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RESEARCH ARTICLE

ADAPTATION TO CLIMATE CHANGE IMPACTS ON THE AGRICULTURAL SECTOR OF SRI LANKA: A COMPUTABLE GENERAL EQUILIBRIUM ANALYSIS

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ABSTRACT

To date, Sri Lanka, like many other South Asian countries, has experienced an above-average level of the negative impacts of climate change. The study uses the ORANI-G-SL, a single-country, static computable general equilibrium model, to analyse the economic impacts of climate change-induced agricultural productivity changes and two possible alternative adaptation strategies. The first adaptation strategy is based on expanding agricultural land area, and the second is on increasing crop productivity by increasing investment in agricultural research and development. According to the findings, Sri Lankans will experience an increase in the consumer price index, associated with reductions in the output of most crops, leading to a decline in overall household consumption in the future, threatening national food security. Further, climate-induced agricultural productivity changes will negatively impact the overall GDP and most Sri Lankan macroeconomic variables. Both explored adaptation strategies will provide economic expansion under the impacts of climate change. However, increasing productivity will lead to greater economic gains compared with the baseline scenario, agricultural land expansion scenario, and no adaptation scenario. Thus, the findings suggest that increasing agricultural productivity by increasing investment in R&D is the most effective adaptation strategy for Sri Lanka to offset the adverse effects of climate change on the agricultural sector and food security.

Keywords: Adaptation, Agriculture, Climate Change, Computable General Equilibrium, Food Security

INTRODUCTION

Climate change is an emerging topic of research in today's world. An enormous amount of literature is available to increase our knowledge on the topic and to make us more aware of its impacts. Based on conducted experiments, it is evident that the mean earth temperature over the period 2006 – 2015 has risen by 1.58°C compared to the mean for the period 1850 – 1900 (Shukla *et al.*, 2019). Moreover, researchers are now shedding light on potential mitigating actions and adaptation strategies. Investigations into the impact of climate change on agriculture have highlighted the increasing importance of food security to feed the growing population.

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Food security is considered to be the key challenge in the struggle to feed the global population (Droogers, 2004). Scientific evidence also reveals that climate change is the most persistent and complex of several existential threats to the agricultural sector, in addition to the existing severity of challenges of global food production (Garnaut, 2013; Nelson & Shively, 2014).

A substantial volume of literature pays attention to the formidable impacts of climate change on the agricultural sector, in terms of the threat to the sustainability of many developing nations. The South Asian region is particularly vulnerable to climate change due to the high population density, levels of poverty, higher dependency on the agricultural sector, and lack of resources to support adaptation (Ahmed & Suphachalasai, 2014). The Intergovernmental Panel on Climate Change (IPCC) projects warming exceeding the global average and a consequential increase in annual monsoon rainfall for the South Asian region (Allen *et al*., 2019). These changes enhance the potential risk to the supply and production of social, economic, environmental, and physical resources on which human well-being and welfare depend (Chalise & Naranpanawa, 2016). Sri Lanka, being a small island and a developing nation in the South Asian region, is no exception.

Climate Change in Sri Lanka

Many research findings on climate change in Sri Lanka agree that the mean annual temperature is increasing. Recent reports from the Department of Meteorology Sri Lanka (2022) indicate that atmospheric temperatures have continued to rise, aligning with recent research (Perera *et al*., 2023; Wickramasinghe *et al*., 2023). Past analyses also suggest an increasing frequency and intensity of extreme weather events, such as floods and droughts (Silva *et al*., 2022; Ranasinghe & Fernando, 2023). Given these trends, the necessity for well-structured adaptation policies is even more urgent. Past mean annual temperature data (Department of Meteorology Sri Lanka, 2018)also indicate that the atmospheric temperature is gradually rising, as verified in the research literature (Chandrapala, 1996; De Costa, 2010; Domroes & Schaefer, 2000; Eriyagama, Smakhtin, Chandrapala, & Fernando, 2010; Sathischandra, Marambe, & Punyawardena, 2014). Conversely, research provides conflicting views on recent national rainfall trends. A few researchers suggest that annual rainfall in Sri Lanka demonstrates a decreasing trend (Ashfaq *et al*., 2009; Esham & Garforth, 2013; Niranjan *et al*., 2013), although the majority of recent studies claim there has been an increasing trend in annual rainfall (Cline, 2007; De Silva, Weatherhead, Knox, & Rodriguez-Diaz, 2007). From 1901 to 1930 and 1950 to 1960, the annual rainfall indicated an increasing trend. For the period 1961-1990, a declining trend was observed over most of the island, except in some isolated areas in the northwest. However, it has been observed that mean rainfall over the most recent decade (2001-2010) has increased compared to the previous decades in most parts of the island, across all three climatic zones (Nissanka, Punyawardena, Premalal, & Thattil, 2011).

Along with these recent changes in the rainfall pattern, climate extremes have become the norm rather than the exception (Panabokke & Punyawardena, 2010). No rain when necessary (drought) and more rain when unnecessary (floods) are the most prominent climate-based natural disasters observed in Sri Lanka (Esham & Garforth, 2013). High rainfall intensity in the upper catchment causes flooding of downstream river basins, and, similarly, in the lowlands when higher rainfalls lead to an inflow that exceeds the outflow (Ministry of Environment, 2011). Past data analyses show clearly that the intensity and frequency of extreme events (floods and droughts) have increased recently (Imbulana, Wijesekara, Neupane, Aheeyar, & Nanayakkara, 2006; Premalal & Punyawardena, 2013; Perera *et al*., 2023; Wickramasinghe *et al*., 2023)The significant impact of these occurrences across Sri Lanka supports the assertion that Sri Lanka is comparatively more vulnerable to climate change than the global norm.

Agricultural Sector in Sri Lanka

Historically, the Sri Lankan economy has been predominantly agricultural. The vast majority of ancient Sri Lankans were involved in paddy and other field crop production, used mainly for domestic consumption. Thus, the structure of the economy and culture was "subsistence agriculture based" and the country was labelled the "Granary of the East".

The legislation of the Western colonial powers, initially the Portuguese, then the Dutch, and finally the British, and thereafter the Sri Lankan Government between 1948 and 1977, made distinct changes to the Sri Lankan economy (Jayasinghe-Mudalige, 2010). The Colonial governors introduced plantation agricultural crops such as tea, rubber, coconut, coffee, and cashews. Today, the agricultural sector of the island is dualist, comprising plantation and nonplantation crops (Esham & Garforth, 2013). Since 1948, following independence, all Sri Lankan governments have considered agriculture the cornerstone of the economy and established national development strategies that promote the activities of these two subsectors (Jayasinghe-Mudalige, 2010).

In 1950, the highest contribution to the Gross Domestic Product (GDP) was from the agricultural sector, accounting for 45%, while industry and the service sector contributed 19% and 36% respectively (Department of Census and Statistics, 2017). In 1980, the contribution of the agricultural sector to the GDP had reduced to 28%, fractionally surpassed by the industrial sector contribution rising to 29% (Department of Census and Statistics, 2017). Most recently, the service sector contributed the highest proportion to GDP with 43% (Department of Census and Statistics, 2017). The industrial and service sectors have rapidly outgrown the food and agricultural sector, the economic contribution of which to GDP has notably declined over the past few years to a current level of 7% (Central Bank of Sri Lanka, 2020). The dominance of the industrial and service sectors over the agriculture sector defines the structural transformation of the modern Sri Lankan economy.

Changes in the availability of major food crops such as paddy for domestic consumption, domestic savings from agriculture, the economically active proportion of the population engaged in agriculture and changes in agricultural exports have all influenced the declining agricultural contribution to GDP (Bandara, Jayasinghe-Mudalige, Udugama, Attanayake, & Edirisinghe, 2014). Notwithstanding the decline of the agriculture sector's contribution to less than a tenth of GDP in national employment, it still outranks the industrial sector, accounting for about 27.1% of total employment in 2020, as it is the main source of livelihood for the rural population. This contribution, however, has also decreased over the past five years. In addition, Sri Lanka's historical agricultural trade pattern reflects a fall in its export share. In the late 1960s, agricultural commodities contributed more than 90 per cent of Sri Lanka's exports. Still, since the early 1990s, this share declined to less than 20 per cent, with industry developing into the major export sector (Bandara & Jayasuriya, 2007).

