Framework Convention on Climate Change

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Assessing impacts of the implementation of response measures

The case study of Senegal and Kenya: A Computable General Equilibrium Analysis

8 DECENT WORK AND ECONOMIC GROWTH

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

10 REDUCED INEQUALITIES

GLOBE Model

STAGE Model

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Executive Summary

Climate change is increasingly acknowledged as a global crisis that will require a reorientation of economic systems (see Carney, 2020b). Despite the widespread acknowledgement of the need for change and the required order of magnitude, e.g., in the Paris Agreement[1], the precise response measures that will be adopted are uncertain. Moreover, the Paris Agreement recognises that some "developing countries" do not have sufficient capacities to address the challenges and that there is a need for "developed countries" to provide "enhanced support for capacity-building actions in developing countries" and to "take the lead in providing financial assistance to countries that are less endowed and more vulnerable". Much of the needed support and capacity-building involves the developing and transferring of 'green' technologies, but it has also been recognised that it is necessary to enhance the capacity and understanding of Parties, through collaboration and input from stakeholders, on the assessment and analysis of the impacts of the implementation of response measures to facilitate the undertaking of economic diversification and transformation and just transition.

Previous studies for the UNFCCC Secretariat had identified general equilibrium economic models, including Computable General Equilibrium (CGE) models, Integrated Assessment Models (IAM)[2] and Input-Output (IO) and Social Accounting Matrix (SAM) multiplier models, as economic models that could provide insights into the impacts of the implementation of response measures at global and national levels and provide information that may assist economies' efforts to mitigate adverse socio-economic impacts. This pilot study was commissioned to provide evidence about the extent to which CGE models, and by extension, other general equilibrium models may provide useful information that governments and economic agents in low-income and small island economies can use to assess the impacts of the implementation of response measures.

This class of general equilibrium models is not used for forecasting purposes, rather the models can form part of a 'laboratory' that analysts can use to explore how complex economic systems might respond to exogenous changes/shocks and endogenous policy

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1 https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

2 The boundaries between IAMs and (some) CGE models are opaque. In practice, IAMs could be defined as CGE models that include enhanced modelling of energy systems, GHG emissions, land use systems and interactions between economic decisions and the environment thorough, *inter alia*, forcing and feedback effects.

choices. Policy experiments using these models are designed to examine the implications of changes and shocks in a controlled environment within which other factors are held constant. As such these models are intended to provide policy makers with information and insights that can be used to inform the formulation of policies.

The pilot project was designed to demonstrate how a 20 percent reduction in CO_2 emissions, achieved by four different policy instruments, might impact on two countries, Senegal and Kenya. The global response measures were modelled using a global CGE model (GLOBE_CC) and the results from those exercises, in the form of changes in the prices of traded goods and services and exchange rates, were passed to single country models (STAGE_CC) of Senegal and Kenya. The global model provided information about the impacts at an aggregate level, while the single country models provided disaggregated information about the impacts on, *inter alia*, multiple household groups, selected Sustainable Development Goals (SDG) indicators, government budgets and labour markets. The main criteria for selecting the two countries were the availability of reliable SAM data for each country; and the existence of economic features that are common across other countries to facilitate drawing lessons potentially applicable to other economies. Kenya and Senegal serve as suitable pilot country studies because they represent two different regions from GLOBE_CC (Kenya in East Africa and Senegal in West Africa), as well as different patterns of energy dependence.

The analyses conducted demonstrate that, with other things unchanged, global response measures will have negative economic implications at the economy level for all countries that implement response measures. The costs will not be spread evenly between countries, nor between consumers and producers within countries, and that the magnitudes of the negative consequences will be influenced by the instruments used as global response measures. These negative consequences may be, partially, offset by changes in technology and economic policies, but such changes may be costly; explorations of these changes were not part of this pilot project. The analyses also demonstrate that individual global response measures are likely to have markedly different economic impacts on different countries. This reflects the differences in the economic relationships within countries and between countries. This result indicates that detailed socio-economic analyses of the impacts of proposed and implemented global response measures on different low-income and small island economies is important for the development of country-specific mitigation strategies.

This conclusion is supported by the analyses of the impacts of global response measures at the level of individual economies. The two case studies (Senegal and Kenya) demonstrated that the patterns of production, consumption and income distribution in a country are important determinants of how the economic impacts of global response measures are translated into domestic socio-economic outcomes. This result indicates that detailed country analyses of the impact of global response measures has the potential to provide information that can guide country specific mitigation policies. Importantly country specific analyses have the potential to identify household groups that are particularly vulnerable to the impacts.

The pilot study clarifies some of the constraints upon the analyses of global response measures and mitigation strategies facing low-income and small island economies. Quantitative socio-economic analyses require data, technical expertise, and an appreciation of the insights that quantitative analyses might provide. Shortfalls in technical expertise are relatively easily addressed by training programmes and/or the use of contracted specialists. Filling shortfalls in data will take longer and cost more: but the benefits from enhanced economic database should have economic benefits for the determination of socio-economic policies well beyond those associated with climate change. Addressing both these shortfalls however will require that policy advisors have sufficient knowledge to instigate the appropriate analyses, evaluate the quality of the analyses and translate the insights into policy responses.

The results from the analyses in this study indicate that this class of models can provide insights into the socio-economic impacts and changes in incentives consequent on climate change response measures, and, therefore, can inform the development of economic and mitigation policies. An important conclusion from this pilot study is that valuable insights can be acquired without recourse to extraordinarily complex models that require large and complex databases. Consequently, this class of model can be used to provide usable insights within a relatively short time horizon and that these insights can be enhanced when more detailed databases have been developed.

1. Introduction

This pilot project for the 'Development of toolkit for assessment of impacts of implementation of response measures', was commissioned by the UNFCCC to illustrate the insights that may be derived when Computable General Equilibrium (CGE) models are used to evaluate the response measures to climate change and their impacts on low-income and small island economies. The terms of reference identified four generic objectives:

- demonstrate how to assess the impacts of the implementation of response measures especially cross-border impacts;
- demonstrate how the tools and methods can be used to assess and analyse the social, economic and environmental impacts arising from the implementation of climate policies and actions;
- identify the technical and policy analyses and data requirements needed to support effective assessments and analyses of response measures using the identified tools and methods; and
- demonstrate how the results from the tools and methods can be reported to communicate the impacts with policy makers and to inform the formulation of ameliorating measures.

The remit for the pilot project was to use simplified models and truncated databases, while using a global CGE model to evaluate the impact of global response measures on countries and single country CGE models to assess the impacts on two case study countries (Senegal and Kenya). The use of slightly simplified CGE models improves the accessibility of the results and policy implications to non-experts, while retaining the richness of information about economic transactions necessary for the results to demonstrate the insights that can be acquired using the methods. Subsequent analyses can readily use more complex models, although care will be needed to ensure the reasons for the realised results are transparent and that the insights remain accessible.

