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AN ASSESSMENT OF THE ECONOMIC IMPACT OF CLIMATE CHANGE ON THE ENERGY SECTOR IN TRINIDAD AND TOBAGO

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Notes and explanations of symbols:

The following symbols have been used in this study:
A full stop (.) is used to indicate decimals
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.
N.d. refers to forthcoming material with no set publication date.

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Executive Summary

The energy sector is a dominant one in Trinidad and Tobago and it plays an important role in the twin-island republic's economy. In 2008, the share of the energy sector in gross domestic product (GDP) amounted to approximately 48% while contributing 57% to total Government revenue. In that same year, the sector's share of merchandise exports was 88%, made up mainly of refined oil products including petroleum, liquefied natural gas (LNG), and natural gas liquids (Central Bank of Trinidad and Tobago, 2009).

Trinidad and Tobago is the main exporter of oil in the Caribbean region and the main producer of liquefied natural gas in Latin America and the Caribbean. The role of the country's energy sector is, therefore, not limited to serving as the engine of growth for the national economy but also includes providing energy security for the small island developing States of the Caribbean. However, with its hydrocarbon-based economy, Trinidad and Tobago is ranked seventh in the world in terms of carbon dioxide (CO_2) emissions per capita, producing an estimated 40 million tonnes of CO_2 annually. Almost 90% of these CO_2 emissions are attributed directly to the energy sector through petrochemical production (56%), power generation (30%) and flaring (3%).

Trinidad and Tobago is a ratified signatory to the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Although, as a non-Annex 1 country, Trinidad and Tobago is not required to cut its greenhouse gas emissions under the Protocol, it is currently finalizing a climate change policy document as well as a national energy policy with specific strategies to address climate change.

The present study complements the climate change policy document by providing an economic analysis of the impact that climate change could have on the energy sector in Trinidad and Tobago under the Intergovernmental Panel on Climate Change alternative climate scenarios (A2 and B2) as compared to a baseline situation of no climate change.

Results of analyses indicate that, in the short-run, climate change, represented by change in temperature, is not a significant determinant of domestic consumption of energy, electricity in particular, in Trinidad and Tobago. With energy prices subsidized domestically and fixed for years at a time, energy price does not play a role in determining electricity demand. Economic growth, as indicated by Gross Domestic Product (GDP), is the single major determinant of electricity consumption in the short-run. In the long-run, temperature, GDP, and patterns of electricity use, jointly determine electricity consumption.

Variations in average annual temperature due to climate change for the A2 scenario are expected to lead to an increase in electricity consumption per capita, equivalent to an annual increase of 1.07% over the 2011 baseline value of electricity consumption per capita. Under the B2 scenario, the average annual increase in electricity consumption per capita over the 2011 baseline value is expected to be 1.01%. The estimated economic impact of climate change on electricity consumption for the period 2011-2050 is valued at US$ 142.88 million under the A2 scenario and US$ 134.83million under the B2 scenario. These economic impact estimates are equivalent to a loss of 0.737% of 2009 GDP under the A2 climate scenario and a loss of 0.695% of 2009 GDP under the B2 scenario.

On the energy supply side, sea level rise and storm surges present significant risks to oil installations and infrastructure at the Petroleum Company of Trinidad and Tobago (PETROTRIN) Pointe-a-Pierre facilities (Singh and El Fouladi, 2006). However, data limitations do not permit the conduct of an economic analysis of the impact of projected sea level rise on oil and gas production.

The climate change policies pursued by major energy-consuming countries have potentially significant impacts on the Trinidad and Tobago energy sector. In particular, the United States of America (the major importer of LNG from Trinidad and Tobago) has signalled its commitment to reducing dependence on foreign oil by one-third by 2025. Part of the strategy to achieve this goal is a shift to renewable energy. If such a policy drive is adopted by other major oil-importing countries like China and India, there will be major impacts on the economy of Trinidad and Tobago.

Energy efficiency strategies are among the available adaptation options for implementation in the energy sector that may be pursued in the immediate term. The present study has established that an adaptation option in which residential electricity consumers switch from incandescent light bulbs to compact fluorescent bulbs is cost-effective with a benefit-cost ratio (BCR) ranging from 1.72 to 1.83 and a net present value (NPV) ranging from US$ 157.01 million to US$ 345.20 million. The adaptation option of replacing electric water heaters with solar water heaters for residential electricity consumers is even more cost-effective, with BCR ranging between 3.43 and 4.66 and NPV ranging between TT$ 1.02 billion and TT$ 2.20 billion. The adaptation option of replacing mini split air conditioners in hotels and guest houses with Variable Refrigerant Volume (VRV) air conditioners is, however, only marginally cost-effective, with a BCR ranging between 0.99 and 1.06 and a NPV ranging between US$ -0.10 million and US$ 1.58 million. The conversion of the motor fleet to Compressed Natural Gas (CNG) is another cost-effective adaptation option that can be implemented in the transport sector if the high initial cost of implementation can be absorbed by motorists. The BCR of switching from super petrol to CNG ranges between 1.68 and 1.98 while the NPV ranges between US$ 37.50 million and US$ 97.60 million.

Singh and El Fouladi (2006) recommend retrofitting oil installations with barriers to prevent inundation from sea level rise and storm surge, as supply-side adaptation strategies in the immediate term to prevent disruptions in future oil supply. However, in the medium- to long-run, market diversification to non-traditional export markets will be a necessity for the Trinidad and Tobago energy sector as an adaptation option in response to the shift in the United States of America towards renewable energy sources.

I. INTRODUCTION

A. BACKGROUND

Historically, the global climate has been marked by a cycle of natural variability in cooling and warming. Within this century, however, there has been an anomalous warming of global atmospheric temperatures which has paralleled the growth in anthropogenic greenhouse gas (GHG) emissions. According to the Intergovernmental Panel on Climate Change (IPCC, 2001), environmental trends have reached a disturbing level at the beginning of the century (UNEP, 2006). Therefore, it is no surprise that, as understanding of the science of climate change advances, increasing attention is being paid to adaptation and mitigation efforts to address it. In light of this, the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 set the goal for stabilizing GHG concentrations in the atmosphere through reducing GHG emissions to those of 1990 levels. The Kyoto Protocol agreed further in 1997 to set a more stringent emission reduction goal for Annex 1 Parties. As Non-Annex 1 Parties, Caribbean countries are not obligated to reduce their GHG emissions under the Protocol. However, the Cancun Agreement, reached at the Conference of Parties (COP) meeting of the UNFCCC in Cancun, Mexico in December 2010, recognizes that adaptation is a challenge faced by all Parties and calls for enhanced action and international cooperation on adaptation to climate change. The Agreement further calls for Parties to undertake vulnerability and adaptation assessments, including economic assessments, of adaptation options.

With its share of global GHG emissions estimated at less than 0.1%, the Caribbean has primarily focused on adaptation strategies. Several initiatives aimed at strengthening the capacity of Caribbean countries to adapt to climate change have been implemented over the years. These include the Caribbean Planning for Adaptation to Climate Change (CPACC), the Adaptation to Climate Change in the Caribbean (ACCC), the Mainstreaming Approach to Climate Change (MACC), and the Special Pilot Adaptation to Climate Change (SPACC) (ECLAC, 2010). Complementing these earlier projects is the Review of Economics of Climate Change in the Caribbean (RECC) project that focuses on the estimation of the costs of adapting to and mitigating projected impacts of climate change in key sectors of the economy. The current study is focused on the energy sector of Trinidad and Tobago.

B. STUDY OBJECTIVES

The specific objectives of this study are to:

(a) Collect relevant data on the energy sector in Trinidad and Tobago for use in the estimation of costs of identified and anticipated impacts of climate change

(b) Perform an economic analysis of climate change impacts on the energy sector and allied sectors over the next 40 years based on various carbon emission trajectories under the business as usual (BAU) scenario and the A2 and B2 scenarios.

C. SCOPE OF THE CURRENT STUDY

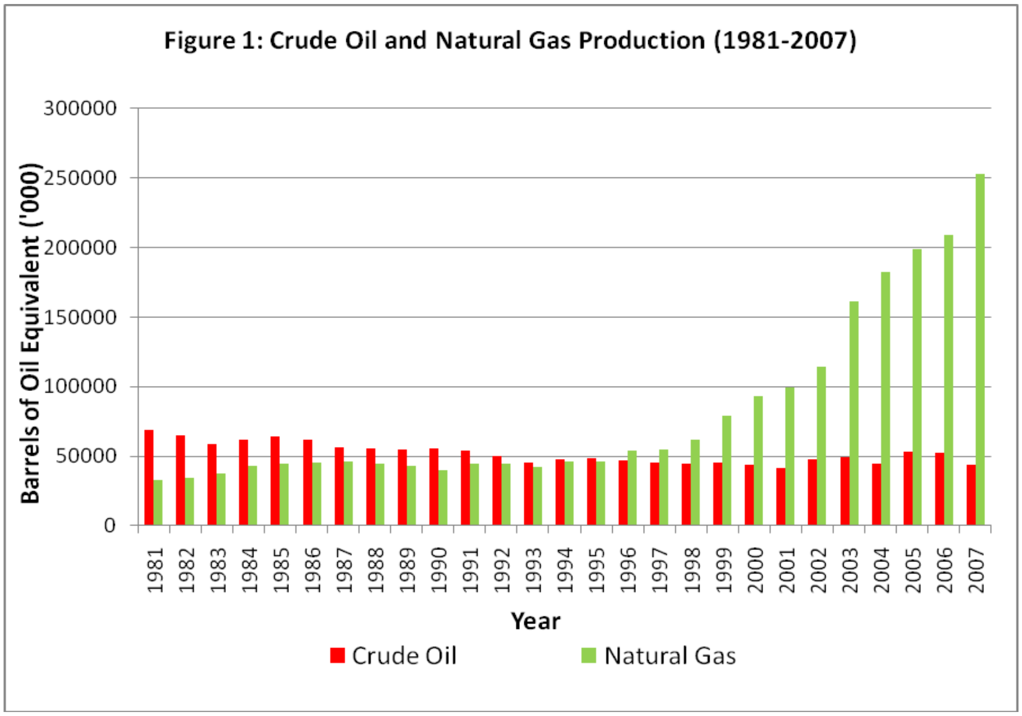
Pursuant with the stated objectives, the present study has focused on the demand and supply sides of the energy sector in Trinidad and Tobago by analysing how climate change, as dictated by different climate scenarios, might impact specifically on domestic demand for electricity and on the export of liquefied natural gas and crude oil. The decision to concentrate on these energy sources was informed by the availability and quality of data on different energy sources in Trinidad and Tobago. Being an energy-producing country, issues of priority concern to policymakers will be expected to differ from those of policymakers in energy-importing countries. In Trinidad and Tobago, the GHG emission trajectory and the associated trends in social, economic, demographic and environmental factors implied by climate scenarios are expected to influence how energy is produced and used domestically, as well as how energy resources are exploited for foreign exchange earnings. In addition, the magnitude and direction of impact will very likely vary with each scenario.

With full understanding of the foregoing issues, the impact of climate change on electricity demand is forecast by examining variations in temperature under different climate scenarios and how these translate to changes in electricity consumption from what would have obtained under the baseline scenario of no climate change. In examining the impact of climate change on energy production and export, greater emphasis is placed on the influence of energy policies (including renewable sources) of major energy-consuming nations. Alternative climate change adaptation options for the energy sectors are considered, and economic evaluation performed to determine the economic feasibility of each option, using cost-benefit analysis. The selection of adaptation options for economic assessment was informed by both the IPCC (2007) Synthesis Report of its Fourth Assessment Report (AR4) and the draft climate change and energy policies of the Republic of Trinidad and Tobago. Results of cost-benefit analysis are presented using two measures: benefit-cost ratio (BCR) and net present value (NPV) of the adaptation options in comparison to a status quo of inaction to adapt to the impacts of climate change. These measures provide policymakers with objective means of assessing alternative adaptation options by focusing on the economic benefits or the return on investment from implementing a particular option. In addition to the direct economic benefit that an adaptation option may present, the potential for mitigating GHG emission is also estimated and valued. This approach provides a more robust calculation of the benefits to society from the implementation of climate change adaptation options.

II. THE ENERGY SECTOR IN TRINIDAD AND TOBAGO

A. ENERGY SUPPLY

The twin island country of Trinidad and Tobago is an oil-rich nation of approximately 1.3 million inhabitants. The country discovered its first oil deposits in 1866 and by 1908 had started to undertake drilling and crude oil production. This later led to the establishment of the country's first oil refinery in 1912 and exploration for offshore oil began in 1954. Crude oil was the major oil product but production of natural gas grew steadily from the mid-1970s and surpassed crude oil production by 1996. Natural gas production increased dramatically since 2000 and has more than doubled in output between 2000 and 2005 (see figure 1). In contrast, crude oil production has remained stable over the last two decades.

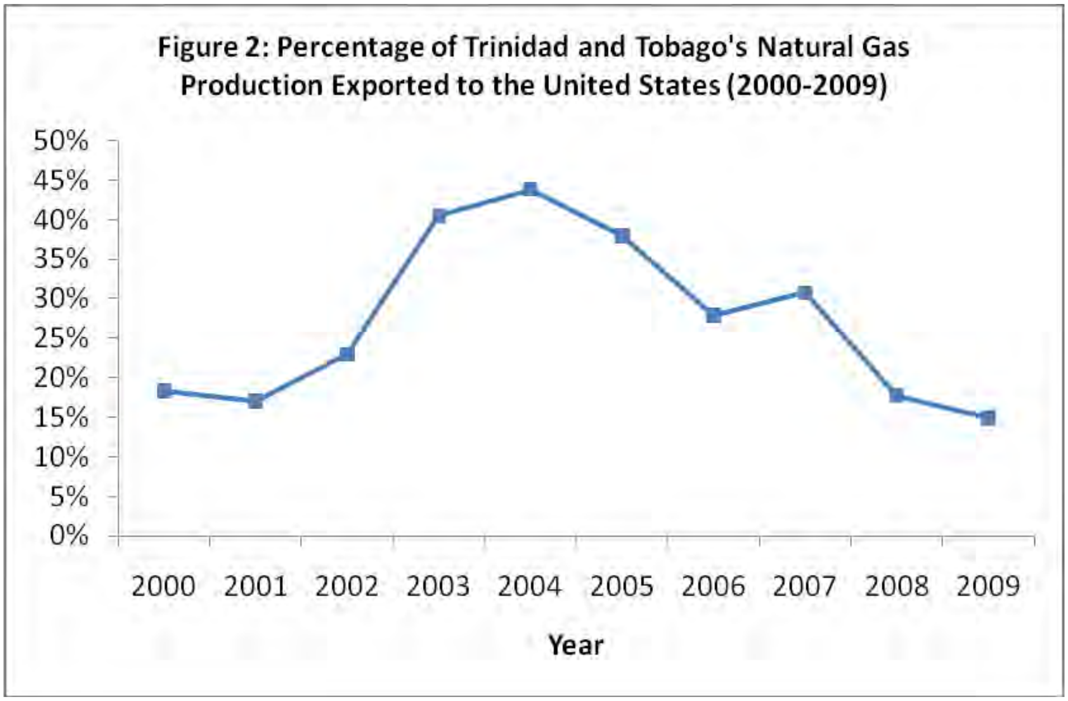


Source: Central Bank of Trinidad and Tobago. 2009. Annual Economic Survey.

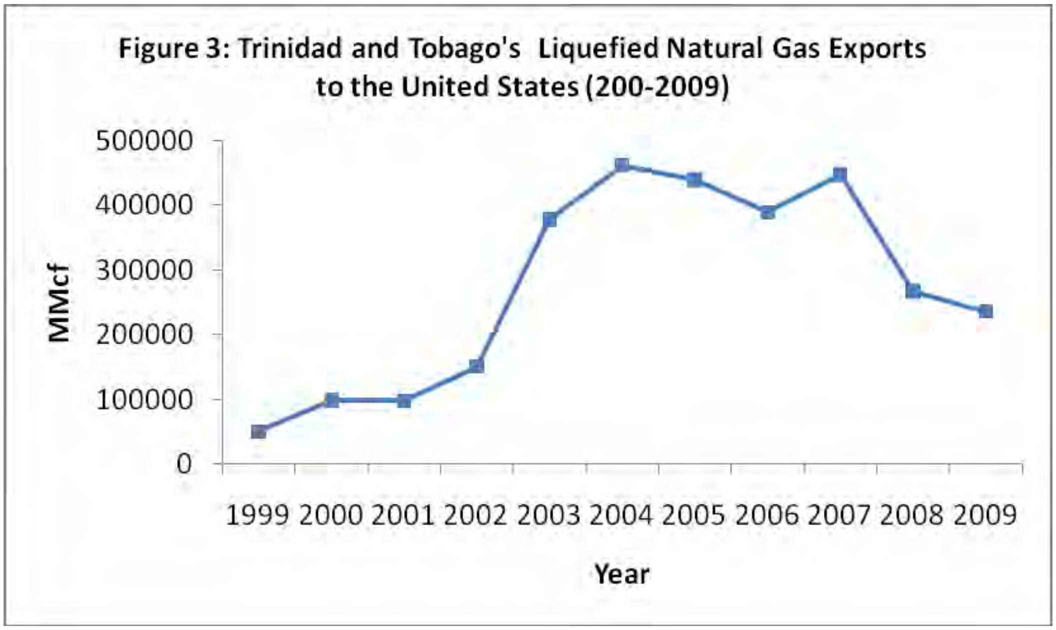
The energy sector plays an important role in the economy of Trinidad and Tobago. In 2008, the share of the energy sector in gross domestic product (GDP) amounted to approximately 48% while contributing 57% to total Government revenue. In the same year, the sector's share of merchandise export was 88%, made up mainly of refined oil products including petroleum, LNG and natural gas liquids (Central Bank of Trinidad and Tobago, 2009).