While multiple factors contribute to GDP fluctuations, climate-induced agricultural productivity reductions directly affect economic growth, as agriculture remains an essential sector, particularly for rural livelihoods (Abeysekara *et al.*, 2023). These changes in proportionate GDP sectoral contributions show the timely necessity of addressing the impacts of climate change on the agricultural sector in Sri Lanka, also signalling that agricultural sector growth is essential relative to the other sectors. Therefore, it is vital that researchers investigate the economic consequences of the impact of climate change on the agricultural sector and possible mitigation and adaptation strategies, which are the primary objectives of this paper. Modelling these climate change scenarios will provide key insights into a range of possible consequences and guide policymakers in identifying key issues and prioritising possible adaptation strategies. Hence, this paper will use a Computable General Equilibrium model (CGE) to expand the knowledge on how climate change might impact the agricultural sector and its consequences for the whole Sri Lankan economy, how the sector may be adapted, and the possible steps to be taken to mitigate these negative consequences.

As discussed above, climate change severely threatens Sri Lanka's agricultural sector, which is critical for food security and rural employment. Existing national adaptation programs, such as the National Adaptation Plan for Climate Change Impacts in Sri Lanka (NAP) and the Agriculture Sectoral Adaptation Strategy (ASAS), emphasise climate-resilient agriculture through R&D, water management, and farmer education. However, further integration of these strategies into macroeconomic policy is necessary.

While the IPCC projects rising temperatures and changing rainfall patterns, their socioeconomic implications are less explored. Climate variability could exacerbate income inequality and accelerate rural-urban migration. This study aims to assess the economywide impacts of climate change on agriculture and the effectiveness of adaptation strategies using a CGE framework.

The remainder of the paper has the following structure: The next section reviews the literature on CGE assessments of the impacts of climate change on agricultural sectors and adaptation strategies. The third section outlines the modelling framework used in our study. The fourth section describes the study's findings, and the final section describes our conclusions.

LITERATURE REVIEW

Investigating the climate change impacts on the agricultural sector and modelling its effects has become critically important due to the increasing demand by policymakers and the public for realistic projections on the possible environmental, social, and economic impacts of future climate changes. Previous assessments are rich in terms of theoretical and methodological approaches. Some studies have relied purely on biophysical approaches using process-based or empirical statistical models, some have estimated the economic effects resulting from changes in productivity using partial equilibrium (PE) models and CGE models, and others have used integrated assessment models (Feenstra, 1998; Fernández & Blanco, 2015). As this paper focuses mainly on the economic consequences of the impacts on and possible adaptation strategies for the Sri Lankan agricultural sector using a CGE model, the literature review section concentrates predominantly on the global studies which have assessed climate change impacts on the agricultural sector and similar models. Table 1 summarises the studies that have used CGE models and integrated assessments to analyse the impacts of climate change on agricultural sectors globally.

Table 1: CGE studies on climate change impacts on agricultural sector

Model	Spatial resolution	Description	Main findings	Reference
		Computable General Equilibrium models		
GTAP-W	Global	Evaluate the potential impacts of climate change and CO_2 fertilization on global agricultural production under two IPCC scenarios.	World food production, GDP, and welfare will decrease. Food prices will increase.	(Calzadilla, Rehdanz, *et al.*, 2013)
GTAP - ICES (modified model)	Global	Analyse the economy-wide impacts of climate change and its consequences on economic growth.	Reductions in land productivity severely affects poorer and agriculture-based economies. Some developed regions will experience trade benefits.	(Eboli, Parrado, & Roson, 2010)
GTAP-AEZ-GHG	Global	Evaluates the impacts of climate policies on agricultural production including livestock, food security, land use and the livelihoods of farmers globally.	Ruminant meat sector has higher greenhouse gas (GHG) emission intensities and limited mitigation possibilities. Implementing a GHG emission tax and a compensation method for tax expenses can reduce GHG emissions and improve non-ruminant sector production.	(Golub *et al.*, 2013)
CGE-multimarket model	Africa, Asia and Latin America	Compares the three continents, in terms of the impacts on macroeconomic performance, household welfare, and resource allocation among sectors.	Agricultural production will decrease. Negative impacts will be highest on the African economy due to its higher dependency on agriculture sector.	(Winters, Murgai, Sadoulet, De Janvry, & Frisvold, 1998)

Table 1 ***continued***

Model	Spatial resolution	Description	Main findings	Reference
GTAP version 6	European regions	Analyses the consequences on European arable agriculture	Most European regions will experience positive GDP and agricultural trade developments.	(Iglesias, Garrote, Quiroga, & Moneo, 2012)
GTAP	15 developing nations	Evaluates the effect of climate induced agricultural productivity changes on global commodity prices, national economic welfare, and poverty in fifteen developing nations by 2030.	Staple food prices in developing countries will increase between 10% and 60%. Higher prices of agricultural products will reduce the overall poverty of people whose livelihood depends mainly on agriculture. In contrast, wage earners and the urban poor will be highly vulnerable to increases in food prices.	(Hertel, Burke, & Lobell, 2010)
SAM-CGE	Tanzanian economy	Analyses the impact of climate change induced adjustments of the agriculture sector and its possible consequences or the Tanzanian economy.	Economic impacts will decrease due to higher factor substitutability. The agricultural sector's contribution to GDP enters a declining trend.	(Bezabih, Chambwera, & Stage, 2011)
ORANI-G model	Nepal	Assesses the economywide impacts for Nepal and evaluates the feasibility of agricultural land reallocation as an adaptation strategy.	Rural livelihoods will be affected mainly by increasing commodity prices. Food production will decline and food prices will increase. Without adaptation, GDP will decrease remarkably. Reallocating agricultural lands to climate-smart crops will reduce crop productivity losses.	(Chalise & Naranpanawa, 2016)
GTAP version 7	People’s Republic of China (PRC) .	Analyses the global climate change impacts on the agricultural sector of the PRC.	The agricultural share of GDP will decrease, with a 1.3% decline in GDP and a 1.1% loss in welfare by 2080. Lower agricultural productivity will lead to a higher dependency on international agricultural markets.	(Zhai, Lin, & Byambadorj, 2009)
Sub-regional CGE model	PRC	Analyses the impacts on interregional agricultural trade flows.	Northwest, South, Central, and Northeast regions of the PRC will experience an increase in agricultural trade outflows, while East, North, and Southwest regions of the PRC will experience reductions in agricultural trade outflows.	(Lin, Liu, Wan, Xin, & Yongsheng, 2011)

Table 1 *continued*

Integrated climate change impact assessment models				
Model	**Spatial resolution**	**Description**	**Main findings**	**Reference**
GCM,CGE and PE models	Global	Analyses the economic impacts on the agriculture sector using two GCMs to analyze changes in climate 5 GGCMs to identify bio-physical effects on crop yield and nine economic models to determine the comparative model economic impacts.	The results of the nine economic models were qualitatively similar and showed similar economic behaviour. Due to the negative impacts on agricultural production, prices increased, triggering intensive management practices and area expansion on the supply side and a reduction in consumption and shift to cheaper products on the demand side.	(Nelson *et al*., 2014)
IMPACT and GTAP-W	Global	Evaluate the impacts on sub-Saharan agriculture sectors and analyse two possible adaptation strategies: increasing irrigated land area and increasing agricultural productivity.	Food production will decrease by 1.6% without any adaptation, with higher impacts on sugarcane and wheat. The number of malnourished children will increase by 2 million. Gains in welfare are due to comparative improvements, with respect to other regions. Increased agricultural productivity proves more beneficial than doubling the irrigation capacity	(Calzadilla, Zhu, Rehdanz, Tol, & Ringler, 2013)
GCM and GTAP	Global	Investigates the global economywide impacts on agriculture.	The negative impacts of climate change will be higher on developing economies than on the developed economies.	(Bosello & Zhang, 2005)
IMPACT and CGE model (Indonesian CGE model for climate change)	Indonesia	Analyses the impact of global climate change on macro and microeconomic performance in Indonesia, with special focus on the agricultural sector.	Indonesia's GDP will decline, predominantly due to the negative performance of the agricultural sector. Commodity prices will increase due to climate change impacts. Agricultural sector labour will decline. Increasing research and development investments on the food crop sector can increase crop productivity and reduce crop losses.	(Oktaviani, Amaliah, Ringler, Rosegrant, & Sulser, 2011)
GCM models and single country dynamic CGE model	Ethiopian economy	Assesses the impact on the Ethiopian economy and evaluates suitable adaptation strategies to offset economic impacts.	GDP will decline by 10% compared to nations undergoing no climate change conditions. Proper adaptation strategies could offset the effects on the whole economy. The cost of investing in adaptation programs will be less than the welfare losses caused by climate change by 2050.	(Robinson, Willenbockel, & Strzepek, 2012)
DCGE model for Syria, IFPRI-IMPACT model, DSSAT Crop model, Palmer drought index.	Syrian economy	Assesses the impact on the Syrian agricultural sector, households, and the whole economy.	Syria will experience reduced agricultural production, greater climate variability, and increasing food prices. Reduced GDP growth and real household income. However, specific farming communities will benefit due to higher global food prices. The agricultural sector will be the most vulnerable sector in the Syrian economy. Both rural and urban households will experience income losses.	(Breisinger *et al*., 2011)