The models used were GLOBE_CC and STAGE_CC, which are simplified variants of the GLOBE 3 and STAGE 3 models. The models used are licensed to the UNFCCC, together with technical documentation and User Guides. The global analyses of the response measures were carried out with the GLOBE CC model using data from the Global Trade Analysis Project (GTAP), while the single country model, STAGE _CC, was used for the selected pilot countries (Senegal and Kenya) using Social Accounting Matrices (SAMs) for the two countries.

This class of economic model is not useful for forecasting purposes, rather the models can form part of a 'laboratory' that analysts can use to explore how complex economic systems might respond to exogenous changes/shocks and endogenous policy choices. Policy experiments using these models are designed to examine the implications of changes and shocks in a controlled environment within which other factors are held constant. The results from the analyses in this study indicate that this class of models can provide insights into the socio-economic impacts and changes in incentives consequent on climate change response measures, and, therefore, can inform the development of economic and mitigation policies.

The rest of this report is organised as follows. Chapter 2 reports on the global analyses of climate change response measure. This is followed by chapters 3 and 4 that report on the single country analyses for Senegal and Kenya, respectively, consequent upon the global impacts of the response measures. Each of these three chapters contains supplementary information annexes. The fifth chapter considers the lessons learned and a potential way forward and is followed in the final chapter by brief concluding comments. The introduction and table of contents to each chapter provide an overview to the content so that each can, if so desired, be read in isolation.

The rest of the introduction provides information about the context of the pilot study, the project aims and constraints, an overview of the analytical processes, the tasks undertaken and a summary of the conclusions.

Context

States that are parties to the Conference of Parties (COP) to the UNFCCC have acknowledged that climate changes are major driving factors in the determination of their economic activities. As parties to COP their international obligations require the inclusion of climate change when considering policies, activities, and investment plans. Among the difficulties confronting low-income and small island economies are the challenges associated with determining economic options with limited information about the likely impacts of global response measures to reduce global greenhouse gas (GHG) emissions on their economies. These difficulties are compounded by challenges when evaluating the effects of alternative domestic policy options, which are consistent with their commitments to the UNFCCC, in the face of different global response measures.

The Paris Agreement recognises that Parties may be affected not only by climate change, but also by the impacts of the measures taken in response. In Katowice, Parties agreed to four work programme areas for its established mechanisms to address the impacts of the implementation of response measures through “the forum on the impacts of the implementation of response measures” and “the Katowice Committee of Experts on the impacts of the implementation of response measures”. The agreed four work programme areas are:

1. economic diversification and transformation;
2. just transition of the workforce and the creation of decent work and quality jobs;
3. assessing and analysing the impacts of the implementation of response measures;
4. facilitating the development of tools and methodologies to assess the impacts of the implementation of response measures.

Accordingly, the UNFCCC is seeking to develop tools and methods that can increase the information available to Parties when examining the effects of response measures. This pilot project was commissioned as a contribution to the work programme.

This pilot project uses global and single country Computable General Equilibrium (CGE) models. The decision to include CGE models among the tools and methods was influenced by prior reports that indicated that economy-wide CGE models were “by far the most widely-used approach to analysing environmental policy at the whole-economy level” (Cambridge Econometrics, 2015, p 27). CGE models can provide quantitative assessments of the effects of various shocks, including global response measures, and information about the implications of different mitigation policies. They are favoured not only because they can assess economy-wide and inter-industry impacts, but also because they can incorporate features that enable the assessment of economic, environmental, and social effects.

The reason for using two models is that a global CGE model can be used to evaluate the economic impacts of response measures on a global scale, while a single country CGE can be used to examine, in detail, the impacts of the global response measures on individual countries. The two pilot study countries are Senegal and Kenya.

Project Aims and Constraints

The quantitative pilot studies were designed to provide illustrations of the insights that CGE models may provide as opposed to providing analyses of a specific series of policy options, which would have required detailed interactions with policy advisors and decision makers.

Accordingly, the simulations implemented are stylised (see below). Moreover, the scope of the pilot project was limited. It is important to appreciate the limits placed on this pilot project to avoid confusion about the interpretation of the results.

The scope of the pilot study was limited in four important ways:

1. the models used were simplified variants of existing CGE models;
2. the analyses were limited to the use of the models in comparative static mode[3];
3. the range of global response measures was limited, and the evaluation of different mitigation policies was not part of the study; and
4. the project was constrained to operate with pre-existing databases.

These limitations derive largely from the budget for the project. While these constraints limit the usefulness of the results from the pilot studies to inform policy decisions, none compromise the objective of illustrating the insights that CGE models can provide. Relaxing the constraints will increase the insights and thereby enhance the information available to inform decision making.

Models

The models used for this study, GLOBE_CC and STAGE_CC,[4] were designed to reduce model complexity and thereby increase accessibility of the method and models to non-experts. The changes included simplifying the operation of factor markets, including reducing constraints on the flexibility of labour markets; simplifying household decision making, including increasing the constraints upon the flexibility of household responses; and removing the endogenous effects of climate change on productivity. The models were also limited to analysing the implications of one Green House Gas (GHG), CO_2. These changes, *inter alia*, reduced the need for additional data and the imposition of additional assumptions.

Limiting the analyses to comparative static mode means that the transition paths that individual countries and the global economy may follow are not examined. The implications of response measures and mitigation policies for interactions between changes in returns to capital and investment decisions were excluded, e.g., decisions to retire prematurely coal fired power stations and invest in 'green' technologies are not explored. Consequently, the economic implications of different rates of changes in technologies are not explored.

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3 The single country, STAGE_CC, and global, GLOBE_CC, models used can be implemented in either comparative static or recursive dynamic modes.

4 GLOBE_CC and STAGE_CC are (simplified) variants of GLOBE_3 and STAGE_3.

Similarly, migration decisions, urban-rural (single country) and international (global), by households are not explored.

Simulations

The simulations of global response measures are implemented by four individual instruments for achieving a common level of reductions in global CO_2 emissions with market mechanisms determining the country specific reductions: the actual global response mechanisms will involve a mix of instruments and country specific reductions in GHG, including trade-offs between the emissions of different GHG. This simplified approach serves to demonstrate the extent to which different instruments for reducing emissions have different global and country specific implications, while demonstrating how such a global model can be used to inform countries understanding of the implications of international agreements. An objective of the study was to demonstrate the method rather than contribute to the process of determining the instruments used as global response measures.

