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AN ASSESSMENT OF THE ECONOMIC IMPACT OF CLIMATE CHANGE ON THE AGRICULTURE SECTOR IN GUYANA

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Notes and explanations of symbols:

The following symbols have been used in the present study:
A full stop (.) is used to indicate decimals
n.a. is used to indicate that data are not available
The use of a hyphen (-) between years, for example, 2010-2019, signifies an annual average for the calendar years involved, including the beginning and ending years, unless otherwise specified.
The word “dollar” refers to United States dollars, unless otherwise specified.
The term “billion” refers to a thousand million.
The boundaries and names shown and the designations used on maps do not imply official endorsement or acceptance by the United Nations.

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Table of contents

List of Acronyms

BAU	business as usual
CARICOM	Caribbean Community and Common Market
CC	climate change
CCCCC	Caribbean Community Centre for Climate Change
CO_2	carbon dioxide
CPACC	Caribbean Planning for Adaptation to Climate Change
ECHAM	European Centre Hamburg Model
ECLAC	Economic Commission to Latin America and the Caribbean
EEA	European Environment Agency
FAO	Food and Agriculture Organization
GDP	gross domestic product
GHG	greenhouse gas
GUYSUCO	Guyana Sugar Corporation Incorporated
IDB	Inter-American Development Bank
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
KPSS	Kwiatkowski–Phillips–Schmidt–Shin
MACC	mainstreaming adaptation to climate change
ppm	parts per million
SPACC	special programme on adaptation to climate change
SST	sea surface temperature
UNDP	United Nations Development Programme

List of tables

List of figures

Executive Summary

Climate change is anticipated to have potentially disastrous impacts on the economic viability of the agricultural sector, insomuch as traditional agricultural practices render the agricultural sector climate-dependent. Increased temperatures and increased intensity, timing and occurrence of hydro events are expected to challenge plant and animal viability. Under such circumstances, vector control is expected to become more difficult, which may further prejudice the prosperity of plant, livestock and fisheries growth. The impact is expected to be on the quality of agricultural produce and thereby, indirectly, on human health outcomes. The key threat mechanisms are debilitated plant vitality and increased propagation of pests, as drought periods increase the breeding of vectors through water pooling and soil erosion associated with the increased intensity of hydro events. In addition, climate change is likely to affect crop productivity in specific geographical areas through its impact on growing seasons and crop patterns, to the extent that crop varieties cannot adapt.

Countries in the Caribbean are in a peculiar position with respect to their ability to adapt to climate change, given their minimal influence through any mitigation efforts and their relatively high debt levels. Specific areas of concern for these countries include: sea-level rise, saltwater intrusion, contaminated water supplies ,and temperature-related stresses on plant, animal and human life. These factors are likely to impact water availability and water quality, nutrient availability and biodiversity. A Strategic Framework developed by the Caribbean Community (CARICOM) Secretariat in 2009 and approved by Caribbean Heads of Government, is intended to achieve climate change resilient development, through mainstreaming adaptation strategies into sustainable development agendas and reducing the vulnerability of natural and human systems to the effects of climate change.

Agriculture has been a major contributor to gross domestic product (GDP), exports, direct and indirect employment and rural transformation in Guyana, through its influence on social and community development. Sugar and rice account for over 50% of the agricultural sector contribution to GDP since 2000. Fishing, forestry and non-traditional crops have been increasing their contribution to GDP, attributable to increased Government support under the agricultural sector diversification programme. Sugar has historically been the largest agricultural and agro-industry in Guyana, representing 10% of GDP and 40% of the agricultural sector in 2009. It is also the largest net foreign exchange earner and principal contributor to Government revenues. The Government, through the Guyana Sugar Corporation Inc. (GUYSUCO), currently operates 5 sugar estates covering 66,397 hectares and 8 factories, all of which are located in the coastal area.

The rice subsector of agriculture is the largest user of agricultural lands, and the major source of income and employment in many coastal areas, with about 80,000 hectares currently double cropped. Rice therefore impacts a larger proportion of the working population – about 12,000 private farmers and 20% of the population – than any other economic activity in Guyana. The industry contributes approximately 10% of agricultural GDP and 12% of export earnings. The average monthly temperature and precipitation data between 1974 and 2008 for the rice-growing areas in Mahaica/Abary, Berbice, Essequibo, New Amsterdam and Rose Hall show increasing trends, with temperatures rising faster than precipitation over the period. Higher temperatures are typically associated with sterility in rice flowers, and reduced yield.

Marine fishing mostly occurs in the relatively shallow waters of the continental shelf. The marine resources exploited in Guyana are mainly demersal fisheries resources and, to a more limited extent, pelagic fish resources, some of which, particularly prawns and shark, are showing clear signs that they are being exploited at unsustainable rates. Average monthly temperature and precipitation data for the period 1975 to

2007 for the marine fishing regions show upward trends, which are likely to reduce fishery abundance, fisheries areas and species mix, thereby leading to reduced fish production.

Forests occupy approximately 80% of the land mass of Guyana, constituting an area as large as Britain. These forested areas are habitat to a wide range of animal and plant species, some of which are yet to be identified and documented. Additionally, the forests provide soil erosion protection, purify water supplies and ensure environmental stability. The forest resources are commercially exploited for wood and related by-products. Guyana, as part of its Low Carbon Development Strategy which includes combating climate change via reduced deforestation, has planned a Reduced Emissions from Deforestation and Degradation (REDD+) mechanism, to protect the forests over the long term, with a voluntary limit of deforestation and related forest-based greenhouse gas emissions.

In Guyana, the livestock agricultural subsector includes the rearing of poultry, cattle, pigs, sheep and goats, and has been identified as a dynamic source of domestic food supply with potential for large-scale export earnings (Ministry of Agriculture; Government of Guyana, 2011). The country is almost self-sufficient in poultry, meat and eggs. There are about 3,000 enterprises, including 50 commercial farms, 3,000 small farmers, and 4 stockfeed plants. Poultry production employs about 5,000 persons directly. There are possible challenges facing the subsector as it experiences competition from low-priced North American imports. Although livestock production is focused on meeting domestic market needs, there is significant potential for export, as Guyana has a comparative advantage in beef production given its large land- and water resources, which are important inputs in cattle rearing. Although beef is not currently exported from Guyana, a Livestock Development Programme has been implemented since 2006, geared towards enhancing livestock production to meet local demand as well export possibilities.

An augmented production function is used in the present study to model the effects of climate change on agricultural output, in order to determine the impact of climate change on the agricultural sector in Guyana. The analysis controls for price effects and typical agricultural inputs. Separate models are estimated for sugarcane, rice and fisheries. Three scenarios are employed to forecast the impact of climate change up to 2050: a business-as-usual (BAU) scenario and the Intergovernmental Panel on Climate Change (IPCC) A2 and B2 climate scenarios. The loss/gain in production under climate change is then computed by comparing the production under the BAU scenario with the production levels under the A2 and B2 climate change scenarios.

Rainfall and air temperature uniquely explain about 14% of the variations in sugarcane production. Rice output is maximal at a temperature of 27.4° C and average rainfall of 1.7 metres/year. The average export price and increases in average rainfall and increases in sea surface temperatures are associated with declines in fishery production. The total cost due to climate change accrued over the next 40 years should be 1-2 times that of 2008 GDP under A2, whereas under B2, it should range between 1% (4% discount rate) and 53% of 2008 GDP (1% discount rate). Several adaptation measures have long been implemented which need to be assessed for efficacy and replicability/expansion.

There are net benefits to adaptation in the case of all three agricultural subsectors – sugar, rice and fisheries –under the A2 scenario vis-à-vis the BAU in relation to the costs associated with no adaptation.

I. INTRODUCTION

This study is part of a comprehensive research project on the Caribbean that is being coordinated by the United Nations Economic Commission for Latin America and the Caribbean (ECLAC). The project results are expected to provide inputs into a *Review of the Economics of Climate Change in the Caribbean*. One of the main objectives[1] of the present research on the agricultural sector in Guyana is to provide policymakers with adequate information and technical tools to facilitate decision-making and provide a basis for further analysis through refinement of the models and forecasts used, as more data become available.

The focus of the present study is the assessment and estimation of the anticipated impact of climate change on the agricultural sector in Guyana and the likely costs that will be associated with these impacts. An economic model is developed to estimate the historical relationships between agricultural outputs and climate, with controls for production-related variables. The model is further used to forecast the likely impact that the anticipated changes in climate will have on selected subsectors in agriculture, using the Special Report on Emissions Scenarios (SRES) developed by the Intergovernmental Panel on Climate Change (IPCC). The IPCC report sets out various development scenarios for the world, and the SRES A2 and B2 scenarios will be used in the assessments. In addition, a third scenario – a reference, business as usual (BAU) scenario, based on a continuation of current economic and social practices, is presented for comparative purposes only. The current assessments project the impact of climate change on the agricultural sector in Guyana for the next 40 years ending in 2050.

In summary, the present study seeks to:

(a) collect relevant data on the agricultural sector in Guyana to estimate the costs of identified and anticipated impacts associated with climate change

(b) present an economic analysis of climate-related impacts on selected subsectors of the agricultural sector in Guyana up to 2050, based on various carbon emission trajectories under various scenarios

(c) identify representative agricultural commodities, analyse their main vulnerabilities and suggest possible adaptation strategies

(d) conduct an economic appraisal of the costs and benefits of adaptation.

Very serious constraints have been experienced during the preparation of the current study, especially in terms of data availability. The Office of the President of Guyana has been particularly supportive of the project and arranged numerous meetings with the Ministry of Agriculture and other relevant institutions and agencies. Given the quantitative nature of the study, requiring a fairly long time series of data for the various indicators used, significant data gaps exist, either because the data have never been collected, have not been properly recorded, or have been lost. In some instances, data collected were not available electronically and required costly and time-consuming methods to locate and input. As result, only the sugar, rice and fisheries subsectors were subject to detailed analysis. It is anticipated , once data are made available, that other

[1] ECLAC, Terms of Reference for Agriculture Sector Experts (2010).

subsectors will be assessed in subsequent studies, especially those which have been projected as critical in the country's future development.

The present report is comprised of six sections, as follows:

- The impact of climate change on agriculture
- Methodologies of estimating the impact of climate change on agriculture
- Guyana – socio-economic background
- Data and econometric analysis
- Adaptation issues
- Cost-benefit analysis, summary and conclusions.

II. THE IMPACT OF CLIMATE CHANGE ON AGRICULTURE

The Fourth Assessment report of the Intergovernmental panel on Climate Change (IPCC, 2007) has identified the presence of carbon dioxide (CO_2) concentrations of 350 ppm in the atmosphere to be typically associated with an average rise in global temperature in excess of 2° C, whilst concentrations of 450 ppm are associated with an increase of 5° C. Given the present CO_2 concentration of 387 ppm, the likelihood is anticipated of temperatures approximately 5° C higher over the period to 2100.

IPCC (2007) reports that global warming leading to average global temperature increases is causing melting of polar zones and related rises in sea levels. Sea-level rise is expected to exacerbate inundation, storm surges, erosion and other coastal hazards, thus threatening vital economic and social infrastructure, settlements and facilities that support the livelihoods of coastal communities.

A. CLIMATE CHANGE AND AGRICULTURE

Agriculture is a climate-dependent activity and is typically a critical part of the economic activity of both developed and developing countries. Climate change is expected to result in the increased intensity, timing and occurrence of hydro events, as well as changes in temperature to extremes of current levels over the coming century (Cline, 2007). These changes are expected to challenge plant and animal viability. In addition, it is expected that vectors will become more difficult to control, which will prejudice the growth and flourishing of plant life, debilitate the robustness of livestock, and reduce fisheries optimality. These stresses will compound those naturally-occurring stresses that are typical of ecosystems, and may ultimately destroy biodiversity. Whilst climate change has been attributed to the accumulation of emissions such as CO_2 that are associated with industrial and consumption activities, agriculture has been identified as a prime source of nitrous oxide emissions.

Most of the positive impacts on agriculture from climate change are expected to arise from carbon fertilization benefits which ought to enhance yields for some commodities; however, if this does not materialize due to water scarcity, then climate change is expected to have a net negative impact on agriculture. Climate change is also likely to have potentially negative impacts on the viability of agriculture, and thereby affect human health both directly and indirectly, through food unavailability and food insecurity, and ultimately the economic viability of many countries worldwide. The critical importance of agriculture to human welfare was demonstrated in the 2007/2008 food price crisis that emerged due to competing demands for agricultural products from the energy sector (Trostle, 2008). Since then, all countries – developed and developing – have placed significant emphasis on achieving and maintaining food security, whilst facilitating relatively open trade in agricultural produce.

Human health outcomes depend very heavily on the quality and availability of agricultural products. This occurs through several mechanisms. Firstly, increased temperatures will debilitate plant vitality in tropical areas and cause wilting and reduced nutritional value. Secondly, rising temperature is likely to result in an increase in numbers and types of pests that attack crops and livestock, as well as those which spread diseases. Thirdly, drought periods are linked with the potential availability of pools of water that attract and facilitate the breeding of a much larger number of vectors than the ecosystem can tolerate. Fourthly, higher levels of rainfall and flash floods will lead to worsening soil erosion as well as increases in the runoff of contaminants that affect plant and animal health, which are likely to reduce nutritional components whilst increasing toxicity.

B. IMPACTS OF CLIMATE CHANGE ON CROP AND CROP PRODUCTIVITY

Cline (1996, 2007) highlights agriculture as the sector that will experience the most serious impact of climate change. The extent of such an impact is projected to vary at the country level, with the expectation that developing countries will be more severely impacted, since the temperatures in these countries are closer to the thresholds that are anticipated with further warming. Increased warming, without the implementation of appropriate protective mechanisms, is likely to reduce the yields associated with traditional agricultural practices, due to increased levels of evaporation.

Climate affects crop productivity and the range of crops that can be grown in a particular geographical area in a number of ways. Temperature and climate affect yields and growing seasons, and there is also a direct (positive) CO_2 fertilization effect. More broadly, there are complex interactions between climate and agriculture, as well as between agriculture and other sectors such as water, that are critical to the proper functioning of the agricultural sector. Such factors as extreme events (summer heat, winter rain, storms), pests and diseases, and complex interactions with other key sectors, (with water availability for irrigation), imply a need to approach climate change through the wider multifunctionality of agriculture in relation to landscape, rural economies and the broader society. Crop patterns and crop varieties are likely to change. These changes are expected to result in negative economic and social impacts associated with the loss of income to farmers and related negative macro-economic effects.

Another aspect of the impact of climate change on agriculture is expected to emerge from the reduced/compromised water quality due to saltwater intrusion of the regular sources of water. This will reduce the volume and flow of water available for irrigation. Given the expected increases in temperature, reduced irrigation water is likely to increase the burning of plant leaves and reduce plant growth. These impacts are likely to require a relocation of agricultural activity, where possible.

C. CLIMATE CHANGE: THE CARIBBEAN SITUATION

Caribbean economies are likely to face particular challenges in the context of climate change due to the fact that these countries, (except for Belize, Guyana and Suriname) are typically small, low-lying islands (Bynoe, 2010; Trotz, 2011; Downes and others, 2009). These characteristic features heighten the exposure to climate change impacts, including the associated problems of sea-level rise, saltwater intrusion, contaminated water supplies and temperature-related stresses on plant, animal and humans. As land cover, soils, atmospheric components, climate variability and water availability and quality change, nutrient availability and biodiversity are likely to be reduced, especially in the context of the expected changes in sea currents, salinity and rising sea levels.

In order to address many of these issues, increased Government spending will be required; given the situation with existing fiscal deficits in many Caribbean countries, their fiscal positions are likely to worsen, moreso in the context of the projected decline in tax revenues. In addition, the high debt-to-GDP ratios will prove a binding constraint on the ability of many Caribbean countries to implement appropriate mechanisms to facilitate adaptation to climate change. Low adaptive capacity is likely to further intensify the anticipated negative impacts of climate change.

Caribbean agriculture is largely reflective of the historical experiences, practices and crops that date back to slavery. Since then, famers have adopted several measures to deal with the challenges impacting the agricultural sector. Various attempts have been made to diversify the product base of the sector; however, in most instances, there has been relatively little success.

Among the more recent policy initiatives for agricultural development across CARICOM countries is the Alleviation of Key Binding Constraints (Jagdeo initiative; CARICOM Secretariat, 2010[2]). Its stated regional objectives include a shift to the production of more value-added goods that can command higher prices and yield higher profits. There have also been policies that attempt to reduce the dependence of a large portion of the labour force on agriculture, which accounts for almost 10% of regional employment. In response to these policy changes, farmers are attempting to enter new markets locally, regionally and internationally.

Given the anticipated impact of climate change and some of the inherent structural issues faced by Caribbean States, CARICOM Heads of Government approved a Strategic Framework (CARICOM Secretariat, 2009a) for achieving development that is resilient to climate change. This Framework focuses, inter alia, on the promotion of: (i) mainstreaming climate change adaptation strategies into sustainable development agendas; and (ii) reducing vulnerability of natural and human systems to the impact of climate change.

The development of the agricultural sectors in CARICOM countries is currently guided by the CARICOM Regional Food and Nutrition Security Policy (RFNSP) which aims "to ensure that the regional food production, processing, distribution, marketing, trade, and food safety and agricultural public health system is capable of providing safe, adequate, nutritious and affordable food for the region's inhabitants at all times, thereby achieving

[2] See CARICOM Secretariat 2010, p 14.

The Strategic Framework is made up of four primary elements:

1. Mainstreaming climate change adaptation strategies into the sustainable development agendas using a learning-by-doing approach to capacity-building and build on the progress achieved through the Caribbean Planning for Adaptation to Climate Change (CPACC), Adapting to Climate Change in the Caribbean (ACCC), Mainstreaming Adaptation To Climate Change (MACC) and Special Programme On Adaptation To Climate Change (SPACC) projects.

2. Promoting actions to reduce greenhouse gas emissions through fossil fuel reduction and conservation, and switching to renewable and cleaner energy sources.

3. Promoting actions to reduce the vulnerability of natural and human systems to the impacts of a changing climate.

food and nutrition security" (CARICOM Secretariat, 2010). The Policy is integrated with the Liliendaal Declaration (2009) which provides details of the key issues to be addressed in meeting the goals related to regional food and nutritional security. Very importantly, it highlights the high levels of vulnerability of Caribbean economies to natural shocks, which are likely to be worsened in the context of future global climate change impacts.

These divergent impacts support the need for detailed country-level studies so that policies and programmes can be appropriately designed and targeted to country-specific situations. Rural and coastal populations are expected to experience negative consequences in terms of serious loss of livelihoods. In order to identify the impact of climate change, it is necessary to properly consider the effects of other variables on agricultural activities including fertilizers, technology, irrigation, pest management, risk reduction measures, finance, labour and soil characteristics.

III. MODELS USED TO ESTIMATE THE IMPACT OF CLIMATE CHANGE ON AGRICULTURE

The published economics literature indicates that a wide range of approaches and models have been used to assess the likely economic impact of climate change on agriculture. These broad categories represent structural models, which combine the agronomic response of plants with economic decisions of farmers; and spatial analogue models that utilize observed differences in agricultural production and climate among countries and regions (Adams and others, 1998; Schimmelpfennig and others, 1996)

A. STRUCTURAL MODELS

Adams and others (1998) discuss structural analysis as an interdisciplinary approach that incorporates concepts from several disciplines to measure the economic effects of climate change on agriculture. Also known as crop response models, structural models usually involve detailed experiments using crop growth simulations to model yield changes by crop and by region (Schimmelpfennig and others, 1996; Adams and others, 1998). This approach provides an estimate of the response of specific crop varieties to different established climatic and other related conditions. It also provides a comprehensive understanding of important physical, biological and economic responses and adjustments of the crop to climate change variables.

This approach therefore directly facilitates the incorporation of the effects of climate change on crop yields (Adams and others, 1998). In addition, farm-level adaptation and management practices, which are critical for policy responses to climate change, may be integrated into the model. Economic impacts are then estimated using the yields obtained from the previous step. These models usually attempt to optimize consumer and producer welfare, subject to climatic factors and other constraints which may be imposed on the model. The disadvantage of this approach emerges in aggregate studies, where inferences about the impact of climate and climate change must be made from relatively few sites and crops, to large areas and diverse production systems; this can cause the results to be unreliable (Schimmelpfennig and others, 1996; Adams and others, 1998).