Table 1 ***continued***

Model	Spatial resolution	Description	Main findings	Reference
DCGE model and a Hydro-crop model	Zambian economy	Analyses climate variability in Zambia and the impact on Zambian economic growth and poverty.	A reduction in rainfall will increase poverty in Zambia, placing an additional 30,000 people below the poverty line within the next decade.	(Zhu, Diao, & Thurlow, 2009)
Global CGE model and M-GAEZ process-based crop model	Global	Assesses the impact on the global agricultural and food sectors. Evaluates how autonomous adaptation to climate change can reduce hunger.	Changing crop varieties and planting dates can mitigate the impact of climate change. Population growth and economic development have a greater impact on hunger than the negative impacts of climate change.	(Hasegawa *et al*., 2017)

The above literature on climate change and agriculture emphasises both biophysical and economic modelling approaches. Studies using CGE models have been instrumental in understanding the broader economic implications of climate-induced productivity changes.

Global CGE studies have examined the global economic impacts of climate change on agriculture, highlighting how climate-induced productivity declines will disproportionately affect developing economies (Hertel *et al*., 2010; Nelson *et al*., 2014).

Regional and country-specific studies focused on South Asia have demonstrated that climate change leads to GDP reductions, trade imbalances, and increased food insecurity (Calzadilla *et al*., 2013; Chalise & Naranpanawa, 2016). Nepal's experience with climate adaptation through land reallocation and R&D investment provides a relevant case for Sri Lanka.

Recent research confirms that Sri Lanka has been experiencing increasing temperatures and erratic rainfall patterns, directly impacting crop yields and rural incomes. However, limited studies have utilised economywide models to assess macroeconomic adaptation strategies (Fernando *et al*., 2021). Additionally, Abeysekara *et al*. (2023) and Abeysekara *et al*. (2024) analyse the economic consequences of climate change on the agricultural sector in South Asia, particularly in Sri Lanka, using a CGE approach. Their findings reinforce the argument that climate change significantly affects agricultural output and household welfare, underscoring the need for adaptation measures.

This study contributes to the literature by integrating a single-country CGE model with climate impact projections to evaluate the effectiveness of adaptation policies at the national level.

METHODOLOGY

The research question to be addressed, data availability, access to modelling tools and resource availability are fundamental considerations in the initial comparative evaluation of approaches. Quantifying the economic impacts of climate change is complex and challenging. As mentioned in the previous section, many researchers have used CGE models for climate change impact assessments in recent years. Some have used global or regional-level CGE models, while others have integrated CGE models with other models to assess the economic impacts.

The present study used the ORANI-G-SL CGE model together with GEMPACK software to assess the economic impacts of climate change and possible adaptation strategies for Sri Lanka. Results of a PE model (IMPACT model) were used to simulate the CGE model.

ORANI-G – SL Model

The ORANI-G-SL model is a modified version of the ORANI – G model (Horridge, 2003), which distinguishes between irrigated and rain-fed land. It is a static model based on neoclassical economics and assumes that agents are price takers and that producers operate in a perfectly competitive market structure and constant return to scale in production with the aim of maximizing company profits and household utilities. According to the market clearing conditions, supply will be equal to demand with prices adjusted to clear commodity and factor markets. The model consists of a group of equations (producer demands for produced inputs and primary factors, producer supplies of commodities, demands for inputs to capital formation, household demands, export demands, government demands, the relationship of basic values to production costs and purchaser prices, market-clearing conditions for commodities and primary factors, and numerous macroeconomic variables and price indices) for a particular period. Like the ORANI–G, the ORANI-G-SL model was developed to provide comparative static simulations.

As illustrated below in the production structure of the ORANI-G-SL model (Figure 1), at the top nest of the model, the final output is a Leontief combination of the intermediate inputs and primary factors. At the Armington nest, imported and domestic goods are combined using a CES function to produce each intermediate input. The primary factor nest combines land, labour, and capital using a CES function to produce the primary factors, and labour and capital are assumed to be perfectly mobile domestically. At the bottom level, skilled and unskilled labour are combined through a CES function, and land comprises a CES combination of irrigated and rain-fed land.

The Input-Output Table

An Input-Output table (I-O table) is an essential part of the database in CGE modelling. A typical I-O table represents information about the supply and use of products in the circular flow of the national economy and shows the structure and interrelationship between industries. A particular sector purchases primary factors of production (land, labour, and capital) and intermediate inputs from other sectors for its production. The output produced is then sold to other sectors (as an intermediate input), households (for consumption), investors, and the government, and the remainder is exported.

Several I-O tables for Sri Lanka have been compiled since 1963. The present study uses the I-O table for 2010, the most recent one published by the Department of Census and Statistics of Sri Lanka. The I-O table has a symmetric industry-by-industry format

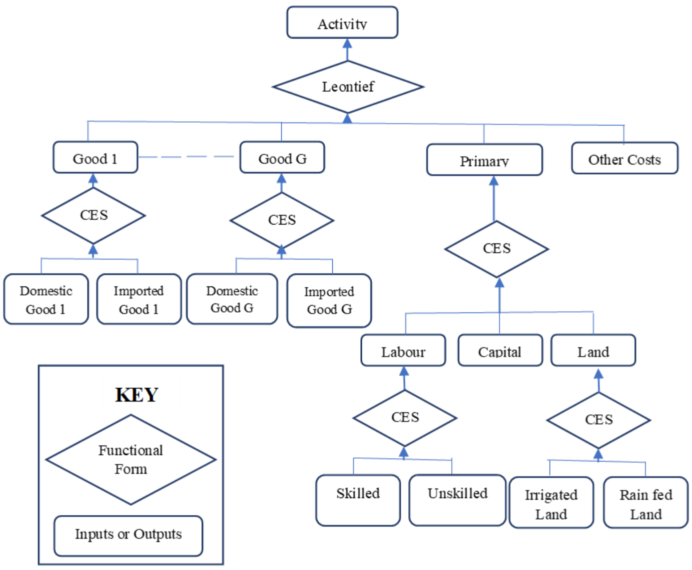

Figure 1: Production structure of the ORANI-G-SL Model

comprising 127 sectors, inclusive of 24 agricultural sectors.

The 2010 I-O table includes both domestically produced and imported commodities. These are used by industries as inputs (intermediate inputs), households for consumption, investors for capital formation, and the government, and the remainder is either exported added to or subtracted from the inventories. In addition, primary factors such as labour and fixed capital are used for production and producers pay a production tax, which includes output taxes or subsidies. The other cost category includes factors such as mixed-income and operating surplus. Ultimately, the total final demand will equal the total supply of the economy.

The database has been updated to account for structural changes in the economy, ensuring relevance for policy analysis. Additionally, sensitivity tests were conducted on key elasticities (e.g., factor substitution, Armington elasticities), with parameter values drawn from literature and econometric estimates.

Simulation Design

IMPACT model data were used to simulate the ORANI-G-SL model using a PE model developed by the International Food Policy Research Institute (IFPRI). The PE model was initially developed in the early 1990s, with the objectives of ensuring food security, reducing poverty and protecting the global natural resources base for the future (Robinson *et al*., 2015). This multi-market model is a blend of different sub-models such as climate, crop, water, and value chain models; land use; nutrition, and health models, and welfare analyses covering 159 countries, 154 water basins, 320 food production units, and 62 agricultural commodity markets. The IMPACT model deals mainly with the agricultural commodity market and uses supply and demand equations and elasticities to simulate national and international market operations, and the behaviour of economic agents.

