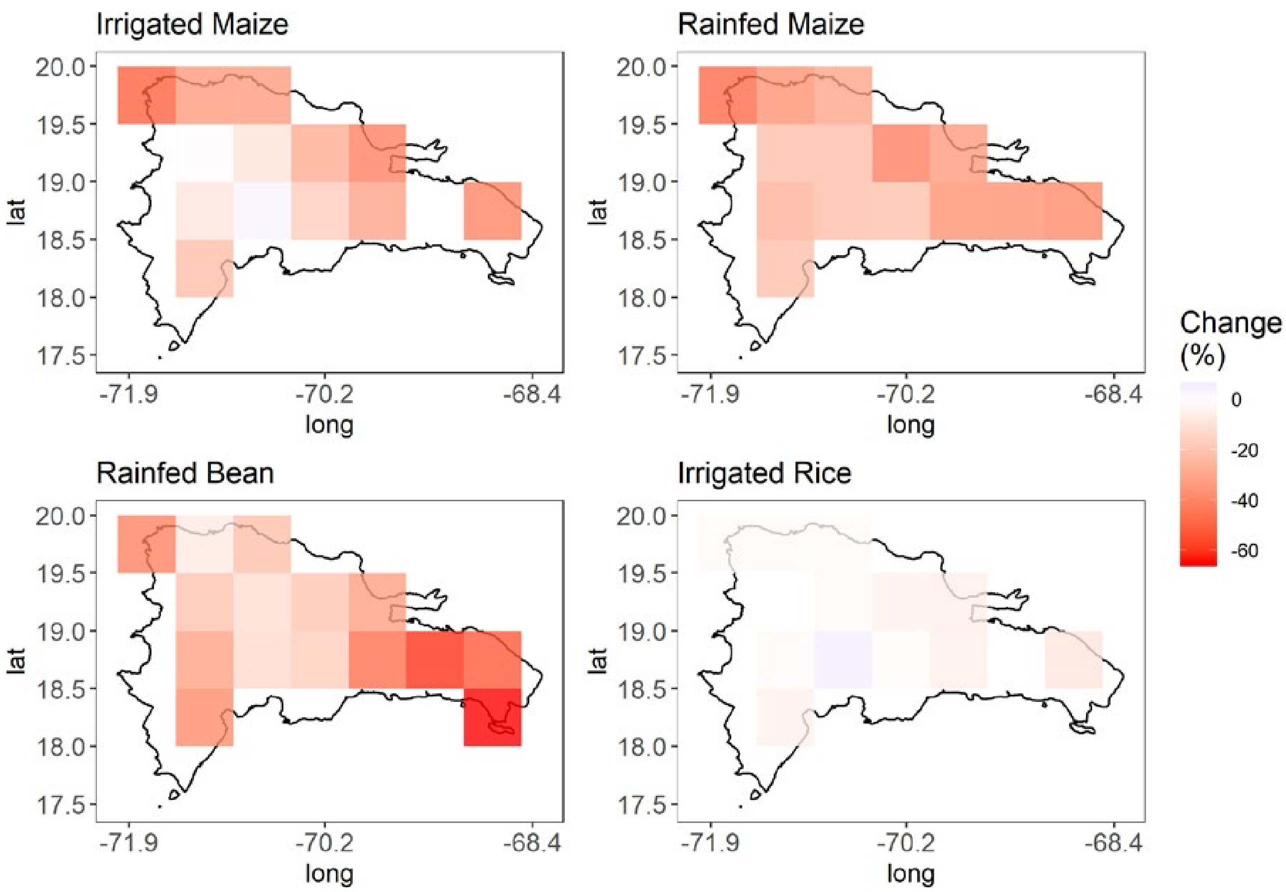

Figure 3: Projected yield impact maps, key crops (2020-2050).

Suitability

Climate change impacts on agro-ecological suitability for coffee (Robusta and Arabica), banana, yam, cassava, potato and sugarcane were assessed using niche based models. In these models, "suitability" is defined based on how well local precipitation and temperature match the biophysical requirements of the given crop.

The suitability of crops that are of particular relevance in the DR is presented in Figure 4. The area suitable for banana is projected to suffer a substantial decline of 57%. The area suitable for arabica and robusta coffee cultivation is also projected to decline considerably, by 37% and 23%, respectively. This is consistent with regional trends for Latin America and the Caribbean with banana, coffee (robusta), and coffee (arabica) all shown to have substantial decreases in suitable area by 2050, with area reductions of 61%, 67%, and 47%, respectively. The area suitable for sugar cane, meanwhile, is projected to increase by 19%. Cassava and yam – key food security crops – also exhibit relative resilience, with a change in suitability of +6% and -12%, respectively).

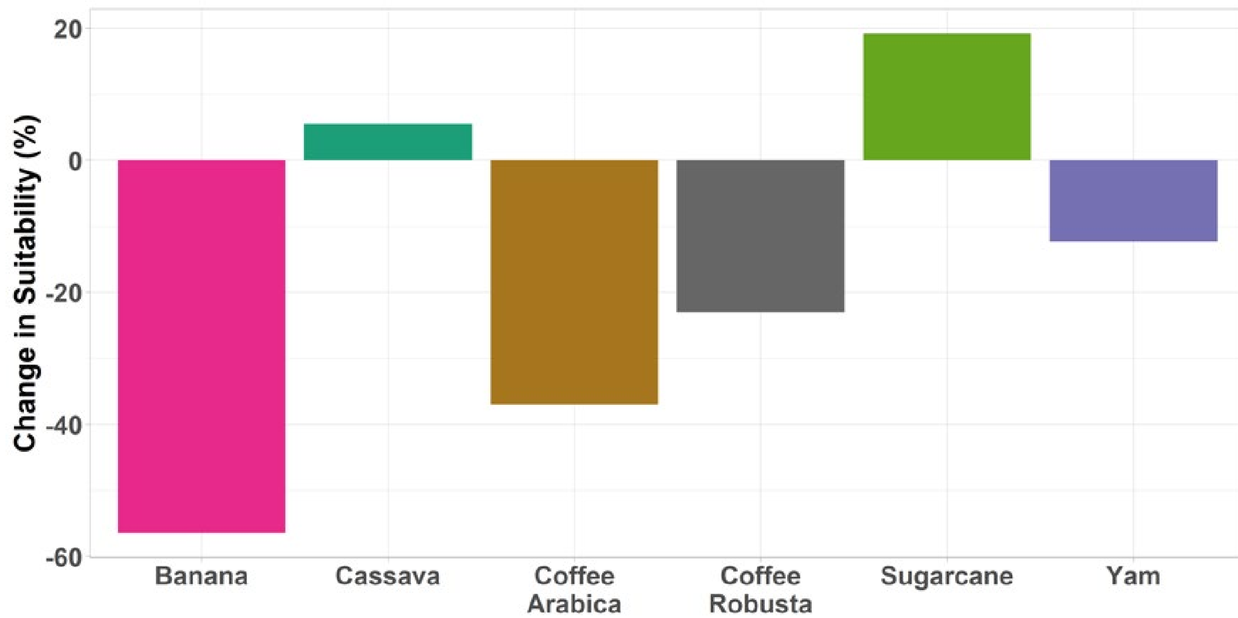

Figure 4: Projected change in suitability for key crops (2020-2050).

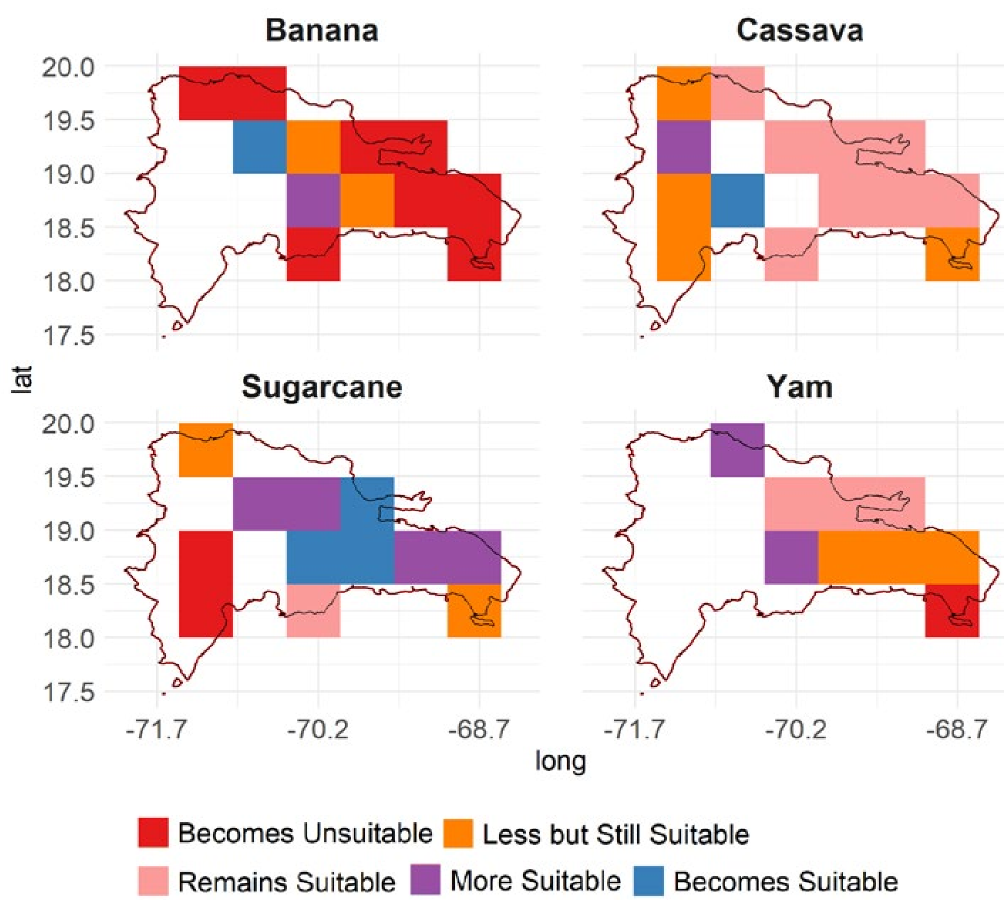

Figure 5: Projected suitability impact maps (2020-2050).

The geographically explicit suitability impact maps presented in Figure 5 show that there is important variation hiding behind these national averages. Note that the sharp decline in banana suitability across much of the north and eastern half of the country is partly offset by a pocket in the central interior where suitability may increase, around La Vega, San Cristóbal, San José de Ocoa, and Monseñor Nouel provinces. An increase in sugar cane suitability is projected for much of the central and eastern parts of the DR; but sugar cane suitability is also projected to decrease in the extreme south of La Altagracia, parts of coastal Monte Cristi and Puerto Plata provinces in the north, and especially in the San Juan, Baoruco, and Barahona provinces in the west. Cassava is projected to either remain suitable or to increase in suitability across most of the country, except for the extreme southeast, northwest, and west. Yam likewise exhibits resilience across much of the country, especially in Puerto Plata, San Cristóbal, and San José de Ocoa provinces. Cassava and yam are not currently cultivated in large quantities in the DR (as compared to their production in Haiti, for example); but this projected resilience in the face of climate change could make them an attractive alternative source of carbohydrates and nutrients, especially considering the yield declines projected for maize and rice in Figures 2 and 3.

The area suitable for coffee cultivation, meanwhile, is projected to decline across most of the country (more so for Arabica than for Robusta), although this is partly offset by an area in the central highlands where suitability is projected to increase (Figure 6).

4. Economic impacts

In order to understand the real impacts of climate change on demand, supply, and international trade flows, the purely biophysical impacts addressed in the sections above must be adjusted for the economic agency of farmers who can adapt to yield and suitability loss by switching to alternative cultivars and practices. Ongoing advances in productivity and yield enhancing agricultural research, as well as the mitigating action (or inaction) of governments on emissions policy, must also be taken into consideration. The interplay of these factors was modeled using the International Model for Policy, Agricultural Commodities, and Trade (IMPACT), developed at the International Food Policy Research Institute. In this section, IMPACT projections are presented for the DSSAT modeled crops, accounting for global economic and climate change contexts of these crops as well as their substitutes.

In the DR, demand, production, and area planted for the modeled crops are projected to increase out to 2050. However, the introduction of climate stressors is projected to lower growth in many of these indicators by several percentage points (pp) below the No-CC benchmark. Climate change is projected to have a particularly negative impact on maize (-32.2 pp) and bean (-8.1 pp) production, and a comparatively slight impact on rice production (+1.2 pp). Bean and rice production are projected to be sufficient to meet internal demand. However, the already substantial trade deficit in maize is projected to grow out to 2050 (Figure 8).

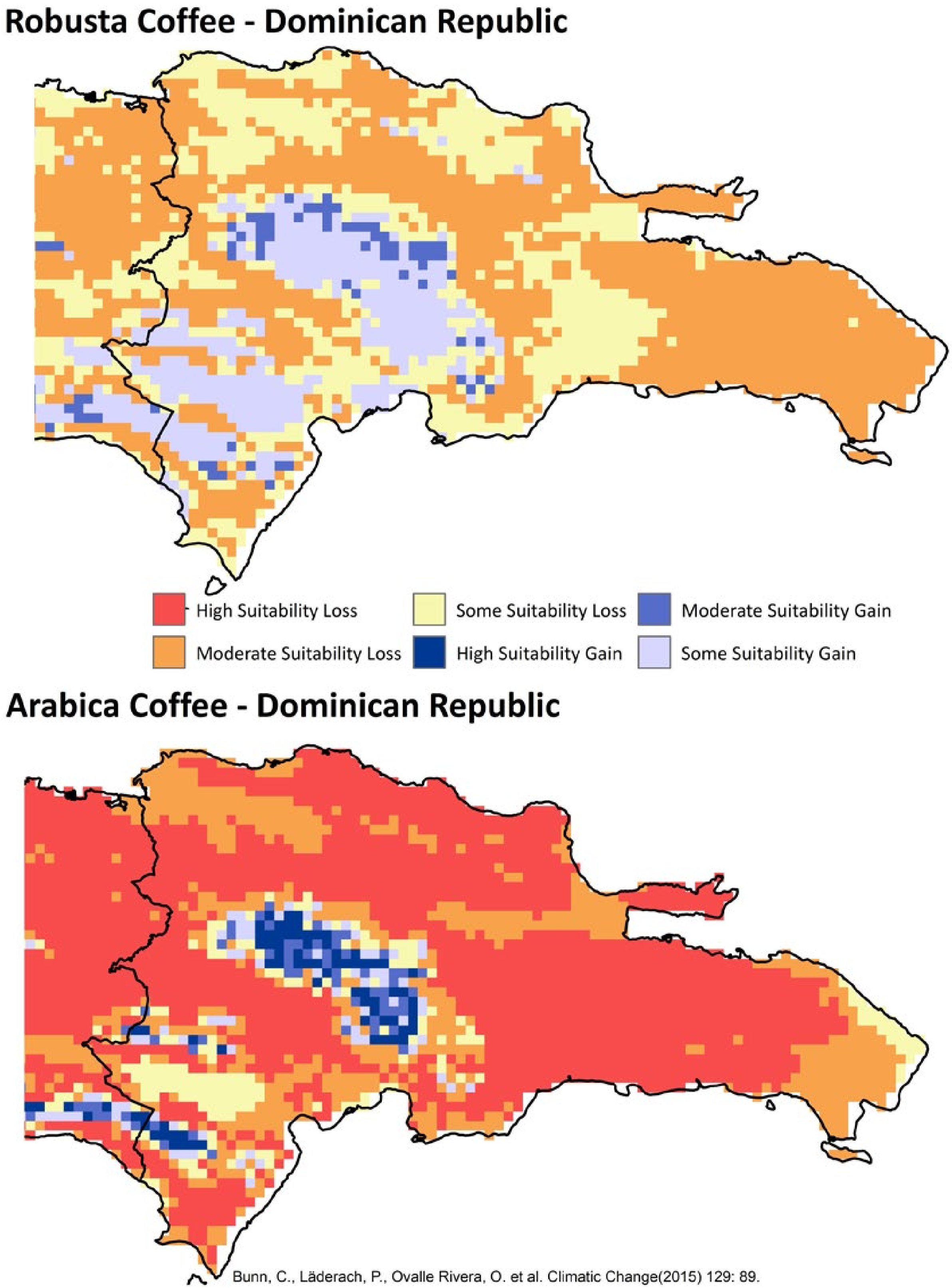

Figure 6: Projected change in suitability for coffee by 2050.

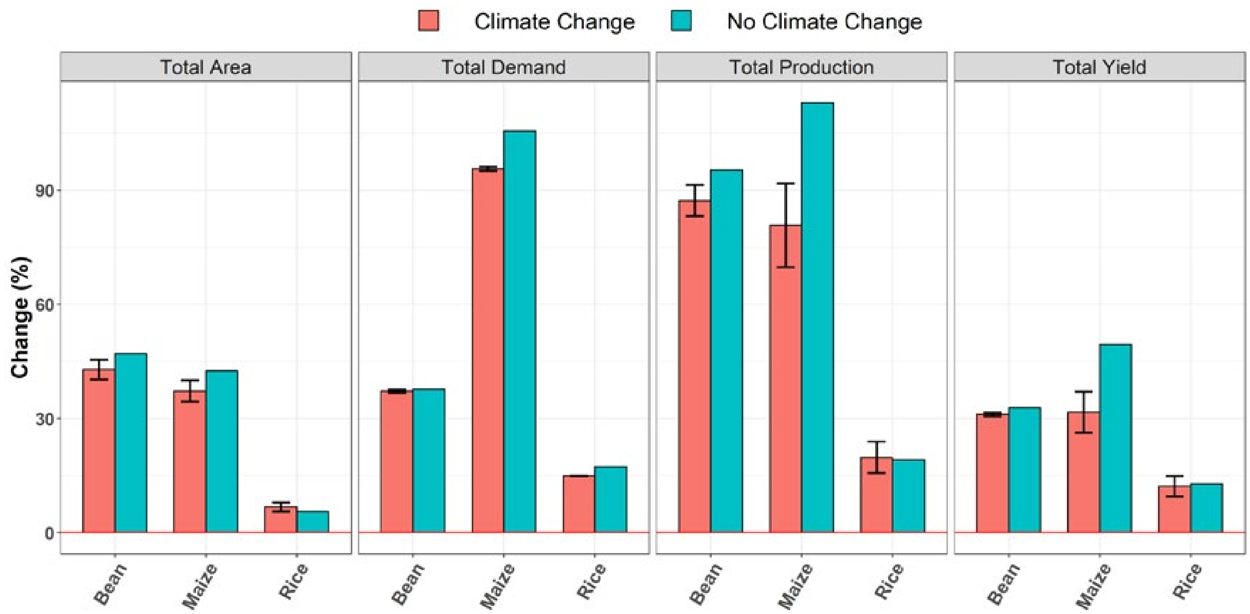

Figure 7: Percentage change in yield, demand, cultivated area, and production (2020–2050), when economic context and agricultural research are taken into account. The error bars indicate the range of output across the nine climate models.

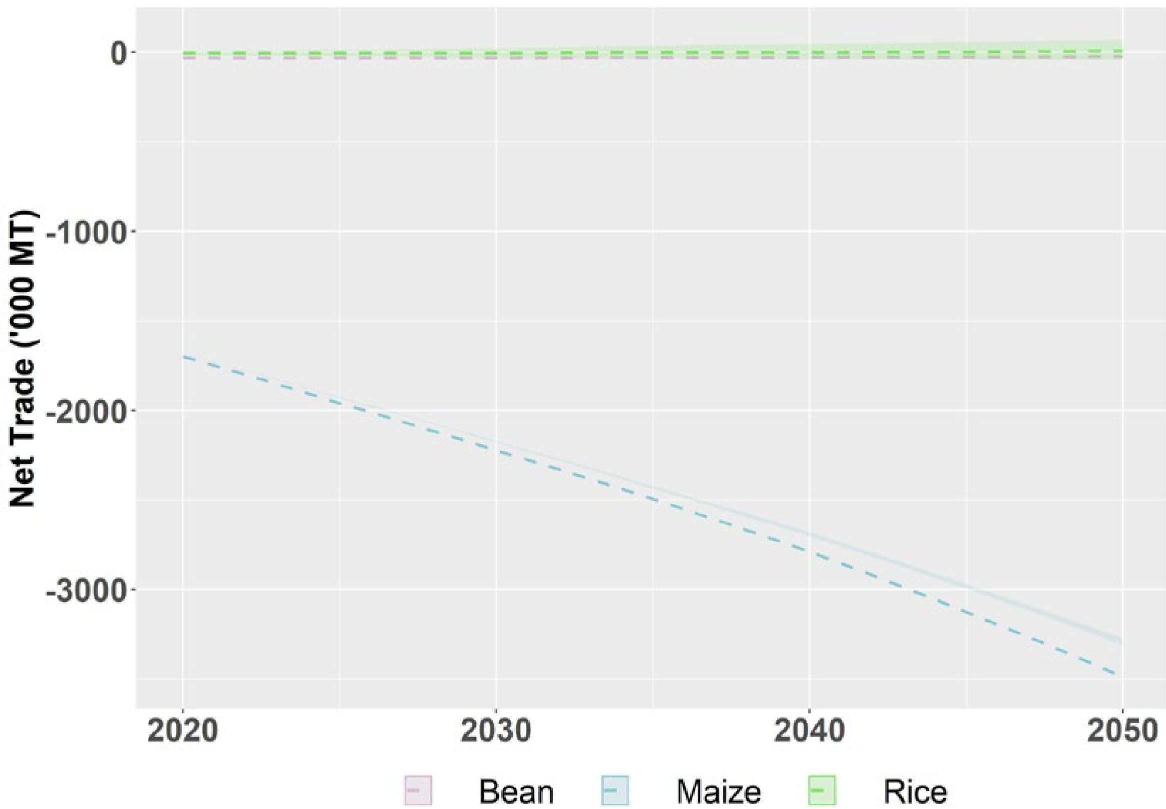

Figure 8: Climate change impact on trade. The dotted lines indicate the no climate change (No-CC) trajectory while the shaded areas correspond to the range of climate change (CC) trajectories given by the nine climate models.

5. The way forward

The Dominican Republic's Nationally Determined Contribution (NDC) to the 2015 Paris Agreement includes integrated agricultural adaptation goals that may work to reduce the magnitude of the trends seen here. In an effort to limit the rise in global mean temperature below 2 °C and ensure food security, most climate change pledges to the United Nations Framework Convention on Climate Change (UNFCCC) cite agriculture and land-use as a key source of adaptation and/or mitigation potential [4]. The Dominican Republic aims to achieve a 25% reduction in emissions across all sectors by 2030, including agriculture, relative to 2010 levels. The country has established a National Policy on Climate Change, a Climate Compatible Development Plan, and a National Adaptation Plan of Action (NAPA- DR) to guide its climate actions. The NAPA-DR document cites the need for improved seed and grain storage, adoption of improved crop and livestock varieties, and efforts to reduce deforestation and burning for sector emissions reductions, among others critical activities [5]. Meanwhile, the country's Second National Communication to the UNFCCC also emphasizes the need to adjust food consumption patterns, consider improved crop rotations, and general provisions to improve soil moisture and water use efficiency. DR and other countries in LAC may be able to reduce the impact of climate change on the agricultural

Table 2: Key messages for policy interventions

Table 2. Key messages for policy interventions		Way forward
Climate	Key Climate Observations • Temperatures are projected to increase by 1–4°C in the Dominican Republic by 2050. Maximum temperatures will increase more than minimum temperatures. • Reduced rainfall in the period between March and August. Meanwhile, rainfall may increase during rainy seasons in both the north and south of the island. In wetter areas, precipitation is likely to increase in both magnitude and frequency.	• Improved seed and grain storage • Agricultural research in the following: » Prioritization of adaptation options for key crops, including land management and alternative crops » Assessment of heat and flood resistant crops (particularly relevant for banana and coffee) » Assessment of roots and tubers like yams and cassava as an alternative carb staple crop.
Agriculture	Key Agriculture Observations • Temperature increases and reduced precipitation are likely to increase the risk of drought across the country, especially impacting rainfed systems. • Crop suitability analysis shows that coffee and banana are particularly vulnerable to climate change in the Dominican Republic. Impacts on key food security crops such as yam and cassava are expected to be minimal. Sugarcane suitability in the southeast may increase. • Irrigated maize and rice, and rainfed bean and maize are likely to see future yield declines. Rainfed maize yields are projected to see the most severe declines. • Increases in imports are expected, especially for maize, further deepening country dependence on cereal imports.	

sector by adopting climate-smart agricultural (CSA) practices that increase productivity while reducing greenhouse gas (GHG) emissions and adapting to shifting growing conditions. This may include the continued expansion of no-till agricultural practices, precision nutrient management (fertilizer) and intercropping, among other practices.

Increased trade and productivity in the face of yield declines and faltering suitability for both domestic food security and export-oriented crops will require continued investment in agricultural research, robust communication between farmers and market intermediaries, and responsible land management and planning. In an island setting in particular, soil conservation and sustainable agricultural practices are vital to ensuring food security. Given the especially severe production losses across LAC, DR will increasingly rely on trade with more temperate zones, including the Southern Cone, to ensure domestic food security. Political and financial market stability will be key to ensuring that these potential opportunities are realized. Key messages for policy interventions and a way forward for adaptation measures are summarized in Table 2.

References:

[1] The World Bank. 2018. World Development Indicators. Washington, D.C., USA. **http://data.worldbank.org/indicator**

[2] MIT Observatory of Economic Complexity. 2018. Dominican Republic Country Profile. **http://atlas.media.mit.edu/en/profile/country/dom/**

[3] Government of Dominican Republic. 2015. Intended Nationally Determined Contribution (INDC-DR). **http://bit.ly/2bml3fX**

[4] CCAFS. 2015. Info Note: Agriculture's prominence in the INDCs. https://cgspace.cgiar.org/rest/bitstreams/62364/retrieve. Detailed country information on agriculture in INDCs available at: **https://cgspace.cgiar.org/handle/10568/73255**

[5] Ministerio de Medio Ambiente y Recursos Naturales. 2018. Tercera Comunicación Nacional de la República Dominicana ante la Convención Marco de las Naciones Unidas sobre Cambio Climático. **http://bit.ly/32BKXCD**

IX. Ecuador

1. Context

Agriculture continues to play an important role in Ecuador. The sector accounts for 9.5% of GDP, down 5.9 percentage points (pp) from a peak of 15.4% in 2000. Crop products accounted for 21.8% of all exports in 2018, down 0.1 pp from 2009. Jobs in agriculture account for 26.9% of all employment in the country, down 1.8 pp from 8 years ago [1]. Climate change presents significant risk to crop yields and the broader economic performance of the agricultural sector. El Niño impacts, flooding, droughts, and declining Andean glacial melt are the major climatic threats currently facing Ecuador's agricultural sector [2]. The impact of long-term progressive climate change on crop yields and suitability – and the resulting impacts on regional trade – are of severe consequence for both farmers and policy makers in Ecuador. A better understanding of the climate change impacts on specific crops will hence assist in decision making. For this purpose, climate, crop, and economic modeling results are presented in this brief (averaged over 2020–2050), regarding agricultural production and trade in the country, set in the LAC regional context. Based on these trends, adaptation measures are proposed at the end of the brief.

2. Climate impacts

In assessing future climate impacts, this study utilized nine general circulation models (see Methodological Summary for detail) selected for their strong performance in the LAC region. Overall, temperatures are predicted to increase by 1-4 °C across the LAC region, with the Caribbean and tropical South America projected to warm at higher rates than Mexico and the Southern Cone.

In Ecuador, increased rainfall (in some cases a 30% increase) is projected across most of the country by 2050 (Figure 1). The projected increase in rainfall is especially pronounced over the eastern Andean piedmont and tropical forest during the December to February period. Over the Andes and coastal areas to the east, projected increases in rainfall are most pronounced during the months June to August. Some decreased rainfall may occur in Ecuador's northeastern midlands during July to November. Maximum and minimum temperatures are projected to increase throughout the country by as much as 4°C, with the most severe increases occurring along the coast. The projected increase is somewhat less pronounced during June to August.

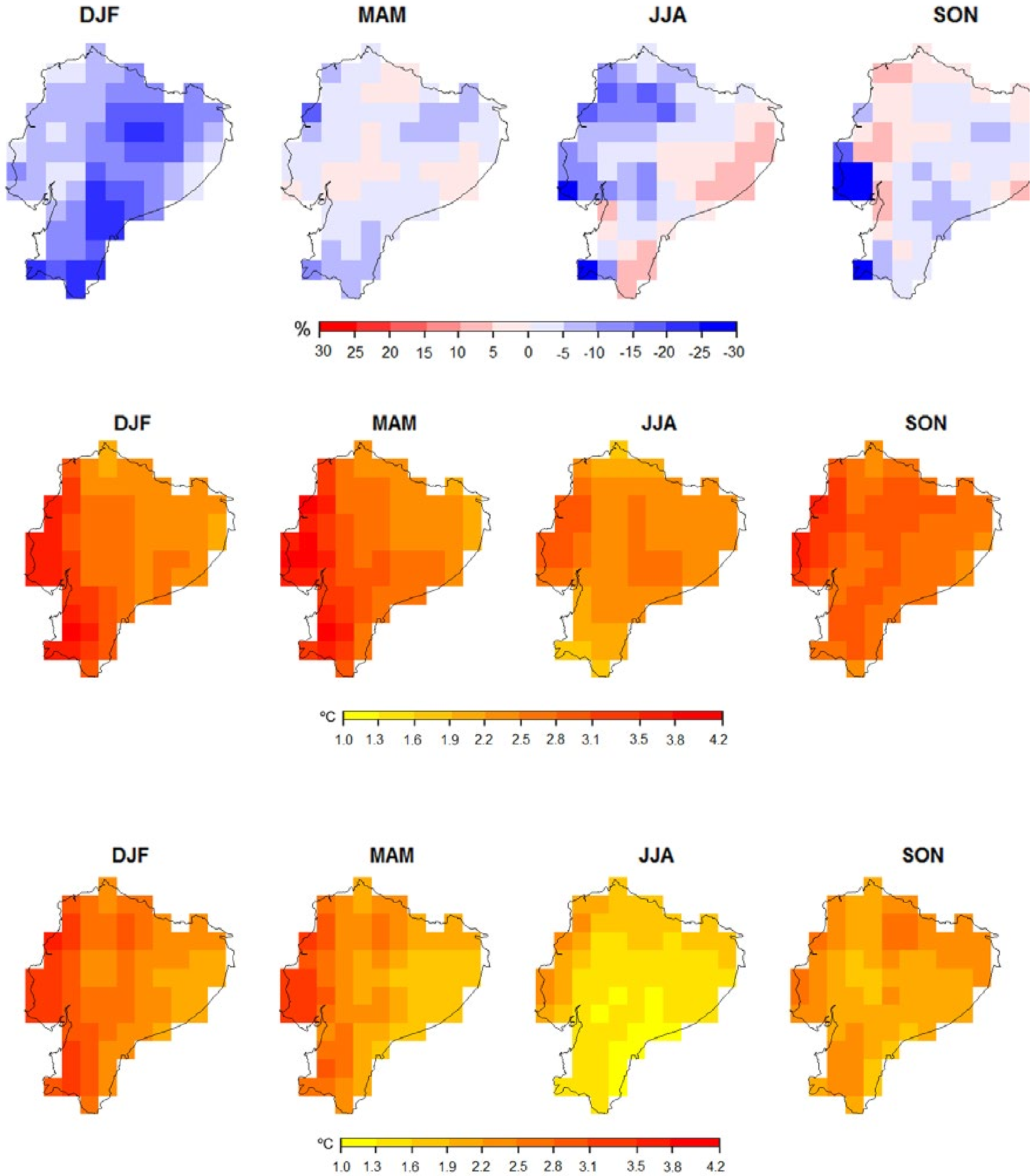

Figure 1: Change in (top to bottom) precipitation, maximum temperature, and minimum temperature averaged across nine GCMs (2020-2050). DJF= December - February, MAM= March - May, JJA= June - August, SON= September - November.

3. Yield and suitability impacts

Yield

Based on the projected changes in climate discussed above, 2050 projections of maize, rice, bean, and soybean yields were modeled using the Decision Support System for Agrotechnology Transfer (DSSAT v4.5) at 0.5 degree spatial resolution. Model runs for each crop were parameterized using genetic coefficients of varieties carefully selected by experts for their relevance in the region.

In Ecuador, the crop modeling results shown in Figure 2 suggest that yield may increase for rainfed bean, irrigated maize, and rainfed soybean by 31.7%, 10%, and 21%, respectively; while decreasing for irrigated rice by 18.4%. This is counterintuitive, since irrigated systems, as a general rule, are more resilient to climate change than rainfed systems. Turning to the geographically explicit yield impact maps in Figure 3, however, it becomes clear that the sharp decline in irrigated yields may, in large part, be attributed to their location along the low-lying coastal plains, where temperature increases are projected to be especially severe (recall Figure 1). Irrigated rice and maize systems in the Manabi and Guayas provinces may be especially hard hit, with yield losses of 20%-30%. While some rainfed bean, rice, maize, and soybean cultivation may also occur in this area, much of it is generally located farther inland and upland, where the modelling projects that a less pronounced increase in temperature combined with increased rainfall may result in yield increases for these crops.

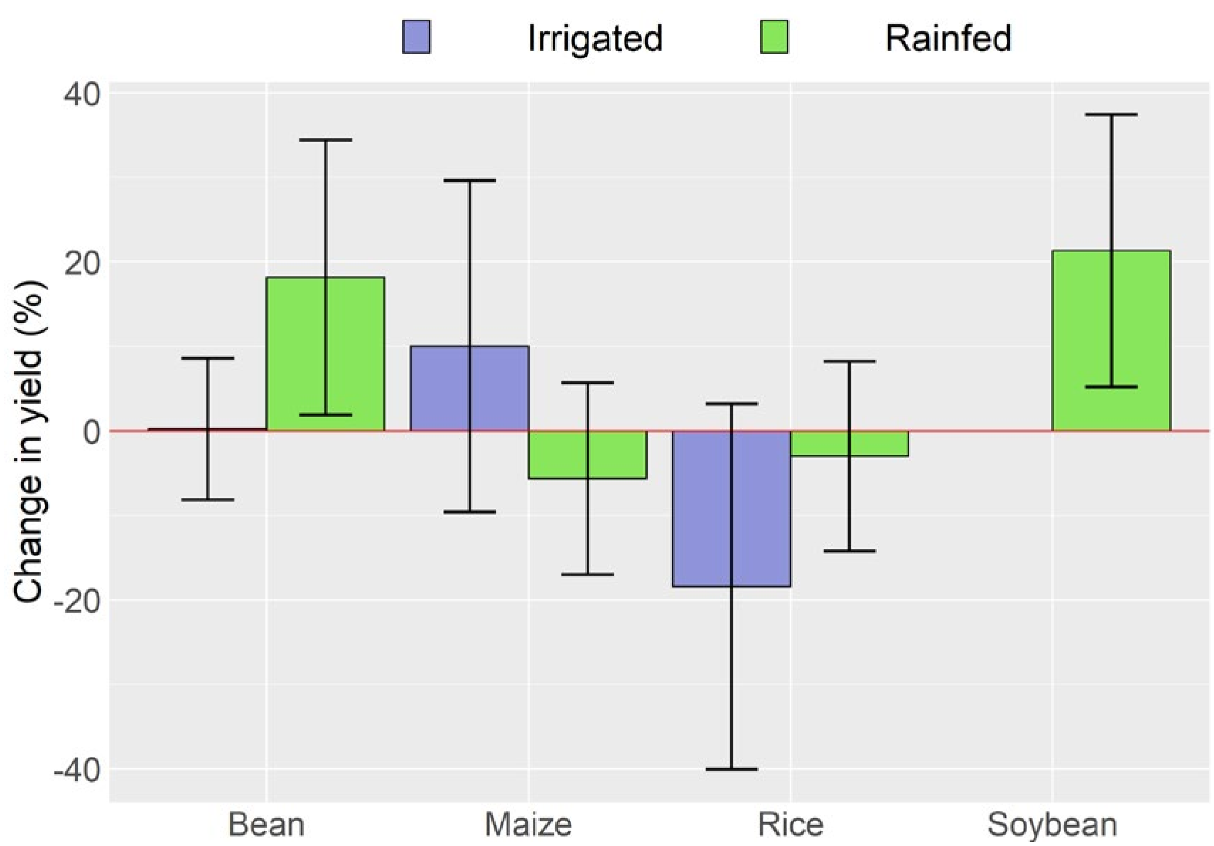

Figure 2: Projected average yield change, key crops (2020–2050). The error bars indicate the range of output across the nine climate models.

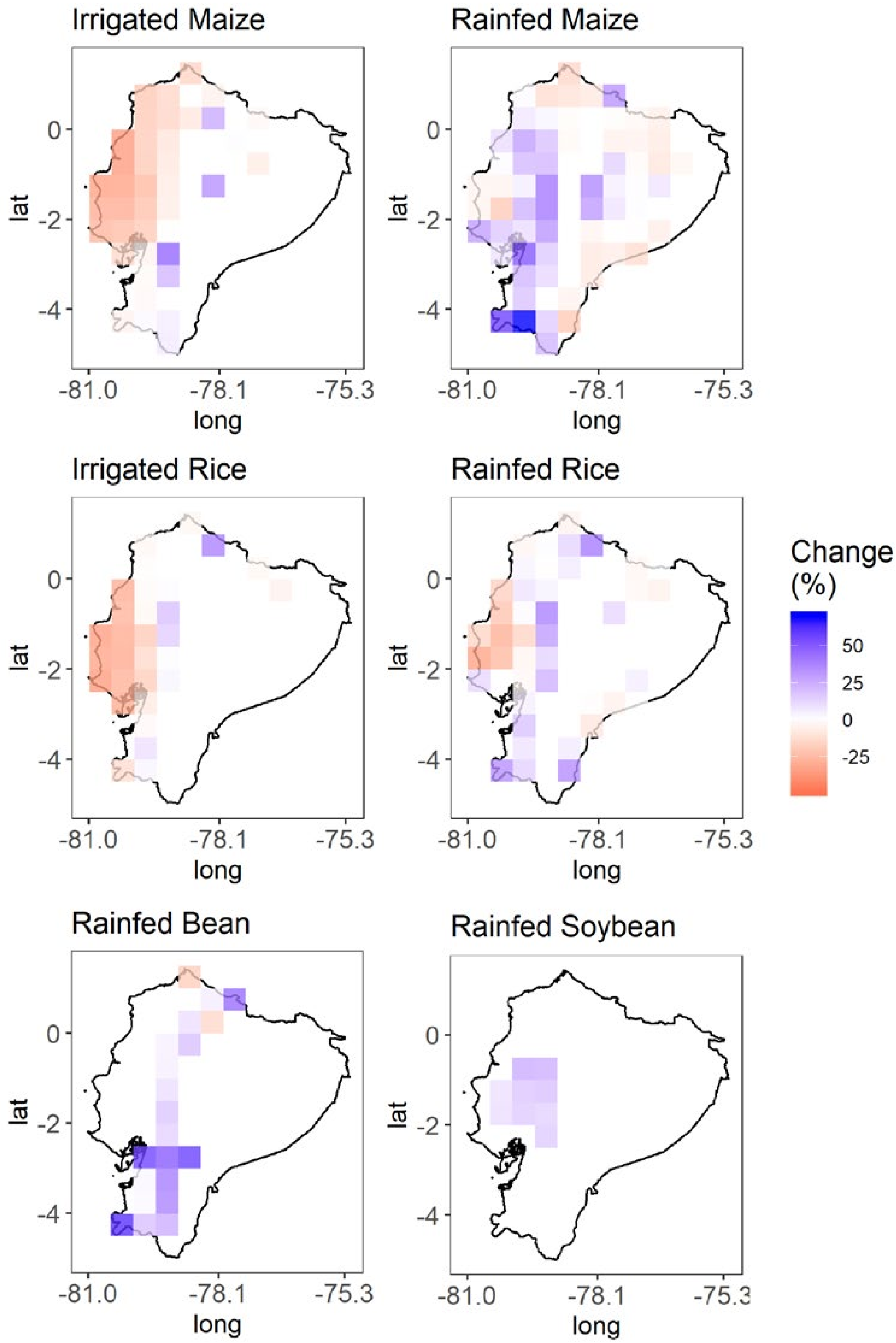

Figure 3: Projected yield impact maps, key crops (2020-2050).

Suitability

Climate change impacts on agro-ecological suitability for coffee (Robusta and Arabica), banana, yam, cassava, potato, and sugarcane were assessed using niche based models. In these models, "suitability" is defined based on how well local precipitation and temperature match the biophysical requirements of the given crop.

The modeling suggests that, on average, suitability for sugarcane, yam, and Robusta coffee may increase by 50.9%, 32.2%, and 100%, respectively. Suitable area for banana and Arabica coffee may decrease by 37% and 26%, respectively, while cassava and potato suitability remain more or less at their current levels. The geographically explicit suitability impact maps in Figure 5 reveal important variation hiding behind these averages. Widespread banana suitability loss is projected along the coastal plain, but note that a swath of area closer to the western Andean piedmont also becomes newly suitable. Increased sugarcane suitability is projected primarily in the coastal lowland areas where temperature increases are expected to be highest. Potato is projected to see suitability gains in the central Andean range, but losses to the north and south of that.

Cassava and yam, meanwhile, exhibit considerable resilience, with projected suitability gains at lower elevations to the west and northeast of the Andes, particularly in the areas where temperature increases are projected to be most severe. Yams and cassava are not currently produced in Ecuador in significant quantities, but this potential resilience in the face of climate change may position them as attractive alterntative sources of carbohydrates and nutrients, especially considering the sharp yield decreases projected for irrigated maize and rice in Figures 2 and 3.

Arabica and Robusta coffee suitability impacts maps are presented in Figure 6. Note that much of the projected decrease in suitability occurs in tropical forest and other low lying areas which are already inapt for coffee cultivation. Increases in suitability, on the other hand, are projected at higher elevations in the Andes. The remarkable doubling of suitable area projected for Robusta coffee is attributable to these extensive highland regions.

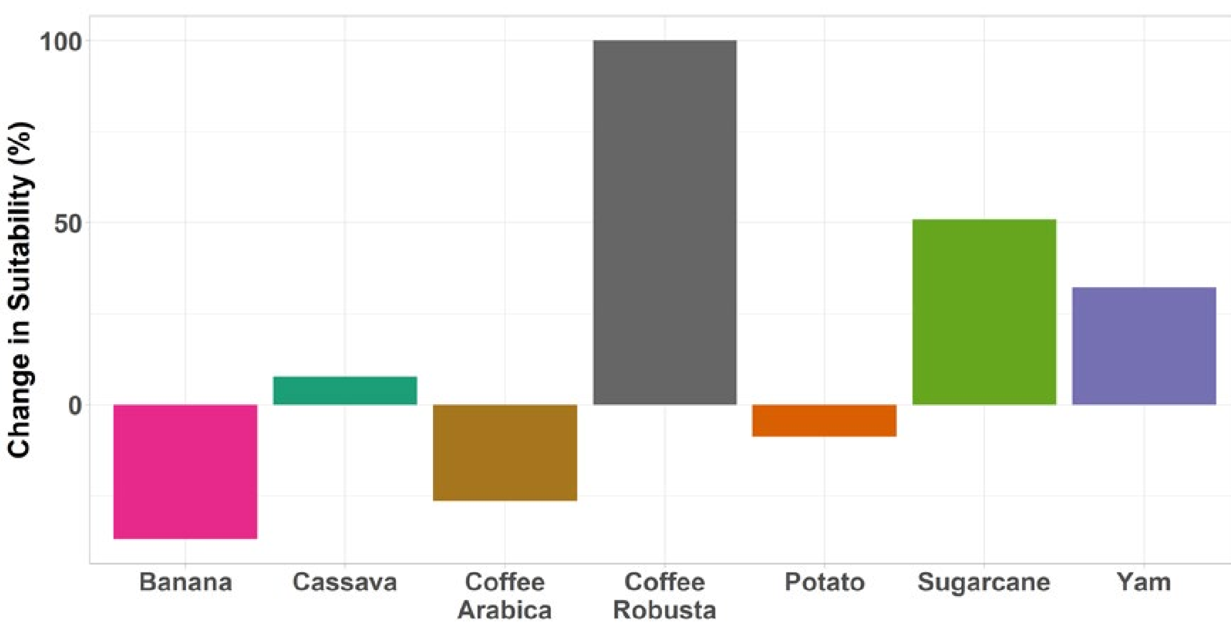

Figure 4: Projected change in suitability for key crops (2020-2050).