1. Spatial analogue models

The spatial analogue approach is used for cross-sectional analysis of climate impacts; it represents an elaboration of the case study approach (Schimmelpfennig and others, 1996). Essentially, this approach attempts to use available cross-section evidence on current output in warm and cool regions to identify the implications of different climatic conditions. By applying statistical analysis across geographic regions, this approach provides direct evidence on the responses of commercial farmers to climatic conditions. It also allows researchers to identify the factors that explain production differences across these regions. This method allows for factors such as land quality to be considered independently, thus isolating effects of climate change; typically, crop response models do not routinely consider these factors.

2. General circulation models (GCMs)

GCMs are computer-based, mathematical simulations of the atmosphere and ocean that are used to predict responses of crop production to changes in climatic conditions and increases in greenhouse gases (Barron, 1995). These models use complex mathematical expressions of the prevailing and potential interactions based on the physical laws that govern the relationships between the atmosphere, oceans, plants and other ground cover on the Earth’s surface. Essentially, GCMs are expressions of mathematical equations and empirical relationships which describe the dynamics of atmosphere and ocean. GCMs allow researchers to test what happens to global climate in response to a wide variety of changes, using mathematical simulations (Barron, 1995).

The primary advantage of these mathematical models lies in their capacity to simulate the behaviour of atmospheric and oceanic systems that are generally too complex or extensive for the application of simple, intuitive reasoning or for partial approaches. There are limits, however, as to the degree of complexity can be handled by the computers on which these models are tested, and the precision of the model at the local level. As a result, the current models of the global climate system cannot include physical processes in geographical areas that are less than several hundred miles. This clearly negatively impacts the extent and accuracy of local analyses at this scale. Analysis at this level has had to incorporate the best possible representation of all the important processes and responses necessary to characterize the climate system, while keeping within practical capabilities of modern computers.

3. Economic impact assessment models

a) Crop simulation models

These models are based on controlled experiments where crops are grown in field or laboratory settings that simulate different climates and levels of CO_2, in order to estimate yield responses of a specific crop variety to certain climatic and other variables. Estimates of these models do not include the effects of farmer adaptation to changing climatic conditions. Consequently, their results tend to overstate damage to agricultural production caused by climate change (Mendelsohn and Dinar, 1999). There are two types of partial equilibrium models. The first is based on crop growth simulation models and the second uses econometric procedures. These two approaches are discussed in further detail in the following paragraphs.

b) Agro-economic zone (AEZ) models

Agro-economic zone analysis combines crop simulation models with land management decision analysis, and captures the changes in agro-climatic resources (Darwin and others, 1995, Fischer and others, 2005). AEZ analysis categorizes existing lands by agro-ecological zones, which differ in the length of growing periods and climate for various crops. The length of the growing period is classified based on temperature, precipitation, soil characteristics and topography. Changes in the distribution of the crop zones, along with climate change, are tracked in AEZ models. Crop modelling and environmental matching procedures are used to identify crop-specific environmental limitations under various levels of inputs and management conditions, and to provide estimates of the maximum agronomically-attainable crop yields for a given unit of land.

As the predicted potential attainable yields from AEZ models are often much larger than current actual yields, these models may overestimate the effects of autonomous adaptation. Cline (2007) observed that AEZ studies tend to attribute excessive benefits to the warming of cold high-latitude regions, thereby overstating global gains from climate change. In addition, these models are limited by the significant variations in regional data quality and reliability.

c) Production function models

The production function approach relies on empirical or experimental production functions to estimate the relationship between agricultural production and environmental changes (Mendelsohn and others, 1994). In this analysis, outputs are determined under a variety of environmental conditions, using carefully calibrated crop-yield models. Climate input variables, such as temperature, precipitation and carbon dioxide levels, are then entered at various levels and the results recorded. A basic production function is then estimated to assess the observed impact of climate change on yield.

Mendelsohn and others (1994) report that, although these models provide a useful baseline for approximating the impact of climate change on agriculture, they reflect an intrinsic bias that is likely to overvalue damage associated with climate change. The estimates produced by these models do not control for adaptation and will, therefore, tend to predict severe yield reductions as a result of global warming. Additionally, these models omit a variety of the adaptations that farmers routinely implement in response to changing economic and environmental conditions. Over time, farmers are likely to respond to changing climate and other environmental factors by varying, among other things, crop mix, planting and harvesting dates, irrigation scheduling and application of fertilizers and pesticides to mitigate the potential harmful impact of climate change. While some studies make assumptions of modest adaptation and calculate the impact of changing temperature on farm yields, Mendelsohn and others (1994) assess that some others allow for limited changes in fertilizer application, irrigation, or cultivars.

Since the impact of climate change on crop yields is determined through controlled experiments, an advantage of this model is that it will more reliably predict how changes in climate affect yields. As noted earlier, the major constraint is that it typically does not control for adaptation (Mendelsohn and others, 1994). In addition, this model does not consider the introduction of new crops, technological changes and changes in land use; its main weakness is its failure to allow for economic substitution as conditions change (Mendelsohn and others, 1994).

d) The Ricardian model

The Ricardian approach uses data from farm surveys or country-level data to analyze the relationships between agricultural capacity, such as land value, and climate variables - usually temperature and precipitation. Instead of studying yields of specific crops, this model uses economic data on the value of net rent or farmland to correct any inherent biases in the production-function technique. By directly measuring farm prices or revenues, Mendelsohn and others (1994) accounted for the direct impact of climate change on a variety of crop yields including the impact of: (i) indirect substitution of different inputs; (ii) introduction of different activities; and, (iii) other potential adaptations to different climates. The model assumes that markets function properly and this allows the researcher to measure economic impacts of climate change on the economic value of different activities.

It is argued that this approach automatically incorporates efficient climate change adaptations by farmers (Zhai and others, 2009). However, a major criticism of the methodology is that it does not account for price changes. Additionally, the model fails to fully control for the impact of other variables that affect farm incomes (Mendelsohn and Dinar, 1999; Cline, 1996).

IV. GUYANA: SOCIO-ECONOMIC BACKGROUND

A. POPULATION

A member of the Caribbean Community (CARICOM), the Republic of Guyana is 83,000 square miles or 215,000 square kilometres in area, with a population of just over 760, 000 persons (see table 1). Since 2002, the population is estimated to have declined somewhat, with the average annual growth rates indicating negative trends. The rural population as a percentage of total population has remained fairly stable since the 1960s, averaging around 70%.

Table 1: Population Census Data

Census Year	Amount ('000)	Average annual population growth rate	Rural population as % of total population
1946	375.7	1.09	-
1960	560.3	2.02	71.0
1970	701.7	-2.39	70.6
1980	759.6	-1.70	69.5
1991	723.8	-1.18	70.6
2002	751.2	0.77	71.6
		-0.33	71.6*
2011 estimate	744.8		

***2009 figure**

Source: Bureau of Statistics*, Population Census 2002, World Bank and World Bank Indicators (selected years)*

Sparsely populated by any standards, some 90% of the population live on a narrow coastal strip which is about 1.5 million hectares in area; these are classified as Regions 2 to 6 (see table 2). This area is below the mean high tide mark and has, historically, experienced flooding from the Atlantic Ocean as well as during the rainy seasons. The main administrative, commercial and business areas are located along this strip, with almost all commercial agricultural activities operating in Regions 3 to 6 (CCCCC, 2009a ; CCCCC, 2009b). The other 10% of the population lives in the hinterland areas; some of these areas are not easily accessible and tend to be flood-prone during the rainy seasons. Hinterland economic activities are mainly mining, logging and subsistence agriculture.

Table 2: Regional distribution of the population

Region	Percentage of total population
1	3.2
2	6.6
3	13.7
4	41.3
5	7.0
6	16.5
7	2.3
8	1.3
9	2.6
10	5.5

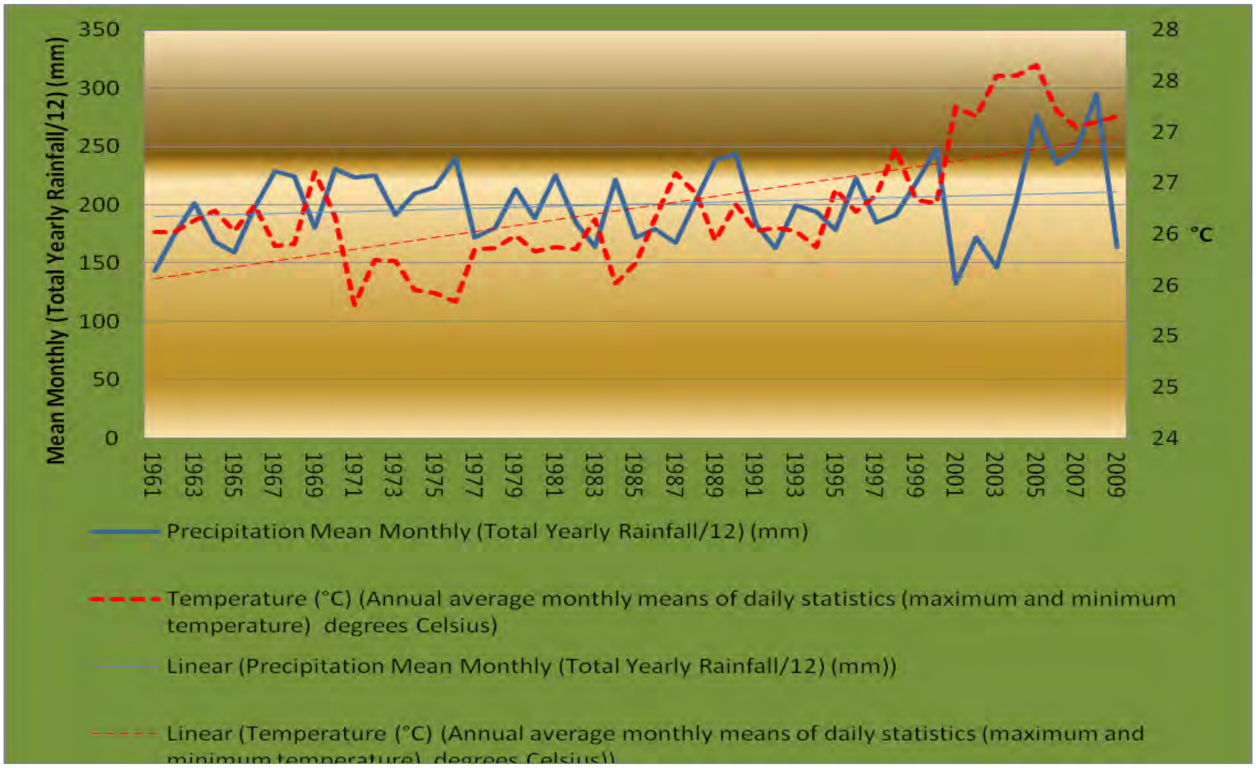
Source: Bureau of Statistics, *Population Census 2002.*

B. CLIMATE

Guyana typically experiences a tropical equatorial climate with seasonal rainfall, high levels of humidity and small temperature variations from an average daily temperature of 80° F (26° C). Although not without its limitations given the large geographical size of Guyana, using Georgetown data as representative of the country indicates that temperature and precipitation have both showed upward trends since 1961 (see figure 1). Two dry and two wet seasons annually are typically identified, with the dry seasons occurring from February to April, and from July to November, and the wet seasons from April to July, and from November to January (CCCCC, 2009b; CCCCC, 2009c).

Given the geographical proximity of Guyana to the Equator, daylight hours reflect little variation across these seasons. Temperature variations on coastal locations are small, ranging from a maximum average of 29.8° C to a minimum of 24° C. The North-East Trade winds are experienced in Guyana's coastal region, with typical wind speeds of 6 metres per second (CCCCC, 2009a).

Figure 1: Average monthly temperature and precipitation for Georgetown, Guyana, 1961-2009.



Source: Hydromet Office, Climate Change Unit, Office of the President, Guyana

C. GEOGRAPHY

The country is physically divided into four categories of landforms:

- a flat coastal area which averages about 2.4 metres (8 feet) below sea level, and where most of the country's agricultural production exists
- a sandy area south of the coast, including intermediate savannas
- an undulating, central area comprising more than half of the country's land area, and including tropical forests and significant mineral deposits
- a mountainous land area which includes the Pakaraima mountain range.

The coastal plain is located along the north coast and accounts for 10% of Guyana's total land area, and 80% of cultivated land. The capital and a large number of small towns and villages are located on the coast; approximately 85% of the total population live in this area. Historically, sea-defence systems, including sea walls and drainage and irrigation canals, have been constructed and maintained (since 1882) in an attempt to protect over 200 kilometres (120 miles) of coastal areas along which the critical economic and residential infrastructure of Guyana is located.

The hilly sand and clay area south of the coast represents about 20% of the total land area of Guyana. It includes forests, hills and savannah lands. The flat savannah areas are well suited for cattle rearing and selected agricultural activities. Significant bauxite deposits are also found in this area. To date, the full potential of this area has not been maximized.

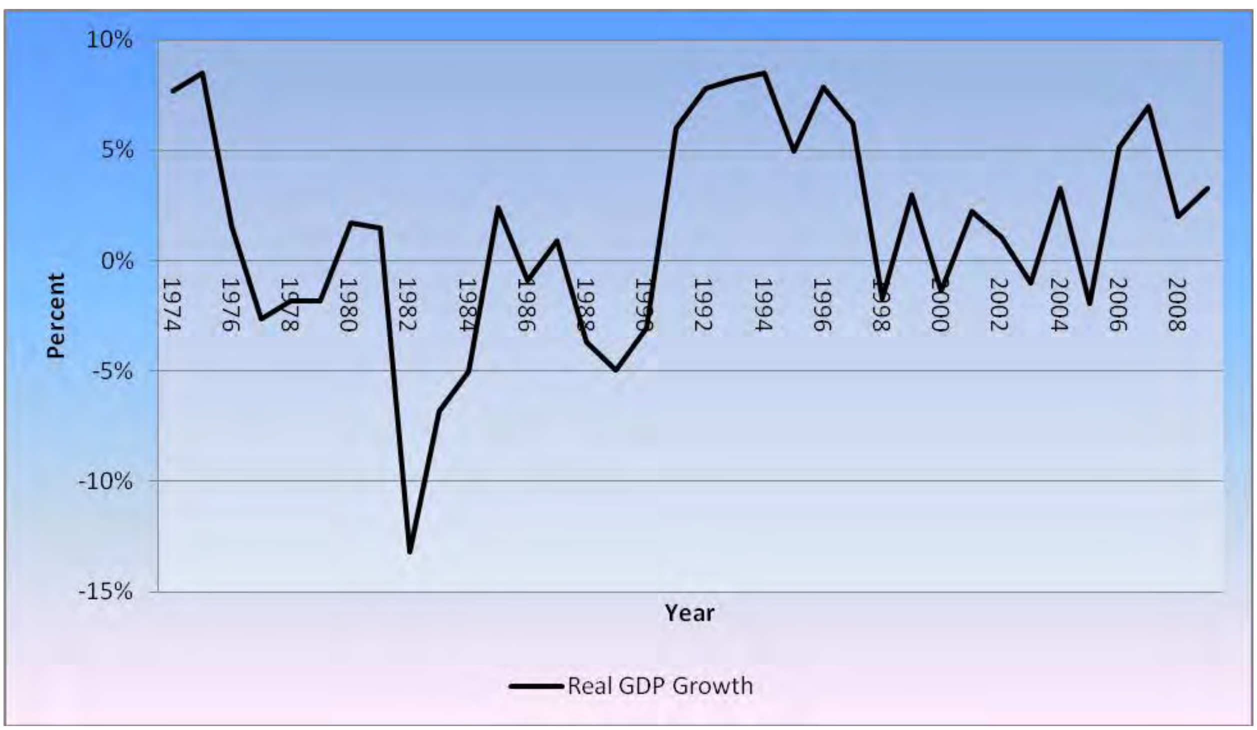
The highland region covers around 60% of Guyana's total land area and is characterized by dense rainforests, various types of wildlife and deposits of gold and diamonds. The mountainous areas are mainly the Pakaraima Mountains, with most of this area being sparsely populated.

D. ECONOMY

During the decade of the 1980s, Guyana experienced negative economic growth, with annual average declines in both GDP and per capita GDP of over 3.5%. Since 1989, the Government has implemented policies which support a liberalized, free market economy, identifying the private sector as the leading source of economic growth. These policies included divestment of State-owned enterprises like the Guyana Rice Board (GRB), liberalization of foreign exchange markets, removal of price controls and easing of trade licence requirements.

During the 1990s, the performance of the Guyanese economy improved significantly, with annual average GDP growth rates exceeding 7%. Since 2000, this growth rate has declined somewhat averaging just above 4% annually between 2000 and 2009 (see figure 2).

Figure 2: Guyana: Real GDP growth rate: 1974-2008.

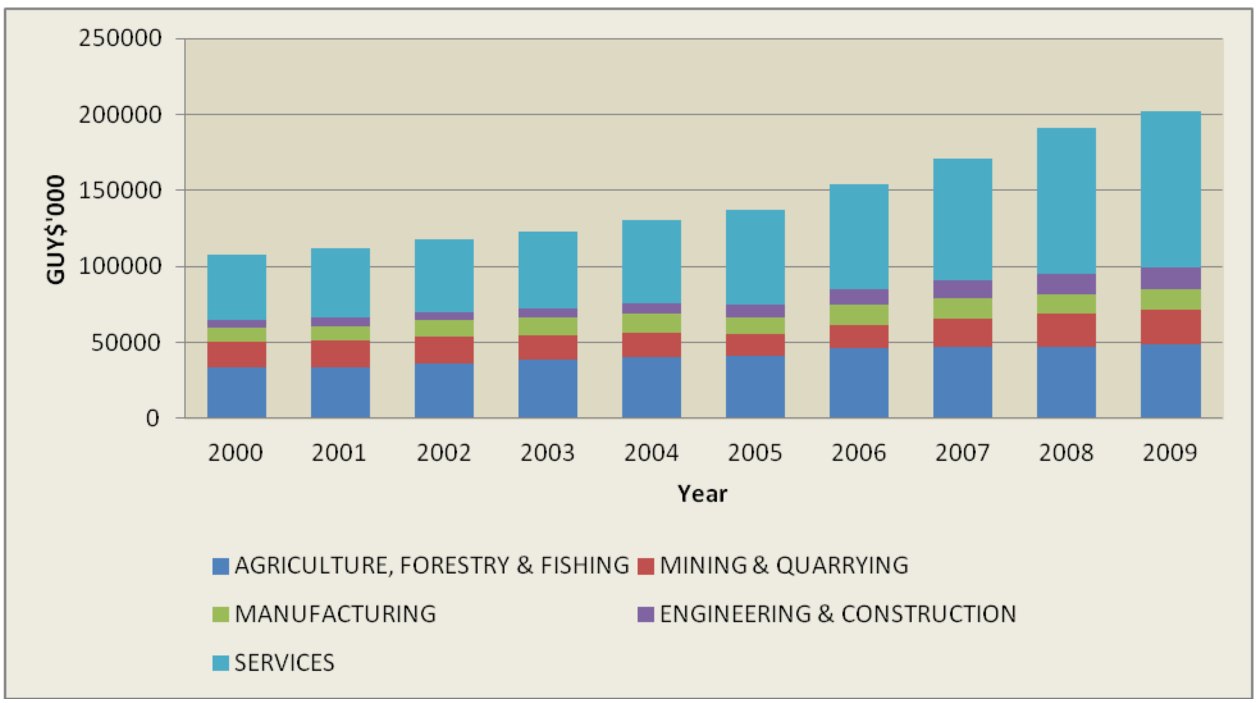


Source: World Bank Database 2010.

The Guyanese economy is primarily based on the production and export of its natural resources, with agriculture (mainly sugar and rice), gold, timber and bauxite, accounting for most of the output of the country's productive sectors (see figure 3). Since 2002, the share of services in the national economy has increased, becoming the leading sector for the past five years.

Historically, the agricultural sector has contributed significantly to gross domestic product (GDP), exports, direct and indirect employment, and rural transformation. As a percentage of GDP, agriculture has averaged over 30% during the period 2000 – 2009, and remains one of the most important economic sectors in the country in terms of its direct and indirect contributions. The agricultural sector in Guyana contributes not only to economic but also social and community development. The dominant subsectors of agriculture in Guyana have been sugar and rice, accounting for an average of over 50% of agricultural sector contribution to GDP since 2000. In more recent years, fishing, forestry and non-traditional crops have received Government support as part of its agricultural sector diversification programme, and are increasing their contributions to national output.

Figure 3: Guyana: Sectoral GDP breakdown (factor cost), 2000-2009.