B. ENERGY EXPORTS

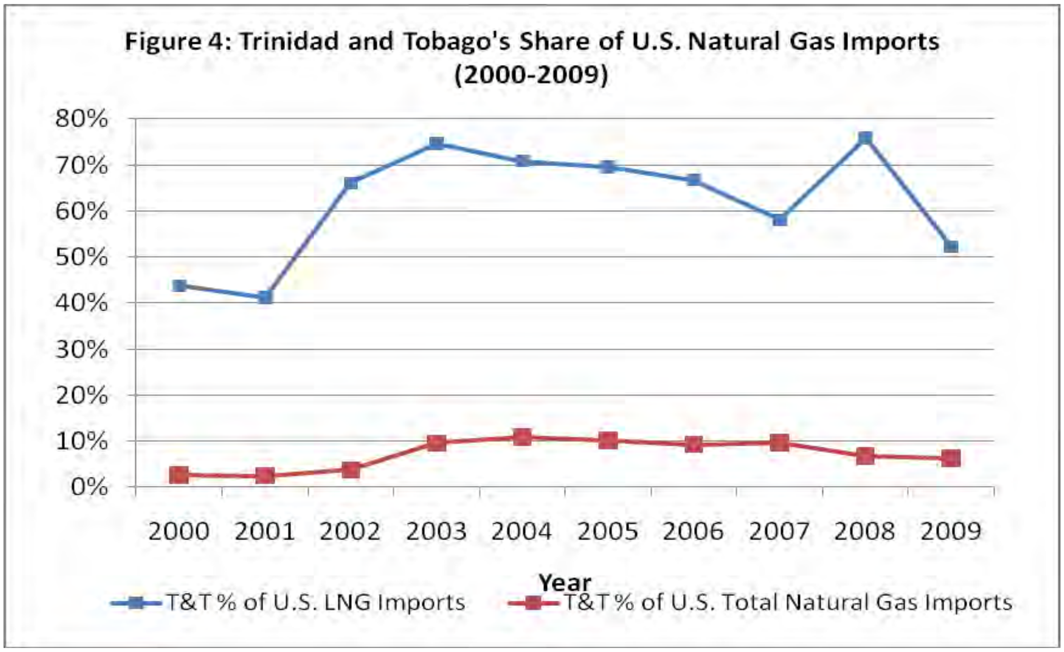
The United States of America has historically been a major importer of Trinidad and Tobago natural gas products. The percentage of Trinidad and Tobago gas products exported to the United States of America grew from 18% in 2000 to about 44% in 2004, representing a 26% point gain within a five-year period. The share of natural gas production exported to the United States of America has, however, declined since 2004, reaching a low of 15% in 2009 (see figure 2). Trinidad and Tobago LNG exports to the United States of America reflect a trend similar to that shown by natural gas over the same period (see figure 3).



Source: United States Energy Information Administration, International Energy Statistics.



Source: United States Energy Information Administration, International Energy Statistics.

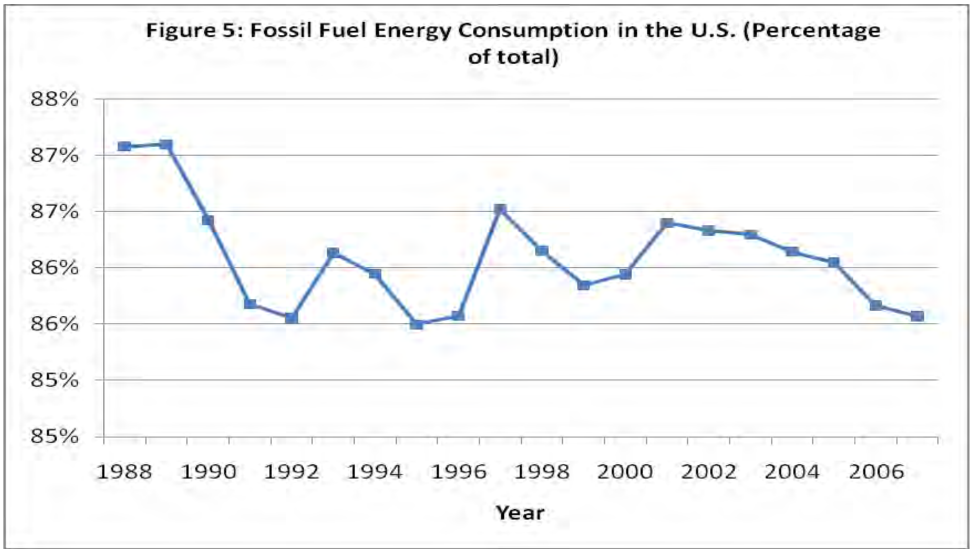


Source: United States Energy Information Administration, International Energy Statistics.

Trinidad and Tobago is the dominant exporter of LNG to the United States market. Between 2002 and 2006, imports from Trinidad and Tobago represented more than 66% of all LNG imports by the United States. The highest share of approximately 76% was recorded in 2008 but, by the following year, the share of LNG imports by the United States of America from Trinidad and Tobago had declined sharply to 52% (see figure 4).

C. CLIMATE CHANGE POLICY FACTORS

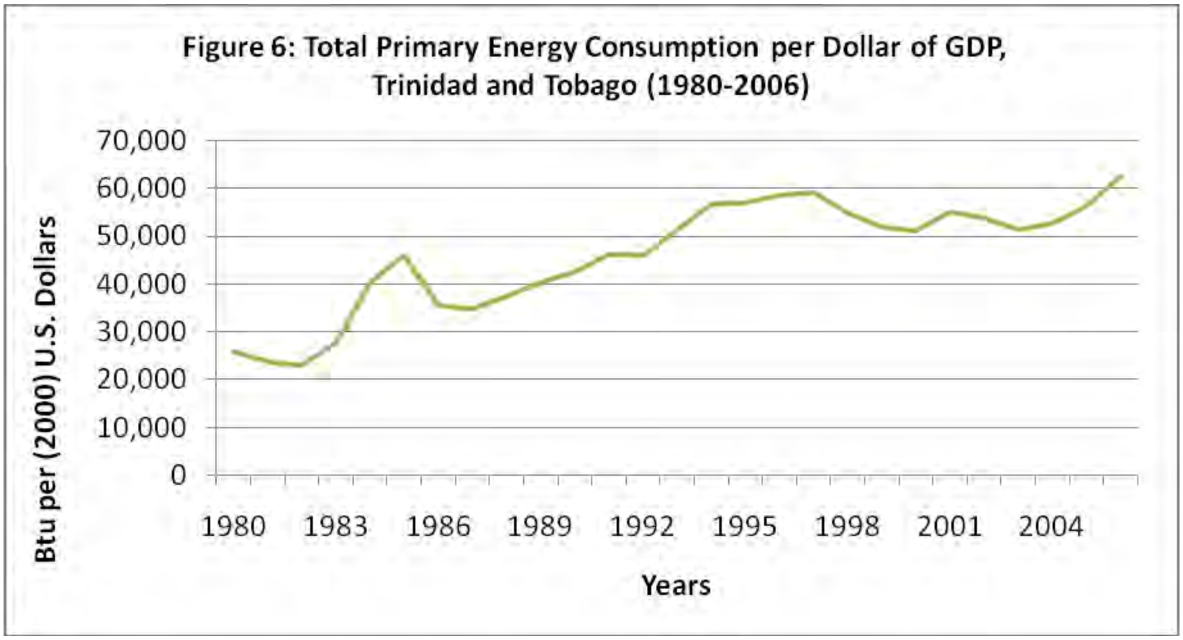
Given the importance of the energy sector in the economy of Trinidad and Tobago, and with the United States of America serving as a major export market for its LNG exports, domestic energy policy in the United States of America as well as global trends in the world oil market are expected to impact on Trinidad and Tobago energy sector export earnings. The United States of America, the world's highest energy intensive country, is currently pursuing a domestic energy policy that is expected to shift consumption away from fossil fuels to renewable energy sources. The Obama administration recently indicated its commitment to reducing dependence on foreign oil by one-third by 2025. Although the impact on fossil fuel energy consumption is still marginal, consumption of fossil fuel energy by the United States of America as a proportion of total energy has been declining consistently since 2001 (see figure 5). If the United States of America and other emerging economies such as China and India were to adopt a climate change policy that emphasizes GHG emission mitigation, and invest considerably in renewable energy, then a shift away from fossil fuel consumption is imminent. This would have significant implications for oil-producing countries like Trinidad and Tobago, whose economies rely heavily on the export of fossil fuels for foreign exchange generation, unless these economies can diversify to absorb the decline in government revenue from crude oil and natural gas (including LNG).



Source: United States Energy Information Administration, International Energy Statistics.

D. ENERGY DEMAND

The importance of the energy sector in Trinidad and Tobago is not restricted to foreign exchange earnings for the Government. The sector plays a critical role in providing energy for commercial, industrial, transport, residential and public purposes. Energy intensity (total primary energy consumption per dollar of GDP) in Trinidad and Tobago has been on an upward trend since the early 1980s, implying that increasing amounts of energy are needed to generate a dollar of GDP in later years relative to earlier years (see figure 6). In absolute terms, energy consumption has been increasing steeply in the industrial and agricultural sectors since 1981, whereas consumption in the residential, commercial and public sectors and the transportation sector have been more or less stable over time (see figure 7).



Source: The World Bank, Country Economic Data.

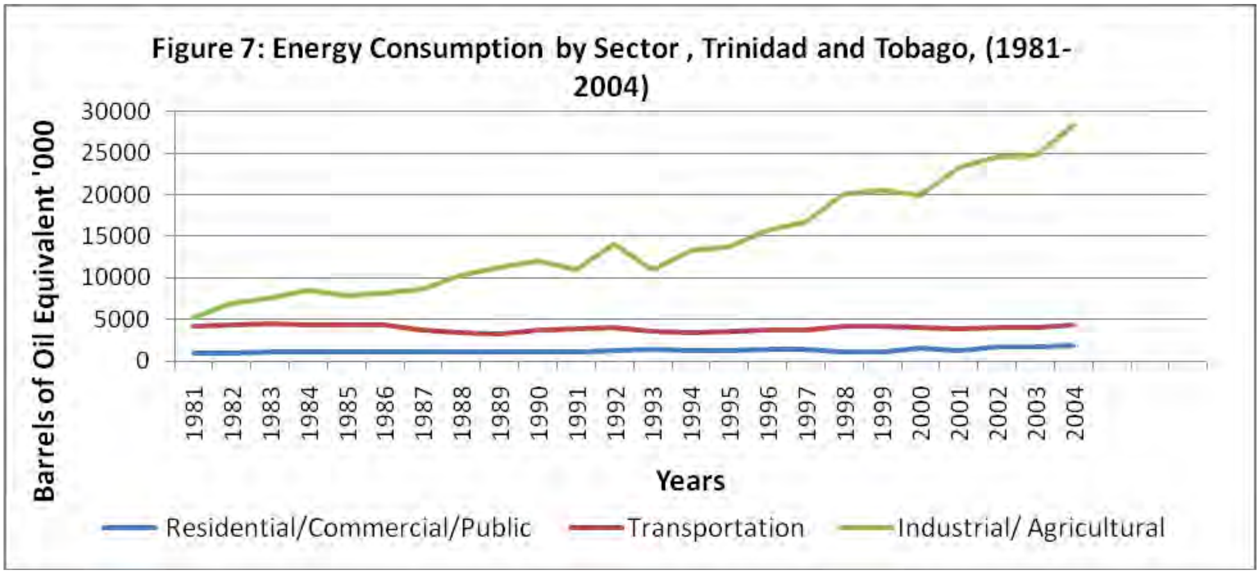
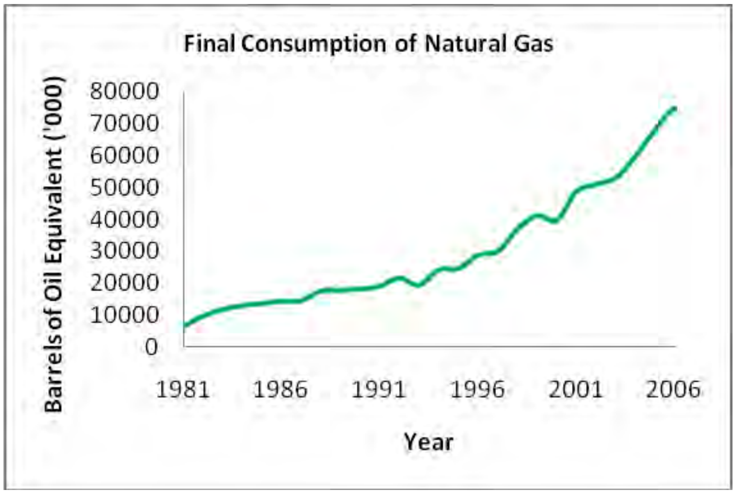


Figure 7: Energy Consumption by Sector , Trinidad and Tobago, (1981-2004)

Source: Ministry of Energy and Energy Affairs. 2011. Energy Balance.

Natural gas is not only a major foreign exchange earner for Trinidad and Tobago. It also serves as a dominant source of domestic energy. As figure 8 shows, final consumption of natural gas has been increasing since 1981. This reflects the fact that electricity is generated predominantly from natural gas on both islands.

Figure 8: Final Consumption of Natural Gas, Trinidad and Tobago (1981-2006)



Source: Ministry of Energy and Energy Affairs. 2011. Energy Balance.

As a major oil producer in the region, Trinidad and Tobago plays an important role in supplying oil products to other Caribbean countries, mainly for transportation and power generation. According to a report by South Trinidad Chamber of Industry and Commerce (2009), Trinidad and Tobago supplies more than 50% of the primary consumption energy in countries such as Jamaica, Barbados, Jamaica, Guyana and the Dominican Republic. Trinidad and Tobago energy services and petroleum marketing companies also export contracted services and distribute and retail petroleum products throughout the region.

III. LITERATURE REVIEW

A. GEOGRAPHICAL AND CLIMATIC CONDITIONS OF TRINIDAD AND TOBAGO

Trinidad and Tobago is considered to be one of the small island developing States (SIDS). The total land area of the twin-island country is 5,126 km^2. Trinidad, the main island, has three major mountain ranges: the Northern Range, which runs east to west across the northern boundary of the island; the Central Range, a hilly zone in the centre of the island with a maximum elevation of 300 metres; and the Southern Range, running along the southern boundary of the island. In Tobago, the Main Ridge covers the north-eastern part while the Southern Lowlands covers the coastal plain. Trinidad and Tobago has two distinct climatic seasons consisting of the dry season that lasts from January to May and the wet season from June to December. The country has a bimodal rainfall pattern with peaks in the months of June, July and November. This rainfall pattern contributes to a perennial flooding problem on the islands, especially in the capital city, Port-of-Spain. With an average annual temperature of 25.7˚ C and average maximum temperatures ranging between 29˚ C and 31˚ C, and average minimum temperatures ranging between 22˚ C and 25˚ C, Trinidad and Tobago as a tropical island experiences relatively warm daytime temperatures and cool night time temperatures (The Republic of Trinidad and Tobago, 2001).

In its initial National Communication under the UNFCCC, Trinidad and Tobago identified flooding as one of the country's major sources of vulnerability. A rise in sea level due to climate change will exacerbate this problem. Existing global climate change research also proposes that rising sea and ocean levels will result in increased instances of intense tropical cyclone activity (IPCC, 2007). While this constitutes a major concern for most Caribbean islands, hurricane events pose a lesser threat to Trinidad and Tobago than the more northerly islands, due to its global position which is situated 11˚ N, just south of the Atlantic hurricane belt (The Republic of Trinidad and Tobago, 2001).