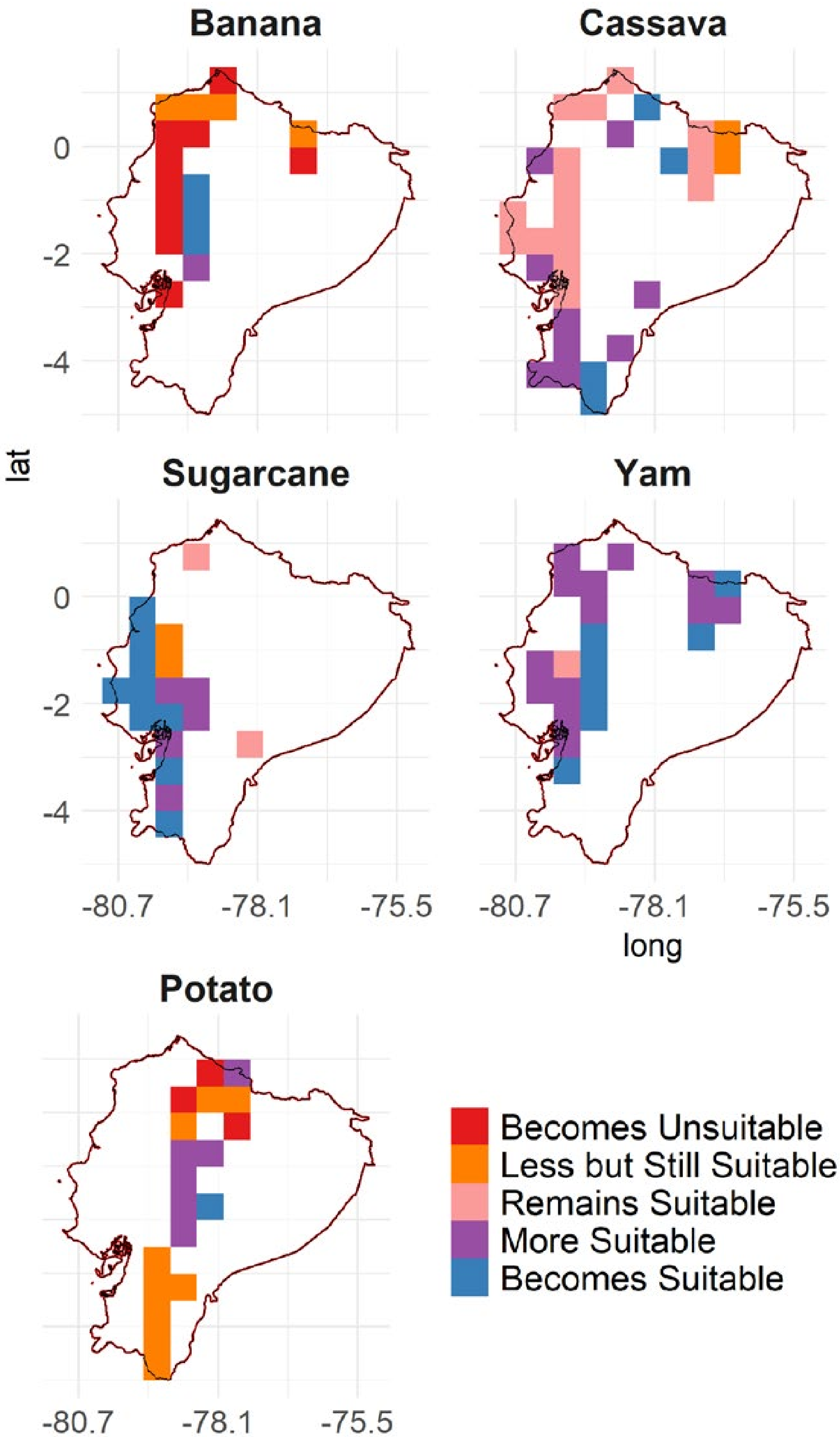

Figure 5: Projected suitability impact maps (2020-2050).

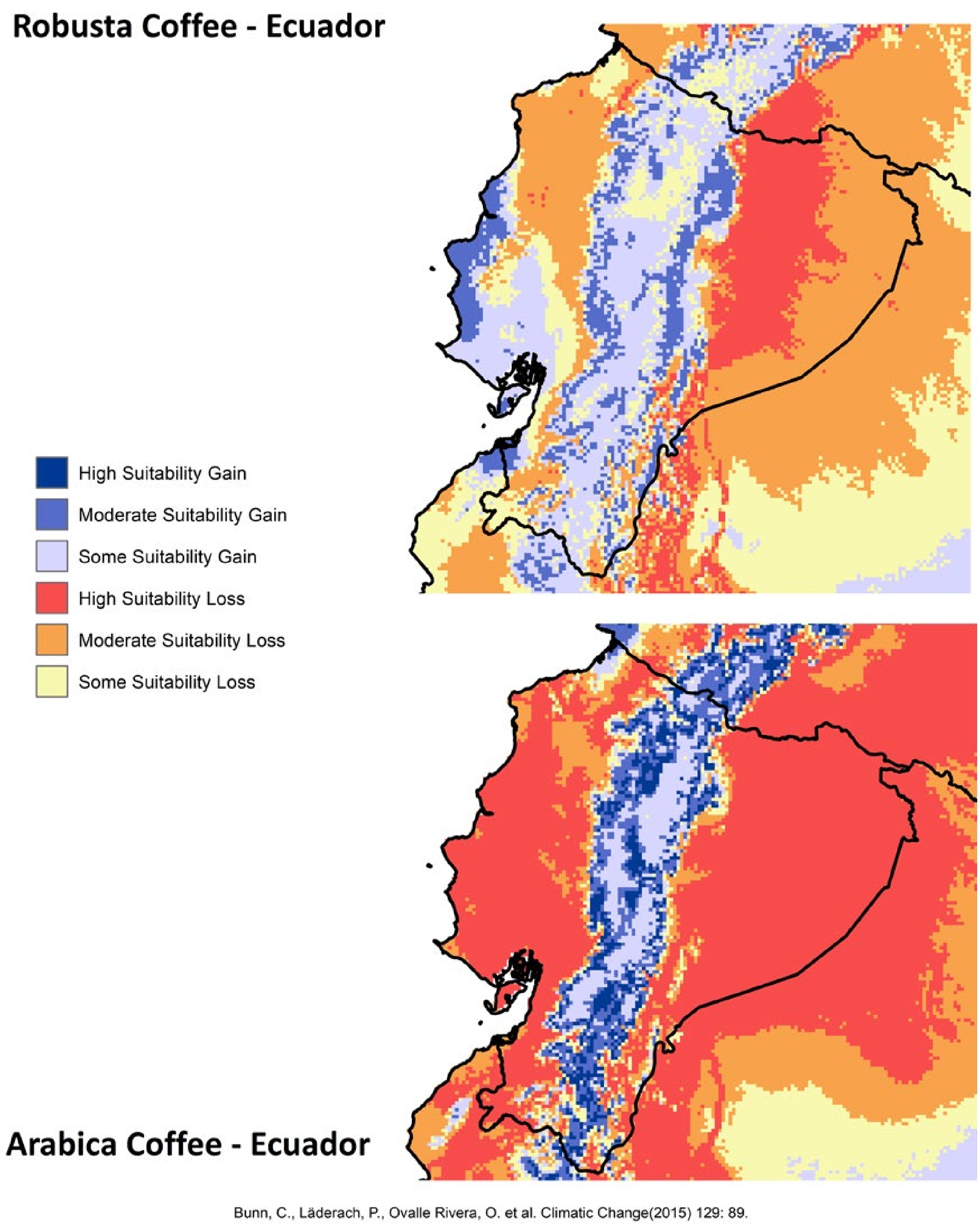

Figure 6: Projected change in suitability for coffee by 2050.

4. Economic impacts

In order to understand the real impacts of climate change on demand, supply, and international trade flows, the purely biophysical impacts addressed in the sections above must be adjusted for the economic agency of farmers who can adapt to yield and suitability loss by switching to alternative cultivars and practices. Ongoing advances in productivity and yield enhancing agricultural research, as well as the mitigating action (or inaction) of governments on emissions policy, must also be taken into consideration. The interplay of these factors was modeled using the International Model for Policy, Agricultural Commodities, and Trade (IMPACT), developed at the International Food Policy Research Institute. In this section, IMPACT projections are presented for the DSSAT modeled crops, accounting for global economic and climate change contexts of these crops as well as their substitutes.

In Ecuador, total agricultural production is projected to increase by 2050 under both CC and No-CC scenarios for all modeled crops except rice, which exhibits a significant decline in production (Figure 7). Rainfed bean production growth is especially pronounced, and may be even greater under climate change, surpassing the No-CC benchmark by 6.1 pp. The introduction of climate stressors may also have a positive impact on maize production (+9.2 pp), but a negative impact on rice production (-7.8 pp), and a comparatively slight impact on soybean (+1.9 pp) and wheat (-2.1 pp) production growth. Turning to trade in Figure 8, Ecuador is projected to continue running a trade deficit in all of these key crops except for bean out to 2050 under both CC and No-CC scenarios. However, CC is projected to aggravate the rice deficit while offsetting the maize deficit to some degree.

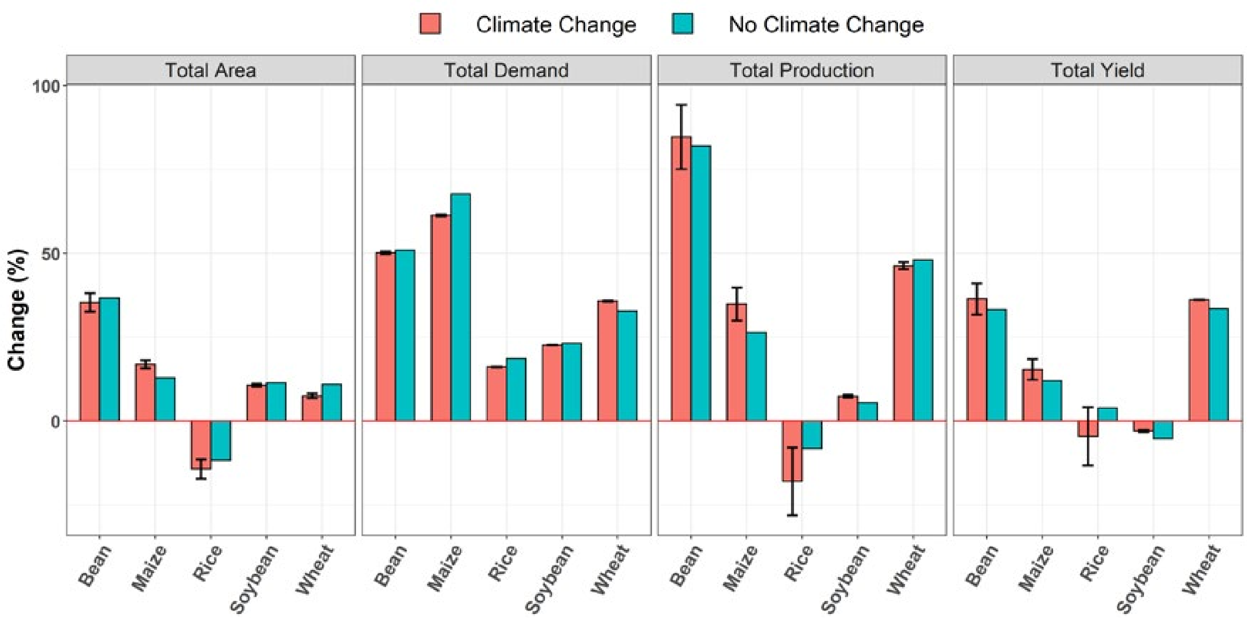

Figure 7: Percentage change in yield, demand, cultivated area, and production (2020–2050), when economic context and agricultural research are taken into account. The error bars indicate the range of output across the nine climate models.

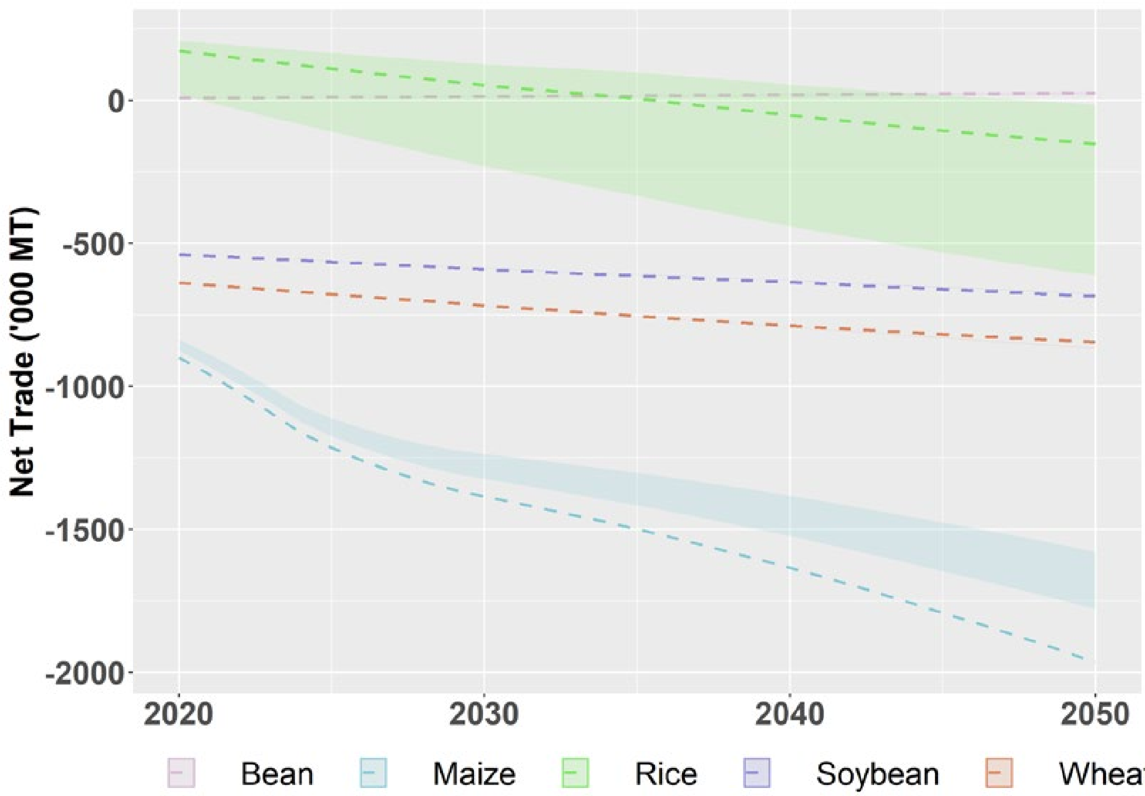

Figure 8: Climate change impact on trade. The dotted lines indicate the no climate change (No-CC) trajectory while the shaded areas correspond to the range of climate change (CC) trajectories given by the nine climate models.

5. The way forward

To limit the rise in global mean temperature below 2 °C and ensure food security, most climate change pledges of the United Nations Framework Convention on Climate Change (UNFCCC) cite agriculture and land use as key elements for climate action [3]. In fact, Ecuador's Nationally Determined Contribution (NDC) to the 2015 Paris Agreement includes explicit agricultural adaptation and mitigation actions such as climate smart livestock production, research and information systems to mainstream climate change in the agricultural sector, and promotion of sustainable practices [4].

Ecuador and other LAC countries in may be able to reduce the impact of climate change on the agricultural sector by adopting other climate smart agricultural (CSA) practices that increase productivity while reducing greenhouse gas (GHG) emissions and adapting to shifting growing conditions. This may include the continued expansion of no-till agricultural practices, precision nutrient management fertilizer, intercropping, and more advanced crop rotations.

Increased trade and productivity in the face of yield declines and faltering suitability for both domestic food security and export-oriented crops will require continued investment in agricultural research, robust communication between farmers and market intermediaries, and responsible land management and planning. Given the especially severe production losses in tropical Latin America, Ecuador will increasingly rely on trade with more temperate zones of the world, including the Southern Cone, to ensure domestic food security. Political and financial market stability will be key to ensuring that these potential opportunities are realized. Key messages for policy interventions and way forward for adaptation measures are summarized below.

Table 2: Key messages for policy interventions

<table>
<tr><th colspan="2">Table 2: Key messages for policy interventions</th><th>Way forward</th></tr>
<tr><td>Climate</td><td>Key Climate Observations
• Maximum temperatures are projected to increase by 1–4 °C by 2050. Warming will be most pronounced on the Pacific coast.
• Increased rainfall is projected across the country by 2050, especially during the December–February period.
• Climate change presents significant risk to crop yields and the broader economic performance of the agricultural sector in Ecuador. El Niño flooding and drought events and decreased glacial melt will continue to negatively impact production.</td><td rowspan="2">Adaptation measures are key mainly those that have the potential to increase productivity while mitigating climate change. Main activities should focus on:
• Agricultural practices (i.e. crop diversification, CSA, use of improved varieties, no-till, intercropping, precision nutrient management, and integration of indigenous knowledge)
• Forest, land and water management
• Increasing the efficiency in water use (i.e. expansion and/or rehabilitation of irrigation systems)
• Develop mechanisms to inform and orient CC adaptation policy at departmental and municipal levels.
• Climate services and seasonal agro-climatic forecasts.
• Agricultural research:
» Conduct necessary analyses to identify and prioritize CC adaptation
» Assessment of drought and heat tolerant maize and rice varieties for irrigated cultivation along the coastal plains
» And/or assessment of alternative crops more suited to the higher coastal temperatures, such as sugar cane, to replace maize and rice systems as their yields decline
» Conduct ex ante impact assessments on potential technologies, with an emphasis on coffee, rice, and banana.
» Assessment of CC resilient crops like yam and cassava as alternative sources of carbohydrates and nutrients.</td></tr>
<tr><td>Agriculture</td><td>Key Agriculture Observations
• Irrigated maize and rice yields projected to decrease sharply due to their location in Manabi and Guayas, where temperature increases are most severe. Irrigation of current cultivars alone may thus not be sufficient to confront CC.
• Rainfed maize, rice, bean, and soybean yields projected to increase, due their location farther inland and upland, where rainfall is projected to increase and temperature increases are less pronounced.
• Conditions for banana – a key export – may become substantially less suitable by 2050 under climate change, with some notable exceptions in Bolívar and Cotopaxi provinces.
• Yam and cassava exhibit CC resilience, with stable or increased suitability in areas where projected temperature increases are most severe.
• Low lying areas become completely unsuitable for Robusta and especially Arabica coffee cultivation, but this is compensated by extensive mountainous regions where conditions become suitable.</td></tr>
</table>

References:

[1] The World Bank. 2018. World Development Indicators. Washington, D.C., USA. **http://data.worldbank.org/indicator**

[2] FAO; IFAD; UNICEF; WFP; WHO. 2017. The State of Food Security and Nutrition in the World 2017. Building resilience for peace and food security. Rome, FAO. **www.fao.org/3/a-I7695e.pdf**

[3] CCAFS. 2015. Info Note: Agriculture's prominence in the INDCs. https://cgspace.cgiar.org/rest/bitstreams/62364/retrieve. Detailed country information on agriculture in INDCs available at: **https://cgspace.cgiar.org/handle/10568/73255**

[4] Ministerio del Ambiente. 2017. Tercera Comunicación Nacional del Ecuador a la Convención Marco de las Naciones Unidas sobre el Cambio Climático. **http://bit.ly/32RagkO**

X. El Salvador

1. Context

Agriculture plays an important but declining role in El Salvador. The sector accounts for 5.8% of GDP, down 1.5 percentage points (pp) from a peak of 7.3% in 2011. Crop products accounted for 25.9% of all exports in 2015, up 11.4 pp from 2006. Jobs in agriculture account for 18.8% of all employment in the country, down 2.1 pp from 8 years ago [1]. Coffee is the main agricultural export, accounting for over 50% of the country's crop exports, destined primarily for the United States. Sugar cane is also increasing in importance as a commercial export. Maize and bean systems, primarily rainfed, struggle to meet domestic dietary demand. El Salvador imports most of its maize from the U.S. [2]. Even so, approximately 12.3% of the population of El Salvador is undernourished, up from 10.7% a decade earlier; and this is above the average of 8.3% for Central America as a whole [3]. Deforestation and soil erosion is widespread, disproportionately impacting farmers in the hilly and mountainous regions in the country's interior [4]. El Salvador is located in the path of tropical storms, as well as in the middle of the drought prone Dry Corridor. The agricultural sector is thus already at a disadvantage in this regard, and is projected to come under increasing pressure in the coming years due to climate change and increased climate variability [5]. A better understanding of the climate change impacts on specific crops will hence assist in decision making. For this purpose, climate, crop, and economic modeling results are presented in this brief (averaged over 2020–2050), regarding agricultural production and trade in the country, set in the LAC regional context. Based on these trends, adaptation measures are proposed at the end of the brief.

2. Climate impacts

In assessing future climate impacts, this study utilized nine general circulation models (see Methodological Summary for detail) selected for their strong performance in the LAC region. Overall, temperatures are predicted to increase by 1-4 °C across the LAC region, with the Caribbean and tropical South America projected to warm at higher rates than Mexico and the Southern Cone.

In El Salvador, the impact of climate change on rainfall patterns varies considerably by season (Figure 1). A decrease in rainfall is projected across the country during the June to August rainy period, while an increase in rainfall is projected during the September to November period, and in the southeast during the December to February period. Both maximum and minimum temperatures in El Salvador are projected to rise between 1 and 3°C. The projected increase in maximum temperatures is especially pronounced along the coast during September to November, while the increase in minimum temperatures is more pronounced during December to February.

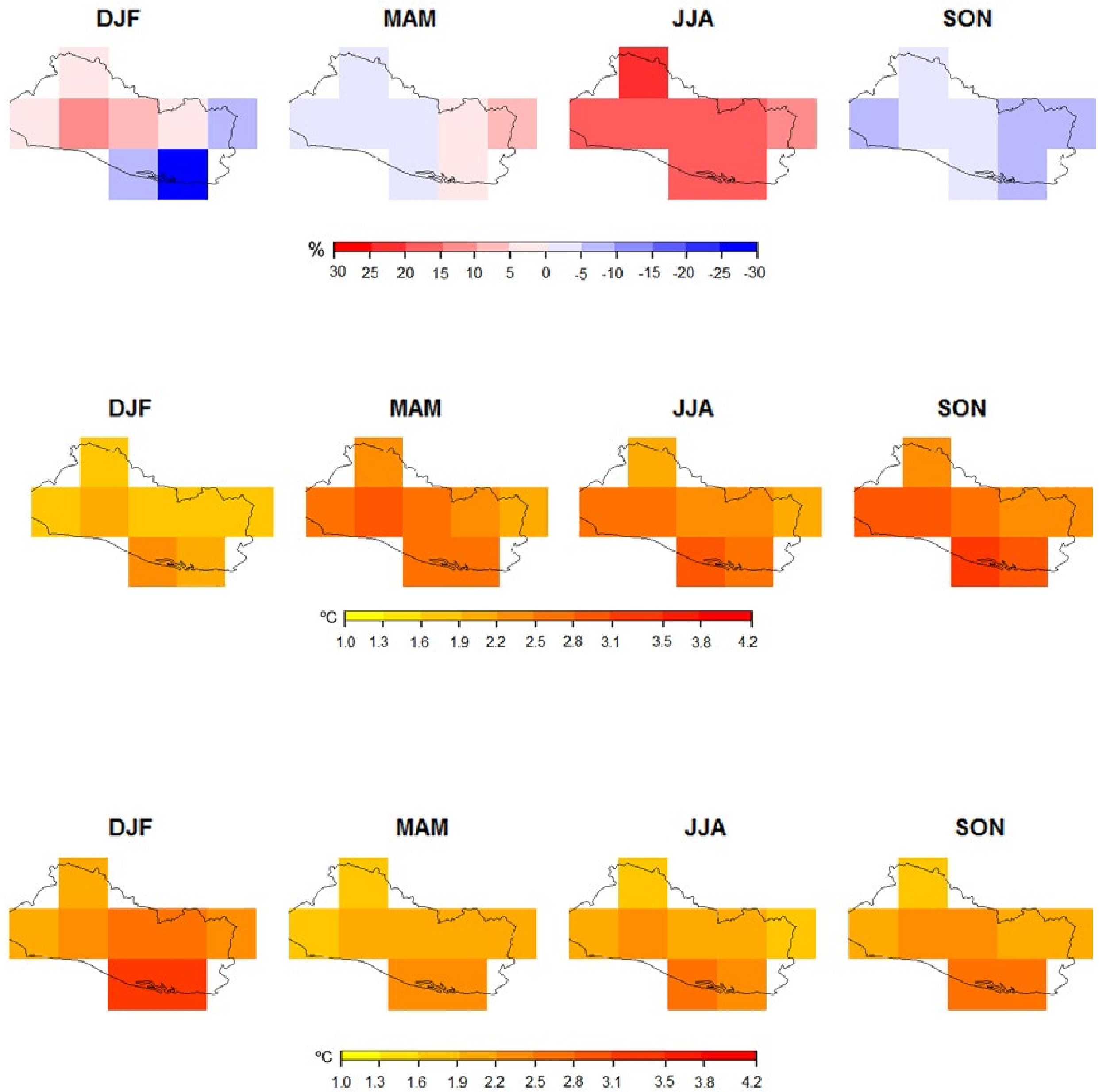

Figure 1: Change in (top to bottom) precipitation, maximum temperature, and minimum temperature averaged across nine GCMs (2020-2050). DJF= December - February, MAM= March - May, JJA= June - August, SON= September - November.

3. Yield and suitability impacts

Yield

Based on the projected changes in climate discussed above, 2050 projections of maize, rice, and bean yields were modeled using the Decision Support System for Agrotechnology Transfer (DSSAT v4.5) at 0.5 degree spatial resolution. Model runs for each crop were parameterized using genetic coefficients of varieties carefully selected by experts for their relevance in the region.

In El Salvador, yield modeling suggests that higher temperatures are likely to take a toll on rainfed bean and maize cropping systems, with yield declines of 31% and 24%, respectively (Figure 3). Irrigated maize bean and maize systems are projected to fare relatively better, with yield declines of 23% and 3%, respectively. Rainfed and irrigated rice, meanwhile, is projected to see slight yield increases under the changed climatic conditions.

The geographically explicit yield impact maps in Figure 3 indicate that there is important variation hiding behind these national averages. Projected maize yield declines are concentrated in the southeast, especially along the Pacific coast; whereas maize yields to the north and west are relatively unaffected, with some areas even projected to see a yield increase. Projected yield declines for rainfed bean are especially severe in the southeast, whereas climate change impacts on irrigated bean yield are projected to be most severe in the western half of the country. The projected yield increase for both rainfed and irrigated rice is uniformly spread across the country, with the exception of the southeast, where a yield decrease is projected.

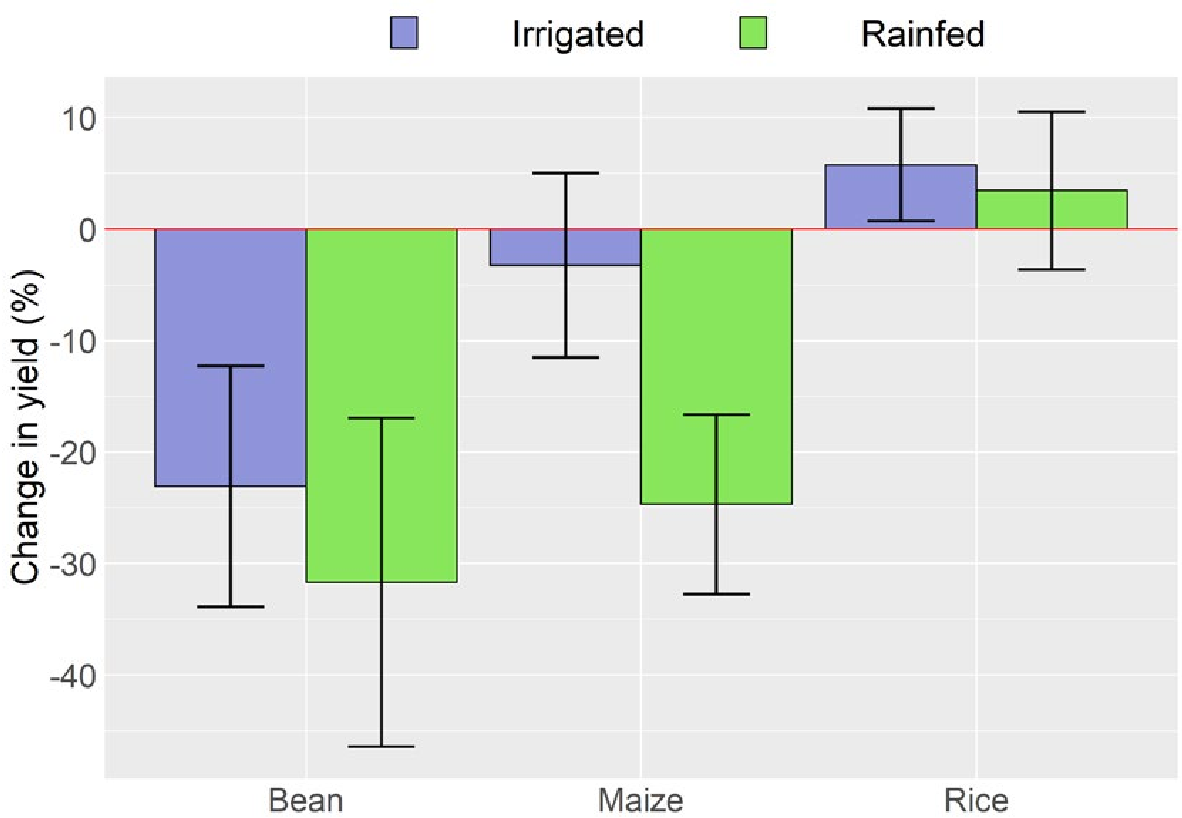

Figure 2: Projected average yield change, key crops (2020–2050). Thve error bars indicate the range of output across the nine climate models.

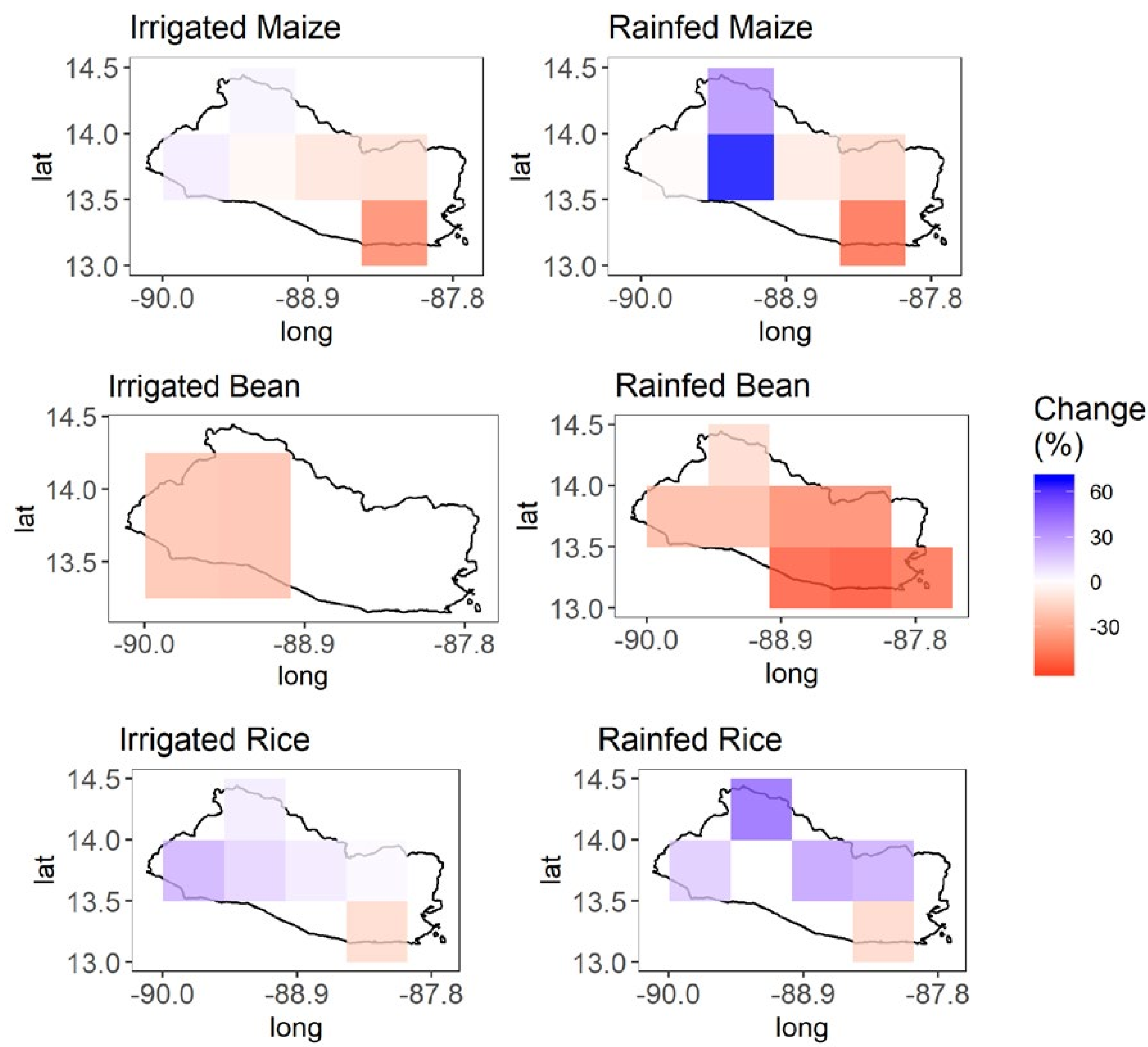

Figure 3: Projected yield impact maps, key crops (2020-2050).

Suitability

Climate change impacts on agro-ecological suitability for key commercial and staple crops, including coffee (Robusta and Arabica), banana, and sugarcane, were assessed using niche based models. In these models, "suitability" is defined based on how well local precipitation and temperature match the biophysical requirements of the given crop.

In El Salvador, suitability modeling suggests that areas suitable for the cultivation of banana, Arabica coffee, Robusta coffee, and sugar cane may decrease by 61%, 77%, 47%, and 18%, respectively (Figure 4). The geographically explicit suitability impact maps in Figure 5 indicate that these changes in suitability may be more pronounced in some areas than in others.

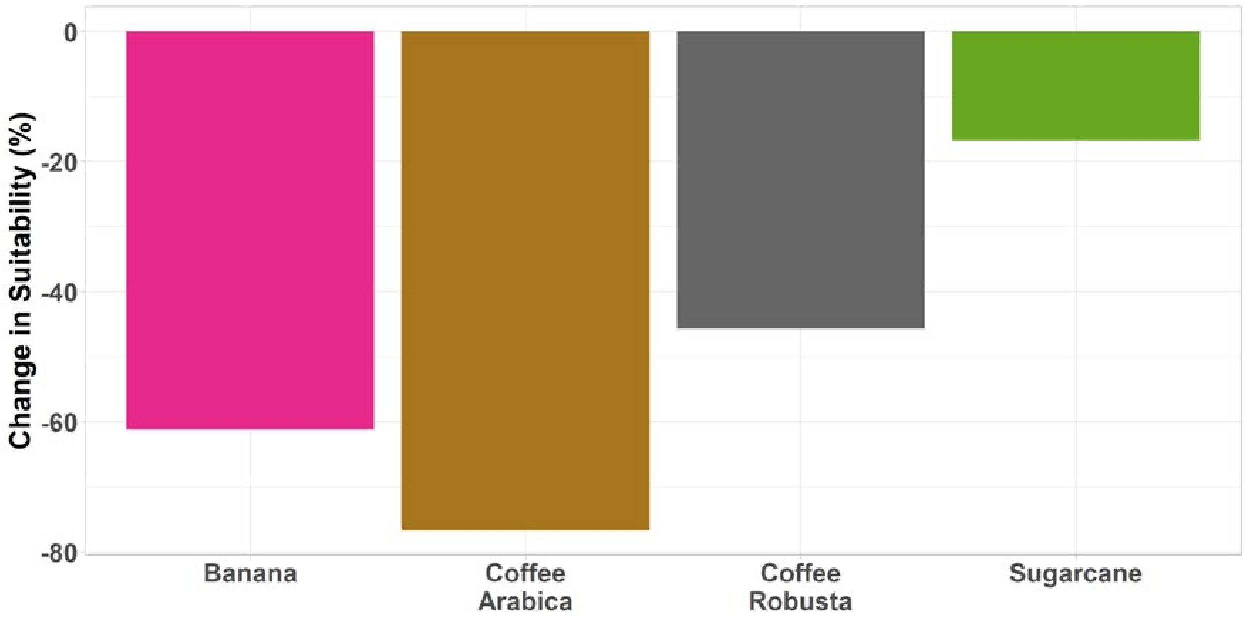

Figure 4: Projected change in suitability for key crops (2020-2050).

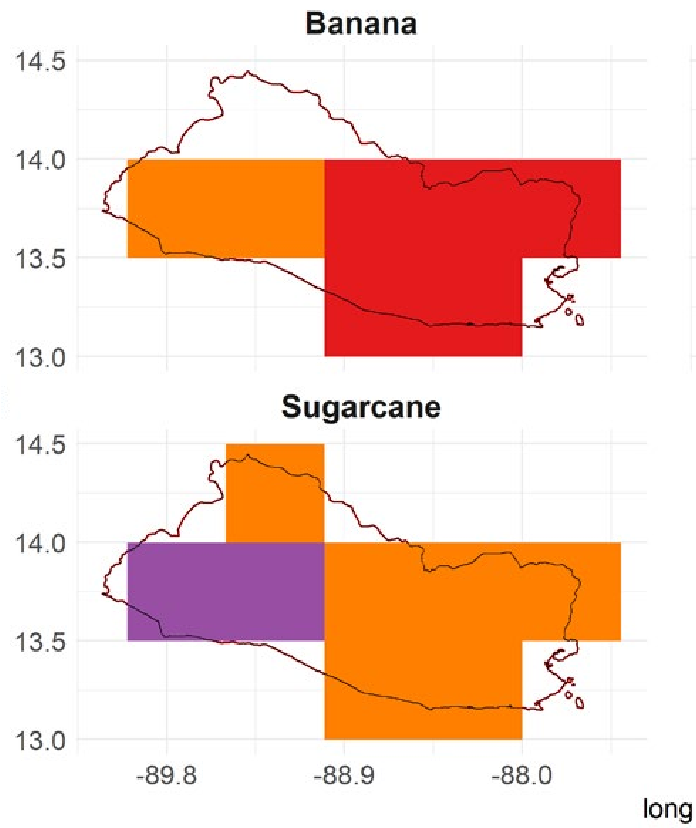

Figure 5: Projected suitability impact maps (2020-2050).

The eastern half of the country is projected to become completely unsuitable for banana cultivation, although banana cultivation may still be suitable in the west. However, this area is also projected to become more suitable for sugar cane cultivation, so banana and sugar cane producers may find themselves competing for land in this region. Cassava suitability, meanwhile, is projected remain unaffected across most of the country. Cassava is not currently grown in El Salvador in significant quantities, but this resilience in the face of climate change may make it an attractive alternative source of carbohydrates and nutrients, especially considering the projected maize yield declines seen in Figures 2 and 3. Finally, areas suitable for Robusta and Arabica coffee production are projected to decline sharply throughout the country, except, perhaps, in a small pocket at the eastern frontier with Honduras (Figure 6).

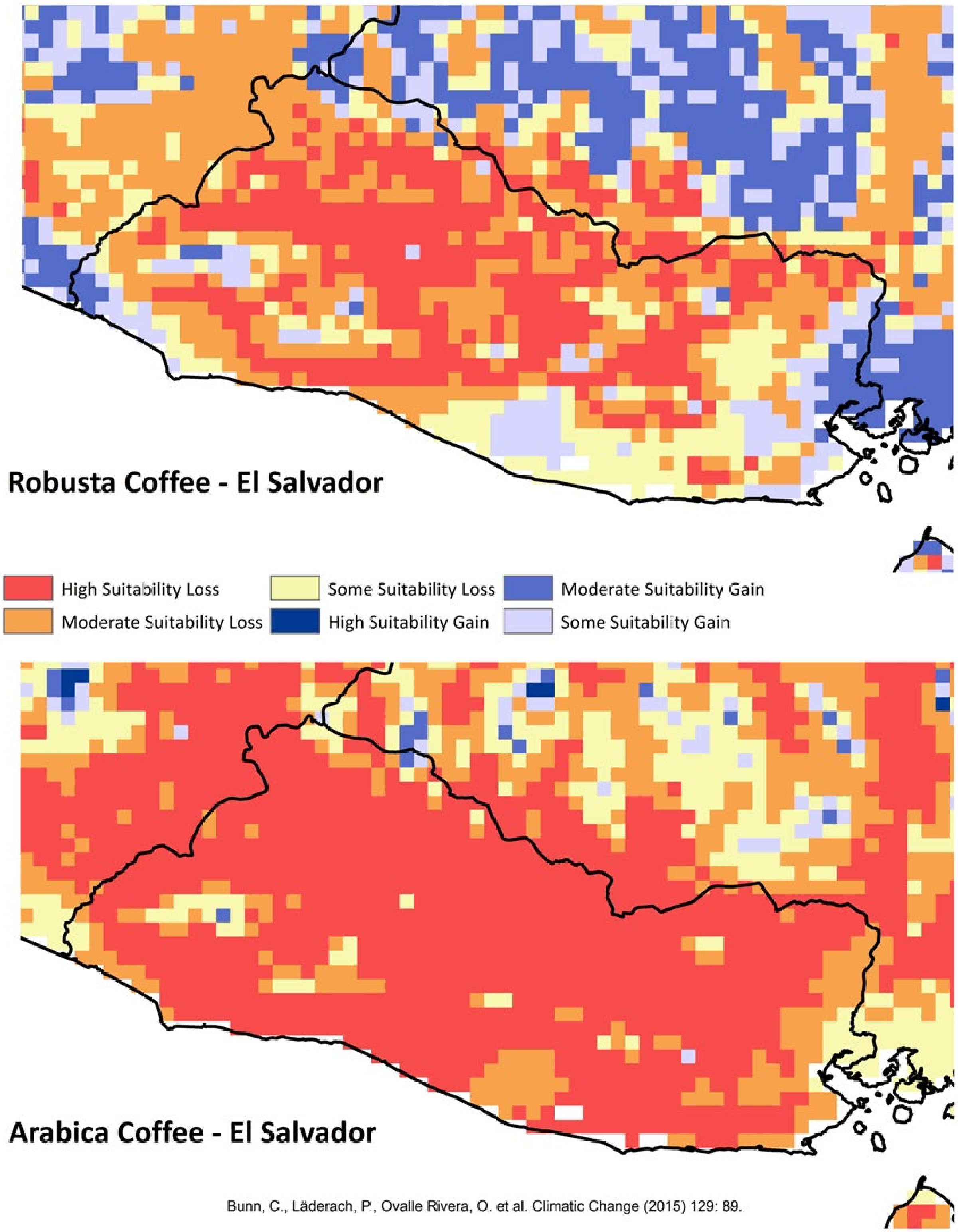

Figure 6: Projected change in suitability for coffee by 2050.

4. Economic impacts

In order to understand the real impacts of climate change on demand, supply, and international trade flows, the purely biophysical impacts addressed in the sections above must be adjusted for the economic agency of farmers who can adapt to yield and suitability loss by switching to alternative cultivars and practices. Ongoing advances in productivity and yield enhancing agricultural research, as well as the mitigating action (or inaction) of governments on emissions policy, must also be taken into consideration. The interplay of these factors was modeled using the International Model for Policy, Agricultural Commodities, and Trade (IMPACT), developed at the International Food Policy Research Institute. In this section, IMPACT projections are presented for the DSSAT modeled crops, accounting for global economic and climate change contexts of these crops as well as their substitutes.

In El Salvador, the economic modelling suggests that yields and production may increase out to 2050 under both CC and No-CC scenarios for the modeled crops (Figure 7). Bean and maize production growth is especially pronounced. However, the introduction of climate stressors may have a severe negative impact on bean production, cutting its growth by 55.6 pp below the No-CC benchmark. The CC impact on maize production is comparatively slight (-1.5 pp), and rice may see a significant increase in production under such conditions (+10.8 pp). In Figure 8, bean and rice trade tendencies are projected to remain at current levels out to 2050 under both CC and No CC. However, the maize trade deficit is projected to grow. Under some of the GCMs, the projected deficit is less given CC than without it, perhaps because maize yield loss throughout the region due to CC levels the playing field as regards comparative advantage.

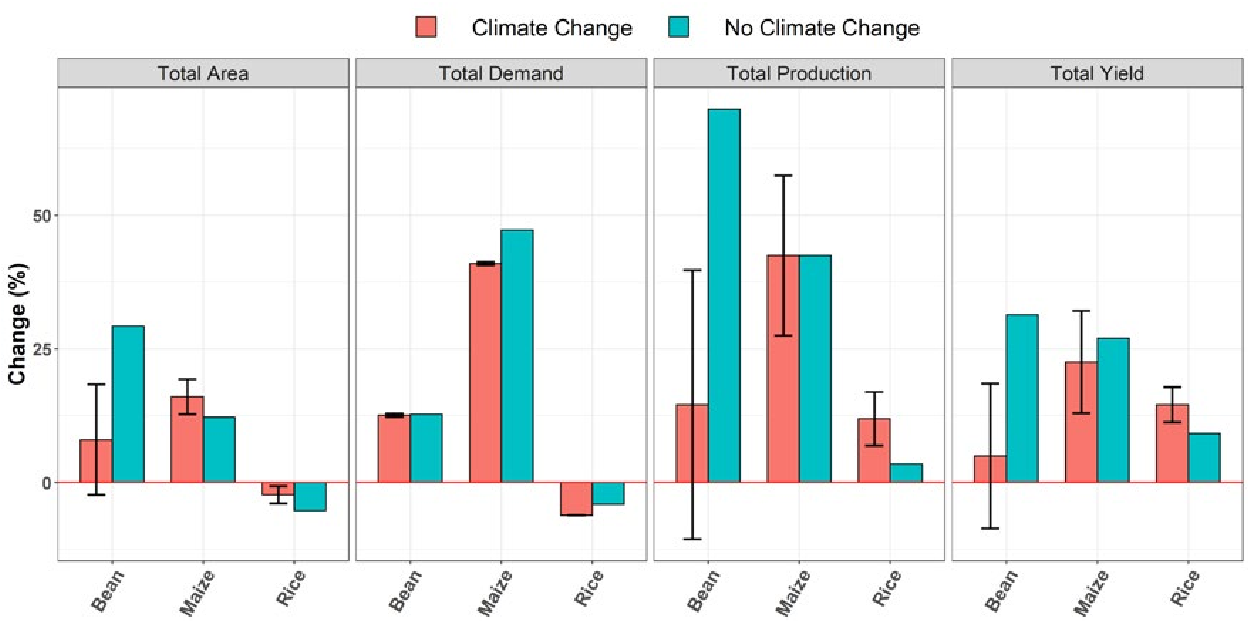

Figure 7: Percentage change in yield, demand, cultivated area, and production (2020–2050), when economic context and agricultural research are taken into account. The error bars indicate the range of output across the nine climate models.