Sources: Bank of Guyana, *Annual Report* (various years); Bureau of Statistics, *Statistical Bulletin*, (various years)

E. AGRICULTURE

The present study uses the definition of agriculture (UNDP, as cited by Downes and Pemberton, 2009) to include "agriculture, hunting, forestry and fishing". In applying this definition to Guyana, the agricultural sector is among the most important in terms of contribution to GDP, employment creation, export earnings, community development (especially in rural areas) and contribution to the country's food security requirements. Intersectoral economic and social linkages are particularly critical elements in terms of the overall macroeconomic impact of the sector.

Plantation agriculture, (mainly sugar) which historically was the main commodity during the colonial period, represents a total institution whose legacy still exists today. For many communities, agriculture remains the main source of community economic and social activity. In many geographical locations, agricultural enterprises provide a range of community services, including health, education, infrastructure and transport facilities. As such, any negative effects of climate change on the operations of these agricultural enterprises are likely to impact not only the enterprise itself, but also the human development of the communities in which these activities occur. The sugarcane, paddy and fisheries subsectors are particularly relevant here, with substantial multipliers resulting from their operations.

Given their importance to the Guyanese economy, the current study planned to focus on assessing the sugar, rice, fisheries and forestry subsectors in terms of the potential impact of climate change on their performance, over the medium to long term. However, given serious data constraints, forestry was not included in the detailed analysis.

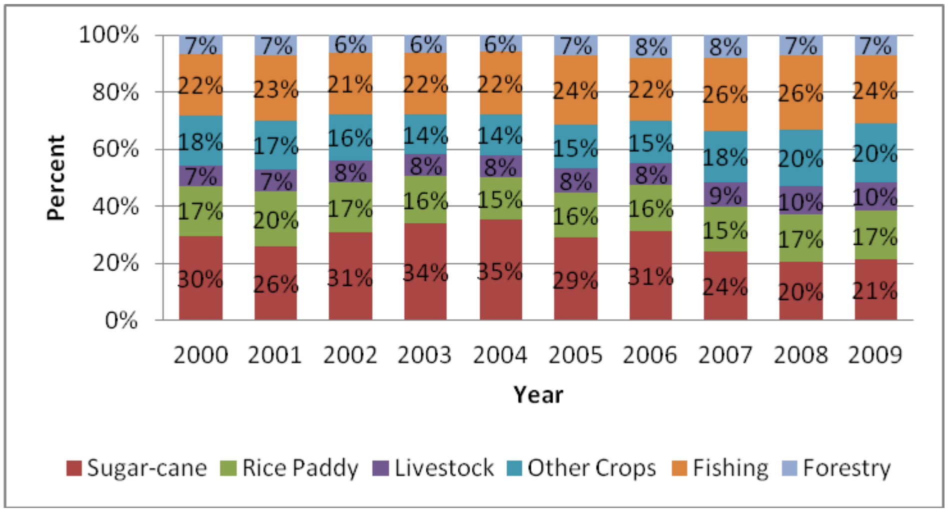
The contributions of the key subsectors to agricultural value added are presented in figure 4. Agriculture is a very critical area of economic activity in Guyana in terms of significance of the sector to food security, poverty reduction, employment generation and foreign exchange earnings. As such, the forecast changes in climate are likely to have a serious impact on the livelihoods of a large part of the population, as well as on the general economic well-being of the country. In this regard, there have already been various observations (CCCCC, 2009a; GUYSUCO, 2007) which articulate the likely impact of the progressive change in climate on the Guyanese landform, with serious implications for the viability of the continuation of existing agricultural practices in Guyana.

Climate change factors that are most likely to affect agriculture in Guyana include: temperature changes, increased rainfall intensity, drought, increased sea levels, risks of salt water intrusion, and sea temperature changes. With the largest percentage of the population located on the coast, as well as approximately 75% of the country's economic infrastructure, it can be expected that climate change will have a negative impact on these economic units and related activities and, therefore, on the livelihoods of large sections of the Guyanese population (CCCCC, 2009a).

The flood experience of 2005-2006 provides an important example of the impact that this type of climate event can have on Guyana. ECLAC (2005, 2006) highlights the significant impact of the flood on agriculture, and indicates that rice experienced greatest damage, at US$ 8.8 million, while other crops (including fruit, vegetables and tubers) realized estimated losses of US$ 7.8 million. Damage to the sugar industry was reported to be minimal. In addition, the ECLAC (2005, 2006) reports indicate that approximately 60% of the entire population was affected, with about 75% of the country's critical national infrastructure threatened as a result of rapidly rising flood waters. The flood damage to the mobile telecommunications industry was estimated at US$ 204.2 million. The total flood damage was estimated at about 60% of national GDP and resulted in widespread infrastructural, economic, social and cultural dislocation.

According to IPCC (2007a), global temperature has increased by 0.3° C to 0.6° C over the past century, with most of this rise occurring in the past 40 years. Guyana has warmed by up to about 0.8° C since 1990, which is higher than the global rate, and implies that the country is likely to experience the impact of climate change at a faster rate than anticipated (Homenauth and Chintamanie, 2010). In Guyana, the future climate situation is expected to include: increases in temperature between 0.5° to 1.5° C by 2050; and, an increase in annual moisture index ratio of between 20% and 30% (CCCCC, 2009a).

Figure 4: Guyana: Components of agricultural GDP, percentage contribution, 2000-2009.



Sources:Bank of Guyana, *Annual Report* (various years); Bureau of Statistics, *Statistical Bulletin*, (various years)

1. Sugar

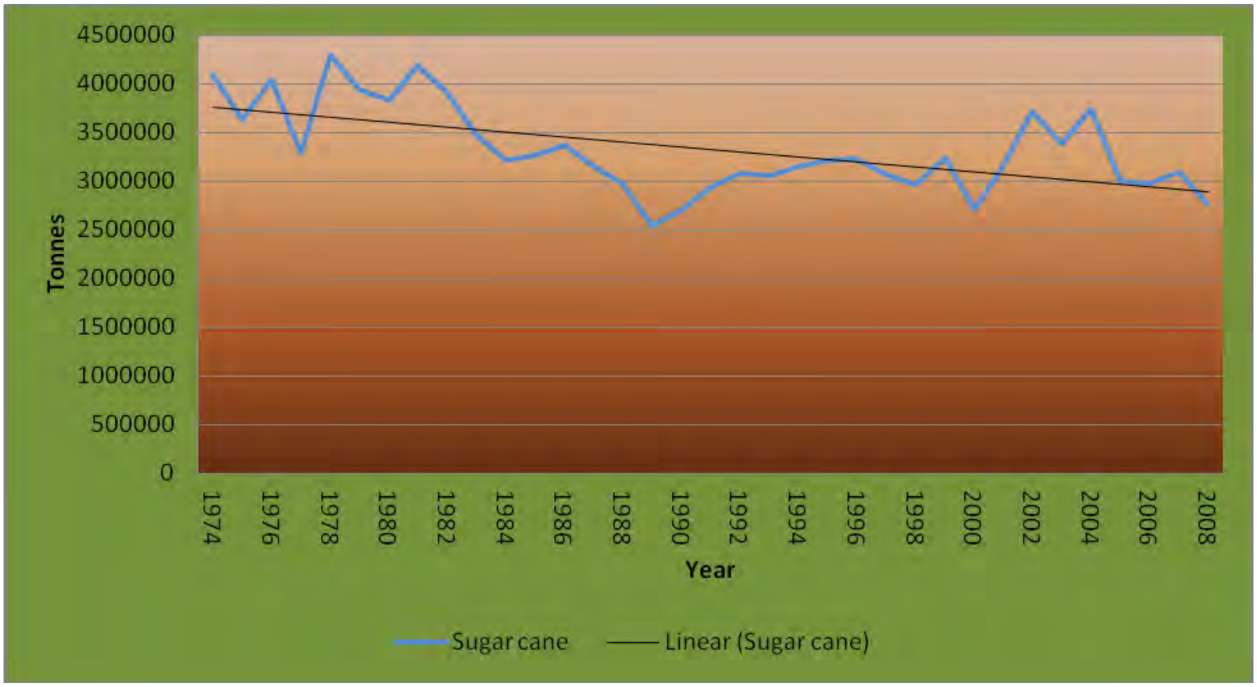
Historically, sugarcane, sugar and sugar-derived products have been the largest agricultural and agro-industrial operations in Guyana. The sugar subsector continues to represent a critical part of the economy of Guyana, accounting for about 10% of total GDP and about 40% of agricultural sector GDP in 2009 (see table 3). The sugar subsector is the largest net foreign-exchange earner in Guyana and the principal contributor to Government revenues. Some 25,000 people are directly employed in the sugar subsector, with approximately 125,000 persons dependent on the sugar industry. There are extensive linkage effects with the rest of the Guyanese economy, particularly in manufacturing, distributive trades and transport. In addition, sugar has strong social linkages, as evidenced by its widespread community activities across the country. The industry is dominated by the State-owned Guyana Sugar Corporation (GUYSUCO), which operates 5 sugar estates (66,397 hectares) and 8 factories located along Guyana's coastal area.

Table 3. Sugar: Selected statistics 2000 – 2009					
Year	Output (tonnes)	Change (%)	Yield/Hectare (tonne)	Export Value (US$ mill)	% of Agri. GDP
2000	273 300	-15	6.2	121.18	47.72
2001	284 477	3.9	6.4	105.16	47.85
2002	331 057	16.4	8	117.52	52.51
2003	302 378	-8.7	6.8	129.77	48.80
2004	325 317	7.6	6.5	138.81	50.89
2005	246 202	-24.3	5.3	107.02	44.61
2006	259 588	5.5	6.1	127.34	44.14
2007	266 482	2.7	6.2	133.93	45.05
2008	226 267	-15.1	4.6	136.22	40.57
2009	233 736	3.3	4.8	119.26	40.82
Sources: Guyana Bureau of Statistics, FAO, ECLAC, Bank of Guyana					

Between 2000 and 2007, sugar yield has averaged over 6 tonnes per hectare annually, declining to less than 5 tonnes per hectare in 2008 and 2009 (see table 3 and figure 5). The marginal increase in sugar production of 3.3% in 2009 resulted, in part, from the implementation of the GUYSUCO Turnaround Plan which is a component of the Guyana National Action Plan. This Plan for 2009-2018 targets increased production and diversification whilst lowering production costs, through the mechanization of agricultural practices, improved management, and the sale of unproductive lands to generate cash for investments. GUYSUCO is expected to invest over G$ 20 billion in the implementation of this Plan.[3]

[3] GUYSUCO senior management (June 2011).

Figure 5: Sugar cane production, 1974-2008.



Source: FAO, FAOSTAT 2010.

Over the last decade, a large proportion of sugar produced in Guyana was not consumed locally. Guyana is typically a high-cost sugar producing country with an annual average cost of US$ 0.40/kg over the last decade 2000-2010; this production cost is not competitive when compared with other sugar-exporting countries such as Brazil, Fiji and Mauritius. In addition, as expected, average export prices typically exceed domestic prices. Despite this, sugar exports accounted for an annual average of almost 90% of domestic production over the past 10 years, with the exception of 2000 and 2003.

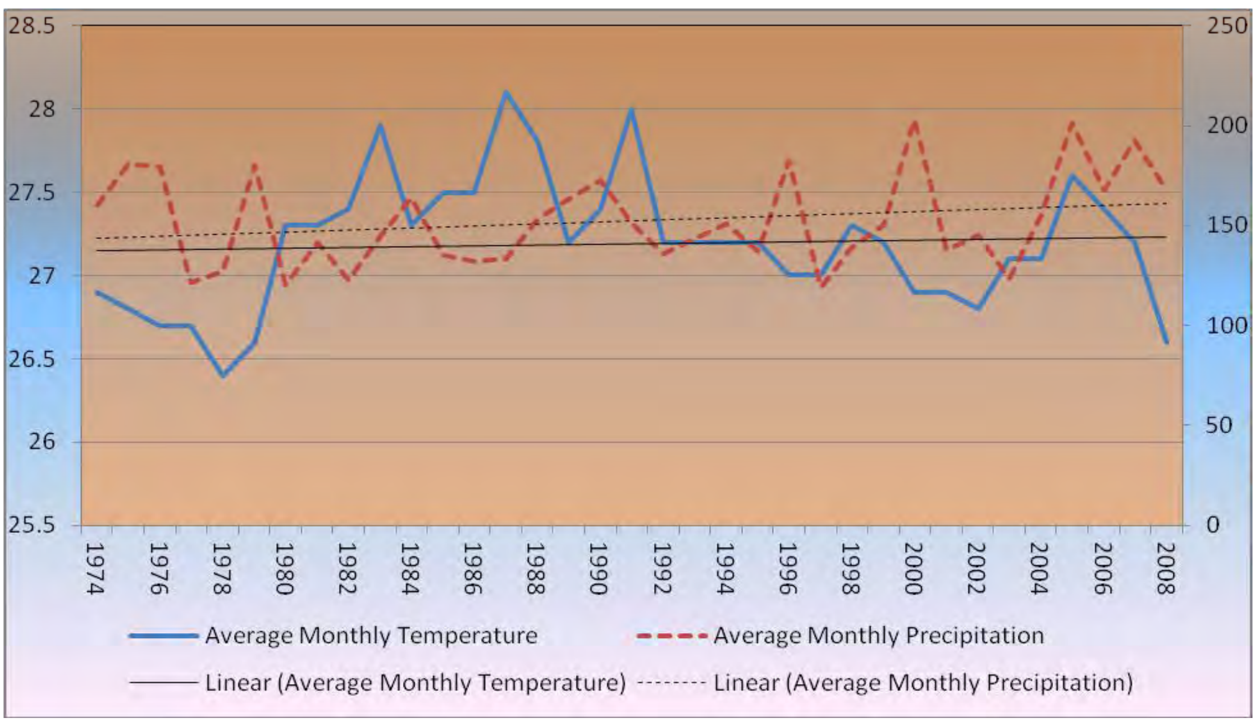
Since the 1970s, the sugar sector in Guyana has operated under preferential agreements with the European Union (EU) (ACP/EU Sugar Protocol), under which the EU agreed to purchase 160,000 metric tonnes of sugar; in 2008, the EU purchase price of Guyana sugar was €485 per tonne. Between October 2009 and September 2012, the minimum EU sugar export price for Guyana sugar has been set at €301.5 per tonne; this is the last guaranteed price provided by the EU in the final years of its preferential agreement with Guyana. With EU preferences removed, Guyana sugar exports and related foreign exchange earnings are likely to be reduced, as EU purchases account for up to 90% of Guyana sugar exports. Elimination of EU preferences will expose the Guyana sugar industry to the rigorous competition of the world sugar market.

World market predictions indicate that global sugar consumption will increase from 161.7 million tonnes in 2011 to 257 million tonnes by 2030. However, since cane sugar production is expected to increase at a slower rate, there is likely to be a continuation of the deficit in the supply of sugar globally. Recognizing this, the Guyana Government has prepared a plan to increase output and reduce costs in order to make its sugar output more competitive internationally. The plan is to achieve this competitive edge through: (i) increased public investments to achieve the full operational capacity of the Skeldon sugar plant, which is one of the largest in Guyana; (ii) improved labour practices and productivity; and, (iii) improved business practices to increase sugar output by 4-5% over the next few years.

The monthly temperature and precipitation trends (1974-2008) for the main sugar cane production areas in Guyana (Skeldon, Albion, Rose Hall, Blairmont, Demerara, Houston and Wales) are presented in figure 6; both trends are slightly upward, with precipitation somewhat higher than that of temperature. The production of sugarcane, both in terms of quality and quantity, is likely to be threatened by various climatic factors, including:

- Increases in temperature at night-time, which affect the ripening process of the crop, while overall increases in the intensity of drought periods affect yields.
- Increased rainfall reduces the days available for planting and reaping.
- Floods from more frequent and intense rainfall and flooding from the Atlantic, due to over-topping and sea-level rise, reduce the discharge window available for coastal drainage and impact output negatively.

Figure 6: Guyana: Average monthly temperature (° C) and precipitation (mm) for the main sugarcane-growing regions (1974-2008)



Source: Guyana, Ministry of Agriculture

2. Rice

The rice subsector is the second most important agricultural industry in Guyana. Up to recently, rice was second to sugar in terms of foreign-exchange earnings. Rice paddy growing is the largest user of agricultural lands, with about 80,000 hectares currently double-cropped; this impacts a larger proportion of the working population than any other economic activity in Guyana. About 12,000 private farmers are involved in rice paddy production, while the industry supports an estimated 20% of the Guyana population directly, with substantial numbers impacted indirectly via involvement in milling, export, transport and related activities. Although not as large as sugar, rice paddy activities have productive linkages with other economic sectors as well as with social and community-oriented activities. Rice production is the major source of income and employment in many coastal areas. In addition, the rice industry contributes approximately 10% of agricultural GDP and 12% of export earnings (see table 4).

Rice is the main staple of the population, with consumption estimated at being around 50 kg per capita. The major by-products, bran and broken rice, are the main inputs for locally-produced animal feed. Broken rice is used in the brewery industry. The hull (shell) of the rice is utilized for cogeneration as fuel for paddy dryers and for electricity generation. Consideration is currently being given to using rice straw as fodder for livestock.

The rice industry has, over the years, operated a preferential market in the EU via the Lomé Convention and the Cotonou Agreement; the EU preferential agreement terminated in 2008. The EU has established a support programme geared towards enhancing the competitiveness of the Guyanese rice industry, following the phasing-out of the preferential access agreement. Guyana has been successful in broadening its marketing base by increasing sales in Caribbean markets, and currently supplies 50% of the CARICOM market. The CARICOM market protects the rice trade through a 25% common external tariff. About 40% of Guyana rice exports are to CARICOM countries.

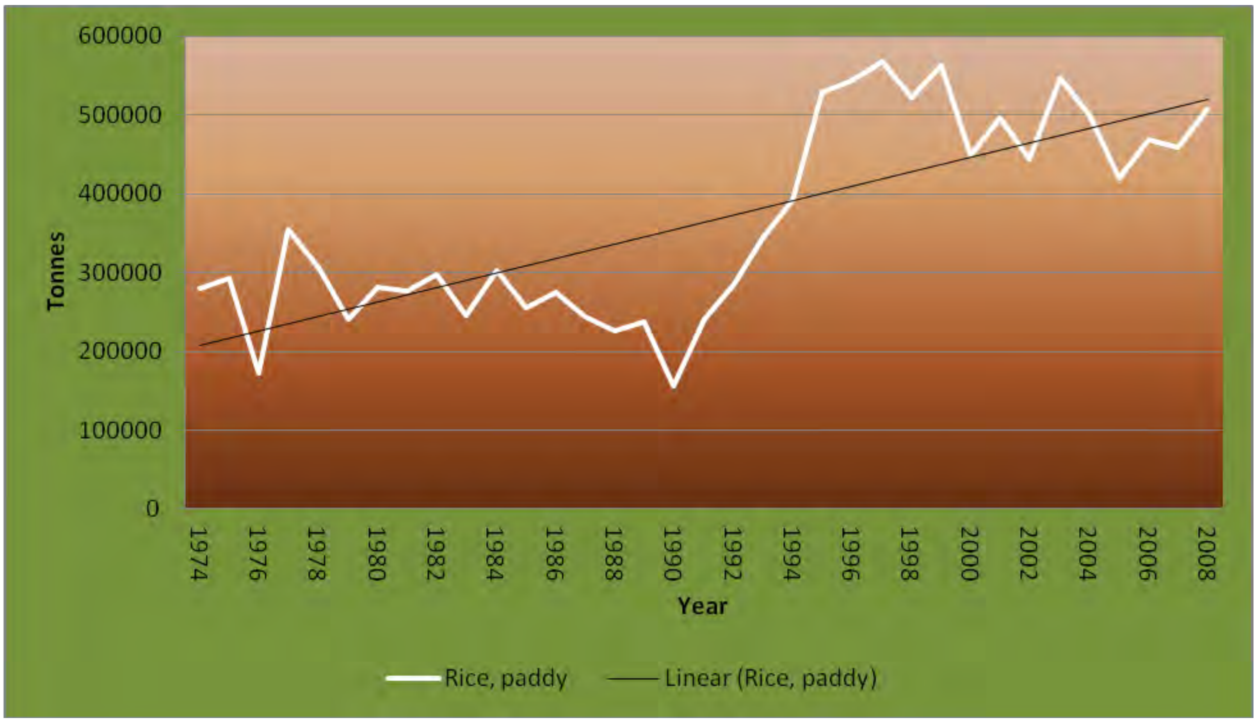
Table 4: Rice: Selected statistics (2000-2009)

Year	Output(tonnes)	Change (%)	Yield/Hectare (tonne)	Export value (US$ million)	% of Agricultural GDP
2000	291 967	-20.1	2.52	40.84	10.15
2001	322 310	10.4	2.59	46.69	10.82
2002	288 375	-10.7	2.67	44.59	9.08
2003	355 019	23.1	2.75	43.65	11.38
2004	325 592	-8.3	2.81	52.80	10.12
2005	273 237	-17.3	2.56	45.28	9.85
2006	307 041	12.4	3	54.37	10.40
2007	298 198	-2.9	2.82	75.07	10.01
2008	329 574	10.5	2.75	117.02	11.78
2009	359 789	9.2	2.88	112.63	12.48

Sources: Guyana Bureau of Statistics, FAO, ECLAC, Bank of Guyana

A statistical review of the performance of the industry indicates a 7.2% increase in the total area under cultivation, along with an increase of 9.8% in harvested area between January and June 2010, compared with the same period in 2009. Productivity in the rice industry has improved considerably; per-hectare yield rose by 55% between 1975 and 2007 (see table 4). Over the last two decades, rice production has fluctuated, from as low as 155,740 tonnes in 1990, through a record high of 568,188 tonnes in 1997, but declining to under 400,000 tonnes by 2009 (see figure 7). Fluctuations in production levels are attributed to disease and inconsistent weather.

