# ASSESSING THE IMPACTS OF CLIMATE CHANGE ON FARMING SYSTEMS IN THE CARIBBEAN: A PILOT STUDY

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# Assessing the Impacts of Climate Change on Farming Systems in the Caribbean: A Pilot Study

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Castries, Saint Lucia
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The authors acknowledge the contribution of Luciano Chi with the sugarcane data, and a description of the region, its sugarcane production and climate adaptation strategies. The authors also acknowledge the contribution of Brandon Murphy for making h is MS Thesis available and providing us with the tomato and pepper data.

# Foreword

The impacts of the climate crisis are intensifying rapidly and the scope and scale of the response has not matched the challenge to date. Building resilience and enhancing productivity while ensuring the sector is on a low emissions development pathway is not an easy task in the agriculture sector as while there are many possible synergies, there are also potential tradeoffs that can put food security or livelihoods at risk.

There is great urgency to make effective decisions and investments, and stakeholders need better decision-making support tools that help them understand the impacts – intended and unintended – of the actions they take on environmental, productive, and socio-economic variables. These decisions are becoming increasingly complex.
Limited time and resources make it possible test every possible response measure on the ground in different agro-ecological contexts around the Caribbean. Different packages of policies, practices and technologies will lead to varying results, with specific groups of farmers being impacted differently. There is no time to waste, so how can we make informed decisions about the most effective way forward, and ensure that we facilitate a just transition?

That is where approaches like the one presented in this document come in. Understanding the challenges decision makers face, IICA has been working for many years with partners from the Agricultural Model Intercomparison and Improvement Project (AgMIP) to enhance the awareness of the potential of this approach in Latin America and the Caribbean and to build capacity for its implementation.

We are pleased to present this work – a first effort at applying a part of AgMIP´s rigorous approach in the Caribbean context, with a focus on applying the Tradeoff Analysis for Multi-Dimensional Impact Assessment Model (TOA-MD). There are still challenges to overcome before the region can fully capitalize on the power of the TOA-MD and before the complete AgMIP approach can be fully implemented but this pilot study provides a strong base on which future efforts can build to provide robust, contextualized information for decision makers from the farm to regional levels.

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# Contents

# 1. Introduction

The GCF-Readiness Project, "Strengthening the Foundation for a Climate Responsive Sector in the Caribbean" (CARICOM AgREADY Project), seeks to raise the profile of the agricultural sector in GCF's climate financing prioritization processes by implementing an evidence-based and intersectoral strategy for developing and rebranding Caribbean agriculture as "low-emission", in order to enhance market opportunities and attract private sector investments. The project logic is premised on a vision of developing "a climate responsive agricultural sector in the Caribbean that supports food security, livelihoods, and uses natural resources sustainably" by addressing barriers of ineffective mechanisms and engaging with agricultural experts and stakeholders in GCF climate programming processes, regarding policy gaps and limited or fragmented data and information applied to climate-risk planning, programming, and action in the sector.

A key component of the project is to strengthen the capacity to use data and tools to produce evidence-based information to support decision-making and position the agricultural sector as a high priority in climate investment planning. The Tradeoffs Analysis team at Oregon State University was tasked to develop a proof-of-concept "Pilot Study" using the Tradeoff Analysis for Multi-Dimensional Impact Assessment Model (TOA-MD) and the Agricultural Model Intercomparison and Improvement Project (AgMIP) approach for regional integrated assessments of impacts of climate change, adaptation, and mitigation on the agricultural sector.

The objective of this Pilot Study is to demonstrate how a novel stakeholder-driven, multi-disciplinary methodology to assess impacts of climate change and adaptation on environmental, social, and economic outcomes can provide key information to support policy decision-making and contribute with evidence-based data to the NAPs and NDCs development processes and other climate and agricultural development policies.

The analysis presented in the three case studies uses available data to characterize agricultural production systems and a set of assumptions based on secondary information and expert opinion in relation to the potential impacts of climate change and adaptation strategies. A full implementation of this approach would require climate, crop and livestock modeling and availability of adequate data to implement these models. The 3 case studies used in this project are:

- ***Sugarcane production in Belize:*** The potential impacts of CC and adaptation strategy on farm income, per-capita income, and poverty rates for 2 sugarcane producing regions in Belize were analyzed using data available for a 7 year-cycle of sugarcane production (year 1 as establishment of the crop and years 2-6 ratoon years). Farms were categorized as micro, small and medium size, based on their production levels. The adaptation strategy is based on implementing climate-smart practices.

- ***Tomato-Pepper production in Trinidad and Tobago***: Impacts of climate change and adaptation were assessed regarding the tomato and chili pepper production on smallholder farms. This analysis includes the use of data collected for a master thesis and secondary information from different sources to obtain a closer characterization of the tomato-pepper farming system. The adaptation strategy is based on improved crop varieties and management.

- ***Cassava production in Guyana:*** This case study focuses only on cassava as a commodity. Due to the lack of whole-farm and household data available to represent the farming system, the results cannot produce outcomes such as poverty rates. The adaptation strategy is based on implementation of integrated pest management and improved cultivars.

The next section of this report discusses the challenges that the Caribbean agricultural sector faces regarding climate change and highlights the need to use data and tools that can inform stakeholders about the likely impacts of climate change. It also shows how proposed adaptation and mitigation strategies can benefit farmers and the environment. Section 3 briefly describes the TOA-MD model and the AGMIP's Regional Integrated Assessment (RIA) key features. Sections 4-6 focus on each case study and describe current conditions and challenges posed by climate change and their likely impacts on the production systems that are the focus of this study (i.e., sugarcane in Belize, tomato and pepper in Trinidad and Tobago, and cassava in Guyana). These sections also describe the data used and the adaptation packages tested for each case study. Section 7 presents the results of the study. First, the TOA-MD model parameterization is briefly described. Then, results are presented by comparing the different outcomes across the different countries, production systems using disaggregated (by strata) and aggregated results (by country). Section 8 presents a set of conclusions and discusses a way forward by discussing elements that should be included in a full project. An Appendix section includes figures and tables of results for each case study. The last section lists a set of references used in this report.

# 2. Background

According to the World Meteorological Organization (2022) report, the global annual mean temperature in 2021 was 1.11±0.13 °C above the 1850–1900 pre-industrial average. The years 2015 to 2021 were considered the seven warmest years on record; with 2016, which started during a strong El Niño, remaining the warmest year yet recorded (WMO 2022). Recent years have been cooler than 2016, with La Niña conditions at the beginning and end of each year. Despite the moderate La Niña effects, the warming trend also continued in 2021 in Latin America and the Caribbean region. The average rate at which temperatures increased was around 0.2 °C per decade between 1991 and 2021, compared to 0.1 °C per decade between 1961 and 1990 (WMO 2022). Regarding rainfall, most of the region recorded below-normal patterns. However, Central America and the Caribbean experienced extreme precipitation and subsequent flooding events associated with tropical cyclones.

Small Island Developing States (SIDS) are a special case as they all have similar characteristics and face common environmental, natural resource and development issues which can be exacerbated by climate change. The region is particularly vulnerable to droughts. The recurring drought events that the region has experienced over the past several years have caused significant distress to the population and damage to the economy. Historical data and future projections indicate that there is a declining trend in rainfall during the summer months (June-August) and this will continue in coming decades (Figures 1 and 2). Rising heat extremes, heat stress, and its corresponding higher evapotranspiration will cause increased aridity and severe agricultural and ecological droughts in the region (Maharaj et al., 2022; IPPC, 2022).

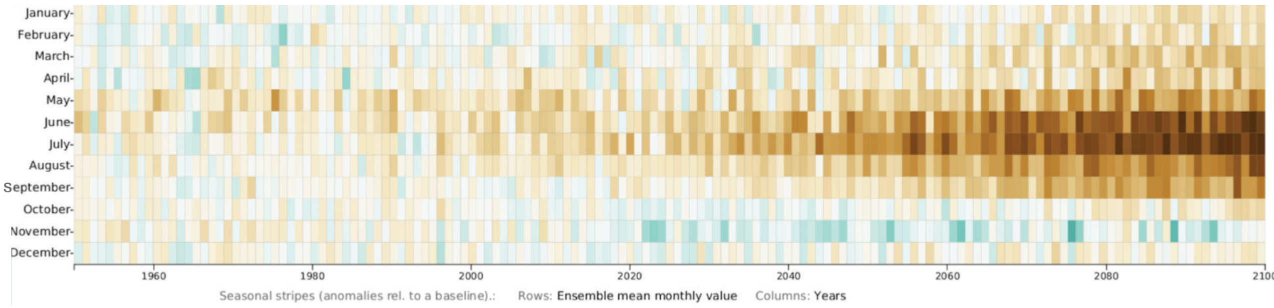



*Figure 1. Change in monthly average precipitation relative to 1995-2014 for the Caribbean under increasing warming levels, ensemble of 28 models, SSP3-7.0. IPCC, 2022*

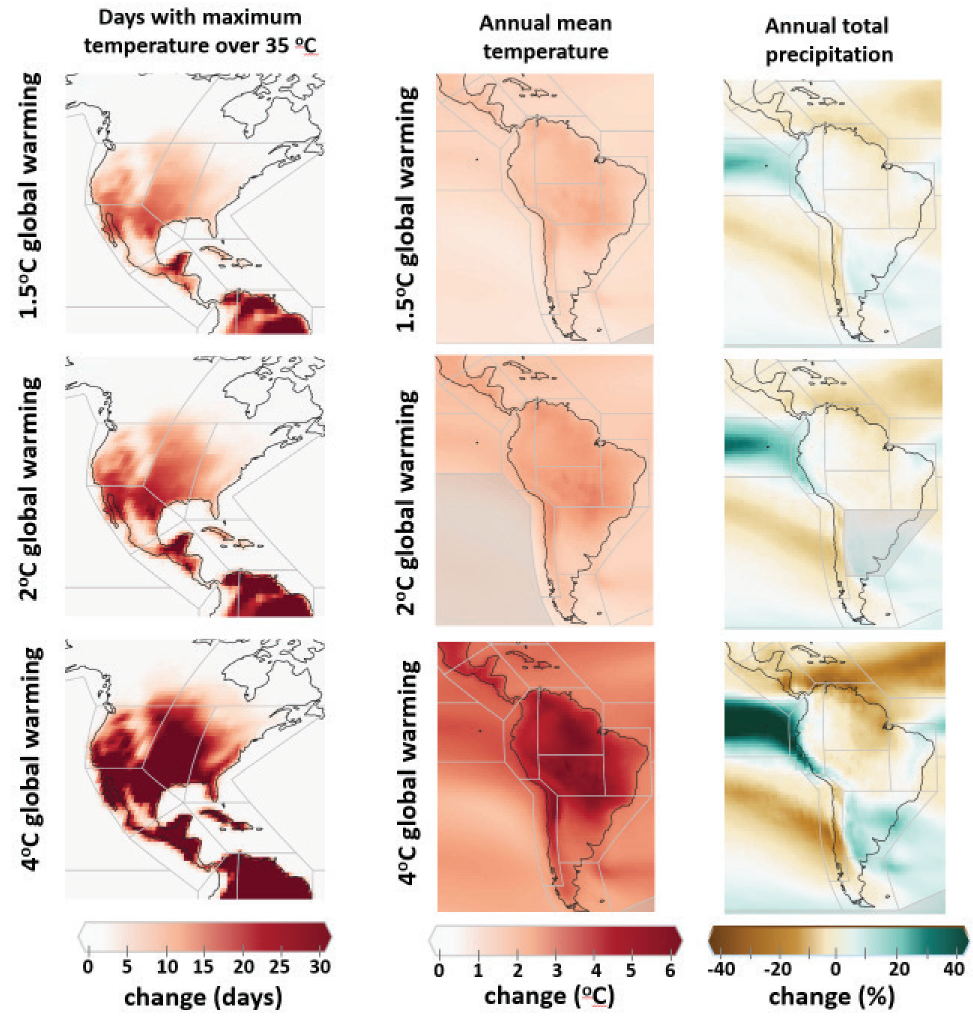



*Figure 2. Left: Projected changes in number of days with daily maximum temperatures over 35oC based on CMIP6 using SSP5 8.5 scenario. Right: Projected changes in annual mean temperature and annual total precipitation, results are based on simulations from the CMIP6 multi-model ensemble (32 global climate models) using the SSP5-8.5 scenario to compute the warming levels. Global warming levels at 1.5°C, 2°C, and 4°C (in rows) are relative to 1850–1900.* **.** *IPCC Interactive Atlas (https://interactive-atlas.ipcc.ch/)*

According to the Food and Agriculture Organization (FAO 2022), the Caribbean region accounts for seven of the world's top 36 water-stressed countries, as water-scarce with less than 1,000 $m^3$ freshwater resources per capita. With droughts becoming more frequent in the Caribbean, agriculture is likely to be seriously impacted, since most of the cropping systems are rainfed. Livestock is also likely to be affected by a shortage of forage and water, leading to negative socioeconomic impacts due to reduced crop and livestock production. The ongoing shift to irrigation to cope with drought will increase demand on the countries' limited fresh-water supply. (WMO 2022).

While there is relatively high confidence regarding the likely temperature and precipitation changes, there is less certainty about the potential impacts on SIDS' agricultural systems. One of the main reasons for this is the limited evidence (e.g., studies) that exists in the region about how climate change may impact crop yields and farmers' livelihoods (Figure 3).

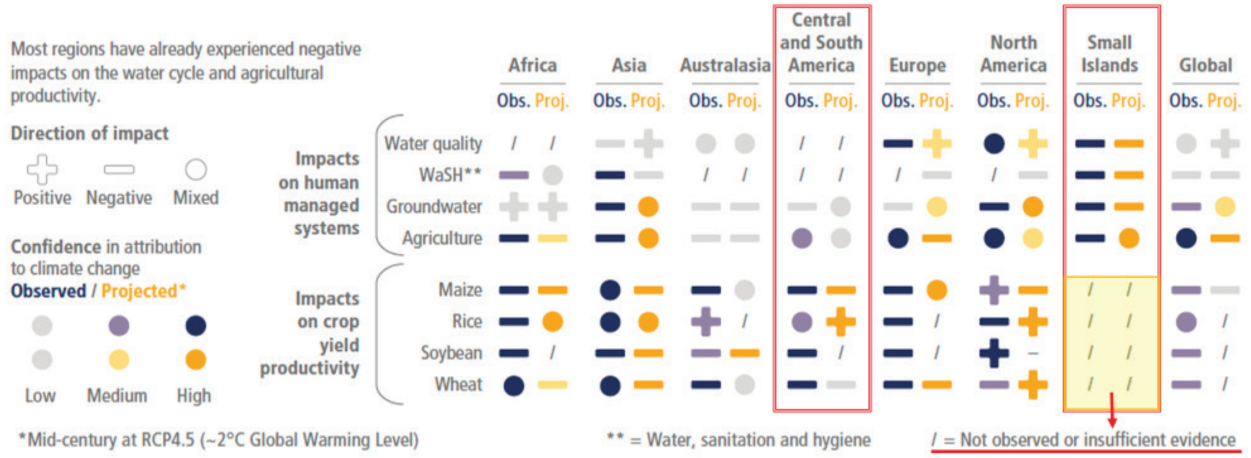



*Figure 3. Observed and projected impacts from climate change in the water cycle for human managed systems and crop yield productivity. Boxes highlight conditions for Central and South America and SIDS*

Countries are currently in the process of developing their National Adaptation Plans (NAPs) and Nationally Determined Contributions (NDCs) aimed at meeting their commitments within the Paris agreement and other international commitments. However, most of the proposed plans and interventions have insufficient science-based evidence to enable a robust understanding of the potential bio-physical, environmental, and socio-economic impacts of climate change and adaptation/mitigation strategies (Witkowski et al.,2021; Witkowski and Medina, 2016). It is necessary to use modeling tools and approaches that can provide science-based information to stakeholders about the likely impacts of climate change, adaptation, and mitigation strategies under current and future conditions. In addition, understanding the potential tradeoffs and co-benefits of proposed adaptation and mitigation options is key to support planning efforts and priority setting for climate action (Valdivia et al., 2019; Witkowski et al., 2021).