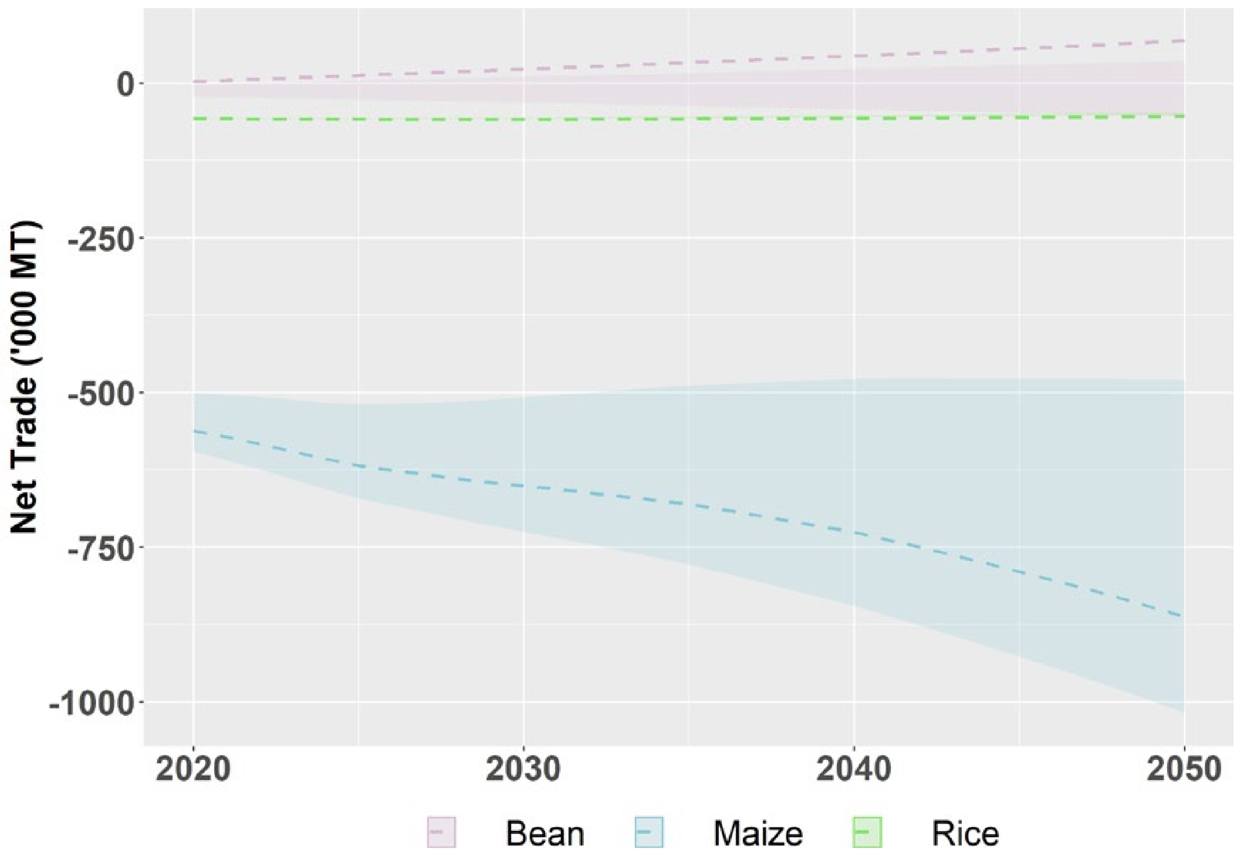

Figure 8: Climate change impact on trade. The dotted lines indicate the no climate change (No-CC) trajectory while the shaded areas correspond to the range of climate change (CC) trajectories given by the nine climate models.

5. The way forward

To limit the rise in global mean temperature below 2°C and ensure food security, most climate change pledges of the United Nations Framework Convention on Climate Change (UNFCCC) cite agriculture and land use as key elements for climate action. In fact, El Salvador's Nationally Determined Contribution (NDC) to the 2015 Paris Agreement recognizes the significant impacts of climate change (i.e. changes in precipitation and temperature) in the agricultural sector and prioritizes adaptation and mitigation actions to increase resilience and reduce emissions [6]. These measures include shifting away from traditional toward sustainable agriculture.

El Salvador and other LAC countries in may be able to reduce the impact of climate change on the agricultural sector by adopting other climate smart agricultural (CSA) practices that increase productivity while reducing greenhouse gas (GHG) emissions and adapting to shifting growing conditions. This may include the continued expansion of no-till agricultural practices, precision nutrient management fertilizer, intercropping, and more advanced crop rotations.

Increased trade and productivity in the face of yield declines and faltering suitability for both domestic food security and export-oriented crops will require continued investment in agricultural research, robust communication between farmers and market intermediaries, and responsible land management and planning. Given the especially severe production losses in tropical Latin America, El Salvador will increasingly rely on trade with more temperate zones of the world, including the Southern Cone, to ensure domestic food security. Political and financial market stability will be key to ensuring that these potential opportunities are realized. Key messages for policy interventions and way forward for adaptation measures are summarized below.

Table 2: Key messages for policy interventions

Table 2: Key messages for policy interventions		Way forward
Climate	Key Climate Observations • Temperatures are projected to increase by 1–3°C by 2050. Warming will be most pronounced in low-lying Pacific Coast region. • Reduced rainfall is generally expected across El Salvador during the current rainy season. In wetter areas, precipitation is likely to increase in both magnitude and frequency. • Increased tropical storm activity, together with an intensification of El Niño/ La Niña-induced droughts and flooding, pose a significant risk to crop yields and the broader economic performance of the agricultural sector in El Salvador.	Adaptation is key, particularly for many increase productivity and resistance of staple crops under conditions of while climate change. Main activities should focus on: • Agricultural practices (i.e. crop diversification, CSA, use of improved varieties, no-till, intercropping, precision nutrient management, and integration of indigenous knowledge) • Forest, land and water management • Increasing the efficiency in water use (i.e. expansion and/or rehabilitation of irrigation systems) • Develop mechanisms to inform and orient climate change adaptation policy at departmental and municipal levels. • Agricultural research: » Conduct necessary analyses to identify and prioritize CC adaptation research options » Conduct viability studies on crop diversification/rotation options. » Evaluate new agricultural technologies for heat and flood resistant crops. » Assess the viability of CC resilient crops like cassava as alternative sources of carbohydrates and nutrients.
Agriculture	Key Agriculture Observations • Substantial decrease projected for bean and maize yields, although less so for irrigated systems. • Modest increase projected for rice yield, more so for irrigated systems. • Projected yield losses especially severe in the southeast. • Areas suitable for banana and coffee (Arabica and robusta) cultivation are projected to decline sharply. • Areas suitable for sugarcane cultivation are projected to increase, especially in low-lying areas of the Sonsonate department along the coast. • The maize trade deficit is projected to increase.	

In an effort to limit the rise in global mean temperature below 2°C and ensure food security, most UNFCCC climate change pledges—177 of 189—cite agriculture and land use as a key source of adaptation and/ or mitigation potential [7]. El Salvador's Intended Nationally Determined Contribution (NDC) to the Paris Agreement indicates that the country will identify quantifiable goals for the transformation of its agricultural system prior to COP22. The NDC highlights efforts to improve the sustainability of its sugarcane production, reduce deforestation, and to develop a plan to transform agricultural production in the eastern part of the country. The NDC also highlights drip irrigation, no-burn production systems (especially for sugarcane), shading for coffee production, and improved livestock management systems. It also calls for the expansion of fruits and cocoa production less sensitive to temperature increases. Meanwhile, the country has already invested considerably in improved climate services, driven by an increase in the number of weather stations across the country. Agroforestry strategies are also currently widely implemented throughout El Salvador's coffee plantations. Other potential adaptation strategies in the country include crop diversification, improved water conservation, and improved livestock manure management including 'cut and carry' pasture systems [8]. These efforts have been guided by several key polices: agriculture is captured centrally in the country's National Environment Strategy and National Biodiversity Strategy, National Climate Change Strategy, the Climate Change Adaptation and Mitigation Strategy for Agriculture, Forestry and Fisheries, and the Family Agriculture Plan, among others.

El Salvador and other countries in Latin American may be able to reduce the impact of climate change on the agricultural sector by adopting other climate smart agricultural (CSA) practices that increase productivity while reducing greenhouse gas (GHG) emissions and adapting to shifting growing conditions. This may include the continued expansion of no-till agricultural practices, precision nutrient management (fertilizer), intercropping, and more advanced crop rotations. Increased trade and productivity in the face of yield declines and faltering suitability for both domestic food security and export-oriented crops will require continued investment in agricultural research, robust communication between farmers and market intermediaries, and responsible land management and planning. Given the especially severe production losses in tropical Latin America, El Salvador will increasingly rely on trade with more temperate zones of the world, including the Southern Cone, to ensure domestic food security. Importantly, the country has demonstrated a longstanding commitment to trade liberalization. El Salvador was the first country to ratify the Dominican Republic-Central American Free Trade Agreement. Political and financial market stability will be key to ensuring that these potential opportunities are realized. Key messages for policy interventions and a way forward for adaptation measures are summarized in Table 2.

References:

[1] The World Bank. 2018. World Development Indicators. Washington, D.C., USA. Available at: **http://data.worldbank.org/indicator**

[2] MIT Observatory of Economic Complexity. 2018. El Salvador Country Profile. **https://oec.world/en/profile/country/slv**/

[3] FAO, IFAD, UNICEF, WFP, WHO. 2017. The State of Food Security and Nutrition in the World 2017, Building resilience for peace and food security. **www.fao.org/3/a-I7695e.pdf**

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[5] USAID. 2017. Climate Risk Profile: El Salvador. Washington, D.C., USA. **http://bit.ly/3a6mo3g**

[6] Ministerio de Medio Ambiente y Recursos Naturales. 2018. Tercera Comunicación de Cambio Climático El Salvador. **http://bit.ly/2PzEe6R**

[7] CCAFS (2015). Info Note: Agriculture's prominence in the INDCs. https://cgspace.cgiar.org/rest/bitstreams/62364/retrieve. Detailed country information on agriculture in INDCs available at: **https://cgspace.cgiar.org/handle/10568/73255**

[8] World Bank; CIAT; CATIE. 2015. Climate-Smart Agriculture in El Salvador. CSA Country Profiles for Latin America Series. 2nd. ed. Washington D.C.: The World Bank Group.

XI. Guatemala

1. Context

Agriculture continues to play an important albeit declining role in Guatemala. The sector accounts for 10.1% of GDP, down 12.7 percentage points (pp) from a peak of 22.8% in 2000. Crop products accounted for 30.5% of all exports in 2017, up 2.7 pp from 2009. Jobs in agriculture account for 29.4% of all employment in the country, down 6.7 pp from 8 years ago [1]. Climate change impacts present significant risk to crop yields and the broader economic performance of the agricultural sector and the economy. In fact, tropical storms, hurricanes, droughts, and extreme rainfall are the major climatic threats currently facing Guatemalan agriculture. A better understanding of the climate change impacts on specific crops will hence assist in decision making. For this purpose, climate, crop, and economic modeling results are presented in this brief (averaged over 2020–2050), regarding agricultural production and trade in the country, set in the LAC regional context. Based on these trends, adaptation measures are proposed at the end of the brief.

2. Climate impacts

In assessing future climate impacts, this study utilized nine general circulation models (see Methodological Summary for detail) selected for their strong performance in the LAC region. Overall, temperatures are predicted to increase by 1-4°C across the LAC region, with the Caribbean and tropical South America projected to warm at higher rates than Mexico and the Southern Cone.

In Guatemala, rainfall is projected to decrease sharply across much of the country by 2050, in some areas by as much as 30%. The projected decrease is especially pronounced in the north during the June to August rainy season (Figure 1). Maximum and minimum temperatures, meanwhile, are projected to increase by 1-2.5°C across the country. Future agriculture in the country may thus have to contend with increasing heat and water stress simultaneously.

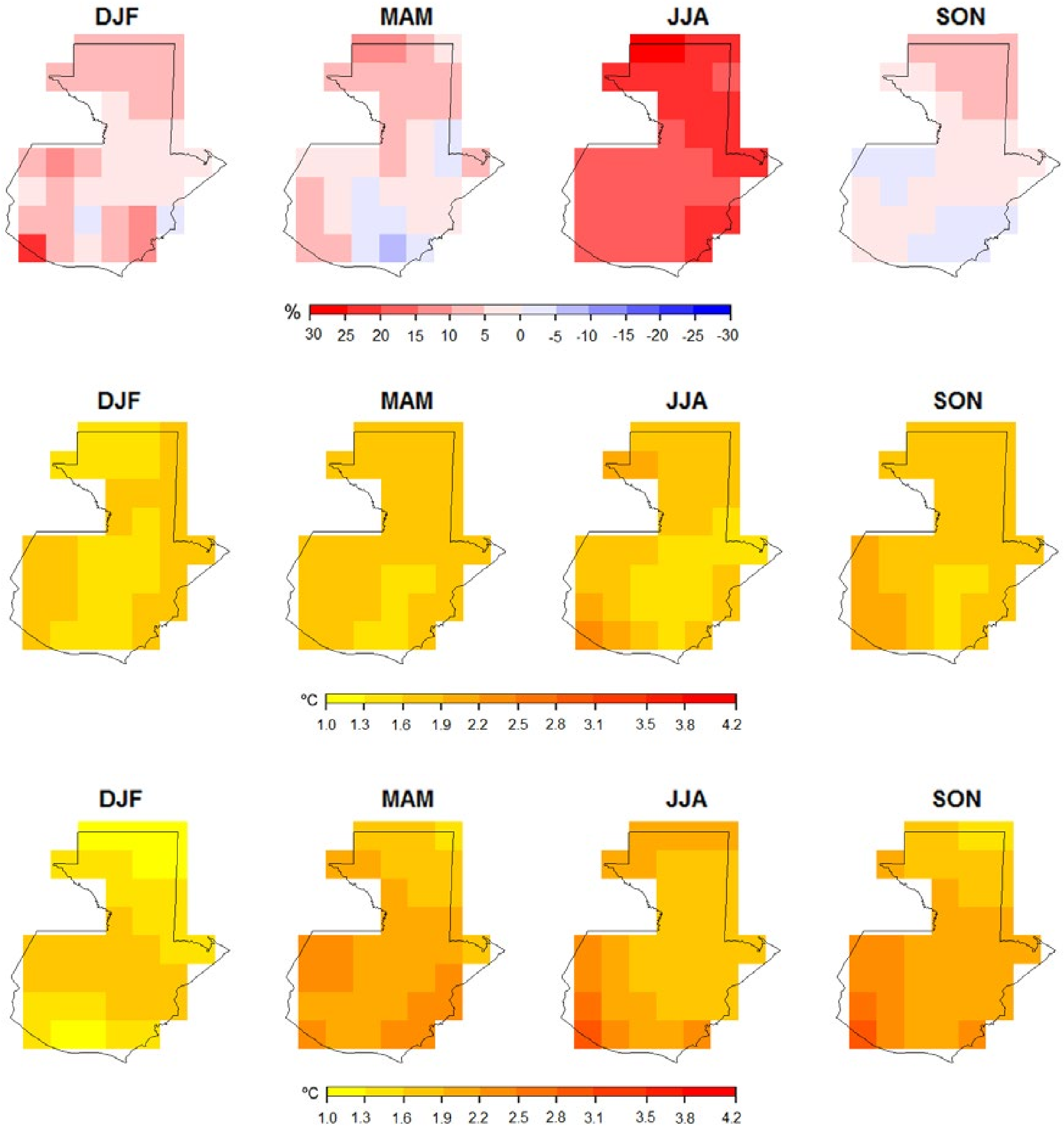


Figure 1: Change in (top to bottom) precipitation, maximum temperature, and minimum temperature averaged across nine GCMs (2020-2050). DJF= December - February, MAM= March - May, JJA= June - August, SON= September - November.

3. Yield and suitability impacts

Yield

Based on the projected changes in climate discussed above, 2050 projections of maize, rice, and bean yields were modeled using the Decision Support System for Agrotechnology Transfer (DSSAT v4.5) at 0.5 degree spatial resolution. Model runs for each crop were parameterized using genetic coefficients of varieties carefully selected by experts for their relevance in the region.

In Guatemala, maize yields are projected to decrease substantially across the country—by 20.2% for irrigated systems and 12.4% for rainfed systems, respectively (Figure 2). This suggest that irrigation alone may be insufficient to counteract the sharp decline in rainfall and higher temperatures seen in Figure 1. Rice yields, on the other hand, exhibit considerable resilience, with a projected yield increase of 38% on average. Bean yields also appear to exhibit some resilience, although the geographically disaggregated view presented in Figure 3 reveals that there is important variation hiding behind this national average. Note also that projected maize yield decreases are especially severe across the northern border and Pacific coastal areas, with highland areas less affected. Rice resilience is especially pronounced in the center of the country.

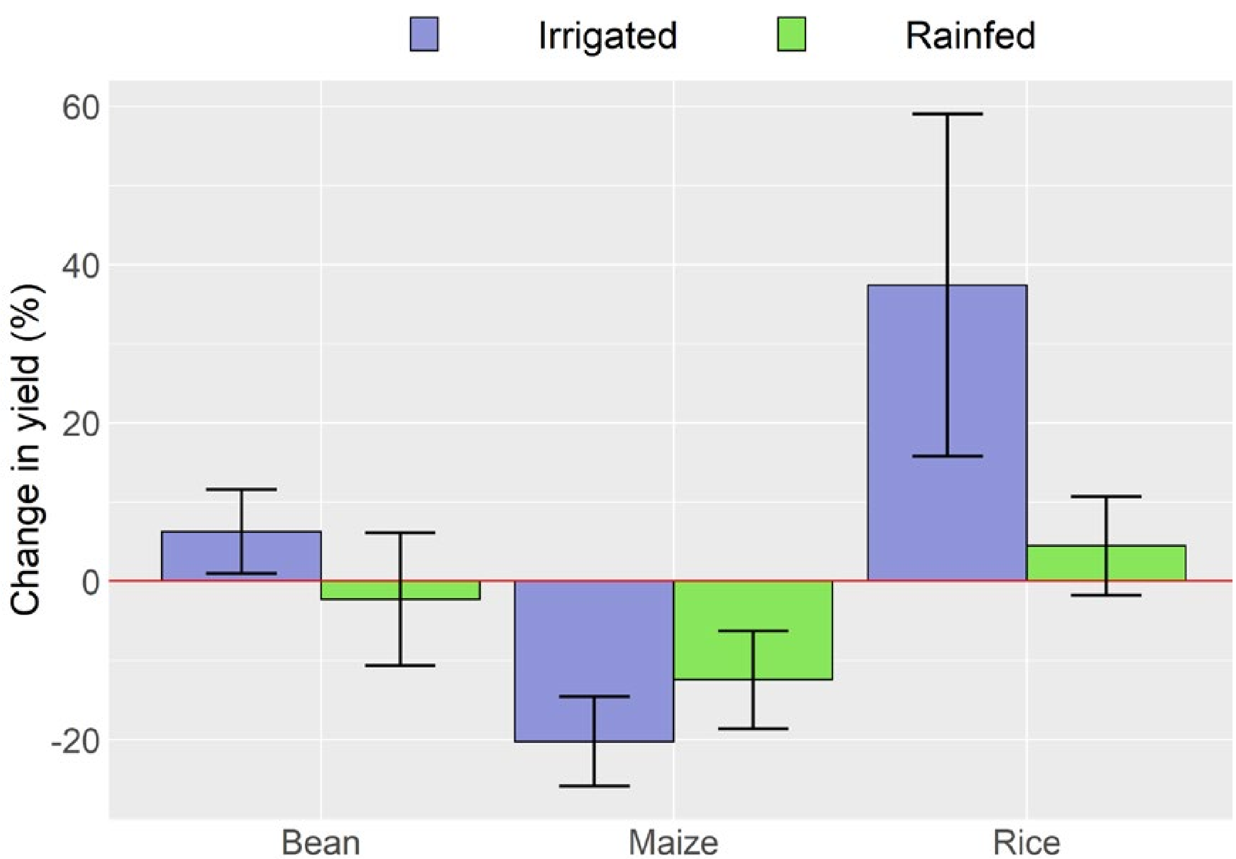


Figure 2: Projected average yield change, key crops (2020–2050). The error bars indicate the range of output across the nine climate models.

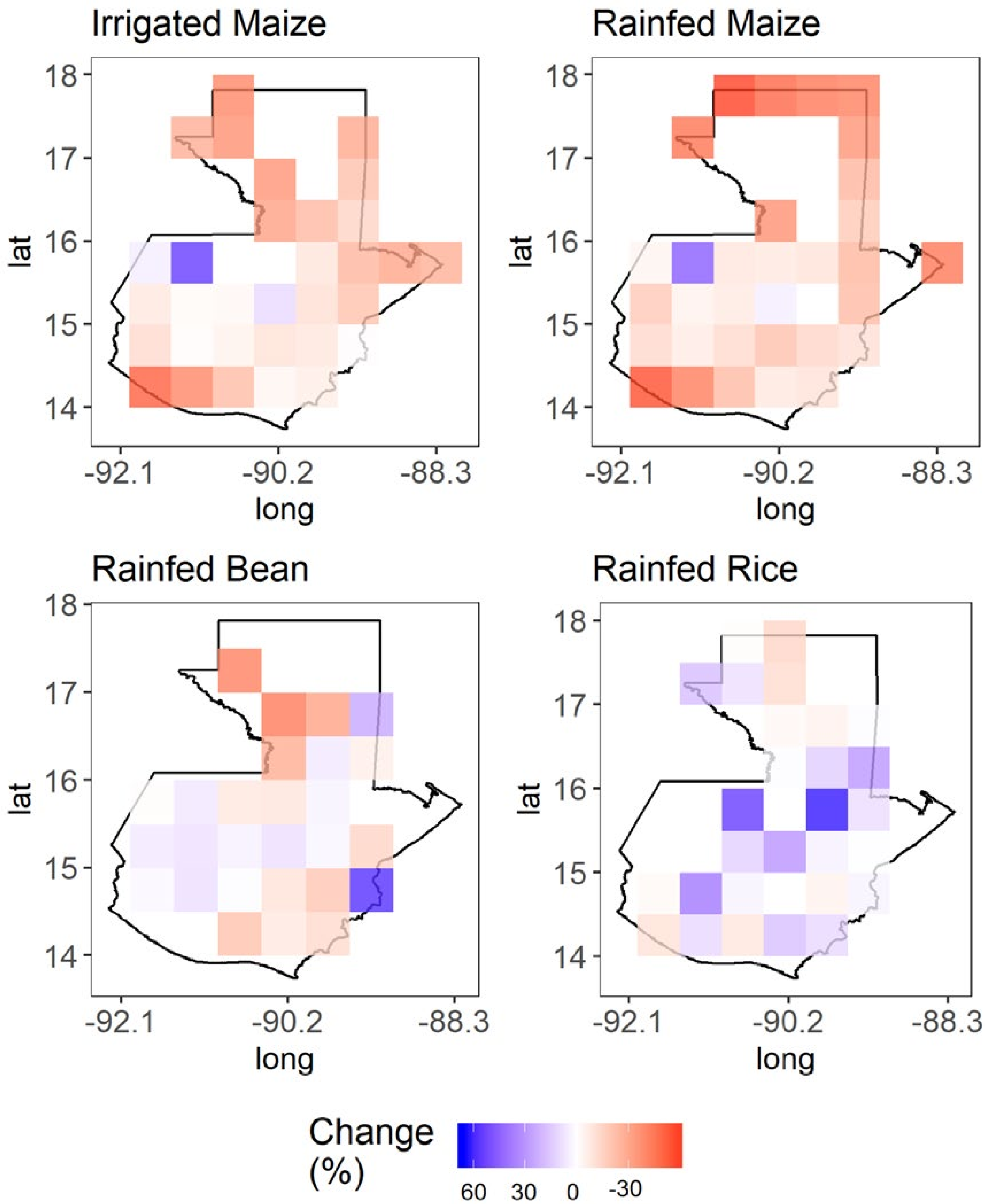


Figure 3: Projected yield impact maps, key crops (2020-2050).

Suitability

Climate change impacts on agro-ecological suitability for coffee (Robusta and Arabica), banana, cassava, potato, and sugarcane were assessed using niche based models. In these models, "suitability" is defined based on how well local precipitation and temperature match the biophysical requirements of the given crop.

The modeling suggest substantial decreases in areas suitable for banana, coffee (robusta and arabica), and potato by 2050 (Figure 2). Areas suitable for sugarcane and cassava, on the other hand, are projected to increase. However, the geographically disaggregated view in Figure 5 reveals important variation hiding behind these national averages. Projected banana suitability loss is concentrated in the north, although this is partly offset by two pockets of resilience and increased suitability in the southern half of the country. Meanwhile, sugarcane suitability is projected to increase in the northern areas where banana suitability declines. It is important to keep in mind that the north is heavily forested, and so expansion of the agricultural frontier in this area implies some degree of deforestation.

Potato suitability loss is concentrated in the highlands where it is currently grown. Cassava, on the other hand, exhibits remarkable resilience across the country. Cassava is not currently cultivated in significant quantities in Guatemala; but this potential resilience may make it an attractive alternative source of carbohydrates and nutrients, especially considering the sharp decrease in maize yields projected in 2050.

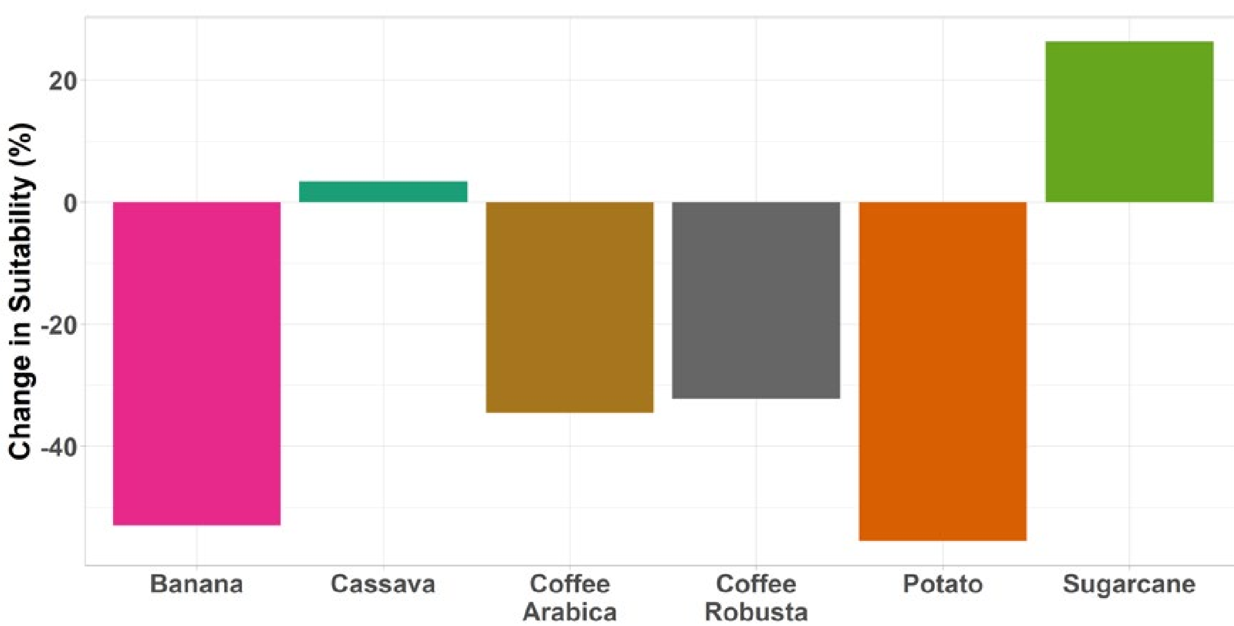


Figure 4: Projected change in suitability for key crops (2020-2050).

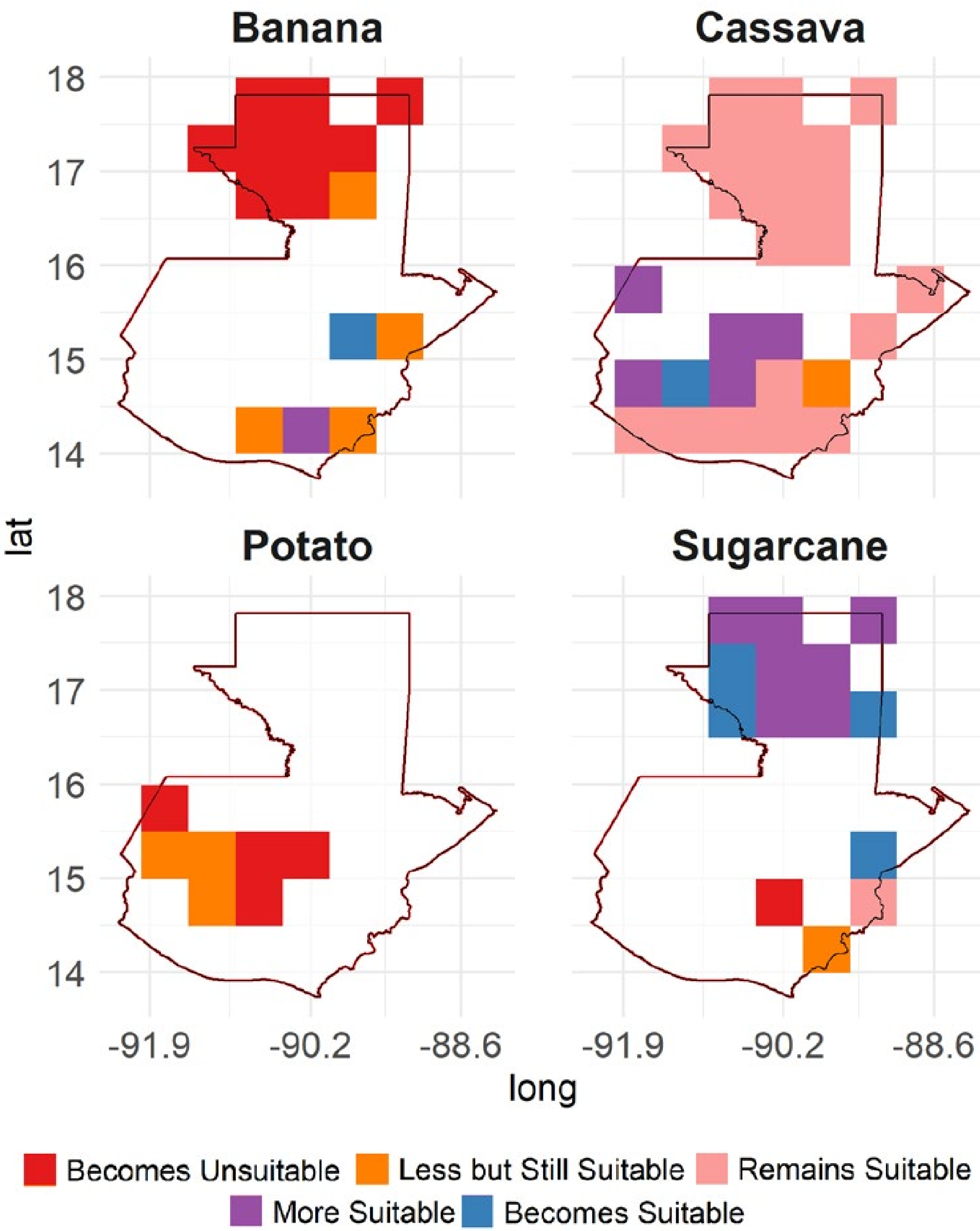
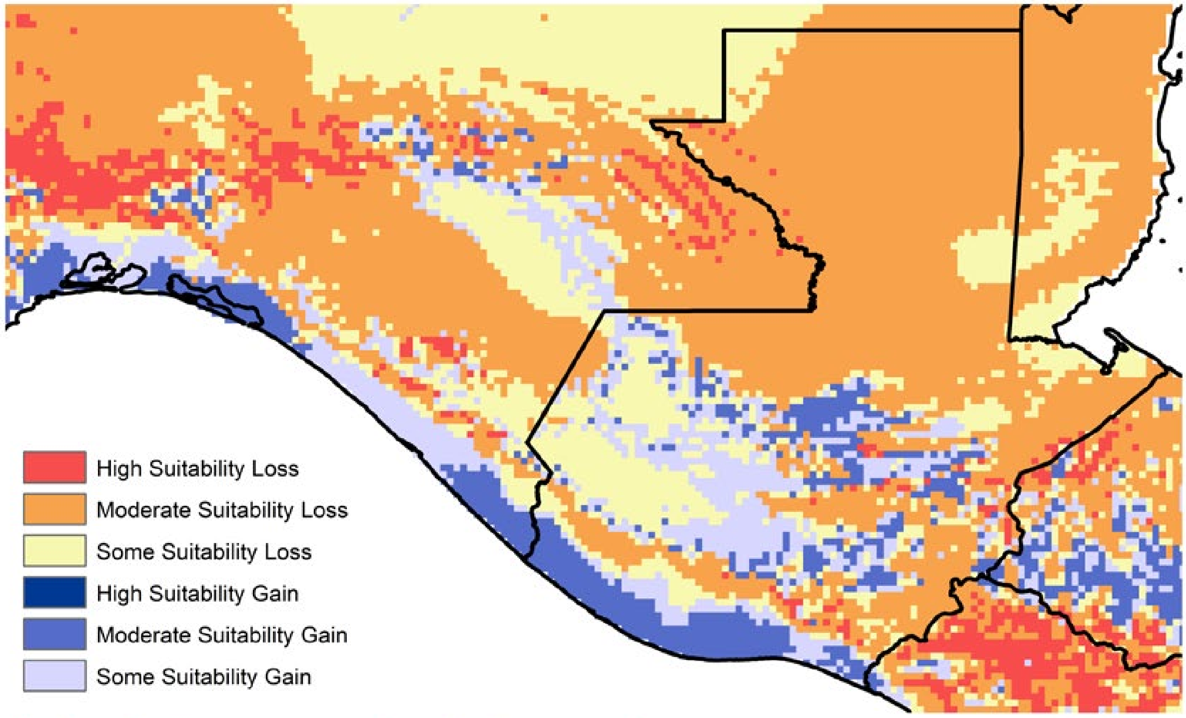
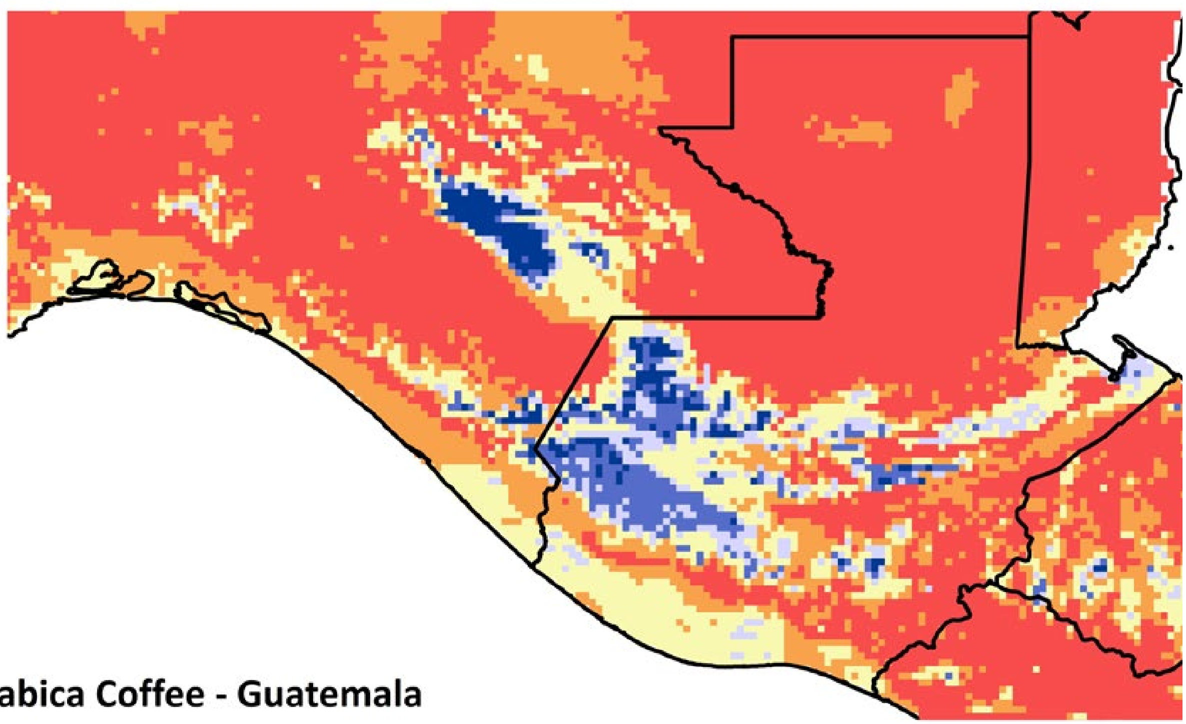


Figure 5: Projected suitability impact maps (2020-2050).

The coffee suitability impact maps in Figure 6, meanwhile, reveal that most of the decline in Arabica and Robusta suitability indicated in Figure 4 is concentrated in low lying areas that are already inapt for coffee cultivation. Moreover, this is compensated by substantial increases in suitability projected in the highlands. For Robusta, a wide swath along the Pacific piedmont is also projected to increase in suitability.

Robusta Coffee - Guatemala





Arabica Coffee - Guatemala

Figure 6: Projected change in suitability for coffee by 2050.

4. Economic impacts

In order to understand the real impacts of climate change on demand, supply, and international trade flows, the purely biophysical impacts addressed in the sections above must be adjusted for the economic agency of farmers who can adapt to yield and suitability loss by switching to alternative cultivars and practices. Ongoing advances in productivity and yield enhancing agricultural research, as well as the mitigating action (or inaction) of governments on emissions policy, must also be taken into consideration. The interplay of these factors was modeled using the International Model for Policy, Agricultural Commodities, and Trade (IMPACT), developed at the International Food Policy Research Institute. In this section, IMPACT projections are presented for the DSSAT modeled crops, accounting for global economic and climate change contexts of these crops as well as their substitutes.

In Guatemala, agricultural production and area are projected to increase under both CC and No-CC scenarios by 2050 (Figure 7). However, climate change may reduce maize production growth by 23.8 percentage points (pp) below the No-CC benchmark. Bean and rice production growth, on the other hand, may increase by 18.3 pp and 53.7 pp above the No-CC benchmark. Turning to trade in Figure 8, this increased production is largely sufficient to meet increasing domestic demand out to 2050, while the lower maize growth under CC is reflected in a steep trade deficit trajectory.

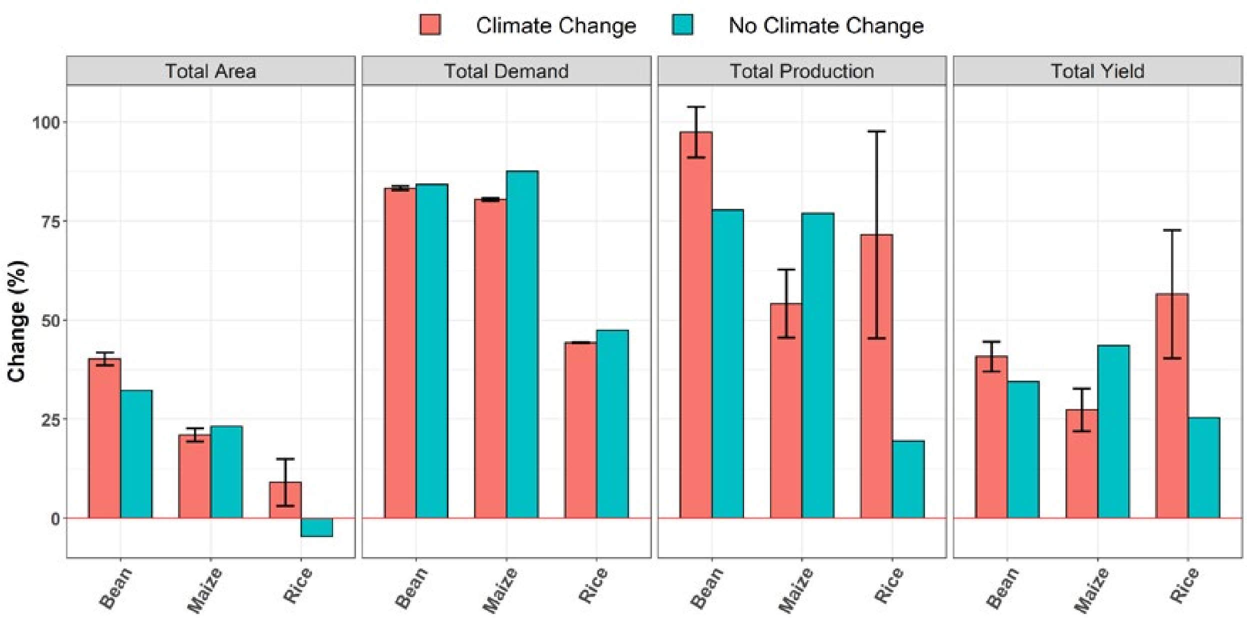


Figure 7: Percentage change in yield, demand, cultivated area, and production (2020–2050), when economic context and agricultural research are taken into account. The error bars indicate the range of output across the nine climate models.

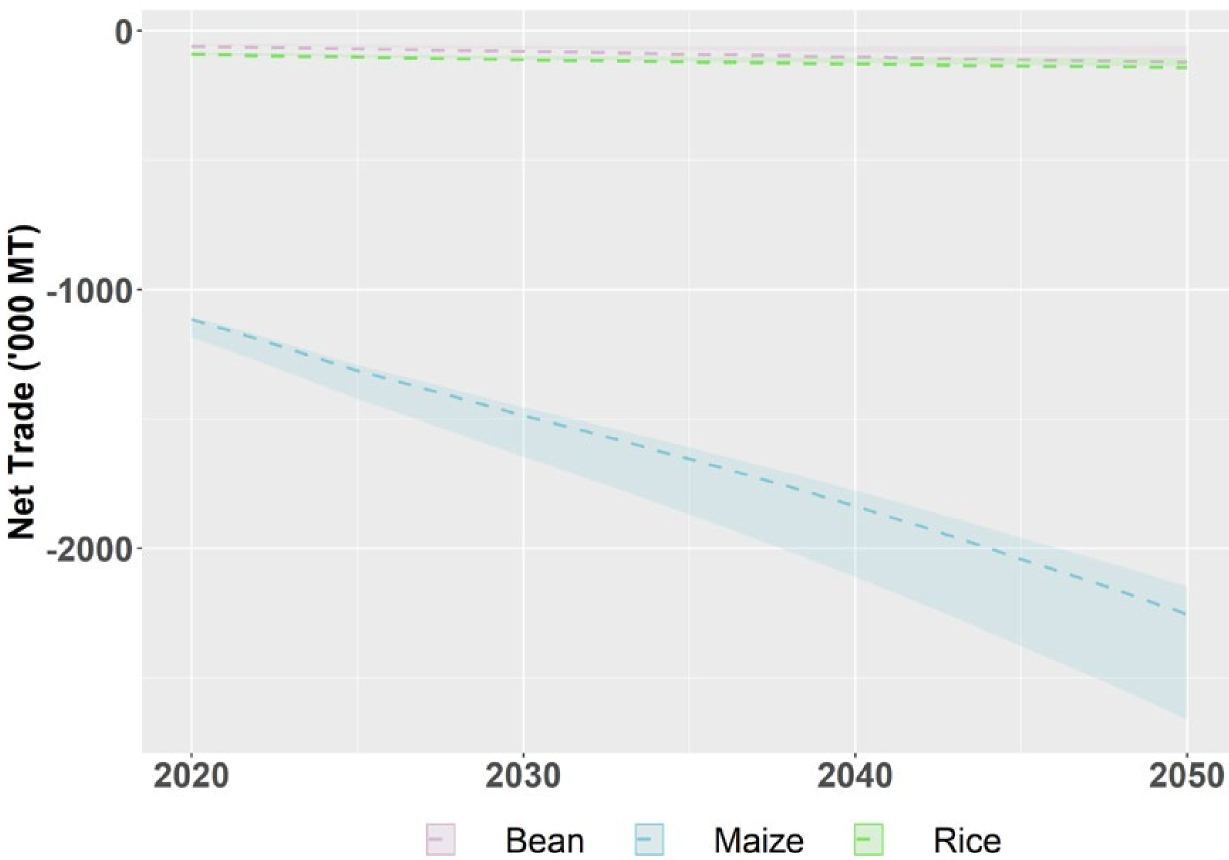


Figure 8: Climate change impact on trade. The dotted lines indicate the no climate change (No-CC) trajectory while the shaded areas correspond to the range of climate change (CC) trajectories given by the nine climate models.