Similarly, the single country simulations illustrate the information that can be gleaned from these models about the impacts of different response measures. The results from the global model demonstrate that the implications of different global response measures will impact differently on different countries: different response measures have different global effects; each country interacts differently with the global economic system because each country has its own distinct economic structure and system. The results illustrate the impacts on the pilot study countries of individual global instruments, i.e., they represent the conditional situation within each country **before** any mitigation policies are implemented.[5] The application of the single country models for the evaluation of different mitigation policies is not part of the study: the design of mitigation policies requires incorporating government objectives, which are beyond the scope of the study. Again, the objective of this study was to demonstrate the method rather than contribute to the policy formation process in individual countries.

Data

Finally, the project was limited to using existing databases. This decision avoided the need for costly data collection and reconciliation but does impose limitations.

5 The simulations do assume government budget neutrality but not targeted mitigation policies.

The global model uses data from the Global Trade Analysis Project (GTAP) (see Aguiar, *et al*., 2019), which produces the only openly available global database. The GTAP database is disaggregated, and aggregation is recommended before use; details of the aggregation used for this study are reported in section 3 of chapter 2. It was decided not to include the two pilot study countries as independent countries in the aggregated database. This reflected two concerns: first, the shares of global GDP of each country are very small (Senegal at 0.02%, and Kenya at 0.08%), which can produce results that are not robust and can introduce difficulties when solving models; and second, the inter-industry data are not a strong point of the GTAP database and are not robust for economically small countries.[6] Moreover, the GTAP database excludes international transactions other than those in goods and services, e.g., aid transfers, remittances, etc., that may be important for low-income economies. It is possible to augment the GTAP database with current account transactions, but it is a major exercise (see McDonald *et al*., 2015) that also requires re-estimation of the database. However, the GTAP databases was adjusted to include savings by household and the government; this provides a richer specification of the household and government accounts.

It was concluded that rather than keeping Senegal and Kenya as separate countries in the global CGE model that it was preferable to include them as part of two larger and contiguous regions: West and East Africa.

The selection of the pilot study countries was partly data driven. A review of available Social Accounting Matrices (SAM) for developing countries concluded that SAMs for Kenya, Senegal and Ethiopia best satisfied the criteria for documentation, detail and timeliness, and that of these the SAMs for Kenya and Senegal provided the best geographic coverage. It was also determined that although the impacts of response measures on small island economies may be critical, none would be a suitable choice for a pilot study because the results might lack generality. It was unfortunate that SAMs for low-income countries outside of the African continent did not satisfy the criteria.

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6 GTAP observes that the "underlying input-output tables are heterogeneous in sources, methodology, base years, and sectoral detail, … For these reasons, the objective of the GTAP Data Base is not to provide I-O tables, but to facilitate the operation of economic simulation models ensuring users a consistent set of economic facts". (GTAP, www. https://www.gtap.agecon.purdue.edu/databases/v10/index.aspx)

Process flowchart

The flow chart, Figure 1.1, depicts the 6 steps needed to assess the impact of response measures at the global and country level. The process is generic and can be applied to other global response measures and countries. The actions of each step are summarised below, including comments on the challenges faced and resolved during the pilot project.

Step 1: Defining the work

The first step in the process of modelling the impact of response measures comprises four actions:

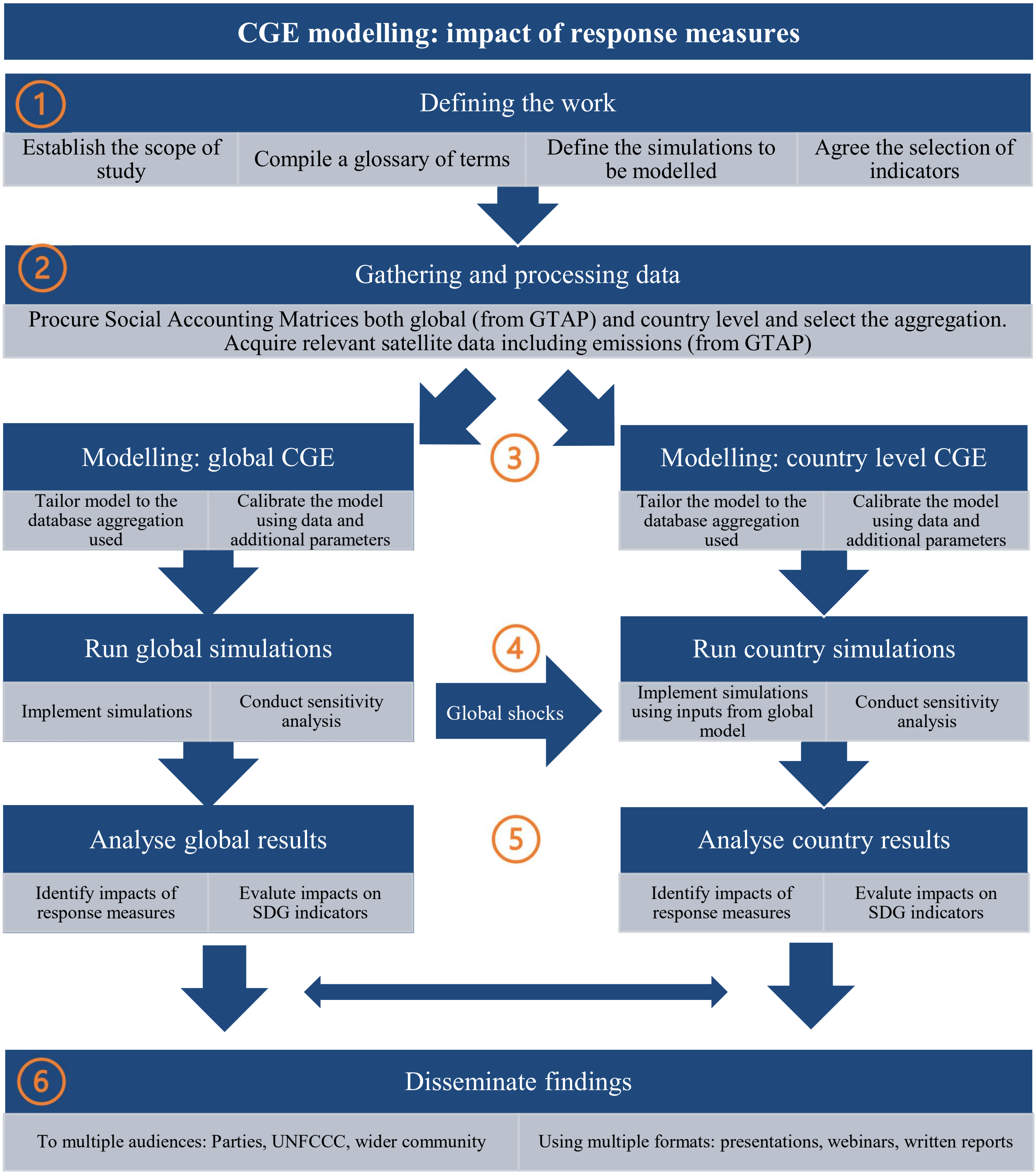
1. establish the scope of the study;
2. compile a glossary of agreed terms;
3. define the simulations to be evaluated, and
4. agree the selection of indicators, e.g., economic, environmental and SDG.