# 3. AgMIP RIA Approach and TOA-MD

AgMIP has developed a transdisciplinary, multi-scale methodology for Regional Integrated Assessment (RIA) of agricultural systems (Antle et al., 2015; Rosenzweig et al., 2021). The approach begins with collaboration between scientists and stakeholders to identify key economic, environmental, and social indicators of system performance. It then  links climate, crop, livestock and economic data and models to design and implement scenario analysis supported by quantitative modeling of the farming system. Representative Agricultural Pathways (RAPs) play a central role in this methodology. RAPs are qualitative storylines that can be translated into model parameters (scenarios) such as farm and household size, prices and cost of production, and policy parameters (Valdivia et al, 2015; 2021). RIA methods are used to implement simulation experiments to evaluate climate change impact, technology adoption and policy interventions.

AgMIP regional research teams in Africa and South Asia are using the Tradeoff Analysis model for Multi-Dimensional Impact Assessment (TOA-MD, Antle and Valdivia, 2022) to implement the economic analysis component of the AgMIP RIA methodology. The TOA-MD model is a, generic model for the analysis of technology adoption, impact assessment, and ecosystem services. The economic model is parameterized with data from the quantified development pathway analysis, outputs of crop and livestock models,  farm surveys collected by project partners and national projects, and is supplemented with secondary national data.

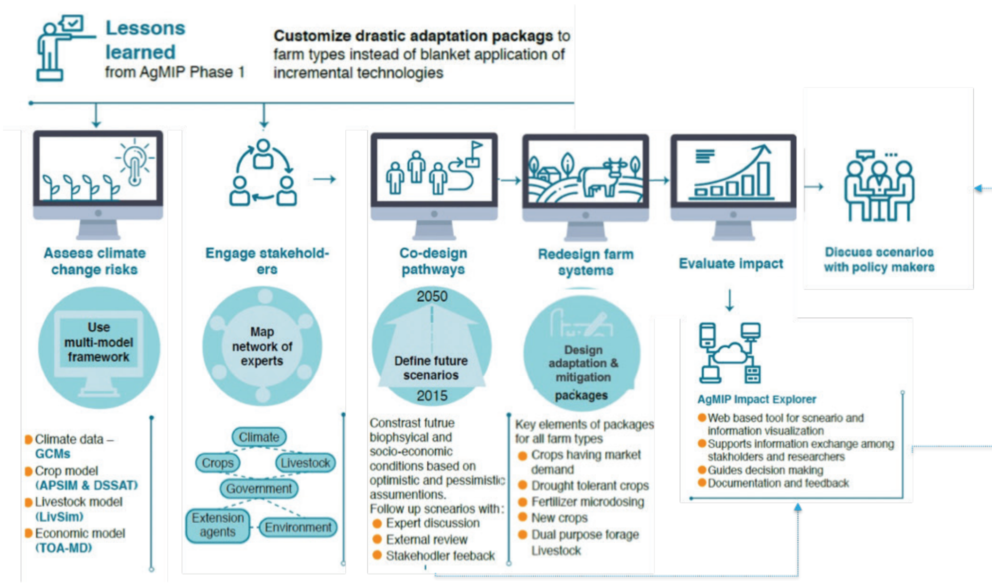



*Figure 4. AgMIP's Regional Integrated Assessment: A stakeholder-driven approach to customize Adaptation & Mitigation Action (Valdivia et al., 2019)*

The tradeoff analysis integrates data from climate, crops and livestock, and ways  to assess the sustainability of development pathways, technologies (e.g., adaptation and mitigation strategies) and policies.  It also examines the impacts of climate change by evaluating the inter-relationships (both tradeoffs and synergies) among economic indicators (farm income, poverty rates), environmental indicators (e.g., GHG emissions), and social indicators (food security and gender).

The TOA-MD simulates impacts that are statistically associated with adoption, using the standard statistical framework for econometric policy evaluation in which economic "agents" – in our context, farms – self-select into "treatment", i.e., choose to adopt or not adopt. The model can be used to estimate the so-called "treatment effects" or the impacts associated with technology adoption. The impacts of climate change estimated by the TOA-MD model are the "treatment effects" of climate change. TOA-MD provides the capability to go beyond the analysis of averaged or aggregated data, by representing the distribution of economic, environmental, and social outcomes in heterogeneous populations of farm households. When used for climate impact assessment, the TOA-MD model can be used to show how the distributions of outcomes are affected by climate and by adaptations farmers may undertake in response to climate change.

The TOA-MD represents the whole farm production system (i.e., includes crops, livestock and aquaculture sub-system, and the farm household characteristics). The TOA-MD is a model of a farm population, not a model of an individual or "representative" farm. Accordingly, the fundamental parameters of the model are population statistics – means, variances and correlations of the economic variables in the models and the associated outcome variables of interest. With suitable bio-physical and economic data, these statistical parameters can be estimated for current systems. Using the methods described in the AgMIP Regional Integrated Assessment Handbook (www.agmip.org), one can estimate how the TOA-MD model parameters would change in response to climate change or technological adaptations. These changes in model parameters are the basis for the climate impact, vulnerability and adaptation analysis used in this Pilot Study.

In the TOA-MD model, it is possible to simulate perennial or multi-year production crops like sugarcane. The analysis is based on annuitized net returns derived from the present value of returns to the production activity over the period of years.  The net returns are then interpreted as the average or annuitized. These annuitized values are estimated for systems 1 and 2 and entered in the TOA-MD (see Antle and Valdivia, 2022 for more details). This approach was used to estimate parameters for the sugarcane case study in Belize, described below.

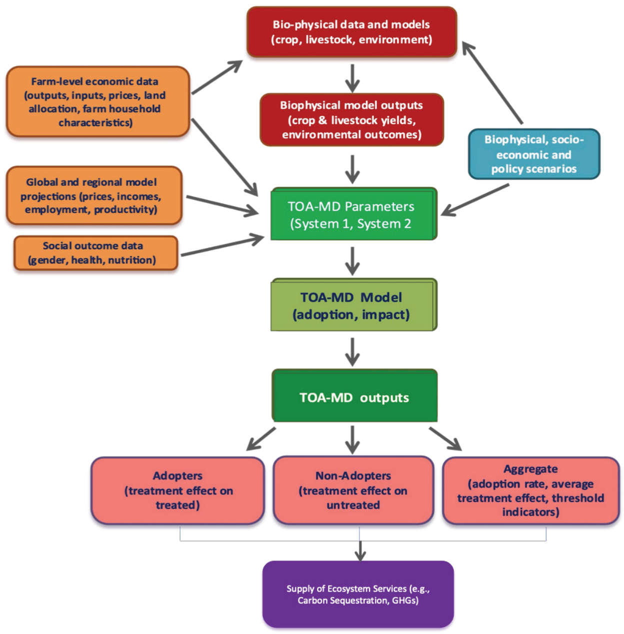



*Figure 5. Tradeoffs Analysis Model: Landscape-scale technology adoption, environmental impacts, and ecosystem services (Antle and Valdivia, 2022)*

# 4. Case Study: Sugarcane Production in Belize

Belize is located on the mainland of Central America between 15°45′and 18°30′ north latitude and 87°30′ and 89°15′ west longitude. The country is bordered by Mexico to the North, Guatemala to the West and South, and the Caribbean Sea to the East.

Mean temperature in Belize ranges from 27°C (max - 30.1°C, min 22.6°C) along the coast to 21°C (max - 25.3°C, min - 17.7°C) in the hills; the coldest month being January and the warmest temperatures experienced in May. Alternatively, the rainy or hurricane season occurs from June to November and brings approximately 60 inches (1524 mm) of rainfall in the north to 160 inches (4064 mm) in the south (NCCO, 2016).

Many low-lying coastal nations such as Belize are vulnerable to the impacts of climate variability and change. These are often seen in the form of increasing frequency and intensity of low-pressure systems such as storms and hurricanes alongside associated drought and flood events, while others in the rise of mean sea level and of average sea and land temperatures. Moreover, these changes are accompanied by intra/inter-annual variability, producing erratic and unpredictable weather that adversely affects the lives and livelihoods of many local communities.

The Government of Belize has made efforts to mainstream climate change action throughout the agriculture sector and has continuously recognized that farming systems and practices are extremely vulnerable to the impacts of climate variability and change. Thus, it is important to stress the fact that crops of economic importance in Belize such as sugarcane will be adversely affected by warmer weather from high temperatures along with flooding, saline intrusion, and soil salinization leading to low agricultural yields.

Notwithstanding, agriculture continues to be amongst the sectors most affected by climate change. This presents a significant risk to Belize's development efforts, as agriculture contributes to 10% of the country GDP (SIB, 2017). This sector is primarily dependent on traditional export crops and by-products such as sugarcane, citrus and bananas. Together these currently account for 60% of all agricultural earnings, of which sugar makes up 25.6% (SIB, 2017).

In Belize, sugarcane is grown in the Corozal and Orange Walk districts covering over 2,508 sq. miles (approximately 70,000 acres under production) and is the largest productive sector in the Belizean economy, representing 5% of GDP. This represents some 5,200 small farmers over 53 rural communities (29 in Corozal and 24 in Orange Walk) and accounts for 15.3% of total direct employment in northern Belize, making it a pillar of the Belizean economy (SIB 2017). According to the Sugar Industry Research and Development Institute (SIRDI, 2020), 60% of sugarcane farmers are male and 40% are female. Annual exports of sugar have increased from around 80,000 tons before 2010 to over 200,000 metric tons in 2019-2020 making it the largest foreign exchange source of income for Belize.

However, the sustainability of the industry is at risk due to the changes in climate during the past years. The increase in drought and flood incidence has led to decreasing yields due to crop loss, decreasing soil fertility, an increase in weeds, and the occurrence of new pests and diseases in sugarcane plants. In particular, the small farmers of the sugarcane belt in Northern Belize continue to experience a significant decline in crop yields due to extended periods of below average rainfall, such as in 2019, coupled with other periods of heavy rainfall over a short period of time. This situation leads to an increase in crop pests, associated diseases, and evapotranspiration rates, thus reducing soil moisture and eventually leading to reduced productivity and crop loss. Furthermore, these challenges have a cascading effect, as they then result in further constraints regarding water availability for irrigation and soil infertility. Climate change is likely to exacerbate these conditions with negative effects on farmers' livelihoods.

## 4.1 Data

The information and data used for the development of the case study is from the base line study of the IDB-IMF funded project "Creating a sustainable sugar cane industry in northern Belize" of 2017 and complemented with updated data from the sugar industry in Belize in 2022. The objective was to conduct a complete baseline assessment of the farmers' field operations, including yields and financial data in a strategic production category.

A representative sample of 871 farmers (16% of the target population) was analyzed via multiple levels of stratification. Firstly, at the district level in an attempt to represent each district proportionally . Other levels of stratification were done according to producer size based on sugarcane delivery statistics during the crop season: large producers (≥ 1,000 ton), medium producers (301 to 1000 tons), small producers (75 to 300 tons), and micro producers (≤ 75 tons).

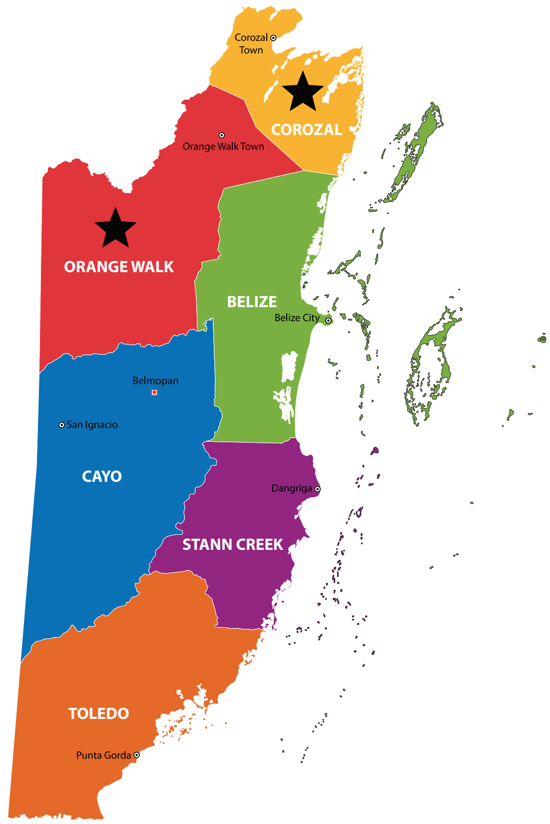



*Figure 6. Belize's sugarcane case study sites: Orange Walk and Corozal districts*

The household survey included basic information such as demographics, productivity, cost of production, farmers' attitudes and their knowledge of technology. For the present study, only micro-, small- and medium-scale farmers were considered since they make up more than 90 percent of the total sugarcane farmers in the studied area. Data (e.g., production costs) on other cropping activities on the farm were not available. Thus, farms that had more than 75% of the land allocated to sugarcane were included in the analysis. Given their small size, these farms can be treated as monoculture farms since their income from other agricultural activities is minimal.

The sugar industry is the main economic driver in the region being studied since it plays a vital socio-economic role for the surrounding communities. 77% of sugarcane growers are small-scale farmers who deliver volumes of less than 200 tons of cane per cycle and with an estimated average yield of 44 t $ha^{-1}$ (De León and González 2011). These yields are much lower than the regional and world averages of 74.2 t $ha^{-1}$ and 70.9 t $ha^{-1}$ respectively. According to Chi et. al (2017), the sugarcane industry in Belize utilizes inappropriate production technologies which lead to soil degradation, environmental deterioration, and nutritional imbalances, further compromising the sustainability of the industry. Therefore, it is necessary to identify the best farming practices for increasing soil fertility to improve yields and for minimizing negative impacts on the environment.