B. VULNERABILITY TO CLIMATE CHANGE OF TRINIDAD AND TOBAGO

A primary objective of UNFCCC is to bring about a reduction of GHG concentrations in the atmosphere to a level that would not interfere with climate systems. In its Initial National Communication under UNFCCC, Trinidad and Tobago discussed the country's role in regard to this effort. In accordance with the requirements of Article 12.1 (a) of the Convention, Trinidad and Tobago National Greenhouse Gas Inventory estimated emission sources and sinks of CO_2, methane ($CH_{4)}$, nitrous oxide (N_2O), oxides of nitrogen ($NO_{X)}$, non-methane volatile organic compounds (NMVOC) and sulphur dioxide ($SO_{2)}$. Various Government agencies, including the Central Bank, the Central Statistical Office (CSO), and the Petroleum Company of Trinidad and Tobago (PETROTRIN), constituted sources of data for the GHG inventory. The inventory showed that CO_2 accounted for 95.4% of the global warming potential (GWP) of the country's emissions. With the main GHG produced by industrial activities being CO_2, the sector contributed 34% of the total anthropogenic CO_2 emissions in 1990. The chemical industries produce ammonia, iron and steel, and the mineral products industries which produce cement accounted for 55%, 41%, and 4% of the sector's GHG emissions, respectively. However, much of the CO_2 emitted during ammonia production is recovered, and later used as feedstock in the manufacture of methanol (The Republic of Trinidad and Tobago, 2001).

The energy sector is the main source of anthropogenic GHG emissions in Trinidad and Tobago. With its hydrocarbon-based economy and small population, Trinidad and Tobago is ranked seventh in the world in terms of carbon dioxide (CO_2) emission per capita, with an estimated 40 million tonnes of CO_2

produced annually. Almost 90% of these CO_2 emissions are attributed directly to the energy sector through petrochemical production (56%), power generation (30%) and flaring (3%) (MEEA, 2011).

Forests and bodies of water remove GHGs from the atmosphere and, as a result, play a key role in controlling GHG concentrations. Despite the fact that, as a Non-Annex 1 country, Trinidad and Tobago is not required under the UNFCCC to take steps to cut GHG emissions, forest cover and land use are important factors to consider in setting climate change mitigation and adaptation strategies. Inasmuch as forests occupy 248,000 hectares of land in the twin-island State, the country's forest soil is particularly prone to erosion which, compounded by poor land management practices, increases the likelihood of flooding and siltation of downstream water sources (The Republic of Trinidad and Tobago, 2001).

PETROTRIN, a major stakeholder in the country's energy sector, has been proactive in assessing the vulnerability of its infrastructure to climate-induced sea-level rise and extreme storm surges. In a study of PETROTRIN infrastructure and operations to storm surge and coastal erosion, Singh and El Fouladi (2006) analysed the vulnerability of PETROTRIN operations on the west coast of the island of Trinidad, from the Vessigny River in the north to Cap-de-Ville in the south, along the Gulf of Paria. Their approach involved the coupling of the Atmosphere-Ocean General Circulation Model (AOGCM) simulations of future sea level rises with The Arbiter of Storms (TAOS) estimates of storm surges, which were then fed into a GIS-based inundation and erosion scheme. The simulations showed that the PETROTRIN field installations at Guapo, and the offshore operations of its marine business enterprise, Trinidad Marine (TRINMAR), are at risk of inundation and erosion resulting from rises in sea level and storm surges.

Certain infrastructure and aspects of PETROTRIN operations were specifically identified as being under threat due to rising sea levels as a result of climate change. These include:

> access roads, power transmission lines, pump jacks, pipelines for the intake of crude and cooling sea water and the outtake of refined products to jetties, storage tanks, refinery installations and administrative buildings, especially along the Gulf of Paria coastline and along the Guaracara River. (Singh and El Fouladi, 2006).

The effects of rising sea levels can be felt both directly and indirectly in the Pointe a Pierre Foreshore area. The consequences of rising sea level and extreme rainfall include the loss and destruction of property as well as disruptions in the transportation of oil as a result of flooding.

The findings of the vulnerability assessment of PETROTRIN operations were derived from the second generation of the Canadian Coupled Global Climate Model (CGCM2) and the third version of the Hadley Coupled Atmosphere-Ocean General Circulation Model (HadCM3) used to estimate future sea level rise for areas around Trinidad up to 2071. The projection of future sea level rise by the first generation of the Canadian Coupled Global Climate Model (CGCM1) indicated that, by 2031, shoreline, beach front areas and a landfill in the Pointe-a-Pierre Foreshore area will be completely inundated, leading to land loss of about 13.51 hectares. The HadCM3 scenario predicts less drastic results with total land loss due to inundation being 9.93 hectares. By 2051, total land loss is estimated to be 25.74 hectares under the CGCM1 scenario, with the most incursions occurring along the Guaracara River and the Regent Park beachfront area in the vicinity of the reclaimed dump site and tank farm. Similar results were found in the HadCM3 model, with total land loss estimated at 9.93 hectares by 2031. According to the CGCM1 model, land loss will be up to 33.47 hectares by 2071.

C. POLICY RESPONSE TO CLIMATE CHANGE

The Government of Trinidad and Tobago has raised the profile of climate change in its policy arena. A climate change policy has been drafted and the Ministry of Energy and Energy Affairs (MEEA) is currently conducting public consultations to inform the drafting of an Energy Policy for the country. Elements of the draft energy policy include strategies for carbon reduction and strategies for introducing renewable energy. Plans for implementing mitigation and adaptation strategies to deal with the effects of climate change have been integrated into national planning; recognizing the fact that climate change affects all sectors of the economy and, if not addressed, can retard steps towards future development (CCP, 2009).

Climate change mitigation strategies under consideration include increased usage of alternative fuels and renewable energy, adoption of cleaner production technology, conservation of natural carbon sinks and implementation of energy efficiency. To foster these, the climate change policy provides "guidance for the development of an appropriate administrative and legislative framework, in harmony with other sectoral policies for the pursuance of low-carbon development path for Trinidad and Tobago" (CCP, 2009). The country has committed itself to lower GHG emissions while improving the performance of all sectors in the country's economic development. The strategies being pursued include increased usage of renewable energy, improved energy efficiency in commercial and residential buildings, fuel switching from gasoline and diesel to compressed natural gas (CNG) in the transportation sector, adoption of cleaner technology in all GHG-emitting sectors, enhancement of natural carbon sinks and maximizing the use of carbon markets. In relation to renewable energy policy, Trinidad and Tobago has identified solar and wind energies as the most viable options for the country. To encourage the use of renewable energy, therefore, fiscal incentives will be instituted to promote domestic use and sale to the national grid. Furthermore, solar powered light emitting diodes (LEDs) will be used to replace conventional street lighting. To increase energy efficiency in buildings, a Green Building Code that enforces the maximization of renewable energy and energy efficiency in both commercial and residential buildings will be developed.

In the transportation sector, fiscal incentives have already been implemented to encourage fuel switching to CNG. A tax incentive has been provided to offset the cost of converting vehicles to CNG by providing tax credit of up to TT$ 10,000 on the cost of CNG kit installation. Use of cleaner energy will be encouraged by retrofitting emitting sectors with cleaner technologies, developing cap-and-trade regimes within and across emitting sectors and making it mandatory for all GHG emitting sectors to monitor emission trends and quantities through inventory, reporting and auditing. The Government also considers it important to protect all natural systems that contribute to carbon sequestration, inclusive of forestry. In terms of international efforts, the Government recognizes the importance of acceding to international GHG emission strategies. This includes participation in the Clean Development Mechanism (CDM) of the Kyoto Protocol and providing incentives for participation in domestic cap-and-trade regimes. The critical role of research and development in finding new and improved means of attaining energy efficiency has been highlighted in the climate change strategies being pursued by Trinidad and Tobago. In particular, the climate change policy of the Government targets the development and manufacture of raw materials to be used for renewable energy technologies, such as fuel cells and solar cells. Research is also to be intensified to develop technology to capture and store carbon as part of efforts towards carbon sequestration.

The climate change policy provides for an assessment of the vulnerability of each sector and the formulation of adaptation policies to address them. National development plans will incorporate climate change issues, and the importance of education in achieving policy objectives has not been overlooked. The role of public awareness in the successful implementation of the policy has been acknowledged. The

Government has assured that policies on climate change mitigation and adaption will be integrated in primary and secondary school curricula. There are also plans for the Government to partner tertiary institutions to enhance climate change programmes.

Complementing the climate change policy is the energy policy. The energy policy comprises different strategies that are being proposed as tools to assist in upgrading the country's energy infrastructure to maximize energy efficiency and incorporate renewable energy sources. It entails the recommendation of ways in which the Government can be energy efficient and thereby reduce GHG emissions. This includes carbon reduction strategies that involve increased use of CNG as transportation fuel, more efficient industrial/petrochemical processes, use of combined-cycle technology in electricity generation, as well as increased use of carbon capture and storage (CCS) to reduce GHG emissions. A goal to generate 5% of present peak electricity demand using renewable energy technologies has been set for 2020. This target is expected to be achieved through the introduction of wind, solar and waste-to-energy technologies. It has been projected that wind energy can be used for both bulk power generation and small, independent rural power providers. Solar energy use comprises photovoltaic (PV) and concentrated solar power (CSP) cells. PV energy is cost-effective and suitable for remote areas off the national grid. It can also be connected to the national grid, although such technology is expensive and requires large expanses of land. CSP energy also requires large land areas for its establishment, but it is particularly useful in providing heating and produces steam to drive turbines for electricity generation. Furthermore, there is the option of converting solid waste to energy. Of the three, wind energy has been identified as the preferred method of power generation from renewable energy sources to supply the national grid.

Currently, short term plans for introducing renewable energy in Trinidad and Tobago include use of solar energy for residential and commercial water heating, for water desalination, and in powering PV systems for households, as well as in the agricultural sector. The use of wind energy in the agricultural sector is also receiving favourable attention from the Government. Energy efficiency will be implemented through the use of fluorescent light bulbs and light emitting diodes to replace incandescent light bulbs. In the heavy industry, LNG is the greatest emitter of CO_2 followed by the iron and steel industry. To reduce GHG emissions, a combined cycle technology was introduced in the production of power by Atlantic LNG (ALNG) for its own use. In the longer term, abatement of GHG emission will be of greater importance. Although Trinidad and Tobago is currently developing its carbon reduction strategies, the energy policy suggests that carbon reduction is not an immediate priority (MEEA, 2011).

IV. MODELLING ENERGY DEMAND AND SUPPLY

A. TRADITIONAL MODELS OF ENERGY DEMAND AND SUPPLY

Energy is essential to modern life and its availability, as well as the price at which it can be obtained, constitute matters of national importance, if not security, for nations. The oil crisis of the 1970s brought energy demand studies to the fore of economic research and energy demand has been extensively studied since then. Bhattacharyya and Timilsina (2009) provide a comprehensive compendium of the different models that have been applied in estimating demand for energy. Based on their systematic review of the literature, previous energy demand studies could be broadly categorized according to the level of development of the country being studied, (developed and developing countries), the sector of the economy being analysed (residential, commercial, industrial and transport) and the level of sophistication of the forecasting technique used (simple and sophisticated). They also differentiated between models of aggregate demand that focus on primary energy demand and those that focus on specific end-use of energy (for example, electricity). They relate that aggregate demand models were popular in developing countries in earlier days because of the lack of disaggregated, sector-specific data. These models were initially specified as single equation models, usually in a reduced form, but were later modified to include co-integration techniques and error correction methods. However, a major flaw of aggregate energy demand models is the fact that, in most studies using these models, price was found to be insignificant in developing countries, where income drives demand. Also, these models were noted to ignore traditional energies, technological diversities, informal economic activities, structural change and urban-rural divide, which are major factors that drive energy demand in developing economies. The implication is that results derived from aggregated energy demand models may lend little to policymaking in developing countries (Bhattacharyya and Timilsina, 2009).

The foregoing suggests that varieties of energy demand models exist and that no single model is applicable to all situations. The economic foundation of any forecasting model is the most important factor in assessing its usefulness. Therefore, energy demand models should be driven by economic theory. Along this principle, established models have been applied to energy demand analysis in specific sectors whereby certain characteristics of individual sectors are more accurately accounted for in those models. For instance, models derived from utility maximizing behaviour of consumers have been applied to residential energy demand analysis (Bohi, 1981), while models derived from cost minimization behaviour of firms have been applied to energy demand in the industrial and commercial sectors. The rigour of the analytical approach employed in energy demand models is dictated, for the most part, by the availability and quality of data. Simple approaches rely on established parameters such as elasticity of demand, energy use growth rates, and energy intensity to forecast future energy demand. Most of these approaches suffer for want of an underlying economic theory and they all lack the ability to explain those factors that drive energy demand (Bhattacharyya and Timilsina, 2009). In contrast, the more sophisticated models applying econometrics, end-use models, input-output models and scenario building, provide varying levels of detail and are generally data-demanding. Bhattacharyya and Timilsina (2009) surmised that the end-use accounting models perform better in providing realistic projections, but that they suffer from huge data deficiencies, especially in developing countries. In practice, lack of data has necessitated that researchers adopt a pragmatic approach that requires the use of simple approaches that provide realistic results as opposed to the use of sophisticated models that yield unbelievable and/or counter-intuitive results.

A review of empirical literature on energy demand shows that methods outlined by Bhattacharyya and Timilsina (2009) have been employed in various studies. For example, Adams and Shachmurove (2007) used an econometric/energy balance model to project future energy use and import requirements in China. This method estimates the linkages between energy use and the economy. It has an advantage over cost minimization routines in that fuel use is linked to recent empirical realities. In contrast, Akinboade and others (2008) and Al-Azzam and Hawdon (1999) modelled energy demand using a log-linear demand function. While Akinboade and others (2008) modelled gasoline demand as an Autoregressive Distributed Lag (ARDL) process of function of per capita income and the real prices of gasoline in South Africa, Al-Azzam and Hawdon (1999) used a dynamic Ordinary Least Squares (OLS) specification of relative prices, incomes, construction activities and political climate for energy demand in Jordan.

While energy demand has been widely studied, empirical studies of energy supply are hard to find, mainly due to the nature of the energy sector. Non-renewable energy resources are a natural endowment and their supply is limited both in the short-run, due to refinery and exploration capacity limitations, and in the long-run, due to limited reserves. Supply studies, therefore, tend to be proprietorial in nature and are protected by stakeholders.

B. ENERGY DEMAND AND SUPPLY MODELS INCORPORATING CLIMATE CHANGE

Although established models of energy demand are widely available, climate change has introduced a new dimension to how demand for energy is modelled and has also engendered interest in research on renewable sources of energy. However, due to its emerging nature, models incorporating climate change in studies of energy demand and supply are few and still evolving. One central issue in the modelling of the impact of climate change on energy demand is the relationship between global warming and residential energy demand (Cian and others, 2007). This matter has been addressed by Henley and Peirson (1998) for Great Britain, Asadoorian, Eckaus and Schlosser (2008) for China, and the United States of America Climate Change Science Program (CCSP, 2008) for the United States of America. Another class of studies including Beenstock, Goldin, and Nabot (1999) and Stern (2000) employ cointegration techniques. A third class of studies applied dynamic econometric techniques and includes Al-Azzam and Hawdon (1999), Bigano and others (2006), and Cian and others (2007).

Residential energy demand studies typically identify two main, but opposite, effects of increase in global temperature on energy demand. The cooling effect describes the change in energy demand for cooling purposes while the heating effect represents the change in energy use for heating purposes. Studies in this group base their projections on micro-level data fed into microeconometric models to estimate demand. Cian and others (2007) used a dynamic panel analysis to investigate climate change and energy demand. The time series data set spanned 22 years for 31 countries and focused on the residential sector, since the demand for energy in the industrial sector was observed to respond insignificantly to price and temperature changes. The relationship between temperature and energy demand can be captured through the heating and cooling effects. It is expected that, with increases in temperature, less energy will be needed for heating in the winter months (heating effect). The summer months will however be warmer and therefore more energy will be needed for cooling (cooling effect). Some studies have captured this non-linear pattern, among which is Bessec and Fouquau (2008), who used a panel of 15 countries over 20 years to show that a non-linear link exists between electricity consumption and temperature in Europe.

Scenario analysis is another intuitive way of accessing the effects of climate change on energy demand. This involves positing various energy scenarios and then examining the possible energy pathways for the future. Using this approach, Ghanadan and Koomey (2005) examined four energy scenarios for the state of California that included one business as usual (BAU) and three cleaner energy alternative strategies. Each scenario did not represent a prediction of future energy paths, although it did demonstrate that there do exist alternatives to current energy consumption paths that can be more environmentally-friendly than the current situation.