The focus during this step is on developing a common understanding of the study, with respect to the terms used, and the simulations examined. Possible pitfalls during this step include misunderstandings of the terms used and a mismatch between the simulations and the capabilities of the models.

Step 2: Gathering and processing the data

The second step involves gathering and processing the data. Both the global and single country models are calibrated to Social Accounting Matrices that need to be procured alongside other satellite data such as emissions data. The challenge of this step is to procure high quality data that are representative of the global and national economies. The choice of aggregation is also crucial as it determines the level of detail in the results, the ease with which information can be passed between the global and single country models, and the information value of SDG indicators.

Figure 1.1 Process flow chart



Step 3: CGE modelling

The process splits into two tracks in step 3: global and country level CGE modelling. The two tracks run in parallel until the dissemination step, providing insights at the global and national level. During step 3, the models are tailored to the data provided in step 2 in the chosen aggregation.[7] The Social Accounting Matrix (SAM) data are augmented with satellite account data and used, together with exogenous data, e.g., elasticity values, to calibrate the models so that they replicate the economic transactions recorded in the SAM and satellite accounts. Challenges during this step typically arise due to data peculiarities and/or the need to tailor the model to features of the national data.

Step 4: Running simulations

The simulations agreed in step 1 are implemented in the models in step 4. In the context of this study, the global simulations are run first and the changes in key variables are passed down to the country models to form the simulations at the national level.[8] The simulations are complemented by sensitivity analyses in which the robustness of the results to variations in exogenous data, including elasticity values, and the model closure setting are evaluated. Challenges that may arise during this step include the process of matching the accounts in the global and country models to translate the global shocks to the national level. Additionally, the size of the shocks may require that the shocks be 'phased-in' to help the software finds solutions to the model.

Step 5: Analyse results

Step 5 comprises two closely related parts: identifying the impact of response measures and evaluating the impact on the selected economic and SDG indicators (Shutes, 2021). Challenges can arise during this step if counter-intuitive results arise. This necessitates 'digging into' the results to discover the drivers of the observed changes and may require the simulations to be refined. This process means that steps 3-5 can require several iterations and, if observed results are due to peculiarities in the data, the iteration may go back to step 2.

Counter-intuitive results are not a problem. In fact, they are often among the most important results because then can often expose errors in expectations and missteps in the logic used to derive expectations. Consequently, many of the most valuable insights are produced from 'digging into' the results.

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7 As a rule, models should be adjusted to reflect the economic relationships captured by the data AND the data should NOT be adjusted to fit the model.

8 Both models can be run independently and can be used for the analyses of policy options other than those associated with climate change.

Step 6: Disseminate findings

The final step is to disseminate the findings to multiple audiences using appropriate formats. A particular challenge faced during the pilot study are the restrictions on gathering data and travel due to COVID-19 that necessitated the delay in COP26.

Summary of Outcomes

The analyses conducted for this pilot project demonstrate that global response measures will have negative economic implications at the economy level for all countries that implement response measures. The costs will not be spread evenly between countries, or between consumers and producers within countries, and that the magnitudes of the negative consequences will be influenced by the instruments used as global response measures. These negative consequences may be, partially, offset by changes in technology and economic policies, but such changes may be costly; explorations of these changes were not part of this pilot project. The analyses also demonstrate that individual global response measures are likely to have markedly different economic impacts on different countries. This reflects the differences in the economic relationships within countries and between countries. This result indicates that detailed socio-economic analyses of the impacts of proposed and implemented global response measures on different low-income and small island economies is important for the development of country-specific mitigation strategies.

This conclusion is supported by the analyses of the impacts of global response measures at the level of individual economies. Using case studies for two African economies, Senegal and Kenya, it is demonstrated that the patterns of production, consumption and income distribution in a country are important determinants of how the economic impacts of global response measures are translated into domestic socio-economic outcomes. This result indicates that detailed country analyses of the impact of global response measures has the potential to provide information that can guide country specific mitigation policies. Importantly country specific analyses have the potential to identify household groups that are particularly vulnerable to the impacts.

The pilot study clarifies some of the constraints upon the analyses of global response measures and mitigation strategies facing low-income and small island economies. Quantitative socio-economic analyses require data, technical expertise, and an appreciation of the insights that quantitative analyses might provide. Shortfalls in technical expertise are relatively easily addressed by training programmes and/or the use of contracted specialists. Filling shortfalls in data will take longer and cost more: but the benefits from enhanced economic database should have economic benefits for the determination of socio-economic policies well beyond those associated with climate change. Addressing both these shortfalls however will require that policy advisors have sufficient knowledge to instigate the appropriate analyses, evaluate the quality of the analyses and translate the insights into policy responses. An important conclusion from this pilot study is that valuable insights can be acquired without recourse to extraordinarily complex models that require large and complex databases. Consequently, this class of model can be used to provide usable insights within a relatively short time horizon.

2. Global response measures

Summary

This chapter details an implementation of the GLOBE_CC model to estimate the impacts arising from the implementation of climate change mitigation policies and actions (response measures), such as changes in trade prices and exchange rates consequent upon each of four different policy instruments that achieve a 20 percent reduction in global CO_2 emissions. Market mechanisms distribute the emission reductions across regions. The results demonstrate that different climate change mitigation policy instruments have different impacts on different regions depending on the structure of the economic systems in each region and the trade patterns that link regions. The implications of response measures are shown to vary widely across regions, which indicates the importance of understanding those implications when formulating mitigation polices and actions. The results from this study are intended to populate simulations for individual countries to provide more detail about the implications of response measures; hence the results are subject to limited discussion.

Policies to reduce carbon emissions increase the costs of production in high-income and middle-income countries: producers shift away from using fossil fuels in production and consumers adjust their expenditure patterns. As a result, outputs of fossil fuels decline, and the outputs of electricity, a clean energy input, also decline in part because of economic contraction and in part because of the use fossil fuels, especially coal, in its generation. For low-income regions, such as West Africa and East Africa, world prices for all commodities, except energy commodities, decline and the exchange rates depreciate.