The livelihoods of most micro-, small- and medium-scale farmers within the northern sugar belt in Belize where the only sugar factory is located, are largely dependent on the cultivation of sugarcane. Farmers who cultivate sugarcane in these communities face the challenges of declining sugarcane yields and soil degradation, which has resulted primarily from decades of a sugarcane monoculture cropping system, along with inadequate management practices.

Sugarcane production in Belize is a monoculture practice with an average cycle of seven harvests, and in some cases continuing for up to more than 20 years before the fields are fallowed. This continuous cropping system often ignores long-term effects on soil fertility as long as profitable yields are maintained (Dominy et al. 2001). However, this system has profound negative effects on organic matter, total nitrogen and cation exchange capacity of the soil in the area (Chi et al. 2017). During the first years of establishment high yields are obtained. However, during the fourth and successive years production declines.

The sugarcane production technology currently used in Belize is typified as low-technology due to limited availability of inputs for production, and poor land preparation practice, and crop maintenance. The amount of cultivating which takes place on cane fields after the harvesting plant cane and ratoon cycles end is low, due to the lack of machinery and finance accessible to producers.

Crop establishment starts in the first year of planting with the selection of the site, preferably on high ground and without drainage problems. The present production system consists of a minimum renewal of the field, with year one as the establishment and years 2-7 as ratoon years. If land is not fallowed, a new 7-year crop cycle continues. Traditionally, sugarcane farmers use the variety B79-474, and seeds are usually obtained from any ratoon field and not from seed nurseries.

Weed control activity in sugarcane fields is either partially mechanized on the surface or achieved through the application of herbicides, or by utilizing both methods. The most common pests (e.g., froghopper, sugarcane borer and mealy bug) that affect the crop are usually only partially controlled. This activity is conducted when pests are already problematic for the crop and not as a preventive measure. The harvesting is semi-mechanized (manual cutting and mechanical lifting), with a previous burning of the area to remove the straw. The cost of harvesting and its delivery to the mill represents the highest cost for the producer. Post-harvest losses attributed to handling of cane from cutting to grinding is about 11.5%.

The practice of burning fields and post-harvest waste has been deeply rooted in the Belizean cane field for many years. It is argued that severe problems of fires or accidental burning can occur, thus promoting pest and disease incidence. Fertilizer and herbicide applications are conducted manually and semi-mechanically by 75% and 45% of the producers respectively, immediately after harvesting.

## 4.2 Adapting to Climate Change

Belize's sugarcane production challenges described above suggest that the need exists to improve soil and crop management practices of small farmers with the goal of sustainably producing sugarcane under changing climate conditions. Recent studies recommend the adoption of climate-smart and conservation agriculture technologies to transform sugarcane production into a more resilient system.

The use of organic residue from sugarcane manufacturing can conserve and improve the chemical, physical and biological properties of soil, thus enhancing crop quality and yield. It can also favor humidity retention. Microorganism's activation improves soil texture and contributes to the conservation of natural resources by recycling carbon and mineral elements (Prado et al. 2013). The elimination of burning and green cane harvesting is another viable option, which would have a positive impact on soil fertility, the environment, and improve yields; as well as provide mitigation co-benefits as land management techniques would improve the sequestration capacity in soils with the reduced burning of organic waste.

The fertilization of fields with mineral fertilizer should be conducted according to a scientific rationale after a soil analysis has been performed to determine the exact amount that the crop requires. Also, the application time needs to be observed to maximize absorption by the plant during its critical growth period. Microdosing is recommended to minimize loss through volatilization and maximize absorption.

Moreover, also important is the use of improved and climate-resilient sugarcane varieties which will tolerate droughts and floods along with climate-induced pests and diseases. An integrated pest management approach that includes cultural practices and biological control agents, would reduce dependency on chemicals and lower production costs in the medium and long terms, as well as decrease negative impacts on the environment (e.g., reduce GHG emissions).

### *4.2.1 Climate-Smart Agriculture Technology*

The recommended climate-smart production practices described below are aimed at moving towards a sugarcane production in Belize that is more efficient while improving the adaptive capacity of small farmers to face climate change and reduce the carbon footprint of the industry.

It is recommended that sugarcane be planted every 5-7 years depending on crop vigor and soil condition. Planting is considered one of the most significant operational activities undertaken on the field. To plant, the old field must be prepared and clean seeds need to be planted in a seedbed with sufficient available moisture to ensure germination. The replanting and subsequent ratoon management of fields using a larger number of sugarcane varieties which are better adapted to the Belize current and projected climatic conditions would help in improving yields. The reliance of the industry on one or few varieties without taking climate change into account makes the industry vulnerable.

An expanded variety pool in the industry with some early, some mid and some late- maturing varieties in balance, will not only improve quality and productivity but will also allow the grinding season to be better managed to avoid periods of high rainfall. It will also ensure that if new pests and diseases become prevalent as a result of climate change as is predicted, then the risk of this event will be spread.

Green cane harvesting will lead to a reduction in the greenhouse gas emissions from the cane farming operations. The pre-harvest burning of sugarcane is one of the most sensitive environmental issues faced by cane growers. In addition to releasing $CO_2$, sugarcane burning also results in acidic fine particle emission, which has a negative impact on air quality and human health (Allen *et al*., 2004). Green cane harvesting lowers the negative impact on nearby communities and environments close to sugarcane fields (Shaochun Ma et al. 2013). The soil chemical fertility under the sugarcane without burning is greatly improved, thus allowing higher yields (Souza et al., 2012). The application of organic soil matter through organic material amendments (vinasse/organic acids) and microbiology augmentation by means of biofertilizer (i.e., beneficial organisms) as soil management practices, will allow for the conservation of soil moisture and nutrient loss. This is very important for the management and improvement of soil health and fertility and to avert the negative effects of climate change.

The increased use of irrigation and drainage technology is needed to mitigate the impacts of changing and erratic rainfall patterns that may cause moisture stress or flooding, inhibiting plant growth and production. Irrigation and drainage as tools to modify the growing environment in sugarcane are technologies that are used in many regions of the world and will have a positive impact on Belize's sugar industry. However, strategies that include these technologies need to consider the associated costs of implementing the technology and how adoption rates may be impacted.

In this pilot study an adaptation package that includes the adoption of improved crop varieties and soil conservation practices that improve soil nutrients, and the use of organic fertilizer and bio-fertilizer (CSA) was tested. Microdosing and irrigation and drainage management are also included in the adaptation package. Initial investment can be a burden to farmers, in particular to smallholder farms. Therefore, a sensitivity analysis of fixed costs was conducted. First it was assumed that farmers bear all fixed costs. A second scenario assumed that microfarms receive support (e.g., subsidy) covering 50% of the investment (small- and medium-sized farms have 100% covered). The third scenario assumed that in addition to the support provided to micro farms, small- and medium-sized farms would also receive a 25% subsidy to cover their fixed costs.

# 5. Case Study: Tomato-pepper Systems in Trinidad and Tobago

The agricultural sector in Small Island Developing States (SIDS) is likely to be adversely affected by climate change and variability. Farmers must cope with changes that occur from one year to the next (climate variability) and with long-term warmer and drier weather trends (climate change).

Like many other SIDS in the Caribbean, Trinidad and Tobago's ability to feed itself is threatened by low resiliency to these impacts. The country is vulnerable to the rise in sea levels, increased flooding, higher unpredictability of weather conditions, hillside erosion, and the loss of coastal habitats. Although the country is located south of the hurricane belt and is least affected by hurricanes and tropical storm surges as compared to the other Caribbean archipelago counterparts. The twin island is severely affected by climate change because of its small land mass, fragile ecosystems, and concentration of infrastructure along the coast. Climate change models predict a temperature increase and decrease in rainfall concurrently for the coming decades (Eitzinger et al. 2015). This suggests an increase in the risk of natural hazards, which can significantly affect agricultural practices and already affects vulnerable rural livelihoods in Trinidad and Tobago. Many farmers have reported many losses directly linked to flood surges, loss of soil productivity, increased proliferation of new and existing pests and diseases, and increased demand for water for irrigation purposes. These threats to agriculture are of major concern to the country as the nation is currently trying to improve its economic conditions.

Trinidad and Tobago's agricultural sector contributes only 0.5% to Trinidad and Tobago's Gross Domestic Product (GDP). It accounts for over 4% of employment and is now considered to play an important role in the country's attempt for diversification of the economy (Shik et al. 2018). Currently, only 10.5% of the total land area is categorized as agricultural land, and the country is highly dependent on food imports. Fruits (65%), vegetables (17%), roots and tubers (8%), and cereals (7%) are the main crops produced (Eitzinger et al. 2015).

Recently, the government has focused its resources on assisting in the areas of training and farm development. Several programs are currently being implemented to expand agricultural production and to promote linkages with the manufacturing sector. The government is considering agro-incentives such as tax holidays, agriculture development grants and other incentives to agricultural processing industries to boost economic activity and industrial reformation. Trinidad and Tobago is one of the Caribbean nations which is most dependent on foreign food imports, and it has only recently placed a high priority on agriculture as an engine for economic growth and sustainability. However, investments in the sector are at risk if climate-smart agricultural practices are not mainstreamed across all sections of the agricultural value and supply chain.

## 5.1 Data

The data used in this case study is based on tomato and pepper farmers that are registered on the National Agricultural Marketing and Development Corporation (NAMDEVCO) and located in the vicinity of both the northern and southern regions of Trinidad that are considered the breadbasket of the island with respect to tomato and hot pepper production (Figure 7). An interview schedule was administered within the first crop cycle (during January to April 2018) to collect information on the socio-economic profile of farmers, farming practices adopted, and cost and returns involved in tomato and hot pepper cultivation. Detailed questions were included to appropriately calculate the cost of production and resource use efficiency. Most of the sampled respondents did not maintain records relevant to input use and cost of production. Consequently, they had to recall the past and current information required. Suitable cross-checks were carried out to minimize the non-sampling errors arising due to recall bias and to ensure the reliability of the information collected. The data was stratified as tomato farms in the northern and southern regions and pepper farms in the northern and southern regions.

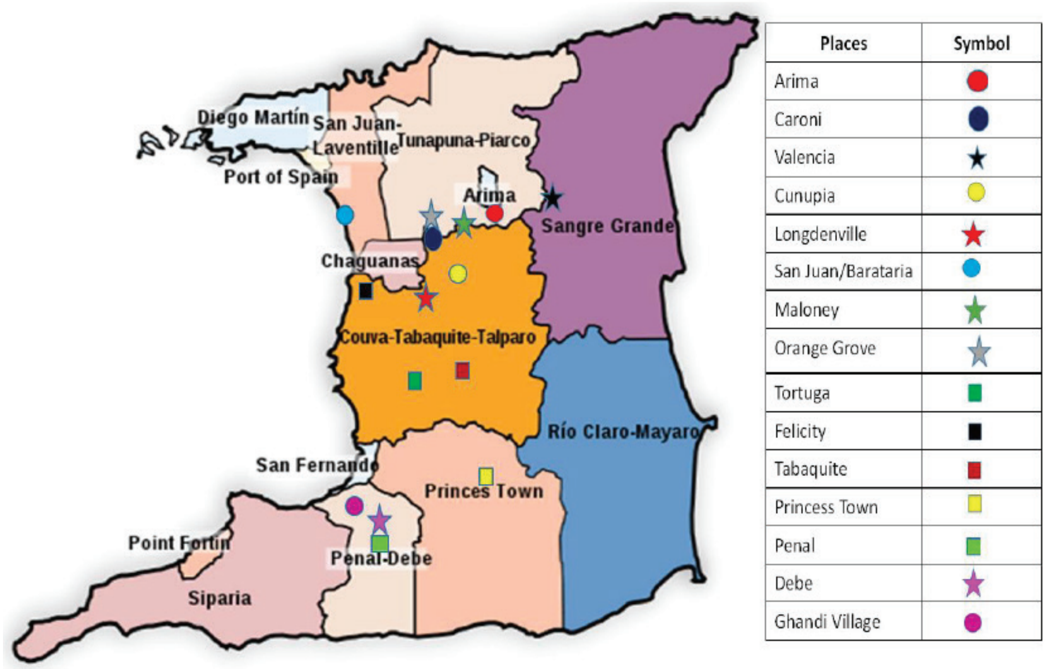



*Figure 7. Trinidad and Tobago: Regions where survey data for tomato and pepper farms were collected*

## 5.2 Adapting to Climate Change

Climate change is expected to cause rising temperatures and a decrease in total annual rainfall in SIDS like Trinidad and Tobago. This is expected to have serious impacts on agriculture, not only affecting yields but also reducing the area of land suitable for growing tomatoes and hot peppers due to higher temperatures and frequent droughts (Eitzinger 2015b; Bunn et al., 2019). In this pilot study, the adaptation package tested includes the introduction of drought and heat-tolerant tomato and hot pepper varieties and improved irrigation systems such as drip systems. Tomato varieties such as IT71 and Versatile are heat-tolerant and can be introduced as an adaptation to climate change (Isaac et al., 2014).

Climate change and variability is also expected to increase extreme events such as the number and intensity of tropical storms (e.g., hurricanes). While this is beyond the scope of this pilot analysis, investment in enclosed or semi-enclosed structures can provide protection to crop production in the region (De Gannes et al., 2014). Other alternative options include implementation of hydroponic systems that can allow consistent crop production throughout the year while saving water and making efficient use of rainwater (Witkowski and Medina, 2017).

# 6. Case Study: Cassava Production in Guyana

Agriculture is an important activity in Guyana where it serves as a basis for sustaining rural livelihoods and domestic food security and is an important source of foreign exchange earnings. Agriculture is responsible for 16% of the Gross Domestic Product (GDP) and 17% of overall employment (ITA, 2021). Guyana's National Land Use Plan estimates that 68% of Guyana's land surface has soils suitable for agriculture (Ministry of Agriculture, 2013). Traditional agricultural crops are sugarcane and rice, while non-traditional crops which are increasing in importance are coconut, cassava, orchard species, vegetables, botanicals and herbals. Fisheries, livestock and small ruminants are also important. Agriculture is highly concentrated geographically, with the exception of cassava, on the narrow strip of coastal plains.

Non-traditional agriculture is similar in input use to subsistence farming in Guyana, and is small scale, uses low technology and is highly labor intensive (Government of Guyana, 2012). Agricultural productivity is generally low, even for Guyana's most important export-oriented crops, namely rice and sugar. Small farmers are responsible for the production of most of the fruits, vegetables and grains; the yield of crops such as corn, beans and small-scale rice production are 40% lower than that of its Caribbean neighbors and 60% lower compared with the rest of South America.