5. The way forward

To limit the rise in global mean temperature below 2°C and ensure food security, most climate change pledges of the United Nations Framework Convention on Climate Change (UNFCCC) cite agriculture and land use as key elements for climate action [2]. In fact, Guatemala's Nationally Determined Contribution (NDC) to the 2015 Paris Agreement prioritize agricultural adaptation and mitigation activities [3].

Guatemala and other LAC countries in may be able to reduce the impact of climate change on the agricultural sector by adopting other climate smart agricultural (CSA) practices that increase productivity while reducing greenhouse gas (GHG) emissions and adapting to shifting growing conditions. This may include the continued expansion of no-till agricultural practices, precision nutrient management fertilizer, intercropping, and more advanced crop rotations. Moreover, given the changing crop suitability (i.e., sugarcane) projected here, intersectoral planning between forestry and agricultural sectors will be key to protecting the country's mega-diversity and vast protected areas. The development of heat- and drought-tolerant wheat and maize varieties may be particularly relevant to Guatemala, given the major yield losses projected for these crops.

Increased trade and productivity in the face of yield declines and faltering suitability for both domestic food security and export-oriented crops will require continued investment in agricultural research, robust communication between farmers and market intermediaries, and responsible land management and planning. Given the especially severe production losses in tropical Latin America, Guatemala will increasingly rely on trade with more temperate zones of the world,

including the Southern Cone, to ensure domestic food security. Political and financial market stability will be key to ensuring that these potential opportunities are realized. Key messages for policy interventions and way forward for adaptation measures are summarized below.

Table 2: Key messages for policy interventions

Table 2: Key messages for policy interventions		Way forward
Climate	Key Climate Observations • Maximum and minimum temperatures are projected to increase by 1-2.5 °C across the country Guatemala by 2050. • A sharp reduction in rainfall is projected across Guatemala, especially during the June to August period. • Climate change presents significant risk to crop yields and the broader economic performance of the agricultural sector in Guatemala. Drought and flooding events, increased temperatures, and tropical storms will continue to negatively impact production.	Adaptation is key particularly for increased productivity and resistance of staple crops under conditions of climate change. Main activities should focus on: • Agricultural practices (i.e. crop diversification, CSA, use of improved varieties, no-till, intercropping, precision nutrient management, and integration of indigenous knowledge) • Forest, land and water management • Increasing the efficiency in water use (i.e. expansion and/or rehabilitation of irrigation systems) • Agricultural research: » Identification and prioritization of adaptation options for the most relevant crops » Ex-ante impact assessment of heat and drought resistant technology for maize and bean. » And/or assessment of commercial alternatives such as sugarcane and rice, which are projected to increase yield under CC. » Conduct viability studies on crop diversification/rotation. » Assess the viability of CC resilient staple crops like cassava as an alternative source of carbohydrates and nutrients. • When expanding the agricultural frontier, planners should carefully consider the tradeoffs involved in replacing forest with agriculture.
Agriculture	• Maize and bean yields projected to decrease substantially by 2050 due to climate change. Irrigation alone not sufficient to counteract this tendency. New heat and drought tolerant varieties may be required. • Irrigated rice yields projected to increase across the country under climate change. • Areas suitable for banana cultivation projected to decline sharply, especially in the north. • Areas suitable for sugarcane projected to increase in the north. • Areas suitable for Arabica and Robusta coffee cultivation projected to decrease at lower elevations; but this is offset by increased suitability at higher elevations. • Guatemala is expected to become increasingly dependent on bean and maize imports.	

References:

[1] The World Bank. 2018. World Development Indicators. Washington, D.C., USA. **http://data.worldbank.org/indicator**

[2] CCAFS. 2015. Info Note: Agriculture's prominence in the INDCs. https://cgspace.cgiar.org/rest/bitstreams/62364/retrieve. Detailed country information on agriculture in INDCs available at: **https://cgspace.cgiar.org/handle/10568/73255.**

[3] **National Determined Contribution** from Guatemala

XII. Honduras

1. Context

Agriculture continues to play an important role in Honduras. The sector accounts for 12.9% of GDP, down just 1.5 percentage points (pp) from a peak of 14.4% in 2000. Crop products accounted for 14.7% of all exports in 2015, up 1.4 pp from 2006. Jobs in agriculture account for 28.5% of all employment in the country, down 8.6 pp from 8 years ago [1]. However, climate change presents significant risk to crop yields and the broader economic performance of the agricultural sector. Honduras is among the countries most vulnerable to climate change in Central America. Much of the country lies in the Central American Dry Corridor and is thus prone to severe droughts. Tropical storms and flooding also affect Honduran agriculture. A better understanding of the climate change impacts on specific crops will hence assist in decision making. For this purpose, climate, crop, and economic modeling results are presented in this brief (averaged over 2020–2050), regarding agricultural production and trade in the country, set in the LAC regional context. Based on these trends, adaptation measures are proposed at the end of the brief.

2. Climate impacts

In assessing future climate impacts, this study utilized nine general circulation models (see Methodological Summary for detail) selected for their strong performance in the LAC region. Overall, temperatures are predicted to increase by 1-4 °C across the LAC region, with the Caribbean and tropical South America projected to warm at higher rates than Mexico and the Southern Cone.

In Honduras, rainfall is generally expected to decline across the country, especially for the June to August rainy period. With some isolated exceptions, minimal changes to current rainfall trends are expected in the September to February period (Figure 1). Generally, in the wetter areas, precipitation is likely to increase in both magnitude and frequency. Maximum and minimum temperatures are projected to rise between 1 and 2.5 °C throughout the country. Maximum temperature increases are most pronounced in the September to November period, especially along the Atlantic Coast.

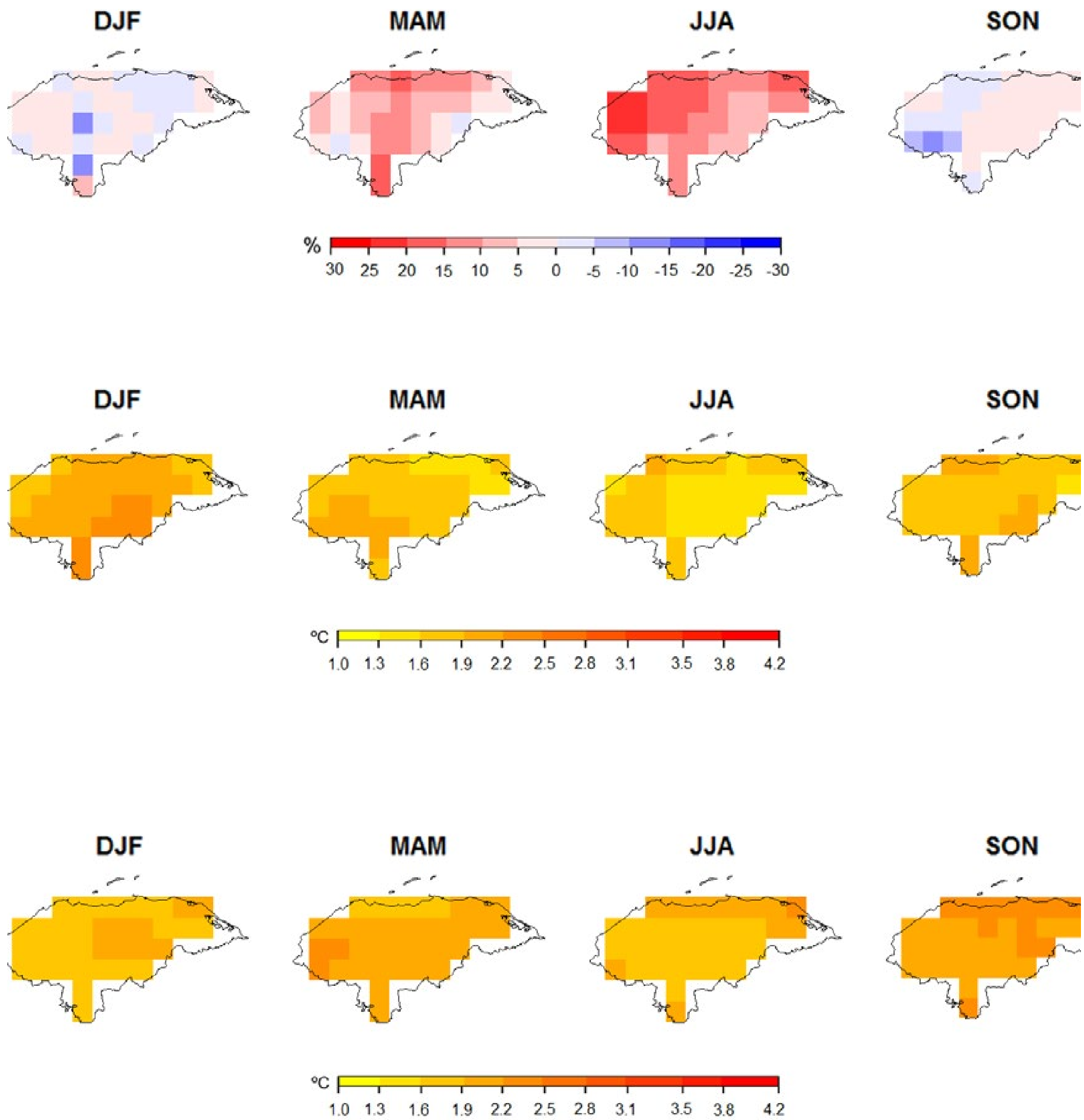


Figure 1: Change in (top to bottom) precipitation, maximum temperature, and minimum temperature averaged across nine GCMs (2020-2050). DJF= December - February, MAM= March - May, JJA= June - August, SON= September - November.

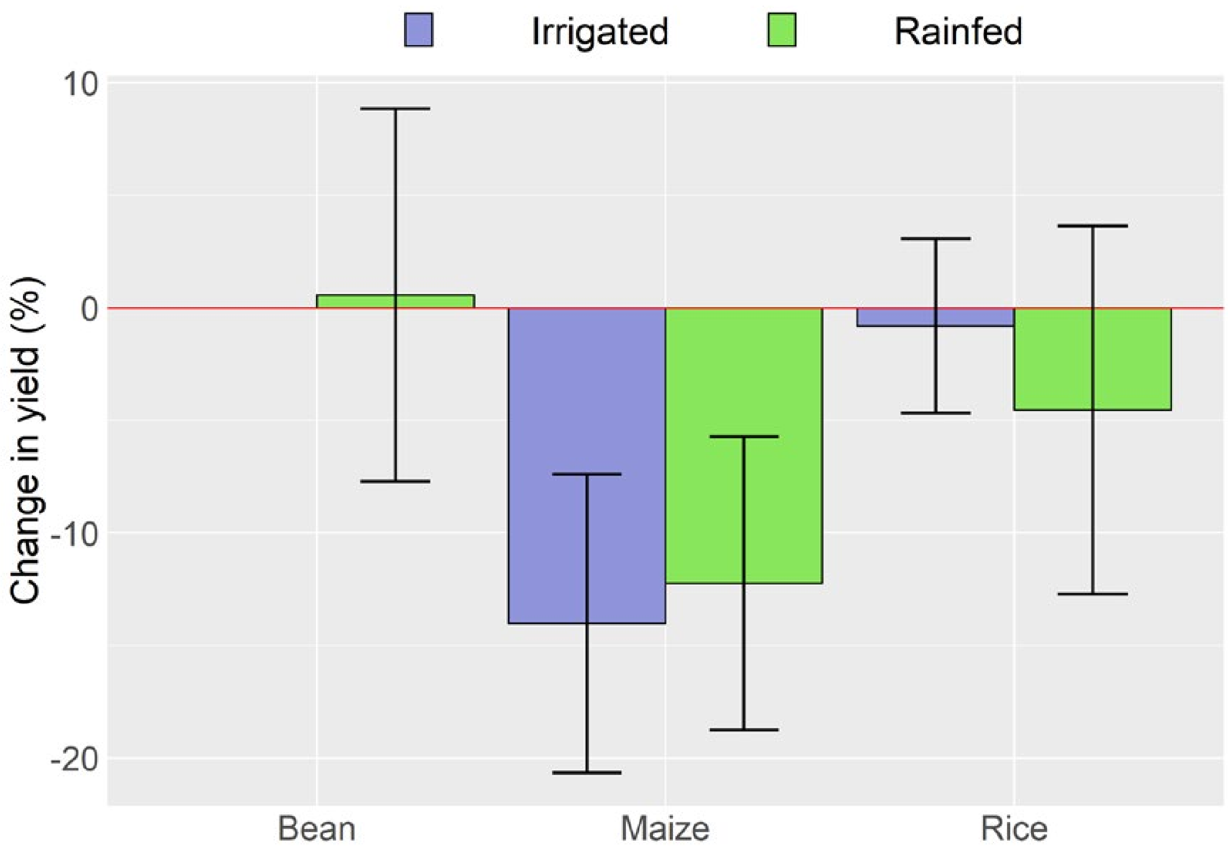


Figure 2: Projected average yield change, key crops (2020–2050). The error bars indicate the range of output across the nine climate models.

3. Yield and suitability impacts

Yield

Based on the projected changes in climate discussed above, 2050 projections of maize, rice, and bean yields were modeled using the Decision Support System for Agrotechnology Transfer (DSSAT v4.5) at 0.5 degree spatial resolution. Model runs for each crop were parameterized using genetic coefficients of varieties carefully selected by experts for their relevance in the region.

In Honduras, the crop modeling results shown in Figure 2 suggest that irrigated and rainfed maize are likely to see declines in average yield of 17% and 18%, respectively, relative to a no-climate change (No-CC) scenario. Irrigated and rainfed rice yields may see declines of 2% and 5%, respectively, while rainfed bean yields will be little affected. The geographically explicit yield impact maps in Figure 3 reveal important variation behind these national averages.

In this geographically disaggregated perspective, rainfed maize yields are projected to decline considerably across the north and east – especially Cortés, Atlántida, and Colón departments – although this loss is partially offset by pockets of yield increase farther west and south. The small countrywide increase in rainfed bean yields hides widespread yield decreases across the north and east. From this map, it is evident that pronounced yield increases in the south and west of the country – especially in Ocotepeque, Lempira, and Intibucá departments – are responsible for the average countrywide yield increase reported in Figure 2. Finally, the small countrywide decrease in irrigated rice yields hides a few pockets of considerable yield increase – with the sharpest increase projected in El Paraíso department.

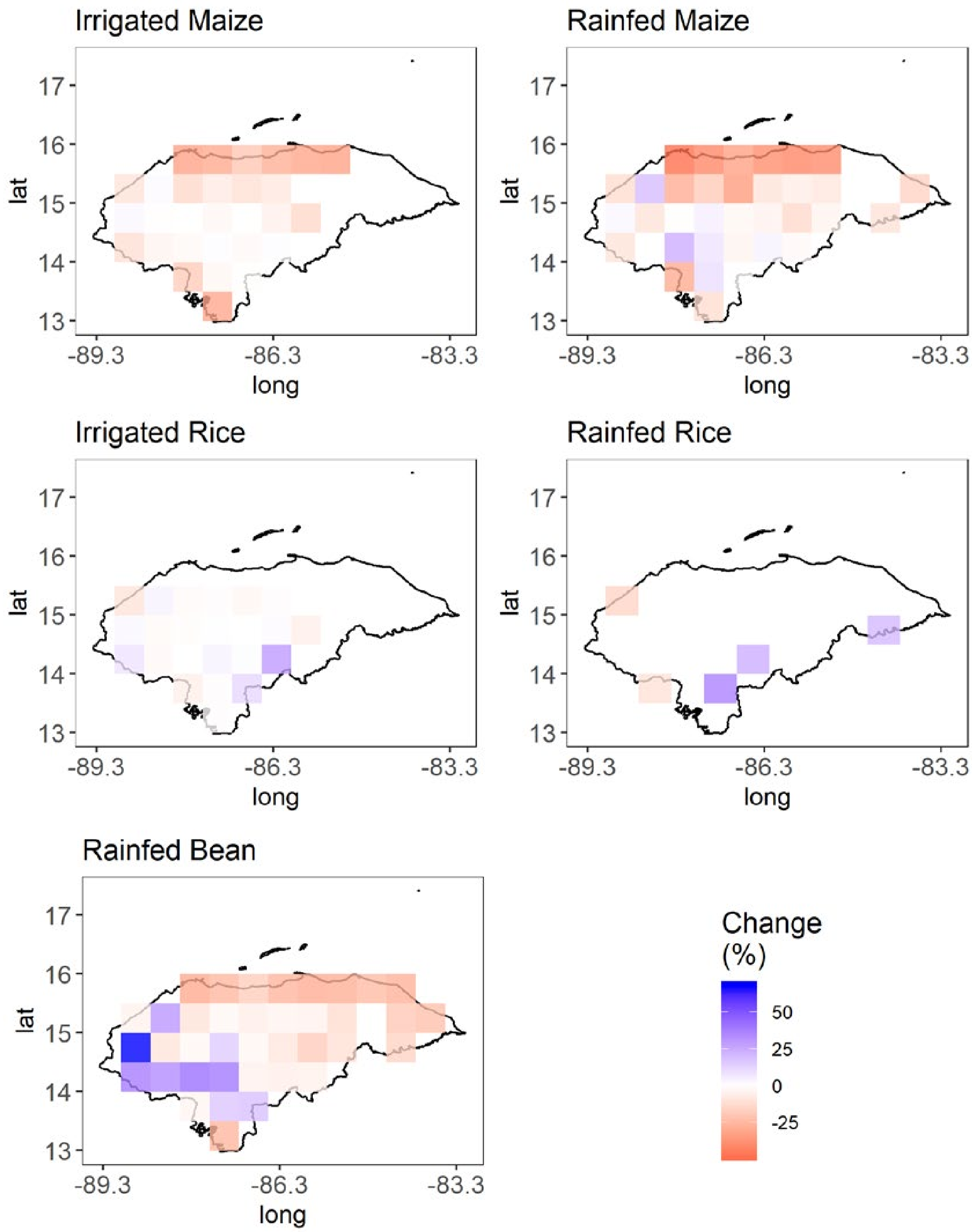


Figure 3: Projected yield impact maps, key crops (2020-2050).

Suitability

Climate change impacts on agro-ecological suitability for key commercial and staple crops, including coffee (Robusta and Arabica), banana, and sugarcane, were assessed using niche based models. In these models, "suitability" is defined based on how well local precipitation and temperature match the biophysical requirements of the given crop.

Future suitability in Honduras varies considerably across crops (Figure 4). The area suitable for banana is projected to see a suitability decline of 8%, especially along the Atlantic coast. This is substantially less than the regional trend of 63%. The area suitable for arabica and robusta coffee cultivation, on the other hand, is projected to decline much more sharply, by 63% and 27%, respectively. The area suitable for sugarcane, meanwhile, is projected to increase by 10%. Improved sugarcane suitability in Olancho and parts of Yoro and Cortés departments could potentially drive deforestation in this heavily forested region.

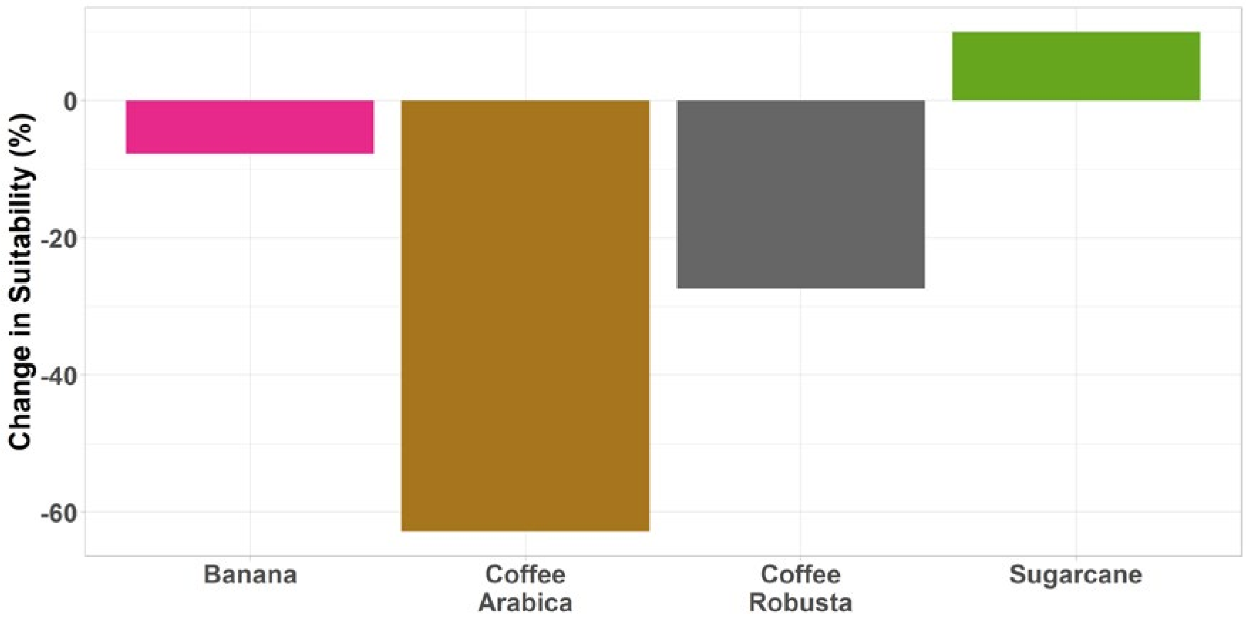


Figure 4: Projected change in suitability for key crops (2020-2050).

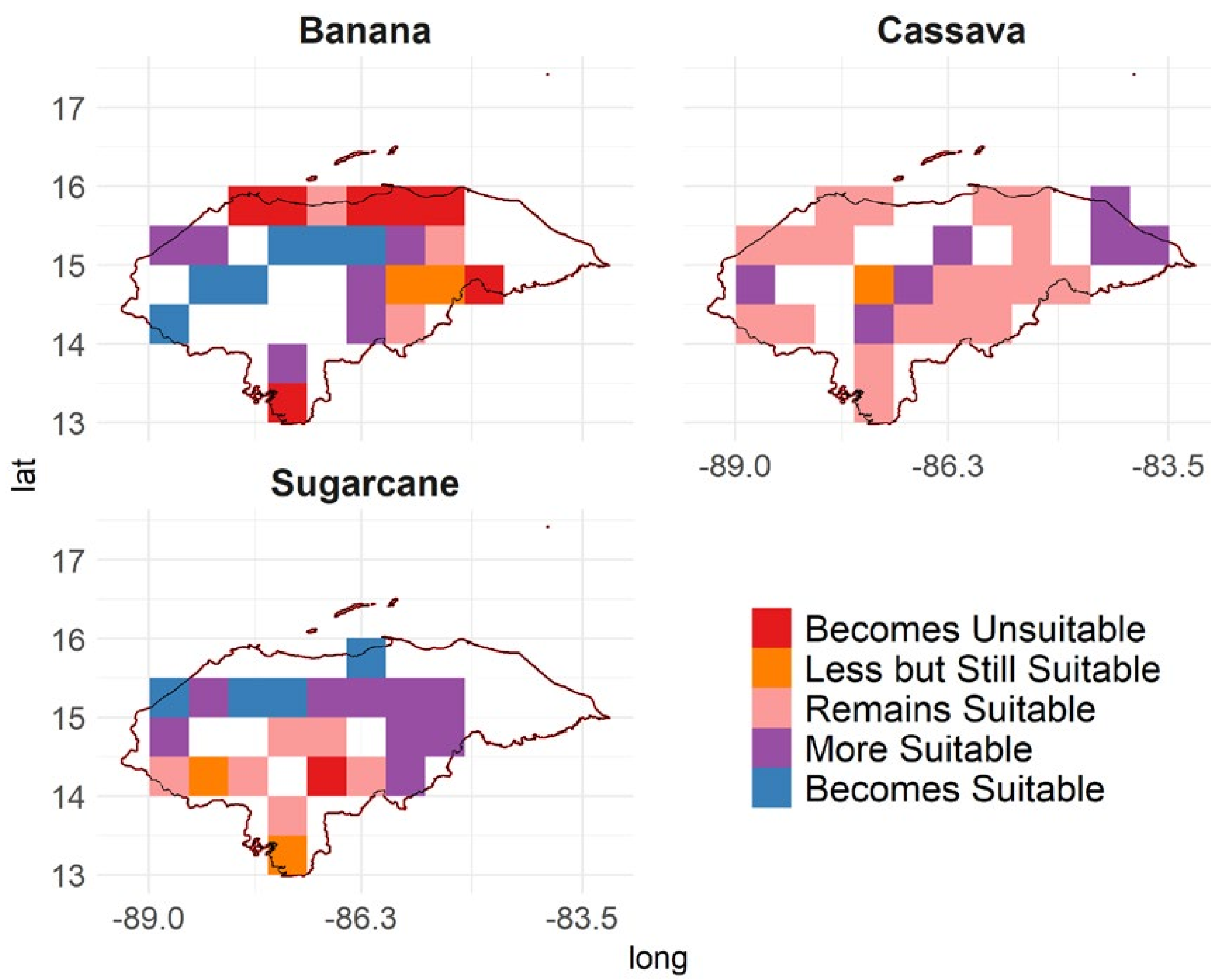


Figure 5: Projected suitability impact maps (2020-2050).

The geographically explicit suitability impact maps in Figure 5 indicate that these changes in suitability may be more pronounced in some areas than in others. The projected banana suitability loss is concentrated along the northern frontier of the country and is offset by areas to the south and west where suitability is projected to increase. Projected increases in suitability for sugar cane are concentrated primarily in the eastern interior, extending north and westward, with much of the rest of the country remaining suitable. Areas suitable for cassava cultivation are projected to remain stable or to improve in the face of climate change throughout the entire country. This may make cassava an attractive alternative source of carbohydrates and nutrients, given the projected decline in maize yield observed in Figures 2 and 3. The coffee suitability maps in Figure 6 indicate that the area suitable for Arabica coffee cultivation may decline sharply throughout the country, although this is partly offset by a small enclave in the remote northeast where conditions may improve. Robusta coffee suitability is also projected to decrease throughout the country, although somewhat less markedly, with substantial pockets of increased suitability at higher elevations in the western half of the country.

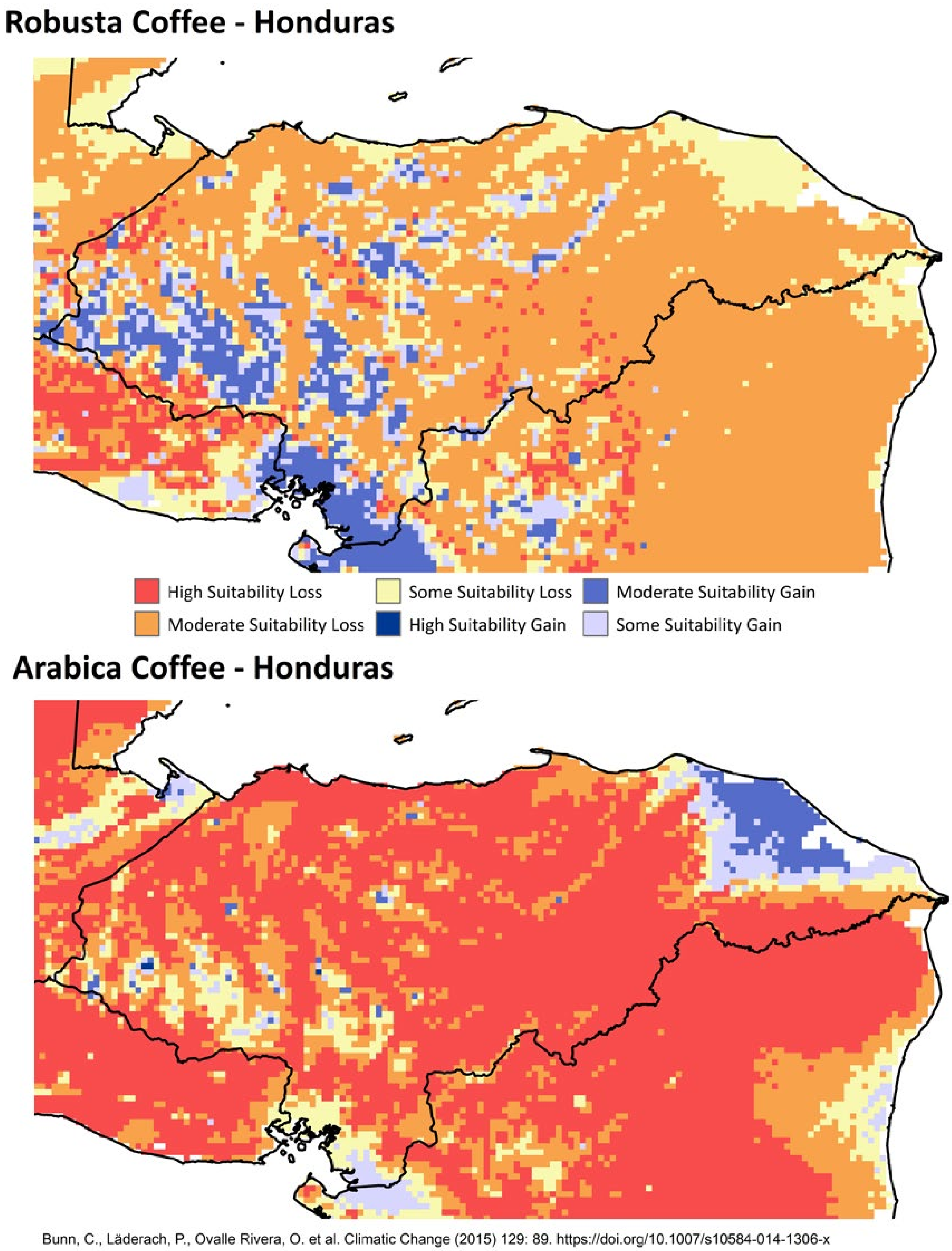


Figure 6: Projected change in suitability for coffee by 2050.

4. Economic impacts

In order to understand the real impacts of climate change on demand, supply, and international trade flows, the purely biophysical impacts addressed in the sections above must be adjusted for the economic agency of farmers who can adapt to yield and suitability loss by switching to alternative cultivars and practices. Ongoing advances in productivity and yield enhancing agricultural research, as well as the mitigating action (or inaction) of governments on emissions policy, must also be taken into consideration. The interplay of these factors was modeled using the International Model for Policy, Agricultural Commodities, and Trade (IMPACT), developed at the International Food Policy Research Institute. In this section, IMPACT projections are presented for the DSSAT modeled crops, accounting for global economic and climate change contexts of these crops as well as their substitutes.

In Honduras, the economic modelling suggests that yields and production may increase out to 2050 under both CC and No-CC scenarios for the modeled crops (Figure 7). However, the introduction of climate stressors into the economic modeling has a considerable impact on the maize production outlook, cutting its growth to 10.1 pp below the No-CC benchmark. This results in a steepening trade deficit in this key staple crop (Figure 8). The CC impact on dry beans is smaller, cutting production growth to 4.3 pp below the No-CC benchmark, and having little influence on terms of trade. Rice production under climate change is projected to be higher than under the No-CC scenario by 5.3 pp.

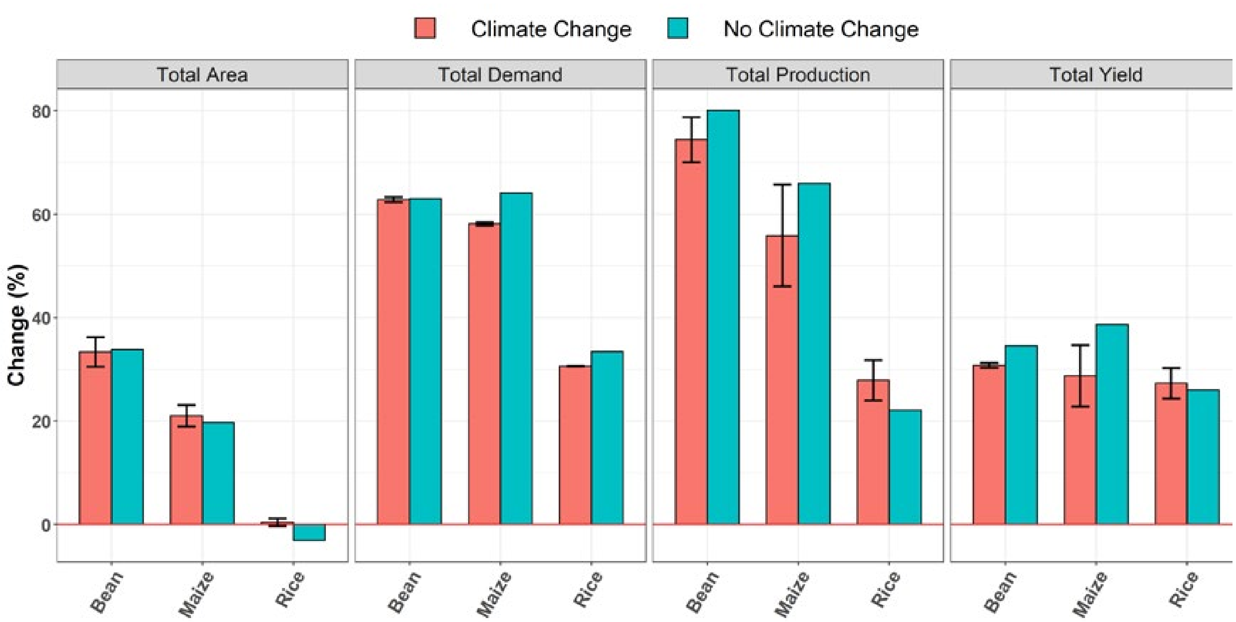


Figure 7: Percentage change in yield, demand, cultivated area, and production (2020–2050), when economic context and agricultural research are taken into account. The error bars indicate the range of output across the nine climate models.

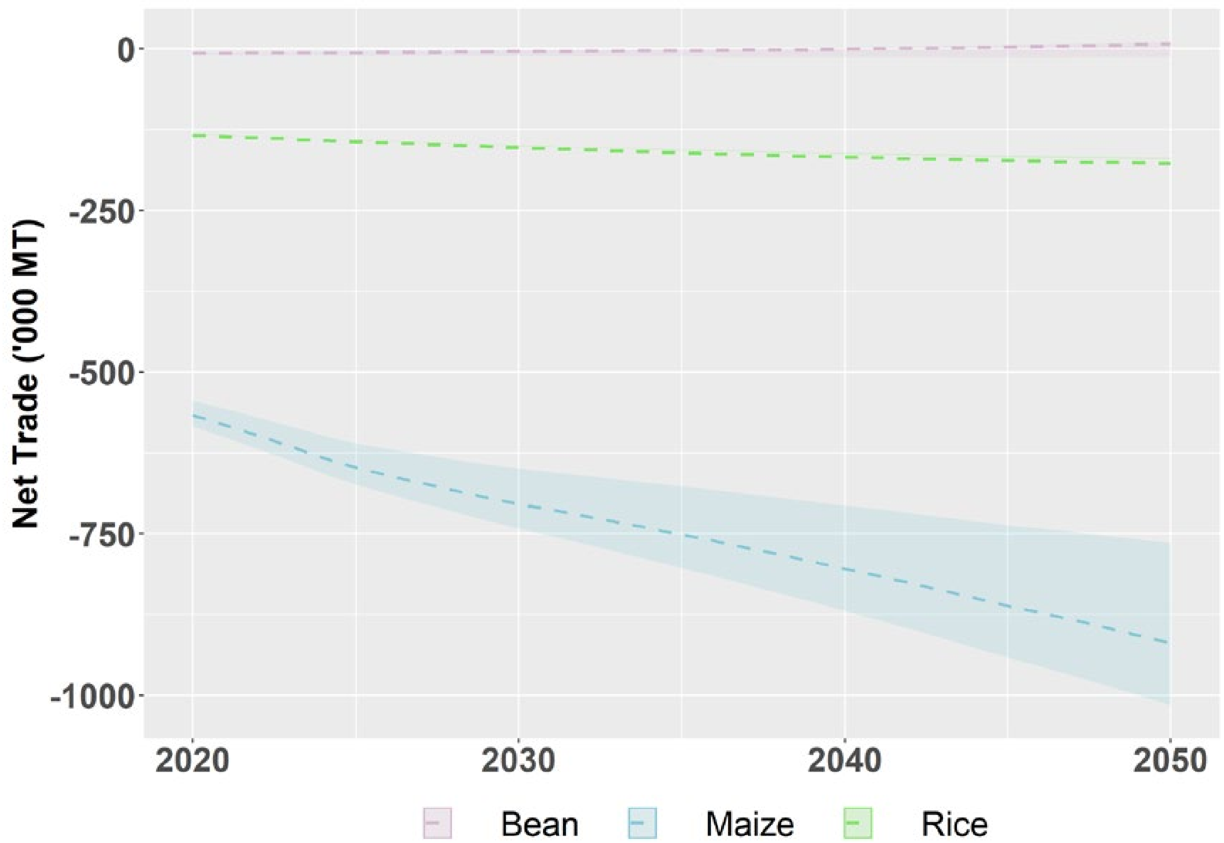


Figure 8: Climate change impact on trade. The dotted lines indicate the no climate change (No-CC) trajectory while the shaded areas correspond to the range of climate change (CC) trajectories given by the nine climate models.

5. The way forward

In an effort to limit the rise in global mean temperature below 2°C and ensure food security, most UNFCCC climate change pledges cite agriculture and land use as a key source of adaptation and/or mitigation potential [2]. The country's Nationally Determined Contribution (NDC) to the Paris Agreement highlights several agricultural interventions aimed at adaptation in the sector and reducing emissions: agroforestry, improved fertilizer efficiency, shifting cultivation dates, locally adapted seed varieties, integrated pest management, reduced burning, and erosion control, among others [3]. Other adaptation measures for the sector identified in the country's Second National Communication to the UNFCCC include agricultural diversification, addressing land tenure and access issues, and the increased adoption of silvopastoral systems.

These adaptation and mitigation targets will also be pursued through the county's National Climate Change Strategy (2010), National Plan (2010-2022) and Food Security and Nutrition Strategy (2010-2022), facilitated by the Inter-Institutional Committee on Climate Change within the Natural Resources and Environment Secretariat (SERNA) [4].

Honduras and other countries in Latin American may be able to reduce the impact of climate change on the agricultural sector by adopting other climate smart agricultural (CSA) practices that increase productivity while reducing greenhouse gas (GHG) emissions and adapting to shifting growing conditions. This may include the continued expansion of no-till agricultural practices, precision nutrient management fertilizer, intercropping, and more advanced crop rotations. Honduras may also pursue improved water management strategies and extension practices.

Table 2: Key messages for policy interventions

<table>
<tr><th colspan="2">Table 2: Key messages for policy interventions</th><th>Way forward</th></tr>
<tr><td>Climate</td><td>Key Climate Observations
• Temperatures in Honduras are projected to rise between 1 and 2.5°C. Maximum temperature increases will be most pronounced along the Atlantic Coast.
• With some notable exceptions, rainfall is generally expected to decline across the country, especially for the current June-August rainy period.
• Climate change presents significant risk to crop yields and the broader economic performance of the agricultural sector in Honduras. Tropical storms, drought and flooding events will continue to negatively impact production.</td><td rowspan="2">Adaptation is key particularly for increased productivity and resistance of staple crops under conditions of climate change. Main activities should focus on:
• Agricultural practices (i.e. crop diversification, use of improved varieties, intercropping, silvopastoral systems, and integrated pest management among others).
• Land and water management.
• Increasing the efficiency in water use (i.e. expansion and/ or rehabilitation of irrigation systems).
• Agricultural research:
» Identification and prioritization of adaptation options for the most relevant crops.
» Exploratory assessment of the potential benefits of heat- and flood-resistant crop technology.
» Improved water management strategies.
» Assessment of CC resilient crops like cassava as alternative sources of carbohydrates and nutrients.
If shifting cultivation into new areas of suitable terrain, planners must carefully consider the costs and benefits of replacing forests with agriculture.</td></tr>
<tr><td>Agriculture</td><td>Key Agriculture Observations
• Rainfed bean yield projected to remain relatively stable despite climate change.
• A sharp decline in banana suitability in the north is offset by substantial areas to the south and west where suitability may increase.
• Areas suitable for Arabica coffee projected to decrease sharply throughout the country.
• Areas suitable for Robusta coffee also projected to decrease, but less sharply, with some pockets of increased suitability at higher elevations.
• Sugarcane suitability is projected to improve throughout much of the country, especially in the heavily forested northeast.
• Due to demand outstripping supply, Honduras will become increasingly dependent on imported maize and rice.</td></tr>
</table>

Increased trade and productivity in the face of yield declines and faltering suitability for both domestic food security and export-oriented crops will require continued investment in agricultural research, robust communication between farmers and market intermediaries, and responsible land management and planning. Given the especially severe production losses in tropical Latin America, Honduras will increasingly rely on trade with more temperate zones of the world, including the Southern Cone, to ensure domestic food security. Political and financial market stability will be key to ensuring that these potential opportunities are realized. Key messages for policy interventions and a way forward for adaptation measures are summarized in Table 2.

References:

[1] The World Bank. 2018. World Development Indicators. Washington, D.C., USA. **http://data.worldbank.org/indicator**

[2] CCAFS. 2015. Info Note: Agriculture's prominence in the INDCs. **https://cgspace.cgiar.org/rest/bitstreams/62364/retrieve Detailed country information on agriculture in INDCs available at: https://cgspace.cgiar.org/handle/10568/73255**

[3] Government of Honduras. 2015. Intended Nationally Determined Contribution to the UNFCCC. **http://bit.ly/2jzAYey**

[4] CCAFS. 2015. La agricultura de Honduras y el cambio climático: ¿Dónde están las prioridades para la adaptación? **https://ccafs.cgiar.org/node/47620#.WAzCp-2Wrw80**

XIII. Jamaica

1. Context

Agriculture plays an important role in Jamaica. The sector accounts for 6.4% of GDP, down just 0.2 percentage points (pp) from a peak of 6.6% in 2016. Crop products accounted for 6.7% of all exports in 2017, up 0.5 pp from 2009. Jobs in agriculture account for 18.6% of all employment in the country, down 1.4 pp from 8 years ago [1]. Climate change presents significant risk to both domestic food security and export crop yields as well as the broader economic performance of the agricultural sector in Jamaica. Two especially relevant risks to the agricultural sector include reduced water availability and increased extreme events from tropical storms and other hydrometeorological hazards producing high winds, flooding, and landslides. The impact of long-term progressive climate change on crop yields and suitability – and the resulting impacts on regional trade – are of severe consequence for both farmers and policy makers in Jamaica. Currently, approximately 8.4% of the population of Jamaica is undernourished, according to most recent estimates. This is up from 6.9% a decade earlier, although it remains half the average of 18.3% for the Caribbean region [2]. Here, climate, crop, and economic modeling provide future trends (2021-2050) regarding agricultural production and trade in the country, set in the Latin American regional context.

2. Climate impacts

In assessing future climate impacts, this study utilized nine general circulation models (GCMs), selected for their strong performance in the LAC region. Overall, temperatures are predicted to increase by 1-4°C across the LAC region, with the Caribbean and tropical South America projected to warm at higher rates than Mexico and the Southern Cone.

Jamaica is projected to become considerably drier during the summer months of March to August, (Figure 1). Rainfall is projected to increase in some parts during the remainder of the year. Meanwhile, minimum and maximum temperatures are projected to increase by 3-4°C throughout the country. This may increase the risk of agricultural droughts, especially in the rainfed systems that predominate Jamaican agriculture.