As the IMPACT model predominantly covers the agricultural commodity market which is only a part of the economy, the results of this model were incorporated into the ORANI-G-SL, a CGE model to analyse the economywide consequences of the impacts of climate change on the agricultural sector and the economic impacts of potential adaptation strategies. Four simulation exercises were conducted in this study. Firstly, it assessed the economic impacts of climate change-induced productivity changes in the agricultural sector in Sri Lanka. Secondly, the effectiveness of increased agricultural land area as an adaptation strategy was assessed in terms of its economic impacts. Thirdly, crop productivity increases due to increased investment in research and development were considered as another adaptation strategy, and two simulations were conducted to evaluate its impact, one with climate change and the other without climate change scenarios, to analyze its economic impacts. Each simulation was based on data obtained from the IFPRI, International Model for Policy Analysis of Agricultural Commodities and Trade Version 3 (IMPACT 3) (Robinson *et al*., 2015), and took into account the extended results of the study "Quantitative Foresight Modelling to Inform the CGIAR Research Portfolio" by Rosegrant *et al*. (2017).

The results of the IMPACT model presented in this study are based on the IPCC Shared Socioeconomic Pathway 2 (Moss *et al*., 2010; O'Neill *et al*., 2017) and RCP 8.5 future climate change scenario. This is known as the "middle-of-the-road" scenario and assumes a medium variant of IIASA-VID-Oxford population projections, which will reach 9.2 billion by 2050 and predicts an economy of US$230 trillion, in which the global average income per person is projected to be US$25,000. The RCP 8.5 scenario which was simulated using The Hadley Centre's Global Environment Model, version 2 (HadGEM), corresponds to an increasing radiative forcing path which leads to 8.5 W/m2 (that is an approximately 1,370 ppm CO_2 equivalent) by 2100 (Van Vuuren, Eickhout, Lucas, & Den Elzen, 2006).

Scenario 1 - Pro-CC

As indicated in the Table 2, temperature and rainfall-induced productivity changes in agricultural crops in Sri Lanka, presented by the above studies which is based on the RCP 8.5 future climate scenario represented by the HadGEM model, were considered as shocks to primary factor productivity in the agricultural industries illustrated below, in the ORANI-G-SL model. This method of analysing the economic consequences of climate change impacts on agricultural sector has been used effectively in many international studies.

Table 2: Climate-induced productivity changes in some agricultural industries

Crop	Climate-induced productivity change compared to baseline scenario
Cereals	-8.90
Rice	5.40
Plantation crops	-3.15
Vegetables	-1.94
Coffee, Cocoa	-4.33
Tea leaves	-3.34

Source : Extended results of Rosegrant *et al*. (2017), Robinson *et al*.

Scenario 2 - LNDAR_CC

As can be seen in Table 3, in comparison with the baseline scenario, the agricultural land area is predicted to expand in Sri Lanka in the future, to meet the demand of future food production. According to global literature, agricultural land area in some countries is predicted to contract, while in others will expand in the future.

For example, China will contract by 0.18% annually, while in sub-Saharan Africa it is predicted to increase at a rate of 0.6% per year (Calzadilla, Zhu, *et al*., 2013). According to the predictions of the IMPACT model, under the SSP2 and RCP8.5 scenarios, there is a possibility of agricultural land area expansion in Sri Lanka. In the original ORANI-G model, land designated as agricultural is fixed, but it is undefined as to how it is allocated among individual crops according to irrigated or rain-fed land. However, the ORANI-G-SL model distinguishes between rainfed and irrigated land areas according to crop type. Hence, this type of adaptation strategy analysis was made feasible by the ORANI-G-SL model developed by the authors.

Scenario 3 - R&D_NOCC (Without climate change impacts) and R&D_CC (With climate change impatcs)

Rosegrant *et al*. (2017), used a research and development investment-yield model to analyze the relationship between investment for research and development into yield, to project the changes in agricultural productivity. This model is based on the perpetual inventory method which follows a gamma distribution, in order to capture the lags between investment into research and time taken to reveal its benefits. Hence, the investment into research will contribute to the stock of knowledge over time. Knowledge and technologies are superseded or become outdated over time. Therefore, the rate of growth or gains in knowledge and technology should be greater than the decay of existing knowledge and technology in order to expect a growth in productivity.

Table 3: Crop area by '000 Ha under land type’, with mid-term climate change for Sri Lanka

Crop	2010 Baseline Scenario		Mid-term expansion of land area due to Climate Change		% Change of Land Area compared to Baseline Scenario *	
	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated
Cereals	21.76	13.01	24.10	14.73	10.76	13.24
Rice	400.29	438.03	420.65	463.21	5.09	5.75
Vegetables	67.96	9.15	75.86	9.62	11.63	5.14
Tropical and subtropical fruits	28.47	15.9	35.35	17.80	24.17	11.95
Other fruits	6.46	3.73	8.63	4.79	33.56	28.34
Nuts	4.18	2.43	4.14	2.17	-1.03	-10.76
Oilseeds	5.13	1.56	6.15	1.78	19.90	14.13
Coffee, cocoa	8.88	5.13	9.58	5.25	7.85	2.33
Tea leaves	146.55	73.71	161.44	77.57	10.16	5.24

Source: Extended results of Rosegrant et al. (2017), Robinson et al. (2015) Note: *authors’ calculations

Table 4 shows the projected changes in agricultural productivity due to investment in research and development to enhance technological improvements. This study mainly considers the investments made by the CGIAR Research Program and National Agricultural Research System (NARS). According to the findings of the above study, the average annual investment of CGIAR and NARS in South Asian countries was US $ 0.26 billion (2005) with an average annual growth rate of 1.9% per year, and US$ 0.71 billion (2005) with an average annual growth rate of 1.4% per year, respectively. These investments will be used to develop new technology or infrastructure and new varieties such as climate-smart agricultural crops, hence increasing the productivity in the agricultural sector. The IMPACT model presents the increase in agricultural productivity due to investment in R&D under two scenarios, one with and the other without climate change scenario. 'Without climate change scenario' assumes a constant climate and 'with climate change scenario considers the changes in climate based on the RCP 8.5 pathway. Agricultural crop productivity is usually measured as the quantity of output per unit land area. Thus, Table 4 presents crop productivity in Mt per Ha.

Values presented in the above tables project the impacts of climate change on specific agricultural industries compared to 2010. As the baseline solution of the ORANI-G-SL model was also for 2010, these values were directly incorporated into the ORANI-G-SL to analyze the economic consequences. In scenario 1, productivity changes were incorporated as percentage changes in technology. In scenario 2, changes in agricultural land were incorporated as percentage changes in agricultural land use, according to land type. Additional investment in research and development was incorporated as changes in agricultural productivity due to investment in research and development in the agricultural sector.

Model closure in CGE exercises moderates the economic environment to define the behaviour of economic agents and any other economywide constraints. For each simulation, real wages and aggregate real investment expenditure are assumed to be exogenous. Therefore, the aggregate household consumption, government expenditure, employment, and inventory demands are assumed to be endogenous. GEMPACK software package (Codsi & Pearson, 1988) was used to implement the ORANI-G-SL model.

Table 4:Mid-term Productivity changes due to investment in research and development in agricultural sector in Sri Lanka (Mt/Ha)

Crop	2010		Without Climate Change		With Climate Change		% Change in Productivity compared to the Baseline Scenario *			
	Baseline Scenario		2030		2030		Without Climate Change		With Climate Change	
	Rainfed	irrigated	Rainfed	irrigated	Rainfed	irrigated	Rainfed	Irrigated	Rainfed	Irrigated
Cereals	3.51	3.05	4.47	3.77	4.22	3.36	27.35	23.61	20.23	10.16
Rice	2.04	3.15	2.7	4.46	2.95	4.34	32.35	41.59	44.61	37.78
Vegetables	8.75	9.95	12.09	13.79	12.1	13.38	38.17	38.59	38.29	34.47
Tropical and subtropical fruits	3.7	4.33	6.58	6.58	6.52	6.52	77.84	51.96	76.22	50.58
Other fruits	4.03	4.74	4.96	5.96	4.83	5.76	23.08	25.74	19.85	21.52
Nuts	0.86	1.01	0.92	1.07	0.9	1.01	6.98	5.94	4.65	0.00
Oilseeds	2.74	1.01	2.9	1.08	2.74	1.01	5.84	6.93	0.00	0.00
Coffee, cocoa	1.36	1.59	1.69	2	1.66	1.95	24.26	25.79	22.06	22.64
Tea leaves	1.59	1.87	2.24	2.65	2.21	2.57	40.88	41.71	38.99	37.43

Source : Extended results of Rosegrant et al. (2017), Robinson *et al*. (2015) Note: *authors' calculations

RESULTS AND DISCUSSION

This section will present the macro and sectorial variables changes as percentage deviations, respective to the baseline scenario represented in the I-O table for Sri Lanka, based on the above-mentioned scenarios.