Introduction

This chapter reports the results from a series of simulations that achieve the same 20 percent reduction in global CO_2 emission using four different instruments. These scenarios do not replicate any Nationally Determined Contributions (NDC) or any internationally agreed programmes for CO_2 emissions. Rather, in line with the remit of the project (a pilot study), the scenarios are designed to illustrate, comparatively, the insights that a global Computable General Equilibrium (CGE) model can provide as to the patterns of the effects of different types of response measures on the global economic system. While the analyses reported in this chapter are of interest in themselves, they are designed to provide estimates of how the different response measures impact on economies through changes in trade prices and exchange rates. Accordingly, the analyses and discussion of the results is limited.

The analyses use the GLOBE_CC Computable General Equilibrium (CGE) model that is calibrated with an aggregation of version 10 of the GTAP database (20 regions, 27 sectors, 5 factors) and GTAP satellite account data for CO_2 emissions and the quantities of energy commodities purchased by agents in each region. The simulations derive estimates of the global impacts of achieving a reduction of 20% of global carbon dioxide (CO_2) emissions using two tax instruments (taxes on CO_2 emissions, referred to hereafter as a carbon tax, and energy input taxes), technology change and quantity restrictions on the use of energy inputs.[9] The estimates are derived in comparative static mode and therefore provide no information on the time paths of changes in economic relationships or the evolution of production technologies in response to the different simulations.[10]

The patterns of shares of global gross domestic product (GDP) and global CO_2 emissions are indicative of the marked differences in CO_2 emissions per unit of GDP. Similarly, marked differences emerge when CO_2 emissions per unit of population are calculated. These differences are clearly important to an understanding of the burdens associated with reducing global CO_2 emissions. Applications of a global CGE model can be used to analyse how, *inter alia*, differences in economic structures and the patterns of emissions across regions interact given different instruments for reducing emissions and greening the global economy; such analyses can contribute to an understanding of NDCs. This mode of analyses is not part of this study although the results demonstrate how different instruments imply markedly different outcome.

The results demonstrate how, *ceteris paribus*, programmes of emission reductions will, in this class of model, necessarily produce results that indicate reductions in measured economic activity: emissions reduction programmes impose additional constraints on economic agents. These reductions in economic activity may be short term as the economic systems adjust technologies in response to the change in incentives. However, such changes

9 In this study, only carbon dioxide emissions were analysed, other greenhouse gas (GHG) emissions were not included. This is due to data availability. Furthermore, carbon emissions represent the majority of GHG. See Annex 1 for a more detailed discussion of the policy instruments used to reduce carbon dioxide emissions.

10 Analysis of the time paths of changes in economic relationships, or the evolution of production technologies in response to the different simulations, can be done using recursive dynamic CGE models, e.g., the GLOBE_CC model in dynamic mode.

take time and evolve as new investments and technologies are installed. The analyses of such longer-term changes were not included in the remit for this study.

The analyses demonstrate that different response measures and mitigation policies can have widely differing implications for the global economy and individual economies. The results provide evidence of the orders of magnitude of the economic implications for each scenario and the differences between the simulations. BUT the results from these analyses do not provide an appropriate basis for guiding or formulating economic and/or emissions reductions strategies. This reflects the fact that the global shocks were stylized shocks designed to illustrate the nature of the information that can be provided, rather than specific shocks designed to reflect the development of response measures. Individual nations seeking the evidence to guide policy options will need to commission case specific studies that reflect the precise specification of response measures.

The rest of this chapter is organised as follows. The next section reviews, very briefly, the background and the magnitude of the global reductions in CO2 emissions that are required. Consideration is also given to the policy instruments used for this study; these are given further consideration in annex A2.1. The third and fourth sections provide information about the data and the model, respectively, with the data section supplemented by annexes A2.2 and A2.3. The simulations and model settings are described in the fifth section with the results being reported and discussed in the sixth section. Annexes A2.4 and A2.6 provide additional results for information. The report ends with some concluding comments.

Background

Response Measures

Response measures, or mitigation policies and actions, adopted by countries to reduce carbon emissions will target energy and carbon markets through tax instruments, which work through the price system, and quantity restrictions on emissions levels and quantities of energy inputs. It is unlikely that these interventions alone will be adequate if the world is to avoid excessive global warming, and therefore simple economic measures will need augmenting with targeted technology changes. These policies will affect supply and demand for various industries, causing changes in world prices that in turn affect all countries, in particular developing ones.

A target to limit global warming by 2-degrees Celsius (2.0°C) by 2025 and 1.5°C by 2030, corresponds to a reduction in net global anthropogenic carbon dioxide (CO_2) emissions to net zero and a limitation of total emissions since the pre-industrial period by staying within a total carbon budget (IPCC, 2018a). While the choice of the measure of global temperature affects the estimated remaining carbon budget, the IPCC (2018a) estimates that the remaining budget for 1.5°C is being depleted by current emissions of 42 ± 3 gigaton of CO_2 ($GtCO_2$) annually (assuming a reduction in the budget by approximately 2200 ± 320 $GtCO_2$ by 2017). The implementation of the UNFCCC's Nationally Determined Contributions (NDCs) is estimated to produce average global emissions levels of 55 gigaton of CO_2 equivalent ($GtCO_2$ eq) by 2025 and 57 $GtCO_2$ eq in 2030. The aggregate effect of the NDCs entails cumulative global CO_2 emissions of, on average, 54% by 2025 and 75% by 2030 of the global cumulative emissions since 2011. These changes are consistent with a global average temperature rise of less than 2°C above pre-industrial levels (NDCs Synthesis Report, 2015). Furthermore, according to the Intergovernmental Panel on Climate Change (IPCC) Global Warming of 1.5°C Special Report, in model pathways with no or limited (less than 0.1°C) overshoot of 1.5°C, net global anthropogenic CO_2 emissions decline by approximately 45% (an interquartile range of 40%-60%) by 2030 from the 2010 levels, reaching net zero by 2045-2055 (IPCC, 2018a).

Policy Instruments

Energy policy reforms to reduce greenhouse gas (GHG) emissions are typically associated with removal of subsidies from carbon intensive fuels resulting in increases in energy prices. This can have substantial income/welfare distribution implications if the increased energy price is passed to consumers. Sometimes energy reforms provide subsidies to clean fuels and remove subsidies on fuels with high carbon emissions. The subsidies on clean fuels also provide a social benefit of increased access to energy.

Thus, reforming energy policies may cause concerns about the ensuing effects of reforms on lower-income households, especially in developing economies. Consequently, governments may perceive that changes in energy policies may necessitate amelioratory action policies to counter adverse distributional concerns. These are a major concern in developing economies. Such action policies can include microeconomic reforms, investments in renewable technology, or cash transfers.