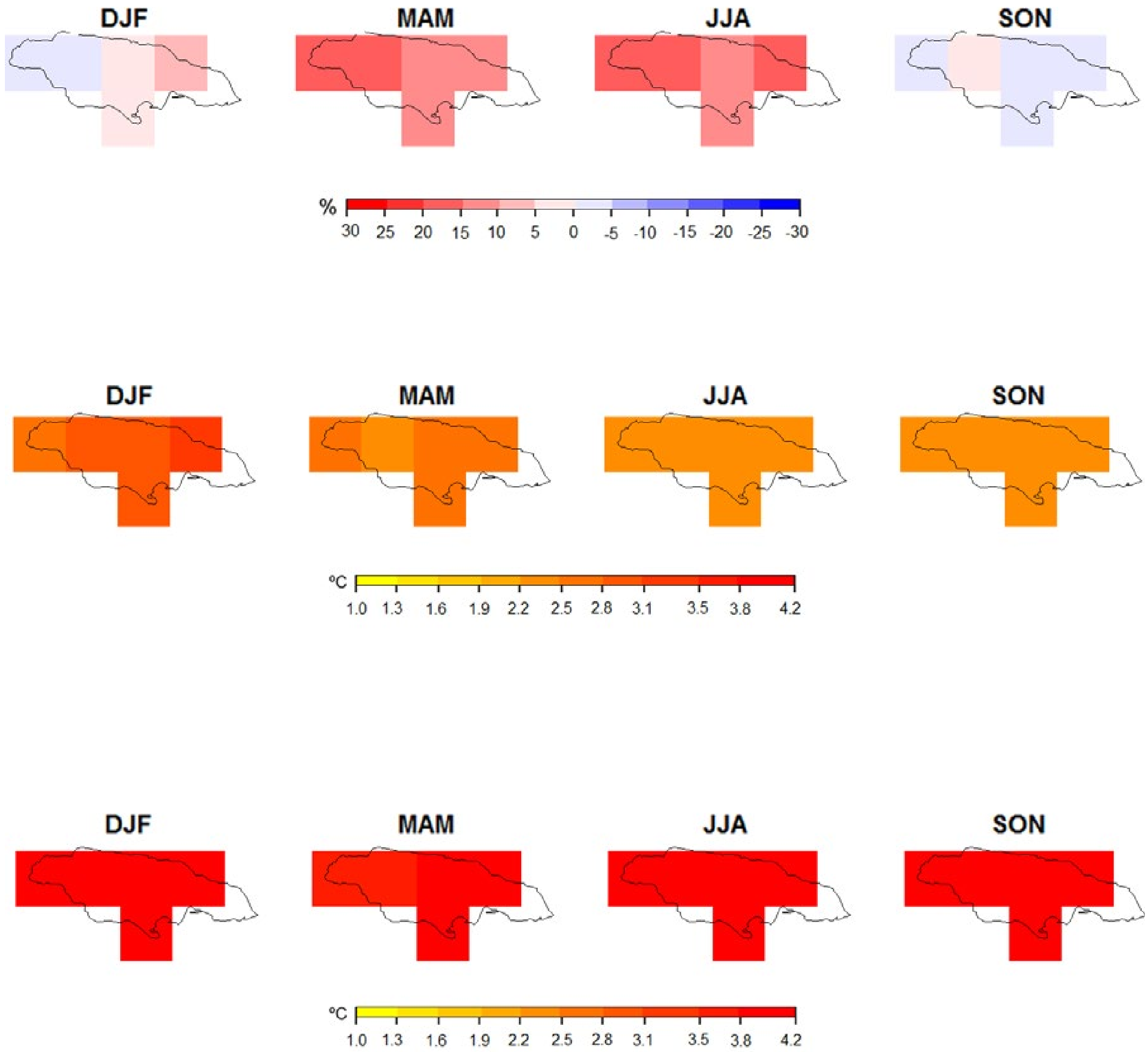


Figure 1: Change in (top to bottom) precipitation, maximum temperature, and minimum temperature averaged across nine GCMs (2020-2050). DJF= December - February, MAM= March - May, JJA= June - August, SON= September - November.

3. Yield and suitability impacts

Yield

Based on the projected changes in climate discussed above, 2050 projections of corn, rice, wheat, and bean yields were modeled using the Decision Support System for Agrotechnology Transfer (DSSAT v4.5) at 0.5 degree spatial resolution. Model runs for each crop were parameterized using genetic coefficients of varieties carefully selected by experts for their relevance in the region.

The modeling projects a sharp decrease of 40% in rainfed corn yield on the island. Production of rice, wheat, and beans is minimal, but Jamaica does depend upon imports of these crops from other countries in the region to meet domestic demand.

In the Central American and Caribbean region more broadly, the modeling projects CC-induced yield declines in irrigated and rainfed corn of about 25%, and rainfed bean losses between 15% and 25%. This could pose challenges for Jamaica's food security in the coming decades.

Suitability

Climate change impacts on agro-ecological suitability for coffee (Robusta and Arabica), banana, cassava, sugarcane, and yam were assessed using niche based models. In these models, "suitability" is defined based on how well local precipitation and temperature match the biophysical requirements of the given crop.

The geographically explicit impacts maps in Figure 2 indicate that areas suitable for the production of banana are projected to decrease sharply throughout the country. Sugarcane suitability, on the other hand, is projected to increase across much of the country.

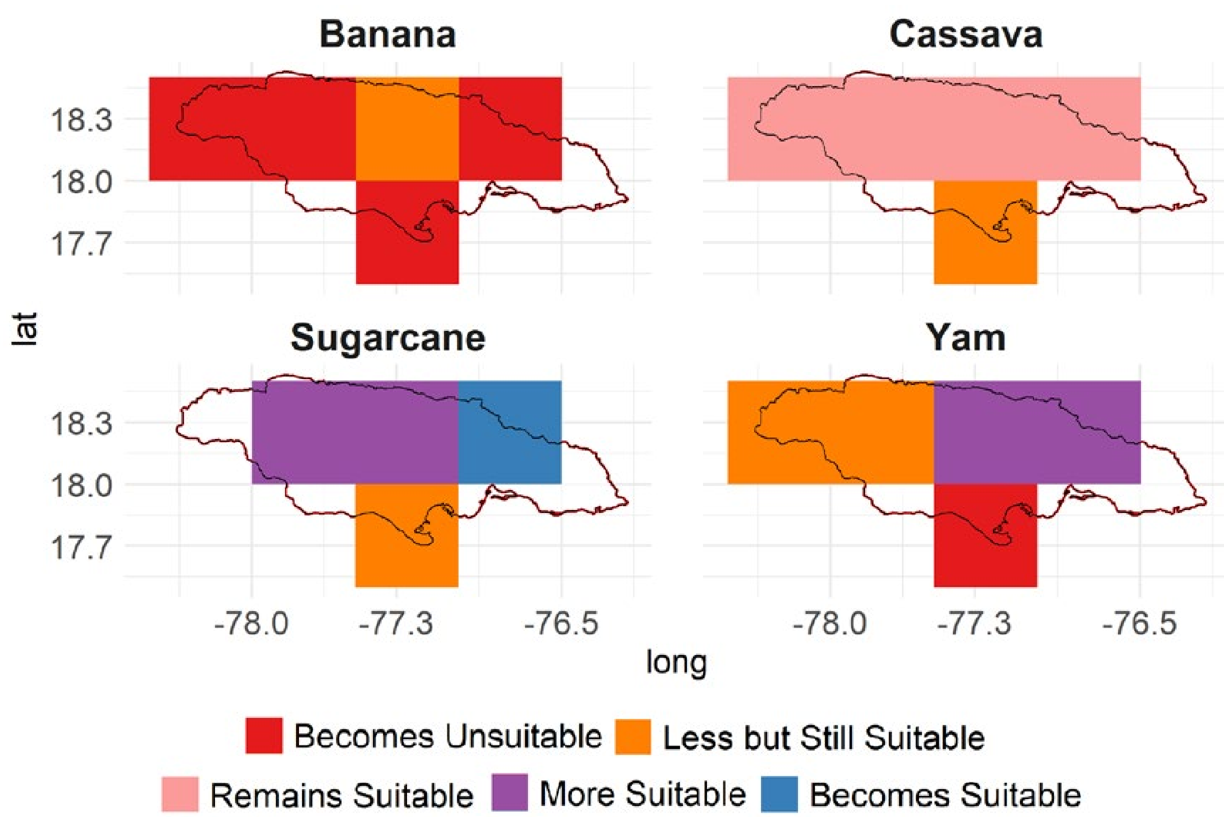


Figure 2: Projected suitability impact maps (2020-2050).

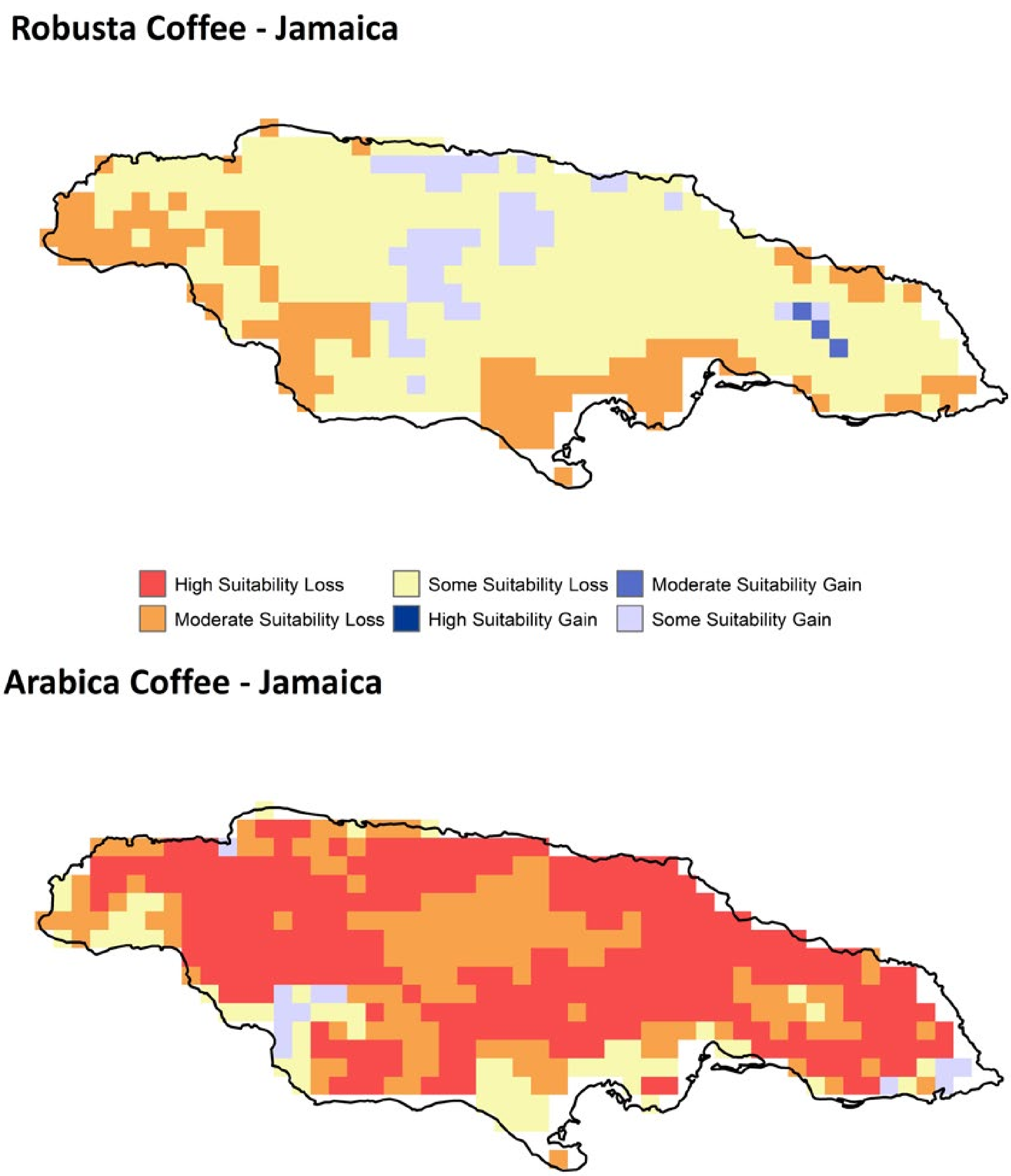


Figure 3: Projected change in suitability for coffee by 2050.

Cassava and yam also exhibit resilience in the face of climate change, making them a potential alternative source of carbohydrates and nutrients as cereal yields decline throughout the Central American and Caribbean region. Geogrpahically speaking, suitability losses are concentrated in the south, especially southern Clarendon province. The coffee impact maps presented in Figure 3 project a general decline in Arabica suitability across most of the country, including a moderate decline in the Blue Mountain coffee growing region. Robusta coffee, on the other hand, exhibits relative resilience, with pockets of high suitability gains in the Blue Mountains, and moderate gains farther west.

4. Economic impacts

In order to understand the real impacts of climate change on demand, supply, and international trade flows, the purely biophysical impacts addressed in the sections above must be adjusted for the economic agency of farmers who can adapt to yield and suitability loss by switching to alternative cultivars and practices. Ongoing advances in productivity and yield enhancing agricultural research, as well as the mitigating action (or inaction) of governments on emissions policy, must also be taken into consideration. The interplay of these factors was modeled using the International Model for Policy, Agricultural Commodities, and Trade (IMPACT), developed at the International Food Policy Research Institute. In this section, IMPACT projections are presented for the DSSAT modeled crops, accounting for global economic and climate change contexts of these crops as well as their substitutes.

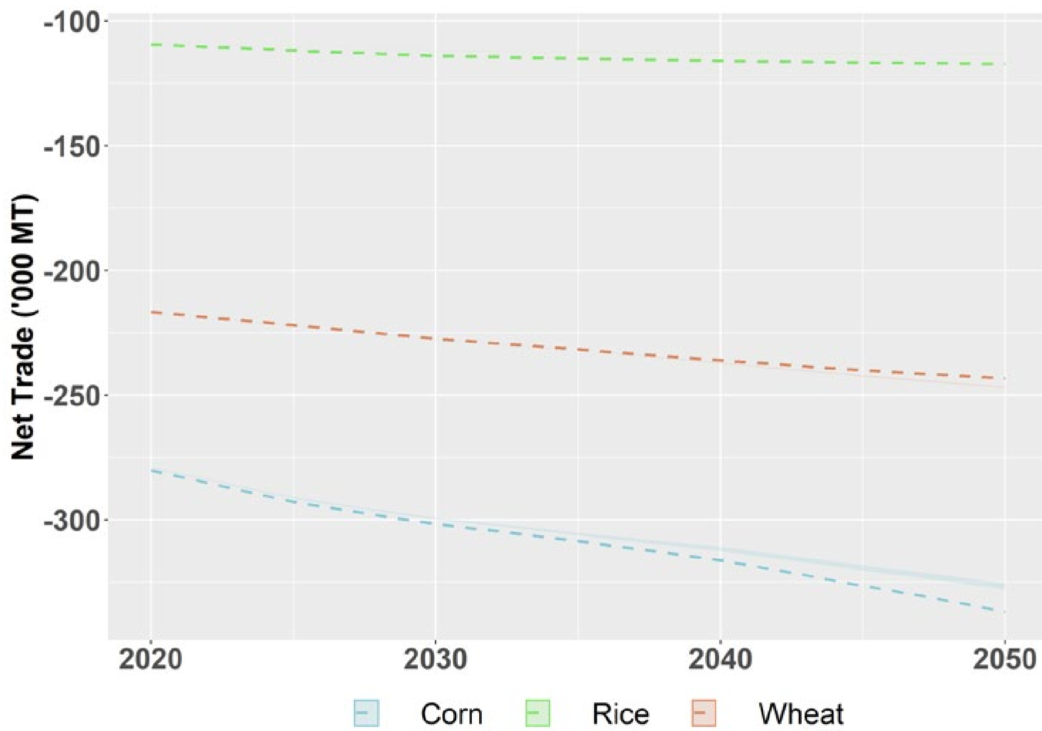


Figure 4: Climate change impact on trade. The dotted lines indicate the no climate change (No-CC) trajectory while any shaded areas correspond to the range of climate change (CC) trajectories given by the nine climate models.

In most LAC countries, IMPACT modelling projects that these factors largely offset the deterioration in biophysical conditions under CC, resulting in overall increases in staple crop production and yield, albeit less so than under a No CC scenario. Jamaica is one of the few countries in the LAC region where corn production is projected to fall sharply—by as much as 40%—under CC. Demand for corn and wheat, meanwhile, is projected to grow by about 15%. Jamaica's trade deficits in wheat, corn, rice, and soybean are projected to steepen or to hold steady out to 2050 regardless of CC (Figure 4).

5. The way forward

To limit the rise in global mean temperature below 2 °C and ensure food security, most climate change pledges of the United Nations Framework Convention on Climate Change (UNFCCC) cite agriculture and land use as key elements for climate action [3]. In fact, Jamaica's Nationally Determined Contribution (NDC) to the 2015 Paris Agreement include agriculture as one of the main sectors for the development of climate change strategies and action plans [4].

Table 2: Key messages for policy interventions

<table>
<tr><th colspan="2">Table 2: Key messages for policy interventions</th><th>Way forward</th></tr>
<tr><td>Climate</td><td>• Severe temperature increase projected throughout the island by 2050.
• Projected decrease in rainfall during the summer months. Some increase in rainfall may occur during the winter months.
• Temperature increases and reduced precipitation are likely to increase the risk of drought across the country, particularly impacting rainfed systems.</td><td rowspan="2">Adaptation measures are key mainly those that have the potential to increase productivity while mitigating climate change. Main activities should focus on:
• Agricultural practices (i.e. crop diversification, CSA, use of improved varieties)
• Forest, land and water management
• Increasing the efficiency in water use
• Agricultural research:
» Analyses to identify and prioritize CC adaptation options for the most relevant crops
» Ex-ante impact assessment of heat and flood resistant crop technology
» Assessment of CC-resilient crops such as yam and cassava as a potential alternative source of carbs and nutrients.</td></tr>
<tr><td>Agriculture</td><td>• Sharp decrease in corn yield projected for 2050.
• Sharp decrease in suitable area projected for banana cultivation.
• Decrease in suitable area projected for arabica coffee cultivation, including in the Blue Mountains. However, there is also an increase in suitability projected for robusta coffee in the Blue Mountains.
• Sugarcane, yam, and cassava exhibit relative resilience under CC.</td></tr>
</table>

Jamaica and other LAC countries in may be able to reduce the impact of climate change on the agricultural sector by adopting other climate smart agricultural (CSA) practices that increase productivity while reducing greenhouse gas (GHG) emissions and adapting to shifting growing conditions.

Increased trade and productivity in the face of yield declines and faltering suitability for both domestic food security and export-oriented crops will require continued investment in agricultural research, robust communication between farmers and market intermediaries, and responsible land management and planning. Given the especially severe production losses in tropical Latin America, Jamaica will increasingly rely on trade with more temperate zones of the world, including the Southern Cone, to ensure domestic food security.

References:

[1] The World Bank. 2018. World Development Indicators. Washington, D.C., USA. **http://data.worldbank.org/indicator**

[2] FAO; IFAD; UNICEF; WFP; WHO. 2017. The State of Food Security and Nutrition in the World 2017. Building resilience for peace and food security. Rome, FAO. Available at: **www.fao.org/3/a-I7695e.pdf**

[3] CCAFS. 2015. Info Note: Agriculture's prominence in the INDCs. **https://cgspace.cgiar.org/rest/bitstreams/62364/retrieve Detailed country information on agriculture in INDCs available at: https://cgspace.cgiar.org/handle/10568/73255**

[4] Government of Jamaica. 2015. Intended Nationally Determined Contribution of Jamaica. **https://bit.ly/3aLWmlI**

XIV. Mexico

1. Context

Agriculture plays a small but constant role in Mexico's economy. Whereas agricultural production as a share of GDP has been declining throughout much of the Latin American and Caribbean (LAC) region over the last 15 years, in Mexico it has held steady at 3%-3.5%. Crop products accounted for 3.2% of all exports in 2015, and jobs in agriculture account for 13.1% of all employment in the country [1]. One third of cultivated area is occupied by maize, considered fundamental to the country's food security. Other important crops are beans, coffee, sugarcane, and wheat [2]. Rainfall patterns are increasingly influenced by the El Niño Southern Oscillation, which raises the incidence of flooding during rainy seasons and of drought during dry seasons. Moreover, climate change has resulted in an increased frequency of hurricanes along both the Atlantic and Pacific coasts. For instance, a once-in-a-hundred-year drought from 2010-2012 in the north resulted in the loss of 3.2 million tons of maize; while a once-in-fifty-year drought in 2017 in the southern state of Oaxaca resulted in the loss of over 1,500 head of cattle. In fact, the agricultural sector is the most affected by climate change, accounting for 80% of weather-related financial losses since 1990 [2].

2. Climate Impacts

In assessing future climate impacts, this study utilized nine general circulation models (see Methodological Summary for detail) selected for their strong performance in the Latin American and Caribbean (LAC) region. Overall, temperatures are predicted to increase by 1-4 °C by 2050 across the LAC region, with Mexico and the Southern Cone projected to warm at lower rates than the Caribbean and tropical South America.

Mexico is likely to experience a large range of climate impacts, due to the extent and variation in its geography. Rainfall is projected to decrease substantially across the country, especially during the December-February and June-August periods, although the Durango and Jalisco region—an important maize growing area—may see a substantial increase in rainfall during March-May. Increases in rainfall are also projected for the southern half of the country during September-November. Maximum and minimum temperatures are projected to increase across the country, especially during June-August in the central valley—a major maize, wheat, and bean production corridor (Figure 1).

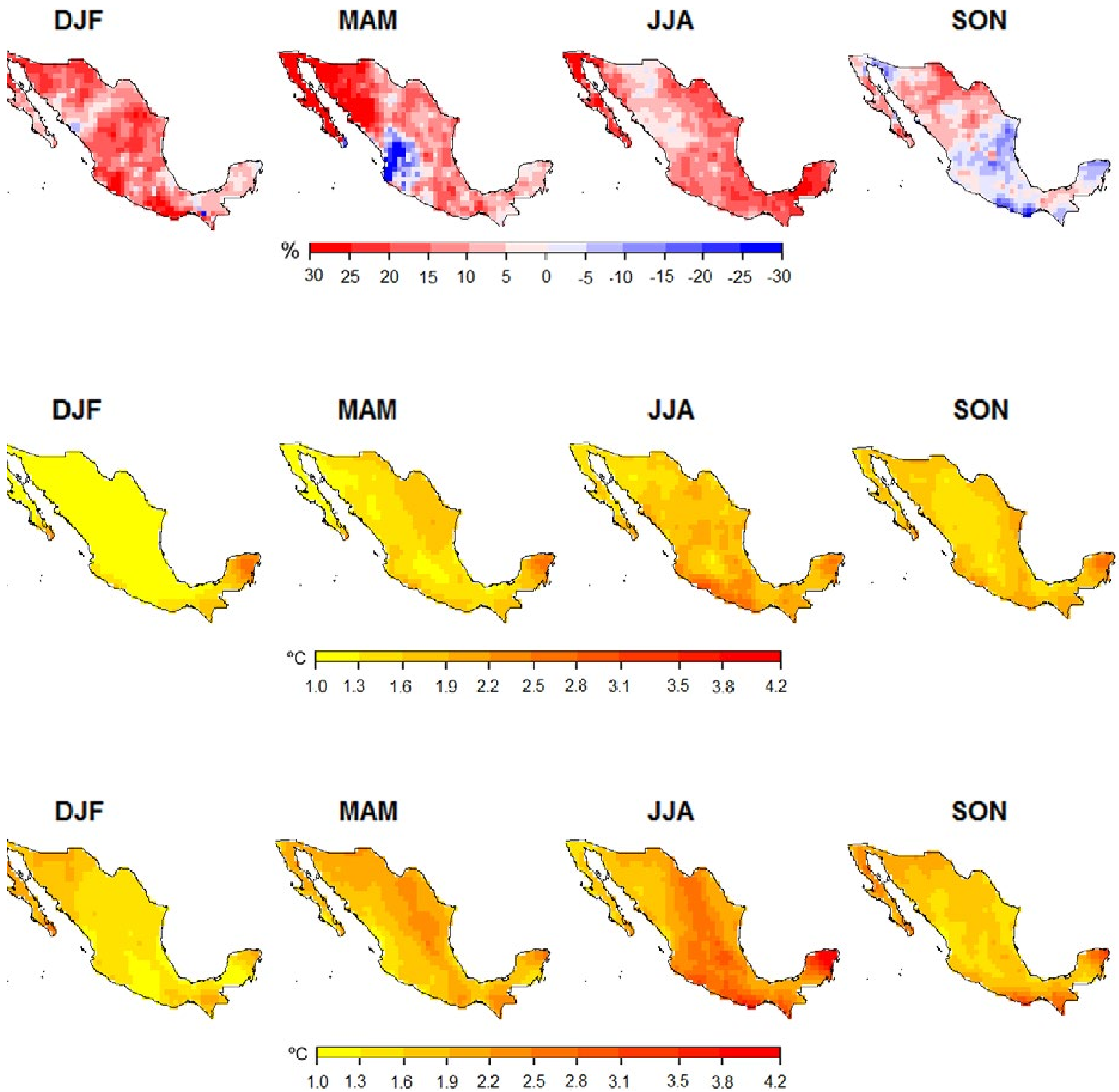


Figure 1: Climate impacts averaged across nine GCMs (2020-2050). DJF = December - February, MAM = March - May, JJA = June - August, SON = September - November.

3. Yield and suitability impacts

Yield

Based on the projected changes in climate discussed above, 2050 projections of maize, rice, wheat, soybean, and bean yields were modeled using the Decision Support System for Agrotechnology Transfer (DSSAT v4.5) at 0.5 degree spatial resolution. Model runs for each crop were parameterized using genetic coefficients of varieties carefully selected by experts for their relevance in the region.

The output of this modeling suggests that, on average, climate change will impact rainfed crops more severely than irrigated crops. For instance, substantial declines of 22.8% and 29.9% are projected for rainfed bean and maize in 2050, while irrigated bean and maize yields may decline by 12% and 17.3%, respectively. Likewise, climate change could result in declines for rainfed rice and wheat yields by 13.6% and 19.6%, respectively, while irrigated yields of these crops are relatively unaffected (Figure 2). This suggests that irrigation has potential as an effective climate change adaptation strategy.

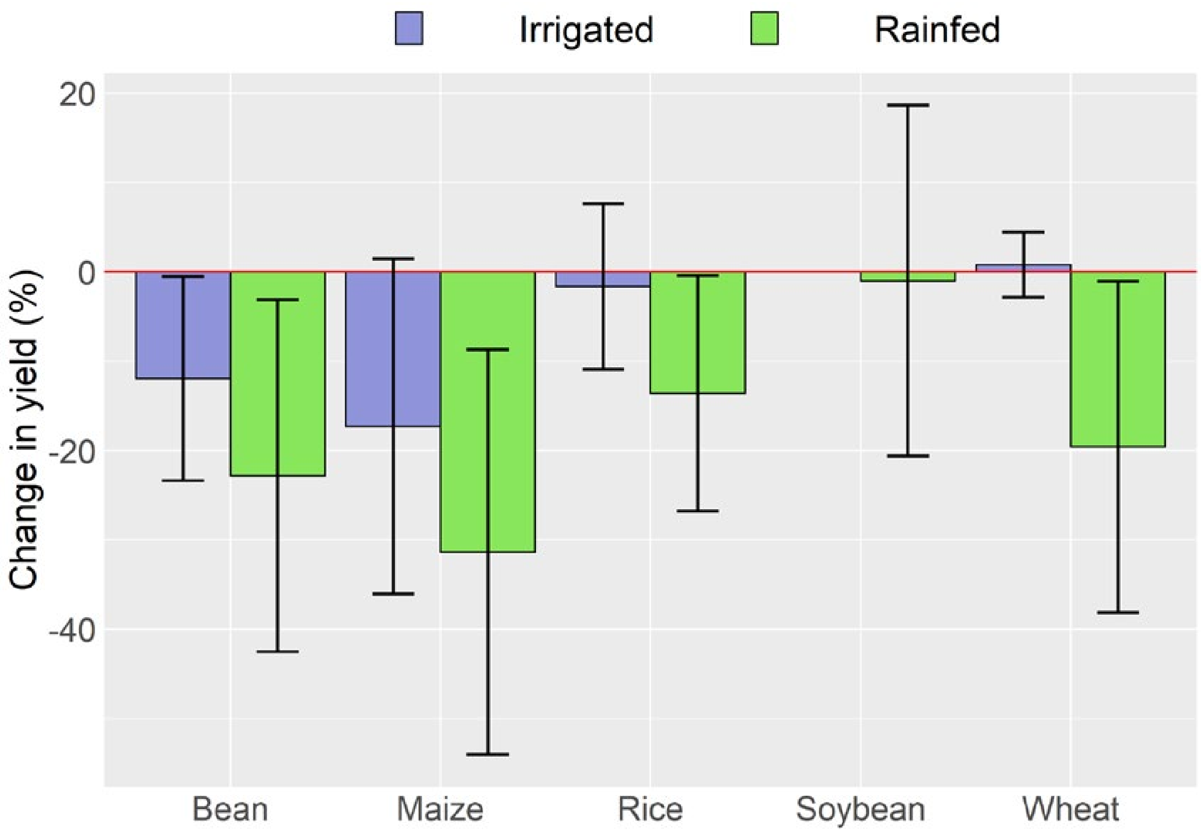


Figure 2: Projected average yield change, key crops (2020-2050). The error bars indicate the range of output across the nine climate models.

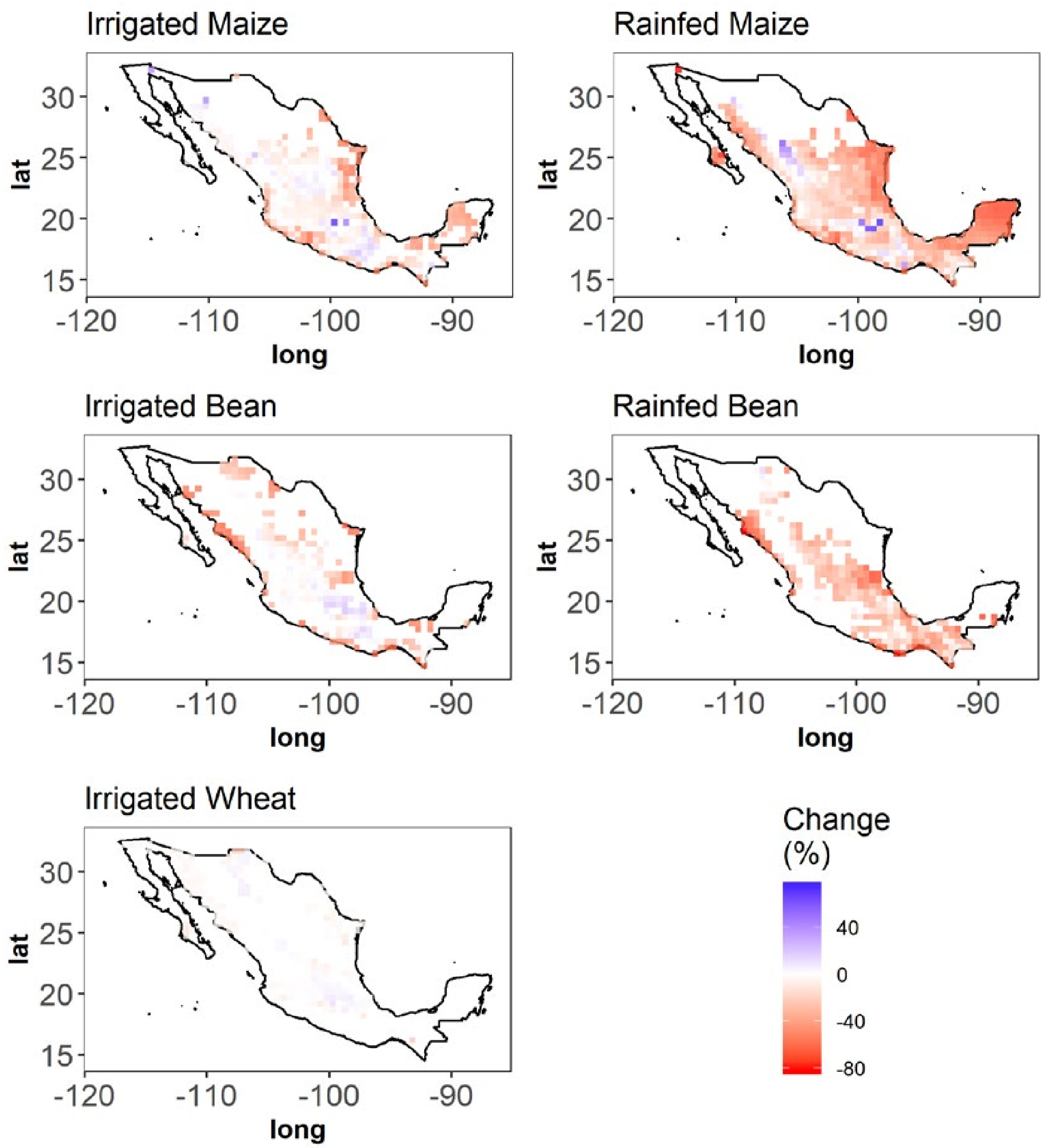


Figure 3: Projected yield impact maps, key crops (2020-2050).

The spatially explicit impact maps in Figure 3 show important geographical variation in impacts. Projected maize and bean yield losses largely correspond to areas where decreases in rainfall are projected to be severe, especially along the northwest coast, while pockets of relative resilience and even yield gains may be seen in the Durango region and parts of the southern central valley, where rainfall is projected to increase. Again, note how irrigated yields exhibit greater resilience than rainfed yields. Irrigated wheat yield projections likewise exhibit potential biophysical resilience and gains in both the north and southern central valley, and relative vulnerability along the coastal areas.

Suitability

Climate change impacts on agro-ecological suitability for coffee (Robusta and Arabica), banana, yam, cassava, potato and sugarcane were assessed using niche based models. In these models, "suitability" is defined based on how well local precipitation and temperature match the biophysical requirements of the given crop.

Suitability modeling suggests that the average area suitable for banana, potato, and yam cultivation is projected to decrease by 83.8%, 58.1%, and 12.1%, respectively, while cassava exhibits relative resilience (Figure 4). In the spatially explicit suitability impact maps (Figure 5), we see that substantial declines in suitability are generally concentrated in the Yucatan peninsula and central valley, where the climate projections in Figure 1 show increasing temperature and diminishing rainfall to be most severe. The spatially explicit suitability impact maps also indicate important variation hiding behind the national averages for yam and cassava. Yam suitability loss in the Yucatan peninsula is offset by gains in the eastern Sierra Madre; while cassava suitability loss along the coastal lowlands is considerably offset by stable suitability farther inland, as well as pockets of suitability gain higher up the slopes of the western Sierra Madre. These crops are not currently grown in Mexico in any significant quantity, but could in the future become important supplements to traditional carbohydrate sources like maize and rice, which exhibit comparatively greater biophysical vulnerability to climate change. They also exhibit considerably more resilience than potato, which is currently grown in the country in small quantities.

The average decline in suitability for Arabica and Robusta coffee is projected to be severe (43.9% and 22.9%, respectively), but a spatially explicit suitability impact map indicates that projected steep declines in Arabica coffee suitability in the western Sierra Madre and southern lowland areas are, to some extent, offset by gains farther inland (Figure 6).

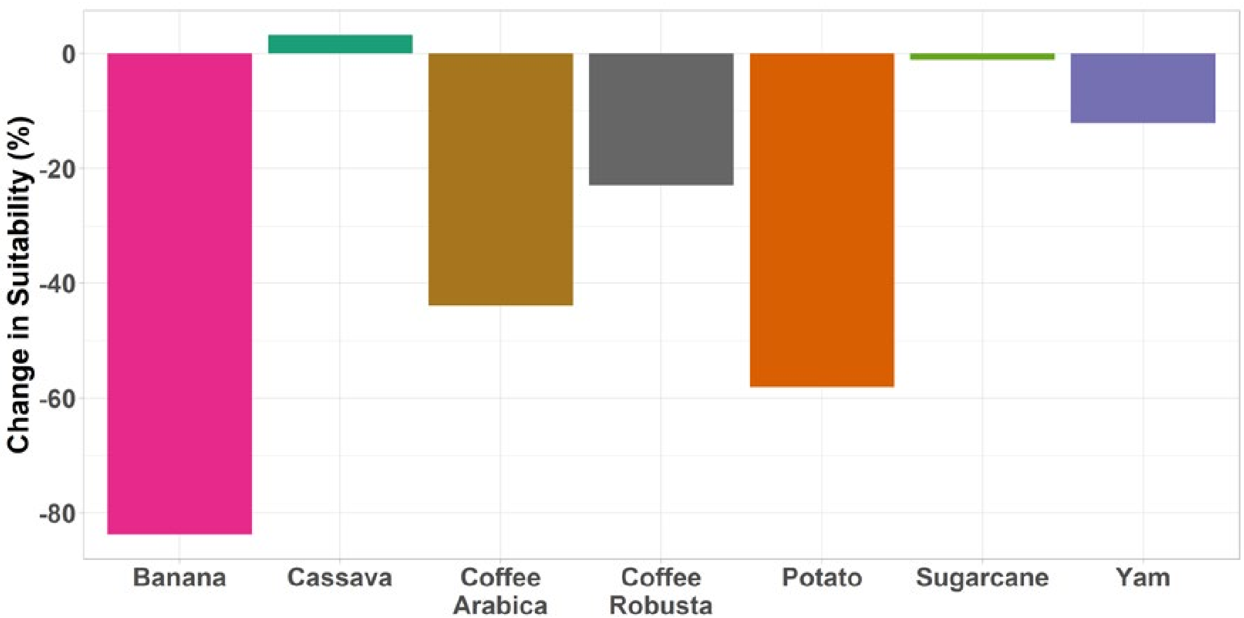


Figure 4: Projected change in suitability for key crops (2020-2050), national average.

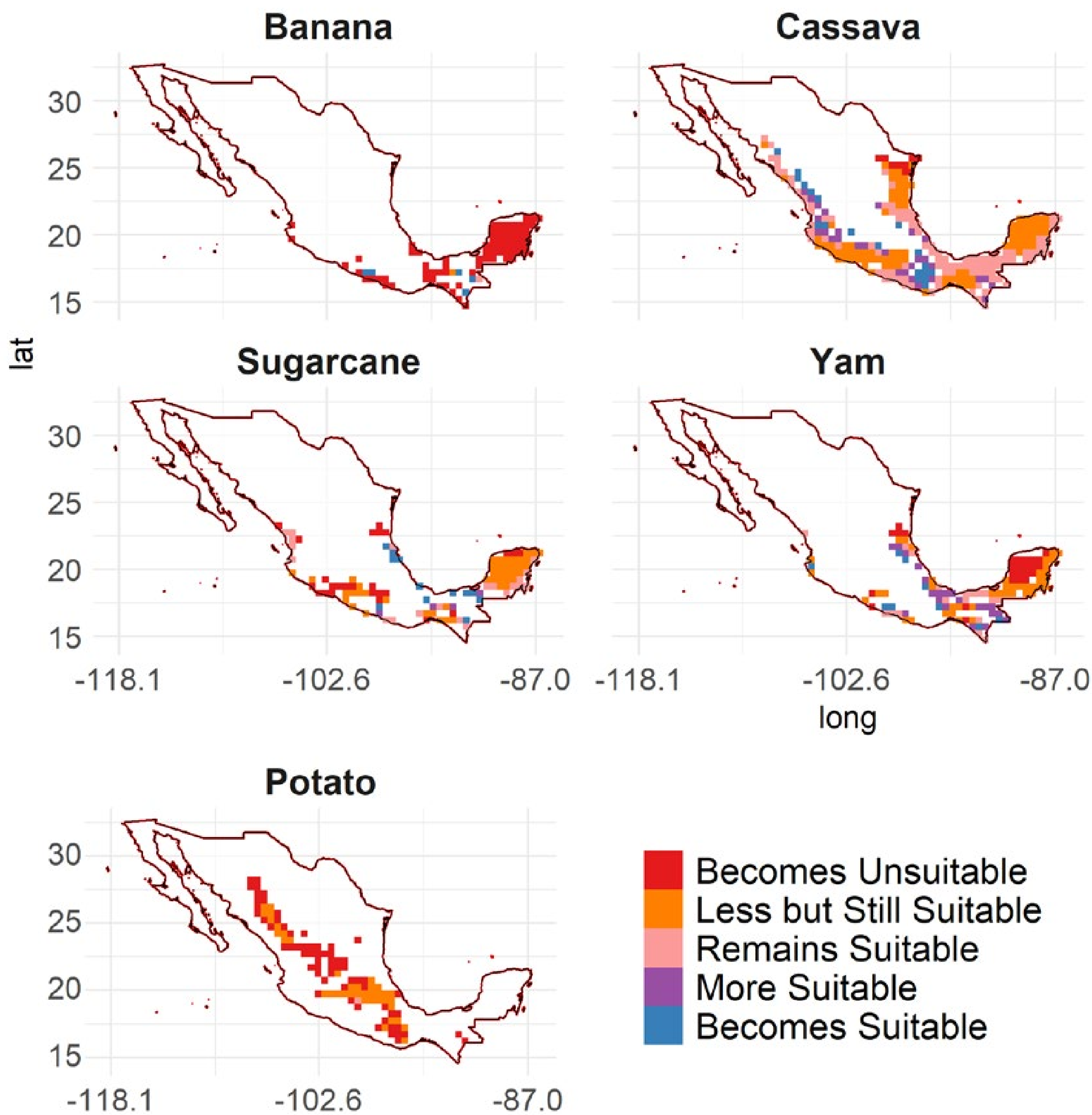


Figure 5: Projected suitability impact maps (2020-2050).

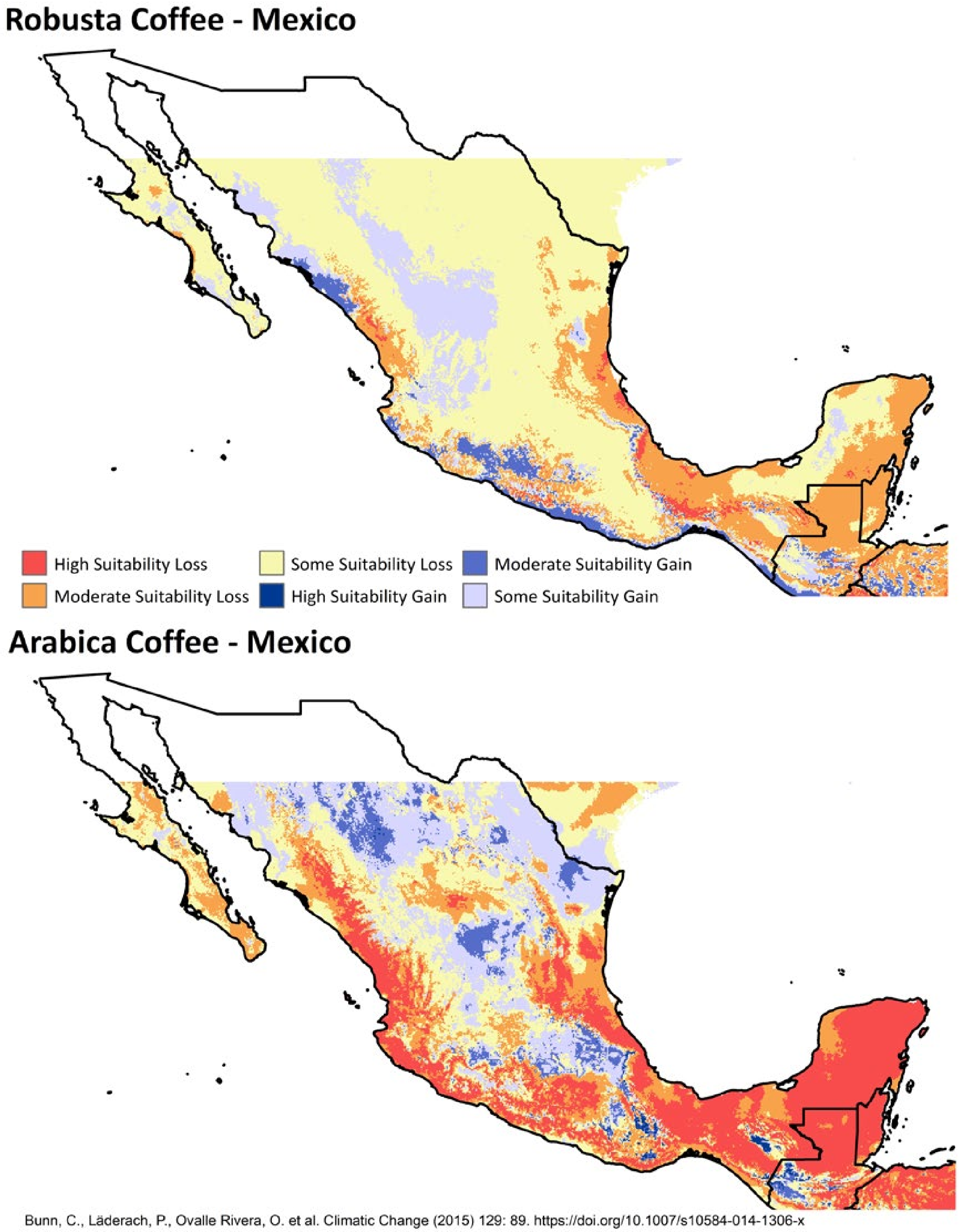


Figure 6: Projected change in suitability for Arabic Coffee by 2050.

4. Economic impacts

In order to understand the real impacts of climate change on demand, supply, and international trade flows, the purely biophysical impacts addressed in the sections above must be adjusted for the economic agency of farmers who can adapt to yield and suitability loss by switching to alternative cultivars and practices. Ongoing advances in productivity and yield enhancing agricultural research, as well as the mitigating action (or inaction) of governments on emissions policy, must also be taken into consideration. The interplay of these factors was modeled using the International Model for Policy, Agricultural Commodities, and Trade (IMPACT), developed at the International Food Policy Research Institute. In this section, IMPACT projections are presented for the DSSAT modeled crops, accounting for global economic and climate change contexts of these crops as well as their substitutes. Under both CC and No-CC scenarios, production is projected to increase out to 2050 for most modeled crops. The one notable exception is wheat production, which is projected to decline substantially. This decline—which is projected to occur regardless of climate change—suggests that, in spite of the biophysical resilience observed in the yield modeling section above, international trade dynamics may evolve to the point where Mexico's competitors end up gaining a comparative advantage in wheat that depresses incentives for domestic production of the crop. The CC production outlooks for bean, soybean, and wheat fall below their No-CC benchmarks by 9.7, 7.8, and 3.4 percentage points (pp), respectively. Meanwhile, rice production is projected to rise above its No-CC benchmark by 8.3 pp (Figure 8).