Figure 7: Rice paddy production,1974-2008 (tonnes).

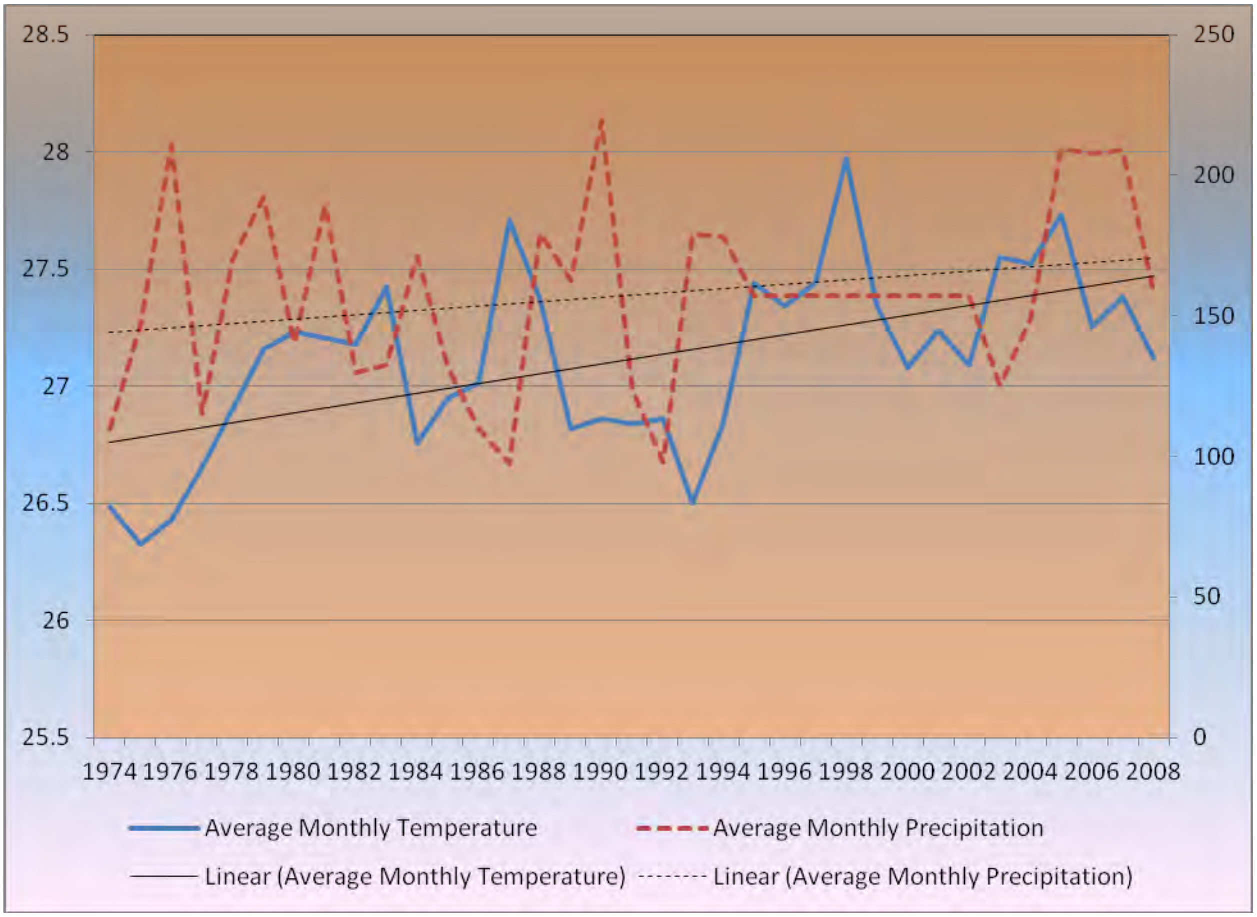


Source: FAO, FAOSTAT 2010.

The volume of rice exports has been fairly steady; the industry contributes approximately 10% of total export earnings. The prices obtained in foreign markets declined sharply until the latter part of 2007. In 2008, rice exports rose 56.8% (in US dollar terms), based on strong global demand and record high prices. A key indicator of the upswing in the performance of the rice industry has been a 15.5% increase in the dollar value of Guyana rice exports. The highest recorded export earnings for Guyana were in 2008, when exports were 196,233 tonnes valued at US$ 118 million.

The average monthly temperature and precipitation trends (1974-2008) for the rice-growing areas in Guyana are presented in figure 8; these areas are: Mahaica/Abary, Berbice, Essequibo, New Amsterdam and Rose Hall. Both temperature and precipitation show increasing trends, with temperatures rising faster over the period.

Figure 8: Guyana: Average monthly temperature (° C) and precipitation (mm) for rice-growing regions (1974-2008)



Source: Guyana, Ministry of Agriculture.

Rice production is most vulnerable to climate change because of the geography of the farmed land as well as the impact that sea-level rise could have on water salinity in the rice fields. Higher temperatures are usually associated with sterility in rice flowers, which would then produce no grain. A 1° C increase in temperature is expected to decrease rice yields by 10%. Changes in growing conditions are expected to result in increased weed and pest infestation. The intensity and frequency of droughts are predicted to increase in rice growing areas, and drought could extend further into irrigated areas and thereby reduce yields.

3. Fisheries

Guyana has a coastline of 432 km. and a continental shelf area of 48,665 sq. km. The average width of the continental shelf is 112.6 km. The area of the Exclusive Economic Zone (EEZ) is 138,240 sq. km. Most Guyana marine fishing occurs in the relatively shallow waters of the continental shelf. The marine resources exploited within the EEZ are mainly the demersal fisheries resources and, to a more limited extent, the pelagic fish resources which are to be found both on the continental shelf and towards the continental slope. Some of the demersal species, particularly prawns and shark, are showing clear signs that they are being exploited at unsustainable rates. In contrast, some deep slope demersal and pelagic species are underexploited, in spite of their greater potential.

The fisheries sector has contributed an annual average of about 8% of the country's agricultural sector GDP since 2000. The export earnings from fisheries in Guyana, which were US$ 51 million in 2000, rose to US$ 64.6 million by 2006, but have declined since (see table 5). The fishing industry employs about 5,000 people in harvesting and 6,000 in processing. Additionally, employment is created indirectly through linkages to fishing-related occupations such as boat-building and boat maintenance.

Table 5: Fisheries: Selected statistics (2000-2009

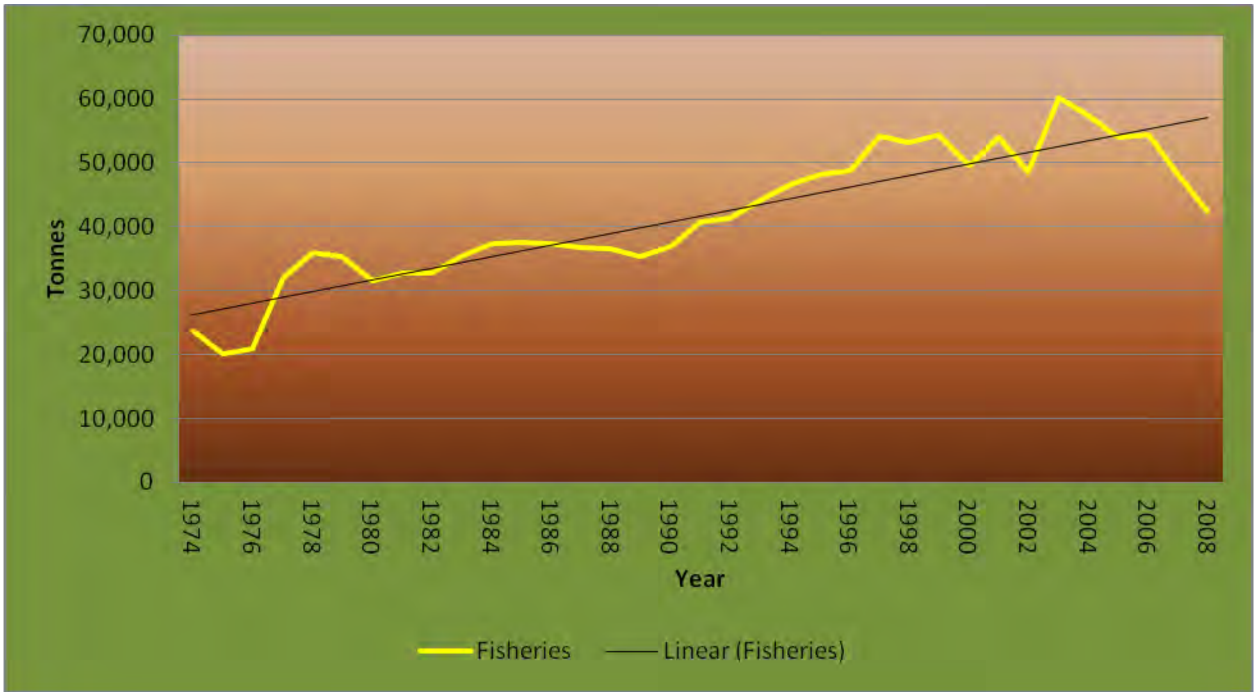
Year	Output (tonne)	Change (%)	Export value (US$ million)	% of agricultural GDP
2000	48 887	-10.2	51.03	9.25
2001	53 405	9.2	60.68	8.97
2002	48 017	-10.1	54.02	8.15
2003	59 695	24.3	36.28	8.30
2004	56 719	-5.0	42.11	7.94
2005	53 370	-5.9	60.98	9.44
2006	53 763	0.7	64.64	8.59
2007	47 448	-11.7	59.9	8.80
2008	42 168	-11.1	60	9.17
2009	41 200	-2.3	45.5	7.96

Sources: FAOSTAT, Bank of Guyana, Guyana Bureau of Statistics

Note: Fisheries output is an accumulation of the output of fish, small shrimp and prawns.

The fisheries sector is an important contributor to the country's economy and has, since 2000, alternated with rice as the second most important contributor to agricultural sector GDP. Total fisheries output has showed an increasing trend since 1974 (see figure 9). Fisheries are important in a number of areas of economic and social life in Guyana. Fish is the major source of animal protein in Guyana; estimated annual per capita consumption of fish has been rising steadily since 1980, and is above average world levels.

Figure 9: Guyana: Total fisheries capture: 1974-2008 (tonnes).



Source: FAO, FAOSTAT 2010.

In Guyana, the fisheries subsector comprises three activities: marine fisheries, inland fisheries, and aquaculture. Industrial fishing dominates the export market, which is mainly based on shrimp, while artisanal and inland fisheries produce for the domestic market. The industrial fisheries consist of about 120 trawlers, a few fish/shrimp processing plants, and some wharves and dry docking facilities. There are also a number of ice and freezing facilities which service these fisheries activities.

Small-scale or artisanal fisheries are not only an important source of food, in both rural and urban areas, but have become an important source of employment, income and foreign-exchange earnings. This aspect of fisheries has recently experienced declining levels of output, due in part to a reduction in the volume of fisheries activity resources available.

Inland fishing is conducted mainly in rivers, creeks, lakes, reservoirs, canals, and in the savannah areas where the seasonal increases in rainfall produce large expanses of seasonally-flooded lands. This type of fishing occurs during the "down time" seasonal periods, when agricultural production activities are reduced, so that, in sugar and rice areas, fishing varies inversely with harvesting of these crops. The limited data available indicate that most inland fishing is carried out by Amerindians, although non-Amerindians fish in inland waters near the coast and in the vicinity of logging and mining communities situated in the country's interior region. Although activities in aquaculture began in Guyana in the 1950s, the development of the industry has been slow (CCCCC, 2009a). Aquaculture has been constrained by the unavailability of finance, limited technical skills and technology, and little research and development. Aquaculture has been identified by the Government as an important activity which is supported by number of incentives.

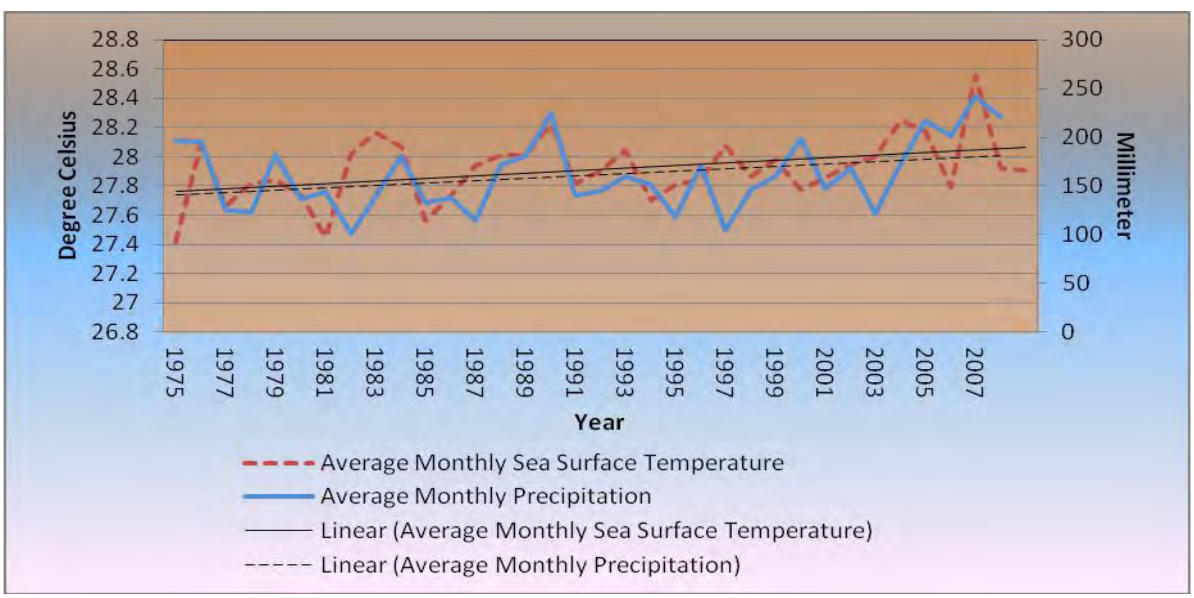
Average monthly temperature and precipitation data (1975-2007) for the marine fishing regions are provided in figure 10. Both of these variables show upward trends over the period. There has been no specific study on the effects of climate change on the fisheries sector in Guyana. In general, the experience of Caribbean countries (Mahon, 1990 and 2002) suggests that the following impacts relate to Guyana:

- Changes in fisheries abundance, fisheries areas and species mix
- Increased levels of vulnerability of the subsistence/small scale fishing community resulting from fewer available options for economic survival
- Destruction of/damage to critical fisheries habitats (mangroves, seagrass beds) and fisheries infrastructure such as landing sites
- Reduced fish production impacting fish/food supplies
- Damage to fishing gear/vessels.

It is projected that, although some local fish stocks are still healthy, others have been impacted negatively. It is likely that climate change will make it difficult to rehabilitate unhealthy stocks, and create difficulties in preserving healthy stocks.

Given the increased number of intense events, those involved in the fishing industry are likely to experience increased risks in terms of loss of lives, households and assets, such as boats, gear, ponds and other fishing infrastructure. In addition, they will face constraints related to the availability, stability, access and utilization of outdated sources of fishing. On the consumer side, the relatively cheap, high-quality protein source that is an important aspect of the nutritional content will become more expensive, and thus relatively inaccessible, especially to lower-income groups. As a result of the decline in fisheries stocks, it is anticipated that unemployment will increase and there will be a concomitant decline in foreign exchange earnings accruing to the subsector.

Figure 10: Guyana: Average monthly temperature (° C) and precipitation(mm) for marine fishing regions (1975-2007)



Source: FAO, FAOSTAT 2010.

4. Forestry

In Guyana, forests occupy approximately 80% of the country's land mass, constituting an area as large as Britain. These forested areas are habitat to a wide range of animal and plant species, some yet to be identified and documented. Additionally, the forests provide soil erosion protection, purify water supplies and ensure environmental stability. The forest resources provide for commercial exploitation of wood and related by-products (Office of President, Republic of Guyana, 2010).

The Low Carbon Development Strategy (LCDS) focuses on the pristine forests of Guyana which are the country's most valuable natural assets. The total forest area covers approximately 16 million hectares. The standing forest can provide substantial volumes of timber and can be used for post-harvest agriculture. In addition, there are known mineral deposits below its surface. Altogether the estimated economic value of the State Forest Estate (Economic Value to the Nation or EVN) is estimated at an annual annuity payment of US$ 580 million (Office of President, Republic of Guyana, 2010). It is argued that these funds could provide for the development of economic infrastructure and social services for the Guyanese population.

However, if Guyana were to extract this value from the forests, there would be negative effects world-wide. Any such deforestation is likely to have very serious negative consequences internationally for biodiversity, water regulation and carbon sequestration. Data presented in the Guyana LCDS (Office of the President, Republic of Guyana, 2010) indicate that a conservative estimate of the Economic Value to the World (EVW) which the Guyana forest can provide, once deforestation does not occur, is US$ 40 billion annually.

The Low Carbon Development Strategy (LCDS) is expected to align with the Reduced Emissions from Deforestation and Degradation (REDD+) mechanism under the United Nations Framework Convention on Climate Change (UNFCCC) which would enable Guyana to help decide whether the choice to place the forest under long-term protection is the best route to facilitate both the climate and socio-economic goals that it has established.

Source: (Office of the President, Republic of Guyana, 2010)

Between 1990 and 2000, forestry contributed an annual average of 6% to Guyana GDP. Although showing a declining output trend, forestry averages just over 10% of agricultural sector GDP (see table 6). The forestry sector accounts for approximately between US$ 44 million and US$ 60 million in export earnings, but has been declining since 2006. About 20,000 persons are employed in forestry and related activities. In 2010, there were 31 large concessions and 348 small concessions granted to private entrepreneurs, operating in the sector. The Guyana Forestry Commission – a Government agency – regulates the activities of forest concessions to ensure that strict, sustainable forest management rules and guidelines are implemented and that forest legislation is implemented effectively. As part of their concessionary provisions and related conditionalities, logging companies are required to implement comprehensive forest management practices and undertake annual planning exercises to manage and preserve the sustainability of the forest inventories.

Table 6: Guyana: Forestry: Selected statistics (2000 – 2009)

Year	Output (cubic metres)	Change (%)	Export value (US$ million)	% of agric GDP
2000	418 948	-15.9	43.81	10.66
2001	438 410	4.65	36.64	10.60
2002	403 337	-8.00	34.74	9.23
2003	410 194	1.70	29.91	9.55
2004	437 348	6.62	44.98	9.31
2005	323 911	-25.94	49.58	11.66
2006	393 968	21.63	70.25	13.04
2007	330 374	-16.14	55.30	11.54
2008	275 320	-16.66	52.84	10.39
2009	266 198	-3.31	40.51	10.05

Sources: Guyana Forestry Commission, Earthtrend, Bank of Guyana, Guyana Bureau of Statistics

As part of its LCDS, Guyana has plans to combat climate change via reduced deforestation and a Reduced Emissions from Deforestation and Degradation (REDD+) mechanism. This REDD+ policy will ensure that the Guyana forests are protected over the long term, with a voluntary limit of deforestation and related forest-based greenhouse gas emissions. In 2010, Guyana was expected to receive between US$ 30 million and US$ 42 million in payment for forest climate service, and between US$ 30 million and US$ 64 million in 2011. These funds will be invested in priority development areas that are identified by Government.