Table 5 shows the macroeconomic effects of climate-induced productivity changes in the agricultural sector and the two adaptation strategies described in the methodology section. It can be seen from the first row of the first column that it is expected that climate change induced changes in agricultural productivity will reduce Sri Lankan GDP by 0.03%. It also shows that climate change was projected to cause an adverse effect on the labour market, which indicates a 0.01% reduction in employment. This reflects that climate-induced productivity change will reduce the demand for labour, making more people unemployed and reducing household income. Worsening the household situation, commodity prices were projected to increase in the future, as indicated by the 0.07% increase in the consumer price index. Moreover, according to the model results, the real consumption was projected to suffer a slightly greater decline than GDP in the first scenario. As mentioned, domestic production was projected to decline by 0.03% and imports by 0.04%, reducing the variety of commodities available for household consumption. On the other hand, exports will also decline by 0.05%, preserving a particular quantity of commodities for domestic consumption. In that the decline in GDP and imports exceeds the decline in exports, this will reduce the number of commodities available for real consumption. Therefore, the impacts of increased unemployment rates, higher commodity prices, and the reduced variety of commodities available for consumption will reduce real household consumption in the future and threaten household welfare. Conventionally, households respond to this shock by using savings, borrowing, or sharing, which helps level consumption. Reducing household consumption could be lessened by increasing government financing of public benefits, such as unemployment benefits, reducing interest rates, and providing a deferral of investment in new technology. These projections clearly show how climate-induced productivity changes in the agricultural sector will affect the economy in the future.

Table 5 Macroeconomic impacts of climate change on the agricultural sector and adaptation strategies

Macro-economic variable	Pro-CC	LNDAR_CC	R&D_NOCC	R&D_CC
Real GDP	-0.03	0.67	1.64	1.48
Real Consumption	-0.40	1.20	2.87	2.60
Export Volume	-0.05	0.63	1.79	1.68
Import Volume	-0.04	0.54	1.55	1.46
Employment	-0.01	0.93	2.37	2.16
Consumer Price Index	0.07	-2.17	-5.20	-4.70

As discussed in the methodology section, two adaptation strategies were considered to ameliorate the impacts of climate change. The first adaptation strategy increases the agricultural land area and Rosegrant *et al.* (2017) have projected possible land area expansion, in terms of rainfed and irrigated land type for Sri Lanka. Based on that simulation (LNDAR_CC), GDP will increase by 0.67% even under the impacts of climate change, which is equivalent to Rs.42,971.6 million (USD 427.87 million as per the 2005 exchange rate). According to the findings of Inocencio (2007), the unit cost for irrigation expansion (cost per hectare) is USD 3,812 (converted as per the 2005 exchange rate). Therefore, the total cost to expand 34270 Ha, as mentioned in the methodology section, will be USD 130.6372 million (as per the 2005 exchange rate), contributing to an increase in real GDP of USD 427.87 million.

Real consumption will increase twice the real GDP. 1.2% increase in real consumption could be observed with a 2.17% reduction in the CPI. Additionally, export and import volumes will increase by 0.63% and 0.54%, respectively. However, terms of trade (TOT) will decline by 0.08%, which indicates a reduction in the amount of imports the economy will be able to purchase per unit of export goods. This may be due to the depreciation of the local currency by 1.46%. On the positive side, employment will increase by 0.93%, increasing household income. This will also encourage greater consumption at the household level.

As illustrated by the results presented in Table 5, it is evident that investment in agricultural research and development will produce more significant economic benefit than expanding agricultural land. It will expand real GDP by 1.64% under the ‘without climate change scenario’ and 1.48% ‘with climate change’ in compensation for the impacts observed under the climate change-induced productivity change scenario. Achieving this output requires an estimated annual investment of US $0.97 billion (converted as per the 2005 exchange rate) in agricultural research and development. This will also increase exports and imports under both the ‘with climate change’ and ‘without climate change’ scenarios. Furthermore, the volume of exports will increase more than that of imports under both scenarios. It is also evident from the first column of Table 5 that in the climate change-induced productivity change scenario (Pro-CC), the decline in exports exceeds that of imports. Alternatively, in all adaptation scenarios, exports increase more than imports. This may be explained by the declining TOT in all adaptation scenarios (LNDAR_CC – (-0.08%), R&D_NOCC – (-0.28%) and R&D_CC- (-0.26%)), in reduction on the purchase of import good for every unit of imports. At the same time, local currency depreciation will also increase the cost of imports. Investment in agricultural R&D will also increase employment opportunities by 2.37% and 2.16% under the ‘without climate change’ and ‘with climate change’ scenarios, respectively. Real consumption will also increase more in the first adaptation scenario, accounting for 2.87% and 2.60% under the ‘without climate change’ and ‘with climate change’ scenarios. However, the last two columns of Table 5 indicate that with the same amount of investment in R&D, greater benefit could be obtained under the ‘without climate change’ than the ‘with climate change’ scenario.

Impacts at the sectoral level

Figure 2 shows the percentage changes in the outputs of the 24 agricultural industries in Sri Lanka. According to the model results, the output of 23 agricultural industries will decline, with rice being the only exception, which also confirms the findings of Droogers (2004). The main reason for this is the positive productivity increase in the rice industry due to future changes in climate projected by the IMPACT model, which is also in line with the findings of Knox, Hess, Daccache, and Ortola (2011).

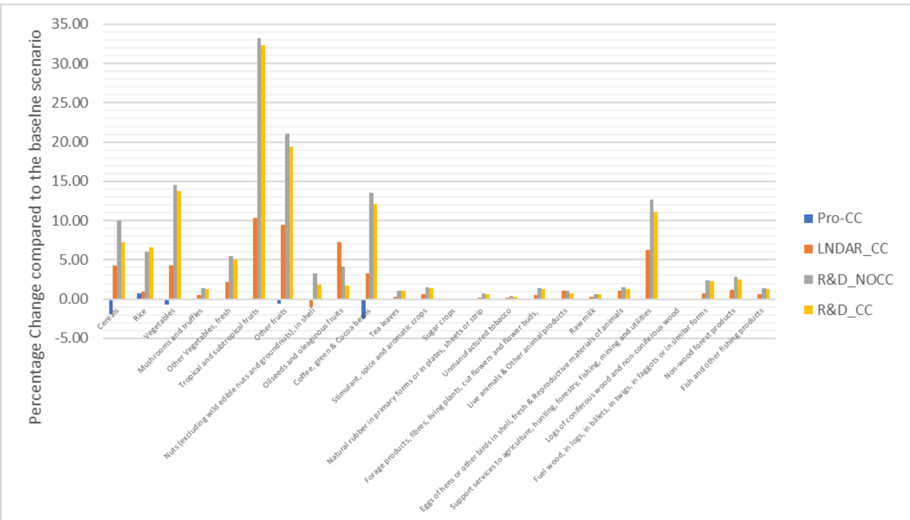

Figure 2: Percentage change in agricultural output under four scenarios

The rice sector will benefit from the increased precipitation while higher temperatures will decrease its productivity. However, the advantages of change in precipitation outweigh the losses from higher temperatures.

The adaptation strategies described in the methodology section will enhance agricultural productivity in the future. The greatest benefits could be obtained by investing in R&D in the agricultural sector. Enhancements in agricultural productivity in rainfed and irrigated land will enable farmers to increase their output per unit of input. As expected, larger outputs can be obtained under the 'without climate change' scenario than the 'with climate change' scenario with the same amount of investment in R&D. However, the benefits for the oilseed and oleaginous fruits sector from investment in R&D exceed those from agricultural land expansion. This is because the R&D investment under the climate change scenario is insufficient to increase the productivity of this sector. Yet, the same amount of investment in R&D will increase the productivity of that sector if climate change does not exist. However, this sector will benefit from a 19.9% increase in rainfed land and a 14.13% increase in irrigated land, on which oilseeds and oleaginous fruits are cultivated. Another noticeable change is the higher percentage output in the fruit sector under all adaptation scenarios. This is because the highest percentage of agricultural land area expansion is projected in the fruit sector and the same sector yields the greatest productivity benefits from investment in R&D. While the fruit sector benefits from adaptation strategies, constraints such as high initial investment, extension services, and market access limitations require consideration.