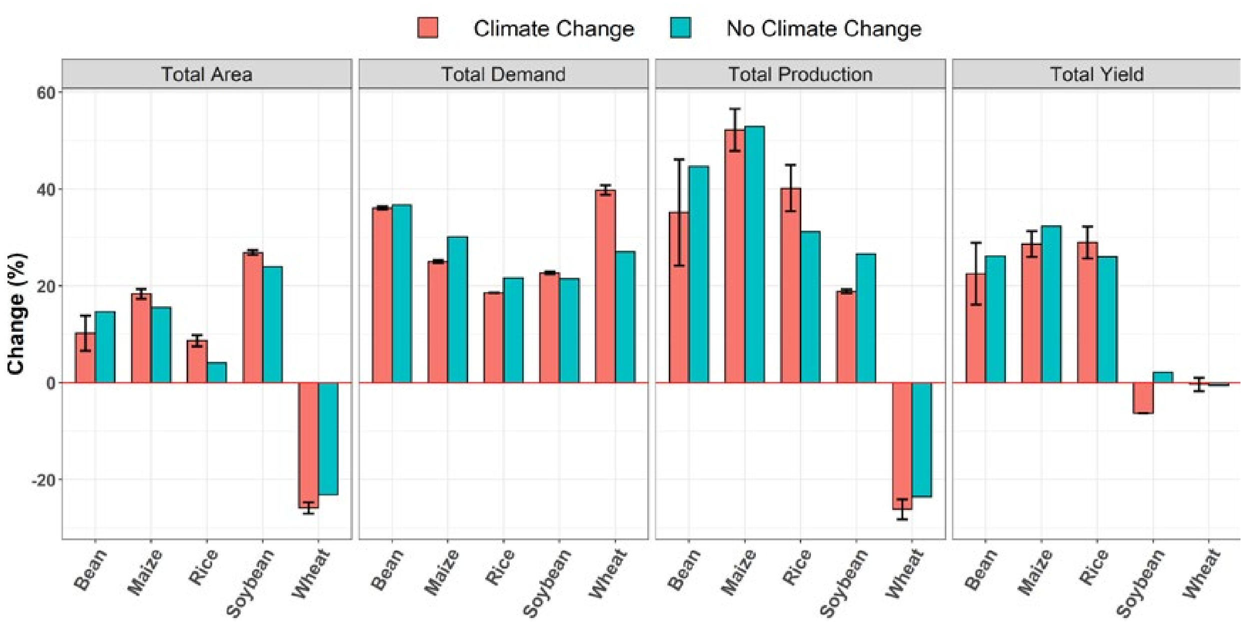


Figure 7: Percentage change in yield, demand, cultivated area, and production (2020–2050), when economic context and agricultural research are taken into account. The error bars indicate the range of output across the nine climate models.

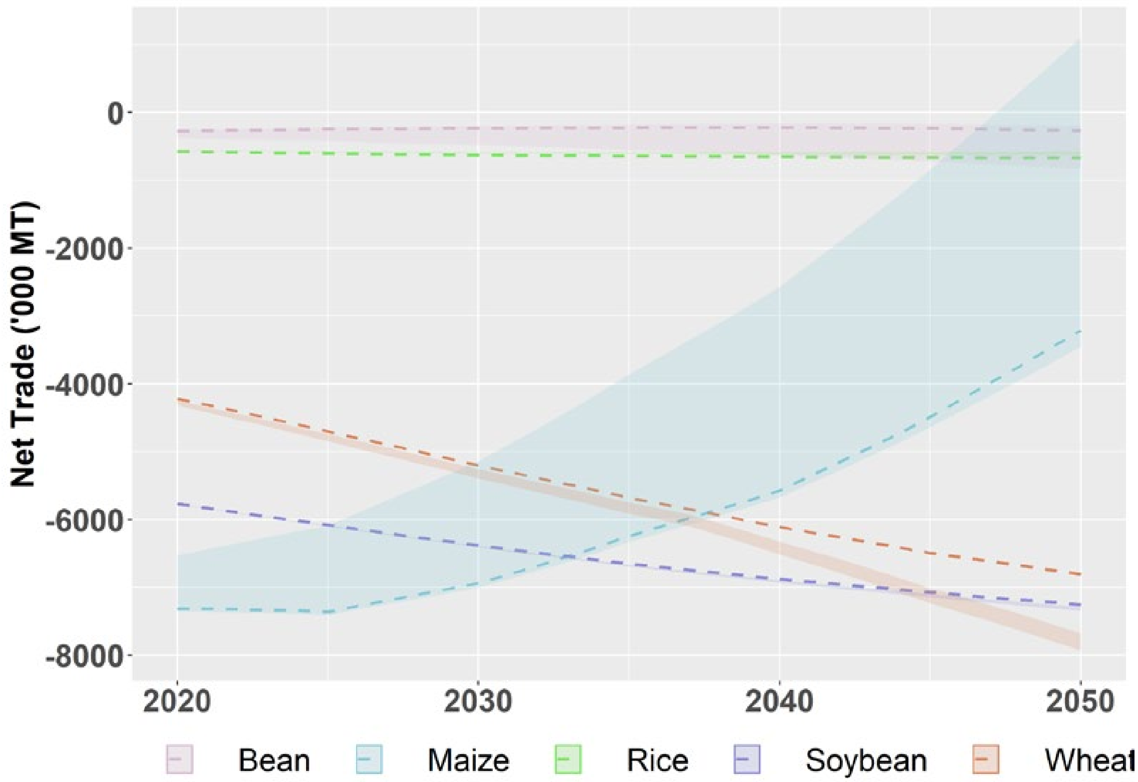


Figure 8: Climate change impact on trade. The dotted lines indicate the no climate change (No-CC) trajectory while the shaded areas correspond to the range of climate change (CC) trajectories given by the nine climate models.

In Figure 8, the current negative balance of trade in soybean and wheat is projected to grow out to 2050 under both CC and No-CC scenarios. Little to no trade is projected in beans or rice, meaning that most of the anticipated increase in production will be consumed domestically. The maize trajectory exhibits a dramatic reduction in import dependence. This is unique in the region, as most LAC countries exhibit a steady rise in maize import dependence out to 2050. Climate change is projected to offset the trend for maize by 27.4 pp, while amplifying the trend for wheat by 21.5 pp (Figure 8).

5. The way forward

Mexico's Nationally Determined Contribution (NDC) to the 2015 Paris Agreement includes integrated agricultural adaptation goals that may work to reduce the magnitude of some of the trends discussed above [3]. Mexico engaged early in the global dialog on climate change adaptation and was the first developing country to submit the Fourth National Communication on climate change strategies to the UNFCCC [4]. Mexico's "10-20-40 National Climate Change Strategy," adopted in 2013, reinforces its commitment to a 50% reduction in greenhouse gas (GHG) emissions by 2050, and includes better agricultural and forestry practices among its mitigation and adaptive measures [3]. Investment and climate adaptation has increasingly focused on regional-scale vulnerabilities and in working to address challenges in key productive areas such as the coastal wetlands along the Gulf of Mexico that support important ecosystem services and productive areas [5]. Mexico may be able to reduce the impact of climate change on the agricultural sector by adopting climate-smart agricultural (CSA) practices that increase productivity while reducing GHG emissions and adapting to shifting growing conditions. Some specific adaptation measures are presented in Table 2.

Table 2: Key messages for policy interventions

	Key messages for policy interventions	Way forward
Climate	Key Climate Observations • Steep decline in rainfall projected for the entire country, especially during December-February and June-August. • A pocket of increased rainfall projected in the Jalisco region during March-May. • Slight increase in rainfall projected for much of the southern half of the country during September-November. • Significant increase in year-round maximum and minimum temperatures projected for the entire country.	Main climate change activities should focus on: • Strengthening of agroclimatic information and market intelligence services, especially in areas of greatest vulnerability. • Promotion of research, release, and adoption of improved/climate resilient varieties. • Assessment of potential adaptive measures and/or alternatives to maize, beans, and banana, which exhibit high vulnerability to climate change. • Promotion of irrigation and efficiency in water management and use. • Follow-up assessment of Mexico's potential regional comparative advantage in maize trade suggested by the IMPACT model. • Assessment and exploitation of the climate change resilient properties of yam and cassava as potential alternatives or supplements to maize, rice, and potato.
Agriculture	Key Agriculture Observations • In general, irrigated systems are less affected by climate change than rainfed systems. Irrigation may play an important role in effective adaptation strategies. • Significant yield loss projected for both irrigated and rainfed bean and maize, although the loss is less severe for irrigated systems. • Economic modeling suggests that Mexico may end up with a regional comparative advantage in maize, thereby dramatically reducing maize imports.-Projected irrigated wheat yields exhibit resilience in the northern and southern central valley, with some vulnerability along the west coast. However, economic modeling suggests that incentives to grow wheat may nonetheless decline due to international competition. • Catastrophic loss of suitable environment projected for banana, especially in the Yucatan region. • Steep decline in suitability projected for coffee in the western Sierra Madre and southern lowland areas, although this may be partially offset by suitability gains farther inland. • Yam and (especially) cassava exhibit relative resilience to climate change, especially along the Sierra Madre piedmonts. While not currently produced in large quantities, these crops show potential as an alternative or supplementary source of carbohydrates, considering that traditional carb sources like maize and rice are projected to come under increasing biophysical stress. • Potato is also an alternative carb source, but exhibits severe vulnerability to climate change, especially in the central valley.	

XV. Nicaragua

1. Context

Agriculture continues to play an important role in Nicaragua. The sector accounts for 15.5% of GDP, down 3.4 percentage points (pp) from a peak of 18.9% in 2011. Crop products accounted for 16% of all exports in 2018, down 15.9 pp from 2009. Jobs in agriculture account for 29.4% of all employment in the country, up 0.7 pp from 8 years ago [1]. Nonetheless, climate change impacts including tropical storms, droughts and flooding present significant risk to crop yields and the broader economic performance of the agricultural sector and the economy. In fact, worldwide, Nicaragua is among the six countries most affected by weather-related losses in the period 1998-2017 [2]. A better understanding of the climate change impacts on specific crops will hence assist in decision making. For this purpose, climate, crop, and economic modeling results are presented in this brief (averaged over 2020–2050), regarding agricultural production and trade in the country, set in the LAC regional context. Based on these trends, adaptation measures are proposed at the end of the brief.

2. Climate impacts

In assessing future climate impacts, this study utilized nine general circulation models (see Methodological Summary for detail) selected for their strong performance in the LAC region. Overall, temperatures are predicted to increase by 1-4 °C across the LAC region, with the Caribbean and tropical South America projected to warm at higher rates than Mexico and the Southern Cone.

In Nicaragua, projected changes in rainfall will vary considerably by season and region. A sharp decrease is projected across the entire country for the summer months of June to August, with a smaller decrease in September to November (Figure 1). However, during the December to February period, increased rainfall is projected in the pacific coastal areas, especially Chinandega and León provinces, while decreasing in the interior and south eastern Caribbean coast. During the March to May period, the pattern reverses, with decreased rainfall projected along the Pacific coast and an increase in the interior and south east. Maximum and minimum temperatures are projected to rise by about 1-3°C throughout the year, with the highest increases occurring along the coasts.

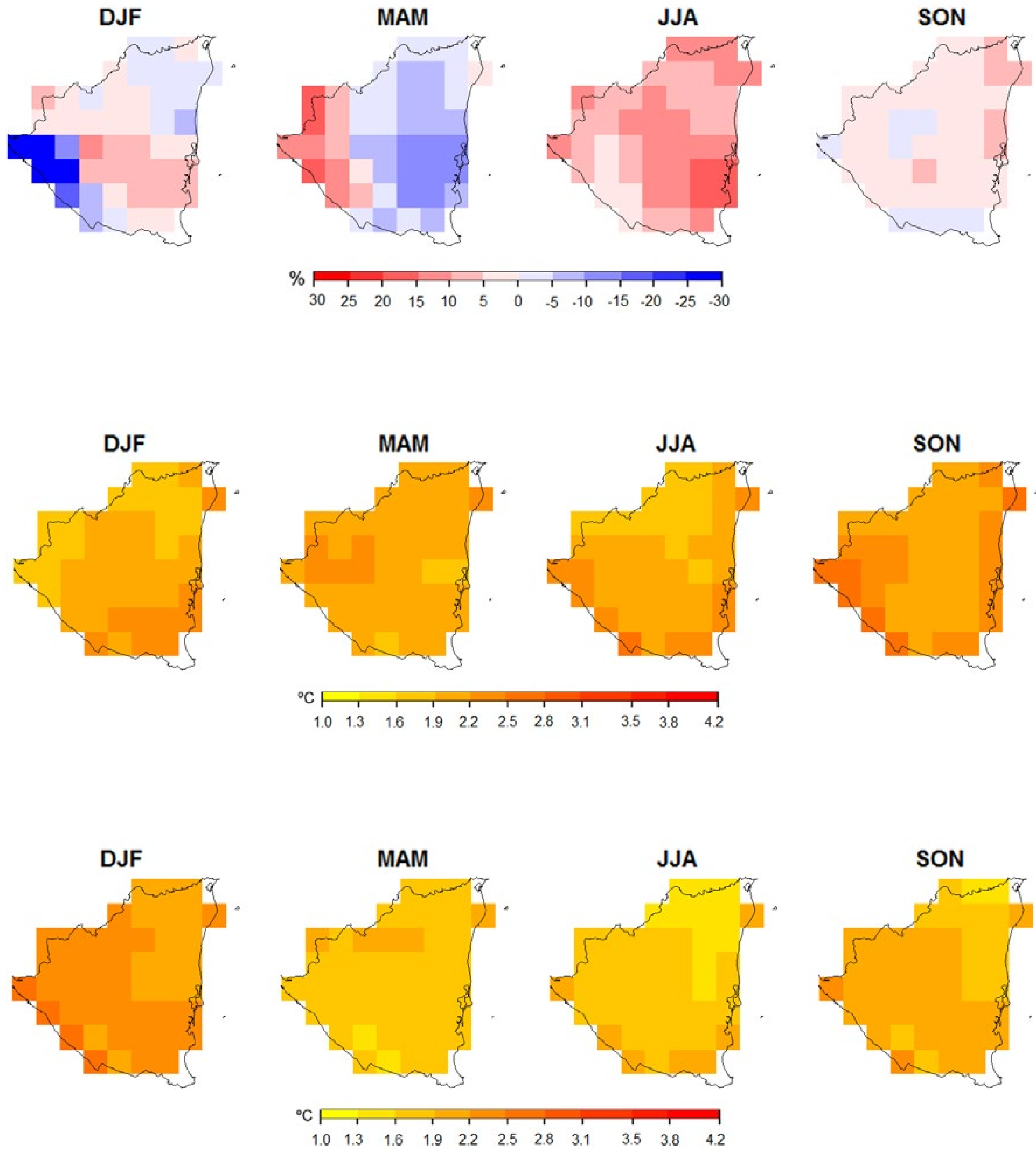


Figure 1: Change in (top to bottom) precipitation, maximum temperature, and minimum temperature averaged across nine GCMs (2020-2050). DJF= December - February, MAM= March - May, JJA= June - August, SON= September - November.

3. Yield and suitability impacts

Yield

Based on the projected changes in climate discussed above, 2050 projections of maize, rice, bean, and soybean yields were modeled using the Decision Support System for Agrotechnology Transfer (DSSAT v4.5) at 0.5 degree spatial resolution. Model runs for each crop were parameterized using genetic coefficients of varieties carefully selected by experts for their relevance in the region.

In Nicaragua, the crop modelling results shown in Figure 2 suggest that both irrigated and rainfed maize and bean systems are likely to see declines in average yield relative to a no-climate change (No-CC) scenario. The geographically disaggregated view offered in Figure 3 indicates that maize and bean systems in the country's northwestern coastal region, particularly Chinandega and León departments, may be especially hard hit, with mean yields falling 20% or more below the No-CC baseline. The greater projected decline in irrigated relative to rainfed yields is due to the concentration of irrigated farming in these vulnerable areas. Rainfed maize and bean systems extend farther inland, where CC impacts are projected to be relatively less severe. Rainfed and irrigated rice yield potential exhibits relative resilience throughout the country, meanwhile, and is even projected to increase in several areas, especially the interior.

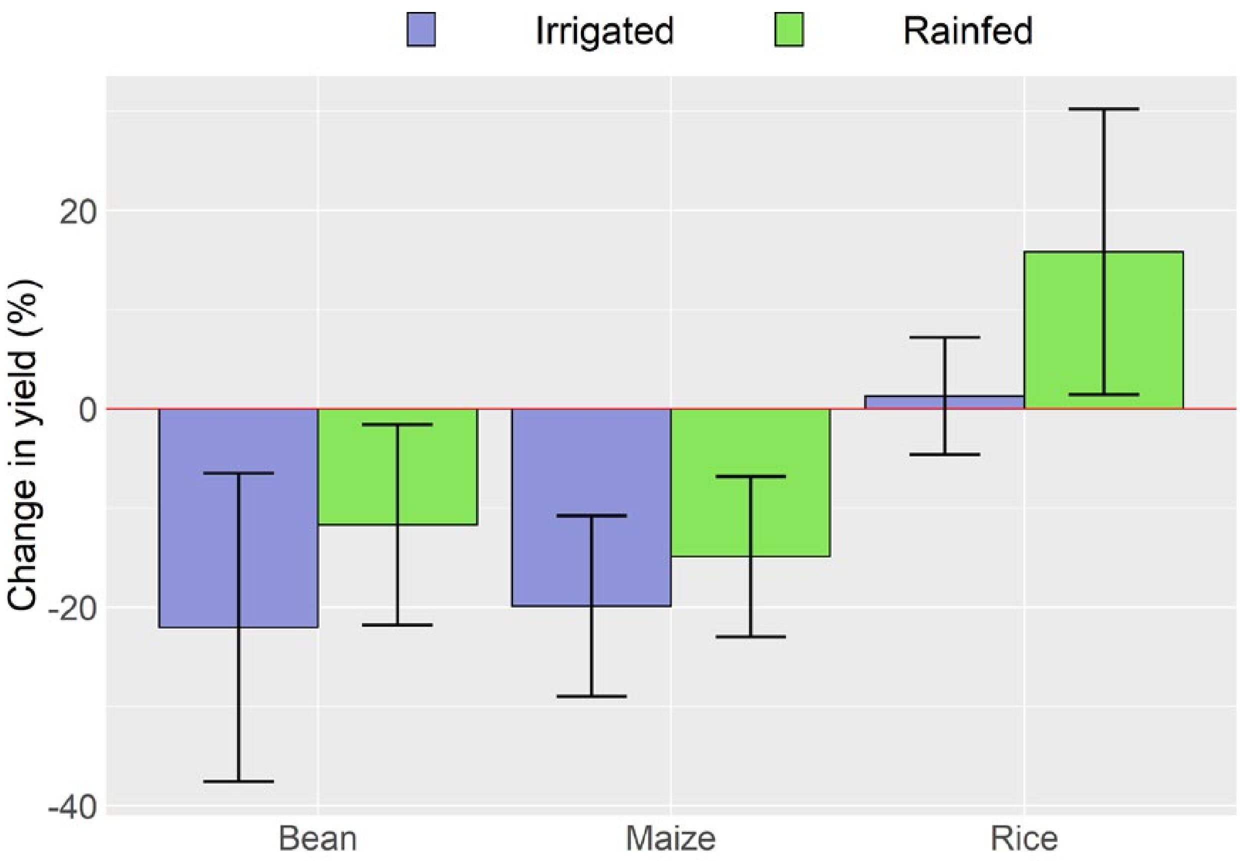


Figure 2: Projected average yield change, key crops (2020–2050). The error bars indicate the range of output across the nine climate models.

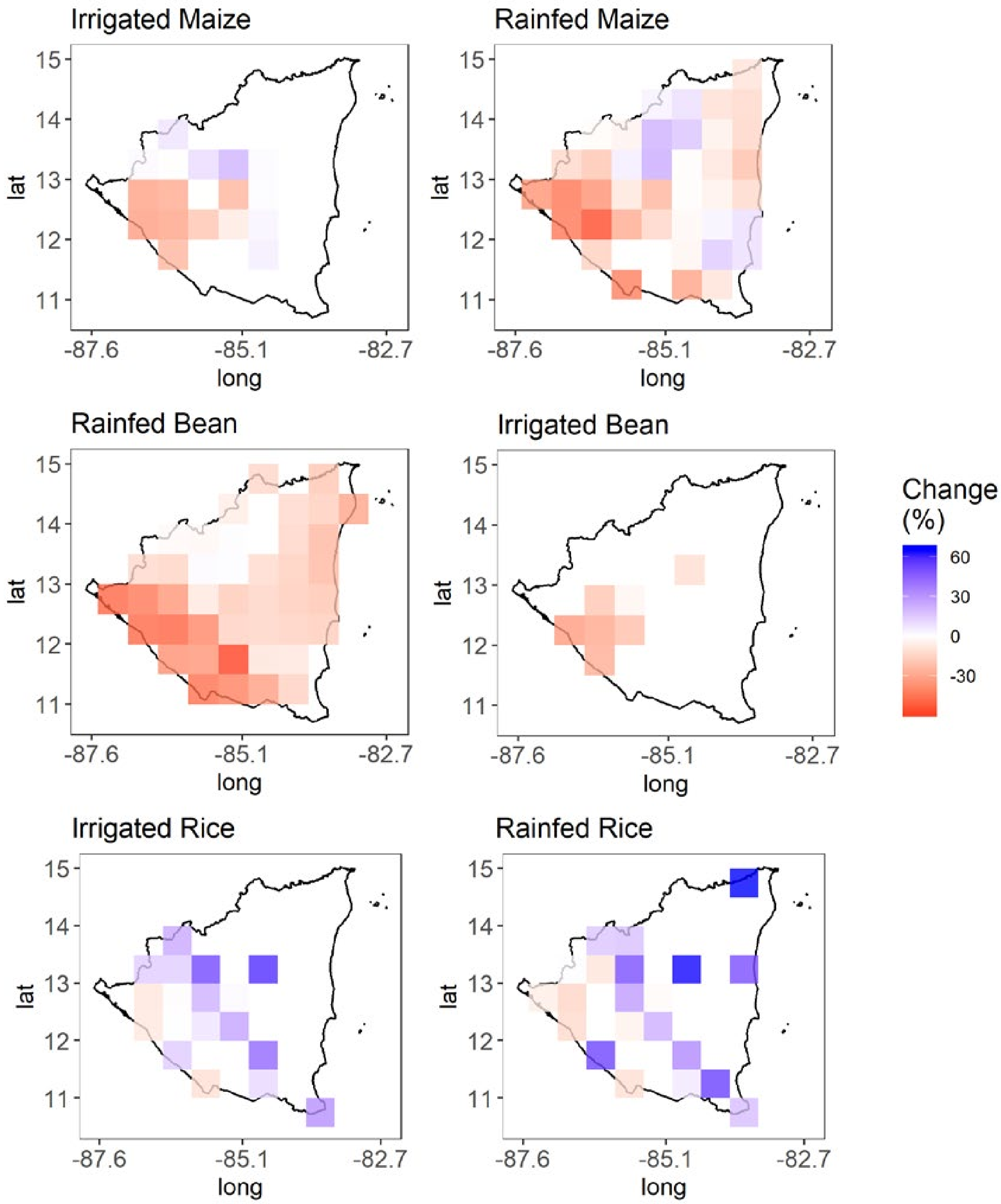


Figure 3: Projected yield impact maps, key crops (2020-2050).

Suitability

Climate change impacts on agro-ecological suitability for key commercial and staple crops, including coffee (Robusta and Arabica), banana, and sugarcane, were assessed using niche based models. In these models, "suitability" is defined based on how well local precipitation and temperature match the biophysical requirements of the given crop.

Suitability modelling suggests that the average suitable area for banana and coffee (Arabica and Robusta) may decline considerably out to 2050 (Figure 4). Sugar cane, meanwhile, exhibits relative resilience. The geographically explicit suitability impact maps in Figure 5 reveal important variation behind these national averages. Banana suitability loss is concentrated along the coastal zones, but there is a pocket of land in the northern interior where suitability is less affected, and may even improve. Sugar cane suitability improves towards the interior and south into the San Juan River, and low-lying areas of the Matagalpa and Jinotega departments, but suitable growing conditions are projected to decline slightly along the Pacific coast. Cassava, meanwhile, exhibits resilience throughout the country, potentially positioning it as an attractive source of carbohydrates and nutrients under climate change. The Arabica and Robusta coffee suitability impact maps in Figure 6 indicate a major decline in areas suitable for coffee cultivation across the entire country. The projected decline is considerably more pronounced for Arabica than for Robusta, with one small pocket of increased Robusta suitability projected in Chinandega, León, and Managua.

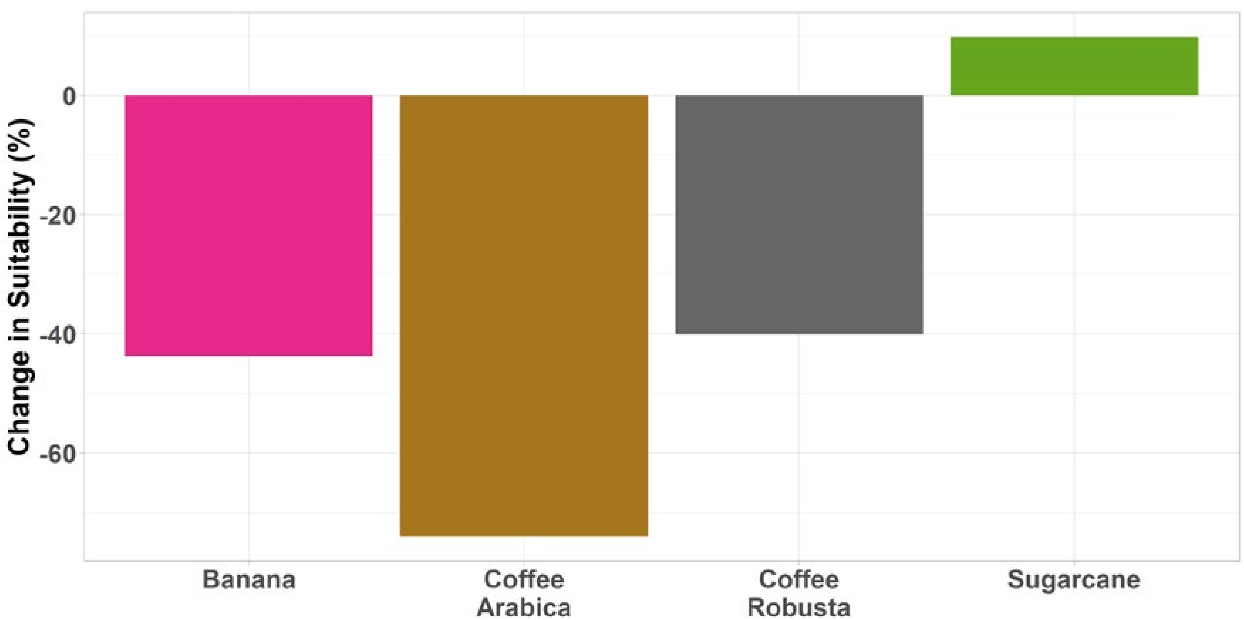


Figure 4: Projected change in suitability for key crops (2020-2050).

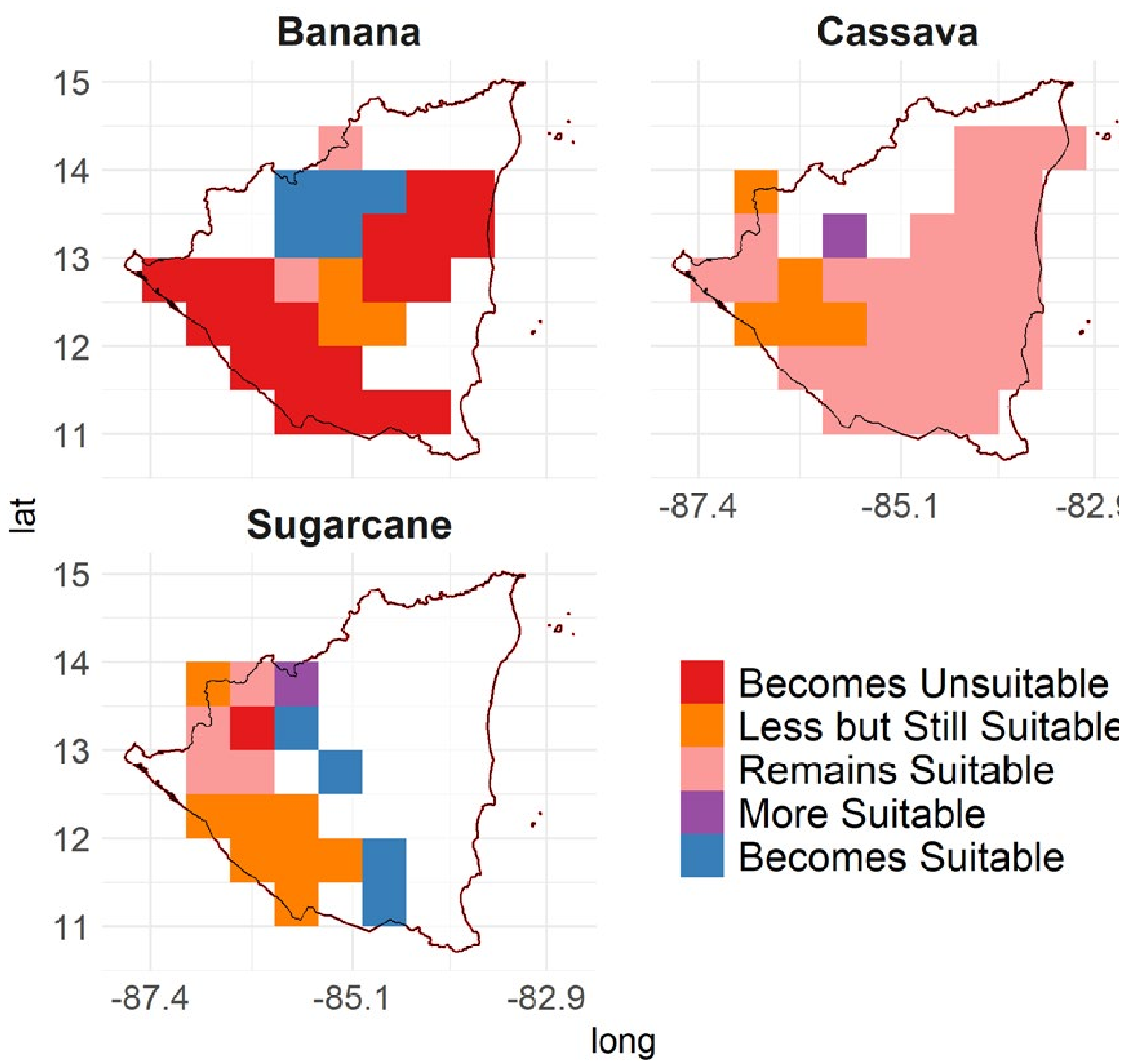
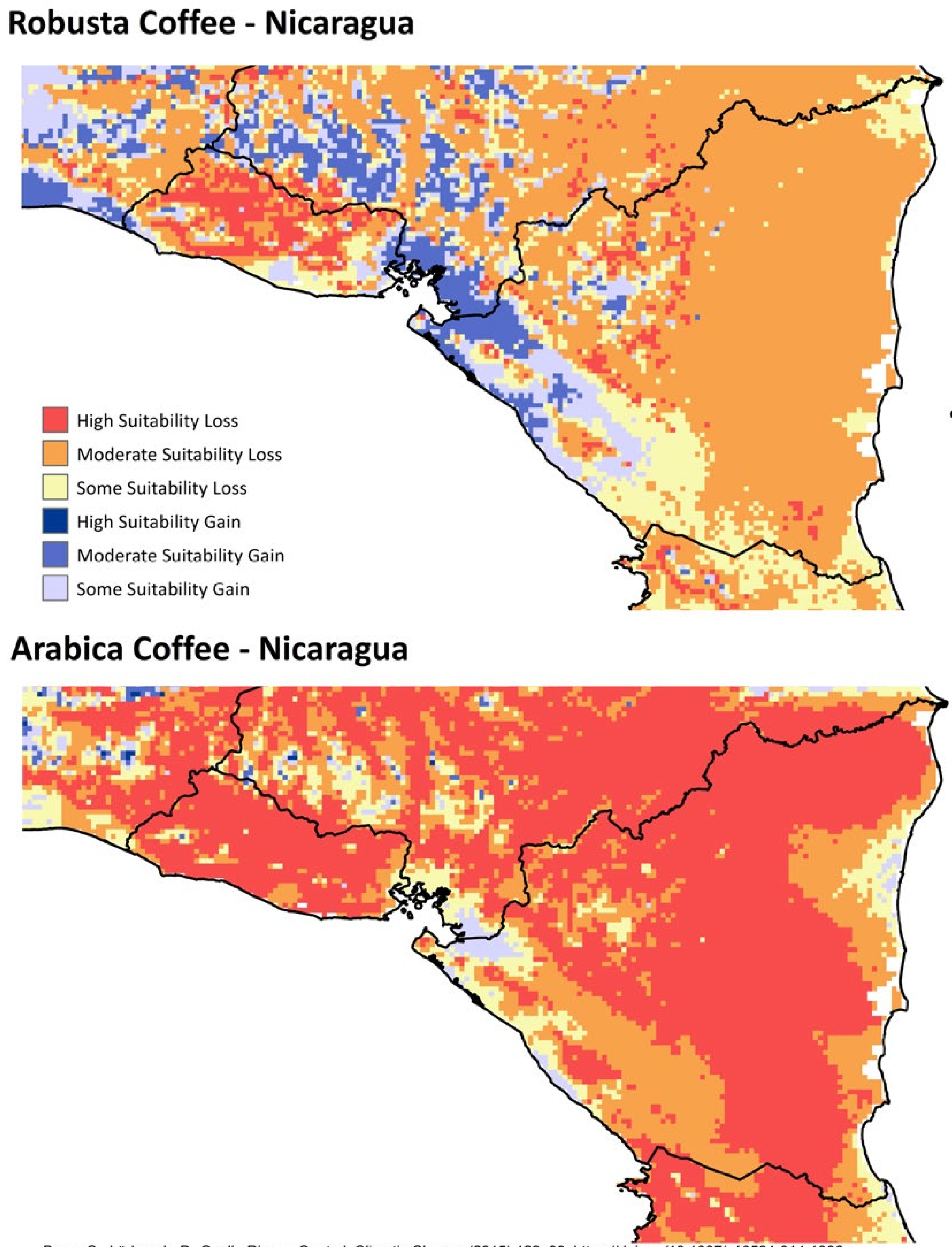


Figure 5: Projected suitability impact maps (2020-2050).



Bunn, C., Läderach, P., Ovalle Rivera, O. et al. Climatic Change (2015) 129: 89. https://doi.org/10.1007/s10584-014-1306-x

Figure 6: Projected change in suitability for coffee by 2050.

4. Economic impacts

In order to understand the real impacts of climate change on demand, supply, and international trade flows, the purely biophysical impacts addressed in the sections above must be adjusted for the economic agency of farmers who can adapt to yield and suitability loss by switching to alternative cultivars and practices. Ongoing advances in productivity and yield enhancing agricultural research, as well as the mitigating action (or inaction) of governments on emissions policy, must also be taken into consideration. The interplay of these factors was modeled using the International Model for Policy, Agricultural Commodities, and Trade (IMPACT), developed at the International Food Policy Research Institute. In this section, IMPACT projections are presented for the DSSAT modeled crops, accounting for global economic and climate change contexts of these crops as well as their substitutes.

Agricultural production is projected to increase out to 2050 under both climate change (CC) and no-climate change (No-CC) scenarios for beans, maize, and rice (Figure 7). Maize and bean production growth are especially pronounced; however, under climate change, this growth is reduced to 25.1 pp and 11.5 pp below the No-CC benchmark, respectively. On the other hand, rice production growth increases moderately under climate change (+10.8 pp). Turning to trade in Figure 8, Nicaragua is projected to become a maize exporter by 2035. Bean exports are also projected to increase steadily out to 2050. These exports, despite the severe biophysical impacts of climate change observed in Figures 2 and 3, is possibly due in part to yield loss being worse in neighboring countries, thereby resulting in a net comparative advantage for Nicaragua in these crops.

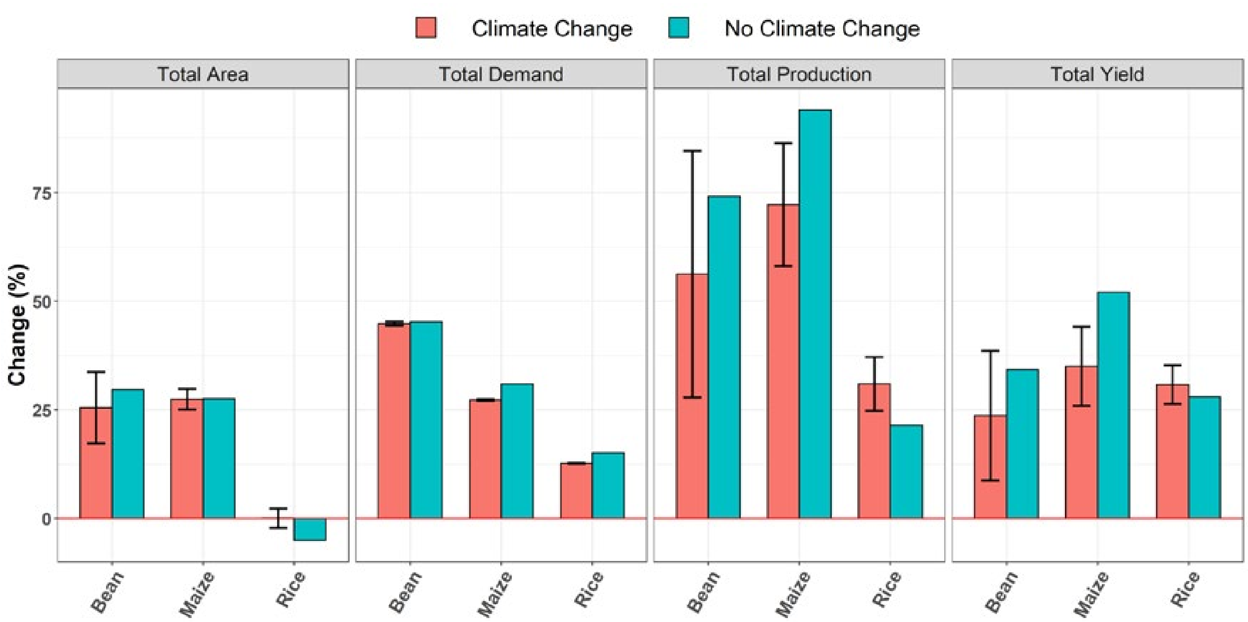


Figure 7: Percentage change in yield, demand, cultivated area, and production (2020–2050), when economic context and agricultural research are taken into account. The error bars indicate the range of output across the nine climate models.

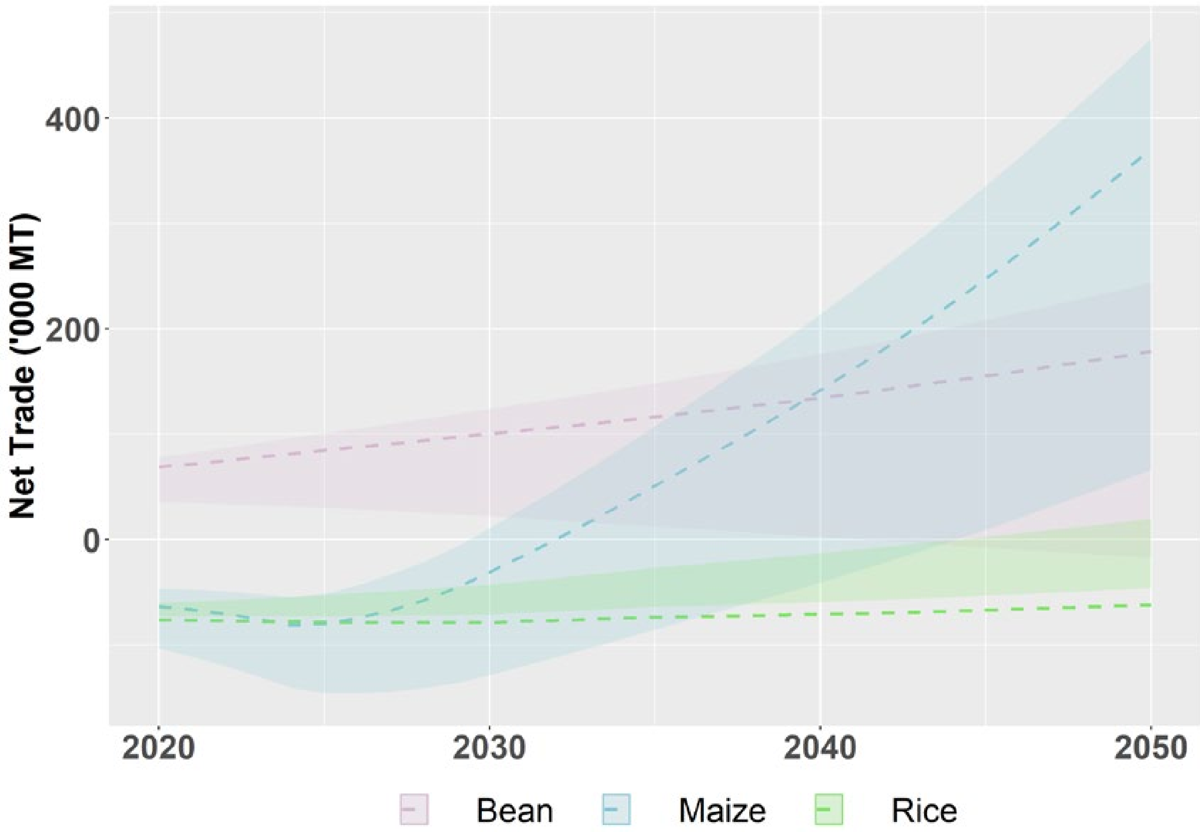


Figure 8: Climate change impact on trade. The dotted lines indicate the no climate change (No-CC) trajectory while the shaded areas correspond to the range of climate change (CC) trajectories given by the nine climate models.

5. The way forward

In an effort to limit the rise in global mean temperature below 2°C and ensure food security, most climate change pledges of the United Nations Framework Convention on Climate Change (UNFCCC) cite agriculture and land use as a key source of adaptation and/or mitigation potential [3]. Nicaragua's Nationally Determined Contribution (NDC) to the Paris Agreement highlights the relevance of the agricultural sector for both adaptation and mitigation actions. Moreover, among key adaptation investments, the NDC recognizes the need for irrigation, water reservoirs and access to technology [4].

Nicaragua and other LAC countries in may be able to reduce the impact of climate change on the agricultural sector by adopting other climate smart agricultural (CSA) practices that increase productivity while reducing greenhouse gas (GHG) emissions and adapting to shifting growing conditions. This may include the continued expansion of no-till agricultural practices, precision nutrient management fertilizer, intercropping, and more advanced crop rotations. With a rural population relying heavily on agriculture and given the sector's potential to reduce poverty and increase GDP, Nicaragua must take steps like these to reduce the impacts of climate change on food production. Increased trade and productivity in the face of yield declines and faltering suitability for both domestic food security and export-oriented crops will require continued investment in agricultural research, robust communication between farmers and market intermediaries, and responsible land management and planning. This must be matched, however, by efforts to preserve and share indigenous varieties of key crops such as beans, cultivated exten-

sively by smallholders across Nicaragua. Given the especially severe production losses in tropical Latin America, Nicaragua will increasingly rely on trade with more temperate zones of the world, including the Southern Cone, to ensure domestic food security. Political and financial market stability will be key to ensuring that these potential opportunities are realized. Key messages for policy interventions and way forward for adaptation measures are summarized below.

Table 2: Key messages for policy interventions

<table>
<tr><th colspan="2">Table 2: Key messages for policy interventions</th><th>Way forward</th></tr>
<tr><td>Climate</td><td>Key Climate Observations
• Temperatures are projected to increase by 1–3 °C in Nicaragua by 2050. Warming will be most pronounced in low-lying coastal areas.
• Rainfall is projected to increase considerably for the northwestern Pacific coastal area during December to February, although also to decrease during these months for much of the rest of the country.
• During the March to May period, this projection is reversed. Rainfall is projected to decrease for the northwestern Pacific coastal area while increasing for much of the rest of the country.
• Rainfall is projected to decrease across the country during the June to August period.</td><td rowspan="2">Adaptation and mitigation measures are key, particularly for increase productivity and resistance of staple crops under conditions of climate change.
Main activities should focus on:
• Agricultural practices (i.e. crop diversification, CSA, use of improved varieties, no-till, intercropping, precision nutrient management, and integration of indigenous knowledge)
• Forest, land and water management
• Increasing the efficiency in water use
• Agricultural research:
» Conduct necessary analyses to identify and prioritize CC adaptation research options for the most relevant crops
» Conduct ex-ante impact assessment of heat and flood resistant crop technology.
» Assess viability of CC resilient crops like cassava as alternative sources of carbohydrates and nutrients.
• If shifting cultivation into new areas of suitable terrain, planners must carefully consider the costs and benefits of replacing forests with agriculture.</td></tr>
<tr><td>Agriculture</td><td>Key Agriculture Observations
• Bean and maize yields are projected to decline considerably by 2050, especially in the northwestern Pacific coastal areas.
• Rice yield is projected to increase.
• Areas suitable for banana cultivation are projected to decline sharply, although this is partly offset by pockets in the northern interior where banana suitability may increase.
• Areas suitable for coffee (robusta and arabica) cultivation are projected to decrease sharply out to 2050 across most of the country, with the exception of Chinandega and León provinces, where conditions may improve for robusta.
• Areas suitable for cassava cultivation are projected to increase or remain the same throughout the country.</td></tr>
</table>

XVI. Panama

1. Context

Agriculture plays a small and declining role in Panama's economy. The sector accounts for just 2.4% of GDP, down 4.5 percentage points (pp) from a peak of 6.9% in 2003 [1]. Crop products accounted for just 0.1% of all exports in 2015 [2]. Jobs in agriculture currently account for 15.1% of all employment in the country, down 2.9 pp from 8 years ago [1]. Service sector industries, on the other hand—especially Panama Canal-related business, banking, and tourism—account for about 70% of GDP. Future growth prospects rest largely on the Panama Canal expansion project, completed in 2016, which has more than doubled the Canal's capacity. Panama's climate is tropical maritime, with a long rainy season from May to January. The geography is mountainous with low plains and rolling hills along the coasts. 7.3% of the land is arable; and less than half of this is under permanent cultivation. Bananas, rice, corn, coffee, and sugarcane are among the most important crops produced in Panama. Another 20.7% of the land is pasture dedicated to livestock, and 43.6% are forests, which are rich sources of biodiversity [3].