Guyana's vision for agriculture is to transform agriculture from a subsistence-based activity to a source of wealth generation and entrepreneurial innovation to produce food and non-food commodities to meet local and export demand. Previous efforts have focused on the 5-C's (citrus, cassava, coconut, cocoa and cattle) while more recently, efforts have been placed on the 4-Ps: pepper, plantain, pineapple and pumpkin.

## 6.1 Data

The data used in this case was obtained from a household survey designed and implemented during the month of July 2016 by the Sustainable Agricultural Development Program of the Inter-American Development Bank (IDB). The survey sample was stratified and focused on regions 5, 9 and 10 (See Figure 8).

The survey sample was taken based on a random selection of villages with the number of households to be sampled within each village defined a priori. Stratification within Region 10 was undertaken according to Amerindian Communities and Non-Amerindian Communities. Regions 9 and 5 were not stratified since Region 9 is largely Amerindian and Region 5 does not have a consolidated Amerindian Community (Bureau of Statistics, 2007, Regional Democratic Council, 2016). In Region 5, 330 households were sampled; in Region 9, 350 households were sampled, and in Region 10, 219 households were sampled.

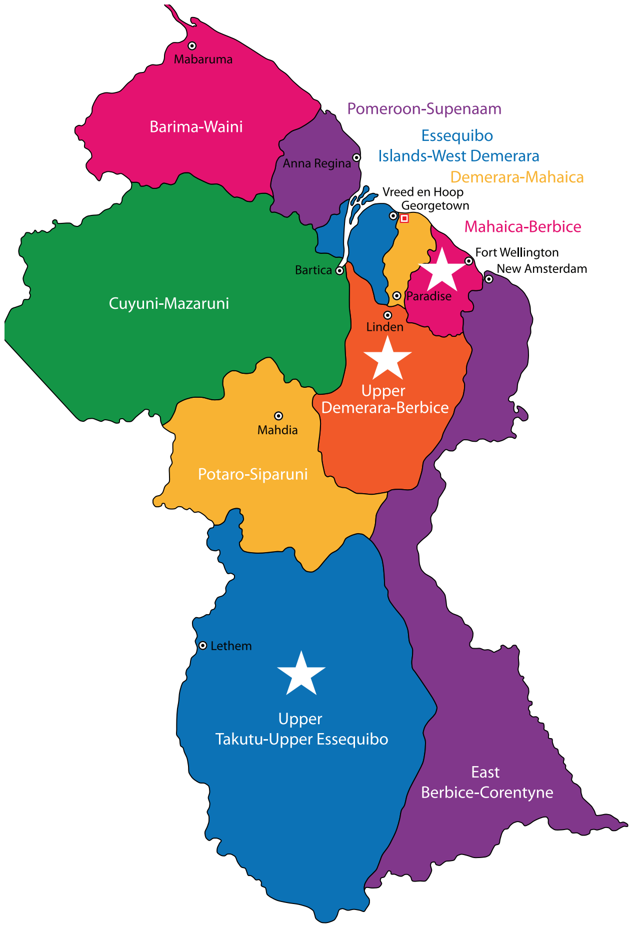



*Figure 8. Guyana: Location of sampled households (IDB, 2016)*

## 6.2 Adapting to Climate Change

Climate change can have serious consequences for Guyana, a country that is heavily dependent on agriculture. Recent studies indicate that temperature has been increasing over the last three decades. Rainfall patterns were observed to be fluctuating with a general increase over time (Lakenarine et al., 2020). Most farmers have been affected by floods, which is becoming much more prevalent in recent years. This resulted in major crop losses and had high financial impacts on farmers.

In 2019, Guyana presented a comprehensive First Voluntary National Review of the Sustainable Development Goals (SDG) at the High-Level Political Forum on Sustainable Development. Particularly related to SDG 13 (Climate Action) and SDG 15 (Life on Land), Guyana has taken concrete steps to mitigate the effects of CC and strengthen resilience and adaptive capacity to climate-related hazards and natural disasters (SDG 13.1), to integrate climate change measures into national policies, strategies and planning (SDG 13.2), and to keep deforestation rates low, in keeping with the national implementation of REDD+ (SDG 15.1; 15.2: 15.a). Various environmental education awareness sessions have taken place as well (SDG 13.3). However, challenges and gaps persist, especially in the areas of technical capacity, data and financing which hinder further progress (RoG, 2021).

Cassava is one of the main agricultural goods produced in the regions where the data was collected, though it remains largely a subsistence crop and activity. Cassava production technology is rudimentary in all its aspects with almost no inputs used for fertility or pest control. Cassava yields are variable and range between 2 - 17 tons per hectare. Some studies have identified cassava cropping systems as adaptation measures because cassava can be tolerant to several climatic stresses such as high temperature and water deficit (Jarvis et al., 2012, Amelework et al., 2021). However, other studies indicate that cassava's issues with pest and diseases would increase and have negative effects on crop productivity (Chavez et al., 2021).

In this case study, the likely negative effects of climate change on cassava yields is tested. Due to the lack of farm-systems data (e.g., crop/livestock yields and management from other activities on the farm, non-farm and off-farm income), the analysis focuses on the economic impacts of climate change on cassava.

As an adaptation strategy, the implementation of integrated pest management practices and an improved crop variety is assumed.

# 7. Results

This section presents the modeling results across the three case studies. First, the key parameters used to setup the TOA-MD model for each case are summarized. Then disaggregated results (by strata) about the impacts of climate change on the production systems and farmer's livelihoods comparing across the three case studies are presented. Next, the results of the analysis of adoption of the adaptation packages tested for each case are discussed. The section concludes comparing the aggregated results across the three countries.

## 7.1 TOA-MD Model Parameters: Characterizing the Production Systems

The TOA-MD model is designed to simulate experiments for a population of farms using a 'base' production system (System 1, *e.g.*, conventional system) and an alternative System 2 (*e.g.*, climate-smart technology). Farmers choose whether to stay under system 1 or switch to System 2. The choice between systems is assumed to depend on the *difference* in expected returns between the two systems, and accordingly data are required to estimate parameters (means, variances, covariances) of the *distribution* of this difference in expected economic returns between the two systems in the farm population. A similar logic applies to the case of impacts of climate change where System 1 is the production system under *current climate* and System 2 is the production system under *climate change*. For this Pilot Study, two simulation experiments were conducted:

***(1)*** ***impacts of climate change***, where System 1 is the conventional production system under the current climate and System 2 is the conventional production system under climate change.

***(2)*** ***adoption of the adaptation package under climate change***, where System 1 is the conventional production system under climate change, and System 2 is the production system using the adapted technology under climate change.

For the case of sugarcane production in Belize, the analysis is based on annuitized net returns derived from the present value of returns to sugarcane over the period of seven years which is a typical production cycle in Belize (establishment year and six ratoon years). These values were estimated following the methods described in section 3.1. Table 1 shows the annuitized net return values by strata used to parameterize the TOA-MD model for the two simulation experiments.

*Table 1. Annuitized net returns for conventional sugarcane production under current and future climate and for the adaptation strategy by district and farm type in Belize.*

| | | Conventional | | Climate change | | Adaptation | |
|---|---|---|---|---|---|---|---|
| District | Farm type | Annuitized net returns (BZ$) | St dev | Annuitized net returns (BZ$) | St dev | Annuitized net returns (BZ$) | St dev |
| *Corozal* | *Micro* | *1629.87* | *1656.62* | *1326.16* | *1356.68* | *1363.68* | *1692.49* |
| *Corozal* | *Small* | *2064.77* | *4288.45* | *1573.05* | *3304.89* | *2620.90* | *4275.34* |
| *Corozal* | *Medium* | *9000.00* | *13193.28* | *6387.04* | *9456.11* | *9163.97* | *12106.34* |
| *Orange Walk* | *Micro* | *1718.90* | *1705.31* | *1400.04* | *1398.43* | *1455.85* | *1690.35* |
| *Orange Walk* | *Small* | *3815.74* | *8164.46* | *2916.65* | *6289.06* | *4539.83* | *8233.90* |
| *Orange Walk* | *Medium* | *9671.94* | *11386.62* | *6850.16* | *8136.15* | *10037.64* | *10837.65* |

*Adaptation values with no subsidy

For the case o

f tomato and pepper systems in Trinidad and Tobago, farm net returns were estimated for each system and strata (northern and southern regions). In this case study two climate change scenarios were tested, one that is projected to be warmer and drier ("climate change (-)") and the second that is projected to be warmer and less dry compared to the first scenario ("climate change (+)"). Table 2 describes the net return values used to parameterize the TOA-MD model.

*Table 2. Trinidad and Tobago: Tomato and hot pepper average net returns per farm, north and south regions under the conventional system, with climate change and adaptation package.*

| Region | System | Conventional | | Climate change (-) | | Climate change (-) | | Adaptation | |
|---|---|---|---|---|---|---|---|---|---|
| | | Average net returns (TT$) | St dev | Average net returns (TT$) | St dev | Average net returns (TT$) | St dev | Average net returns (TT$) | St dev |
| North | Tomato | 117078.60 | 105370.74 | 98346.02 | 101788.02 | 120590.96 | 124811.64 | 122932.53 | 110639.28 |
| South | Tomato | 121686.67 | 146024.04 | 85180.69 | 117549.35 | 119252.97 | 164569.09 | 106475.86 | 127771.04 |
| North | Pepper | 354117.50 | 311623.40 | 297458.70 | 301028.20 | 371823.38 | 376285.26 | 327204.57 | 261763.66 |
| South | Pepper | 378452.08 | 397374.71 | 227071.26 | 274188.55 | 302761.68 | 365584.73 | 249778.39 | 299734.06 |

For the case of cassava in Guyana, the estimated farm net returns are described in Table 3. It is important to highlight that the decrease in net returns under climate change is due to possible losses caused by a high incidence of pests and diseases.

*Table 3. Guyana: Cassava average farm net returns*

| System | Conventional | | Climate change | | Adaptation | |
|---|---|---|---|---|---|---|
| | Average net returns (US$) | St dev | Average net returns (US$) | St dev | Average net returns (US$) | St dev |
| Cassava | 3220.41 | 2189.88 | 2833.96 | 2080.38 | 4392.64 | 3953.38 |

## 7.2 Impacts of Climate Change

The economic modeling results, summarized in Figure 9, suggest that between 45% and 75% of the households in the three countries under study are vulnerable to climate change (i.e., proportion of households that are at risk of losing income due to climate change). Average farm net returns are likely to decrease from 3% to 40%. Southern farmers in Trinidad and 'medium-' sized sugarcane farmers in Belize are likely to lose the most. In Trinidad, even in the climate scenario that is less dry, pepper and tomato farms in the southern region still suffer from the negative effects of climate change (see Clim2 scenario in Figure 9). These impacts lead to increases in poverty rates in the region between 8% to 25%[1].

In the case of sugarcane production in Belize, medium-sized farmers are likely to have a larger decrease in farm returns compared to micro and small farms. One explanation is that medium-sized farms have "more to lose" compared to small and micro farms. Thus, their relative losses are larger. This is consistent with findings in other regions where the larger farms are managed more intensively and thus are less resilient than small farms (see for example Homman et al., 2021).

In the case of tomato and pepper production in Trinidad and Tobago, the southern region appears to have larger negative effects compared to the northern region. Additional research is needed to understand what drives the southern region to have greater losses under climate change.

1 Poverty rate is the Headcount poverty rate with a poverty line = USD1.25/person/day

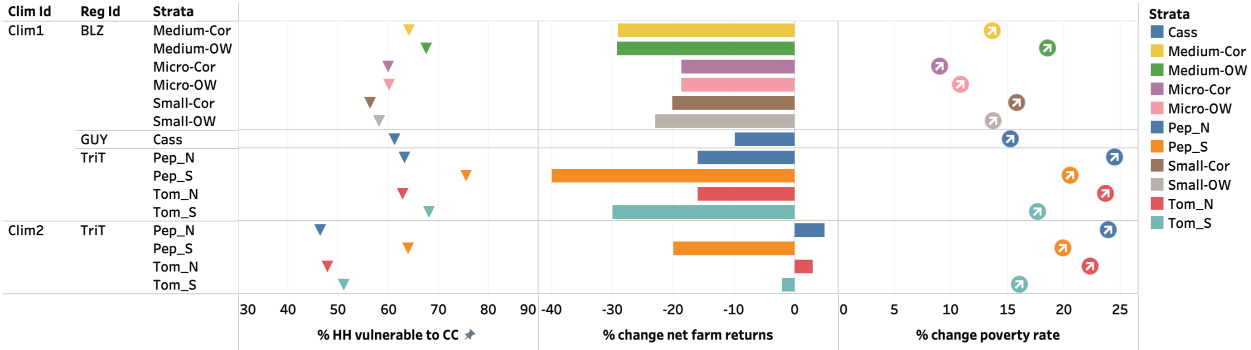



*Figure 9. Climate change impacts on tomato and pepper (Trinidad and Tobago), sugarcane (Belize) and cassava (Guyana). First column: % households vulnerable to climate change; second column: % change in mean net farm returns; third column: % change in poverty rates.*

The results in Figure 9 (percent change in net farm returns) show that in most cases the average net economic impact, defined as the difference between the gains and losses across all farms, is negative. Figure 10 shows these net impacts disaggregated by the strata (sub-regions) in each country. Consistent with the change in net returns in Figure 9, tomato and pepper production in Southern Trinidad have largest losses. Even under the assumption of a more favorable climate projection, only tomato and pepper production in the northern region in Trinidad may see positive net economic impacts, on average. See Table 1 in the Appendix for the disaggregated gains, losses, and net economic impacts across all regions.