In Figure 2, it can be seen that the output of the nut sector decreases under the first adaptation scenario (LNDAR_CC). This is because both rainfed and irrigated lands previously used for nut cultivation in the baseline scenario have been converted to cultivate other crops, as indicated by the 1.03% reduction in rainfed land area and 10.76% in irrigated land area. This indicates decreased total land area allocated for nut cultivation in the SSP2 and RCP 8.5 conditions. The output of the rice sector shows only a slight increase (0.97%) due to the expansion of rain-fed and irrigated agricultural land area. Even with the impacts of climate change, the rice sector shows a 0.78% increase in output. This is because the highest proportion of agricultural land area is already used for rice cultivation in Sri Lanka; hence, the projected expansion of agricultural land area for rice cultivation is very limited. Therefore, it is evident that climate change will threaten food security in the future if no adaptation is taken.

As depicted in the fifth column of Table 6, the commodity prices of most agricultural crops will increase with the climate change impacts if no adaptation measures are taken. Similarly, a decline in household demand is projected for these agricultural products. However, the decline in demand for meat, milk and eggs is less than for crop-based agricultural commodities, which shows a demand shift towards animal-based products. However, the prices of those animal-based products are expected to increase the same as those of grain products. This may be due to the higher demand for crop-based products and to the increased cost of production as these industries utilize grains as animal feed. It also shows an increase in the prices of prepared animal feeds under all adaptation scenarios (Table 6). However, both climate change adaptation scenarios are expected to reduce agricultural commodity prices while increasing household demand. The magnitude of changes in demand and prices differs by industry and scenario. Similar to the output level, higher benefits could be expected with additional investment in R&D. Increased productivity in the agricultural sector will reduce production costs. Hence, sellers will be able to sell their products at lower market prices, leading to greater demand for these products, while reducing food prices will make food more affordable for the poor. As discussed above, the output of the nut industry will decline in the second scenario due to the reduction of nut-cultivated land area. This will lead to an increase in the nut prices in the same scenario, resulting in a decline in household demand for nuts.

As a CGE model, the ORANI-G-SL model can account for the impact on non-agricultural sectors. Climate-induced productivity changes and adaptation strategies will have a mixed effect on both manufacturing and service sectors. The fertilizers and pesticides sector will receive a considerable increase, ranging from 3.3% - 16% in its production under all

Table 6: Percentage change in household demand and prices of agricultural commodities

Industries	Household demand				Commodity Price			
	Pro-CC	LNDAR_CC	R&D_NOCC	R&D_CC	Pro-CC	LNDAR_CC	R&D_NOCC	R&D_CC
Cereals	-4.40	8.38	19.64	14.65	10.03	-17.11	-39.85	-28.72
Rice	8.97	9.70	59.35	65.36	-18.8	-15.56	-52.63	-53.98
Vegetables	-1.14	6.93	23.37	22.07	2.52	-14.64	-52.03	-49.41
Mushrooms and truffles	-0.13	1.05	2.54	2.28	0.02	0.12	0.32	0.31
Other vegetables	-0.20	2.32	5.73	5.21	0.11	-2.36	-5.93	-5.41
Tropical and subtropical fruits	-0.05	13.69	44.11	42.94	-0.17	-22.78	-65.02	-63.36
Other fruits	-0.16	1.39	3.33	3.02	0.34	-5.28	-11.62	-10.72
Nuts (excluding wild edible nuts and ground-nuts), in shell	0.03	-3.39	8.46	4.26	0.32	8.27	-10.54	-3.31
Oilseeds and oleaginous fruits	-0.31	12.91	7.36	2.86	0.30	-21.46	-8.45	-0.74
Coffee, green & cocoa beans	-1.30	2.61	9.00	8.06	5.70	-7.37	-30.99	-27.66
Tea	-12.99	29.99	41.04	30.30	23.29	-52.33	-60.65	-61.70
Stimulant, spice and aromatic crops	0.00	0.99	2.21	1.97	-0.27	0.24	0.97	0.93
Sugar crops	0.00	0.00	0.00	0.00	2.10	-5.24	-11.66	-8.73
Natural rubber in primary forms or in plates, sheets or strip	0.00	0.00	0.00	0.00	14.01	-4.05	-17.21	-15.74
Unmanufactured tobacco	0.00	0.00	0.00	0.00	3.76	-6.76	-14.35	-9.71
Foraging products, fibres, living plants, cut flowers and flower buds,	-0.09	1.08	2.60	2.34	-0.39	0.25	0.91	0.90
Live animals & other animal products	-0.09	0.99	3.95	3.83	0.10	0.23	-2.27	-2.52
Raw milk	-0.03	1.28	3.21	2.94	0.20	-0.30	-0.90	-0.89
Eggs of hens or other birds in shells, fresh & Reproductive materials of animals	-0.01	1.87	2.60	2.08	0.24	-1.37	0.21	0.67
Support services to agriculture, hunting, forestry, fishing, mining and utilities	0.00	0.00	0.00	0.00	0.07	-2.14	-5.11	-4.65
Logs of coniferous and non-coniferous wood	0.00	0.00	0.00	0.00	-0.12	-2.75	-3.57	-2.81
Fuel wood in logs, billets, twigs, faggots and similar forms	-0.20	1.37	4.26	3.91	0.11	-0.46	-2.80	-2.63
Non-wood forest products	-0.18	2.12	5.12	4.64	0.07	-2.10	-5.02	-4.56
Fish and other fishing products	-0.01	0.97	2.39	2.19	0.23	0.26	0.59	0.48
Agriculture based manufacturing sector industries								
Processing and preserving of meat	-0.04	0.83	2.09	1.91	-0.20	0.55	1.22	1.06
Processing and preserving of fish, crustaceans and molluscs	-0.09	1.11	2.67	2.41	-0.63	0.03	0.54	0.49
Processing and preserving of fruit and vegeta-bles	-0.17	2.03	5.74	5.35	0.09	-3.08	-10.23	-9.80
Manufacture of vegetable and animal oils and fats	-0.04	2.45	2.86	2.14	0.34	-4.54	-0.51	1.08
Manufacture of dairy products	-0.03	1.01	2.48	2.27	0.28	0.28	0.61	0.48
Manufacture of grain mill products	0.16	1.25	3.55	3.42	-0.57	-0.26	-1.60	-1.84
Manufacture of prepared animal feeds	0.06	0.96	2.53	2.36	0.38	0.30	0.36	0.18
Manufacture of sugar	-0.13	1.19	2.89	2.62	-0.27	-1.53	-3.72	-3.47
Manufacture of macaroni, noodles, couscous and similar farinaceous products	-0.11	1.08	2.63	2.39	-0.06	0.06	0.15	0.13
Manufacture of other food products	-0.11	1.21	3.18	2.90	-0.07	-0.19	-0.90	-0.88
Manufacture of rubber tyres and tubes	-0.03	1.14	2.66	2.40	0.30	-0.05	0.14	0.13
Manufacture of other rubber products	-0.19	1.56	3.82	3.47	0.10	-0.99	-2.46	-2.28

the adaptation scenarios. The last twelve rows of Table 6, shows how consumer demand and prices change in the agriculture-based manufacturing industries under the scenarios described in the methodology section. The table shows a reduction in the prices of fruit and vegetables, grain mill products, manufactured sugar, other manufactured food products and manufactured rubber products under the adaptation scenarios. As explained above, adaptation measures will increase the output of the fruit, vegetables, and rice sectors, leading to a decrease in the market price of those industries. Manufacturing industries which use these products as intermediate inputs will be able to decrease their production costs due to reduced input prices. Hence, selling their outputs at a lower market price will be possible. Similarly, the price of sugar and natural rubber crops will decline under the adaptation scenarios. Hence, the market price of sugar and rubber products will also decline.