BENEFITS TO GUYANA UNDER THE REDUCED EMISSIONS FROM DEFORESTATION AND DEGRADATION (REDD+) MECHANISM

I. Guyana can avoid cumulative forest-based emissions of 1.5 gigagtonnes of CO_2(carbon dioxide equivalent which includes other greenhouse gases) by 2020 that would have been produced by an otherwise economically rational development path.

II. REDD+ payments can enable the Guyana economy to be realigned onto a low-carbon development trajectory. To achieve this, Guyana must:

a. Invest in strategic low carbon economic infrastructure, such as: a hydroelectricity plant at Amaila Falls; improved access to arable, non-forested land; and improved fibre optic bandwidth

b. Nurture investment in high-potential low-carbon sectors, such as fruits and vegetables, aquaculture, business process outsourcing and ecotourism.

c. Reform existing forest-dependent sectors, including forestry and mining

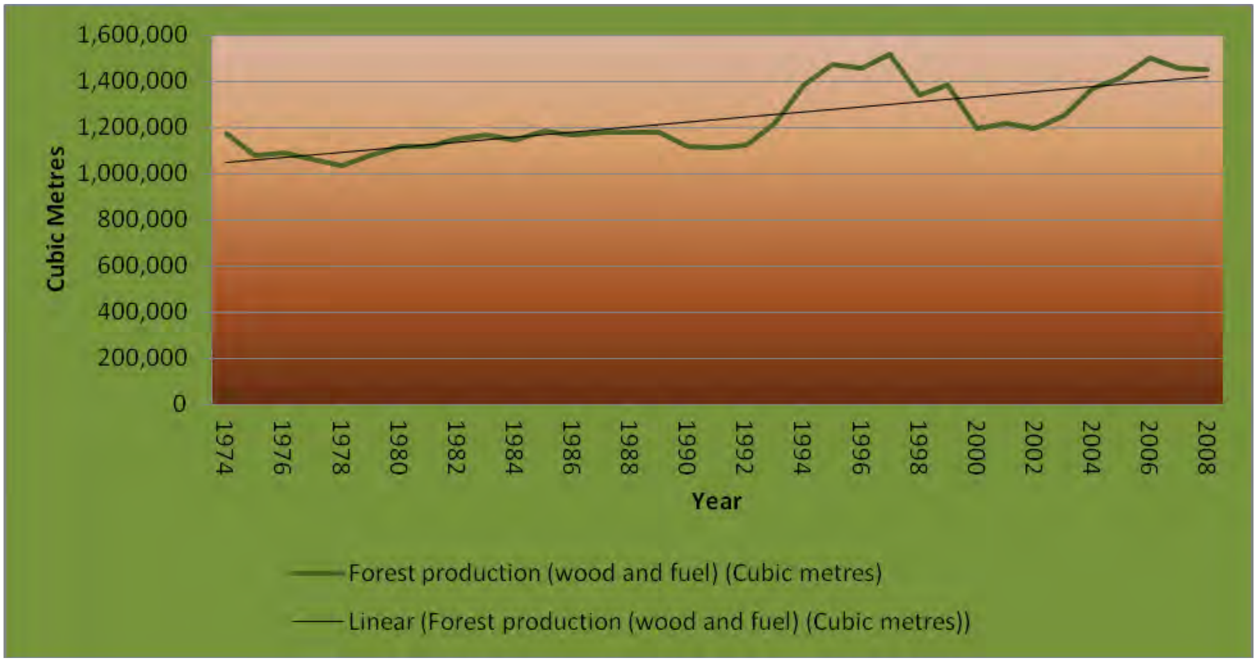
d. Expand access to services, and create new economic opportunities for Amerindian communities

e. Improve services to the broader Guyana citizenry

III. Invest in the people of Guyana and productive patterns. Investments in priority climate adaptation infrastructure can reduce the 10% of current GDP which is estimated to be lost each year as a result of flooding.

Source: Office of the President, Republic of Guyana, 2010

Figure 11: Guyana forest production 1974-2008



Source: FAO, FAOSTAT 2010.

Recognizing the devastating impact that unchecked climate change can have on the Guyanese population and economy as well as the global destitution that it is likely to cause, and recognizing the tangible and intangible benefits of the Guyanese rainforest to the moderation of global climate, biodiversity, regulation of water flows and carbon sequestration, the Government of Guyana has made substantial attempts to provide the world with alternative paths through the use of these forestry assets. The absence of a market for these services provided the motivation for the country to develop the LCDS and to attempt to create these markets within the context of economically rational development and investment.

The Strategy includes two proposals which, if implemented, provide a workable example of the requirements to transform an economy into one that is characterized as low carbon, low deforestation and climate resilient. The proposals were: (i) placement of the entire forest under long-term protection subject to the right economic incentives; and (ii) use of the payments received for the forests' climate services to reorient the economy to a low-carbon and environmentally-sound trajectory. This strategy was developed through comprehensive consultations and discussions with the country's population (Office of the President, Republic of Guyana, 2010).

5. Livestock and non-traditional agriculture

Although not included in the commodities for detailed analysis in the current project, livestock and other crops are identified as potentially important subsectors of agriculture. Given the ongoing nature of research related to the impact of climate change on agriculture, analyses of the related effects on these crops will need to be prioritized once data are available.

Guyana's livestock agricultural subsector includes the rearing of poultry, cattle, pigs, sheep and goats and has been identified as a dynamic source of domestic food supply with potential for large scale export earnings (Ministry of Agriculture; Government of Guyana, 2011).

The country is almost self-sufficient in poultry, meat and eggs. There are about 3,000 enterprises including 50 commercial farms, 3,000 small farmers and 4 stockfeed plants. Poultry production employs about 5,000 persons directly. There are possible challenges facing the subsector as it experiences competition from low-priced North American imports.

Although livestock production is focused on meeting domestic market needs, there is significant potential for export, as Guyana has a comparative advantage in beef production, given its large land- and water resources which are important inputs in cattle rearing. Although beef is not currently exported from Guyana, a Livestock Development Programme has been implemented since 2006, geared towards enhancing livestock production to meet local demand and export possibilities.

Non-traditional agriculture includes all subsectors of agricultural production except sugar, rice, forestry and fishing. These commodities are categorized as follows:

- Cereals and legumes: corn, black-eyed peas
- Oilseeds: peanut, coconut
- Root crops: cassava, sweet potato, eddoe, yam, Tania/dasheen, plantain
- Vegetables: tomatoes, cabbage, pumpkin, bora, okra, squash, cucumber, eggplant
- Herbs, spices and seasonings: eschallot, hot pepper, ginger, turmeric
- Fruit: banana, pineapple, pear, carambola, and watermelon
- Other fruit: mango, cherry, awara, genip
- Citrus: lime, orange, grapefruit
- Other crops: coffee, cocoa, cotton, ornamentals, floriculture and pasture/forage.

Most of the producers in the non-traditional agricultural subsector are small, poor farmers and households engaged predominately in subsistence activities. The subsector has increased its output substantially in recent years, both as a result of the 'Grow More Food' Government policy and of the considerable support from the New Guyana Marketing Corporation. Both domestic output levels and exports have increased since 2007. This subsector has been identified as a critical part of the National Food and Nutrition Security Strategy for Guyana:

> "To enhance the production and availability of quality non-traditional agricultural commodities for domestic consumption and export markets." (Ministry of Agriculture, 2011, pp. 9)

V. QUANTIFYING AND PROJECTING CLIMATE CHANGE IMPACTS

A. ECONOMETRIC MODEL AND DATA

The present study uses an augmented production function as the general framework to model the effects of climate change on agricultural output. The selection of this approach was based primarily on issues related to data availability: more specifically, data were only available on an aggregate basis for the selected subsectors. Consistent time series of climate data (temperature and precipitation) were not available for the relevant commodity-producing regions in Guyana. The available data did not allow other competing models to be utilized.

In an attempt to identify the effect of climate change, the analysis controls for price effects and typical agricultural inputs such as area harvested, labour, machinery, fertilizer and pesticides, where applicable. Intuitively, a long-run equilibrium relationship is expected between agricultural production, on one hand, and their related agricultural inputs, price and climate factors, on the other. The long-run models for sugarcane, rice and fisheries are considered separately below in Equations (1) to (3), since the conditions underlying their production are somewhat different. The data characteristics and source for each variable identified in the equations are presented in tables 7 and 8.

<u>*Sugarcane production* (S_t)</u>:

$$\begin{aligned}\ln S_t = \alpha_1 + \alpha_2 \ln A_{St} + \alpha_3 \ln L_t + \alpha_4 \ln L_t^2 + \alpha_5 \ln Fert_t + \alpha_6 Pest_{t-1} \\ + \alpha_7 Temp_{Nt} + \alpha_8 Temp_{Nt}^2 + \alpha_9 Rain_{Bt} + \alpha_{10} Rain_{Bt}^2 + \alpha_{11} D_t + v_t\end{aligned} \qquad (1)$$

<u>*Rice production* (R_t)</u>:

$$\begin{aligned}\ln R_t = \alpha_1 + \alpha_2 \ln A_{Rt} + \alpha_3 \ln(M \mid L)_t + \alpha_4 \ln Fert_t + \alpha_5 Pest_{t-1} \\ + \alpha_6 Temp_{Gt} + \alpha_7 Temp_{Gt}^2 + \alpha_8 Rain_{Mt} + \alpha_9 Rain_{Mt}^2 + \alpha_{10} D_t + v_t\end{aligned} \qquad (2)$$

<u>*Fisheries production* (F_t)</u>:

$$\ln F_t = \alpha_1 + \alpha_2 t + \alpha_3 \ln P_t + \alpha_4 SST_t + \alpha_5 Rain_{Ct} + v_t \qquad (3)$$

where α_j represents long-run elasticities (for natural logarithmic variables) and semi-elasticities (otherwise) and

lnA_t	= Logarithm of land area harvested
lnL_t	= Logarithm of agricultural labour, which can be expressed as a quadratic
$ln(M\|L)_t$	= Logarithm of machinery to labour ratio
$lnFert_t$	= Logarithm of fertilizer consumption
$Pest_{t-1}$	= Logarithm of imported cost of pesticides last period
lnP_t	= Logarithm of average export price of fish and its by-products
$Temp_t$	= Air temperature, which can be expressed as a quadratic variable
$Rain_t$	= Rainfall, which can be expressed as a quadratic variable
SST_t	= Sea surface temperature

D_t = Dummy variable, where 1 captures the Guyana agricultural production crisis from 1988 to 1990, and 0 is otherwise.[4]

Table 7: Variable Description and Source

Variable	Description	Data Source
R_t	Paddy rice production (tonnes)	Food & Agriculture Organization
S_t	Sugarcane production (tonnes)	Food & Agriculture Organization
F_t	Marine fisheries production (Aquaculture & Capture) (tonnes)	Food & Agriculture Organization and Earth Trends
A_{Rt}	Rice area harvested (hectares)	Food & Agriculture Organization
A_{St}	Sugarcane area harvested (hectares)	Food & Agriculture Organization
L_t	Number of economically active persons engaged in agriculture, hunting, forestry or fishing.	Food & Agriculture Organization
M_t	Agricultural machinery, tractor (number per 100 sq. metre of arable land)	World Bank (2010)
$Fert_t$	Fertilizer consumption (kg per hectare of arable land)	World Bank (2010)
$Pest_t$	Pesticides (imported value US$ '000)	Food & Agriculture Organization
P_t	Average export value (export value: US$million/export volume: tonnes) (US$/kg)	Food & Agriculture Organization
$Temp_{Gt}$	Georgetown average temperature (degrees Celsius)	Ministry of Agriculture, Guyana
$Temp_{Nt}$	New Amsterdam average temperature (degrees Celsius)	Ministry of Agriculture, Guyana
SST_t	Cell 37 Sea surface temperature (degrees Celsius)	Sheppard & Rioja-Nieto (2005)
$Rain_{Mt}$	MMA annual rainfall (metres)	Ministry of Agriculture, Guyana
$Rain_{Bt}$	Berbice (Blairmont, Rose Hall, Albion and Skeldon) average annual rainfall (metres)	Ministry of Agriculture, Guyana
$Rain_{Ct}$	Coastal (Georgetown, New Amsterdam, Skeldon) average annual rainfall (metres)	Ministry of Agriculture, Guyana

Source: Data compiled by author

[4] http://www.guyana.org/features/postindependence/chapter18.html

Table 8: Data characteristics (1974 – 2008)

Variables	Descriptive Statistics					PP
	Mean	Median	Maximum	Minimum	Std. Dev.	
R_t	363 502.40	305 000.00	568 188.00	155 740.00	124 890.80	I(1)
S_t	3 324 697.00	3 213 380.00	4 285 700.00	2 541 000.00	450 623.70	I(1)
F_t	41 529.50	40 271.50	59 499.00	20 123.00	9 880.37	I(1)
A_{Rt}	104 190.60	102 100.00	147 012.00	51 347.00	23 787.09	I(1)
A_{St}	46 698.80	44 494.00	67 217.00	37 000.00	6 944.99	I(0)
L_t	60	58	67	53	4.62	I(1)
$(M\|L)_t$	1.60	1.41	2.49	1.06	0.51	I(1)
$Fert_t$	296.71	309.52	450.28	123.27	71.08	I(0)
$Pest_t$	3 252.49	2 250.00	8 766.00	1 223.00	1 747.77	I(1)
P_t	2.36	1.44	5.25	0.45	1.58	I(1)
$Temp_{Gt}$	27.11	27.16	27.97	26.32	0.39	I(1)
$Temp_{Nt}$	27.19	27.20	28.10	26.40	0.40	I(1)
SST_t	27.91	27.90	28.56	27.42	0.23	I(0)
$Rain_{Mt}$	1.88	1.89	2.63	1.17	0.39	I(0)
$Rain_{Bt}$	1.82	1.75	2.44	1.43	0.29	I(0)
$Rain_{Ct}$	2.43	2.33	3.25	1.91	0.38	I(0)

Source: Data compiled by author

Note: PP indicates Phillip-Perron Unit Root Test with only a constant in the auxiliary regression.

Based on the specifications for rice, sugarcane and fisheries, several points are worth noting, as follows:

- Firstly, the analysis does not make the restrictive assumption that the explanatory variables only influence yield (Y|A). As such α_2 and β_2 are not restricted to 1, but are allowed to be determined by the data. In fact, it is expected that changes in land area harvested can proxy changes in Government policies and institutional arrangements that have improved or hampered competitiveness within the rice and sugar sectors.[5]
- Secondly, a one-year lag of the imported value of pesticides is used in specifications (1) and (2). The imported cost of pesticides is used rather than the amount consumed, due to data unavailability. However, due to the exogenous nature of imported pesticides, the decision as to the amount of imported pesticides to use in production this period is assumed to have been made in advance to allow for time for supply decisions to be implemented (the so-called cobweb phenomenon). As such, the quantity of pesticides expected to be consumed this period would be based on last period's import cost.

[5] For instance, in the late 1980s, the Government abandoned a pricing policy for rice that was thought to be seriously distorting the incentives to rice farmers and instituted a free market. See Volume 4: *Productive Sectors of the National Development Strategy* (April, 1996) at http://www.guyana.org/NDS/NDS.htm

- Thirdly, specifications for sugarcane and rice are different in two important respects. The machinery to labour ratio (M|L) is used in the rice production model to capture the simultaneous increasing mechanization (in particular, wheeled tractors) and the consistent decline in the total number of farmers engaged in rice cultivation. Currently, rice farming in Guyana is a fairly mechanized practice and employs about 8,000 rice farmers in comparison to 12,600 in 1978 (World Bank, 2010). Increases in the ratio are therefore an indication of innovation or transition with the subsector to becoming more capital intensive. In fact, the M|L ratio has increased from 1.0 in 1980 to 2.5 in 2007. The machinery to labour ratio could not be used for the sugarcane production function, as the machinery data available are based on wheel and crawler tractors, whereas sugarcane cultivation relies mainly on mechanical harvesters. However, since sugarcane production is relatively labour-intensive for harvesting purposes, the sugarcane production function employs agricultural labour with a quadratic structure. This agricultural labour variable is used to proxy labour employed in sugarcane production. This proxy is reasonable since the sugar industry is the largest employer in Guyana and employs about 19,000 workers (7% of the country's labour force).[6]

The second difference is based on fact that sugarcane and rice production depend on different climatic regions in Guyana. Rainfall effects ($Rain_{Mt}$) are considered for the Mahaica-Mahaicony-Abary (MMA) Scheme, the largest rice producing site, representing just under 40% of total paddy rice growing area and production in 2008. Further, the MMA and Frontsland and Black Bush Polder areas contribute to the majority of the total variation in rice production (World Bank, 2010).[7] Temperature data were sparse for the MMA region; therefore, given its proximity to said region, Georgetown temperature ($Temp_{Gt}$) was used as proxy. In terms of sugarcane production, GUYSUCO owns two groups of four sugar estates in the country: Berbice and Demerara. The Berbice sugar estates are Albion, Blairmont, Rose Hall and Skeldon. The Berbice sugar estates are the larger and generate the larger proportion of GUYSUCO sugar production (58% in 2008 and 64% in 2009)[8] since they have higher productivity, lower production costs and different agro-climatic conditions relative to the Demerara estates.[9]

Based on the Guyana National Development Strategy 2000-2010 (Government of Guyana, 2000), the Berbice estates were the focus of the planned sugar expansion programme. Therefore, it is important to consider the prospects for sugarcane under climate change based on the Berbice estates. The average rainfall corresponding to each Region of the Berbice estates ($Rain_{Bt}$) is used to represent rainfall in the Berbice region. There was a paucity of temperature data directly for the areas of the Berbice estates. However, given that Albion, Blairmont and Rose Hall are in the vicinity of New Amsterdam, temperature data for New Amsterdam ($Temp_{Nt}$) were used as proxy for the Berbice region. Note that the temperature and rainfall variables in specifications (1) and (2) are structured to have an inverted U-shape (quadratic) relationship with crop output.

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[6] Development Policy and Management Consultants (February, 2009) and Embassy of the United States of America, Guyana (2009).

[7] The Frontsland and BlackBush Polder areas are not used in the analysis since rainfall data are not available.

[8] GUYSUCO *Annual Report* 2009

[9] http://www.sdnp.org.gy/nds/chapter9.html

Finally, the fish production function in (3) differs from that of rice and sugarcane in all respects. A measure of fishing effort such as labour would have been a useful addition to equation (3). In this regard, the agricultural labour variable was not useful, since it may have been too aggregated. Based on the 2002 Guyana Census, only about 10% of the persons economically active in agriculture (including hunting, forestry and fishing) are employed in fisheries (Private Sector Commission, 2007). However, a time-trend variable is included to capture broad deterministic movements in fish output that may be due to unobserved factors such as labour productivity, technical change, and investment. In fact, strong growth in the fisheries sector in the 1990s over the 1980s is credited to new market entrants and expansion of three processing companies within the sector (Ministry of Public Works and Communications [MPWC], 2005). Since two thirds of fisheries output is exported (mainly to the United States of America), an export price variable is included in equation (3). Export prices for rice and sugarcane are not considered, because prices are distorted by preferential agreements and fixed quota arrangements are established. The industrial-scale fisheries are based in the Demerara River close to port Georgetown (MPWC, 2005), and artisanal fisheries are scattered all along the coast; therefore, since Georgetown, New Amsterdam and Skeldon are three main geographical and fisheries points covering the stretch of the coastline, their average rainfall ($Rain_{Ct}$) effect on fisheries production is considered.

B. A PRIORI EXPECTATION OF CLIMATE CHANGE EFFECTS

Generally, terrestrial plants such as rice and sugarcane are adversely affected by high temperatures and flooding/drought. High temperature increases heat stress, as well as the transpiration and evaporation rates in crops, and results in a high incidence of pests and diseases. Excessive rainfall or prolonged drought stunts the growth and development of plants by clogging the soil, thereby reducing the uptake of moisture and nutrients.

A GUYSUCO (2009) survey of farmers at Mahaica-Mahaicony-Abary (MMA) and Wales rice and sugar estates, respectively, reported that 90% of farmers incurred total losses due to flood or drought conditions. A majority of 66% of rice farmers were affected by high temperatures, whilst only 12% of sugarcane farmers attributed their low yields to high temperature. Based on these findings, it can be safely assumed that rice production is expected to be lowered by both flooding and high temperature; flooding is likely to be the more important climate event that impacts sugarcane. The implication is that an inverted U-shape (quadratic) relationship is expected between these climate variables and crop output. This is in accordance with the expectation of the existence of an optimal point for rainfall and temperature effects on crops.