This study considers four policy instruments – two tax instruments, quantity constraints and technology changes. The comments below about the instruments used for this study are limited; more details about each instrument are summarised in Annex A2.1.

Carbon Taxes

A carbon tax is a tax levied on the carbon emissions from the use, or burning, of fossil fuels (coal, oil products, and natural gas). If the tax is applied to producers, they will be incentivised to reduce costs, but will, ultimately pass cost increases onto consumers in the form of higher prices: this ensures that both producers and consumers have incentives to reduce GHG-emitting energy use. Producers will change input mixes to minimize costs and consumers will change consumption patterns to optimize welfare. Carbon taxes are also intended to induce changes towards technologies with lower emissions, e.g., renewable energies, by directly targeting the pollutant. As noted in the Carbon Pricing Leadership Report (World Bank 2020), a carbon tax generates the correct incentives as the cost to users increases. A tax on carbon addresses the negative externality of climate change. Revenue from a carbon tax can then be used to promote growth.[11] It has been argued (Weitzman, 1974) that price instruments are more effective than quantity instruments, and, if there is uncertainty about abatement costs, price instruments are more effective than quantity instruments. Some studies argue that the choice of instrument (price versus quantity) must consider uncertainty over business cycles due to the possibility that carbon tax revenues fluctuate more (or less) than GHG emissions in different business cycles. Furthermore, a fixed price instrument may be more advantageous than a fixed quantity instrument owing to the procyclical behaviour of abatement costs (Grodecka & Kuralbayeva, 2015).

Energy (input) Taxes

Energy input taxes seek to induce changes towards technologies with lower emissions by indirectly targeting the pollutant. A viable market policy instrument is therefore increased taxes and/or reduced subsidies on fossil fuels that seek to reduce fossil fuel consumption and thereby reduce emissions. Fossil fuel taxes are mostly applied on producers, while subsidies are mostly applied on consumers, both intermediate and final.

Fossil fuel taxes are more prevalent among developed countries, and common in Europe. Developing countries, on the other hand, tend to have energy subsidies for, variously, socio-economic, development and energy poverty purposes. Fossil fuel subsidies reduce the cost of energy inputs, creating the incentive to increase use of fossil fuels.[12]

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11 See World Bank (2019) for a discussion of carbon pricing in different countries.

12 See World Bank (2019), section 5.2, for a description of the geographic distribution of fossil fuel subsidies.

Quantity Constraints

Quantity constraints can target the level of emissions and/or energy input use; these can be applied at the level of the economy and/or the producers and consumers. By constraining the use of selected energy inputs, they effectively cause an economy to contract and thereby ensure reductions in emissions. They are appealing because they seem simple and easy to understand.

Quantity constraints have an intuitive appeal. Controlling the quantities of fossil fuels used can be a crude mechanism for limiting emissions, e.g., restricting the total use of coal, the fossil fuel with the highest emissions, by removing coal-fired electricity generation capacity[13] and limiting domestic use[14] can be a transparent policy option. At the level of an activity, e.g., electricity generation, they can be a proxy instrument for government-imposed constraints, e.g., constraints of the quantities of electricity generated using different fossil fuels when data are unavailable for different electricity generating technologies. Quantity constraints can also be used in simulations to quantify the potential economic benefits from allocations by market mechanisms.

Technology Change

Technology changes are implicitly perceived as the panaceas that will solve the problem of global warming. The importance of technology changes as explanations for economic development are well understood although the processes by which new technologies emerge are less well understood. In the current context this lack of understanding is compounded by the limitations of standard economic analyses with respect to the inclusion of externalities and the comparative static method used for this pilot study.

Hence, this study does not seek to evaluate the impacts of known technology changes. Rather this study illustrates how the model can evaluate the magnitudes of technology changes required to achieve a given reduction in carbon emissions.

<u>Outcomes</u>

Reforming energy policies in developing economies raises concerns about the effects of energy price changes on lower-income households. A major concern is that energy expenditures constitute a relatively larger share of household expenditures for lower-income

[13] Most probably achieved by proscribing the building of new coal-fires power stations.
[14] Most limits on domestic use of fuels are justified as protecting air quality.

households. These distributional implications may be perceived as necessitating action policies, especially in developing countries. Relevant action policies may include microeconomic reforms, investments in renewable technology, or cash transfers.

A global model can provide some information about the distributional effects across countries but has little to say about the effects within countries. Some information can be inferred from changes in the rates of return to different factors of production, combined with information about the patterns of factor ownership by households, and changes in commodity prices, combined with information about the patterns of consumption by households.

Data

The data encompass the heterogeneities of technologies, energy products, emissions rates, economic structures, wealth and inter regional income distribution. The data also record the bilateral patterns of trade in goods and services between countries and hence interdependencies between countries.

Database

The data for the model are from GTAP v10, the base year is 2014[15], presented in Social Accounting Matrices (SAM) format. The GTAP data are aggregated to form a (3-dimensional) SAM with 19 regions, 27 commodities and activities and 5 factors (see Table 2.1; details of the aggregation used, and the aggregation schema are in Annex A2.2).[16] There are six energy commodities in the database: coal, oil extraction, gas extraction, petroleum, electricity, and gas distribution-manufacturing.

Transactions Data

The transactions data in the GTAP database are recorded as millions of US dollars at six decimal places. The reasons for this choice of units are historic and reflect the mathematical methods used in the generation of the GTAP database, rather than arguments that this degree

15 See Aguiar et al. (2019) for a detailed description of the GTAP 10 database, version 10 is the latest GTAP data available.

16 A more disaggregated version of the GTAP v10 database was considered, but the model had difficulty solving due to scaling issues. The regions and sectors in Table A2.3.1a and Table A2.3.1c provide the detail needed to match the results from the Globe model to the single country models.

of precision can be sustained. For this study, the transactions data were truncated at one decimal place ($(USD)100,000).[17]

Energy Data

The GTAP database reports quantities of energy commodities used, in millions of tonnes of oil equivalent (MTOE) and CO_2 emissions; these are recorded as satellite accounts to the SAM.[18] Most energy inputs are demanded are by activities and households, with demand by government and investment close to zero in all regions. The underlying structure of the database with satellite accounts for a single region with a single energy commodity is illustrated in Table 2.2. The table includes elements of the transaction SAM that could involve payments to energy commodities – commodities, factors, activities, household, government, and capital (which is the savings-investment account).