CONCLUSIONS

This paper analyses the economic impacts of climate change on the agricultural sector in Sri Lanka, and two adaptation strategies to reduce these impacts. The models used some results from the PE-type IMPACT model to simulate the ORANI-G-SL CGE model. The validity of this combination is that it incorporates the results of the IMPACT model, which provides detailed water, crop, land use and investment-yield linkages to simulate the CGE model. The ORANI-G-SL model simulations analyse and report the economywide impacts based on the results of the PE model, which, in the case of the IMPACT model, is confined to the agricultural sector. From the results of the above CGE model, it is evident that climate change will have a negative impact on the agricultural sector, as well as on the whole economy of Sri Lanka, if no adaptation measures are undertaken. Total food production of the country will be reduced in the future, in compared with the baseline scenario, threatening food security. This will contract the Sri Lankan economy and reduce household consumption, labour demand and, consequentially, the welfare of Sri Lankans. Two adaptation strategies were considered to counteract these negative climate change impacts. The first scenario increased the agricultural land area to meet the increasing demand for food of an increasing future population. This simulation was based on the projection made by the IMPACT model on the potential for agricultural land area expansion in the future in Sri Lanka. The second adaptation scenario increased the agricultural productivity due to the investment in R&D for the agricultural sector.

Both adaptation scenarios will be beneficial to the Sri Lankan economy as they predict increases in the major macroeconomic variables such as GDP, real household consumption, exports, and employment opportunities. Both adaptation scenarios will increase total national crop production and reduce production costs, thus increasing the market price of those agricultural products, making them more affordable for poorer population sectors. Moreover, the manufacturing and service sectors will experience mixed benefits from the impacts of climate change, according to the alternative adaptation scenarios. However, it is noticeable that most non-agricultural production sectors, mainly reliant on agricultural intermediate inputs, will benefit under both adaptation scenarios. According to the model results, increased agricultural productivity will produce greater benefits than expansion of the land area due to the limited ability to expand the agricultural land area. This indicates that the Sri Lankan agricultural sector operates far beyond its potential productivity. As expected, the same amount of investment in R&D will provide higher returns under the 'without climate change' scenario than the 'with climate change' scenario. Hence, prioritising agricultural R&D and investment in specific crops and technologies suited to Sri Lanka's agro-ecological conditions is critical. Moreover, a combined adaptation approach—integrating land expansion with targeted R&D—may yield optimal results. Such an approach balances short-term expansion benefits with long-term gains in agricultural productivity. Additionally, complementary policies such as improving rural infrastructure, providing accessible credit, and strengthening extension services can help farmers translate these adaptation strategies into tangible productivity gains and poverty reduction. To strengthen the applicability of these findings, we draw on successful adaptation strategies from other countries. In Nepal, climate-smart agricultural practices have been widely adopted, providing farmers greater access to drought- and flood-resistant seed varieties. This approach has improved crop resilience and ensured stable yields despite adverse weather conditions. In India, public-sector research collaborations with private seed companies have led to developing higher-yielding, climate-resilient crop varieties. The country's extensive agricultural extension services have played a crucial role in disseminating knowledge and enabling smallholder farmers to adopt new technologies effectively. Bangladesh has focused on implementing flood and cyclone risk management programs. The country has integrated farming systems that enhance resilience against waterlogging, ensuring that agricultural productivity remains stable even in extreme weather conditions. Vietnam has invested significantly in rural infrastructure, including roads and irrigation canals, and strengthened agricultural extension services. These improvements have facilitated the rapid adoption of improved rice varieties, helping Vietnam become a major rice exporter and increasing farmers' adaptive capacity to climate change. Several limitations apply to the above results. We did not consider the costs of agricultural land area expansion or productivity enhancement in the ORANI-G-SL model, which may lead to overestimating the benefits. Secondly, we did not consider other adaptation strategies that farmers are already using to protect against the impacts of climate change.

AUTHOR CONTRIBUTION

WCSMA, MS, and SM conceptualised and designed the study. WCSMA conducted the research and analysed the data. WCSMA drafted the manuscript, and MS and SM critically reviewed and revised the manuscript

REFERENCES

Abeysekara, W. C. S. M., Siriwardana, M., & Meng, S. (2023). Economic consequences of climate change impacts on the agricultural sector of South Asia: A case study of Sri Lanka. *Economic Analysis and Policy*, *77*, 435-450.

Abeysekara, W. C. S. M., Siriwardana, M., & Meng, S. (2024). Economic consequences of climate change impacts on South Asian agriculture: A computable general equilibrium analysis. Australian Journal of Agricultural and Resource Economics, 68(1), 77-100.

Ahmed, M., & Suphachalasai, S. (2014). *Assessing the costs of climate change and adaptation in South Asia*: Asian Development Bank.

Allen, M., Antwi-Agyei, P., Aragon-Durand, F., Babiker, M., Bertoldi, P., Bind, M., . . . Cartwright, A. (2019). Technical Summary: Global warming of 1.5° C. An IPCC Special Report on the impacts of global warming of 1.5° C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

Ashfaq, M., Shi, Y., Tung, W. w., Trapp, R. J., Gao, X., Pal, J. S., & Diffenbaugh, N. S. (2009). Suppression of south Asian summer monsoon precipitation in the 21st century. *Geophysical Research Letters, 36*(1).

Bandara, E., Jayasinghe-Mudalige, U., Udugama, J., Attanayake, A., & Edirisinghe, J. (2014). Has the food and agriculture sector played its intended role in socio-economic development of Sri Lanka? An empirical investigation. *Journal of Agricultural Sciences, 9*(2).

Bezabih, M., Chambwera, M., & Stage, J. (2011). Climate change and total factor productivity in the Tanzanian economy. *Climate policy, 11*(6), 1289-1302.

Bosello, F., & Zhang, J. (2005). Assessing climate change impacts: agriculture.

Breisinger, C., Zhu, T., Al Riffai, P., Nelson, G., Robertson, R., Funes, J., & Verner, D. (2011). Global and local economic impacts of climate change in Syria and options for adaptation. *International Food Policy Research Institute, Discussion Paper, 1091*, 23.

Calzadilla, A., Rehdanz, K., Betts, R., Falloon, P., Wiltshire, A., & Tol, R. S. (2013). Climate change impacts on global agriculture. *Climatic Change, 120*(1-2), 357-374.

Calzadilla, A., Zhu, T., Rehdanz, K., Tol, R. S., & Ringler, C. (2013). Economywide impacts of climate change on agriculture in Sub-Saharan Africa. *Ecological economics, 93*, 150 -165.

Chalise, S., & Naranpanawa, A. (2016). Climate change adaptation in agriculture: A computable general equilibrium analysis of land-use change in Nepal. *Land Use Policy, 59*, 241-250.

Chandrapala, L. (1996). Long term trends of rainfall and temperature in Sri Lanka. *Climate variability and agriculture*, 153-162.

Cline, W. R. (2007). *Global warming and agriculture: Impact estimates by country*: Peterson Institute.

Codsi, G., & Pearson, K. R. (1988). GEMPACK: General-purpose software for applied general equilibrium and other economic modellers. *Computer Science in Economics and Management, 1*(3), 189-207.

De Costa, W. (2010). Adaptation of agricultural crop production to climate change: a policy framework for Sri Lanka. *Journal of the National Science Foundation of Sri Lanka, 38* (2).

De Silva, C., Weatherhead, E., Knox, J. W., & Rodriguez-Diaz, J. (2007). Predicting the impacts of climate change—A case study of paddy irrigation water requirements in Sri Lanka. *Agricultural water management, 93*(1-2), 19-29.

Department of Census and Statistics, M. o. N. P. a. E. A. S. L. (2017). *Economic Census 2013/14*. Retrieved from Battaramulla

Department of Meterology Sri Lanka. (2022, 22.02.2025). Climate of Sri Lanka. Retrieved from http://www.meteo.gov.lk/index.php?option=com_content&view=article&id=94&Itemid=310&lang=en

Department of Meterology Sri Lanka. (2018, 27.03.2018). Climate of Sri Lanka. Retrieved from http://www.meteo.gov.lk/index.php?option=com_content&view=article&id=94&Itemid=310&lang=en

Domroes, M., & Schaefer, D. (2000). *Trends of recent temperature and rainfall changes in Sri Lanka.* Paper presented at the Proceedings of the International Conference on Climate Change and Variability.

Droogers, P. (2004). Adaptation to climate change to enhance food security and preserve environmental quality: example for southern Sri Lanka. *Agricultural water management, 66* (1), 15-33.

Eboli, F., Parrado, R., & Roson, R. (2010). Climate-change feedback on economic growth: explorations with a dynamic general equilibrium model. *Environment and Development Economics, 15*(5), 515-533.