In terms of aquatic life, greater rainfall intensity (or storms) leads to increased risk of flooding and chemical runoffs, which can cause damage to onshore infrastructural facilities and productive assets (e.g. gear, equipment, vessels, wharves, fishing communities, etc.) and fishing (spawning) grounds. Furthermore, increased rainfall can cause more opportunity days at sea to be lost, and increase the risk of accident. Increased sea surface temperature is expected to have adverse effects on aquatic ecosystems (e.g. changes in plankton composition leading to predator/prey mismatch, increased fish metabolic rates leading to increased risk of uptake of aquatic pollutants), which would affect both the distribution and availability of fish stocks.

C. ECONOMETRIC METHODOLOGY

It is necessary to establish that there exists a long-run equilibrium relationship among the variables in equations (1) - (3). In this regard, the study employs the Autoregressive Distributed Lag (ARDL) Bounds test (Pesaran and others, 1995, 1996, and 2001) for cointegration. It should be noted that the Bounds test is useful in three respects: (1) the procedure is applicable to a mixture of I(0) and I(1) stationary variables (Pesaran and others, 2001); (2) it can identify long-run relationships relatively more efficiently in small samples ranging from 30 to 80 observations (Nayaran, 2004)[10]; and (3) the procedure allows for the inclusion of dummy variables in the cointegrated relationship (Habibi & Rahim, 2009; Frimpong & Oteng-Abayie, 2006; Keong and others, 2005). Essentially, the Bounds testing employs a Wald or F-test of significance of the lagged levels of the variables in equations (1) - (3), both of which are reformulated in a conditional error correction version of the ARDL model generally represented as follows:

$$\Delta \ln z_t = \pi_0 + \sum_{i=1}^{p} \pi_i \Delta \ln z_{t-i} + \sum_{i=0}^{p} \kappa_i \Delta \ln x_{t-i} + \tau_1 \ln z_{t-1} + \tau_2 \ln x_{t-1} + \psi_1 t + \psi_2 D_t + u_t \qquad (4)$$

where z_t refers to the sugarcane, rice paddy and fisheries output variables, x_t is a *k*-vector comprised of the independent variables corresponding to equations (1) - (3); D_t and t are a dummy variable and a time-trend variable, respectively; specifically, κ' and τ_2' coefficients could be considered as column vectors of the parameters and all others are non-vector coefficients.

In the present study, the Bounds procedure follows three steps:

i. Optimal lag length *p* for equation (4) must be selected to correct simultaneously for endogeneity and serial correlation. Pesaran and Shin (1999) and Narayan (2004) suggest a maximum lag order of 2 based on annual observations. Then, the Schwarz-Bayesian criterion (SBC) is used to select the optimal lag length. The Hendry (1979) general-to-specific approach is used (where non-significant differenced variables are removed) to attain a parsimonious model while ensuring that there is no presence of serial correlation.
ii. Once the lag length is confirmed, the long-run relationship in equations (1) - (3) is tested by estimating equation (4) over the baseline period 1974-2008 and then computing the F-statistic corresponding to the null hypotheses that $\tau_1 = \tau_2 = 0$. The *F*-statistic has a non-standard distribution which depends on the number of regressors (k); the sample size; whether the variables are I(0) or I(1); and whether the model includes a constant and/or a trend. The critical values based on these criteria can be found in Narayan (2004). The test has two critical values: a lower and an upper bound critical value. If the *F*-statistic is greater than the upper critical value, there is evidence of cointegration; otherwise, the test is either inconclusive or there exists no cointegration. Note that, in a cointegration process, for long-run equilibrium to be maintained (that is, for a stable system), $\tau_1 < 0$.
iii. Like Nayaran (2004) and Frimpong and Oteng-Abayie (2006), once it is determined that the variables in equation (1) to (3) are cointegrated, the following long-run conditional ARDL (p, q) is estimated using ordinary least squares (OLS) over the baseline period 1974-2008. The SBC is used to determine the orders p and q of the ARDL.

[10] Other studies have used the procedure on even less observations, such as Blin and Ouattara (2009), which used 26 observations with 6 (aside from the constant) parameters to be estimated; and Tang (2001, 2002) that used 24 and 25 annual observations, respectively.

$$\ln z_t = \delta_0 + \sum_{i=1}^{p} \delta_i \ln z_{t-i} + \sum_{i=0}^{q} \phi_i \ln x_{t-i} + \gamma_1 t + \gamma_2 D_t + u_t \qquad (5)$$

where specifically ϕ' coefficient is a column vector of long-run parameters to estimate; and the residual $\varepsilon_t \sim N(0,\Sigma)$, and Σ is a variance-covariance matrix that supports homoskedastic and serially independent error terms. The Ramsay RESET test is used to judge the appropriateness of speciation (5). In light of the limited observations available to estimate equation (5), a reduced form of this equation is considered to attain parsimony by removing insignificant non-climate variables.

D. FORECASTING METHODOLOGY

Three scenarios are employed to forecast the impact of climate change up to 2050: a business-as-usual (BAU) scenario and the A2 and B2 climate scenarios as set out by IPCC. The BAU scenario used in this study is a "no climate change" or "inaction" scenario, since it represents a continuation of the historical trends (average changes) in rice paddy, sugarcane and fisheries production that are due to historical climate. In particular, the trends (average changes) in production under the BAU scenario are computed as follows:

(a) The percentage of variation in sugarcane, rice paddy and fisheries production that is uniquely due to historical climate is determined from equation (5) based on a partial correlation statistic.

(b) The average annual change in overall production is multiplied by the percentage computed in Step (a) to determine the average annual change in production that has been due to historical climate. This single value represents the rate at which production is expected to change under the BAU scenario, for both sugarcane and rice paddy production over the forecast horizon. Of note is the distinct shift in regime since the 1988-1990 production crisis, and the more recent regime is used to form the BAU forecasts. The expected changes are presented in table 9.

Table 9: BAU Scenario for production for sugarcane, rice paddy and fisheries, 2011-2050.

BAU Scenario	Sugarcane	Rice	Fisheries
Absolute changes in production (tonnes/year)	517.2	1 756.3	26.8

Source: Data compiled by author

Unlike the BAU scenario, changes in climate – rainfall and air temperature – are projected based on the IPCC A2 and B2 scenarios and then used to forecast changes in production. The future values of rainfall and air temperature under A2 and B2 were derived from the PRECIS European Centre Hamburg Model (ECHAM). In terms of sea surface temperature (SST), the median warming scenario for cell 37 SST (Sheppard & Rioja-Nieto, 2005) from 2009 to 2050 was considered. Based on the trend component of the Holt-Winter Exponential Smoothing model, the rate of increase in SST is expected to be 0.0287. Given that cell 32 SST is in the proximity of Georgetown, the scenarios for SST are assumed to follow the same pattern as that of Georgetown air temperature. The difference across the scenarios is assumed to be 0.01° C per year (see table 10).

Table 10: Scenarios for rainfall and temperature changes 2011-2050

Scenarios	△Rainfall (mm/year)			△Temperature (° C/year)		
	$Rain_{Mt}$	$Rain_{Bt}$	$Rain_{Ct}$	$Temp_{Gt}$	$Temp_{Nt}$	SST_t
A2	12.45	12.24	13.99	0.0307	0.0471	0.0387
B2	-6.03	-6.27	-7.25	0.0423	0.0499	0.0487

Source: Data compiled by author

The average absolute changes in rainfall, air temperature and SST over the period 2011 to 2050 under the A2 and B2 are shown in table 10. Rainfall is expected to increase under the A2 scenario and decline under B2. Further, temperature at Georgetown and New Amsterdam is expected to be lower under A2. It is important to note that, based on the PRECIS ECHAM model, this is not expected to be the trend in temperature under the scenarios beyond 2050. Beyond 2050, A2 temperature is expected to be significantly higher than B2 temperature.

Equation (5), and by extension Equations (1) to (3), are then used to forecast rice paddy, sugarcane and fisheries production up to the year 2050 under the A2 and B2 climate change scenarios. Note that the forecast of production is benchmarked on the assumption that all explanatory variables are held constant at the last observed value. The analysis attests to the quality of the model forecasts by testing the accuracy of out-of-sample forecasts. The procedure involves: (i) reducing the estimation sample by 5 observations; (ii) computing out-of-sample forecasts based on restricted sample; and (iii) comparing out-of-sample forecasts with the 5 observed values using the Theil inequality coefficient (Theil's U) and the Bias Proportion, where in each case a value of 0% indicates a perfect fit.

The loss/gain in production under climate change is then computed by comparing the production under the BAU scenario with the production levels under the A2 and B2 climate change scenarios. The cost of climate change is therefore defined as the value of the loss/gain in production due to climate change under A2 and B2. Values are based on the agricultural and manufacturing contributions to GDP and related linkages with the wider economy. The costs are measured in 2008 US dollars, discounted using three discount rates: 1%, 2% and 4%, and cumulated on a decadal basis. Decadal forecasts are employed in the study as a more prudent and reliable means of ascertaining the effects of climate change amidst the uncertainty in measuring these effects.

E. MODEL RESULTS

1. Bounds testing results

Firstly, given that the Bounds testing procedure is not applicable for I(2) variables, it is important to ascertain whether variables in Equations (1) to (3) are I(0) and I(1). Using the Philip-Perron unit root test, table 8 reports the results of the test. It confirms that none of the variables has I(2) properties. Secondly, Bounds test of cointegration is carried out using Equation (4) and the results of the F-test are reported in table 11. Since, for all models, the calculated F-statistic is greater than the upper bound critical value at the 5% level, the null hypothesis of no cointegration is rejected in favour of a cointegration relationship between each commodity and their respective independent variables in Equations (1) to (3). Moreover, the negative and highly significant coefficient τ_1 in Equation (4) at the 1% level is indicative of a stable model that would adjust back to long-run equilibrium in the event of short-run disturbances.

Table 11: Results of bounds test of cointegration

Model	F-statistic	SBC Lag	Features+	Bounds critical values at 5% level	
				I(0)	I(1)
Sugarcane	5.500	0	(33, 6, Case II)	2.749	4.044
Rice Paddy	8.554	1	(34, 7, Case II)	2.658	3.973
Fisheries	9.589	1	(32, 3, Case III)	3.653	4.965

+Features refer to the number of observations, number of regressors and whether intercept and/or trend is included in the model, respectively.

Source: Data compiled by author

Following step (iii) outlined in the bounds testing procedure, Equation (5) is estimated and the results of the respective ARDL representations of Equations (1) to (3), that is, R1-R3, are reported below. For all of these, econometric theory and the Schwartz Bayesian Criterion (SBC) selected an ARDL (1,0). The diagnostics for each of the equations indicate the appropriateness of the specifications and the reliability of the results.

2. Estimated long-run (ARDL) relationships for sugarcane production (St)

Based on equation (R1), the results show that sugarcane production rises by 0.3% when land area harvested (A_{St}) increases by 1%. Land is a critical input factor in sugarcane production and, as expected, it positively impacts output. Labour supply (L_t) is found to have a quadratic relationship with sugarcane production. That is, given the labour-intensive nature of the production process, labour must be increased beyond a certain point before increasing sugar output can be realized. Imported pesticides costs and fertilizer consumption were found to have no statistically significant impact on sugarcane production and were removed from the model for the sake of parsimony. It is to be noted that the production crisis dummy (D_t) effectively captures the decline in sugarcane production experienced over the period 1988 to 1990; this decline is estimated to be over 9%.

$$\begin{aligned}
&\ln \hat{S}_t = 173.506 + 0.131 \ln S_{t-1} + 0.291 \ln A_{St} - 80.268 \ln L_t + 9.844 \ln L_t^2 \\
&t = . \quad (2.413) \quad (0.882) \quad (2.500) \quad (-2.316) \quad (2.322.) \\
&\qquad - 0.050\, Temp_{Nt} + 1.521 Rain_{Bt} - 0.419 Rain_{Bt}^2 - 0.091 D_t \\
&\qquad (-1.579) \quad (2.624) \quad (-2.751) \quad (-2.070) \\
&Diagnostics: \quad Adj\,R^2 = 0.771 \quad JB = 1.993 \quad RESET\,F(1,23) = 0.147 \\
&\qquad BGSC\,F(2,22) = 1.697 \quad ARCH\,F(2,28) = 0.097
\end{aligned} \qquad \textbf{(R1)}$$

Further, Equation (R1) suggests that, historically, temperature has had no significant effect on sugarcane output. Although the impact estimate for temperature is insignificant at conventional levels, it has the expected negative sign. The coefficient indicates that, if temperature increases by 1° C, sugarcane production will decline by 5%. This is in accord with the pilot study on the Wales sugar estate, in which it was reported that only 12% of sugarcane farmers surveyed attributed their low yields to high temperature; but these farmers reported that flooding is likely to be the more important climate event that impacts sugarcane production

(GUYSUCO, 2009). Based on rainfall data from the Berbice sugar estates, the results show that, when rainfall exceeds an optimum of about 1.8 metres/year at each estate (as in 1996, 2000 and 2005), sugarcane production is adversely affected. That is, if average rainfall across the four Berbice estates increases by 0.1 metres above that optimum, sugar production would fall by about 8.4%. Overall, rainfall and air temperature uniquely explain about 14% of the variations in sugarcane production.

3. Estimated long-run (ARDL) relationships for rice production (Rt)

Equation (R2) reveals that, for every 1% increase in land area harvested, rice production increases by 0.7%, which is in line with expectations. The results suggest that a 1% increase in the machinery to labour (M|L) ratio is associated with a 0.65% increase in rice production. Increases in the M|L ratio are an indication of innovation or transition to becoming more capital intensive. The M|L ratio has increased from 1.0 in 1980 to 2.5 in 2007. As such, the ratio is consistent with an increase in rice production. The results suggest that the market risk associated with an increase in the cost of imported pesticides by US$ 1 million reduces rice production by about 3%. This response of rice production must be assessed in light of the importance of pesticides to protect against the paddy bug and the red rice weed. As with sugarcane, fertilizer consumption was found not to have any statistically significant relationship with rice production. The production crisis dummy (D_t) is not in Equation (R2) because it was insignificant. The insignificance of D_t can be explained by the A_t variable already accounting for the variation since for rice production, the effect of the crisis was directly reflected in the amount of land area harvested.

$$\begin{aligned}
\ln \hat{R}_t &= -248.037 + 0.015 \ln R_{t-1} + 0.717 \ln A_{Rt} + 0.649 \ln(M \mid L)_t - 0.029 Pest_{t-1} \\
t &= . \quad (-3.552) \quad (0.015) \quad (6.719) \quad (6.013) \quad (-1.820) \\
&\quad + 18.346 Temp_{Gt} - 0.335 Temp_{Gt}^2 + 0.824 Rain_{Mt} - 0.240 Rain_{Mt}^2 \\
&\quad (3.575) \quad (-3.535) \quad (1.876) \quad (-2.096)
\end{aligned} \qquad \textbf{(R2)}$$

$$\begin{aligned}
&Diagnostics: \quad Adj\,R^2 = 0.934 \quad JB = 0.406 \quad RESET\,F(1,24) = 0.963 \\
&BGSC\,F(2,23) = 0.461 \quad ARCH\,F(2,29) = 0.371
\end{aligned}$$

The results show that there is an optimal temperature for rice of 27.4° C. It appears that temperatures higher than this optimum are detrimental to rice production. That is, every 0.1° C increase above this optimal temperature level reduces rice production by 6.7%. In addition, based on rainfall data at MMA, the optimal rainfall for rice is on average about 1.7 metres/year. The results suggest that any amount of rainfall in excess of this optimum, which would capture heavy rains or flooding events (as in 1981, 1990, 2005-2007), would have adverse effects on rice production. The study estimates that a 0.1metre increase in rainfall above 1.7 metres can reduce rice production by 4.8%. Overall, rainfall and air temperature uniquely explain about 9% of the variations in rice production.

4. Estimated long-run (ARDL) relationships for fisheries production (Ft)

The results of Equation (R3) show that there has been an upward trend (*t*) in total fish production of about 1.2% per year. Further, there appears to be moderate (0.459) persistence in the production of fish, in that the previous year's output is significantly related to current output.

$$\begin{array}{l} \ln \hat{F}_t = 5.980 + 0.459 \ln F_{t-1} + 0.012t - 0.034 \ln P_t - 0.011 SST_t \; - 0.133 Rain_{Ct} \\ t = \quad (2.307) \quad (3.580) \qquad (2.951) \quad (-1.800) \quad (-0.150) \quad (-3.592) \\ \\ Diagnostics: \quad Adj R^2 = 0.908 \quad JB = 0.912 \quad RESET F(1,25) = 2.622 \\ \qquad BGSC F(2,24) = 2.259 \quad ARCH F(2,27) = 0.924 \end{array} \qquad \textbf{(R3)}$$

It would imply that those unobserved factors that have contributed to high fish production in the past, also contribute currently to high fish production. This trend, or persistence, may be explained by the following events:

- Growth-enhancing Government policies. For example, the Government provides research and development subsidies to the fisheries industry. In addition, aquaculture projects focused on capacity-building have been developed. These policies have resulted in an increase in cultivated acreage from 10.1 hectares in 1997 to 1,619.4 hectares in 2006.[11]

- Strong growth in the fisheries sector in the 1990s over the 1980s is credited to new market entrants and the expansion of three processing companies within the sector (MPWC, 2005)

The results show that a 1% increase in the average export price of fisheries commodities is associated with a 0.03% decline in fish output. This presents some evidence that there exists a target income such that when export price increases, fishers see no need to put in as much effort into fisheries production. However, the reduction in effort appears to be quite small relative to the price increase.

Equation (R3) further indicates that an increase in average rainfall along the coast by 0.1 metres is associated with a 1.3% decline in fisheries production. This result is expected since increased rainfall reduces fishing effort and can cause damage to coastal fish-related infrastructure. As expected, an increase in sea surface

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[11] Development Policy and Management Consultants (February, 2009). National Adaptation Strategy to address climate change in the agriculture sector of Guyana: Synthesis and Assessment Report prepared for the Caribbean Community Climate Change Centre in Belize.

temperature appears to adversely impact fish production; however, it is not statistically significant. The same is true when air temperature is introduced. The magnitude of the effect is so small that a 1° C rise in SST only lowers fisheries production by 1.1%. Overall, rainfall and sea surface temperature uniquely explain about 4% of the changes in fisheries production.

It should be noted here that the forecast for each model was evaluated using the Theil Inequality Coefficient and the Bias Proportion statistic. The Theil's U and the Bias Proportion for the sugarcane, rice and fisheries model were (3.48%, 1.31%), (5.07%, 0.59%) and (3.46%, 7.63%), respectively. These statistics largely support the forecasting accuracy of the models. In particular, the Bias Proportions, being low, indicates that the mean of the out-of-sample forecast does a good job in tracking the mean of the observed values.

F. THE PROJECTED COST OF CLIMATE CHANGE ON AGRICULTURE

Given that the model provides satisfactory estimates and shows good forecasting potential, the task is now to value the losses/gains in production that are expected under future changes in climate (see table 10). The three discount rates employed in the present study allow for a range of costs to be identified. Table 12 shows the projected cost related to the sugar, rice and fisheries sectors under the A2 and B2 climate change scenarios. These costs are cumulated up to each end of decade until 2050. It is to be noted that values in parentheses represent benefits, but otherwise, values represent costs.

Table 12: Cumulative costs (2008 US$ million) of climate change by sector

Decade	Sugar		Rice		Fisheries		Cost to GDP ratio	
	A2	B2	A2	B2	A2	B2	A2	B2
				At 1% discount rate				
2020	4.63	(48.03)	130.88	(379.25)	(3.53)	0.67	0.14	(0.46)
2030	65.05	(15.82)	426.08	(295.76)	5.54	(10.98)	0.53	(0.34)
2040	156.86	57.81	881.54	(100.60)	13.75	(21.99)	1.13	(0.07)
2050	300.13	176.68	1577.10	340.17	33.74	(19.68)	2.04	0.53
				At 2% discount rate				
2020	4.47	(46.35)	124.93	(367.78)	(3.45)	0.78	0.13	(0.44)
2030	57.05	(18.69)	380.67	(296.89)	4.72	(9.45)	0.47	(0.35)
2040	130.01	39.78	740.28	(142.06)	11.15	(18.14)	0.94	(0.13)
2050	232.72	125.58	1240.11	173.30	25.59	(16.79)	1.60	0.30
				At 4% discount rate				
2020	4.17	(43.28)	114.18	(346.64)	(3.30)	0.95	0.12	(0.42)
2030	44.27	(22.78)	307.24	(295.40)	3.34	(6.95)	0.38	(0.35)
2040	90.74	14.42	533.44	(197.11)	7.33	(12.44)	0.68	(0.21)
2050	144.20	59.67	794.66	(33.74)	14.98	(12.03)	1.02	0.01

Source: Data compiled by author

Note: 2008 exchange rate of G$ 204:US$ 1was used. GDP at current factor cost was US$ 935 million in 2008

With the onset of climate change, the sugar subsector should realize early gains by 2020 under B2 varying from US$ 43 million at the 4% discount rate to US$ 48 million at the 1% discount rate. By 2050, the sugar subsector is expected to lose between US$ 144 million (4% discount rate) and US$ 300 million (1% discount rate) under A2, which is around twice the amount of losses under B2. By 2050, under A2, the rice subsector is expected to accumulate losses between US$ 794 million (4% discount rate) and US$ 1,577 million (1% discount rate). Under B2, gains are realized up to 2040. For fisheries, while losses are expected to range from US$ 15 million (4% discount rate) to US$ 34 million (1% discount rate) under A2 by 2050, under B2 gains ranging from US$ 12 million (4% discount rate) to US$ 20 million (1% discount rate) are expected to be realized by 2050. These results are mainly reflective of the expected increase or decrease of rainfall under the A2 or B2 climate scenarios, respectively. It should be noted that the gains under B2 are attenuated by the higher temperature expected under the scenario.