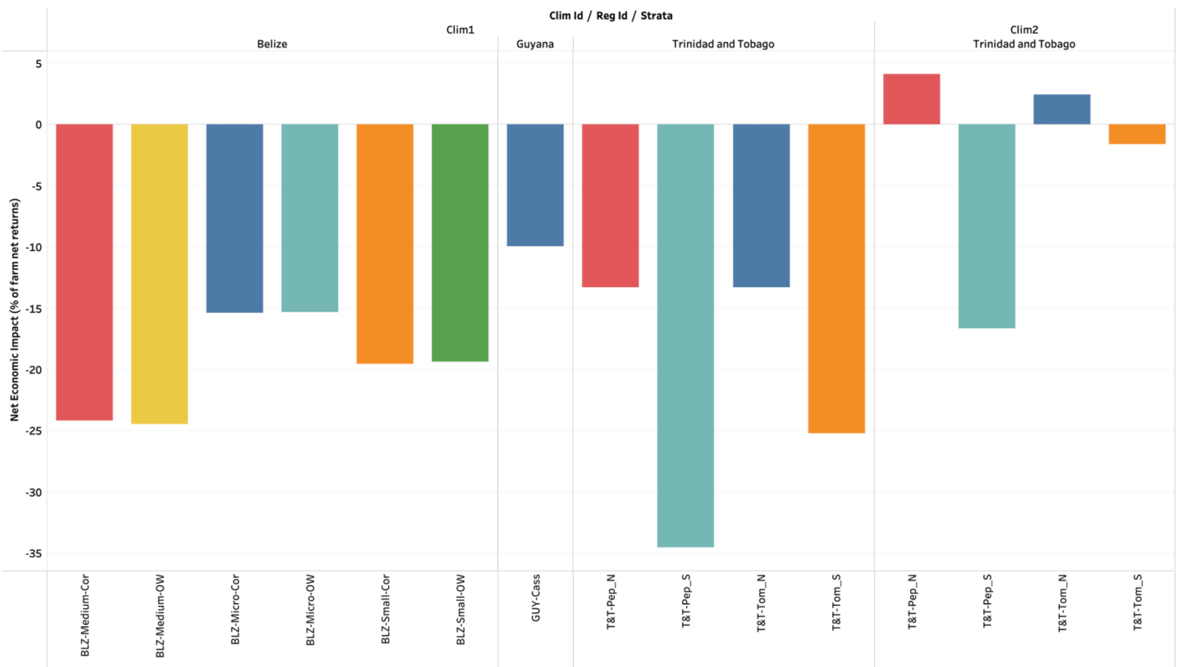



*Figure 10. Net economic impact as a percentage of mean net farm returns for all the countries, disaggregated by strata.*

The net economic impacts presented above can be interpreted similarly to the results of a cost-benefit analysis designed to represent the overall impacts of climate change. A major limitation of this type of analysis is that it does not represent how a heterogeneous population of farms (i.e., farms that differ in physical differences such as soils and climate, and economic differences such as size and productive capability) can be differentially affected by climate change. This heterogeneity means that there are typically both gainers and losers from climate change. A feature of the TOA-MD model and the AgMIP RIA approach is that it can estimate not only the average impacts but also the proportion of households that are vulnerable to climate change (i.e., those which are at risk of losing due to climate change). The results from this pilot study show that even in cases where there are positive net economic impacts (gains larger than losses), the proportion of farms that are vulnerable to climate change is high (around 45%-50%). The overall range of vulnerability across the different regions is between 45% to 77% (Figure 11).

This kind of information has important implications for climate policy and development of NAPs and NDCs and implementation of adaptation and mitigation strategies. Focusing on average impacts (i.e., results from a C-B analysis) may lead policy decision-makers to be unaware of the severity of impacts on vulnerable groups, and thus could lead to policies that do not address the challenges faced by the most vulnerable. Tradeoff analysis and information as shown in Figure 11 can help communicate this message to policymakers and thus support decision-making, which will benefit the more vulnerable populations.

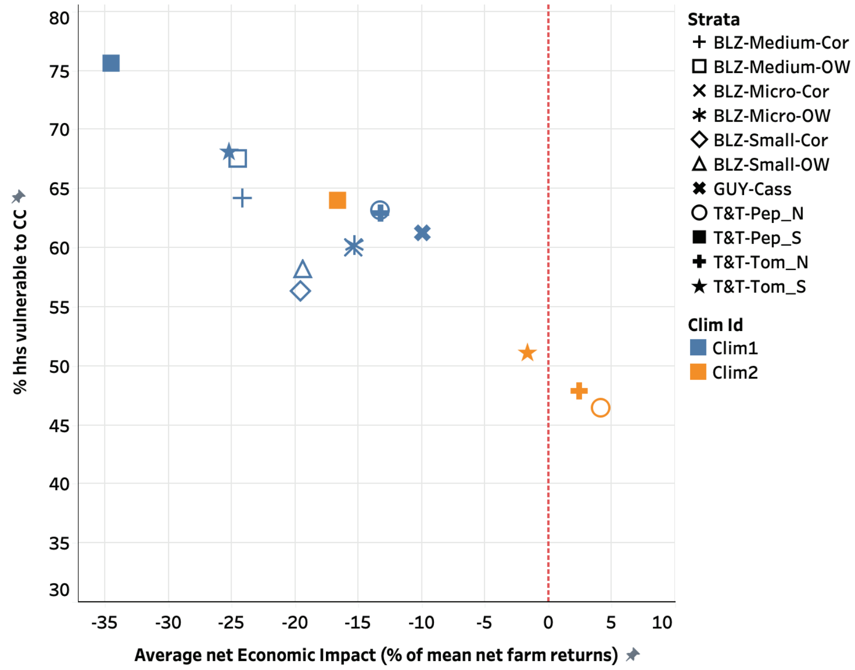



*Figure 11. Tradeoffs between net economic impacts and the proportion of households vulnerable to climate change across all countries and regions*

## 7.3 Adaptation to Climate Change

For this pilot study, a set of adaptation packages for each country/production system was tested as described above under each case study description and in Table 4. For the tomato and pepper systems, the adaptation strategy focused on promoting the adoption of drought- resistant varieties as well as improved irrigation systems.

In the case of sugarcane, research is currently underway to observe changes in the production system based on Climate-Smart Agriculture and Conservation Agriculture principles. In addition, the use of improved crop varieties, microdosing and irrigation drainage systems are being recommended as adaptation and mitigation strategies. In this study, a sensitivity analysis of the initial investment costs (new microdosing irrigation systems) was conducted. First, it was assumed that farms bore all the investment costs (A1). A second scenario assumed a 50% subsidy of those costs for the micro sugarcane farms (A2), and a third scenario included 25% support for small and medium-sized farms, in addition to the support provided to the micro farms (A3).

In the case of cassava, available research suggests that this crop might benefit from climate change. However, these studies also suggest that while crop yields might not be (negatively) affected by climate change, the incidence of pest and diseases can result in a decrease in cassava yields. Thus, improved varieties that are resistant to most common diseases, along with an integrated pest management strategy are recommended as an adaptation package.

Published studies with secondary data and expert knowledge were used to characterize and quantify the potential changes in crop yields and production costs for each adaptation package. Average net returns and standard deviations are included in tables 1-3 in previous sections.

*Table 4. Summary of adaptation packages for all case studies*

| **Farming system** | | **Adaptation package** |
|---|---|---|
|  | Tomato | Drought resistant varieties and improved irrigation systems |
|  | Pepper | Drought resistant varieties and improved irrigation systems |
|  | Sugarcane | Soil conservation practices, improving soil nutrients, organic matter and bio-fertilizer 9CSA, CA) |
| | | Improved crop varieties and diversification |
| | | Microdosing and irrigation and drainage management |
| | | Support on initial investments |
|  | Cassava | Integrated Pest Management and improved crop varieties (CSA) |

Results (Figure 12) indicate that the adaptation package for sugarcane with no subsidy (A1) has potential adoption rates between 58% to 65% for the small and medium farms, while the potential adoption rates for the micro farms are about 48%. The low adoption rate might be explained by the initial investment required to adopt the adaptation strategy. Consequently, the average increase in net returns is only about 35% for the micro-sized farms compared to about 58% for medium-sized farms and between 78-85% for small farms. A 50% subsidy on the initial investment for micro farms increases the potential adoption rates to about 63% and mean net farm returns to 52-55%. If, in addition, the small and medium-sized farms receive a 25% subsidy on the initial investment, adoption rates increase within a range of 64% to 73% and mean net farm returns increase between 63% to more than 100%.

The adoption rate for the cassava case is 73%, resulting in an increase in mean net farm returns of about 23%. In the case of tomatoes and peppers, adoption rates range between 57% to 66% and the increase in mean net farm returns ranges between 23% and 45%.

The TOA-MD model also outputs the poverty rates associated with the adoption of the adaptation strategy. The results show that the adaptation packages that were tested would reduce poverty rates between 10% and 40% across the different regions as shown in Figure 12.

The adaptation analysis demonstrates that adaptation packages can be beneficial to farmers. However, these results also show that strategies that are based only on the available agronomic changes (e.g., changing planting dates, cultivars) are not enough to achieve high levels of adoption. Further research is needed to improve understanding of the factors limiting the adoption of existing adaptations, as well as to develop better agronomic adaptations. AgMIP's research has shown that the most impactful adaption strategies involve a package of interventions that includes on and off-farm elements, and economic and social aspects, accompanied by a set of incentivizing policies that promote the adoption.

### 7.4 Aggregated Results

The TOA-MD model produces disaggregated data by strata (sub-regions/farm type) as described above. In addition, the model also outputs the results aggregated for the region under analysis. Figure 13 shows the results for Belize aggregated for the farm type. For the two districts, Trinidad and Tobago, the results are aggregated from the tomato and pepper farms in the northern and southern regions. In the case of Guyana, there is only one stratum that covers the 3 regions producing cassava. In this case the aggregated results are the same as the disaggregated ones.

The results suggest that a large sector of the population in these regions is vulnerable to climate change (between 50% to about 69% of the households). The economic losses and reduction in mean net farm returns due to climate change can also be significant and contribute to increased poverty rates in the region between 10% to 25%. The adaptation packages that were tested can benefit between 55% to 75% of households in the region by increasing the mean net farm returns between 23% to 79% on average and reducing poverty rates between 18% to 35%.

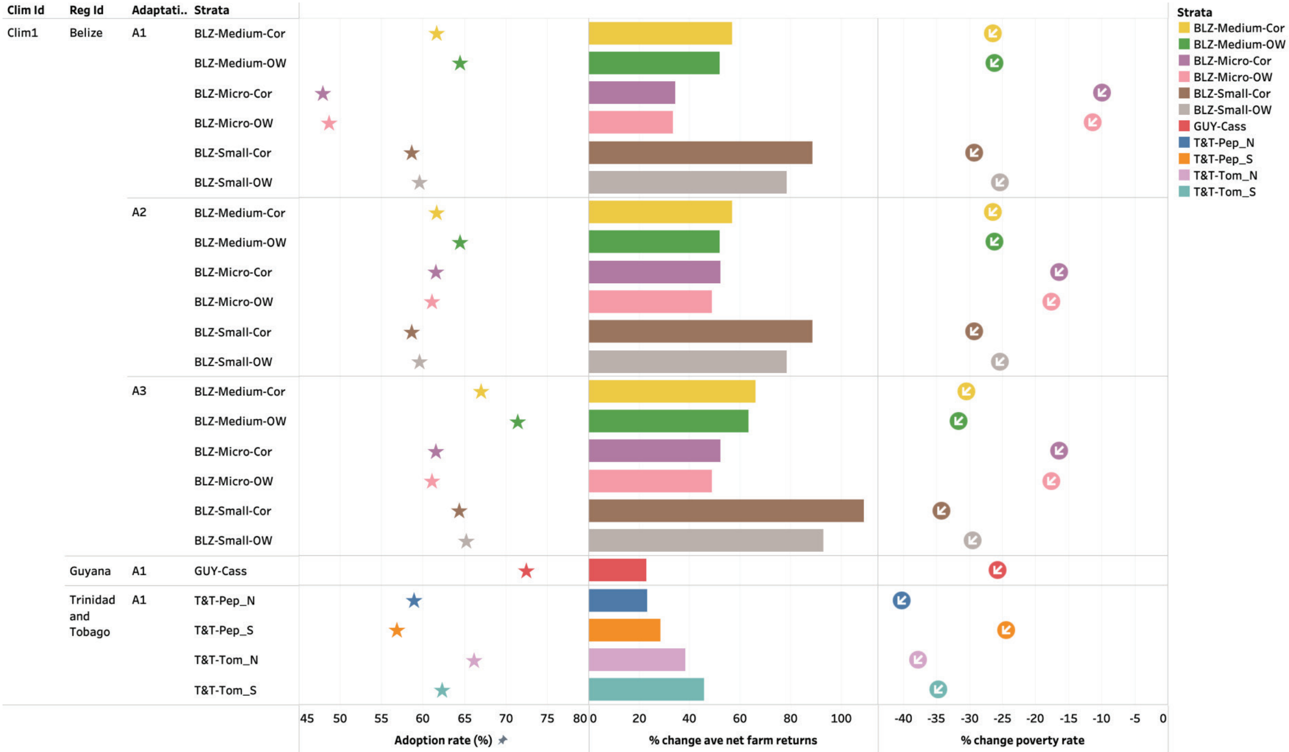



*Figure 12. Impacts of adaptation packages across all case studies, disaggregated by stratum.*

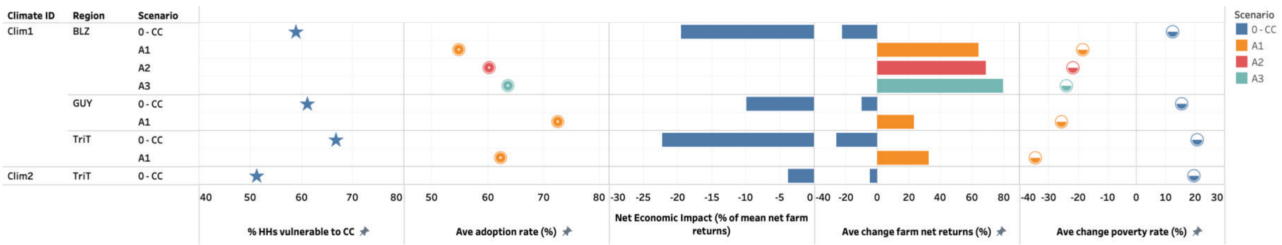



*Figure 13. Aggregated results: Climate change and adaptation impacts across case study regions. First row in each country (scenario 0-CC) shows impacts of climate change. Rows A1-A3 show impacts of the adaptation packages*

# 8. Conclusions

- Climate change is likely to have net negative effects on some farming systems in the Caribbean region.
- There will likely be both gainers and losers as a result of climate change due to heterogeneity (variations) in bio-physical and socio-economic conditions.
  – Even in cases where there are net average gains due to climate change, many households will be vulnerable to large losses.
  – An important policy challenge is to identify the most vulnerable groups and develop adaptation strategies to reduce this vulnerability.
  – Climate-resilient crops in the region can be used with CSA and IPM management practices to adapt to climate change.
- The AgMIP protocol-based approach to climate impact and adaptation assessment facilitates collaborative analysis, research synergies and learning across regions and countries.
  – Methods and models are available to be leveraged by research teams across the LAC region.
  – Investment in capacity-building for scientists (on the use and implementation of the RIA methods and tools) and stakeholders (on the understanding and use of the results).
- Investment in bio-physical and socio-economic data is needed to identify vulnerable populations and develop science-based adaptation strategies.
- There is a need to assess the impacts of climate change, adaptation & mitigation under future socio-economic conditions (e.g., RAPs).

## 8.1 Mitigation-Adaptation Co-benefits, Representative Agricultural Pathways and Tradeoff Analysis

The lack of data on emissions from the production systems in this pilot study did not allow for an assessment of the potential tradeoffs and benefits of mitigation/adaptation strategies on farmers' livelihoods and the environment. AgMIP modeling approach and tools are suited to test and demonstrate the benefits of improved agricultural practices, prospective mitigation options for agricultural productivity, profitability, and greenhouse gas emissions and mitigation costs.