Eriyagama, N., Smakhtin, V., Chandrapala, L., & Fernando, K. (2010). *Impacts of climate change on water resources and agriculture in Sri Lanka: a review and preliminary vulnerability mapping* (Vol. 135): IWMI.

Esham, M., & Garforth, C. (2013). Climate change and agricultural adaptation in Sri Lanka: a review. *Climate and Development, 5*(1), 66-76.

Feenstra, J. F. (1998). Handbook on methods for climate change impact assessment and adaptation strategies.

Fernández, F. J., & Blanco, M. (2015). Modelling the economic impacts of climate change on global and

European agriculture. Review of economic structural approaches. *Economics, 9*(10), 1.

Fernando, W. V. N. (2021). *Assessing smallholder farmers' vulnerability and adaptive capacity to climate change in Sri Lanka: Towards a sustainable livelihood framework* (Doctoral dissertation, Deakin University).

Garnaut, R. (2013). Removing climate change as a barrier to economic progress. *Economic AnAlysis & Policy, 43*(1).

Golub, A. A., Henderson, B. B., Hertel, T. W., Gerber, P. J., Rose, S. K., & Sohngen, B. (2013). Global climate policy impacts on livestock, land use, livelihoods, and food security. *Proceedings of the national academy of sciences, 110*(52), 20894-20899.

Hasegawa, T., Fujimori, S., Shin, Y., Takahashi, K., Masui, T., & Tanaka, A. (2017). Global Assessment of Agricultural Adaptation to Climate Change using CGE Model. In *WORLD SCIENTIFIC REFERENCE ON NATURAL RESOURCES AND ENVIRONMENTAL POLICY IN THE ERA OF GLOBAL CHANGE: Volume 3: Computable General Equilibrium Models* (pp. 247-272): World Scientific.

Hertel, T. W., Burke, M. B., & Lobell, D. B. (2010). The poverty implications of climate-induced crop yield changes by 2030. *Global Environmental Change, 20*(4), 577-585.

Horridge, M. (2003). ORANI-G: A generic single-country computable general equilibrium model. *Centre of Policy Studies and Impact Project, Monash University, Australia*.

Iglesias, A., Garrote, L., Quiroga, S., & Moneo, M. (2012). A regional comparison of the effects of climate change on agricultural crops in Europe. *Climatic Change, 112*(1), 29-46.

Imbulana, K., Wijesekara, N., Neupane, B., Aheeyar, M., & Nanayakkara, V. (2006). Sri Lanka Water Development Report 2010. In: UNESCO and Ministry of Irrigation and Water Resources Mangement, Colombo, Sri Lanka.

Inocencio, A. B. (2007). *Costs and performance of irrigation projects: A comparison of sub-Saharan Africa and other developing regions* (Vol. 109): IWMI.

Jayasinghe-Mudalige, U. (2010). Role of Food and Agriculture Sector in Economic Development of Sri Lanka: Do We Stand Right in the Process of Structural Transformation? *Journal of Food and Agriculture, 1*(1).

Knox, J., Hess, T., Daccache, A., & Ortola, M. P. (2011). What are the projected impacts of climate change on food crop productivity in Africa and S Asia. *DFID Systematic Review Final Report. Cranfield University, 71*.

Lin, T., Liu, X., Wan, G., Xin, X., & Yongsheng, Z. (2011). Climate Change and Agricultural Interregional Trade Flows in the People's Republic of China.

Ministry of Environment. (2011). *Second National Communication on Climate Change submission to UNFCCC Secretariat*. Retrieved from Sri Lanka: https://unfccc.int/resource/docs/natc/lkanc2.pdf

Moss, R. H., Edmonds, J. A., Hibbard, K. A., Manning, M. R., Rose, S. K., Van Vuuren, D. P., . . . Kram, T. (2010). The next generation of scenarios for climate change research and assessment. *Nature, 463*(7282), 747-756.

Nelson, G. C., & Shively, G. E. (2014). Modeling climate change and agriculture: an introduction to the special issue. *Agricultural Economics, 45*(1), 1-2.

Nelson, G. C., Valin, H., Sands, R. D., Havlík, P., Ahammad, H., Deryng, D., . . . Heyhoe, E. (2014). Climate change effects on agriculture: Economic responses to biophysical shocks. *Proceedings of the national academy of sciences, 111*(9), 3274-3279.

Niranjan, F., Jayathilake, M., Uddika, N., Dhananjani, T., Bantilan, C., & Singh, N. (2013). Vulnerability to Climate

Change: Adaptation Strategies and Layers of Resilience Farmers' Perceptions of Climate Change in Sri Lanka: Qualitative Analysis, Research Report No. 17.

Nissanka, S., Punyawardena, B., Premalal, K., & Thattil, R. (2011). *Recent trends in annual and growing seasons' rainfall of Sri Lanka.* Paper presented at the Proceedings of the International Conference on the Impact of Climate Change in Agriculture. Faculty of Agriculture, University of Ruhuna, Mapalana, Sri Lanka.

O'Neill, B. C., Kriegler, E., Ebi, K. L., Kemp -Benedict, E., Riahi, K., Rothman, D. S., . . . Kok, K. (2017). The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. *Global Environmental Change, 42*, 169-180.

Oktaviani, R., Amaliah, S., Ringler, C., Rosegrant, M. W., & Sulser, T. B. (2011). The impact of global climate change on the Indonesian economy. *International Food Policy Research Institute (IFPRI), Washington, DC Google Scholar*.

Panabokke, C., & Punyawardena, B. (2010). *Climate change and rain-fed agriculture in the dry zone of Sri Lanka.* Paper presented at the Proceedings of the national conference on water, food security and climate change in Sri Lanka. Volume 2: water quality, environment and climate change. Colombo, 9-11 June, 2009.

Perera, S., Ariyabandu, M. M., & Withanachchi, A. (2023). Policy Implications of the Gender, Inclusion and Climate Change Nexus: Experiences from Sri Lanka: Development Futures Series No. 52.

Premalal, K., & Punyawardena, B. (2013). *Occurrence of extreme climatic events in Sri Lanka.* Paper presented at the Proceedings of the international conference on climate change impacts and adaptations for food and environment security. Hotel Renuka, Colombo.

Robinson, S., Mason-D'Croz, D., Sulser, T., Islam, S., Robertson, R., Zhu, T., . . . Rosegrant, M. W. (2015). The international model for policy analysis of agricultural commodities and trade (IMPACT): model description for version 3.

Robinson, S., Willenbockel, D., & Strzepek, K. (2012). A dynamic general equilibrium analysis of adaptation to climate change in Ethiopia. *Review of Development Economics, 16*(3), 489-502.

Rosegrant, M. W., Sulser, T. B., Mason-D'Croz, D., Cenacchi, N., Nin-Pratt, A., Dunston, S., . . . Robinson, S. (2017). *Quantitative foresight modeling to inform the CGIAR research portfolio*: Intl Food Policy Res Inst.

Sathischandra, S., Marambe, B., & Punyawardena, R. (2014). Seasonal changes in temperature and rainfall and its relationship with the incidence of weeds and insect pests in rice (Oryza sativa L) cultivation in Sri Lanka. *Climate Change and Environmental Sustainability, 2*(2), 105-115.

Shukla, P., Skea, J., Calvo Buendia, E., Masson-Delmotte, V., Pörtner, H., Roberts, D., . . . Van Diemen, R. (2019). IPCC, 2019: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.

Van Vuuren, D., Eickhout, B., Lucas, P., & Den Elzen, M. (2006). Long-term multi-gas scenarios to stabilise radiative forcing-exploring costs and benefits within an integrated assessment framework. *The energy journal*(Special Issue# 3).

Wickramasinghe, D., Prematilaka, L., Witharana, A., Halwatura, D., & Perera, T. (2023). Cities and climate change: Responding to the impacts of water-related disasters in Sri

Lanka. *International Handbook of Disaster Research*, 2331-2353.

Winters, P., Murgai, R., Sadoulet, E., De Janvry, A., & Frisvold, G. (1998). Economic and welfare impacts of climate change on developing countries. *Environmental and Resource Economics, 12*(1), 1-24.

Zhai, F., Lin, T., & Byambadorj, E. (2009). A general equilibrium analysis of the impact of climate change on agriculture in the People's Republic of China. *Asian Development Review, 26* (1), 206.

Zhu, T., Diao, X., & Thurlow, J. (2009). The impact of climate variability and change on economic growth and poverty in Zambia.