2. Climate Impacts

In assessing future climate impacts, this study utilized nine general circulation models (see Methodological Summary for detail) selected for their strong performance in the Latin American and Caribbean (LAC) region. Overall, temperatures are predicted to increase by 1-4 °C across the LAC region, with the Caribbean and tropical South America projected to warm at higher rates than Mexico and the Southern Cone.

In Panama, rainfall is projected to increase across the country, especially during September-November and December-February. The increase is particularly pronounced in the area of Veraguas, Herrera, and Los Santos, important for banana and sugarcane production. Maximum and minimum temperatures are also projected to increase across the country, especially during June-November; and are more pronounced in the western half of the country than in the eastern half (Figure 1).

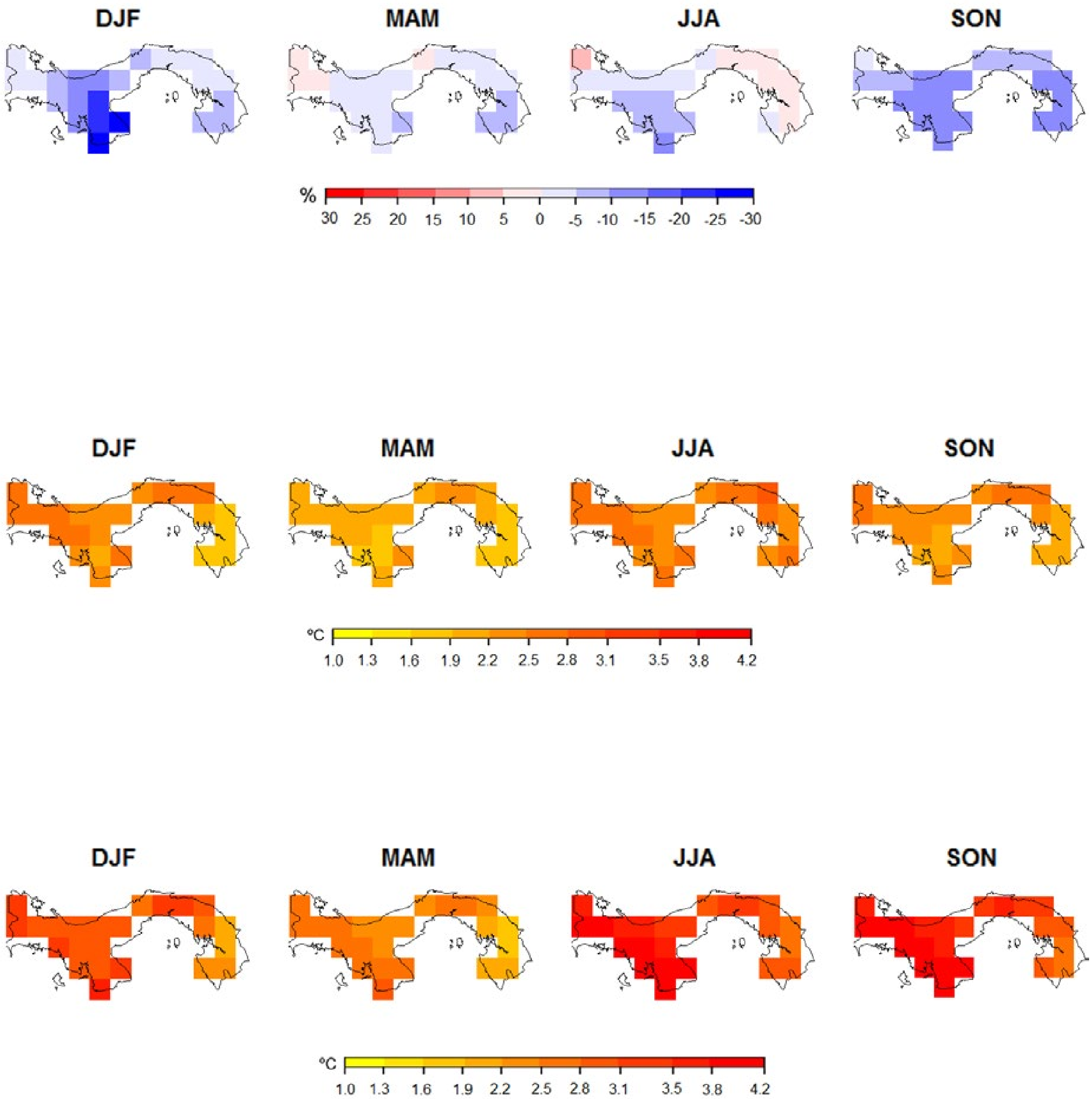


Figure 1: Climate impacts averaged across nine GCMs (2020-2050). DJF= December - February, MAM= March - May, JJA= June - August, SON= September - November.

3. Yield and suitability impacts

Yield

Based on the projected changes in climate discussed above, 2050 projections of maize, rice, and bean yields were modeled using the Decision Support System for Agrotechnology Transfer (DSSAT v4.5) at 0.5 degree spatial resolution. Model runs for each crop were parameterized using genetic coefficients of varieties carefully selected by experts for their relevance in the region.

Yield impact modeling suggests that in 2050, on average, climate change could result in substantial declines in yields for both irrigated and rainfed maize—by 25.6%, and 31.1%, respectively—while irrigated and rainfed rice yields exhibit relative resilience, with declines of less than 5% (Figure 2). Rainfed bean yields are projected to decline by 26.9%. The maps in Figure 3 indicate important variation in rice yield impacts, with yield increases projected in the west where increased rainfall is expected to be greatest and temperature increases least severe, and yield declines elsewhere. Likewise, projected maize yield declines are slightest in the northwest.

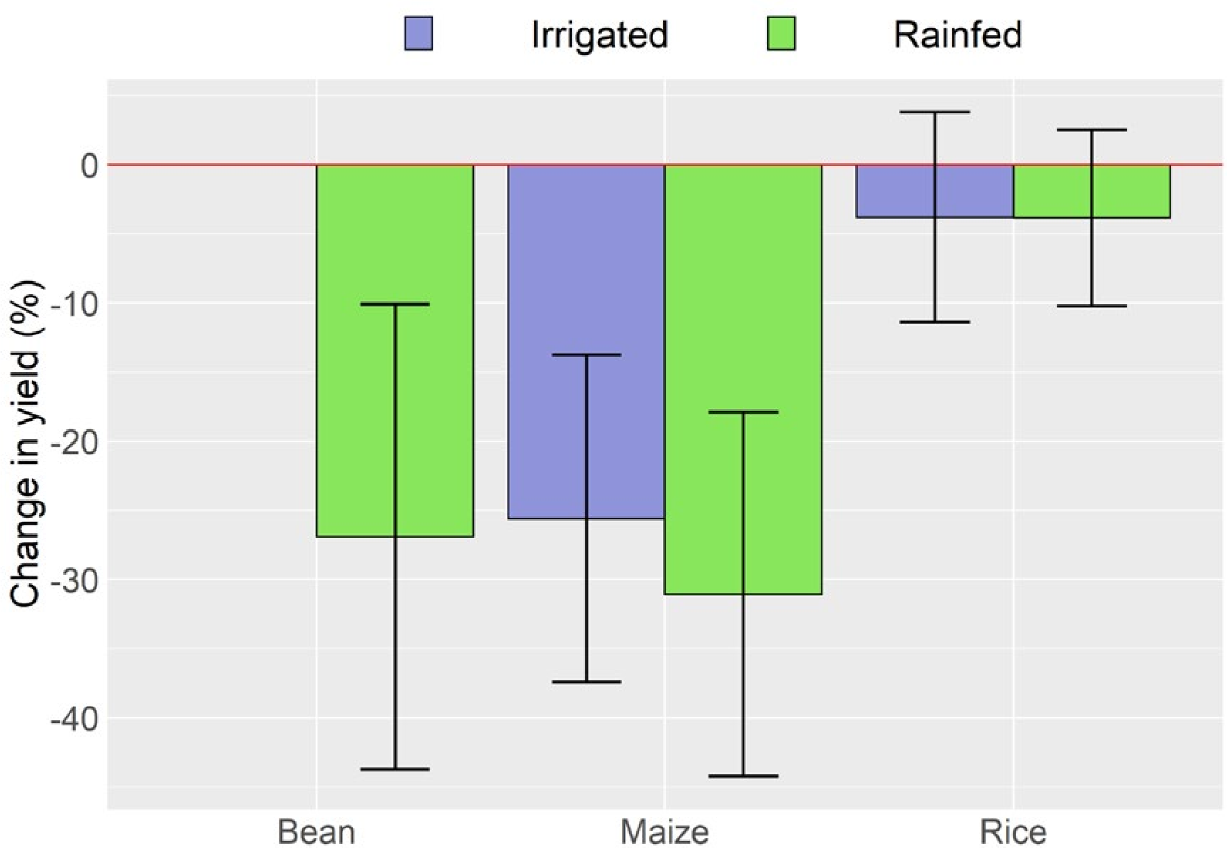


Figure 2: Projected average yield change in Panama, key crops (2020–2050). The error bars indicate the range of output across the nine climate models.

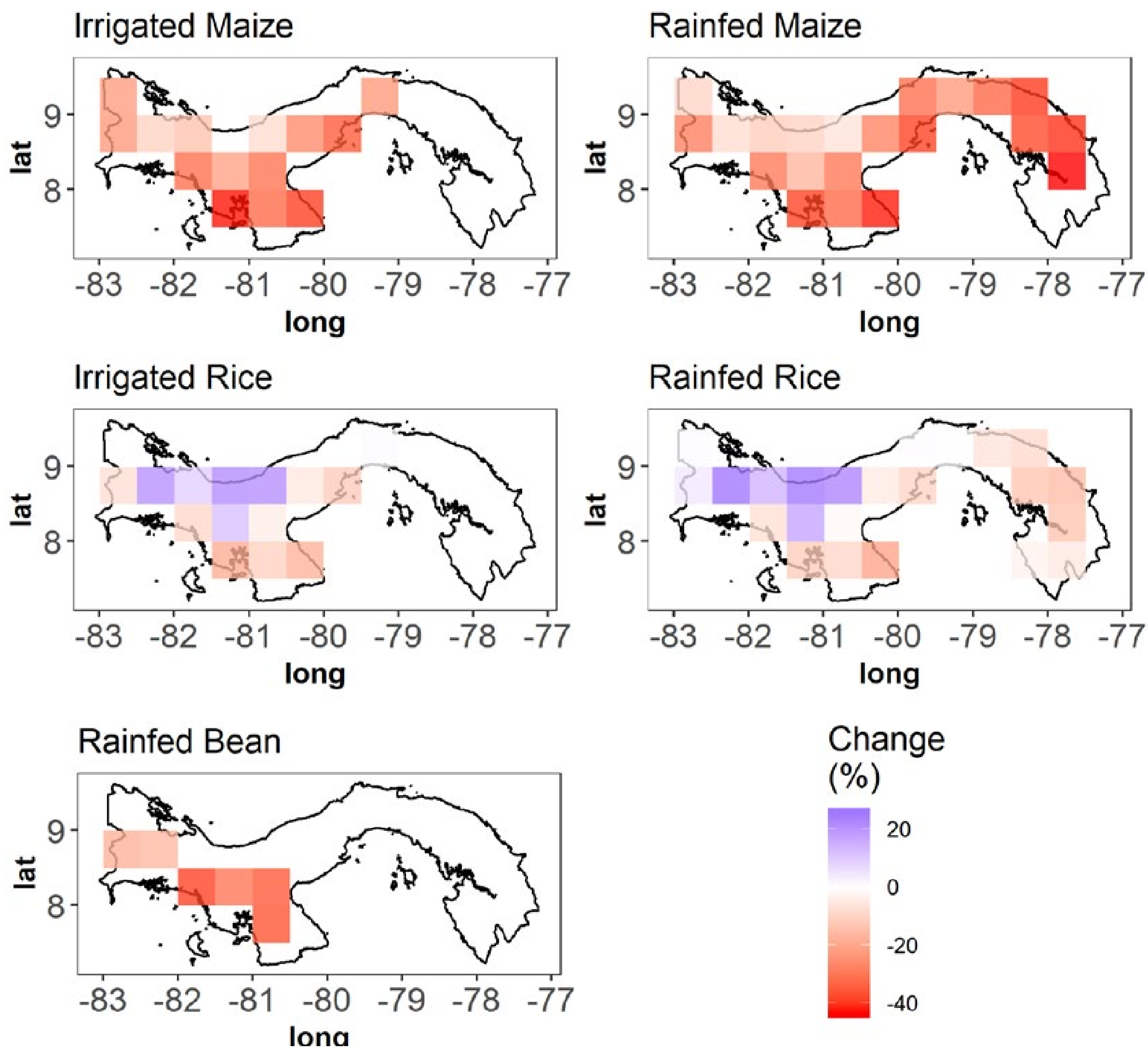


Figure 3: Projected yield impact maps, key crops (2020-2050).

Suitability

Climate change impacts on agro-ecological suitability for coffee (Robusta and Arabica), banana, yam, and cassava were assessed using niche based models. In these models, "suitability" is defined based on how well local precipitation and temperature match the biophysical requirements of the given crop.

Suitability modeling suggests that suitable area for banana cultivation may decrease sharply by 77.8%. Arabica and Robusta coffee suitability is also projected to decline steeply, by 53% and 30.7%, respectively (Figure 4). The impact maps show projected suitability loss for banana evenly distributed across the country, whereas food security crops such as yam and cassava—the latter of which is not currently grown in any significant quantity—exhibit potential resilience to climate change impacts, especially in the west (Figure 5). The suitability impact map for Arabica coffee indicates that these losses are spread evenly throughout the country (Figure 6).

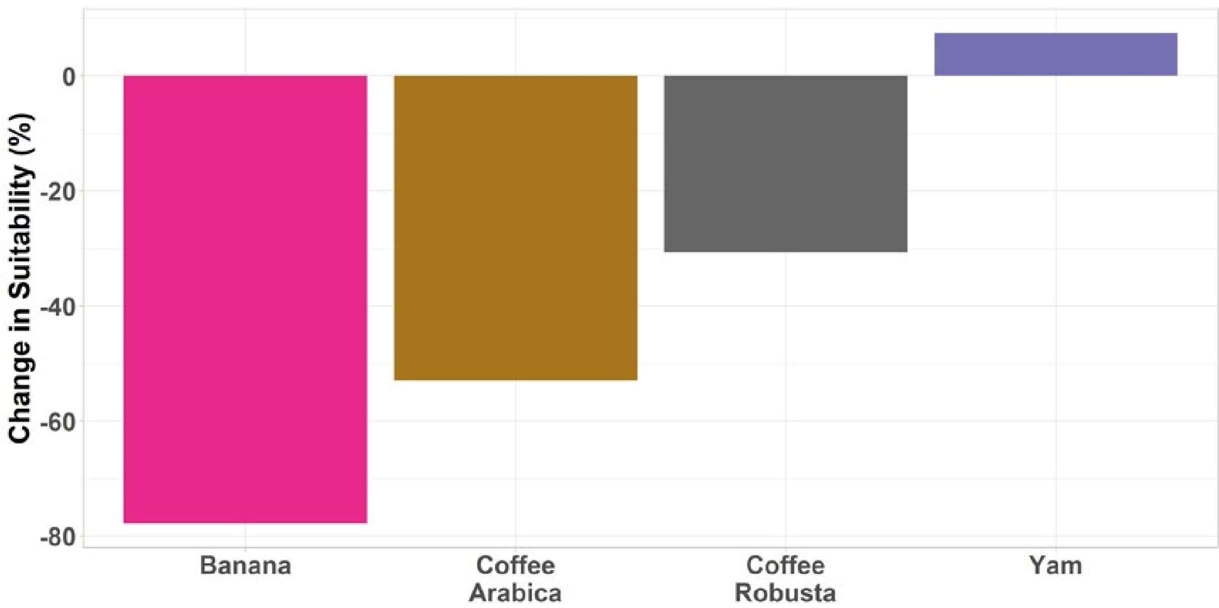


Figure 4: Projected change in suitability for key crops (2020-2050), national average. Cassava suitability, not shown here but included in the analysis, is projected to change very little under climate change (see Figure 5).

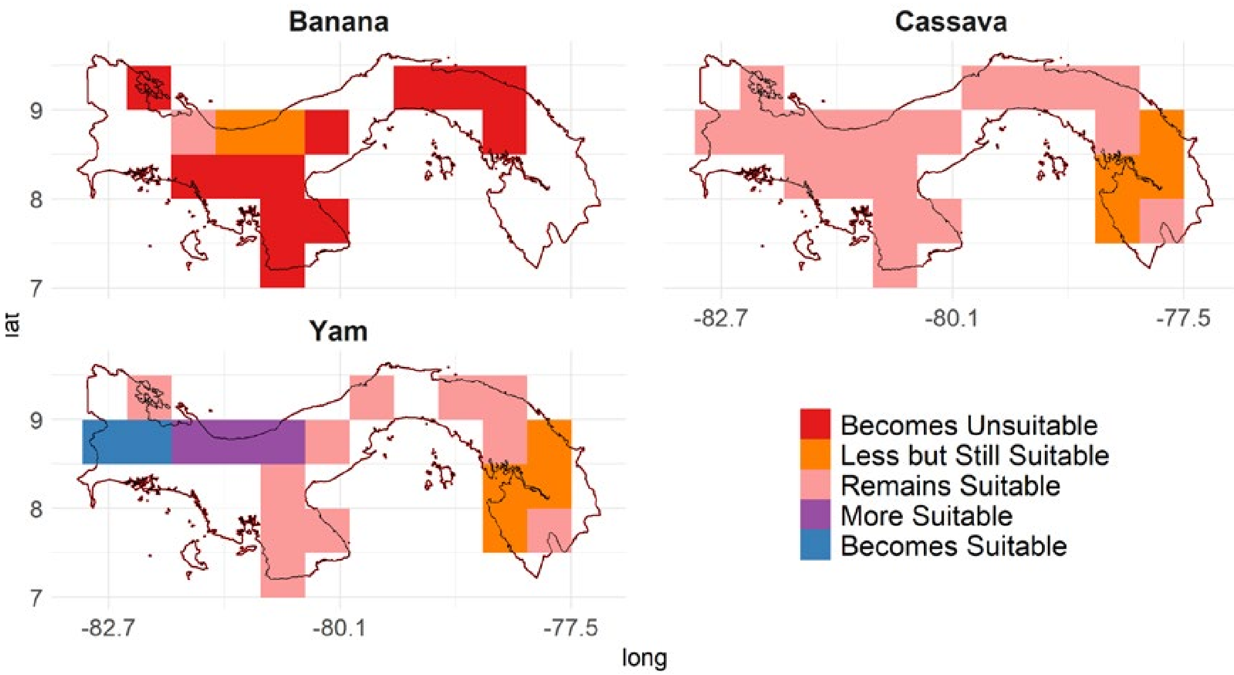


Figure 5: Projected suitability impact maps (2020-2050).

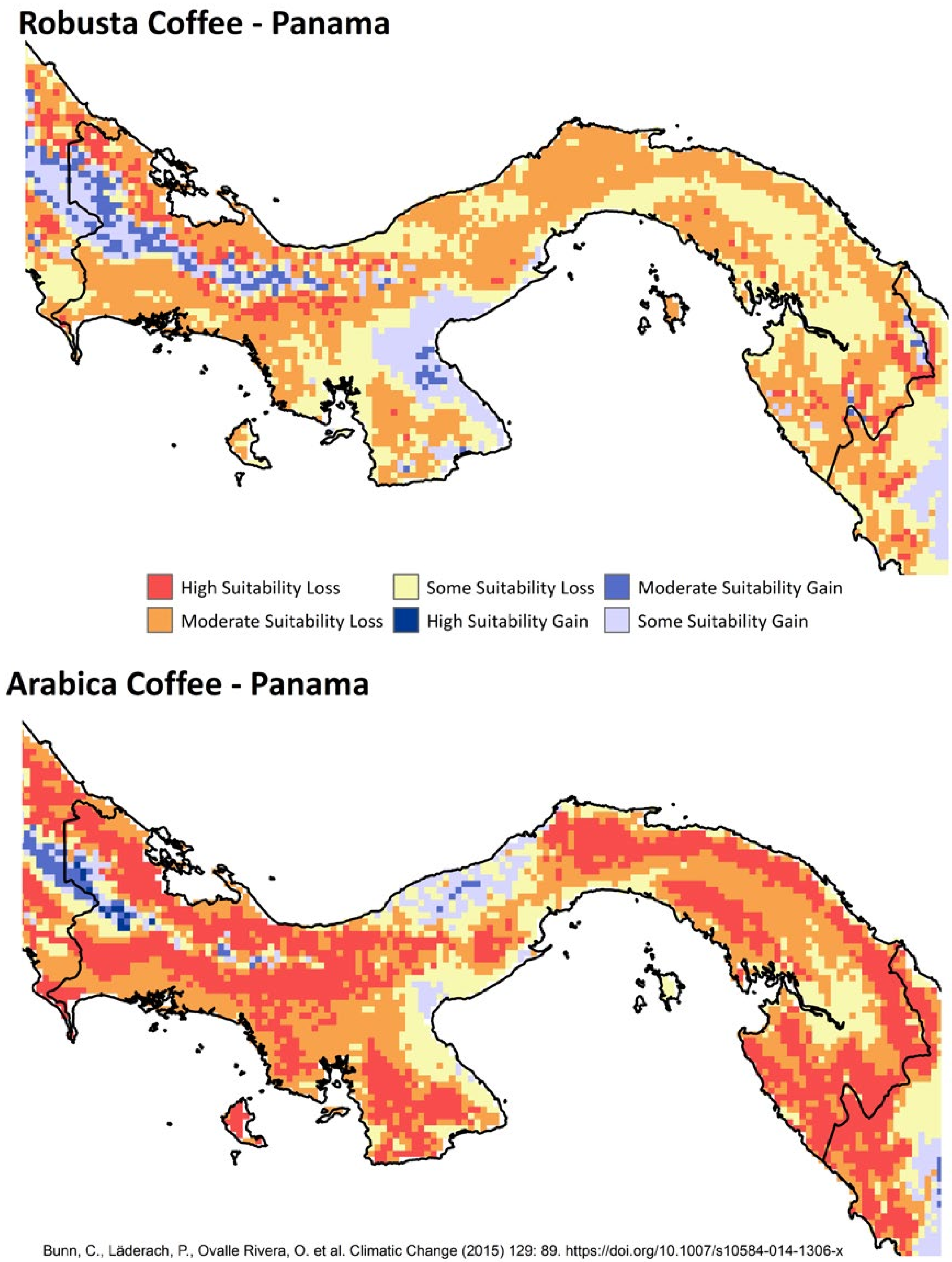


Figure 6: Projected change in suitability for Coffea arabica by 2050.

4. Economic impacts

In order to understand the real impacts of climate change on demand, supply, and international trade flows, the purely biophysical impacts addressed in the sections above must be adjusted for the economic agency of farmers who can adapt to yield and suitability loss by switching to alternative cultivars and practices. Ongoing advances in productivity and yield enhancing agricultural research, as well as the mitigating action (or inaction) of governments on emissions policy, must also be taken into consideration. The interplay of these factors was modeled using the International Model for Policy, Agricultural Commodities, and Trade (IMPACT), developed at the International Food Policy Research Institute. In this section, IMPACT projections are presented for the DSSAT modeled crops, accounting for global economic and climate change contexts of these crops as well as their substitutes.

Rice production is projected to increase under both CC and No-CC scenarios, reflecting the biophysical resilience observed in the yield modeling section above. In the No-CC scenario, bean and maize production are projected to increase by a large percentage—partly attributable to the relatively small quantities of these crops currently produced in the country. However, under climate change, bean and maize production fall beneath their No-CC benchmarks by 6.2 and 37.8 percentage points, respectively, reflecting the biophysical vulnerability observed in the yield modeling section above. Panama's residual level of soybean production is projected to vanish in 2050, with climate change accelerating this decline.

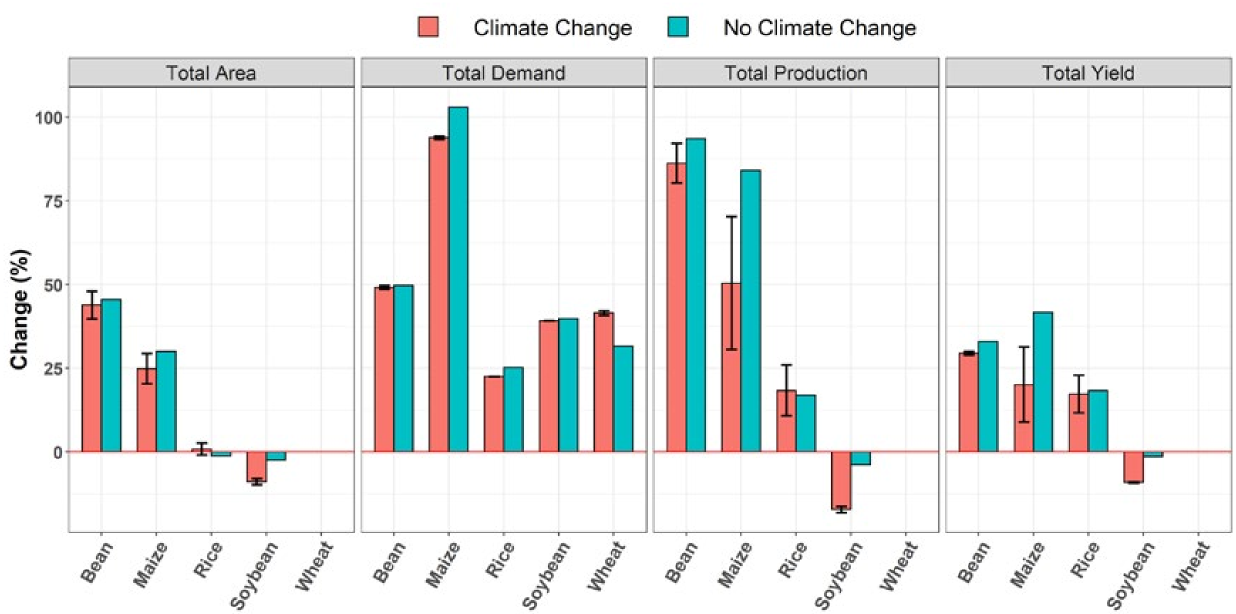


Figure 7: Percentage change in yield, demand, cultivated area, and production (2020–2050), when economic context and agricultural research are taken into account. The error bars indicate the range of output across the nine climate models.

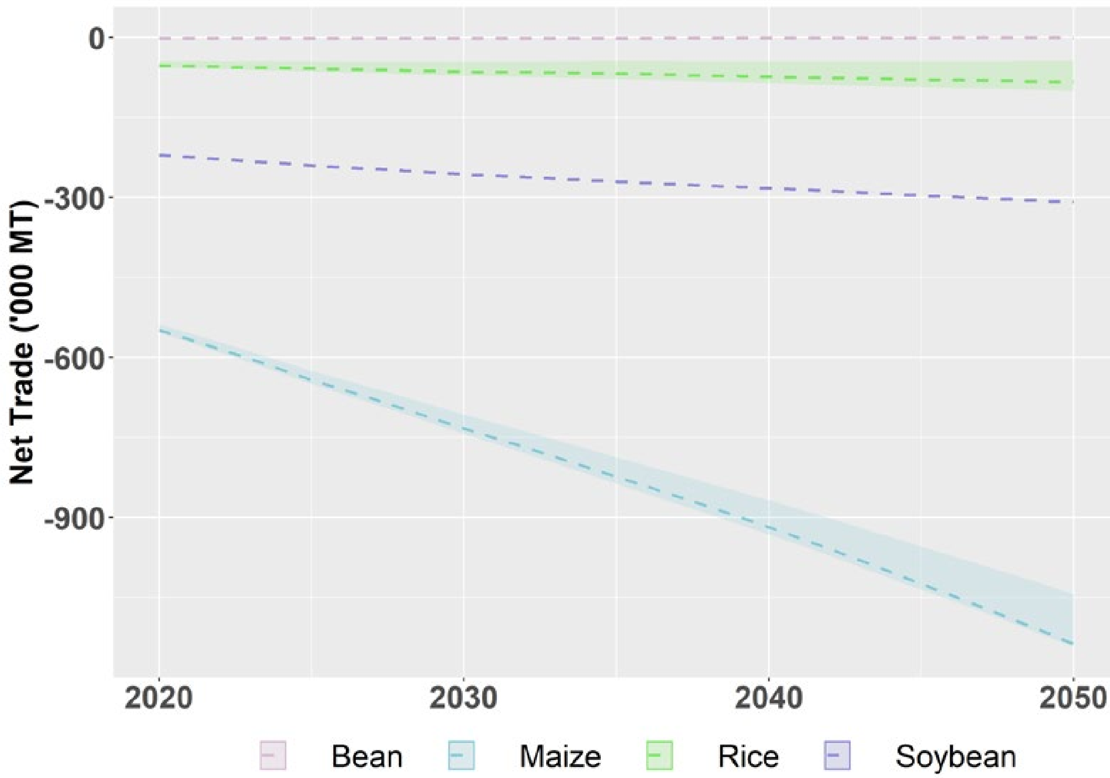


Figure 8: Climate change impact on trade. The dotted lines indicate the no climate change (No-CC) trajectory while the shaded areas correspond to the range of climate change (CC) trajectories given by the nine climate models.

Demand for rice, soybeans, and maize is projected to outpace production, resulting in a continued negative balance of trade in these key commodities out to 2050 under both CC and No-CC scenarios (Figure 8). Interestingly, maize demand is lower under climate change—substituted, perhaps, by wheat demand, which is higher under climate change. Deepening import dependence for maize is thus somewhat offset under climate change.

5. The way forward

Panama's Nationally Determined Contribution (NDC) to the 2015 Paris Agreement includes integrated agricultural adaptation goals that may work to reduce the magnitude of the trends seen here. Panama is a net carbon sequestering country, and has taken important steps in the creation of a national climate change mitigation policy framework. In 2009, the National Climate Change Committee was established within the National Environmental Authority for the purpose of implementing a multi-sectorial National Climate Change Policy [4]. Efforts have focused on tropical forestry and food security, with Panama's Ministry of the Exterior assuming leadership of the CELAC 2025 Food Security Program [5]. Panama and other countries in Latin American may be able to reduce the impact of climate change on the agricultural sector by adopting climate-smart agricultural (CSA) practices that increase productivity while reducing greenhouse gas (GHG) emissions and adapting to shifting growing conditions. Some specific adaptation measures are presented in (Table 2).

Table 2: Key messages for policy interventions

<table>
<tr><th colspan="2">Table 2: Key messages for policy interventions</th><th>Way forward</th></tr>
<tr><td>Climate</td><td>Key Climate Observations
• Climate modeling projects substantial increases in minimum and maximum temperatures across the country.
• Pronounced increase in seasonal rainfall projected across much of the country, especially in Veraguas, Herrera, and Los Santos.</td><td rowspan="2">Main activities should focus on:
• Climate smart agricultural practices, especially agroforestry.
• Development of agroclimatic information and extension services.
• Prioritization and harmonization of intervention goals (food security, poverty eradication, adaptation to climate change, etc.)
• Assessment of non-traditional food security crops like cassava that exhibit resilience to climate change.
• Strengthen cooperation and technology transfer agreements such as those established with the Latin American Irrigated Rice Fund (FLAR).
• Improve access to gene banks to facilitate research and release of new varieties exhibiting resilience under climate change.</td></tr>
<tr><td>Agriculture</td><td>Key Agriculture Observations
• Steep declines in suitability projected for banana and coffee.
• Suitability for yam and cassava cultivation projected to remain stable or increase in 2050. Cassava, not currently cultivated in Panama in any significant quantity, could therefore play a future food security role under climate change.
• Widespread steep declines projected for maize and bean yields.
• Increase in rice yield projected in the northwest, decreases projected elsewhere.</td></tr>
</table>

References:

[1] The World Bank. 2018. World Development Indicators. **http://data.worldbank.org/indicator**

[2] The World Bank. 2018. World Integrated Trade Solution. **http://bit.ly/2ZRfxqc**

[3] CIA Factbook. 2018. **https://www.cia.gov/library/publications/the-world-factbook/geos/pm.html**

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[5] Panamá y la FAO. 2016. Food and Agriculture Organization. **http://www.fao.org/3/a-az537s.pdf**

XVII. Peru

1. Context

Despite growing urbanization, the agricultural sector continues to play an important role in Peru, accounting for 7% of GDP. Crop products accounted for 11.6% of all exports in 2015, up 5.7 pp from 2006. Jobs in agriculture account for 28.4% of all employment in the country [1]. Arid desert covers much of Peru's coastal and southwestern region, limiting agricultural cultivation to highland areas in the Andes range or wet tropical lowlands farther east. Rainfall patterns are highly influenced by the El Niño Southern Oscillation. 71% of the world's tropical glaciers—a critical source of water for agriculture—are located in Peru. However, glacial volume has receded by 40% since 1970 due to rising temperatures associated with climate change [2]. Moreover, increasing frequency of El Niño/La Niña events resulting from climate change may lead to higher incidence of floods, droughts, soil erosion, landslides, and pest/disease outbreaks in the mountainous and wet lowland areas where most of the population lives and farms [2]. One of the factors that drives the local impacts of climate change is the association with different global processes and cycles. The teleconnections between Peruvian climate characteristics are well known and linked to a variety of issues from environmental phenomena [3] to health related issues [4].

2. Climate Impacts

In assessing future climate impacts, this study utilized nine general circulation models (see Methodological Summary for detail) selected for their strong performance in the Latin American and Caribbean (LAC) region. Overall, temperatures are predicted to increase by 1-4 °C across the LAC region, with the Caribbean and tropical South America projected to warm at higher rates than Mexico and the Southern Cone.

Climate modeling projects sharp percentage increases in coastal rainfall throughout the year. Sharp increases are also projected for the southern interior during June-November. However, it should be kept in mind that these projected changes occur in desert areas where current rainfall is extremely low. The high percentage increases are thus partly attributable to low baseline values. Decreased rainfall is projected for the central interior during June-November. Year round maximum and minimum temperatures are projected to increase across the country, especially along the central coastal lowlands and southern interior (Figure 1), which are important cereal growing areas.

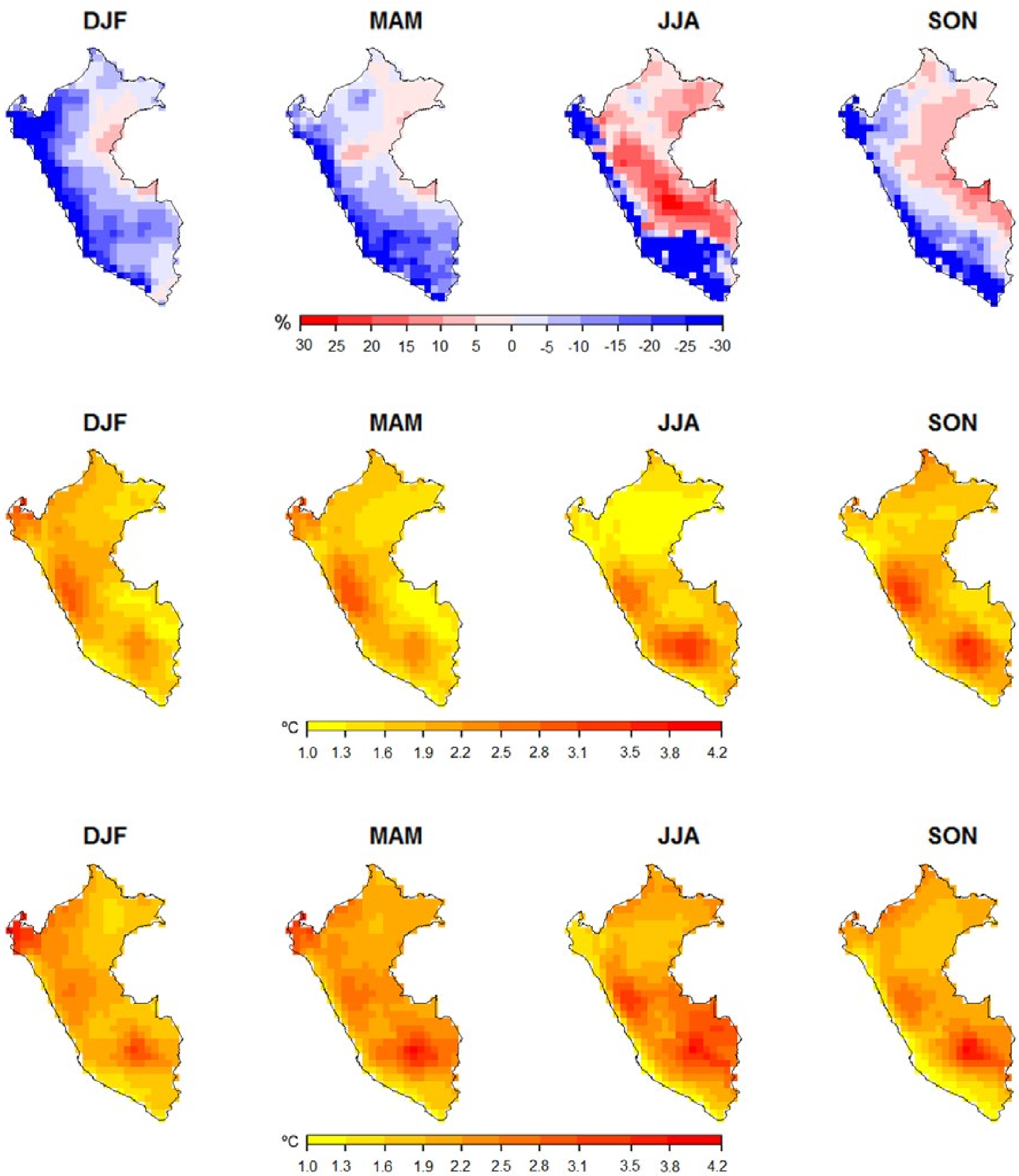

Figure 1: Climate impacts (2020-2050). DJF= December - February, MAM= March - May, JJA= June - August, SON= September - November.

3. Yield and suitability impacts

Yield

Based on the projected changes in climate discussed above, 2050 projections of maize, rice, bean, and wheat yields were modeled using the Decision Support System for Agrotechnology Transfer (DSSAT v4.5) at 0.5 degree spatial resolution. Model runs for each crop were parameterized using genetic coefficients of varieties carefully selected by experts for their relevance in the region.

Yield impact modeling suggests that in 2050, climate change could result in a substantial average decline of 31.7% for rainfed rice, and a less severe 8% for rainfed bean. Irrigated systems are projected to fare considerably better, with irrigated rice yields falling by 21% and irrigated bean yields actually rising by 7%. The average projected yield for irrigated maize and rainfed wheat, meanwhile, exhibits relative resilience, declining by just 9.4% and less than 5%, respectively (Figure 2).

The yield impact maps in Figure 3 reveal important geographical variation hiding behind these national averages. Projected irrigated maize yield loss is concentrated in the arid northwest, where temperature increases are projected to be severe. Projected yield losses for both irrigated and rainfed maize are also scattered all along the eastern tropical piedmont. These losses are partly offset by projected yield gains higher up in the Andes, but the question remains as to whether the slope of this new terrain will be too steep for cultivation. Projected irrigated wheat yield loss in the Andes, meanwhile, is partly offset by pockets of gains in the south. Projected yield gains for irrigated bean and rice are concentrated along the coast, while gains for rainfed bean and rice are concentrated along the Andes.

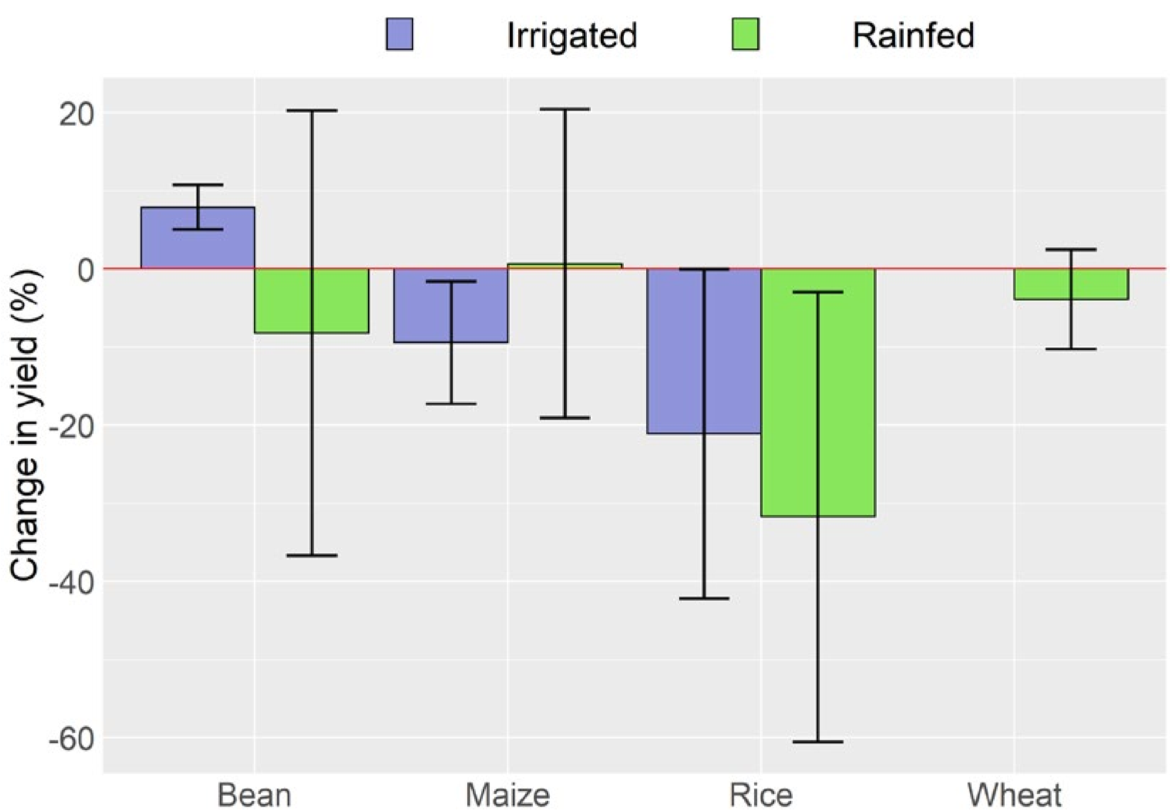

Figure 2: Projected average yield change, key crops (2020–2050). The error bars indicate the range of output across the nine climate models.