Assessing the benefits of mitigation (or adaptation options) should not rely solely on how much GHG emissions can be reduced or how much income can be increased. Other elements of sustainability should be included in the analysis. Thus, assessing the tradeoffs between social, economic, environmental, and bio-physical outcomes is key to understanding not only the benefits of innovations but also how these may impact the different outcomes (Antle and Valdivia, 2021).

The TOA-MD model can include different socio-economic, environmental and bi-physical indicators and is designed to numerically and visually assess the potential tradeoffs (and synergies) across outcomes. Table 5 shows a list of potential indicators that can be used depending on available and suitable data.

Over the past years, AgMIP has advanced methods for improving projections on the future performance of agricultural and food systems, integrating stakeholder-informed scenarios into global and regional assessments of current and future agriculture given different socio-economic conditions and climate scenarios. It has also provided evidence-based information to national and sub-national decision makers and contributed to the development of NAPs, NDCs and agricultural development plans. Development of RAPs for the CARICOM region can support the understanding of short and long-term impacts of climate change adaptation and mitigation on these countries.

*Table 5. Economic, environmental and social indicators that can be included in Tradeoffs Analysis*

| Economic Indicators | Environmental Indicators | Social Indicators |
|---|---|---|
| **Farm productivity**<br>- Crop yields<br>- Livestock production<br>- Dairy production | **Land area cultivated**<br>- By conventional practices<br>- By conservation practices | **Income distribution**<br>- Poverty rates<br>- Poverty gap |
| **Regional Commodities**<br>- Commodity area<br>- Aggregate regional production | **Soil characteristics**<br>- Soil erosion<br>- Soil N losses | **Food security and nutrition**<br>- Various objective and subjective indicators<br>- National and subnational |
| **Local commodity consumption**<br>- Food costs<br>- Livestock feed costs<br>- Energy costs<br>- Fertilizer costs<br>- Irrigation costs | **Agricultural input use**<br>- Crop and livestock species, varieties, breeds<br>- Organic and inorganic fertilizers<br>- Pesticides<br>- Feeds and fodder | **Gender equity**<br>- Education<br>- Labor participation<br>- Asset ownership<br>- Decision-making power<br>- control over Income<br>- Participation in climate action relevant community decisions |
| **Agricultural commodity prices** | **Energy use** | |
| **Agricultural trade**<br>- Imports<br>- Exports | **Water resources**<br>- irrigation<br>- net water use | |
| **Household income**<br>- Farm income<br>- Off-farm income<br>- Non-farm income | **Net greenhouse gas emissions**<br>- carbon dioxide<br>- nitrous oxide<br>- methane | |
| **Per capita income** | | |

# 9. Appendix

The Appendix section presents disaggregated results for each case study as well as a summary of the output of the TOA-MD model for the two simulation experiments.

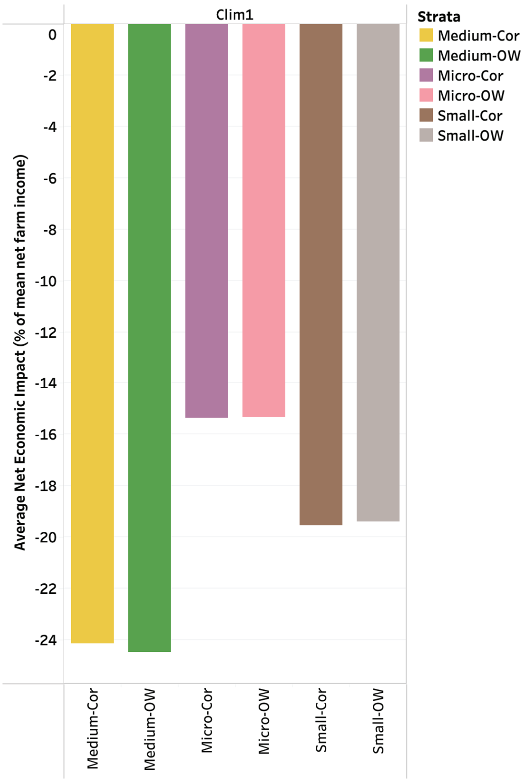



*Figure A - 1. Belize: Net Economic Impacts by stratum*

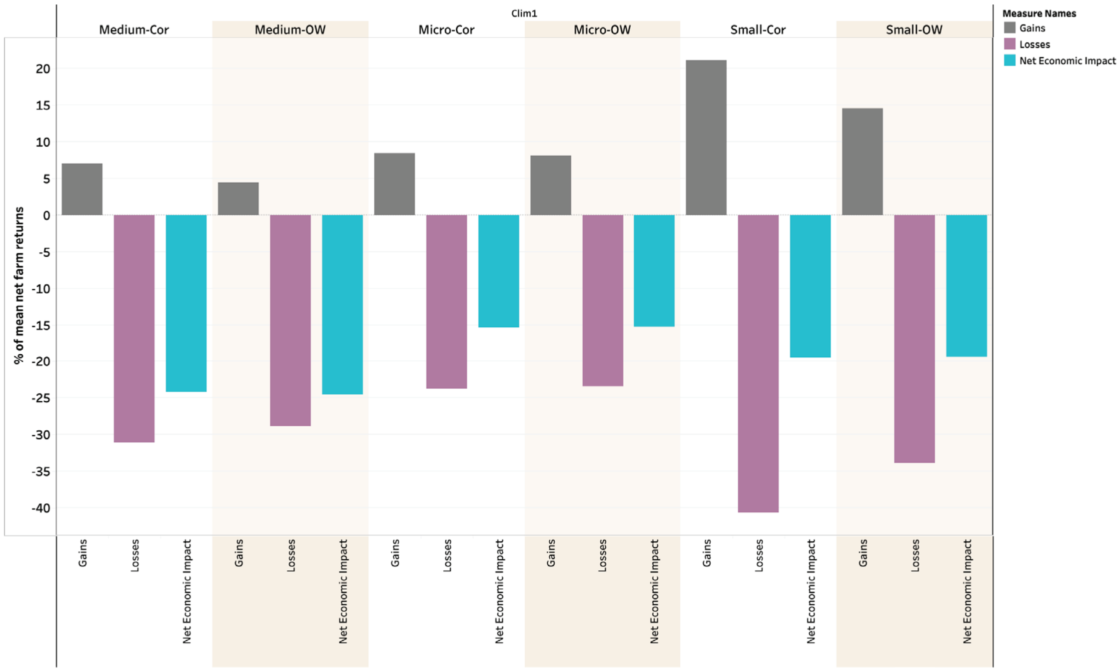



*Figure A - 2. Belize: Gains, loses and net economic impact by stratum*

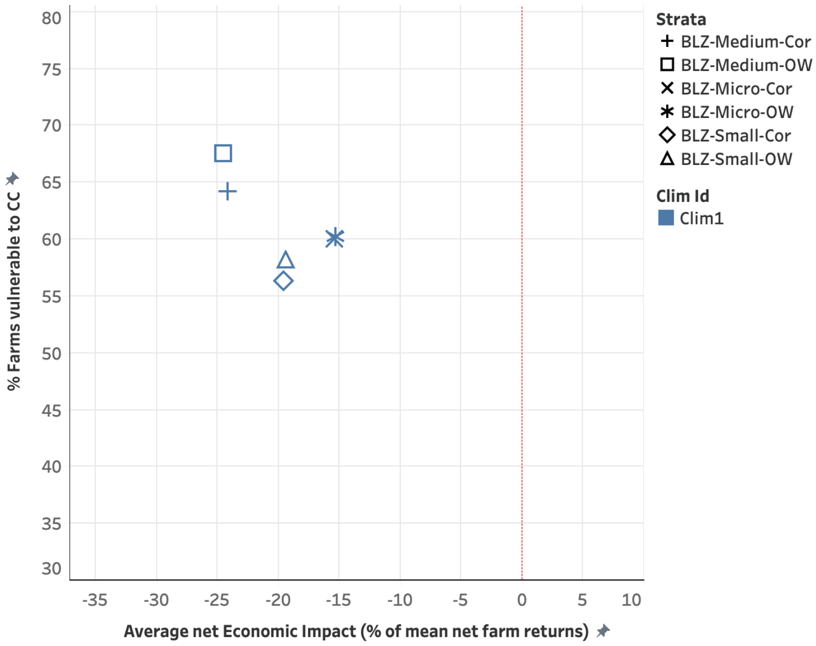



*Figure A - 3. Belize: Tradeoffs between net economic impact and vulnerability*

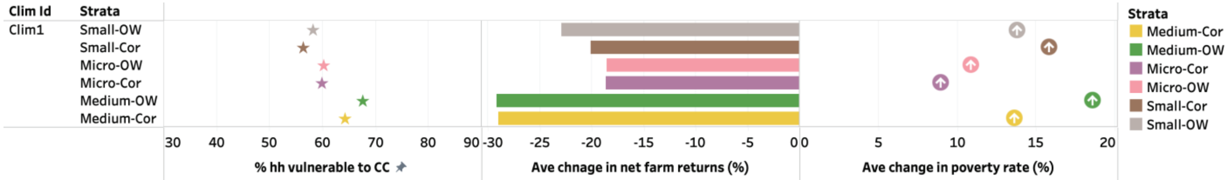



*Figure A - 4. Belize: Climate change impacts: vulnerability, change in mean net farm returns and poverty rates by stratum*

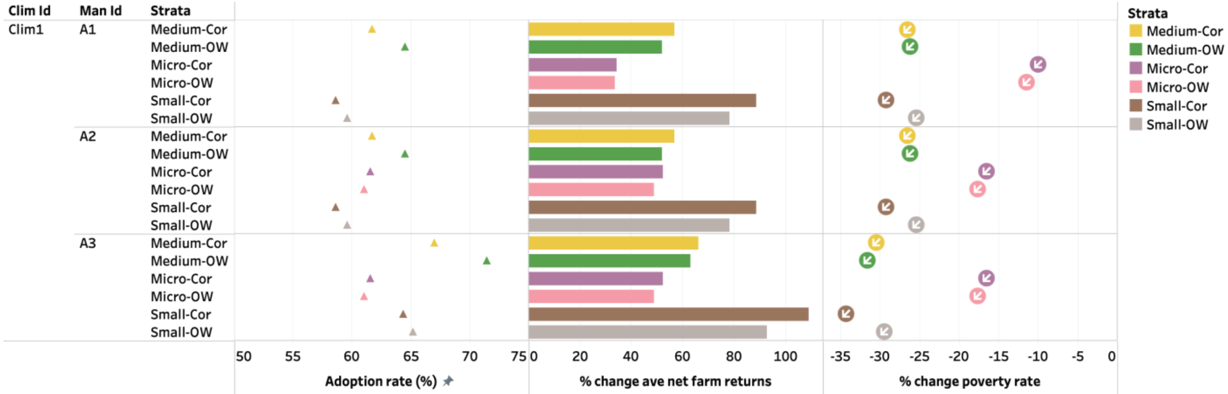



*Figure A - 5. Belize: Adoption of adaptation package and associated change in mean farm net returns and poverty rates by stratum*

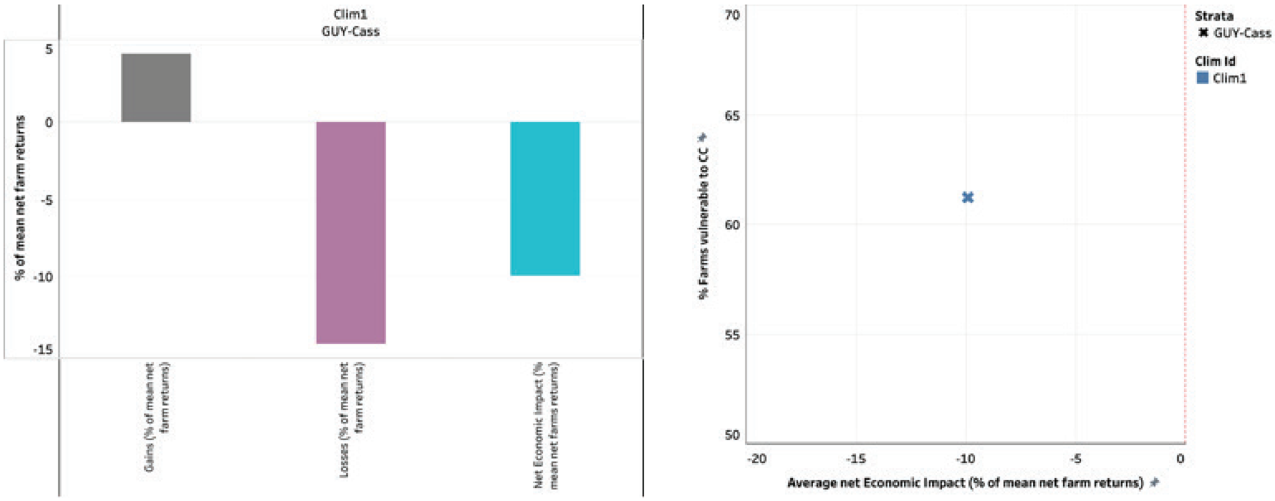



*Figure A - 6. Belize: Gains, losses and net economic impact (left). Vulnerability and net economic impact (right)*