In Table 2.2, the satellite data are recorded as 6 (three dimensional) matrices that record the volumes of energy inputs used by activities and purchased by domestic institutions in terms of million tonnes of oil equivalent (MTOE) ("Quantity of Energy Input") and 6 (three dimensional) matrices that record the CO_2 emissions associated with each energy commodity and using agent ("CO_2 by Energy Input"). These data capture inherent differences in emission rates associated with differences in the technologies used by the agents in different regions.

17 The decision to truncate the data reflects arguments about the performance of the functional forms used in CGE models where the ranges of values in transactions are large.

18 The additional accounts are referred to as satellite accounts because they are not part of the transactions data that constitute a SAM.

Table 2.1 Model sectors, Regions and Factors

Regions	Sectors	Sectors
North Africa	Grain	Autos parts & transport equip
West Africa	Other agriculture	Electricity
East Africa	Oilseed	Gas manufacture
SACU (South African Customs Union)	Livestock	Construction
Other Asia	Coal	Trade services
India	Extraction of crude petroleum	Transport services
Other South Asia	Extraction of natural gas	Other services
Brazil	Other mining extraction	Financial services
Other Latin America	Cattle meat and other meat	
Central America	Vegetable oils and fats	**Factors**
Russian federation	Other food	Capital
Former Soviet Union	Textiles and wearing apparel	Land
Middle East	Leather products	Natural resources
China and Hong Kong	Wood and Paper	Skilled labour
High-income Asia	Coke and refined petroleum	Unskilled labour
NAFTA (North America Free Trade Area)	Chemicals	
Australia and New Zealand	Basic pharmaceutical products	
EU_27	Other manufacturing	
Other Europe	Metals	

Table 2.2 Transaction and Satellite Accounts for Energy and Emissions

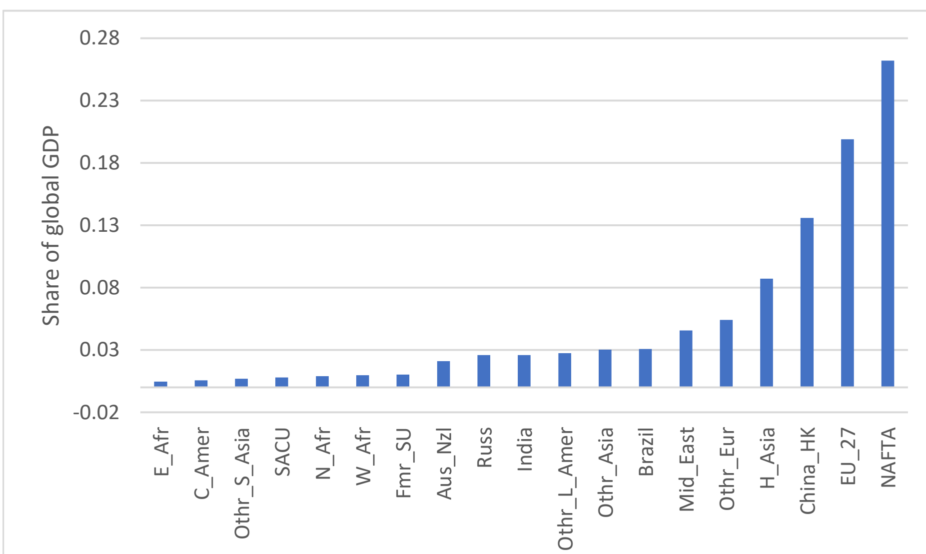
	Commodities	Activities	Households	Government	Capital
Commodities	0	Energy Commodity Intermediate Use Matrix	Energy Consumption	Energy Consumption	Energy Consumption
Factors	0	Expenditure on Primary Inputs	0	0	0
Government	Taxes on Energy Commodities	Taxes/Subsidies on Energy Use in Production	0	0	0
Totals	Total Supply of Commodities	Total Expenditure on Inputs by Activities	Total Household Expenditure	Total Government Expenditure	Total Investment
Quantity of Energy Input		Quantities of Intermediate Energy Input	Quantities of Final Demand Energy Input	Quantities of Final Demand Energy Input	Quantities of Final Demand Energy Input
CO_2 by Energy Input		Quantities CO_2 Emissions from Energy Input	Quantities CO_2 Emissions from Energy Input	Quantities CO_2 Emissions from Energy Input	Quantities CO_2 Emissions from Energy Input

Economic structure

NAFTA (North America Free Trade Area), China & Hong Kong, and EU_27 have the largest shares of global GDP, while African countries account for the smallest shares (see Figure 2.1). East Africa reports the lowest share. China & Hong Kong and NAFTA account for the largest shares of global CO_2 emissions (see Figure 2.2). The EU_27 accounts for less than half of NAFTA's CO_2 emissions, while East Africa and West Africa account for minimal shares of global CO_2 emissions.

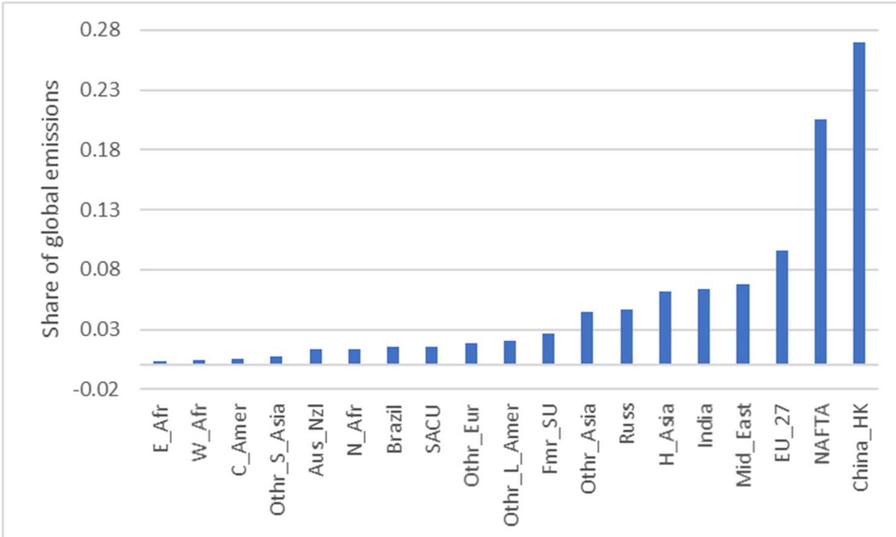
The patterns of shares of global GDP and global CO_2 emissions are indicative of the marked differences in CO_2 emissions per unit of GDP. Similarly marked differences emerge when CO_2 emissions per unit of population are calculated. These differences are clearly important considerations for nation states to understand the sharing of the burdens associated with reducing global CO2 emissions. The analyses for this study do not involve evaluating different patterns of emissions reductions for inclusions in NDCs.