In examining the implications of climate change on the energy sector in the Commonwealth of Massachusetts, Amato and others (2005) focused their analysis on the residential and commercial sectors. Their approach consisted of a two-step process that first used monthly time series data to measure the historic sensitivity of end-use energy demand to temperature variables, after which future energy consumption under different climate change scenarios was estimated using the results obtained from the first step. Amato and others (2005, p. 24) highlighted the main methodological lessons derived from their study. They noted that the possible impact of climate change was dependent on the spatial scale of analysis and, as such, the time period of the data used for such analysis should reflect the intra-annual variation in historic energy demand. This is necessary for the model to capture the climate dynamics that occur throughout the year. Their results also support the notion that it is important to disaggregate data used for energy demand analysis, in order to capture the unique responses of energy types and economic sectors to climate change. In addition, they emphasized the importance of considering the dynamics of historic energy sensitivity in assessing future energy demand responses.

In their study examining changes in energy demand due to climate change, Pilli-Sihvola, Aatola, Ollikainen and Tuomenvirta (2010) adopted a multivariate regression model in analysing the impact of warming climate on the demand for heating and cooling. This involved the use of an econometric time series model to estimate the impact of weather on electricity consumption. The results of the regression model were then used to examine how climate change will impact the cost of electricity use, including carbon costs. They observed that electricity consumption was characterized by a rising trend and seasonal fluctuations.

Employing a similar approach to that of Pilli-Sihvola and others (2010), Mirasgedis, Sarafidis, Georgopoulou, Kotroni, Lagouvardos and Lalas (2006) examined the potential impact of climate change on electricity demand in Greece, through examining changes in demand with respect to climatic, economic, technological and population changes. The methodological framework was implemented in three stages. With respect to climate and socio-economic factors, the sensitivity of electricity demand in the power generation system was first examined. This was done using historical data for ten years to estimate multiple regression models. The next step entailed estimating future climatic conditions using a regional climate model, Providing Regional Climates for Impacts Studies (PRECIS). Following IPCC, two different emission scenarios were generated and analysed. In the final step, the previously estimated regression model was used to predict future electricity demand under the different emission scenarios while factoring in changes in the socio-economic factors.

On the supply side, only the United States Climate Change Science Program (USCCSP) (2008) addressed the impact of climate change on energy production and distribution in the United States of America. Temperature and extreme weather events were identified as having the most varied effects on production and distribution, with wind and humidity having some effects as well. Off-shore production facilities were noted to be particularly susceptible to extreme weather events, while variation in temperature and humidity is expected to affect energy production efficiency. USCCSP (2008) reported that the effects of climate change on the existing infrastructure in the United States of America have been modest. The study looked at possible ways in which energy production and distribution can be affected by changes in temperature, precipitation, water resources, severe weather events and rising sea levels. They posited that turbine power output and efficiency fluctuate with changes in temperature and that research indicates that rising sea levels will have a greater impact on onshore than on offshore oil and gas activities. With a great percentage of the United States energy infrastructure lying along the coast, rising sea levels can lead to equipment damage from flooding and erosion, and may necessitate relocation or retrofitting of oil facilities. Also, future development of energy resource technology can be complicated by the unpredictability of climatic conditions.

In studying the impact of climate change on energy demand and supply, many of the existing studies focus on the economic phenomenon of climate change while ignoring the social effects. Integrated Assessment Models (IAMs) try to bridge this gap by combining the scientific and socio-economic aspects of climate change for climate change control (Kelly and Kolstad, 1999). IAMs differ in their use and composition and vary in scope from policy evaluation, to assessing the cost-benefit of adaptation and mitigation, to minimization of costs to achieve a particular climate control goal.

The Energy and Climate Policy and Scenario Evaluation (ECLIPSE) model is a class of IAM that represents a policy analysis tool offering some flexibility for treating uncertainties in climate change policy analysis (Turton, 2008). The ECLIPSE model builds on the Energy Research and Investment Strategy (ERIS) model. ECLIPSE and ERIS are both bottom-up energy-systems models that explore the long-term (to 2100) relationship between energy, transport systems and the wider economy. While IAMs are a good attempt at providing a more comprehensive climate change policy analysis tool, they have the limitation of not adequately capturing the relationships between sectors.

The Integrated Model to Assess the Global Environment (IMAGE) is a "global, single-region model describing global trends in driving forces and the ensuing consequences for climatic change and impacts on key sectors through a coupled set of modules representing the main processes involved" (Bouwman and others, 2006). IMAGE deciphers the dynamics of the interaction of humans with their environment. It examines how human activities in industry, housing, transport, agriculture and forestry place pressure on the natural system. IMAGE incorporates demographics, energy supply and demand, agricultural demand and the trade and production, land cover and land use, carbon cycle, nutrients and climate variability. Basically, the model assesses changes in land cover, climate and the carbon and nitrogen cycles by using physical indicators for the energy industry and agricultural land-use systems.

The Long Range Energy Alternatives Planning System (LEAP) [1] is another model used in formulating energy policies and in assessing climate change mitigation. It is particularly useful in identifying greenhouse gas emission sources and sinks and in analysing the emission of local and regional air pollutants. LEAP supports numerous modelling methodologies for both the demand and the supply side. Demand side methodologies supported include bottom-up, end-use accounting techniques, top-down macroeconomic modelling, and stock-turnover modelling used in fields like transport planning. It supports accounting and simulation methodologies that can be used to model electric sector generation and capacity expansion planning on the supply side.

Lucena, Schaeffer and Salem (2010) used integrated energy models to calculate least-cost adaptation options for certain effects of climate change on an electric power system in Brazil. A parametric long-term energy demand projection model called Model for Analysis of Energy Demand (MAED) and an energy supply optimization model called Model for Energy Supply Strategy Alternatives and their General Environment impact (MESSAGE) were employed for this purpose. MAED provides the sectoral energy demand projections based on demographic evolution, economic development, technology advances and lifestyle changes, while MESSAGE provides the least-cost energy and electricity supply mix scenario. The study adopted the IPCC emission scenarios.

C. STUDY OF ENERGY DEMAND AND SUPPLY IN THE CARIBBEAN

The Caribbean islands, being SIDS, are considered vulnerable to the effects of global warming. In recent years, studies have been conducted on energy demand and climate change in the region. Contreras-Lisperguer and de Cuba (2008), in their assessment of the potential impact of climate change on the energy sector, noted that the effects of climate change can be detrimental to both the consumption and production of traditional and renewable energy systems within the region. Energy production can be affected through limited water availability, changes in temperature and humidity and extreme weather patterns. Also, climate change can affect hydropower systems, biofuel production systems, the operation of wind farms, solar energy systems and geothermal energy production systems. Specifically, the vulnerabilities of the sector to the effects of climate change include variations in temperature and precipitation on timing of peak electricity demand, weather-related energy supply disruption resulting from increased intensity and frequency of severe weather events, and increased incidence of power outages due to higher electricity demand for cooling induced by higher temperatures.

Complementing the qualitative work of Contreras-Lisperguer and de Cuba (2008) is the empirical analysis of climate change effects on the Caribbean (John, n.d.). Separate OLS models were used to estimate the impact of climate change on energy use in Barbados, the Dominican Republic, Guyana, Jamaica, and Trinidad and Tobago. The results indicated that energy use is positively related to temperature and oil prices. The relationship between energy use and temperature conforms to

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[1] http://www.energycommunity.org/default.asp?action=47

expectation, but the positive relationship between oil prices and energy use was contrary to expectation. John (n.d.) attributed this to the economic growth-energy utilization nexus which may be clouding the real relationship that exists between oil prices and energy use. Although not discussed in the study, another possible explanation is the use of OLS to fit regression models using times series data. While the use of OLS in fitting times series data may be ideal if series are stationary, no unit root tests were reported in the study to assist in verifying the stationarity of data series. Unit root testing is important since it has been recognized that most time series data are non-stationary and that applying OLS to non-stationary data results in spurious regressions.

Using the results of the energy demand model, John (n.d) employed different scenarios to estimate the future impact of climate change. This entailed a baseline case scenario assuming no change in temperature patterns up to the year 2100. This was then compared to the A2 and B2 climate scenarios. The results indicated that, for the period 2010 to 2100, temperature-induced energy use change was higher for the B2 than for the A2 scenario for Guyana, higher for the A2 than the B2 scenario for the Dominican Republic and Trinidad and Tobago, and negative for the baseline case scenario for Trinidad and Tobago.

Climate change studies have been hampered by numerous constraints. Limited data availability is one such constraint, especially for studies done in developing countries. In this context, Asadoorian and others (2008, p.1579) stated that the “availability of data at relatively low levels of disaggregation is essentially the „horse that pulls the carriage‟” in formulating their econometric models of electricity demand that incorporate climate change variables.

V. METHODOLOGY

A. ANALYTICAL FRAMEWORK

The methodological approach adopted for the present study is informed by the review of the literature on energy demand and supply modelling in the context of climate change, and on the availability and quality of data to operationalize postulated theoretical models. Since energy demand models have sound economic foundation, an econometric approach has been adopted in estimating the relationship between economic and climate variables on one hand and energy demand on the other. This will make it possible to isolate the impact of these factors on future energy demand. On the supply side, a scenario-building approach that looks at a number of factors and how they might affect the production and supply of fossil fuels in the future has been adopted. Key among these is the way climate change adaptation and mitigation strategies pursued by major energy-consuming nations could impact the world energy market. Other important factors include short-run supply limitations due to refinery capacity constraints, long-run supply limitations constrained by energy reserves, and disruptions in supply due to sea level rise and extreme weather events.

This approach is implemented within the framework set for conducting the Economics of Climate Change in Latin America and the Caribbean (ECLAC, 2009a) and as used for the Economics of Climate Change in Central America (ECLAC 2010a) study. Within this framework, a “baseline” scenario for economic factors that does not take the impact of climate change into account is defined. Under this baseline scenario of no climate change, electricity consumption was projected from 2011 to 2050 using historical data, and then the change in electricity consumption due to temperature was forecast from the projected baseline scenario under the A2 and B2 temperature trajectories. The value of the deviation in yearly electricity consumption under the A2 and B2 scenarios when compared to the baseline represents the climate change impact on electricity consumption.

In order to estimate this demand-side impact of climate change on the energy sector, an approach similar to that used by Amato and others (2005) for Massachusetts and by Pilli-Sihvola and others (2010) for European Union (EU) countries was used. This involves first establishing the historical relationship between electricity consumption and associated economic and climatic variables. This is achieved by estimating a demand function from historical data and using the parameter estimates from the demand function to predict future changes in electricity consumption resulting from projected temperature values under the A2 and B2 climate scenarios. The results of forecast energy demand are then used to estimate the economic impact of climate change (using temperature as the proxy) on energy demand. The economic impact figures are reported in US dollars as well as proportion of GDP.

The supply side analysis is limited by data availability; only the impact of possible foreign government climate change policies on energy (LNG) production for export could be analysed. Lack of engineering data on the extent to which sea level rise and extreme weather events could impact oil production and/or transportation at PETROTRIN and other oil-company facilities imply that no reliable estimate could be made for direct impact of climate change on energy production.

Considering the impact of climate change on energy consumption, an economic assessment of alternative climate change adaptation options using cost-benefit analysis (CBA) was performed. The CBA results formed the basis for proffering policy recommendations.

B. EMPIRICAL MODELS

1. Baseline projection for electricity consumption

In constructing a baseline for electricity consumption under the baseline of no climate change, it was observed that the historical trend of electricity consumption per capita from 1980 to 2007 showed a rising trend. Hence, a linear trend was specified for electricity consumption per capita as follows:

$$ECPC_t = \beta_0 + \beta_1 Year + \varepsilon_t \quad (1),$$

where *ECPC* is per capita electricity consumption;

Year is the corresponding year in which electricity is consumed;

ε is an error term; and

t is the year index.

The estimated coefficient of the *Year* variable (β_1) represents the annual increase in per capita electricity consumption. Using this coefficient, a baseline projection for electricity consumption per capita in future years was performed by adding the forecasted amount of annual increase in electricity consumption per year to the immediate year’s value.

2. Energy demand model

Informed by the empirical literature on energy demand studies that account for climate change, it is hypothesized that the impact of climate change on energy consumption in Trinidad and Tobago will be reflected in the response of energy demand to variations in temperature. Therefore, in estimating the demand for energy in the context of climate change, temperature becomes an important explanatory variable, in addition to the usual economic variables such as income and prices, and demographic variables such as population. Consequently, the demand function for energy is implicitly specified as:

$$Q_d = f(Price, Income, Temp, Population), \qquad (2)$$

where Q_d is quantity of energy consumed;

Price is price of energy or a price index for energy goods;

Income is a measure of national income, typically represented by gross domestic product (GDP);

Temp is average temperature; and

Population is the population of the country.

Different specifications of this generic model are possible when empirically estimating and forecasting demand for energy. The dependent variable, quantity of energy consumed, may be estimated as total consumption or as per capita consumption. The model may be estimated using variables at the level or after differencing. The variables may also be transformed through the choice of a functional form for estimation. The choice of a particular approach or combination of approaches will largely be dictated by the availability of data and the performance of the model results.

For the current study, data limitations restricted the estimation of a demand function for electricity only. For the same reasons, demand for electricity could not be estimated at the sectoral level, hence, only an aggregate demand function for electricity was estimated. Price of energy is regulated in Trinidad and Tobago and electricity price is fixed for many years at a time. This reality implied that the price variable does not contain enough variations to provide useful information for estimating quantity of electricity consumed in response to price. This was confirmed in preliminary estimations with the price variable consistently returning insignificant coefficients and at times with an unintuitive sign. Hence, the final demand function for electricity demand in Trinidad and Tobago was specified as:

$$LnECPC_t = \beta_0 + \beta_1 \ln GDPPC_t + \beta_2 \ln Temp_t + \varepsilon_t, \qquad (3)$$

where *GDPPC* is GDP per capita;

Temp is average annual temperature;

Ln is natural logarithm; and

ECPC, ε, and *t* are as previously defined.

3. Energy supply model

The scenario analysis of energy supply is based on an implicit supply function of the form:

$$Q_s = f(Prices, Capacity, Reserve, Sea\ Level, Extreme\ Events, DomPolicy,\ IntPolicy) \tag{4}$$

where Q_s is energy supply;

Prices represent prices of different energy forms;

Capacity is national energy production capacity;

Reserve is proven energy reserve for the country;

Sea Level is projected sea level rise;

Extreme Events are extreme weather conditions occasioned by climate change;

DomPolicy represents domestic energy policy; and

IntPolicy represents climate change policy of major stakeholders in the world energy market.

These factors are combined to simulate scenarios for energy production for export that could result for Trinidad and Tobago over the next four decades as these factors take on different values that reflect different circumstances. This approach was applied to simulate LNG production for the export market and the implications of future projected supply of LNG for export for the economy.

4. Forecasting climate change impacts on the demand and supply of energy

Climate change variables in the demand and supply models were based on two climate scenarios: A2 and B2. The projected changes in demand and supply under these alternative climate scenarios are individually compared with the projection for the baseline of no climate change. The A2 scenario represents a high emission trajectory with relatively weak global environmental concerns while the B2 scenario represents a low emission trajectory that is "characterized by increased concern for environmental and social sustainability" (ECLAC 2009b, p.7).

For the demand model, the impact of temperature on per capita electricity consumption was measured by the magnitude of β_2, which shows the elasticity of per capita electricity consumption due to changes in average annual temperature. Using the trajectory for future temperature under A2 and B2 climate scenarios, the projected year-to-year percentage change in temperature was computed, and then the corresponding percentage change in per capita electricity consumption was calculated by multiplying the year-to-year percentage change in temperature by the elasticity estimate (β_2). The forecast for future changes in electricity consumption per capita for a particular year as a result of climate change was calculated by multiplying the percentage change in per capita electricity consumption by the baseline projection for electricity consumption for that year.

For the supply side analysis, emphasis was placed on estimating the possible impact of policy measures that could be implemented by major stakeholders in the world energy market in response to climate change. Rather than provide a unique estimate of impact as is the case for the demand model, this approach will reflect possible "*if-then*" situations that depict what the resultant impact on energy supply for export would be if certain conditions were to exist.

C. DATA

Several sources were used for data collection for the present study. These sources include the Ministry of Energy and Energy Affairs (MEEA, 2011), the Central Bank of Trinidad and Tobago (2009), the Central Statistical Office of Trinidad and Tobago (CSO), the World Bank, the International Energy Agency (IEA), the United States Energy Information Administration (EIA), the Power Generation Company of Trinidad and Tobago (POWERGEN), Trinidad and Tobago Electricity Company (TTEC), and the Climate Change group at the University of the West Indies.

Macroeconomic data, including data on GDP and the performance of the energy sector, were collated from several issues of Annual Economic Survey and Economic Bulletin both published by the Central Bank of Trinidad and Tobago. Socioeconomic data, including data on price indices, were collected from several issues of Economic Statistics published by CSO. Collection of energy data was more challenging as there were few available publications of MEEA in the public domain. Data on energy balance, prices of energy goods and natural gas reserve were supplied by MEEA officials. POWERGEN provided data on electricity generation while TTEC supplied data on electricity consumption by consumer category and the rates charged to the various customer categories. Data from Trinidad and Tobago sources were largely supplemented with data from international sources. Historical data on electricity power consumption and production and per capita real GDP were sourced from the World Bank World databank (World Bank, n.d.). Data on energy trade were collected from multiple sources including Statistical Review of World Energy published by BP (BP, 2010), International Energy Statistics (IES) of the EIA (US EIA, n.d.) and from the IEA (IEA, 2010).