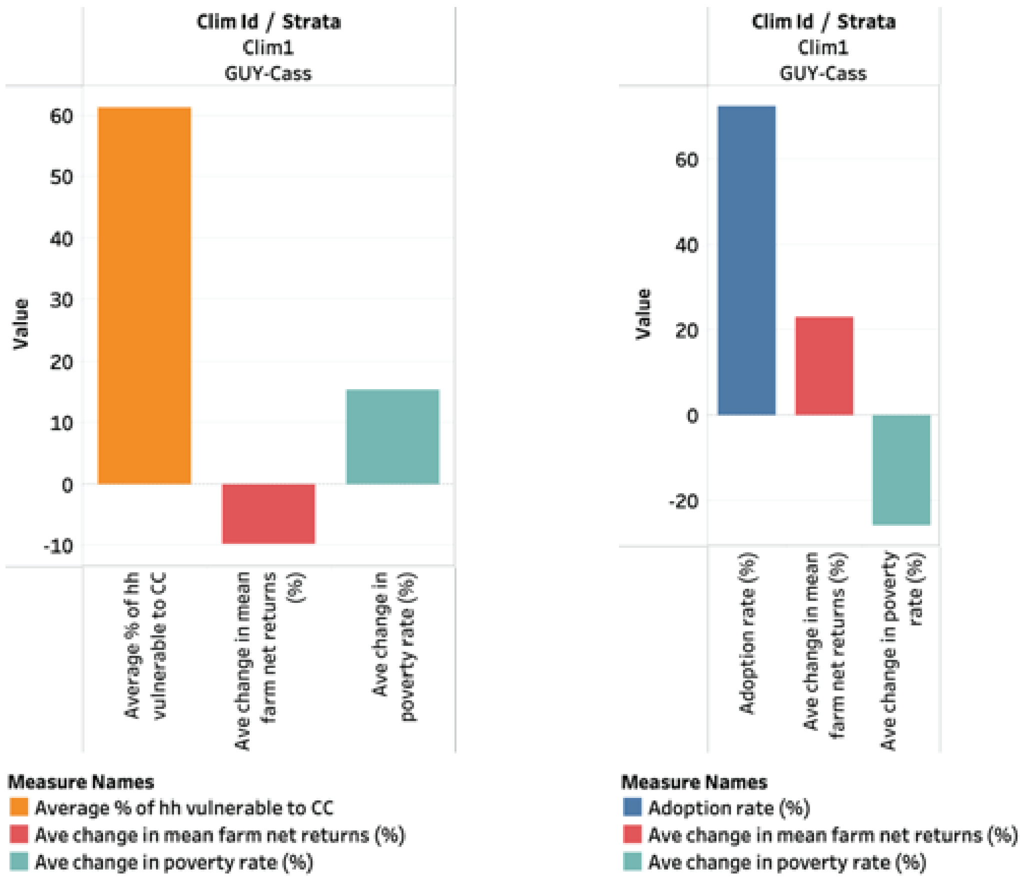



*Figure A - 7. Guyana: Climate change impacts: vulnerability and associated change in mean net farm returns (left). Adoption of the adapted package and associated change in mean net farm returns and poverty rates (right).*

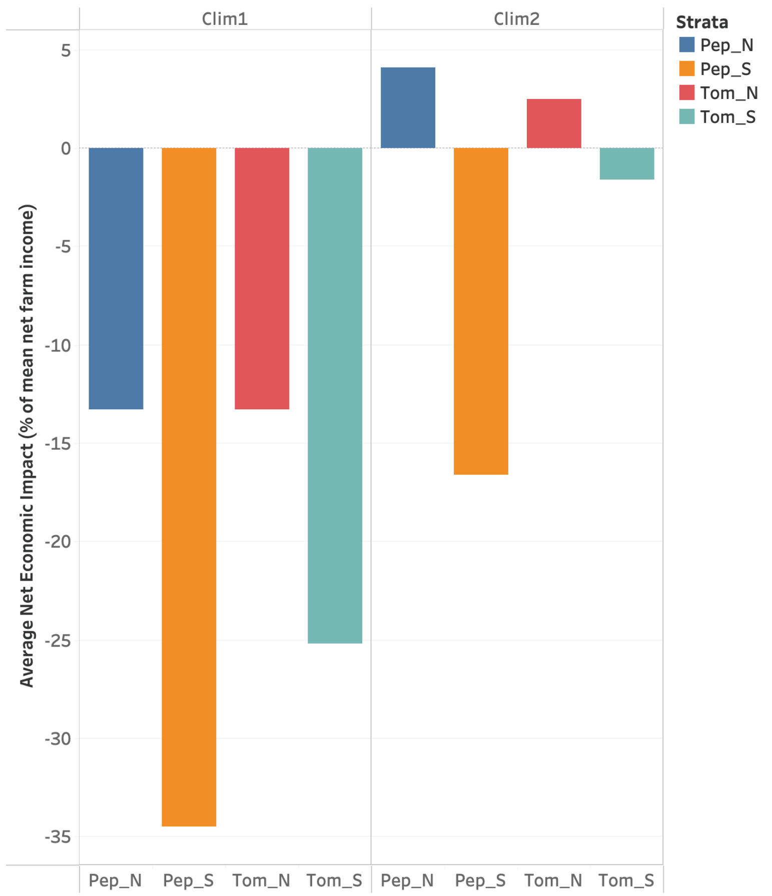



*Figure A - 8. Trinidad & Tobago: Climate change impacts: net economic impact by stratum and climate assumptions (Clim1): assumed increase in temperatures and large reduction in precipitation; Clim2 assumed increase in temperatures and moderate reduction in precipitation*

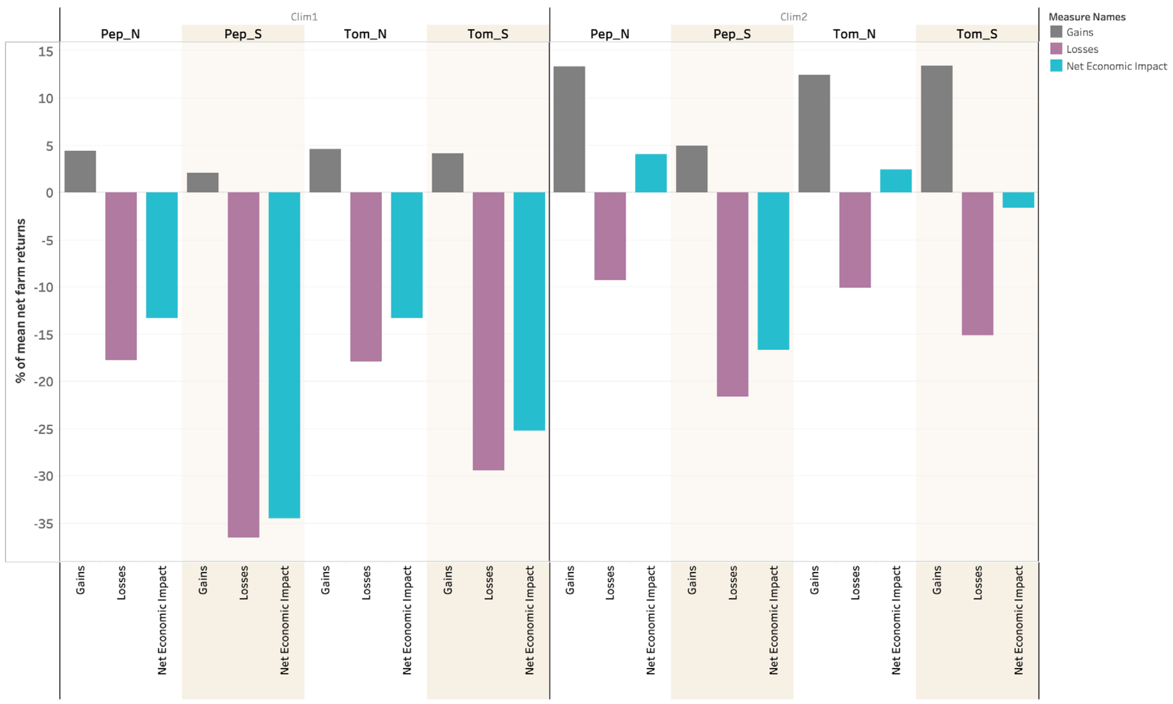
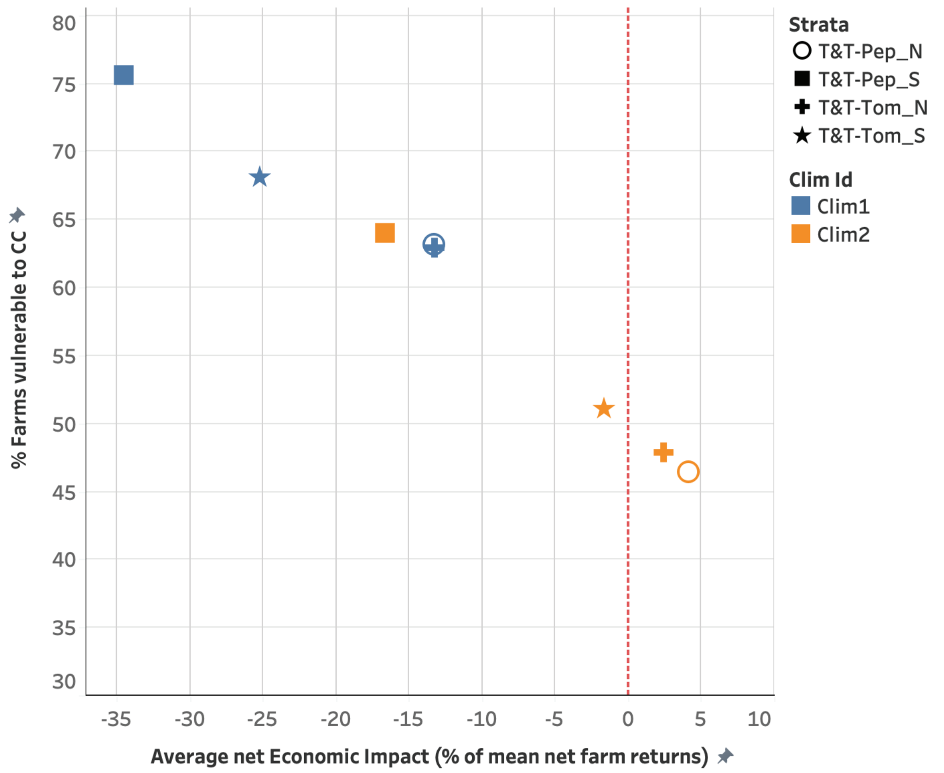



*Figure A - 9. Trinidad & Tobago: Climate change: Gains, losses, and net economic impact*




*FigureA - 10. Trinidad & Tobago: Tradeoffs between vulnerability and net economic impact*


*Figure A - 11. Trinidad & Tobago: Climate change impacts: Vulnerability and associated change in mean net farm returns and poverty rates*

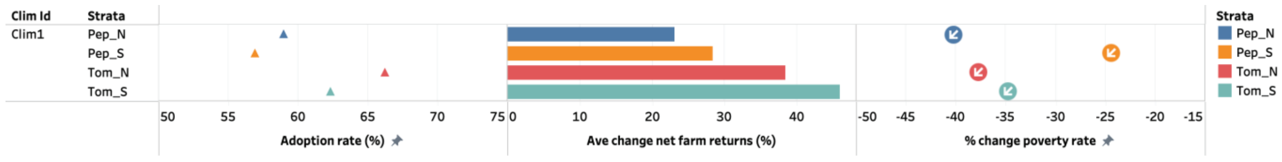



*Figure A - 12. Trinidad & Tobago: Adoption of adaptation package and associated changes in mean net farm returns and poverty rates*

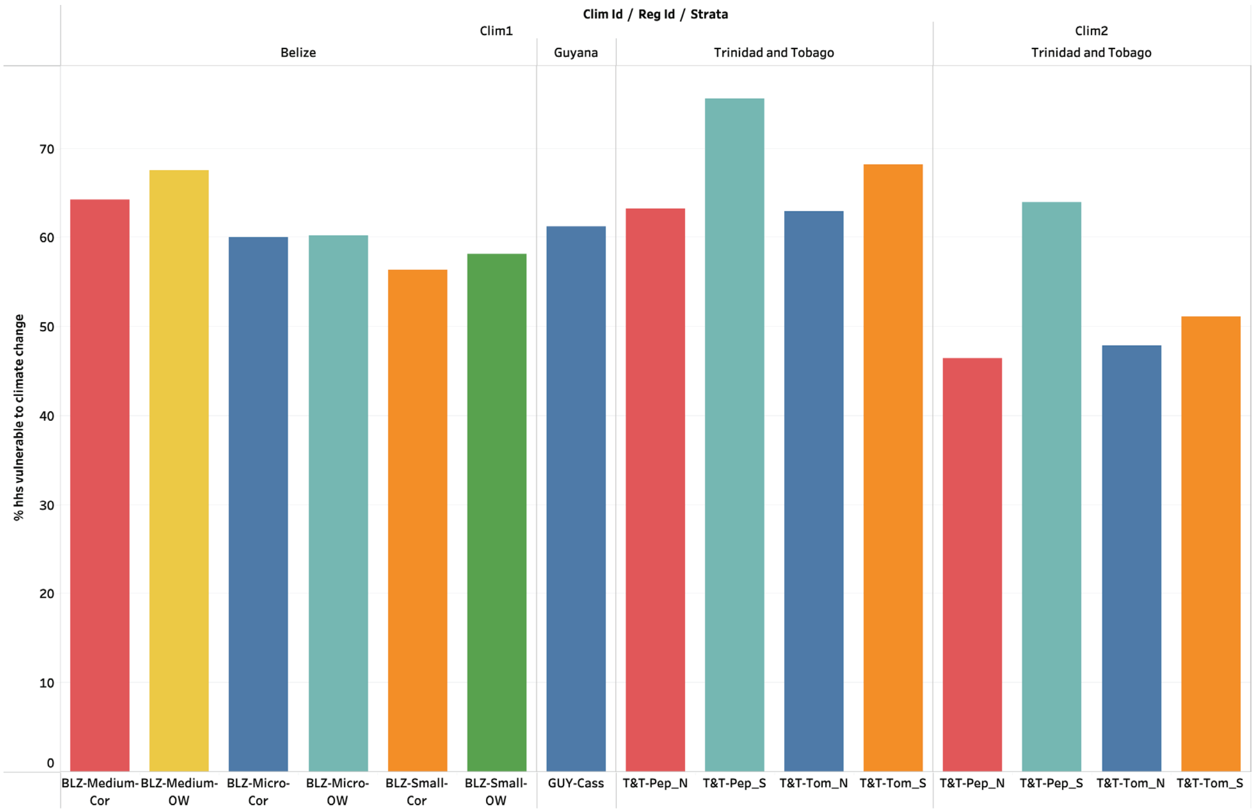



*Figure A - 13. Comparing vulnerability across all case studies by stratum*

*Table A - 1. Climate change impacts summary results for all case studies by stratum*

| Clim Id | Reg Id | Strata | Average % of hh vulnerable to CC | Gains (% of mean net farm returns) | Losses (% of mean net farm returns) | Net Economic Impact (% mean net farms returns) | Ave change in mean farm net returns (%) | Ave change in poverty rate (%) |
|---|---|---|---|---|---|---|---|---|
| Clim1 | Belize | BLZ-Medium-Cor | 64.2 | 6.9 | -31.1 | -24.2 | -29.0 | 13.6 |
| | | BLZ-Medium-OW | 67.6 | 4.4 | -28.9 | -24.5 | -29.2 | 18.6 |
| | | BLZ-Micro-Cor | 60.0 | 8.4 | -23.8 | -15.4 | -18.6 | 9.0 |
| | | BLZ-Micro-OW | 60.2 | 8.1 | -23.4 | -15.3 | -18.5 | 10.9 |
| | | BLZ-Small-Cor | 56.3 | 21.1 | -40.6 | -19.6 | -20.1 | 15.8 |
| | | BLZ-Small-OW | 58.2 | 14.5 | -33.9 | -19.4 | -23.0 | 13.8 |
| | Guyana | GUY-Cass | 61.2 | 4.4 | -14.4 | -9.9 | -9.8 | 15.2 |
| | Trinidad and Tobago | T&T-Pep_N | 63.2 | 4.4 | -17.7 | -13.3 | -16.0 | 24.5 |
| | | T&T-Pep_S | 75.6 | 2.0 | -36.5 | -34.5 | -40.0 | 20.6 |
| | | T&T-Tom_N | 62.9 | 4.6 | -17.9 | -13.3 | -16.0 | 23.7 |
| | | T&T-Tom_S | 68.2 | 4.2 | -29.4 | -25.2 | -30.0 | 17.7 |
| Clim2 | Trinidad and Tobago | T&T-Pep_N | 46.4 | 13.4 | -9.3 | 4.1 | 5.0 | 24.0 |
| | | T&T-Pep_S | 64.0 | 4.9 | -21.6 | -16.6 | -20.0 | 19.9 |
| | | T&T-Tom_N | 47.9 | 12.5 | -10.0 | 2.5 | 3.0 | 22.3 |
| | | T&T-Tom_S | 51.1 | 13.4 | -15.1 | -1.6 | -2.0 | 16.1 |