Results presented in Table 12 shows that the total cost due to climate change accrued over the next 40 years should be 1-2 times that of 2008 GDP under A2, whereas under B2, it should range between 1% (4% discount rate) and 53% of 2008 GDP (1% discount rate). These percentages should be considered in the context that the true reflections (in terms of both direction and difference) of climate change under A2 and B2 are more obvious beyond the year 2050.

VI. ADAPTATION ISSUES

Adaptation to climate change has been defined as a process, action or outcome in a system (household, community, group, sector, region, country) in order for the system to better cope with, manage or adjust to some changing condition, stress, hazard, risk or opportunity (Smit and Wandel, 2006). According to IPCC, adaptation involves “initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist, for example, anticipatory and reactive, private and public, and autonomous and planned.” (IPCC, 2007b). Autonomous adaptation, for example, represents the response of a farmer to changing precipitation patterns, through crop changes or using different harvest and planting/sowing dates. Planned adaptation measures indicate conscious policy options or response strategies targeted towards altering the adaptive capacity of the agricultural sector. Farm-level analyses have shown that large reductions in adverse impacts from climate change are possible when adaptation is fully implemented (Mendelsohn and Dinar, 1999).

Climate change is ongoing and will continue to impact growth and development globally, and more specifically in CARICOM countries. It must be noted that the agricultural sector adaptations represent an integral part of national adaptation strategies, which incorporate activities in all sectors of the economy and society. In agriculture, adaptations to climate change by farmers and fishers have been ongoing for many years as they seek to respond to these various changes. In the Guyana context, changes in temperature and rainfall are projected to impact agriculture and related activities. Guyanese policymakers are expected to continue their focus on adaptation to climate change through actively developing and implementing policies which respond to these expected changes.

In terms of policy responses to climate change, Guyana signed the United Nations Framework Convention on Climate Change (UNFCCC) in June 1992, which was ratified in 1994. Since 1994, Guyana has introduced and implemented a number of policy initiatives, which include:

- Guyana Climate Change Action Plan, 2001
- Initial National Communication to UNFCCC, 2002
- Guyana Climate Change Adaptation Policy and Implementation Strategy for Coastal and Low Lying areas, CPACC Project, 2002
- National Agricultural Sector Adaptation Strategy to Address Climate Change (2009 -2018), 2009
- Guyana Low Carbon Development Strategy, 2010.

According to Pulwarty and others (2010), Caribbean countries have focused on developing capacities to adapt to climate change effects since 1997 following the guidelines of the Barbados Programme of Action (BPoA). The Caribbean Community Climate Change Centre (CCCCC) has articulated various broad strategies and related programmes and projects geared towards supporting climate change adaptation in CARICOM countries. These include:

a) Education and public awareness programmes

b) Enhancing the capacity of the CCCCC to assist Caribbean Governments in managing adaptation to climate change

c) Sharing information on “successful adaptation experiences” which deal with climate change effects.

Guyana policy responses to climate change are fairly well developed and already impacting the economy and wider society. These policies are prepared and monitored by a National Climate Change Committee which includes representatives from the agricultural subsectors, the Ministry of Agriculture and other national agencies. A "Climate Smart" agricultural policy has been articulated and is already being implemented by the Government (GUYSUCO, 2009); the policy seeks to maintain a viable sector in the context of climate change impacts. It includes crop and disaster insurance, research into crop varieties and breeds better adapted to changing climatic conditions, and incentives for more efficient use of water.

In terms of legal, institutional and related arrangements, the following have already been implemented:

- **Environmental Protection Act (1998)**– Guyana was part of the Caribbean Planning for Adaptation to Climate Change (CPACC) project, which supported Caribbean countries like Guyana in conducting a socio-economic assessment of sea-level rise, in order to develop a climate change development policy for coastal and low-lying areas.
- **Sea Defence Act (1998)** – ensures that sea and river defence systems are properly constructed and maintained; protects and conserves the foreshore from the removal of sand and shells, and prohibits the cutting of trees.
- **Fisheries Advisory Committee (2002)** - established to advise the Government on climate change impacts that are affecting the fisheries subsector.
- **Drainage and Irrigation Act (2004)** –deals with mechanisms for managing and financing the drainage, irrigation and flood control systems.

In response to climate change in recent years, Guyanese sugar and rice farmers have engaged in various adaptation strategies and techniques (CCCCC, 2009b), such as:

- Cultivation of flood-tolerant, high-yielding varieties
- Experimentation with mixed farming methods
- Increasing farm size to achieve economies of scale
- Establishing cooperative farms through farm mergers
- Diversification of income-generating activities
- Rehabilitation of selected drainage and irrigation schemes
- Improvements in in-field drainage systems
- Construction of new water outlets geared towards reducing the occurrence of coastal flooding
- Upgrading and rehabilitation of coastal sea defence systems.

These strategies represent ongoing private and public sector policy responses to climate change which are already being implemented. To date, there are no published reports which evaluate these measures and assess the extent to which they have met their objectives. Such reports are necessary to determine what measures have been successful and are economically feasible and socially supported. This will require data collection on the current assessment of these policies. An important recommendation, therefore, is an assessment of the benefits and costs of those adaptation techniques that have already been implemented. In the context of climate change policy, this assessment should be prioritized.

The present study focuses on adaptation measures for sugar, rice and fisheries. In general, the proposed adaptation measures can be broadly categorized as follows:

- Crop/commodity specific measures
- Education
- Drainage and irrigation
- Investment in infrastructure, machinery and equipment.

Crop-specific measures include plant breeding and the introduction of new varieties based on research into plant adaptability. The Guyana National Agricultural Research and Extension Institute (NAREI) is actively involved in identifying and researching selected varieties of crops which are tolerant to various climatic stresses, including high temperature, intensive precipitation, flooding, drought, increases in soil and water salinity and pest/disease infestation. NAREI is also involved in assessing the usefulness of various agricultural techniques, including drip irrigation and hydroponics, as agricultural policy responses to climate change. NAREI is not involved in sugar and rice crop research and development as these activities are conducted by GUYSUCO (sugarcane) and the Guyana Rice Development Board (GRDB)(rice paddy).

Other crop-specific measures which can be implemented in Guyana by policymakers relate to research on critical pests and diseases which are likely to emerge as a result of climate change. The specific impacts of pests and diseases are difficult to project given their complex nature. The scientific literature reports that wetter seasons facilitate those pests and disease which react favourably to water, while drier conditions assist the spread of those which enjoy such conditions.

Education is an integral part of sharing knowledge on addressing climate change responses with critical stakeholders in a timely and accessible way. If there is limited awareness of climate change effects and related adaptation measures for the agricultural sector, implementation of policy responses will be severely constrained. The various institutions involved in education and building awareness will need access to up-to-date information to fully understand the implications for the agricultural sector.

Drainage and irrigation adaptation strategies are critical in responding to climate change impacts. Since coastal areas in Guyana are below the average high tide level, adaptation measures have historically been implemented to deal with the attendant problems. Such measures include natural methods as well protective concrete sea walls. Both natural and man-made methods of drainage and irrigation have managed rainfall levels and related intensity fairly adequately. More recent experience (in 2005) indicates that existing systems can no longer handle increases in rainfall levels and as such, there are more frequent occurrences of flooding and related economic losses. ECLAC (2005) estimated that the impact of the 2005 floods reduced Guyana real GDP by 2.5%, representing costs of over US$ 450 million.

Investment in infrastructure, machinery and equipment is an important element in the Guyana climate change adaptation strategy and is closely linked with drainage and irrigation measures. Adaptation strategies will need to consider road systems, storage facilities and sea/river defences. Use of machinery and equipment which can withstand climate change impacts is very important for enhanced production.

A. SUGAR

1. Crop-specific measures

GUYSUCO has been involved in developing different sugar varieties for decades, but the focus has typically been on disease-resistant cultivars, as opposed to those which tolerate climate change effects. In more recent years, GUYSUCO has been researching the use of flood resistant varieties. GUYSUCO has strengthened its links with the Central Sugar Cane Breeding Station located in Barbados with a view to further researching and developing breeding material. One variety of sugarcane, which has already been introduced in response to climate change (Sugar 93409), is generating positive results.[12]

Although some new varieties have been identified, decisions related to development and implementation of such varieties typically require between 15 to 20 years. In direct response to climate change, and based on planned utilization of new, more climate change -resistant varieties, it is recommended that replanting of new varieties be implemented as soon as feasible. The study supports plans by GUYSUCO to implement such crop-specific measures.

In the case of sugar, research is ongoing in terms of identifying different varieties of pesticide which can reduce some of the negative output effects of pests and diseases on sugarcane production. However, further research is required to evaluate these vulnerabilities that impact sugar cane production.

2. **Education programmes for farmers**

GUYSUCO has, for many years, implemented farmer education programmes targeting ongoing improvements in agronomic practices. In the context of a response to climate change impacts, these education programmes will need to be upgraded and further developed to train all farmers, including the 6,000 non-GUYSUCO farmers (or "outgrowers") as well as the wider community which is directly linked with GUYSUCO agricultural operations. Farmers and other stakeholders will need to be continuously informed about climate change risk and response strategies.

3. **Drainage and irrigation**

Adaptation to higher rainfall intensities will necessitate implementation of more efficient drainage systems, to ensure that discharge capacities are satisfactory and can handle greater volumes of water. The National Drainage and Irrigation Authority (NDIA) has explored adaptation strategies to redesign drainage systems geared toward accommodating increases in rainfall-induced water volumes.

Available data indicate that, without any sea-level rise, coastal areas are usually inundated when there are unusually high tides. Climate change projections predict sea-level rise which will significantly impact coastal areas, causing flooding and rising water table levels, and increasing the salinity of fresh water rivers and streams, which are typically brackish. Decisions will need to be taken as to policy responses targeting improved sea defences and other plans to protect coastal areas. The development of a Master Plan, for new sea defence systems and ongoing maintenance of existing systems, needs to be prioritized.

Currently, some 60% of 5,400 hectares of GUYSUCO sugarcane-growing lands are drained and irrigated using about 50 pumps.[13] Given the community-oriented implications of its operations, GUYSUCO is also involved in providing (both directly and indirectly) drainage and irrigation services for households and economic units in areas adjoining their estate operations. Expansion and upgrading of drainage and irrigation systems in the sugar producing areas should be prioritized as a critical adaptation strategy.

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[12] GUYSUCO senior management (June 2011).

[13] GUYSUCO senior management (June 2011).

4. **Infrastructure, machinery and equipment**

An impact of climate change on sugar harvesting operations is reduced productivity of the current stock of machines used for harvesting. Given their rubber-based wheels, these machines are not readily adaptable to wet conditions (25 mm of rainfall or heavier) and their use has been limiting output levels. In addition, with more rainy days over the last five years, the "opportunity days" (or dry days which are optimal for harvesting) have been reduced from 120 to 75.[14] Given this development, harvesting operations have to be completed under wet conditions resulting from increased rainfall. As a policy response to climate change, the existing stock of machines should be changed and replaced with new, specialized machines which can operate under very wet conditions. GUYSUCO is currently examining this option.

B. RICE

1. Crop-specific measures

Development of new rice varieties has been researched for many years. Recently, new rice varieties are being assessed for tolerance to increased water levels as well as saline soil and water tolerance. The rice plant breeding programme is ongoing, with specific plans to utilize more advanced varieties geared towards increasing yields from average current levels of around 4.6 tonnes per hectare to 8 tonnes per hectare over the next 5 years.[15]

The Guyana Rice Producers Association (GRPA) reports that it is working closely with the Guyana Rice Development Board (GRDB) in developing climate change resistant varieties, and various test trials are being conducted.[16] Further research will have to be implemented to identify whether there already exist commercial varieties of rice being grown internationally under climatic conditions which are similar to those projected for Guyana.

Variants of rice which can withstand delayed harvesting are to be evaluated. Typically, harvesting days range between 105 and 120 days annually. A fundamental requirement for successful harvesting is the presence of sunshine. Therefore, rainfall can delay harvesting and impact yields of the traditional rice paddy crop, using existing varieties. GRDB and GRPA are currently researching rice paddy varieties which respond to delayed harvesting time periods, while maintaining yields.

There are various ongoing experiments on the use of urea as well as other new types of fertilizers. Suppliers are requested to respond to requests for more climate-responsive fertilizers, as part of a policy thrust towards improved fertilizer inputs for rice paddy growing. Detailed research is being conducted into fertilizer and pesticide usage for rice paddy.

Reports indicate recent increases in disease manifestation impacting the autumn crop, arising from increases in relative humidity. GRDB and GRPA have developed a new strategy which is based on seed

[14] GUYSUCO senior management (June 2011).

[15]Senior management Guyana Rice Development Broad and Guyana Rice Producers Association.

[16] Senior management Guyana Rice Development Broad and Guyana Rice Producers Association

treatment, targeting more productive use of pesticides; as part of this strategy, seeds are treated with pesticides prior to sowing, with the result that reducing spraying for diseases is required.

2. Education programmes for farmers

In recent years, rice paddy producers have been exposed to more up-to-date farming practices which target the use of more productive varieties of paddy based on climate change adaptation responses. This is an integral part of upgrading the agronomic practices of these farmers. A Six-Point Programme which encompasses education and training materials has been developed and is currently being widely used.[17]

3. Drainage and irrigation

The paddy-growing subsector continues to prioritize drainage and irrigation expenditure as part of improved agronomic practices in response to climate change. Sea-defence maintenance and rehabilitation, which also involves mangrove rehabilitation, is being implemented. The subsector continues to access about 30% of Government funding allocated to drainage and irrigation annually.

4. Infrastructure, machinery and equipment

Improvements in farm-to-market roads are identified as requiring support. In addition, as indicated above, drainage and irrigation infrastructure is a priority.

Participation in the Global Initiative on Plant Breeding Capacity Build (GIPB) is critical for the agricultural sector in Guyana as a whole, and more so for the crops under consideration in the present study, as a means through which some of the existing constraints to national plant breeding can be overcome. These constraints include long-term financing, access to new technologies, especially biotechnologies, and limitations of trained personnel and institutional capabilities. Membership of GIPB will assist Guyana in areas such as:

(a) policy and strategy guidance on national plant breeding and associated biotechnology capacity building.

(b) training in plant breeding and related biotechnology capacities.

(c) access to technologies in the form of tools, methodologies, and know-how.

(d) identification and access to genetic resources from public and private sources.

(e) information sharing among GIPB partners in order to provide access to newly available information.

C. FISHERIES

Although climate change impacts on fisheries in Guyana have not been assessed, some of the key issues have been articulated (Geer, 2010). These include: implementation of policies to increase fisheries sustainability, focusing on efforts to reduce fishing effort and fleet capacity; technological innovations, such as increased

[17] Senior management Guyana Rice Development Broad and Guyana Rice Producers Association.

capture efficiency, storage, transportation and handling; implementing an ecosystem approach to fisheries; enhancing public awareness and facilitating greater fisher safety at sea.

Commodity-specific adaptation measures to mitigate the impacts of climate change on fisheries habitats include:

- Mangroves monitoring, development and research
- Develop and implement re-planting programme for mangroves
- Promote and support mangrove conservation programmes, policies and legislation
- Monitor compliance with environmental impact assessment requirements for coastal mangrove alterations (Mahon, 2002).

The following adaptation measures to deal with direct impacts of climate change on fisheries stocks are relevant for Guyana:

- Monitoring fish catch and effort data
- Establish Fisheries Reserve or expand no catch/take zone in Marine Protected Areas
- Develop Fisheries Management Plan
- Conduct research to aid and support sustainable fisheries management goals

In developing adaptation measures which respond to climate change impacts on fishing communities and shore-based facilities, the following have been identified:

- Monitoring socio-economic status of fishers in coastal communities
- Encourage involvement in non-fisheries related (tourism) economic activity
- Encourage diversification in targeted fish species
- Assess vulnerability of coastal communities to climate change impact, determine the suitability of current structure and construct new infrastructure
- Develop and implement a sustained public information programme on impacts of climate change and alternative livelihood programmes

Contextually, for these policies to be successfully implemented, there is the need to develop and implement a sustained public information programme targeting fishermen especially and the public in general. Some of these measures outlined above are currently being implemented, while others are under active consideration.

VII. COST-BENEFIT ANALYSIS

The approach used in the present study draws on that used by Witter (2011) which focuses on a comparison of costs if there is no adaptation as against the cost of adaptation. The definition of the cost if there is no adaptation is the projected value of production under BAU less the projected value of production under A2 for each year, accumulated over the forecast period. The cost of adaptation is defined as the cost of executing the adaptation strategies pertaining to each agricultural commodity, namely, sugarcane, paddy rice and fisheries. The net benefit (or avoided cost) of adaptations is the difference between the cost if there is no adaptation and the cost of adaptation.

The model assumes that, when compared to B2, A2 represents the case where there is little or no adaptation for each year, accumulated over the forecast period. It also explicitly identifies and values those adaptation strategies necessary to combat climate change in Guyana, as reported below, specifically for the three major subsectors analysed, namely: sugarcane, paddy rice and fisheries.

It is important to recognize that this approach does not incorporate a range of non-measured benefits of adaptation, such as food security and is, therefore, likely to underestimate the overall benefits. Additionally, this approach ignores adaptation strategies that may be implemented by sectors other than agriculture that are likely to have an impact on the agricultural sector; in such situations, the cost of adaptation could be understated.

A. SUGARCANE

For the purpose of estimating the cost if there is no adaptation for sugarcane, the difference is taken between the expected future values of sugarcane production under BAU and under A2. Historically, sugarcane production has been exhibiting a downward trend over the period 1974-2008. If this historical downward trend in sugarcane production continues, the cost if there is no adaptation at the 1% discount rate is US$ 300.13 million, US$ 232.72 million at 2%, and US$ 144.20 million at the 4% discount rate.

The cost of adaptation is dependent on the strategies recommended and being implemented. These strategies are valued using information from existing studies as well as from interviews[18] conducted with experts in the respective fields. The adaptation strategies valued and included in the cost-benefit analysis for sugarcane production include:[19]

- **Drainage and irrigation upgrade** – GUYSUCO has indicated that its plans to upgrade its sugarcane drainage and irrigation systems. This proposed upgrade is scheduled for completion by 2018, at an estimated cost of US$ 14 million (2008 prices). For the cost-benefit model, this cost is divided over 7 years 2012-2018, and adjusted for inflation[20] on an annual basis. The cumulative cost of the upgrade is then divided over the expected life span of the project, which is assumed to be 100 years.
- **Purchase of new machinery for planting and harvesting** – GUYSUCO has reported that new machines are necessary to enhance the company's response to the projected changing climatic conditions. Ideally, this approach will require 110 new machines which are expected to enhance GUYSUCO's ability to harvest sugarcane even under those conditions which are not typically defined as normal harvesting "opportunity days". Each machine is estimated to cost US$ 0.2 million (2008 prices). This cost-benefit model assumes that GUYSUCO will purchase 5 machines per year up to 2050. Each machine is assumed to depreciate by 10% per year. The purchase price is adjusted for inflation each year to 2050.
- **Developing and replanting climate-tolerant sugarcane varieties –** The cost of replanting is estimated at US$ 600-US$ 700 per hectare. The model assumes that with the development of climate-tolerant

[18] GUYSUCO (June 2011).

[19]Note that there are other strategies that are not included because they are either difficult to value or are not limited to the sugar cane industry (i.e. they are better implemented under a National Adaptation Strategy)

[20] Inflation is assumed to be approximately 4% per year. This is the average inflation rate in the United States of America over the period 1962-2010.

sugarcane, replanting will take place three times during the forecast period 2012-2050: in the periods 2015-2019, 2030-2034 and 2045-2049. The present cost of replanting per hectare is adjusted for inflation for the aforementioned periods.