Climatological data on temperature, rainfall and sea level pressure were based on regional model (RCM) and PRECIS and forced by ECHAM. These include simulated A2 and B2 scenarios for these variables. Historical data on rainfall were provided by the Climate Section, Trinidad and Tobago Meteorological Services. Climatological data were sourced through the Department of Physics, The University of West Indies (UWI), Mona, and the Climate Change Group at UWI. Apart from climatological data and data sourced from the World Bank that date back to 1960, most data series were available from 1980 to 2007. A few macroeconomic data were available until the year 2010. Many of the data series were available as national aggregates and not by sector. Apart from climatological data, power generation data and commercial consumption of electricity that were reported as monthly observations, all other series were annual series. This has implications for the energy demand analysis since seasonal variation in demand could not be accounted for by using annual series.

D. MODEL ESTIMATION

Time series data usually are non-stationary and present a challenge for estimation when using the OLS estimation technique as they are known to produce spurious regression results in such cases. Therefore, it is necessary to establish the stationary status of variables in the empirical model before deciding on an estimator to use. If data series are non-stationary but are shown to be co-integrated of the same order, then OLS could still be applied as an estimator. Stationarity of data series were examined using the Augmented Dickey-Fuller test for unit root.

In the presence of cointegration, and when more than one endogenous variable is included in the model, a Vector Error Correction Model (VECM) can be used. They are particularly useful in discriminating between short-run adjustment effects and long run relations (Juselius, 2007). However, based on the order of integration of the data series, VECM may not be an appropriate estimator. The

Autoregressive Distributed Lag (ARDL) approach to integration (Pesaran and others, 2001) is a relatively new technique that has an advantage over the traditional cointegration approach in that it could handle data series that include variables with different orders of integration. This method has recently been applied by Dergiades and Tsoulfidis (2008) to estimate electricity demand by residential consumers in the United States of America, by Akinboade and others (2008) to estimate gasoline demand in South Africa, and by Odhiambo (2010) to estimate energy consumption in sub-Saharan African countries.

The presence of variables with mixed order of integration necessitated that the ARDL approach be used in this study. The ARDL approach was applied in estimating a long-run model to examine the impact of climate change, represented by change in temperature, on per capita consumption of electricity in Trinidad and Tobago, while accounting for the influence of GDP on electricity consumption as well. This was done by estimating the following Unrestricted Error Correction Model (UECM) by OLS:

$$\begin{aligned}\Delta LnECPC_t &= \alpha_0 + \sum_{i=1}^{n} \alpha_{1i} \Delta \ln ECPC_{t-i} + \sum_{i=0}^{n} \alpha_{2i} \Delta \ln GDPPC_{t-i} + \sum_{i=0}^{n} \alpha_{3i} \Delta \ln Temp_{t-i} + \alpha_4 \ln ECPC_{t-1} \\ &\quad + \alpha_5 GDP_{t-1} + \alpha_6 Temp_{t-1} + v_t \end{aligned} \qquad (5).$$

The optimal lag lengths (*n*) were determined using the Akaike Information Criterion (AIC) and the Schwartz Information Criterion (SIC) from series of estimation using alternative lag lengths. Once the optimal lag lengths were established, equation (5) was then re-estimated with the optimal lag lengths. In order to establish whether the variables are cointegrated, ARDL-bounds test were performed by jointly testing for the significance of the lagged level explanatory variable and pre-determined variable in the UECM. This is equivalent to a null hypothesis of $\alpha_4 = \alpha_5 = \alpha_6 = 0$ against the alternative that at least one of the parameters is not equal to zero. In the presence of cointegration, the null hypothesis should be rejected in favour of the alternative. Cointegration in this situation implies that the variables have a long-run relationship and the long-run elasticities are calculated in terms of the UECM coefficients as follows:

$$\beta_1 = -\frac{\alpha_5}{\alpha_4} \qquad \beta_2 = -\frac{\alpha_6}{\alpha_4} \qquad (6)$$

In addition, the short-run dynamics are established via the following Error Correction Model (ECM):

$$\Delta LnECPC_t = \theta_0 + \sum_{i=1}^{n} \theta_{1i} \Delta \ln ECPC_{t-i} + \sum_{i=0}^{n} \theta_{2i} \Delta \ln GDPPC_{t-i} + \sum_{i=0}^{n} \theta_{3i} \Delta \ln Temp_{t-i} + \theta_4 ECT_{t-1} + e_t \qquad (7)$$

where ECT is the error correction term (residuals) from the UECM.

All econometric models were estimated using EViews version 6. Diagnostic tests were done to establish robustness of estimated models and the reliability of the model forecast. Tests of normality were performed on residuals using the Jarque-Bera test. The null hypothesis of no serial correlation was tested for using the Breusch-Godfrey LM test. The null hypothesis of no ARCH was tested for using the F-statistics. Model misspecification was tested for using the Ramsey RESET test. The stability test on the estimated coefficient was performed using the Cumulative Sum of Recursive Residuals (CUSUM) and CUSUM of Squares tests.

E. COST-BENEFIT ANALYSIS

CBA was performed on alternative climate change adaptation options that could be implemented in the energy sector. The choice of adaptation options for assessment was informed by the IPCC (2007) Synthesis Report and the draft energy policy of Trinidad and Tobago, that suggest general and specific climate change adaptation options, respectively, for the Government to consider. CBA was conducted by calculating the sunk cost (capital cost) that would be required for a particular adaptation option to be implemented. Then the operating costs and the benefits of adapting were projected to 2050. Benefits of adaptation were measured in two ways. The direct benefit from adaptation was measured in terms of the cost savings achieved by implementing an adaptation option. The indirect benefit was measured in terms of the value of CO_2 abated from the implementation of an adaptation option. The stream of future costs and benefits were then discounted to their present value using 1%, 2%, and 4% discount rates. CBA results are presented using two different instruments: Net Present Value (NPV) and Benefit Cost Ratio (BCR). A NPV greater than zero indicates that a strategy is cost-effective, that is, the benefit from implementing it is greater than the cost to implement it. Conversely, a BCR greater than one signifies that an option is cost-effective, that is, every dollar invested in the option yields more than a dollar in benefits. Either instrument would produce the same conclusion, in the sense that an adaptation option with a positive NPV must generate a BCR greater than unity. The difference between the two is that, while NPV provides an absolute measure of cost-effectiveness, BCR provides a relative measure. The two measures are calculated as follows:

$$NPV = \sum_{t=1}^{T} \frac{B_t}{(1+r)^{t-1}} - \sum_{t=1}^{T} \frac{C_t}{(1+r)^{t-1}} B_t \qquad (8)$$

$$BCR = \frac{\sum_{t=1}^{T} \frac{B_t}{(1+r)^{t-1}}}{\sum_{t=1}^{T} \frac{C_t}{(1+r)^{t-1}}} \qquad (9)$$

where *NPV* is net present value;

BCR is benefit-cost ratio;

B is the value of benefit from adaptation in a particular year;

C is the cost of adaptation in a particular year;

r is annual discount rate; and

t is a time index with value of one for the first year of implementing an adaptation option.

In performing the CBA, adaptation was assumed to start in 2011 and the stream of costs and benefits were estimated from 2011 to 2050. The NPV and BCR for the present study indicate the cost-effectiveness of adaptation for the 40-year period. In addition, NPV was calculated as a proportion of

2009 GDP to provide a measure of the magnitude of costs or benefits that could accrue to the Trinidad and Tobago economy from the implementation of a particular climate change adaptation option.

VI. RESULTS

A. BASELINE PROJECTION

The results of OLS estimation of equation (1) representing the trend in electricity consumption per capita in Trinidad and Tobago is reported in table 1. The coefficient of the year variable is statistically significant at 1% level and implies that electricity consumption per capita increases by 111.572 kWh every year. The $\overline{R}^2$ indicates that the estimated equation explains 87.6% of historical variations in electricity consumption per capita.

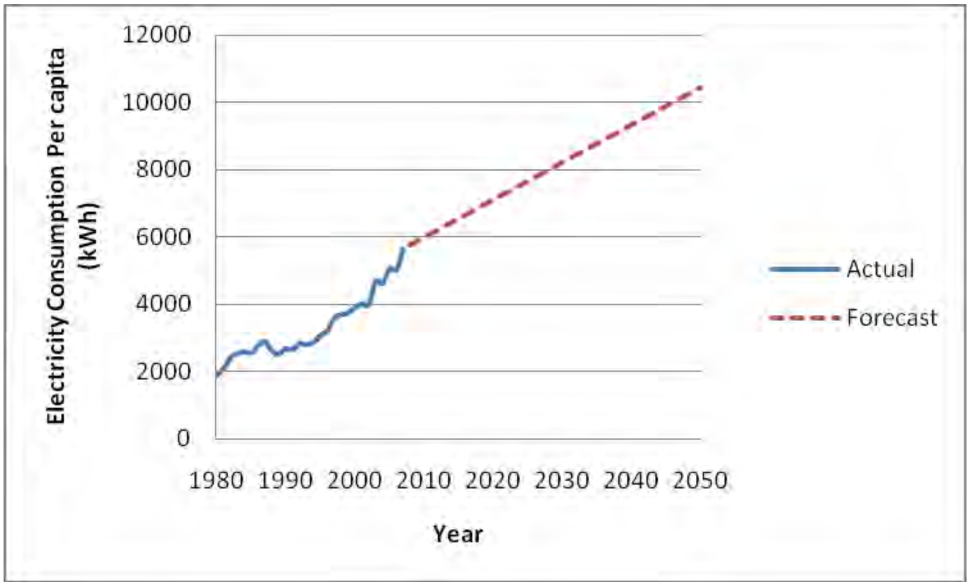
Table 1: Results of linear trend equation for projecting baseline scenario of electricity consumption per capita for Trinidad and Tobago

Variable	**Coefficient**	**Std. Error**
Constant	-2.19×10^5	1.60×10^4***
Year	111.572	8.048***
$\overline{R}^2 = 0.876$		
F-stat. = 1.7897		
Log Likelihood = -202.2297		

*** represents statistical significance at 1%.

Based on the good fit observed, the coefficient estimate reported in table 1 was used to make a projection for the baseline scenario for electricity consumption from 2011 to 2050. This approach assumes that the growth observed in the past 27 years for electricity consumption per capita in Trinidad and Tobago will continue for the next 40 years. This conforms to the methodological approach of ECLAC (2009a) for projecting economic scenarios. Figure 9 shows actual and projected per capita consumption of electricity for the baseline scenario resulting from this approach.

Figure 9: Projection of electricity consumption per capita for Trinidad and Tobago under the baseline scenario (2011-2050)



Source: Data compiled by author

B. STATIONARITY AND COINTEGRATION TESTS

Results of unit root tests performed on data series indicated that temperature was stationary, I(0), while per capita GDP and per capita electricity consumption were non-stationary, I(1). The ADF test results for unit root are reported in table 2 and show that annual average temperature is stationary while annual electricity consumption per capita and GDP per capita are both integrated of the first order. With data series in the demand model consisting of a combination of I(0) and I(I) series, it was necessary to conduct a test of cointegration to establish that the variables have a long-run relationship. This was done via the ARDL approach.

Table 2: Results of Augmented Dickey-Fuller Test of Unit Root

Variable	P-value for level test			P-value for first difference test			Order of integration
	Intercept only	Intercept & trend	No intercept, no trend	Intercept only	Intercept & trend	No intercept, no trend	
ECPC	0.999	0.977	1.000	0.000***	0.000***	0.120	I(1)
GDPPC	0.965	1.000	0.904	0.229	0.072*	0.050*	I(1)
Temp	0.246	0.018***	0.971				I(0)

Source: Data compiled by author

***, **, and * represent statistical significance at 1%, 5% and 10% level, respectively.

The results of OLS estimation of equation (5) are presented in table 3 for the optimal lag lengths along with model diagnostics. The estimated model does not suffer from normality problem, serial correlation, autoregressive heteroskedasticity, nor model misspecification. In addition, results of stability tests of model coefficients using CUSUM and CUSUM of Squares are presented in figures 10 and 11, respectively. They both show that the estimated parameters are stable and within 5% significance bounds. With the model performing satisfactorily, a test of cointegration was performed using the Wald test. The results, presented in the last row of table 3 show that the null hypothesis of no cointegration was rejected at the 1% level, implying that electricity consumption per capita, GDP per capita and temperature have a long-run relationship in Trinidad and Tobago.

Table 3: Results of Unrestricted Error Correction Model for electricity consumption per capita in Trinidad and Tobago

Variable	Coefficient	Std. Error
Constant	-9.2084**	4.1777
$\Delta \ln ECPC_{t-1}$	-0.3023*	0.1731
$\Delta \ln GDPPC_{t-1}$	0.5555**	0.2504
$\Delta \ln Temp_{t}$	1.9699*	1.1259
$\ln ECPC_{t-1}$	-0.3388***	0.0839
$\ln GDPPC_{t-1}$	0.1776***	0.0586
$\ln Temp_{t-1}$	3.1511**	1.3462
$\overline{R}^2 = 0.4404$		
F-stat = 4.2793		
Log Likelihood = 48.5230		
Durbin-Watson = 2.1910		

Diagnostic Test	F-stat/JB-stat	P-value
Breusch-Godfrey LM test	0.5370	0.5941
ARCH(2)	0.5909	0.5628
Ramsey RESET(2)	0.0026	0.9974
Jarque-Bera test	0.0507	0.9750

Cointegration Test	F-stat	P-value
$\alpha_4 = \alpha_5 = \alpha_6 = 0$	5.976***	0.0048

Source: Data compiled by author

***, **, and * represent statistical significance at the1%, 5% and 10% levels, respectively.

Figure 10: Graph of CUSUM Test for stability of long-run model coefficients

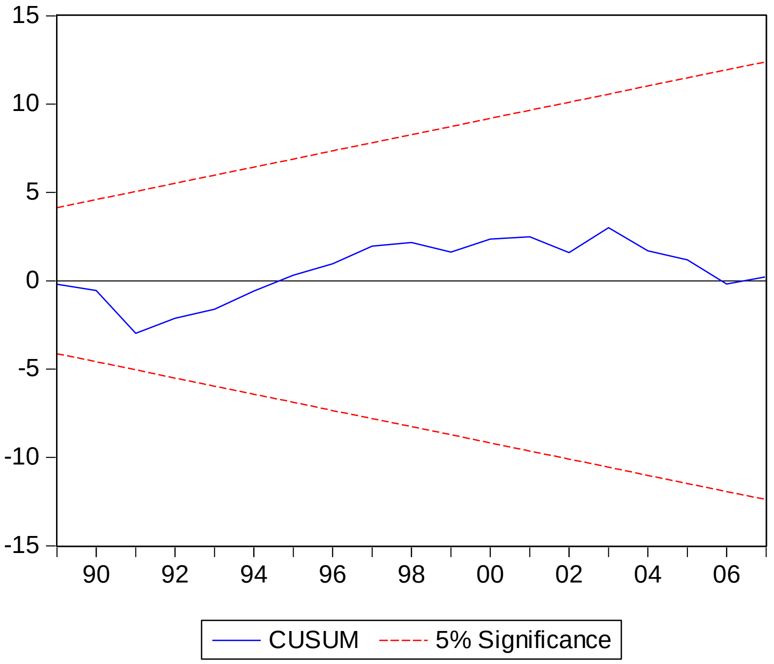
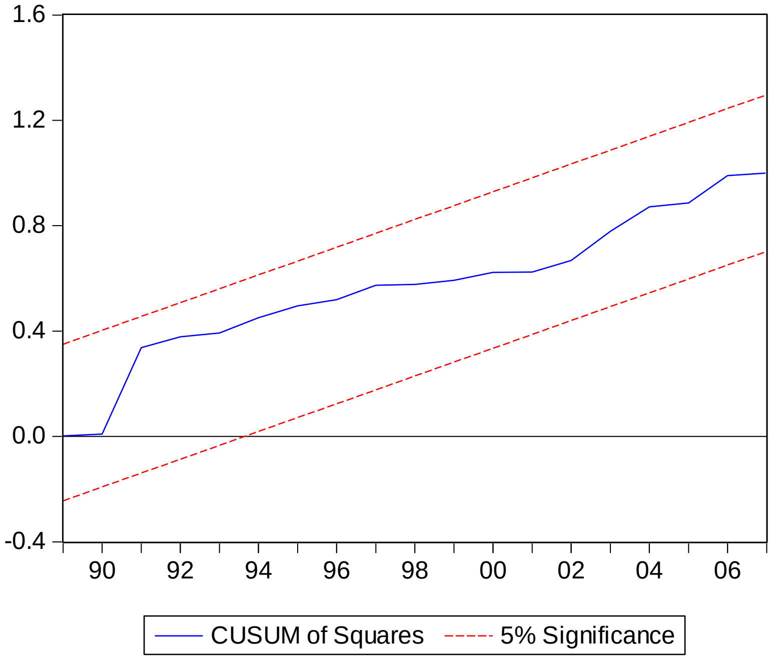


Figure 11: Graph of CUSUM of Squares Test for stability of long-run model coefficients



Source: Data compiled by author

C. IMPACT OF CLIMATE CHANGE ON ELECTRICITY CONSUMPTION

With a long-run relationship established based on results of the UECM between electricity consumption per capita, GDP per capita and temperature, the long-run elasticities were calculated using the relationships presented in equation (6). These elasticity estimates, along with their standard errors, are presented in table 4.