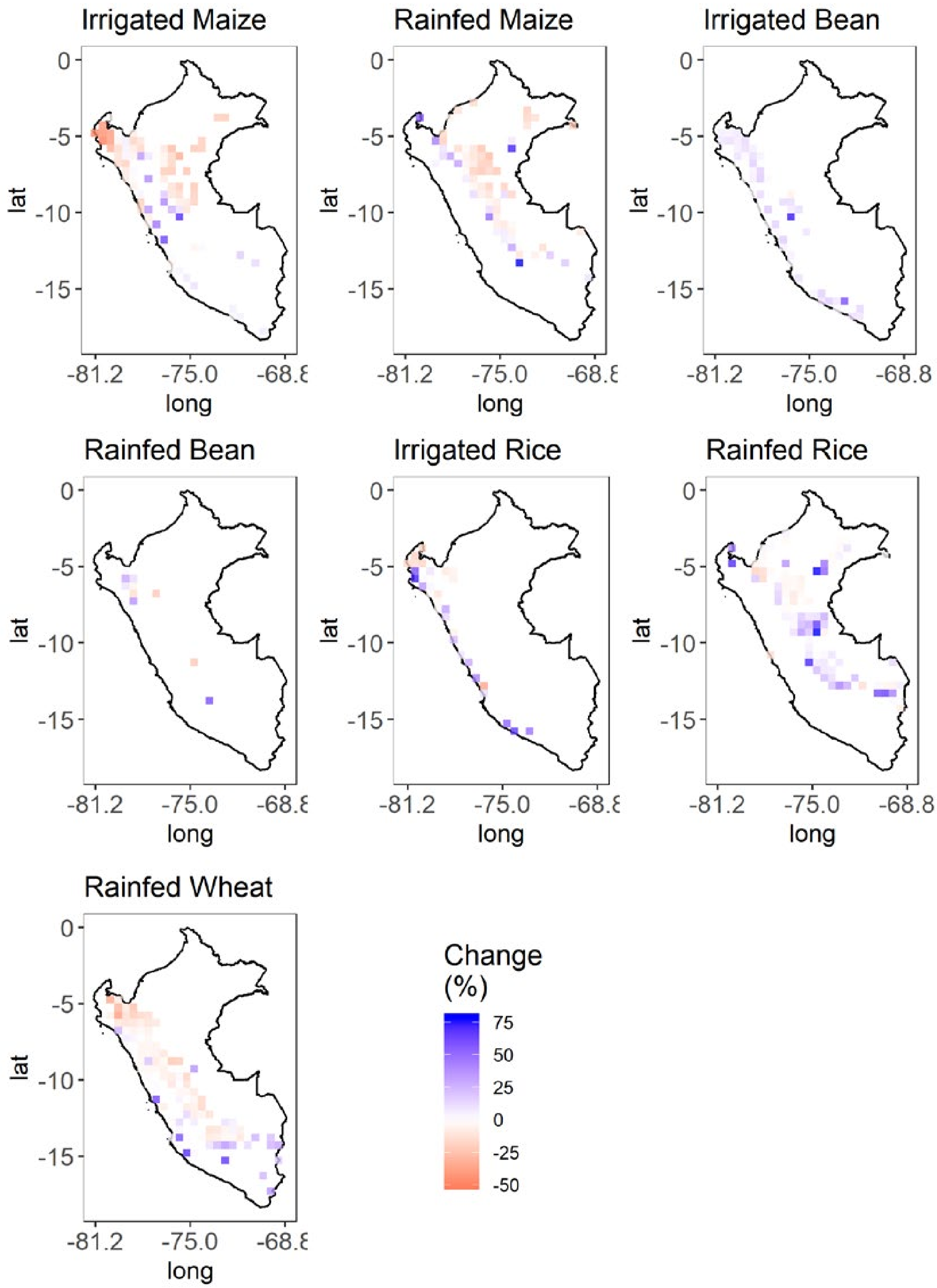

Figure 3: Projected yield impact maps, key crops (2020-2050).

Suitability

Climate change impacts on agro-ecological suitability for coffee (Robusta and Arabica), banana, yam, cassava, potato and sugarcane were assessed using niche based models. In these models, "suitability" is defined based on how well local precipitation and temperature match the biophysical requirements of the given crop.

Suitability modeling suggests that the average suitable areas for cassava, potato, sugarcane, and yam cultivation could increase substantially—by 24.7%, 19.9%, 54.4%, and 18.1%, respectively. The area suitable for Peru's budding banana industry, meanwhile, may decline by 40.8%. However, it must be kept in mind that the steep percentage decline in banana suitability, and the steep rise in sugarcane suitability, is partly attributable to the small quantity of current production of these crops.

The spatially explicit suitability impact maps in Figure 5 indicate that potato suitability gains are projected to occur in regions where production is currently concentrated—along the western and southern Andean flank—although this is partly offset by pockets of suitability loss in the north and eastern Andean flank. Projected cassava and yam suitability remains stable in the northeastern tropical forest, and increases in the Andes (Figure 5). Cassava production in Peru is low compared to potato production, and yams are not currently grown anywhere in the country in significant quantities. However, the projected resilience of these crops may make them an attractive alternative carbohydrate source in areas where cereals are projected to succumb to the heat and water stress brought about by climate change.

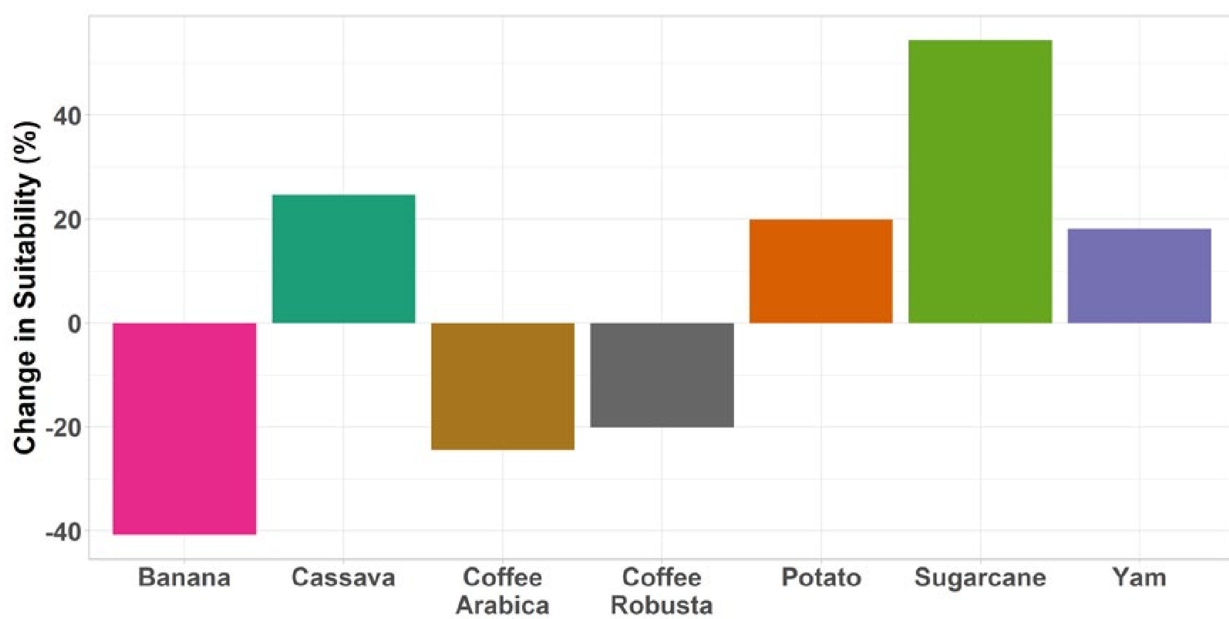

Figure 4: Projected change in suitability for key crops (2020-2050), national average.

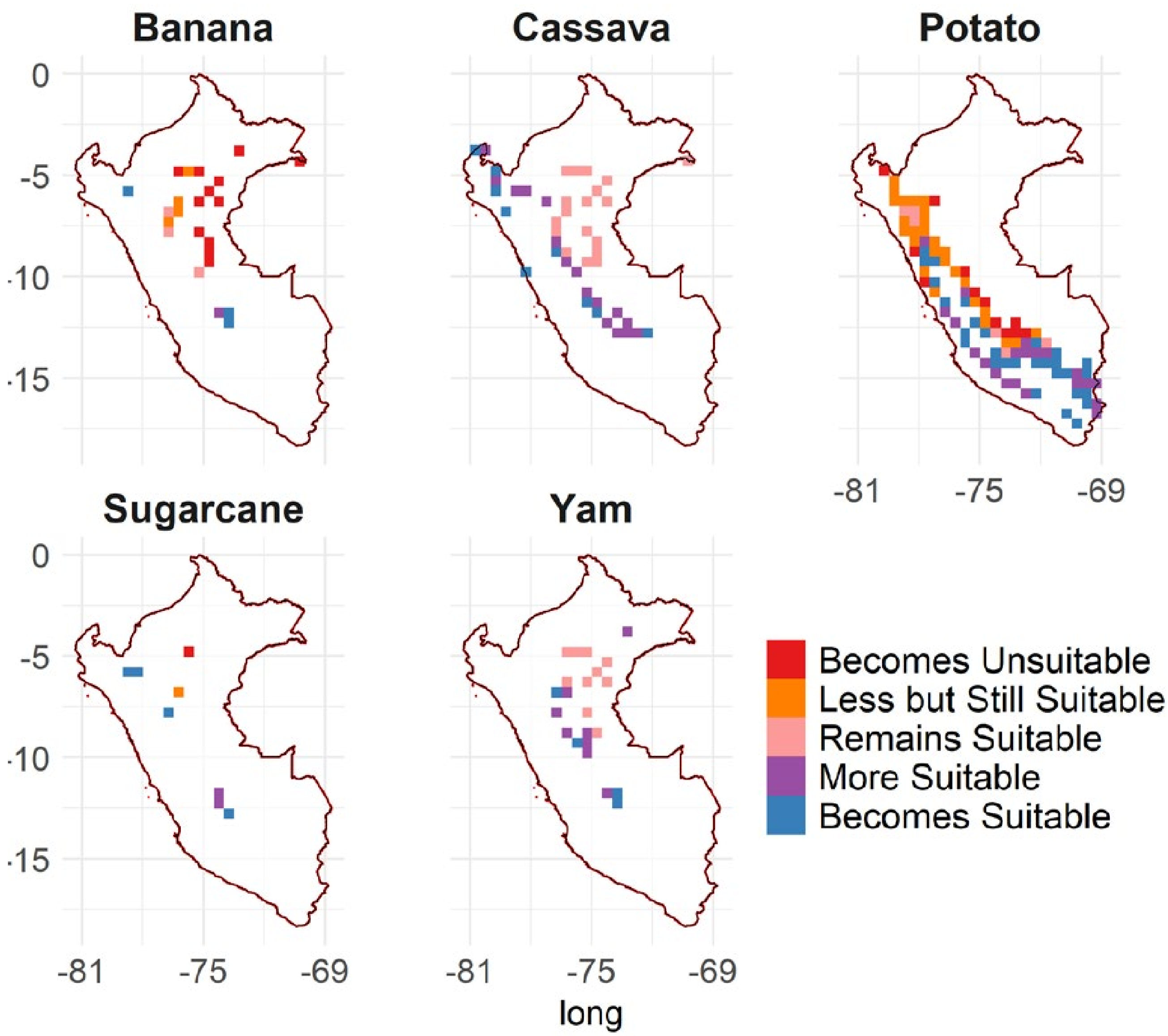

Figure 5: Projected suitability impact maps (2020-2050).

The average suitable area for Arabica and Robusta coffee cultivation is projected to decrease steeply—by 24.5%, and 20.1%, respectively. However, these national averages are misleading. The Arabica coffee suitability map in Figure 6 reveals that Arabica suitability losses are concentrated in a broad area extending from the eastern Andean flank into the north and western tropical forests—where coffee is not currently produced. Moreover, these losses are considerably offset by suitability gains in the coffee growing reagions along the eastern Andean flank and western piedmont.

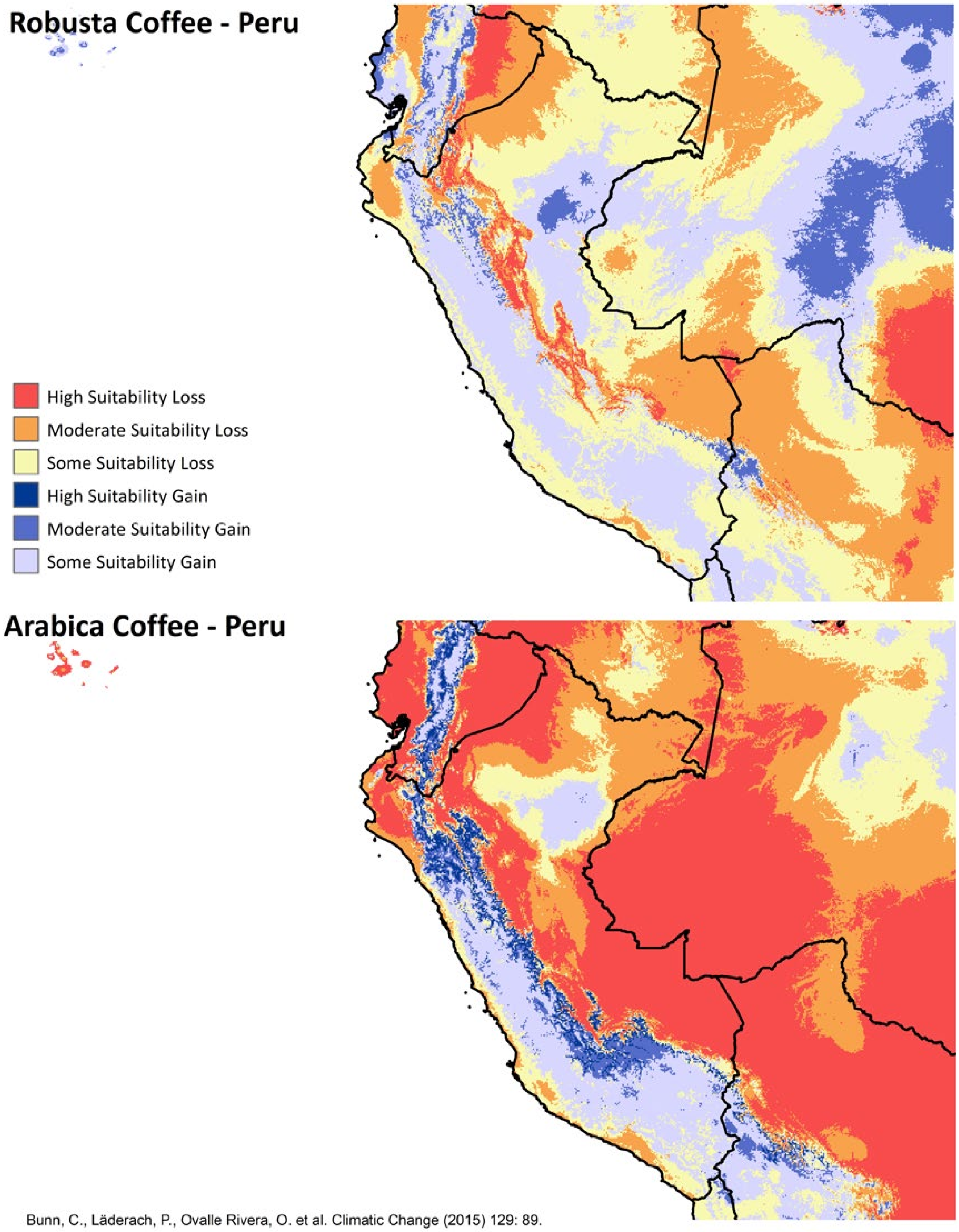

Figure 6: Projected change in suitability for Coffea arabica by 2050.

4. Economic impacts

In order to understand the real impacts of climate change on demand, supply, and international trade flows, the purely biophysical impacts addressed in the sections above must be adjusted for the economic agency of farmers who can adapt to yield and suitability loss by switching to alternative cultivars and practices. Ongoing advances in productivity and yield enhancing agricultural research, as well as the mitigating action (or inaction) of governments on emissions policy, must also be taken into consideration. The interplay of these factors was modeled using the International Model for Policy, Agricultural Commodities, and Trade (IMPACT), developed at the International Food Policy Research Institute. In this section, IMPACT projections are presented for the DSSAT modeled crops, accounting for global economic and climate change contexts of these crops as well as their substitutes.

Maize and wheat production is projected to increase substantially under both No-CC and CC scenarios, reflecting the biophysical resilience observed in the yield modeling section above (Figure 7). Rice production, meanwhile, is projected to fall. A steep percentage increase is projected for beans, but this is largely attributable to the small quantities of this crop currently produced in the country. The bean production outlook is 24.1 percentage points higher under the climate change scenario than under the No-CC benchmark, reflecting the biophysical resilience observed in the yield modeling section.

Demand for maize is projected to rise sharply in 2050 under both the No-CC and CC scenarios, outpacing increased production. This results in the steepening maize trade deficit observed in Figure 8. An increasingly negative balance of trade is also projected for soybean and rice. The current wheat trade deficit is projected to hold steady, neither increasing nor decreasing. Little or no trade is projected for beans, meaning that the increased production would be consumed domestically.

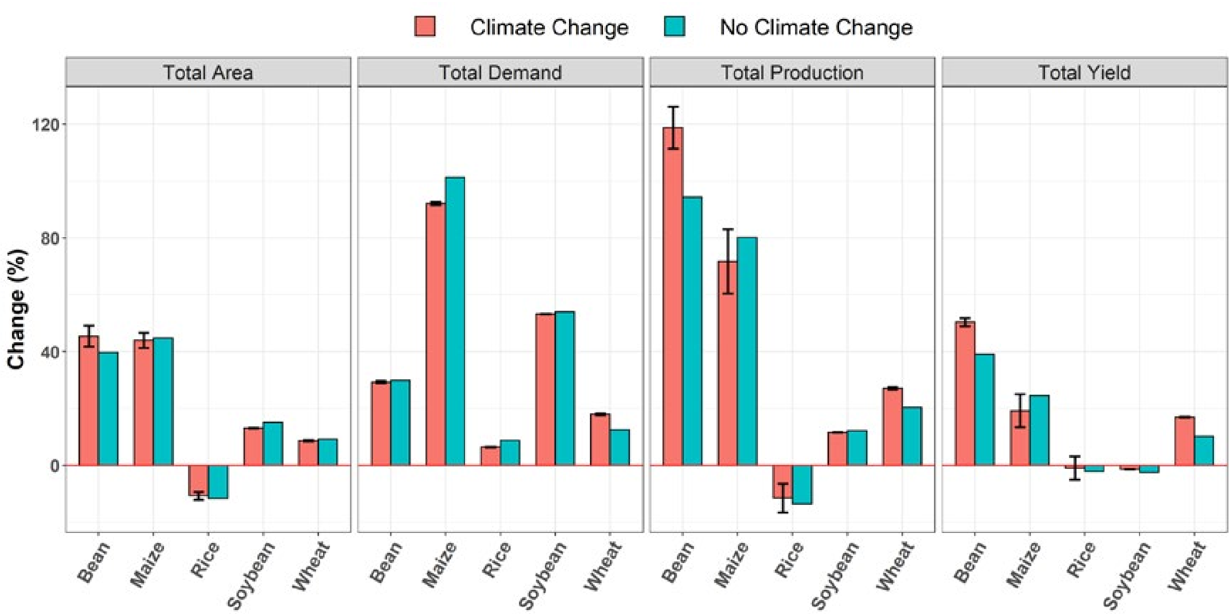

Figure 7: Percentage change in yield, demand, cultivated area, and production (2020–2050), when economic context and agricultural research are taken into account. The error bars indicate the range of output across the nine climate models.

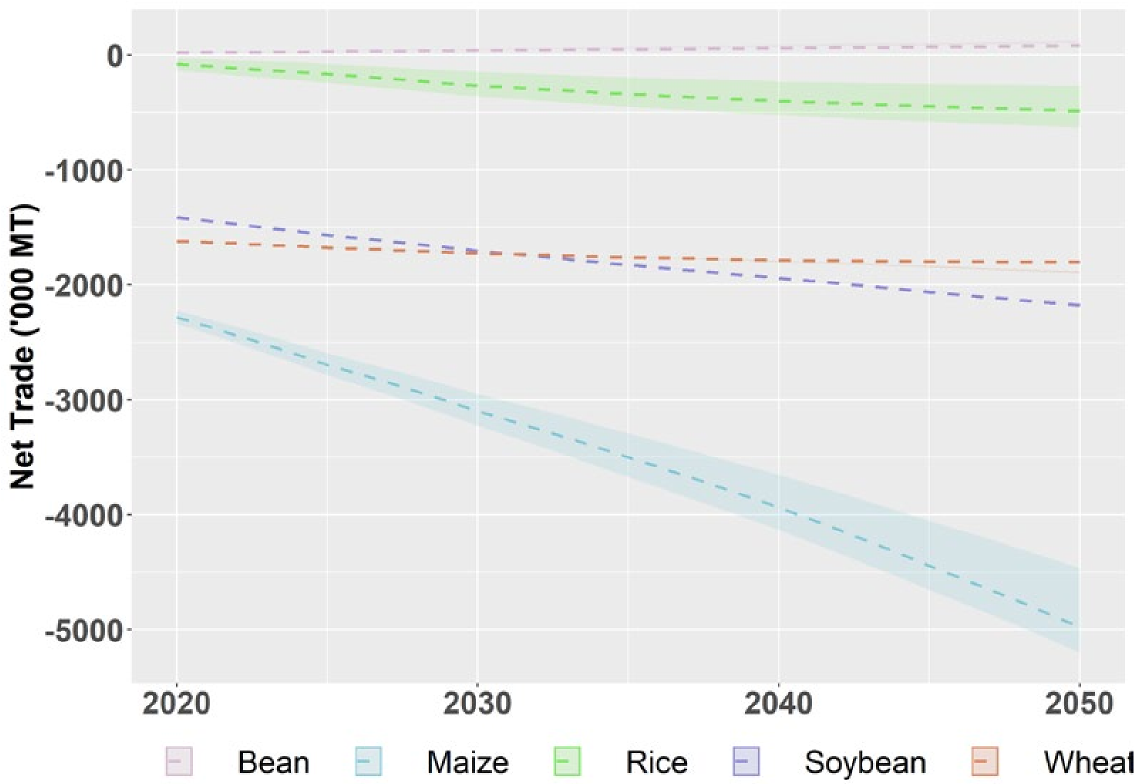

Figure 8: Climate change impact on trade. The dotted lines indicate the no climate change (No-CC) trajectory while the shaded areas correspond to the range of climate change (CC) trajectories given by the nine climate models.

5. The way forward

Peru's Nationally Determined Contribution (NDC) to the 2015 Paris Agreement includes integrated agricultural adaptation goals that may work to reduce the magnitude of the trends seen here. Peru has taken substantive steps toward the creation of a policy framework for climate change mitigation and adaptation, voluntarily pledging to end deforestation and to source 33% of its national energy consumption from alternative sources by 2020 [5]. In 2014-2015 the National Climate Change Strategy was established, together with numerous laws supporting various aspects of its implementation [6]. Peru and other countries in Latin American may be able to reduce the impact of climate change on the agricultural sector by adopting climate-smart agricultural (CSA) practices that increase productivity while reducing GHG emissions and adapting to shifting growing conditions. Some specific adaptation measures are presented in (Table 2).

Table 2: Key messages for policy interventions

<table>
<tr><th colspan="2">Table 2: Key messages for policy interventions</th><th>Way forward</th></tr>
<tr><td>Climate</td><td>Key Climate Observations
• Projected increase in rainfall along the coast and western and southern slopes of the Andes.
• Projected decrease in rainfall for the eastern and northern tropical forest zones, especially during June-November.
• Projected increase in minimum and maximum temperatures, especially in the central coastal lowlands and southern interior.</td><td rowspan="2">Main activities should focus on:
• Strengthening of agroclimatic information and market intelligence services, especially in areas of greatest vulnerability.
• Promotion of the research, release, and adoption of flood and drought tolerant varieties of key staple crops.
• Assessment of irrigation as a CC adaptation mechanism in bean and rice systems.
• Assessment of yam and cassava as climate change resilient alternatives to potato in the north and eastern Andean slopes, where potato suitability is projected to decline.</td></tr>
<tr><td>Agriculture</td><td>Key Agriculture Observations
• Irrigated bean and rice systems projected to fare better under climate change than rainfed systems.
• Projected decrease in maize yield in the northwest and eastern highland forest, partially offset by projected increases in the western slope of the Andes.
• Projected increase in irrigated rice yield along the coast, and projected increase in rainfed rice yield in the Andes.
• Projected increase in irrigated bean yield along the coastal lowlands.
• Substantial projected increase in cultivable area for potato in the south and western Andean slopes, but also considerable loss in area along the north and eastern Andean slopes.
• Yam and cassava exhibit resilience to climate change, with cultivable areas remaining stable or increasing throughout the Andes.</td></tr>
</table>

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[1] The World Bank. 2018. World Development Indicators. Washington, D.C., USA. Available at: **http://data.worldbank.org/indicator**

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XVIII. Uruguay

1. Context

Agriculture plays an important but declining role in Uruguay. The sector accounts for 5.2% of GDP, down 6 percentage points (pp) from a peak of 11.2% in 2004 [1]. Crop products accounted for 25.9% of all exports in 2015, up 11.4 pp from 2006 [2]. Jobs in agriculture account for 8.1% of all employment in the country, down 2.8 pp from 8 years ago [1]. Uruguay is located in a temperate zone with well-defined summer, autumn, winter, and spring seasons [3]. The geography is generally flat and open, with few forests and no major mountains. 83% of the land is agricultural, most of which is dedicated to cattle ranching [4]. Rice, wheat, corn, and soybean are among the most important crops produced in the country [5]. Long term (100 year) temperature and rainfall trends have largely remained stable under climate change. However, temperature and rainfall patterns exhibit high inter-annual variability; and this variability is increasing. Rainfall, in particular, is highly influenced by the El Nino Southern Oscillation phenomenon [3]. Extreme weather events such as droughts, floods, heat waves, hail storms, and tornadoes also affect the country; and have become more frequent over the last 10 years [3]. Global warming is intensifying the hydrological cycle, which in turn is expected to further increase inter-annual variability and incidence of extreme events. All of this aggravates the already high levels of risk inherent in agricultural planning.

2. Climate Impacts

In assessing future climate impacts, this study utilized nine general circulation models (see Methodological Summary for detail) selected for their strong performance in the Latin American and Caribbean (LAC) region. Overall, average temperatures are predicted to increase by 1-4 °C across the LAC region, with Mexico and the Southern Cone projected to warm at lower rates than the Caribbean and tropical South America.

In Uruguay, temperatures are projected to increase relatively slightly in 2050—by about 1 to 1.3 °C across the country. Rainfall is projected to increase across the country during March-May, persisting in the central and northern parts of the country through to November while abating in the south. Rainfall is then projected to decrease across the country during December-February (Figure 1).

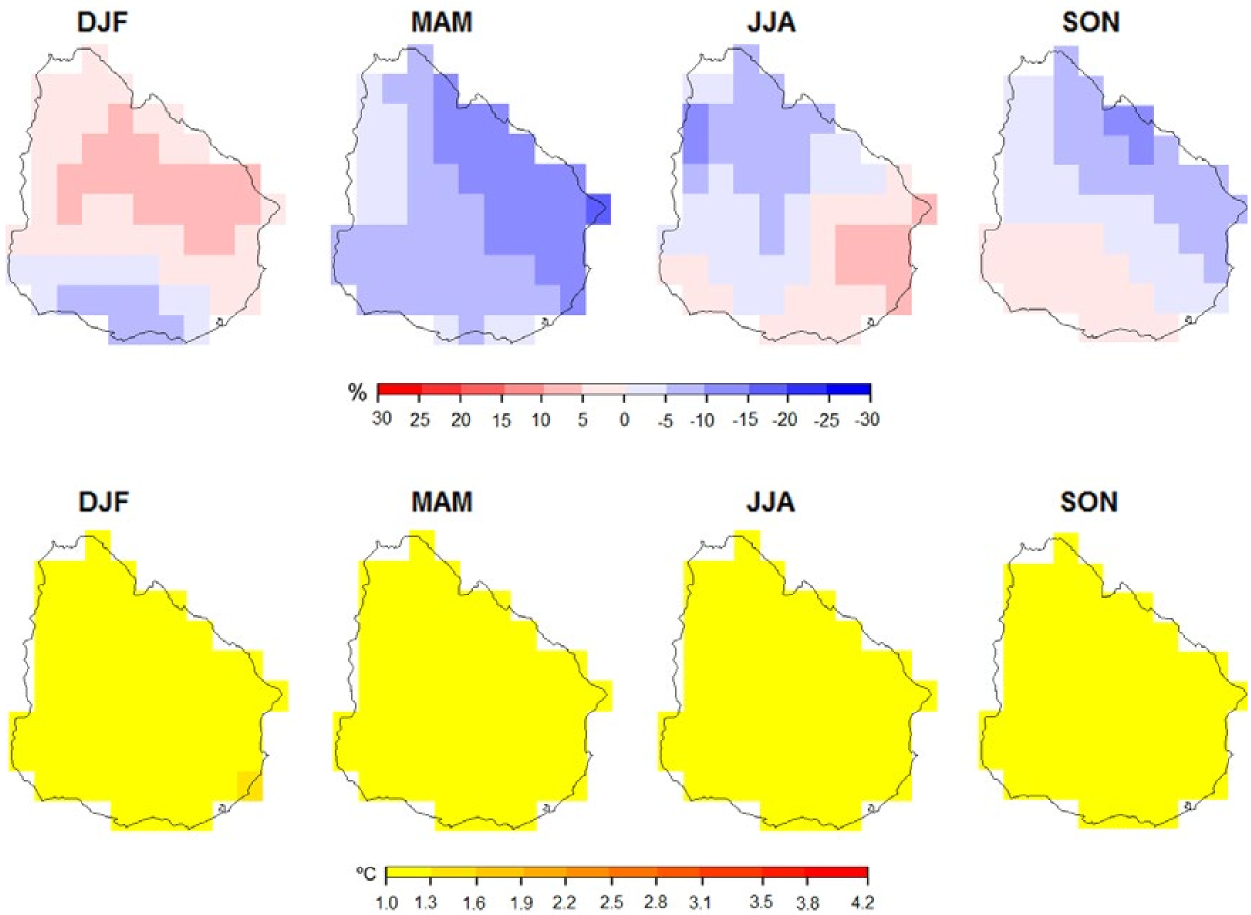

Figure 1: Climate impacts averaged across nine GCMs (2020-2050). DJF= December - February, MAM= March - May, JJA= June - August, SON= September - November.

3. Yield and suitability impacts

Yield

Based on the projected changes in climate discussed above, 2050 projections of maize, rice, wheat, and soybean yields were modeled using the Decision Support System for Agrotechnology Transfer (DSSAT v4.5) at 0.5 degree spatial resolution. Model runs for each crop were parameterized using genetic coefficients of varieties carefully selected by experts for their relevance in the region.

In tropical LAC, climate change is generally projected have a negative impact on rice, maize, and wheat yields. In temperate Uruguay, on the other hand, where the projected temperature increase is relatively slight, irrigated rice and soybean yields are projected to rise by 8% and 13.1%, respectively, while maize yields are projected to hold steady (Figure 2). Irrigated wheat yields, meanwhile, are projected to fall by about 5%, perhaps due to waterlogging from increased rainfall. Impact maps show the projected irrigated rice yield increases are most pronounced in the southeast, whereas increases in irrigated soybean yield are most pronounced at the country's eastern and western borders (Figure 3). The projected wheat yield losses are most pronounced in the northwest, where rainfall is expected to decrease during December to February.

Again, this yield impact assessment is based on projected changes to long term climate trends, which, given Uruguay's temperate latitudes, account for a small fraction of Uruguay's total variation in climatic conditions. The results presented here should be adjusted for expected increases in climate variability not captured in the GCM ensemble.

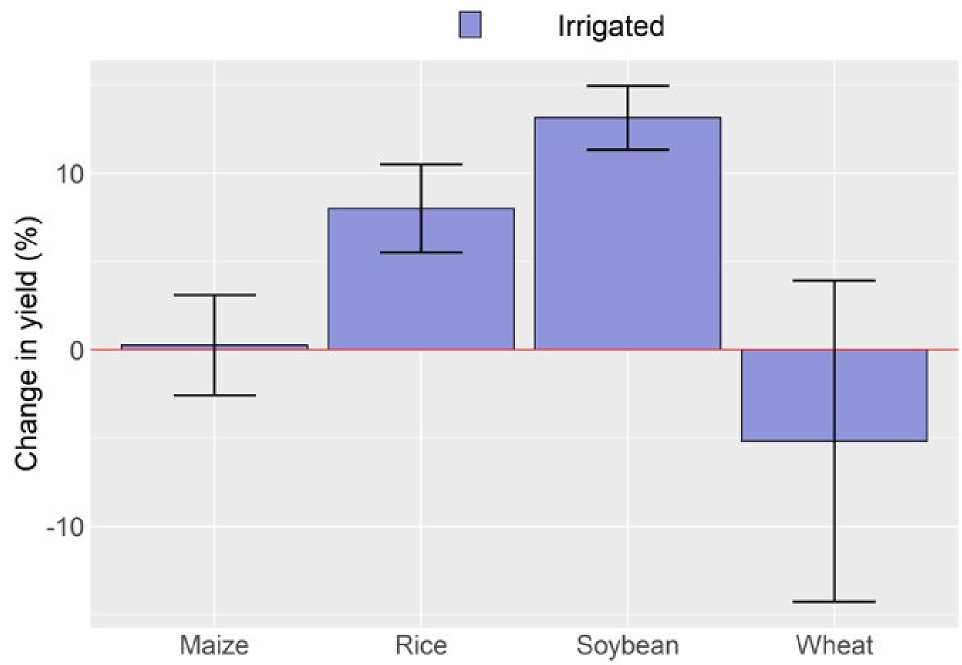

Figure 2: Projected average yield change in Uruguay, key crops (2020–2050). The error bars indicate the range of output across the nine climate models.

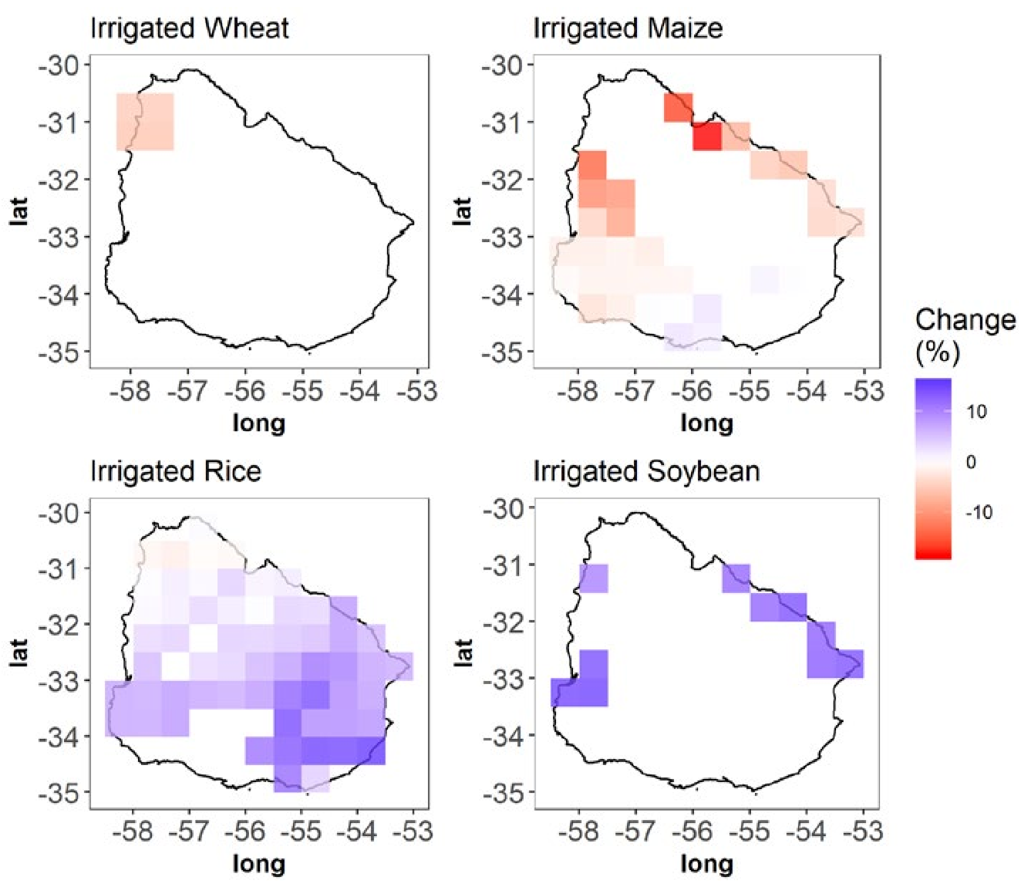

Figure 3: Projected yield impact maps, key crops (2020-2050).

4. Local and regional economic impacts

In order to understand the real impacts of climate change on demand, supply, and international trade flows, the purely biophysical impacts addressed in the sections above must be adjusted for the economic agency of farmers who can adapt to yield and suitability loss by switching to alternative cultivars and practices. Ongoing advances in productivity and yield enhancing agricultural research, as well as the mitigating action (or inaction) of governments on emissions policy, must also be taken into consideration. The interplay of these factors was modeled using the International Model for Policy, Agricultural Commodities, and Trade (IMPACT), developed at the International Food Policy Research Institute. In this section, IMPACT projections are presented for the DSSAT modeled crops, accounting for global economic and climate change contexts of these crops as well as their substitutes.

A steep percentage increase in production of maize and beans is projected in 2050 under both CC and No-CC scenarios (Figure 4). In the case of beans, the large percentage increase is mostly due to the low level of current production. The projected increase in maize, on the other hand, is noteworthy given the significant quantities currently grown. The relatively small percentage increases in rice, soybean, and wheat also represent significant increases in the quantity grown given their current high levels of production. Under climate change, rice and soybean production is projected to rise above the No-CC benchmark by 9.3 and 6.8 percentage points (pp), respectively, reflecting the beneficial biophysical CC impact observed in the yield modeling section above. The CC trajectory for wheat production, meanwhile, differs little from its No-CC benchmark, suggesting that international trade may offset the biophysical vulnerability observed in the yield modeling section. Maize production under climate change is projected to fall 14 pp below its No-CC benchmark, suggesting that international trade may offset the biophysical resilience observed for this crop in the yield modeling section.

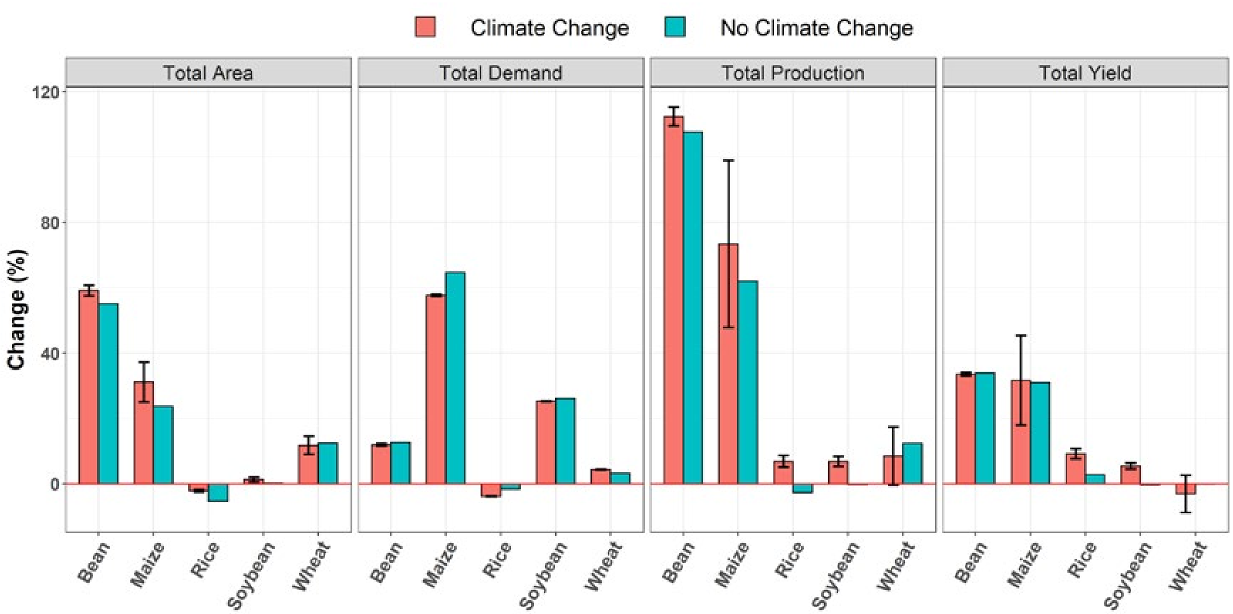

Figure 4: Percentage change in yield, demand, cultivated area, and production (2020–2050), when economic context and agricultural research are taken into account. The error bars indicate the range of output across the nine climate models.

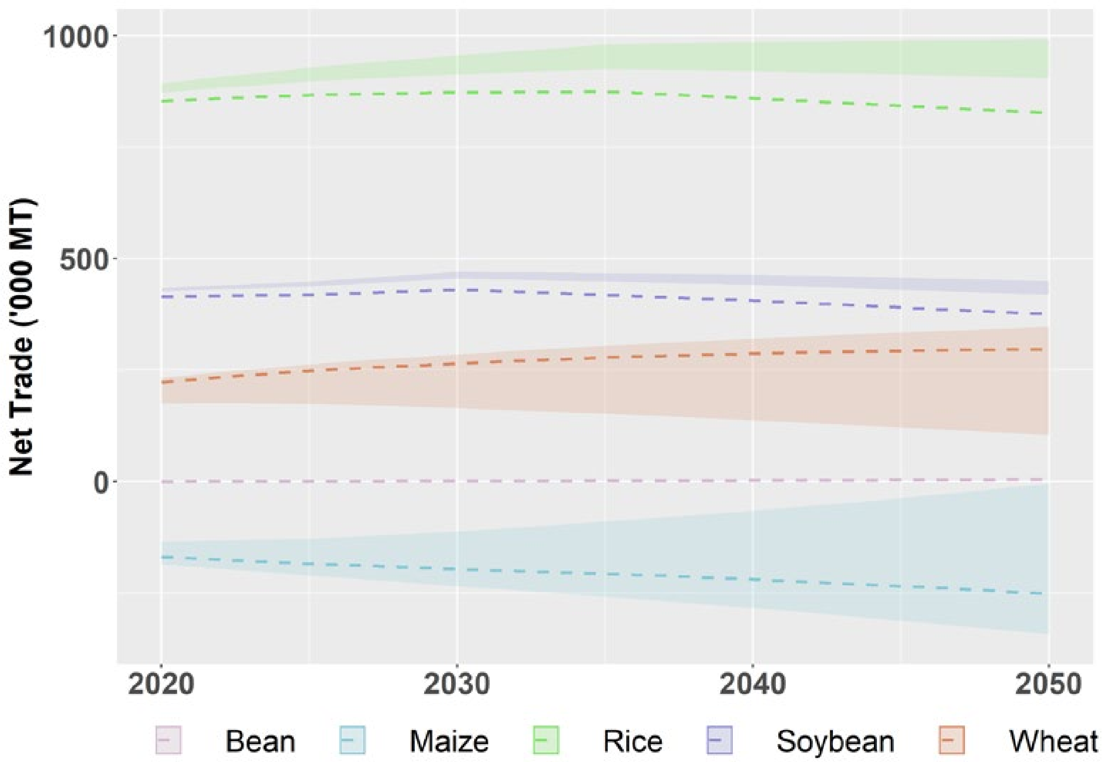

Figure 5: Climate change impact on trade. The dotted lines indicate the no climate change (No-CC) trajectory while the shaded areas correspond to the range of climate change (CC) trajectories given by the nine climate models.

Internal demand for rice, soybean, and wheat is projected to rise only slightly over this period, meaning that the increased production of these crops will further solidify Uruguay's role as a major cereal and soybean exporter (Figure 5). Climate change is projected to give a boost to rice and soybean exports, while reducing wheat exports somewhat. The impact of climate change on the current negative balance of trade in maize is ambiguous, with some GCMs indicating a substantial reduction in the negative balance, while others indicate little change or even a steepening of the negative balance.

5. The way forward

Uruguay's Nationally Determined Contribution (NDC) to the 2015 Paris Agreement includes integrated agricultural adaptation goals that may work to reduce the magnitude of the trends seen here. Uruguay aims to achieve a 27% reduction in carbon emissions across all sectors by 2030, including agriculture, relative to 2010 levels [6]. In 2009, the government established the National System to Respond to Climate Change and Variability (SNRCC) to guide its climate actions. In 2016, The SNRCC set forth the National Climate Change Policy (PNCC), a long-term strategic framework with an emphasis on adaptation. As of November 2018, Uruguay is finalizing its National Adaptation Plan for climate change and variability in the agricultural sector [3]. The document calls for increased resilience and adaptive capacity in agricultural systems and proposes a number of key actions, including development of research and data collection on the impacts and adaptation to climate change and variability, development of information systems, climate services, and monitoring programs, and the development of soil use and management plans to reduce erosion and preservation of organic matter in croplands. Uruguay and other countries in Latin American may be able to reduce the impact of climate change on the agricultural sector by adopting climate-smart agricultural (CSA) practices that increase productivity while reducing greenhouse gas (GHG) emissions and adapting to shifting growing conditions. Some specific adaptation measures are mentioned in (Table 2).

Table 2: Key messages for policy interventions

Table 2: Key messages for policy interventions		Way forward
Climate	Key Climate Observations • Climate modeling projects a slight increase in temperature (1-1.3°C), and a more pronounced increase in rainfall. • However, in Uruguay, climate change accounts for just 6% of the total observed variation in temperature and precipitation. Most of the variation is explained by inter-annual variability, which is not captured by the models. • Inter-annual variability has been, and is expected to continue, increasing, bringing increased risk of extreme events such as drought and storms.	Main activities should focus on: • Climate Smart Agricultural practices, especially to strengthen existing soil conservation practices. • Development of climate information services, especially seasonal and sub-seasonal forecasting. • Land and water management. • Assessment of flood resistant crop varieties.
Agriculture	Key Agriculture Observations • Increased waterlogging and erosion of soils. • Potential for increased incidence of pest and disease. • The relatively slight projected increase in temperature compared to the rest of LAC may further bolster Uruguay's comparative advantage in rice and soybeans.	

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Vulnerability to climate change and economic impacts
in the agriculture sector in Latin America and the Caribbean

Steven Prager, Ana R. Rios, Benjamin Schiek, Juliana S. Almeida, Carlos E. Gonzalez

IDB

CIAT
International Center for Tropical Agriculture
Since 1967 Science to cultivate change