Complementing the abovementioned strategies, the estimated accumulated cost of adaptation for the period 2012-2050 is US$ 220.63 million at a 1% discount rate, US$ 177.16 million at a 2% discount rate, and US$ 118.93 million at a 4% discount rate.

With an estimated adaptation cost of US$ 220.63 million (1% discount rate) based on the strategies put forward, if the BAU projections hold, then the net benefit of adaptation is positive under A2. The cost if there is no adaptation under A2 is US$ 300.13 million; if BAU holds, however, it would cost US$ 220.63 million to adapt, which results in a net benefit of US$ 79.5 million. Thus, the benefits of adaptation to sugar production will not be realized until about the third decade of the forecast period (2012-2050).

Table 13: Guyana: Cost-benefit analysis for the sugar industry

Decade	Cost if there is no adaptation, US$ million	Cost of adaptation	Net benefit of adaptation A2, US$ million	Benefit/Cost Ratio
		At 1% discount rate		
2020	4.63	30.14	-25.51	0.15
2030	65.05	76.57	-11.52	0.85
2040	156.86	137.61	19.25	1.14
2050	300.13	220.63	79.50	1.36
		At 2% discount rate		
2020	4.47	28.71	-24.24	0.16
2030	57.05	69.31	-12.26	0.82
2040	130.01	117.74	12.27	1.10
2050	232.72	177.16	55.56	1.31
		At 4% discount rate		
2020	4.17	26.13	-21.96	0.16
2030	44.27	57.36	-13.09	0.77
2040	90.74	88.12	2.62	1.03
2050	144.2	118.93	25.27	1.21

Source: Data compiled by author

B. Rice paddy

The cost if there is no adaptation is estimated using the same approach outlined above. The BAU projection is calculated, using the historical trend of rice paddy production. The historical data exhibit an upward trend and, therefore, rice paddy production is expected to increase over time under BAU. If this projection holds, the cost if there is no adaptation under A2 is US$ 1,577.1 million at a 1% discount rate, US$ 1,240.11 million at 2% and US$ 794.66 million at a 4% discount rate.

The recommended adaptation strategies for rice paddy production include:

- **Maintenance of drainage and irrigation systems** – This cost is estimated at around one third[21] of the annual Guyana budget for drainage and irrigation maintenance, which is approximately US$ 3 million. The figure is adjusted annually for inflation for the period 2012 to 2050.
- **Research and development** (R&D) – R&D is estimated at US$ 1 million per year. This figure is adjusted for inflation for the period 2012-2050.
- **Education and training** – This is estimated at US$ 0.5 million and adjusted for inflation for the period 2012 to 2050.

The above adaptation strategies cost approximately US$ 318.67 million using a discount rate of 1%, US$ 255.90 million at a discount rate of 2% and US$ 172.00 million at a discount rate of 4%.

Given the cost to adapt using the strategies identified, and the cost if there is no adaptation under A2, the net benefit of adaptation is positive at all three discount rates. At a discount rate of 1%, the cost if there is no adaptation is US$ 1,577.1 million and the cost of adaptation is US$ 318.67 million. The net benefit of adapting is US$ 1,258.43 million. The benefits of adaptation to rice production will be realized for the four decades of the forecast period ((2012-2050)

Table 14: Guyana: Cost-benefit analysis for the rice industry

Decade	**Cost if there is no adaptation, US$ million**	**Cost of adaptation**	**Net benefit of adaptation A2, US$ million**	**Benefit/Cost Ratio**
		At 1% discount rate		
2020	130.88	43.52	87.36	3.01
2030	426.08	108.54	317.54	3.93
2040	881.54	204.80	676.74	4.30
2050	1 577.1	326.12	1 250.98	4.84
		At 2% discount rate		
2020	124.93	41.77	83.16	2.99
2030	380.67	98.57	282.10	3.86
2040	740.28	175.11	565.17	4.23
2050	1 240.11	262.14	977.97	4.73
		At 4% discount rate		
2020	114.18	38.60	75.58	2.96
2030	307.24	82.21	225.03	3.74
2040	533.44	131.08	402.36	4.07
2050	794.66	176.40	618.26	4.50

Source: Data compiled by author

[21] Rice Development Broad and Guyana Rice Producers Association (June 2011).

C. FISHERIES

The historical trend of fish captured exhibited an upward trend, hence the BAU projections for fish captured are expected to increase over the period 2012 to 2050. Given the projections under BAU, the cost if there is no adaptation under A2 at a 1% discount rate is US$ 33.74 million, US$ 25.59 million at a 2% discount rate, and US$ 14.98 million at a 4% discount rate.

The suggested adaptation strategies for fisheries production include:

- **Mangrove development and restoration**– this is estimated to cost US$ 5.2 million over 3 years, starting in 2012. The cost to develop and restore the mangroves is divided over the 3 years and adjusted for inflation annually.
- **Public education** – this refers to informing and sensitizing the fishing community about climate change, the possible impacts on their livelihoods, as well as methods by which they could adjust their lifestyles. The estimated to cost of public education is US$ 0.5 million per year, starting in 2012 and ending in 2018. The US$ 0.5 million is adjusted for inflation annually.

The estimated cost of these fisheries adaptation strategies is US$ 13.74 million at a 1% discount rate, US$13.36 million at a 2% discount rate, and US$ 12.66 million at a 4% discount rate.

Given the cost to adapt using the above strategies, and the cost if there is no adaptation under A2, the net benefit of adaptation is positive for all three discount rates. Under A2, if the industry adapts then the net benefit of adaptation is US$ 20 million, US$ 12.24 million and US$ 2.32 million at discount rates 1%, 2% and 4%, respectively. The benefits of adaptation to the fisheries sector will not be realized until the third to fourth decade of the projected period.

Table 15: Cost-benefit analysis for fisheries

Decade	Cost if there is no adaptation, US$ million	Cost of adaptation	Net benefit of adaptation A2, US$ million	Benefit/Cost Ratio
		At 1% discount rate		
2020	-3.53	13.74	-17.27	-0.26
2030	5.54	13.74	-8.20	0.40
2040	13.75	13.74	0.01	1.00
2050	33.74	13.74	20.00	2.46
		At 2% discount rate		
2020	-3.45	13.36	-16.81	-0.26
2030	4.72	13.36	-8.64	0.35
2040	11.15	13.36	-2.21	0.83
2050	25.59	13.36	12.23	1.92
		At 4% discount rate		
2020	-3.3	12.66	-15.96	-0.26
2030	3.34	12.66	-9.32	0.26
2040	7.33	12.66	-5.33	0.58
2050	14.98	12.66	2.32	1.18

Source: Data compiled by author

D. Selected Subsectors of Agriculture

This section aggregates the information above to assess at the overall impact on the agricultural sector. Although ignoring other important subsectors such as livestock, forestry, and other crops, this section provides some general quantitative assessments of the impact climate change and related adaptation can have on the output of the agricultural sector.

If BAU projections for sugarcane, rice paddy and fisheries production hold, the cost if there is no adaptation is US$ 1,910.79 million at a 1% discount rate, US$ 1,498.42 million at a 2% discount rate, and US$ 953.84 million at a 4% discount rate.

Given the abovementioned strategies for the sugarcane, rice paddy and fisheries subsectors, the cost of adaptation amounts to US$ 560.48 million using a discount rate of 1%, US$ 452.66 million at a discount rate of 2% and US$ 307.99 million at a discount rate of 4%.

The difference between the cost if there is no adaptation and the cost of adaptation is positive overall for the agricultural sector, with benefits ranging from US$ 645.85 million (at a 4% discount rate) to US$ 1,350 million (at a 1% discount rate).

Based on the results of the present study, the agricultural sector should realize benefits from the recommended adaptation strategies. Cumulatively, the three major subsectors of the agricultural sector exhibit benefits as a result of implementation of adaptation measures (see table 16). The cost if there is no adaptation in greater than the cost of adaptation for all four decades of the projected period, resulting in benefit- cost ratios which are greater than one. This is driven mainly by the rice subsector, which is expected to benefit significantly from adaptation to climate change.

Table 16: Guyana: Cost-benefit analysis for selected agricultural subsectors

Decade	Cost if there is no adaptation, US$ million	Cost of adaptation	Net benefit of adaptation, A2, US$ million	Benefit/Cost Ratio
		At 1% discount rate		
2020	131.98	87.40	44.58	1.51
2030	496.67	198.85	297.82	2.50
2040	1 052.15	356.15	696.00	2.95
2050	1 910.97	560.48	1 350.49	3.41
		At 2% discount rate		
2020	125.95	83.84	42.11	1.50
2030	442.44	181.23	261.21	2.44
2040	881.44	306.21	575.23	2.88
2050	1 498.42	452.66	1 045.76	3.31
		At 4% discount rate		
2020	115.05	77.38	37.67	1.49
2030	354.85	152.23	202.62	2.33
2040	631.51	231.86	399.65	2.72
2050	953.84	307.99	645.85	3.10

Source: Data compiled by author

VIII. CONCLUSIONS

Unlike many developing countries, Guyana has prepared a National Adaptation Strategy (CCCCC, 2009b) development policy and plan to address the impact of climate change on agriculture. The Strategy focuses on three areas:

(a) a contextual analysis which examines climate change impacts on the agricultural sector in Guyana

(b) an assessment of the challenges posed in response to climate change

(c) identification of adaptation options and opportunities.

The Strategy identifies the risks to Guyana of following a business as usual (BAU) approach, which include:

(i) devastation of most of the country's agricultural sector which is based on the coast

(ii) destruction of almost all coastal economic activity and some hinterland activities

(iii) increased flooding and related public health impacts

(iv) increased unemployment, reduced incomes and revenue, which will constrain national development.

The fundamental objectives of the Guyana National Adaptation Strategy are:

- To enhance the capacity within the agricultural sector to adapt to climate change and position this Strategy to foster a nationally-consistent policy framework.
- To build resilience and adaptive capacity within the agricultural sector.
- To assist the Government of Guyana in providing primary producers with a policy framework that embraces research and development and promotes climate change adaptation techniques in agriculture.
- To build greater awareness about adaptive techniques.

In order to facilitate successful implementation of the Strategy, five enablers have been identified, as follows:

1. **Mainstreaming adaptation:** There is the recognition that climate change is a cross-cutting issue; as such, the strategy targets building partnerships, complementing existing programmes, and harmonizing sectoral development assistance.

2. **Research and development:** Policy decisions and actions of stakeholders are to be informed by analytical/technical assessments, given the highly complex nature of climate change.

3. **Awareness and communication**: Groups likely to be most severely impacted by climate change are the poor and vulnerable in rural, coastal and hinterland areas. Any threats that are identified must be communicated widely, along with opportunities, adaptive techniques and research findings.

4. **Policy coordination:** Successful sustainable agricultural policy development and implementation requires national policy leadership, to both monitor and coordinate the development and implementation of an adaptation policy, and to ensure that the goals of this Strategy are adhered to, the interventions and actions are implemented according to a strict timetable, the results are monitored, actions are altered in light of changing realities, and new actions are taken as necessary.

5. **Public-private partnerships**: Strategic collaboration between the private sector and the Government is crucial to identifying the most significant obstacles to competitiveness, determining what types of interventions are most likely to remove them, and engaging public and private sector stakeholders in all aspects of the implementation of activities geared towards strengthening the competitiveness of the economy.

The Strategy is guided by a number of principles which target its stated objectives. These principles indicate that the proposed strategies should: target capacity-building in critical, vulnerable areas of agriculture; develop resilience and adaptive capacity; support agricultural sector profitability and sustainability; facilitate the research and development capacity of the agricultural sector to adapt to climate change; ensure that strategic actions deal with key issues impacting the sector; policies should be coordinated and cohesive, thus increasing the possibility of beneficial outcomes through synergies and complementarities with other policy initiatives; strategies and actions should enhance communication of climate change implications for the agricultural sector.

The articulation of the Strategy covers action under most of the areas which are outlined in the present study, and includes:

- Capacity enhancement (technical and institutional)
- Infrastructure management
- Policy and legislation
- Research and development
- Awareness and communication

Capacity-enhancement targets technical, institutional and informational improvements which support the sustainability of agriculture in the context of climate change adaptation strategies. Effective adaptation strategies require timely, accurate, relevant data and information. Infrastructure management deals with critical areas like sea defence, drainage and irrigation. Policy preparations are expected to incorporate climate change implications for agriculture and necessitate review and updating of sectoral policies within the framework of the country's National Development Policy and Poverty Reduction Strategy. Laws are also to be amended, and new legislation implemented, to apply to issues related to climate change. Research and development requires addressing innovations in science and technology which are expected to facilitate sectoral resilience to climate change. Enhancing awareness and communication allows stakeholders to be informed about relevant issues related to climate change adaptation, and facilitates integration of scientific knowledge into farm management decisions.

The agricultural sector plays a critical role in the Guyanese economy and society, with major contributions to GDP, export, employment and rural development, and with substantial linkages with other sectors. The present study attempts to assess the impact of climate change on the agricultural sector, isolating temperature changes and variations in precipitation patterns as critical climate variables.

An augmented production function model is developed to project the likely impact of climate change to 2050. Three forecasting scenarios are used: a business as usual scenario and the IPCC A2 and B2 scenarios. The availability of time-series data for the subsectors of agriculture chosen for the study severely constrained detailed analysis and, therefore, one of the subsectors– forestry – had to be omitted. An important implication here is the need to ensure that data collection is prioritized to ensure improvements in coverage, quality and availability. This is even more critical as the more sophisticated economic modelling techniques become more data-intensive.

The models developed in the current study concentrated on sugarcane, rice paddy and fisheries, which represent the three leading subsectors in the agricultural sector in Guyana. The results for the sugar subsector indicate that precipitation levels, as opposed to temperature, impacting flooding were the more important climate events. Trends in both temperature and precipitation explained projected variations in rice paddy output. In the case of fisheries, increases in both average rainfall and sea surface temperatures were associated with declining output.

In estimating costs, by 2050, the sugar subsector is projected to experience losses under A2 of between US$ 144 million (at a 4% discount rate) and US$ 300 million (at a 1% discount rate); comparative statistics for rice are US$ 795 million (at a 4% discount rate) and US$ 1,577 million (at a 1% discount rate), respectively; while for fisheries, the results show that losses range from US$ 15 million (4% rate) and US$ 34 million (1% rate).

In general, under B2 scenarios, there are gains for sugar up to 2030 under all three discount rates, while rice performance is somewhat better, with gains realized under all three discount rates up to 2040. Gains are forecast for fisheries under all three rates up to 2050, following marginal losses to 2020. In terms of the benefit-cost analysis, applying selected adaptation measures, there are net benefits for all three commodities under A2 scenarios, under all three discount rates.

ANNEX

GUYANA DATA PROFILE, 1999-2009	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
POPULATION											
Population, total (mid-year) ('000)	770.6	772.2	750.1	751.2	760.8	756.34	763.8	763.9	738	763.4	762.5
Population growth (annual%)	0.5	0.5	0.1	0.2	0.27	0.24	0.15	0.06	-0.02	-0.09	-0.09
Population density (people per square km)	3.58	3.59	3.85	3.85	3.87	3.87	3.88	3.88	3.88	3.88	3.55
Life expectancy at birth (years)	65.0	66.0	63.5	63.9	64.4	64.9	65.5	66	66.6	67.7	66.8
Urban population (% of total)_	37.6	38.2	28.5	28.4	28.4	28.3	28.2	28.3	28.3	28.4	28.4
Rural population density (per sq. km of arable land)	108.0	105.0	109.93	110.31	110.72	111.11	119.78	119.73	119.62	119.41	120.87
HEALTH											
Fertility rate, total (births per woman)	2.3	2.3	2	2	2	2	2	2	2.3	2.3	2.48
Maternal mortality rate, infant (per 100,000 live births)	190	188	120	n.a.	n.a.	n.a.	190	n.a.	113	270	n.a.
Infant mortality rate (per 1,000 live births)	56	57	n.a.	n.a.	n.a.	n.a.	33	32	31	30	29
Malnutrition prevalence (% of children under 5)	12.8	13.5	11.9	n.a.	n.a.	11.4	n.a.	n.a.	10.8	10.8	n.a.
EDUCATION											
School enrollment, primary (% of net)	96.6	96.6	122.5	121	120.4	121.1	120.4	112.2	110.2	108.7	n.a.
School enrollment, secondary (% of net)	53	53	75	91	n.a.	98	n.a.	79	n.a.	75	n.a.
School enrollment, secondary (% of gross)	80.35	87.3	93.6	93	89.89	97.76	101.36	101.55	102.81	102.07	n.a.
School enrollment, primary (% of gross)	117.52	121.5	122.52	121.02	120.37	121.15	120.41	112.18	110.23	108.68	n.a.
ENVIRONMENT											
Surface area (sq. km) ('000)	215	215	214.97	214.97	214.97	214.97	214.97	214.97	214.97	214.97	214.97
Forest area (sq. km) ('000)	169	168.8	151.035	151.035	151.035	151.035	151.035	151.035	151.035	n.a.	n.a.
Annual deforestation (% of change)	0.2	0.3	0	0	0	0	0	0	0	n.a.	n.a.
Freshwater reserves per capita (cubic meters) ('000)	281.6	281.6	n.a.	317.6	n.a.	n.a.	n.a.	n.a.	315.4	315.7	n.a.
CO_2 emissions (Metric tonnes per capita)	1.2	1.2	2	2	2	1.9	2	2	2	n.a.	n.a.
Improved water source, urban (% of urban population with access)	92	92	n.a.	83	n.a.	83	96	98	n.a.	98	n.a.
Electric power consumption per capita (kwh) ('000)	443.2	476.9	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	813	n.a.	n.a.

GUYANA DATA PROFILE, 1999-2009

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
ECONOMY											
GNI Atlas method (current US$ million)	524.6	552.6	645.18	657.78	680.65	695.62	813.88	807.54	979.45	1108.98	n.a.
GNI per capita, Atlas method (current us$)	760	750	850	870	890	910	1070	1060	1280	1420	n.a.
GDP (current US$)	593.6	596.9	696.28	722.46	741.93	785.92	824.88	914.56	1075.14	1159.24	1463.79
GDP growth (annual %)	3	-0.8	2.2	1.1	-1	3.3	-2	5.1	5.4	3	3.6
Inflation	8.6	5.9	32.9	14.8	26.7	12.6	6.9	6.6	12.3	8.1	2.9
Agriculture, value added (% of GDP)	34.6	31.1	30	31	31	31	35	35	31	28	n.a.
Industry, value added (% of GDP)	30	29	28.92	28.58	27.19	26.97	23	19.7	21.71	21.7	n.a.
Services, etc., value added (% of GDP)	35.4	39.9	40.78	40.59	41.37	41.73	45.43	45.04	47.15	50.23	n.a.
Export of goods and services (% of GDP)	99	102	95	93	90	96	85	63	64	68	n.a.
Import of goods and services (% of GDP)	103.4	102.9	111	105	100	106	119	89	90	102	n.a.
Gross capital formation (% of GDP)	45.3	46.3	22	21	21	24	32	45	40	40	n.a.
Current revenue, excluding grants (% of GDP)	29.9	31.8	n.a.	n.a.	30.14	32.38	33.53	n.a.	n.a.	n.a.	n.a.
Overall budget deficit, including grants (% of GDP)	1.7	6.3	n.a.	n.a.	8.7	4.5	13.6	11.2	n.a.	n.a.	n.a.
Money and quasi money (annual %)	12.1	10.9	16.9	8.1	9.5	9.7	6	17	13	12.2	n.a.
TECHNOLOGY AND INFRASTRUCTURE											
Telephone mainlines (per 1'000 people)	64	71.7	75	76	91.4	104	110	124.4	124.8	125	n.a.
Telephone average cost of local call (US$ per three minutes)	3.5	3.7	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
TRADE AND FINANCE											
Foreign direct investment (US$ million)	48	67.1	56	43.6	26.1	30	76.8	102.4	152.4	168	144.27
Total debt service (US$ million)	70	74	45.27	64.29	57.72	47.74	34.26	32.7	27.36	26.66	n.a.
Aid per capita (current US$)	29.7	47.8	144	n.a.	n.a.	193	n.a.	n.a.	n.a.	n.a.	n.a.

Sources:

Ministry of Health, Guyana; Bureau of Statistics, Guyana; World Health Organization; International Monetary Fund; World Bank, United Nations Children’s Fund; United Nations; Children’s Rights Information Network; Bank of Guyana

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