Table 4: Long-run elasticity estimates of electricity consumption per capita for Trinidad and Tobago

Economic variable	Elasticity estimate	Std. Error
GDP per capita	0.524***	0.1514
Temperature	9.302***	2.8181

Source: data compiled by author
*** represents statistical significance at the 1% level.

The elasticity estimate for GDP per capita is a proxy for the income elasticity of electricity consumption, while that for temperature represents the temperature elasticity of electricity consumption. Both estimates are statistically significant at the 1% level and both have the expected positive sign. An elasticity of 0.524 for GDP per capita indicates that electricity is a normal good and electricity per capita is positively impacted by economic growth, but the increase in electricity consumption per capita is inelastic to economic growth with 1% increase in GDP per capita only resulting in a 0.524% increase in electricity consumption per capita. However, a value of 9.302 for *Temp* implies that electricity consumption per capita is elastic to change in temperature with a 1% increase in average annual temperature resulting in 9.3% increase in electricity consumption per capita. The estimates represent long-run impacts of economic growth and climate change on electricity consumption in Trinidad and Tobago. The results of the ECM presented in table 5 represent the dynamics in the short-run when the time period is too short for electricity consumption to adjust fully to all determinants of demand. These results are derived from the estimation of equation (7).

Table 5: Results of Error Correction Model for electricity consumption per capita in Trinidad and Tobago

Variable	Coefficient	Std. Error
Constant	0.0182	0.0125
$\Delta \ln ECPC_{t-1}$	0.2442	0.2363
$\Delta \ln GDPPC_{t-1}$	0.3511**	0.1557
$\Delta \ln Temp_{t}$	1.4489	0.9888
ECT_{t-1}	-0.9426***	0.3201

$\overline{R}^2 = 0.3668$

F-stat = 4.4753

Log Likelihood = 45.3789

Durbin-Watson = 1.8923

Diagnostic Test	**F-stat/JB-stat**	**Prob.**
Breusch-Godfrey LM test	0.2605	0.7735
ARCH(2)	0.0141	0.9860
Ramsey RESET(2)	0.5518	0.5854
Jarque-Bera test	0.4134	0.8133

Source: Data compiled by author
***, **, and * represent statistical significance at the 1%, 5% and 10% levels, respectively.

As shown in table 5, the coefficient of the error correction term has the expected negative sign and is statistically significant at the 1% level. This provides further evidence that a long-run relationship exists between electricity consumption per capita, on one hand, and GDP per capita and temperature, on the other. The coefficient of ECT_{t-1} shows the speed of adjustment of short-run deviations in electricity consumption per capita to the long-run equilibrium. The results also indicate that only economic growth has a significant impact on electricity consumption per capita in the short run, with only the coefficient of $lnGDPPC_{t-1}$ being significant at the 5% level. Variations in temperature have no significant impact on electricity consumption per capita in the short run.

Results of diagnostic tests performed on the short-run electricity demand model and reported in table 5 indicate that the model does not suffer from a normality problem, serial correlation, autoregressive heteroskedasticity, nor model misspecification. Results of CUSUM and CUSUM of Squares stability tests which confirm the stability of model coefficient estimates are presented in figures 12 and 13.

Figure 12: Graph of CUSUM Test for stability of short-run model coefficients

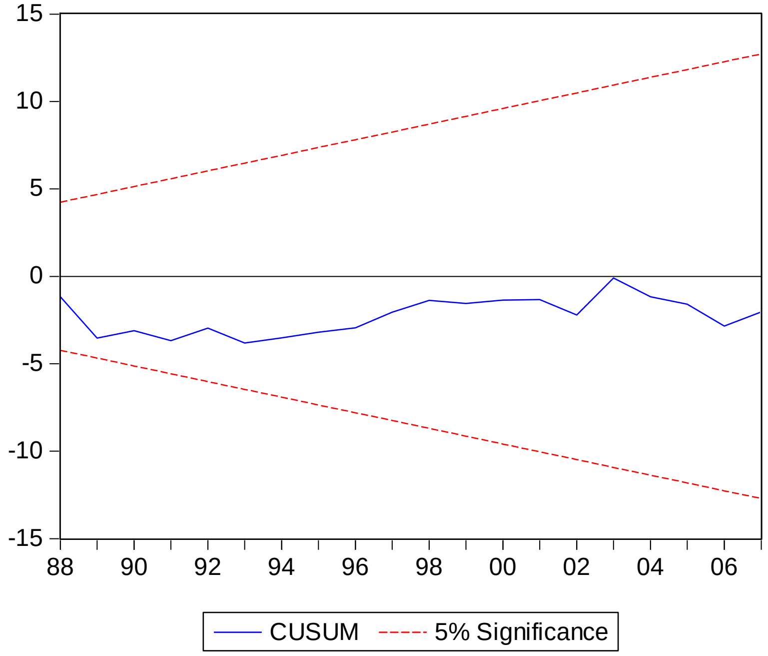
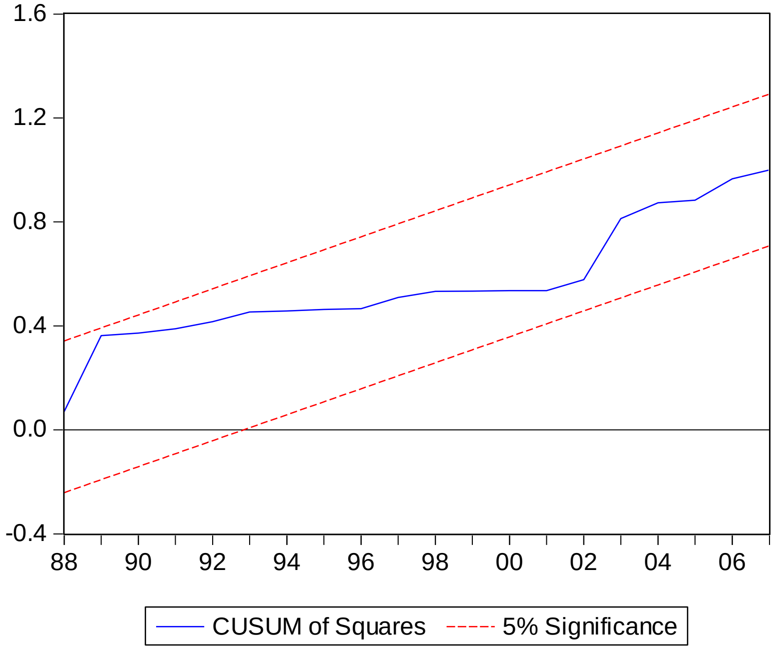


Figure 13: Graph of CUSUM of Squares Test for stability of short-run model coefficients

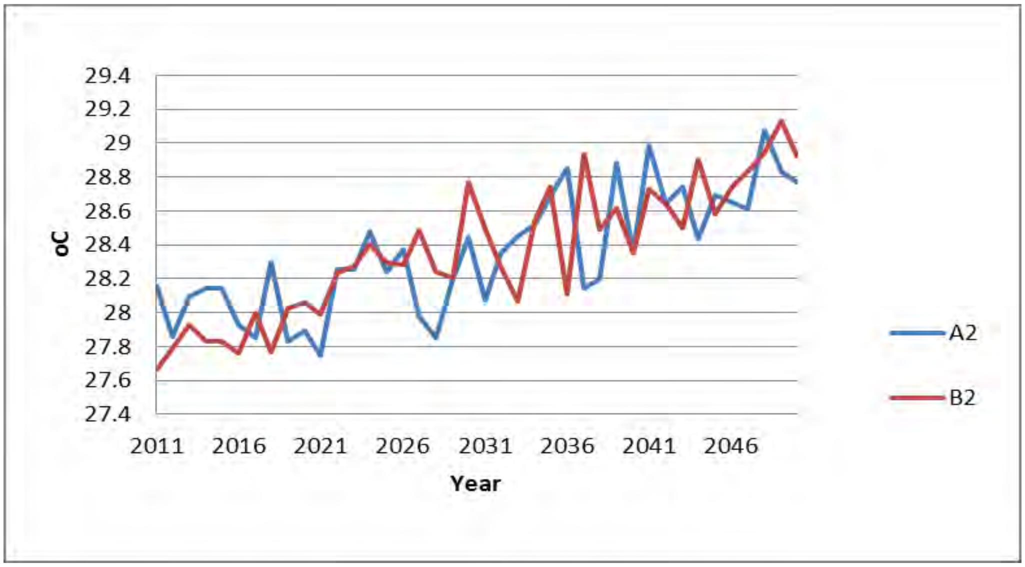


Source: Data compiled by author

1. Economic impact estimates

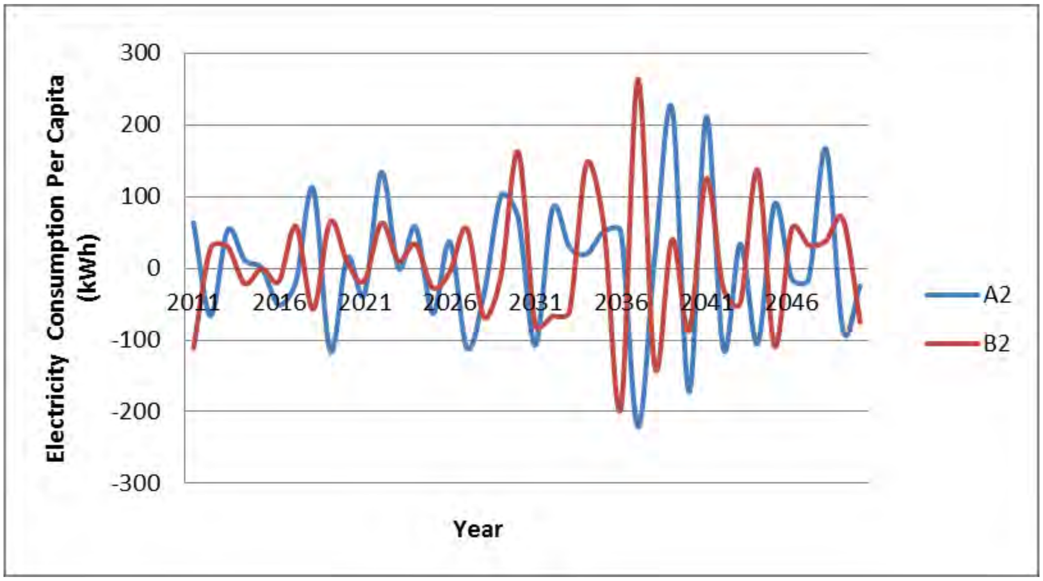
Using the estimated temperature elasticity of electricity consumption of 9.302 and the temperature trajectory for Trinidad and Tobago under A2 and B2 scenarios, forecasts for future changes in per capita electricty consumption resulting from year-to-year variation in temperature were generated. The trajectory for future annual temperature for Trinidad and Tobago under A2 and B2 is shown in figure 14 while the projection of future change in electricity consumption as a result of temperature change is presented in figure 15. Changes in electricity consumption per capita represented in figure 15 are relative to the baseline projection and show deviations from the baseline forecast. The level of electricity consumption per capita for the baseline and A2 and B2 scenarios are shown in figure 16. These projections of future consumption of electricity on a per capita basis are influenced by the pattern of temperature change and show higher volatility in later decades than in earlier ones. As a result, no one scenario gave a consistently higher or lower prediction of the level of electricity consumption per capita for the entire 40-year forecast period.

Figure 14: Temperature trajectory under A2 and B2 scenarios for Trinidad and Tobago (2011-2050)



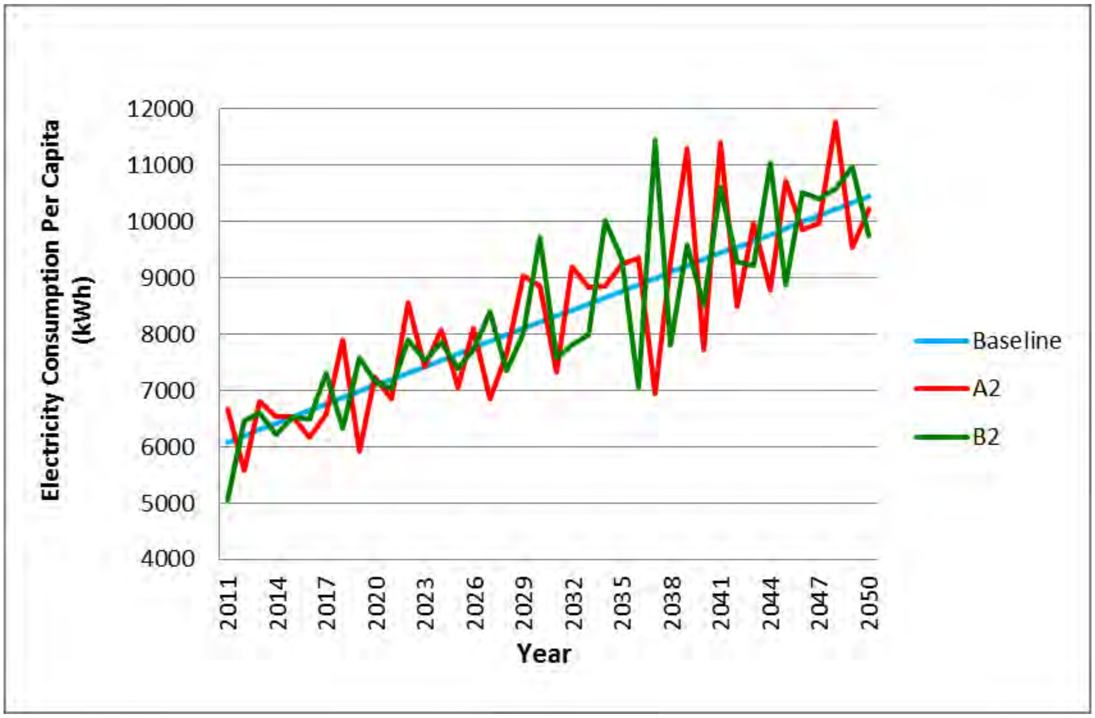
Source: Data compiled by author

Figure 15: Forecast change in future electricity consumption per capita due to climate change for Trinidad and Tobago (2011-2050)



Source: Data compiled by author

Figure 16: Forecast electricity consumption per capita under different climate scenarios for Trinidad and Tobago (2011-2050)



Source: Data compiled by author

On a decadal basis, forecast changes in electricity consumption per capita show that, for the A2 scenario, electricity consumption per capita will increase during 2011-2020 whereas, for the B2 scenario, electricity consumption per capita will decline for the same period. Both scenarios show increases in electricity consumption per capita during 2021-2030 and 2041-2050 but a decrease in electricity consumption per capita during 2031-2040. Over the 40-year period, electricity consumption will increase on average for both scenarios. Specifically, as reported in table 6, electricity consumption per capita will increase by an average of 3.14 kWh annually under A2, but decrease by an average of 16.12 kWh under B2 during 2011-2020. During 2021-2030, electricity consumption per capita will increase by an average of 143.76 kWh annually under A2, and by an average of 185.66 kWh annually under B2. During 2031-2040, electricity consumption per capita will decrease by an average of 20.66 kWh annually under A2, and by an average of 107.72 kWh annually under B2. In the final forecast decade (2041-2050), electricity consumption per capita will increase by an average of 134.28 kWh annually under A2, and by an average of 184.03 kWh annually under B2. Over the entire period of 2011-2050, electricity consumption per capita is projected to increase on average by 65.13 kWh annually under A2, and by 61.46 kWh annually under B2. Therefore, the A2 scenario will lead to higher consumption of electricity than the B2 scenario over the entire forecast period, although electricity consumption under the B2 scenario will be more varied from year to year and from decade to decade. The projected average annual change in electricity consumption per capita for the A2 scenario represents an annual increase of 1.07% over the 2011 baseline value of electricity consumption per capita, while that for the B2 scenario represents an annual increase of 1.01% over the 2011 baseline value of electricity consumption per capita.