*Table A - 2. Adoption of adaptation package, summary results for all case studies by stratum*

| Clim Id | Reg Id | Strata | Adaptation | Adoption rate (%) | Ave change in mean farm net returns (%) | Ave change in poverty rate (%) |
|---|---|---|---|---|---|---|
| **Clim1** | Belize | BLZ-Medium-Cor | A1 | 61.7 | 56.9 | -26.5 |
| | | | A2 | 61.7 | 56.9 | -26.5 |
| | | | A3 | 67.0 | 66.2 | -30.4 |
| | | BLZ-Medium-OW | A1 | 64.5 | 51.9 | -26.2 |
| | | | A2 | 64.5 | 51.9 | -26.2 |
| | | | A3 | 71.4 | 63.2 | -31.6 |
| | | BLZ-Micro-Cor | A1 | 47.9 | 34.3 | -10.0 |
| | | | A2 | 61.5 | 52.2 | -16.5 |
| | | | A3 | 61.5 | 52.2 | -16.5 |
| | | BLZ-Micro-OW | A1 | 48.7 | 33.5 | -11.4 |
| | | | A2 | 61.0 | 48.8 | -17.6 |
| | | | A3 | 61.0 | 48.8 | -17.6 |
| | | BLZ-Small-Cor | A1 | 58.6 | 88.8 | -29.3 |
| | | | A2 | 58.6 | 88.8 | -29.3 |
| | | | A3 | 64.4 | 109.2 | -34.2 |
| | | BLZ-Small-OW | A1 | 59.6 | 78.4 | -25.4 |
| | | | A2 | 59.6 | 78.4 | -25.4 |
| | | | A3 | 65.2 | 92.9 | -29.5 |
| | Guyana | GUY-Cass | A1 | 72.5 | 22.9 | -25.7 |
| | Trinidad and Tobago | T&T-Pep_N | A1 | 58.9 | 23.1 | -40.2 |
| | | T&T-Pep_S | A1 | 56.9 | 28.3 | -24.4 |
| | | T&T-Tom_N | A1 | 66.2 | 38.4 | -37.7 |
| | | T&T-Tom_S | A1 | 62.3 | 45.9 | -34.7 |

# 10. References


Allen, A.G., Cardoso, A.A. and Da Rocha, G.O. 2004. Influence of sugar cane burning on aerosol soluble ion composition in Southeastern Brazil. *Atmospheric Environment*, *38*(30): 5025-5038.

Amelework AB, Bairu MW, Maema O, Venter SL and Laing M (2021). Adoption and Promotion of Resilient Crops for Climate Risk Mitigation and Import Substitution: A Case Analysis of Cassava for South African Agriculture. Front. Sustain. Food Syst. 5:617783. doi: 10.3389/fsufs.2021.617783

Antle, J. M., Valdivia, R. O. 2022. TOA-MD: Multi-dimensional Impact Assessment of Agricultural Systems: 112. https://bit.ly/3gD1iCD

Antle, J.M. and Valdivia, R.O. 2021. Trade-off analysis of agri-food systems for sustainable research and development. *Q Open*, *1*(1), p.qoaa005.

Antle, John, Roberto O. Valdivia, Ken Boote, Jerry Hatfield, Sander Janssen, Jim Jones, Cheryl Porter, Cynthia Rosenzweig, Alex Ruane, and Peter Thorburn. 2015. AgMIP'sTrans-disciplinary Approach to Regional Integrated Assessment of Climate Impact, Vulnerability and Adaptation of Agricultural Systems. InHandbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project (AgMIP). C. Rosenzweig, and D. Hillel, Eds., ICP Series on Climate Change Impacts, Adaptation, and Mitigation Vol. 3. Imperial CollegePress, doi:10.1142/9781783265640_0002.

Bunn, C; Lundy, M; Wiegel, J; Castro-Llanos, F. 2019. Impacto del cambio climático en la producción de cacao para Centroamérica y El Caribe. Centro Internacional de Agricultura Tropical (CIAT), Cali, CO. 34 p.

Bureau of Statistics. 2007. Population and Housing Census 2002. *In:* STATISTICS, B. O. (ed.). Georgetown: Republic of Guyana.

Chavez, A.; V., Milne, A.E., van den Bosch, F., Pita, J. and McQuaid, C.F. 2021. Modelling cassava production and pest management under biotic and abiotic constraints. *Plant molecular biology*: 1-25.

Chi, L., Mendoza-Vega, J., Huerta, E., Álvarez, D. 2017. Effect of long-term sugarcane (Saccharum spp.) cultivation of chemical properties of soil in Belize. Communications in soil science and plant analysis, 48:7, 741-755.

De León, M., González, R. 2011. Informe del estudio de suelo para recomendaciones de fertilizantes en el área cañera de la BSCFA en Belice. Tecnoazúcar, La Habana, Cuba.

DeGannes, A., Heru, K.R., Mohammed, A., Paul, C., Rowe, J., Sealy, L. and Seepersad, G. 2014. Tropical Greenhouse Growers Manual for the Caribbean.

Dominy, CS., Haynes, RJ., van Antwerpen, R. 2001. Long-term effect of sugarcane production on soil quality in the south coast and the midlands areas of Kwazulu-natal. Proc S Afr Sug Technol Ass 75: 222-227.

Eitzinger A; Farrell A; Rhiney K; Carmona S; van Loosen I; Taylor M. 2015b. Trinidad & Tobago: Assessing the impact of climate change on cocoa and tomato. CIAT PolicyBrief No. 27. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. 6 p

Eitzinger, A., Carmona, S., Argote, K., Läderach, P. and Jarvis, A., 2015. Climate impacts and resilience in Caribbean agriculture: Assessing the consequences of climate change on cocoa and tomato production in Trinidad & Tobago and Jamaica (CIRCA).

Food and Agriculture Organization of the United Nations (FAO). 2022. Crops Prospects and Food Situation – Quarterly Global Report No. 1; FAO: Rome, March 2022. Retrieved from https://www.fao.org/3/cb8893en/cb8893en.pdf.

Government of Guyana. 2012. Second Report on the State of Plant Genetic Resources for Food and Agriculture in Guyana. *Submitted to FAO Commission on Genetic Resources for Food and Agriculture.* Georgetown: Government of Guyana.

IPCC. 2022: *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.

Isaac, W.A., Eudoxie, G., Cortbaoui, P., Ganpat, W. and Borucki, S. 2014. Agricultural technologies bring healthy diversity to school meals. *Stories of change*.

ITA. 2021. Guyana -Country commercial Guide. International trade Administration. https://www.trade.gov/country-commercial-guides/guyana-agriculture-sector

Jarvis, A., Ramirez-Villegas, J., Herrera Campo, B.V. and Navarro-Racines, C. 2012. Is cassava the answer to African climate change adaptation? *Tropical Plant Biology*, *5*(1): 9-29.

Lakenarine, R., Diana Seecharran, Mark Ram. 2020. Impacts of Climate Change on Farmers and their Adaptive Strategies along the Essequibo Coast, Guyana; International Journal of Scientific and Research Publications (IJSRP) 10(02) (ISSN: 2250-3153), doi: http://dx.doi.org/10.29322/IJSRP.10.02.2020.p9861

Maharaj, S., Mycoo, M., Nalau, J. and Wairiu, M. 2022. IPCC Sixth Assessment Report (AR6): Climate Change 2022-Impacts, Adaptation and Vulnerability: Regional Factsheet Small Islands.

Medina Hidalgo, D., Ipenza Peralta, C., & Cascante Ocampo, R. 2017. Abordajes Institucionales en Cambio Climático y Agricultura: Un análisis de instrumentos y mecanismos de política pública y gobernanza en Chile, Guatemala y Perú. San Jose. Retrieved from: https://bit.ly/3F8h2qE

Ministry of Agriculture. 2013. Agriculture- Our Vehicle for Sustained Economic and Social Prosperity: A National Strategy for Agriculture in Guyana 2013-2020. Georgetown: Ministry of Agriculture.

NCCO. 2016. Belize's Third national communication to the United Nations Framework Convention on Climate Change. Belize National Climate Change Office, 2016. Ministry of Agriculture, Fisheries, Forestry, the Environment and Sustainable Development.

Prado, R.D.M., Caione, G. and Campos, C.N.S. 2013. Filter cake and vinasse as fertilizers contributing to conservation agriculture. *Applied and Environmental Soil Science*, *2013*.

Regional Democratic Council. 2016. Master List, Region 9 Agricultural Households. Lethem: RDC.

Republic of Guyana. 2019. First Voluntary National Review. High Level Political forum on Sustainable Development. July 2019. https://guyana.un.org/sites/default/files/2020-07/24297Guyana_VNR2019_Report.pdf.

Republic of Guyana. 2021. Multi-annual Indicative Programme 2021-2027. https://international-partnerships.ec.europa.eu/system/files/2022-01/mip-2021-c2021-9101-guyana-annex_en.pdf

Rosenzweig, Cynthia; Carolyn Z Mutter, Alex C Ruane, Erik Mencos Contreras, Kenneth J Boote, Roberto O Valdivia, Joske Houtkamp, Dilys S MacCarthy, Lieven Claessens, Roshan Adhikari, Wiltrud Durand, Sabine Homann-Kee Tui, Ashfaq Ahmad, Nataraja Subash, Geethalakshmi Vellingiri, and Swamikannu Nedumaran. 2021. AgMIP Regional Integrated Assessments: High-level Findings, Methods, Tools, and Studies. In: Handbook of Climate Change and Agroecosystems: Climate Change and Farming System Planning in Africa and South Asia: AgMIP Stakeholder-driven Research (In 2 Parts) (Vol. 5). World Scientific Publishing. [Rosenzweig, C., C.Z. Mutter and E. Mencos Contreras (eds.)]. June 2021.

Shaochun Ma, Manoj Karkee, Patrick A. Scharf, Qin Zhang. 2014. Sugarcane Harvester Technology: A Critical Overview. Applied Engineering in Agriculture. 30(5): 727-739. doi: 10.13031/aea.30.10696.

Shik, O., Boyce, R.A., De Salvo, C.P. and Egas, J.J. 2018. *Analysis of agricultural policies in TRINIDAD AND TOBAGO* (Vol. 576). Inter-American Development Bank.

Souza, R.A., Telles, T.S., Machado, W., Hungria, M., Tavares Filho, J. and de Fátima Guimarães, M. 2012. Effects of sugarcane harvesting with burning on the chemical and microbiological properties of the soil. Agriculture, Ecosystems & Environment, 155: 1-6.

Statistical Institute of Belize (SIB). 2017. Estimated Mid-Year Population 2017 and Merchandize Trade, Population and household. Belmopan, Belize.

Valdivia R.O., Antle, J.; Homann-Kee Tui, S., Subash, N., Hathie, I., Neduraman, S., Harbir, S., **Çlaessens**, L., Dickson, C., Sisito, G. 2021. Developing Representative Agricultural Pathways: A Multi-Scale Co-Designing Process to Support Transformation and Resilience of Agricultural Farming Systems. In: Handbook of Climate Change and Agroecosystems: Climate Change and Farming System Planning in Africa and South Asia: AgMIP Stakeholder-driven Research (In 2 Parts) (Vol. 5). World Scientific Publishing. [Rosenzweig, C., C.Z. Mutter and E. Mencos Contreras (eds.)]. June 2021.

Valdivia, R.; Antle, J.; Homann-Kee Tui, S.; Mutter, C.; Evengaard, A.; Ruane, A.; Witkowski, K. 2019. Enhancing Agricultural Production and Food Security amid a Changing Climate: **A** New Approach to Inform Decision-Making. The Inter-American Institute for Cooperation on Agriculture - Climate Change, Natural Resources and Management of Production Risks and the Agricultural Model Intercomparison and Improvement Project. A Policy Brief presented at the Joint Inter-American Agricultural Ministers Exchange. Pre-COP 25. San José.

Valdivia, Roberto O., John M. Antle, Cynthia Rosenzweig, Alex C. Ruane, Joost Vervoort, Muhammad Ashfaq, Ibrahima Hathie, Sabine Homann-Kee Tui, Richard Mulwa, Charles Nhemachena, Paramasivam Ponnusamy, Herath Rasnayaka, Harbir Singh. 2015. Representative Agricultural Pathways and Scenarios for Regional Integrated Assessment of Climate Change Impact, Vulnerability and Adaptation. In Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project (AgMIP). C. Rosenzweig, and D. Hillel, Eds., ICP Series on Climate Change Impacts, Adaptation, and Mitigation Vol. 3. Imperial College Press: 101-156, doi:10.1142/9781783265640_0005.

Witkowski, K. and Medina, D. 2017. Climate-smart agriculture in the Eastern Caribbean States: a compendium of stories from farmers. *Climate-Smart Agriculture in the Eastern Caribbean States*. Instituto Interamericano de Cooperación para la Agricultura (IICA). Proyecto Insignia Resiliencia y Gestión Integral de Riesgos en la Agricultura.

Witkowski, K., & Medina, D. 2016. Agriculture in the new climate action plans of Latin America. San Jose. Retrieved from: https://bit.ly/3Uf3xJM

Witkowski, K., Valdivia, R. O., Medina, D. 2021. *Integrated modelling under a changing climate in Latin America and the Caribbean: Bridging the Gaps between Supply and Demand of Information for Decision Making*. World Scientific Publishing. In: Handbook of Climate Change and Agroecosystems: Climate Change and Farming System Planning in Africa and South Asia: AgMIP Stakeholder-driven Research (In 2 Parts) (Vol. 5). World Scientific Publishing. [Rosenzweig, C., C.Z. Mutter and E. Mencos Contreras (eds.)].

World Meteorological Organization. 2022. State of the Climate in Latin America and the Caribbean 2021. WMO-No. 1295. Geneva. https://library.wmo.int/doc_num.php?explnum_id=11270

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