Table 6: Annual change in electricity consumption per capita (kWh) in Trinidad and Tobago due to climate change (2011-2050)

Period	**Climate scenario**	
	A2	**B2**
2011-2020	3.15	-16.12
2021-2030	143.76	185.66
2031-2040	-20.66	-107.72
2041-2050	134.28	184.03
2011-2050	65.13	61.46

Source: Data compiled by author

The total cost of meeting the additional demand for electricity during years of temperature increase and the savings in cost of electricity during years of temperature decrease were estimated for the entire population using the current electricity tariff of TT$ 0.26 per kWh for residential customers and assuming that this tariff will not change for the 40-year forecast period. These estimated net costs, representing the economic impact of climate change on electricity consumption for the Trinidad and Tobago economy, are shown in table 7.

Table 7: Economic impact of climate change on electricity consumption in Trinidad and Tobago (2011-2050)

Period	Economic impact at different discount rates (US$ million*) (Percentage of 2009 GDP)							
	A2				B2			
	0%	1%	2%	4%	0%	1%	2%	4%
2011-2020	1.727 (0.009)	3.195 (0.016)	4.538 (0.023)	6.895 (0.036)	-8.841 (0.046)	-11.204 (0.058)	-13.377 (0.069)	-17.217 (0.089)
2021-2030	78.841 (0.407)	67.987 (0.351)	58.829 (0.303)	44.485 (0.230)	101.82 (0.525)	86.451 (0.446)	73.616 (0.380)	53.839 (0.278)
2031-2040	-11.331 (0.058)	-8.167 (0.042)	-5.923 (0.031)	-3.190 (0.016)	-59.077 (0.305)	-47.143 (0.243)	-37.817 (0.195)	-24.689 (0.127)
2041-2050	73.643 (0.380)	54.262 (0.0280)	40.111 (0.207)	22.129 (0.114)	100.93 (0.520)	73.154 (0.377)	53.215 (0.274)	28.464 (0.147)
2011-2050	142.88 (0.737)	117.28 (0.605)	97.55 (0.503)	70.32 (0.363)	134.83 (0.695)	101.26 (0.522)	75.64 (0.390)	40.40 (0.208)

Source: Data compiled by author

* Using the monthly average selling rate of US$ 1=TT$ 6.40 by the Central Bank of Trinidad and Tobago for December 2010.

Table 7 represents net costs of electricity consumption due to climate change for Trinidad and Tobago for 10-year periods and for the 40-year forecast period. The values in parentheses below the figures represent the corresponding proportions of costs to 2009 GDP. The economic impact estimates indicate that the B2 scenario will result in electricity cost savings during the 2011-2020 and 2031-2040 decades. The A2 scenario, however, only results in cost savings during the period 2031-2040. The economic impact under the A2 scenario ranges from US$ 1.727 million when no discounting is applied, to a present value of US$ 6.895 million with a 4% discount rate for the first decade. For the second and fourth decadal periods under the A2 scenario, impact ranges from US$ 44.485 million with a 4% discount rate to US$ 78.841 million with no discounting; and from US$ 22.13 million with a 4% discounting to US$ 73.643 million when no discounting is applied, respectively. During the decade 2031-2040, however, the A2 scenario will result in cost savings that range between US$ 3.19 million with 4% discounting and US$ 11.331 million without discounting.

In the case of the B2 scenario, cost savings range from US$ 8.841 million with no discounting to US$ 17.217 million with a 4% discount rate for the 2011-2020 decade; and from US$ 24.689 million at a 4% discount rate to US$ 59.077 million without discounting, for the 2031-2040 decade. Conversely, for the 2021-2030 and 2041-2050 decades, the B2 scenario results in additional costs. The costs range from US$ 53.839 million at a 4% discount rate to US$ 101.82 million without discounting, for the 2021-2030 decade; and from US$ 28.464 million at a 4% discount rate to US$ 100.93 million without discounting, for the 2041-2050 decade.

For the entire 40-year period, the economic impact of climate change generates costs to the economy for both the A2 and B2 scenarios and for all discount rates. The economic impact ranges from US$ 70.32 million under the A2 scenario at a 4% discount rate to US$ 142.88 million under the A2 scenario when no discounting is applied. In the case of the B2 scenario, economic impact ranges from

US$ 40.40 million at a 4% discount rate to US$ 134.83 million when no discounting is applied. As a proportion of GDP, these economic impact estimates represent 0.737% of 2009 GDP for the case of no discounting and 0.363% of 2009 GDP for the case of a 4% discount rate under A2. Similarly, for the B2 scenario, the economic impact estimates represent 0.695% of 2009 GDP for the case of no discounting, and 0.208% when a 4% discount rate is applied. When economic impact estimates under the A2 and B2 scenarios are compared, A2 results in higher costs over the entire 2011-2050 period and for all discount rates.

The results of the electricity demand model indicate that habit or culture of electricity use, economic growth, and climate change (as reflected by changes in temperature) will have an impact on average electricity consumption in Trinidad and Tobago in the long-run. However, in the short-run, only economic growth drives electricity consumption in Trinidad and Tobago, and patterns of behaviour and climate change play no significant role. This finding is intuitive since behaviour patterns take time to develop and a specific pattern or culture of electricity usage may not be developed in the short-run. Also, with the rapid economic growth experienced by Trinidad and Tobago over the last two decades, it is justifiable that improvements in the standard of living of the populace may have resulted in the use of more electronic gadgets in the residential sector, and modern technologies and appliances in the manufacturing and commercial sectors. All of these changes in consumption patterns have the potential to increase the demand for electricity. Given that electricity is heavily subsidized in Trinidad and Tobago, and the fact that there has been a steady increase in the purchasing power of consumers as a result of economic growth, the results suggest that electricity consumers have been using electricity irrespective of changes in temperature in the immediate term. It is only in the long run that electricity consumption will be responsive to temperature change. Consequently, future climate change-induced alterations in electricity demand are predicted to have minimal economic impact equivalent to losing 0.737% of 2009 GDP for the entire 40-year period from 2011 to 2050 under the A2 scenario or 0.695% of 2009 GDP for the same period under the B2 scenario.

D. IMPACT OF CLIMATE CHANGE POLICIES ON EXPORTS OF LIQUID NATURAL GAS

As a net exporter of energy and a country whose economy depends on energy exports, the impact of climate change on the Trinidad and Tobago energy supply will be mostly driven by the climate change policies pursued by energy exporting countries. In 2009, one-third (33.84%) of Trinidad and Tobago LNG exports went to the United States of America, and another one-third (34.80%) to Spain, the United Kingdom and France combined. Less than 1% (0.41%) of Trinidad and Tobago LNG exports went to China, and 3.4% to India. Trinidad and Tobago exports to the United States of America accounted for more than half (52.19%) of United States LNG imports. Trinidad and Tobago LNG exports to China and India accounted for 1.05% and 5.39% of LNG imports of each country, respectively (BP, 2010).

When the foregoing is measured against the trend in domestic production and consumption of natural gas, a clear pattern is discernible. Between 1999 and 2009, domestic production of natural gas in the United States of America increased by 11.27% while consumption only increased marginally by 1.92%. This contrasts with the situation in China and India within the same time period. Domestic production of natural gas in China increased by 238.10% whereas consumption increased by 312.56%. In India, domestic production of natural gas increased by 56.57% against an increase of 106.77% in consumption. In 2009, the United States of America accounted for 20.1% of world natural gas production and 22.2% of world natural gas consumption. In contrast, China accounted for 2.8% of world natural gas production and 3% of consumption, while India accounted for 1.3% of world production and 1.8% of world consumption. With both China and India representing more than one-third (37%) of world population and projected to remain the two most populous countries by 2050 (PRB, 2008), the energy policies pursued by these countries in general, and more specifically the climate change mitigation strategies adopted, will be major determinants of future world trade in fossil fuels.

The Obama administration recently declared its resolve to reduce United States of America dependence on foreign oil by one-third by 2025. Using 2009 figures, and assuming that the policy results in an across the board reduction by 33% in all energy imports to the United States of America, then the value of Trinidad and Tobago LNG exports to the United States of America in 2009 would have declined by US$ 422 million. Such a reduction in export earnings from LNG would be the equivalent to a 2.2% reduction in GDP for that year. With the rapid growth in domestic production of natural gas in the United States of America and a more or less stagnant growth in consumption, the United States of America is predicted to become a net exporter of natural gas within the next few years. If the United States of America Government policy of energy import substitution is predicated on an aggressive switch to renewable energy, then the decline in foreign oil dependence may be higher than the projected one-third, or the target of one-third reduction may be reached much earlier than 2025. Either of these scenarios has significant implications for the Trinidad and Tobago energy sector, unless a replacement market is found for LNG currently exported to the United States of America.

In China, rapid economic growth has necessitated an increase in the use of energy. China was a net exporter of oil and became a net importer of oil for the first time in 1993. Although coal remains the main source of energy in China, representing about 69% of total energy consumption in 2006, the share of petroleum is substantial, standing at 21% while that of natural gas is only 3% (Ni, 2009). China started importing LNG in 2006 and its LNG imports have increased tremendously since then. China has a clean energy policy that includes a shift to natural gas and hydroelectric power, and its renewable energy strategy involves the development and use of solar, geothermal and wind energies. China is not expected to make a drastic switch from coal to cleaner or renewable energy, but developments in the United States of America and UNFCCC post-Kyoto agreements may signal a change in thrust for China in climate change mitigation strategies. In a BAU scenario of GHG emissions, China may be expected to continue on the path of rapid economic growth with a gradual move to cleaner energies such as natural gas, but with sustained consumption of coal and crude oil to support growth. In an A2 scenario, economic growth continues on a rapid path and the use of cleaner energies gains more prominence as well. Under this scenario, natural gas and hydroelectric power are substituted for coal at a faster pace than in BAU. Under the B2 scenario, environmental sustainability becomes important and the Government, in addition to promoting use of cleaner energy, is encouraging and investing in renewable energy to substitute for coal and crude oil.

The impact of the United States of America policy of foreign fuel substitution on Trinidad and Tobago LNG exports could be analysed under the scenarios developed for China. Under BAU, China will not serve as an alternative market for the lost United States of America market for Trinidad and Tobago LNG. This is because the demand for natural gas by China is not expected to increase significantly with the country’s continued reliance on coal as the primary source of energy. In addition, China has established trade in LNG with Australia and is developing a pipeline with Russia that will supply LNG through Siberia. These factors mean that increase in LNG consumption under BAU can be satisfied from existing or planned additional supply sources.

The situation is different under either the A2 or B2 scenarios. Under A2, China’s consumption of natural gas will increase significantly. This has several implications for the Trinidad and Tobago energy sector. A substantial increase in LNG consumption in China could lead to a significant increase in Trinidad and Tobago LNG exports to China which is expected to more than compensate for the lost United States of America export market, given China’s population. Another possibility is that the price of natural gas on the world market could increase as China and India compete for available supplies. This will translate to higher export earnings from LNG exports for Trinidad and Tobago. Better still, an increase in LNG exports at higher prices could result, should increases in demand and competition among major consumers for available supplies co-exist. The A2 scenario provides the best situation for the Trinidad and Tobago energy sector. In contrast, the B2 scenario does not augur well for Trinidad and Tobago. Under the B2 scenario, China is expected to pursue a climate change mitigation strategy that emphasizes renewable energy and devotes resources to developing renewable energy technology. This implies that growth in the use of natural gas will remain steady, at or below the growth level under the BAU scenario. However, with the emphasis on renewable energy and a marginal increase in consumption of natural gas, China will not provide Trinidad and Tobago with an alternative for the loss of the United States of America export market. In addition, a shift to renewable energy has the potential to depress the price of natural gas on the world oil market. This implies that, under the B2 scenario, LNG export volume and unit price would fall. The consequence would be a decline in export revenue for Trinidad and Tobago.

The scenario analyses of the potential impact of climate change policies of the United States of America and China on the Trinidad and Tobago energy sector presented above are analytical rather that prescriptive. Lack of disaggregated data on energy commodities trade flows, unit price between countries, and transportation costs have limited the supply-side analysis in terms of providing forecasts under the climate change scenarios. As more disaggregated data become available, a Computable General Equilibrium (CGE) model or a trans-shipment model could be applied to forecast LNG export flows from Trinidad and Tobago to major trading partners under the different scenarios.

E. COST-BENEFIT ANALYSIS OF CLIMATE CHANGE ADAPTATION OPTIONS IN THE ENERGY SECTOR

The economic impact estimates show that changes in electricity consumption as a result of climate change would have minimal economic impact, that is, less than 0.1% of 2009 GDP for the 2011-2050 period under each of the A2 and B2 climate scenarios. Arguably, factors other than temperature change drive electricity consumption, and these include patterns of electricity usage and economic growth, as both the long-run and short-run electricity demand models suggest. Consequently, energy efficiency becomes a crucial policy instrument around which adaptation should be developed for the energy sector. This fact is recognized in the energy policy of Trinidad and Tobago currently being drafted. This draft policy emphasizes energy efficiency in the immediate to medium term, and proposes carbon reduction through the introduction of renewable energy to substitute fossil fuel as a long term strategy. The draft policy indicates areas of potential energy efficiency in the energy sector, to include introduction of energy efficient bulbs (CFL and LED), adoption of CNG as an alternative transport fuel, introduction of energy-efficient building codes, and adoption of twin-cycle technology in electricity generation, among others. The draft policy also highlights solar, wind and biomass as viable renewable energy sources for Trinidad and Tobago. Table 8 provides a matrix of adaptation options that promote energy efficiency and the feasibility of their implementation in Trinidad and Tobago.

To further inform the development of the energy policy, CBA was applied to the adoption of CFL bulbs by residential electricity consumers, the introduction of solar water heaters to replace electric water heaters by residential consumers, the introduction of variable refrigerant volume (VRV) air conditioners to replace split air conditioning units in the hospitality industry, and the introduction of CNG to replace gasoline as a transport fuel.

Table 8: Climate change adaptation options with energy efficiency potential for the energy sector in Trinidad and Tobago

Adaptation option	Sectors of impact	Implementation time frame	Policy/tax incentive needed	Required technology	Cost of adaptation
Compact fluorescent light bulbs	Residential Public Industrial	Immediate	Little or none	Available locally	Low
Light emitting diodes	Industrial Public	Immediate	Little or none	Available locally	Low
Solar water heaters	Residential Hospitality	Immediate to Medium term	Medium	Available locally or regionally	Medium
VRV air conditioning	Hospitality Public	Immediate to medium term	Medium	Available internationally	Medium
Compressed natural gas	Transport	Medium to long term	High	Available locally	High
Electric vehicles	Transport	Medium to long term	High	Available internationally	High
Building codes	Housing	Long	High	Available locally	Medium
Retrofitting building with smart electrical switches	Housing Public	Immediate	Little to none	Available locally	Low

1. Compact fluorescent light (CFL) bulbs

Data from the Trinidad and Tobago Electricity Company (TTEC) indicate that there were 376,084 residential electricity consumers in 2010. It was assumed that each consumer represents a household and that each household currently uses ten 60-Watt incandescent (IC) bulbs for four hours per day, every day of the year. The adaptation option considered is to replace these 60-Watt incandescent bulbs with 13-Watt compact fluorescent light (CFL) bulbs in all households. An IC bulb is estimated to have a useful life of 1,500 hours while the lifespan of a CFL bulb is 10,000 hours. The NPV and CBR of switching all households to CFL bulbs were calculated for the 40-year period from 2011 to 2050. This would involve replacing all IC bulbs approximately every year and all CFL bulbs approximately every six years. The price of a 60-Watt IC bulb was estimated to be TT$ 3.99 and that of a CFL bulb to be TT$ 57.99. This would result in a net capital or instalment cost of TT$ 540.00 per household or a capital cost of TT$ 204.75 million for all 379,168 households in the first year of adaptation. At a unit price of TT$ 0.26 per kWh for residential consumers of electricity in Trinidad and Tobago, the cost per household of running light bulbs for the first year would amount to TT$ 227.76 for IC bulbs and TT$ 49.39 for CFL bulbs. Switching from IC to CFL bulbs would therefore save each household TT$ 178.41 in the cost of electricity for the first year, amounting to total savings of TT$ 67.65 million or US$ 10.57 million in electricity costs for all 379,178 residential consumers for the year.

In order to project future costs of electricity, it was assumed that the real unit price of electricity would remain at the same value of TT$ 0.26. Growth in population was projected using a linear trend of historical population for Trinidad and Tobago that suggests that the population would grow at an annual rate of 0.82%. It is assumed that the number of residential electricity consumers would grow at the same rate as the population. This yielded a NPV of US$ 345.20 million for the adaptation option and a payback period of less than 3 years for the initial capital outlay, to be recovered in terms of savings in the cost of electricity. As a proportion of 2009 GDP, NPV represents savings over a 40-year period equivalent to 1.78%.

The adaptation option resulted in a BCR of 1.83, implying that every dollar invested in switching from IC to CFL bulbs will pay for itself and yield a return of 83 cents. In this case, returns would be in the form of lower future electricity costs. When discounting is applied to the yearly net cost of switching, the BCR ranged between 1.80 at a 1% discount rate to 1.77 at a 4% discount rate. Similarly, NPV ranged between US$ 277.51 million at a 1% discount rate and US$ 157.01 million at a 4% discount rate.

In addition to saving households future electricity expenditure, the adaptation option of switching to CFL bulbs also contributes to GHG emission abatement. Reduction in electricity consumption translates into a reduction in the amount of natural gas used for generating electricity. The reduction in CO_2 emissions as a result of implementing the adaptation option was calculated to be 7.74 metric tonnes. If Trinidad and Tobago were to be adequately positioned to participate in the Clean Development Mechanism (CDM), and using a carbon price of US$ 15 per credit, it is estimated that the country could receive a total payment of US$ 116.03 million from carbon trading. If this indirect benefit is accounted for in the total benefits derived from switching to CFL bulbs, then NPV would increase to US$ 461.23 million. The results of the cost-benefit analysis for the CFL bulb adaptation option are presented in the first row of table 9.

Table 9: Results of cost-benefit analysis of climate change adaptation options for the energy sector in Trinidad and Tobago

Adaptation option	**Measure of net benefit at different discount rates**								**CO_2 abatement**	
	Net Present Value (NPV) [1] (US$ million*)				**Benefit-Cost Ratio (BCR)**				**Quantity**	**Value**
	0%	1%	2%	4%	0%	1%	2%	4%	(kt)	(US$ million*)
CFL bulbs	345.20	277.51	226.38	157.01	1.83	1.80	1.77	1.72	7 735.36	116.03
SWH	344.09	278.71	228.85	160.30	4.66	4.29	3.97	3.43	6 194.39	92.92
VRV AC	1.58	0.95	0.50	-0.10	1.06	1.04	1.03	0.99	170.09	2.55
CNG	97.60	75.70	59.33	37.50	1.98	1.90	1.83	1.68	131.26	1.97

Source: Data compiled by author

* Using the monthly average selling rate of US$ 1=TT$ 6.40 by the Central Bank of Trinidad and Tobago for December 2010.

2. Solar water heaters (SWHs)

Based on a previous study conducted by the Engineering Institute at the University of the West Indies (UWI), St. Augustine Campus, 26,538 residential electricity consumers were reported to each have an electric heater (MEEA, 2011). Using this as the potential population for implementing an adaptation option to replace electric water heaters with solar water heaters (SWHs) among residential consumers, a

CBA was performed to estimate the NPV, BCR and the potential payment from carbon trading that such adaptation would yield. The results are reported in the second row of table 9.

A single element electric water heater was estimated to cost TT$ 3,150 while a SWH of equal capacity was estimated to cost TT$ 9,450, resulting in a net cost of installation or a capital outlay of TT$ 6,300 for a residential consumer to adopt a SWH instead of an electric water heater. A single element electric water heater has a lifespan of 10 years while a SWH has a lifespan of 20 years. Based on the UWI study, it was estimated that a single element electric water heater will consume 630 kWh of electricity per month, amounting to a total operating cost of TT$ 1,965.60 per year in electricity charges. This figure represents the potential yearly savings in electricity costs per household by using a SWH instead of an electric water heater. Switching the entire population of consumers using electric water heaters to SWHs will result in a total net installation cost of TT$ 168.56 million for 26,538 residential consumers at a total saving of TT$ 52.59 million or approximately US$ 8.22 million in electricity costs in the first year of switching to SWH. It was assumed that the number of residential electricity consumers using water heaters would grow at the same rate as the projected growth of the general population, and the number of residential consumers using water heaters was forecast to 2050. In addition, it was assumed that the real per unit price of electricity would remain at the 2011 rate. These would result in savings with a NPV of US$ 344.09 million and a BCR of 4.66. Identical to the outcome of the CFL option, switching from electric water heaters to SWHs would save residential consumers electricity costs over the forty year period equivalent to 1.77% of Trinidad and Tobago 2009 GDP. CBA also indicates that every dollar invested in a SWH would pay for itself and yield a return of $ 3.66. When the stream of costs is discounted, NPV ranged from US$ 278.71 million at a 1% discount rate to US$ 160.30 million at a 4% discount rate. BCR also ranged from 4.2 at a 1% discount rate to 3.4 at a 4% discount rate.

Additionally, switching from electric water heaters to SWHs will reduce CO_2 emissions, as a reduction in electricity consumption would lead to a reduction in power plant utilization of natural gas for electricity production. It is estimated that, over the forty-year period of implementing the adaptation option, a total of 6.01 metric tonnes of CO_2 would be abated, worth US$ 92.92 million in carbon credit payments to Trinidad and Tobago. When this indirect benefit from implementing the adaptation option is factored into the total benefit, NPV increases to US$ 437.01 million.

3. Variable refrigerant volume (VRV) air conditioners

An adaptation option considered for commercial electricity consumers is the replacement of mini split air conditioners with variable refrigerant volume (VRV) air conditioners. A CBA was performed on the implementation of this adaptation option for the hospitality industry in Trinidad and Tobago. Based on the verified room stock of hotels and guest houses reported in Trinidad and Tobago for 2004 and the occupancy rate (Ministry of Tourism, 2004), it was assumed that 3,000 hotel and guest house rooms will operate an air conditioner for eight hours on average every year. It was further assumed that the rooms are currently operating 1.15 kW/ton mini split air conditioners that could be replaced by 0.9 kW/Ton VRV air conditioners. Results of the CBA are reported in the third row of table 9.

A one-ton mini split air conditioner was estimated to cost TT$ 3,780 and a one-ton VRV air conditioner was estimated to cost TT$ 7,560. The net capital cost of replacing mini split air conditioners with VRV air conditioners is therefore TT$ 3,780 per room. When aggregated for the total stock of hotel and guest house rooms, the total net capital cost of implementing the adaptation option amounts to TT$ 5.67 million. At a unit price of TT$ 0.61 per KWh of electricity for commercial consumers, the net saving in operating cost (electricity charges) per room in the first year of adaptation is TT$ 222.65. When aggregated for the total room stock, the net saving in electricity cost for the first year equals TT$ 0.68

million or approximately US$ 0.11 million. The NPV of implementing the adaptation option for the 40-year period is TT$ 10.09 million and the BCR is 1.06. As a proportion of 2009 GDP, the net savings from implementing the VRV option are negligible, at 0.01%. When the stream of costs is discounted, NPV ranges between US$ 0.95 million at a 1% discount rate and US$ -0.10 million at a 4% discount rate, while BCR ranges between 1.04 at a 1% discount rate and 0.99 at a 4% discount rate. These imply that the adaptation option of replacing split air conditioners with VRVs is only marginally cost-effective at discount rates below 4%. If future costs and benefits are discounted at a 4% rate, the option changes from being a cost-saving to a cost-generating alternative. However, when the indirect benefit of CO_2 abatement resulting from the use of the more energy-efficient VRV system is considered, the adaptation option would be regarded as being cost-effective. This is because 170.09 kt of CO_2 valued at US$ 2.55 million would be abated by switching to VRV air conditioners, resulting in an increase in NPV to US$ 4.13 million. By implementing this adaptation option, the indirect benefit of CO_2 abatement surpasses the direct benefit of savings in electricity costs.

4. Compressed natural gas (CNG)

The results of CBA performed on compressed natural gas (CNG) as an alternative to petrol as a transport fuel are presented in the fourth row of table 9. The adaptation option considered in this case is the conversion of 5,000 vehicles to CNG in 2010, with a projected annual growth in the population of CNG-converted cars by 3.5% based on the CNG fuel growth rate. The conversion of vehicles to CNG would require the installation of a CNG kit at a cost of TT$ 10,000. It was assumed that a vehicle would be driven for 12,000 km on average annually. A car running on gasoline is estimated to use 972 litres of petrol annually, while a car running on CNG is estimated to consume 1,008 litres annually based on a United States of America Environmental Protection Agency (EPA) vehicle efficiency rating of a 2010 Honda Civic car. In Trinidad and Tobago, a litre of super petrol costs TT$ 2.70 while a litre of CNG costs $TT 1.78. At these prices, the annual fuel cost of operating a car on super petrol is TT$ 2,624.4 and that of operating a car on CNG is TT$ 1,078.56. In essence, a motorist switching from petrol to CNG will incur a one-time installation or capital cost of TT$ 10,000 and save TT$ 1,545.84 in fuel cost in the first year of adopting CNG. It was assumed that the real unit prices of CNG and petrol will remain at the 2011 levels for the 40-year period of implementing the adaptation option, thus implying that a motorist would save TT$ 1,545.84 annually in fuel costs. At these prices, accrual of annual savings in fuel costs would be enough to have paid for the initial cost of CNG kit installation during the seventh year. At the aggregate level, the cost of converting 5,175 cars to CNG in 2011 would be TT$ 51.75 million, and the total savings in fuel costs from operating these CNG-converted cars in the first year of conversion would be TT$ 8.00 million or about US$ 1.25 million. Over the 40-year period of implementation, the NPV of converting gasoline cars to CNG would amount to US$ 97.60 million and the BCR would equal 1.98. When the stream of costs is discounted, NPV ranges between US$ 75.70 million at a 1% discount rate and US$ 37.50 at a 4% discount rate. BCR ranges from 1.90 at a 1% discount rate to 1.68 at a 4% discount rate. The net savings from implementing the CNG adaptation option would be equivalent to 0.50% of 2009 GDP.

The replacement of cars running on petrol with those running on CNG would reduce CO_2 emissions by 131.264 kt over the implementation period. This has the potential of yielding a payment of US$ 1.97 million to Trinidad and Tobago in carbon credits. When this indirect benefit is factored into the total benefits, NPV increases to US$ 99.57 million.

VII. CONCLUSION

A. STUDY FINDINGS

This study of the impact of climate change on the energy sector in Trinidad and Tobago is the first attempt at comprehensively estimating the quantitative impact of climate change on the sector. Findings from the study suggest that change in temperature has no statistically significant impact on electricity consumption in the short-run. The main driver of electricity use in the short-run is economic growth. However, over the long-run, electricity demand will be sensitive to changes in temperature. Specifically, a 1% increase in annual average temperature would result in a 9.302% increase in electricity consumption per capita. When the trajectory of future temperature changes under the A2 and B2 scenarios is considered, electricity consumption per capita would increase by an annual average of 65.13 kWh for A2 and by an annual average of 61.46 kWh for the B2 scenario during 2011-2050. This would represent an annual increase in electricity consumption per capita over the baseline value for 2011 of 1.07% and 1.01% for the A2 and B2 scenarios, respectively. Economic growth would result in an increase by 0.524% in electricity consumption per capita for every 1% increase in GDP per capita. The economic impact of climate change during 2011-2050 would be similar under the A2 (US$ 142.88 million) and B2 (US$ 134.83 million) scenarios, with the A2 scenario producing slightly higher costs, equivalent to 0.737% of 2009 GDP for the entire 40-year period, and the B2 scenario generating a cost equivalent to 0.695% of 2009 GDP for the same period.

On the supply side, analyses indicate that the Trinidad and Tobago energy sector will be susceptible to the climate change policies of major energy-importing countries, and especially to their renewable energy strategies. The United States of America foreign oil import substitution policy was used as a baseline for analysing the impact of foreign policies on Trinidad and Tobago LNG exports. Implementation of foreign oil substitution policy by the United States of America would result in a decline in Trinidad and Tobago LNG exports, unless an alternative market were to be secured to replace the lost United States of America LNG market. The magnitude of the fall in export earning is estimated to be equivalent to a 2.2% reduction in 2009 GDP.

China, with its rapid economic growth and the highest population in the world, offers a potential replacement market for Trinidad and Tobago LNG exports. Using storylines that align with the IPCC climate scenarios, it was estimated that the A2 scenario offers the best option for the Trinidad and Tobago energy sector. Under this scenario, China is expected to pursue a clean energy strategy of substituting coal with cleaner energy sources such as natural gas and hydroelectricity. This will boost demand for LNG and/or improve the price of LNG on the world market. Under the BAU scenario, China is expected to continue its path to economic growth with heavy reliance on coal as the primary source of energy. This strategy will offer little or no opportunity for Trinidad and Tobago to find a replacement for the lost United States market for its LNG. In such a situation, the economy will be expected to lose at least 2.2% of 2009 GDP permanently. This loss would be minimal when compared to the likely situation under the B2 scenario. Under the B2 scenario, China pursues a renewable energy strategy that emphasizes environmental sustainability and switches from coal to hydroelectric power, wind, solar and geothermal sources of energy. This would result in a combination of possible outcomes, ranging from a stagnant or declining demand for natural gas on the world market to a fall in the price of natural gas on the world oil market.

Informed by the draft energy policy of Trinidad and Tobago, cost-benefit analyses were performed on some climate change adaptation options that the Government is contemplating. The results revealed that the adaptation option of converting incandescent light bulbs by residential electricity consumers to compact fluorescent light bulbs is the most cost-effective, in terms of the net present value of electricity cost savings that implementing the option will generate over a 40-year period. However, when adaptation options are assessed for their benefit-cost ratio, the option of replacing electric water heaters with solar water heaters was the most cost-effective. This implies that, on an individual level, the use of a solar water heater is most effective but, on an aggregate level, the use of compact fluorescent light bulbs is more effective, reflecting the mass of households that can implement the CFL adaptation option relative to the few that can implement the SWH option.

The adaptation option of replacing mini split air conditioners in hotels and guest houses with VRV air conditioners is only marginally cost-effective when the discount rate is below 4%. At a discount rate of 4% or above, the option becomes a net cost-generating rather than a cost-saving alternative. This is a reflection of the small number of hotel and guest house rooms in Trinidad and Tobago, their low occupancy ratio, and the cheap price of electricity in Trinidad and Tobago.

The conversion of motor fleets to CNG is a cost-effective adaptation option for the transport sector, although it has a high initial cost of implementation and the highest per capita among the four adaptation options evaluated in this study. However, there are tax incentives already in place to encourage motorists to convert to CNG by getting a tax rebate on their annual tax returns.

B. STUDY LIMITATIONS

The current study has a number of limitations arising as a result of data challenges. Due to lack of sector-specific data on energy consumption for the different sources of energy, a disaggregated fuel-type demand analysis at the sectoral level could not be performed. The most updated and comprehensive data on electricity were available only on an annual basis, thus making it impossible to investigate the possible impact of seasonal variation in temperature on electricity consumption. The price of energy resources is regulated in Trinidad and Tobago and fixed for years at a time. This circumstance makes price variables redundant in analysing consumption of electricity and other energy sources. The use of proxies such as the ratio of energy price to CPI did not offer an improvement to the results. In estimating total electricity demand, attempts were made to correct for the share of manufacturing by including two proxies as additional explanatory variables. These were the share of manufacturing value added of GDP, and energy intensity. Including these proxies actually worsened the results of estimated demand function and they were therefore not used.

Engineering data are essential in performing economic assessment of climate change impact on oil and gas production, as well as in conducting economic assessment of many adaptation options in the energy sector. Although vulnerability studies have been conducted for PETROTRIN facilities that identify installations at risk of sea level rise and inundation, data are not available on how this vulnerability translates to oil and gas supply interruption, nor are data available on the estimated cost of implementing corrective measures to adapt to these predicted climate change impacts. Therefore, due to these data limitations, this study is constrained in performing an assessment of the direct impact of sea level rise and extreme events on the production of oil and natural gas.

The lack of an energy audit of major energy-consuming sectors in Trinidad and Tobago limits the array of adaptation options that could be evaluated using cost-benefit analysis. The need for an energy audit is recognized and the performance of such an audit has been recommended to the Government in the draft energy policy. The findings of such an audit will greatly facilitate economic assessment of several other adaptation options in the energy sector.

C. POLICY RECOMMENDATIONS

Findings emanating from the current study of the impact of climate change on the energy sector in Trinidad and Tobago indicate that economic growth, patterns of electricity use, and temperature, affect electricity consumption. However, at an aggregate level, changes in electricity consumption in response to climate change are not expected to have a significant economic impact. This suggests that, regardless of variations in temperature, electricity consumption will continue to grow into the immediate future. This phenomenon makes energy efficiency an important policy instrument for addressing growth in electricity consumption and the associated GHG emissions. Cost-Benefit Analysis of the effects of introducing CFL and VRV air conditioners shows that the economic benefit of adopting these energy-saving practices surpasses the projected cost of increased electricity consumption due to climate change, and provides an economic rationale for the adoption of these energy-saving climate change adaptation options even in a situation of increased electricity consumption occasioned by climate change.

It is also apparent from the conduct of the present study that quality data are crucial to assessing the full impact of climate change on the energy sector. Economic data are generally available but not usually at the desirable level of disaggregation. Likewise, engineering data relating to energy audits are difficult to access and, in most cases, non-existent. Resources need to be devoted to the conduct of energy audits to facilitate a proper evaluation of energy consumption in the various sectors.

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