Figure 2.1 Region GDP as a share of global GDP



Source: GTAP database aggregate

Figure 2.2 Region shares of global CO_2 emissions



Source: GTAP database aggregate

Regions differ in terms of the source of CO_2 emissions (see Table 2.3). In China & Hong Kong, SACU (South African Customs Union) and India most of the CO_2 emissions are from coal (75.6, 74, and 71.4 percent respectively). EU_27, High-income Asia, Australia & New Zealand and NAFTA have the highest share of emission from petroleum (52.5, 42.5, 41.1 and 42 percent respectively).

Agent-specific taxes on the use of fossil fuels differ widely by regions.[19] In EU-27 and Other Europe tax rates on fossil fuels are high. The average tax on petroleum used in production is 69% in Other Europe and 42% in EU_27 while in NAFTA, High-income Asia and Australia & New Zealand the rate ranges from 11 to 13%. Likewise, the taxes that households pay for petroleum in Other Europe and EU_27 far exceed the taxes paid by households in the other high-income regions (see Annex Figure A2.3.1). For middle income regions (Annex Figure A2.3.2), tax rates also vary widely across the regions with the household tax rate at 124% in Russia and 70% in Brazil, while the rates in West Africa and East Africa are 7 percent and 6 percent respectively (Annex Figure A2.3.3).

[19] All tax rates used in the analyses are derived from the transactions data in GTAP version 10.

Table 2.3 Share of emission by fuel type, selected regions

	SACU	China HK	Russ	India	Aus_NZ	NAFTA	EU_27	H_Asia	Mid_East	N_Afr	W_Afr	N_Afr
Coal	74.0	75.7	17.7	71.9	39.0	27.8	25.8	34.8	7.6	3.9	1.8	3.9
Oil	0.0	0.3	0.2	0.0	0.1	0.0	0.3	1.0	5.9	0.5	1.7	0.5
Gas	1.6	1.9	36.1	1.1	14.0	9.4	16.8	21.0	23.9	38.6	10.7	38.6
Petroleum	23.9	19.5	26.9	24.8	41.1	42.0	52.2	42.5	43.8	52.8	64.2	52.8
Gas distrib	0.4	2.7	19.1	2.2	5.8	20.7	4.8	0.7	18.8	4.2	21.6	4.2

Source: GTAP database aggregate

The regions West Africa and East Africa have different patterns of trade dependency by partner (see Table 2.4). West Africa relies more heavily on imports from EU_27 (25% of total imports), while East Africa sources 13% of its imports from EU_27. Both regions have similar trade dependence on China & Hong Kong. West Africa imports more from NAFTA than does East Africa (12% verses 5%); while East Africa imports more from the Middle East than does West Africa (11% verses 3%). Note the trade dependency does not go both ways - West Africa and East Africa are only small shares of the total imports for EU_27, NAFTA, the Middle East or China & Hong Kong.

Table 2.4 Trade Dependency (import shares from row region in each column region)

Partner	West Africa	East Africa	China & Hong Kong	India	NAFTA	EU_27	Middle East	North Africa
			Importing region:					
West Africa	0.054	0.001	0.003	0.038	0.003	0.008	0.014	0.001
North Africa	0.011	0.013	0.003	0.012	0.004	0.015	0.020	0.032
East Africa	0.001	0.055	0.007	0.007	0.002	0.002	0.007	0.003
SACU	0.015	0.125	0.025	0.032	0.006	0.007	0.009	0.003
Other Asia	0.057	0.040	0.095	0.085	0.045	0.025	0.041	0.028
Other South Asia	0.003	0.009	0.002	0.005	0.005	0.005	0.005	0.002
Central America	0.010	0.001	0.003	0.002	0.012	0.004	0.002	0.003
Other Latin America	0.006	0.002	0.023	0.034	0.025	0.009	0.010	0.020
Brazil	0.014	0.004	0.023	0.010	0.012	0.007	0.013	0.022
China & Hong Kong	0.238	0.223	0.041	0.144	0.179	0.073	0.139	0.117
Russia	0.007	0.011	0.018	0.010	0.008	0.041	0.028	0.031
India	0.054	0.129	0.014	0.000	0.019	0.014	0.054	0.025
Middle East	0.034	0.112	0.085	0.241	0.041	0.033	0.120	0.103
Other Europe	0.046	0.032	0.046	0.075	0.043	0.093	0.058	0.038
Former Soviet Union	0.006	0.006	0.011	0.009	0.004	0.017	0.026	0.021
Australia & New Zealand	0.007	0.008	0.047	0.026	0.007	0.004	0.013	0.008
NAFTA	0.123	0.049	0.111	0.070	0.329	0.078	0.110	0.088
EU_27	0.248	0.129	0.152	0.124	0.162	0.526	0.246	0.404
High-income Asia	0.067	0.050	0.291	0.075	0.096	0.039	0.083	0.050

Source: GTAP database aggregate

Model [20]

GLOBE_CC is a version of the GLOBE CGE global model prepared for the UNFCCC. The GLOBE model is a SAM based Global Computable General Equilibrium (CGE) model that can be calibrated with data from the GTAP database.[21] The model is a member of a family of CGE models that model trade relationships using principles described in the 1-2-3 model (de Melo and Robinson, 1989; Devarajan, *et al*., 1990).[22] In addition the model owes a lot to the

[20] A comprehensive technical document for GLOBE_CC is available (McDonald & Thierfelder, 2020b).

[21] The use of the GTAP database is mandated by the contract with the UNFCCC. There is no discussion in this technical document relating to concerns about the adequacy of the GTAP database.

[22] The 1-2-3 model is a CGE model that has one region, two production activities and three goods.

development of the SAM approach to national accounting, e.g., Stone (1962a and b) and Pyatt (1991), and the SAM approach to modelling, e.g., Pyatt (1987), Drud *et al*., (1986), and the on-going development of the General Algebraic Modelling System (GAMS).

The underlying approach to multi-region modelling for this CGE model is the construction of a series of single country CGE models that are linked through their trading relationships. As is common with all (known) CGE models the price systems in the model are linear homogenous and hence the focus is upon movements in relative, rather than absolute, prices. Each region in the model has its own numéraire price, typically the consumer price index (CPI), and a nominal exchange rate, while the model as a whole requires a numéraire, which is an exchange rate index for a number of (reference) regions. As such this model contains a different philosophical approach to global modelling to that found in the other global models.[23] Behind this difference lies a theoretical debate about how comparative static and finite time horizon dynamic CGE models should value transfers associated with the capital account of the balance of payments (see Robinson, 2006).

A distinctive feature of the model is the use of a 'dummy' region, known as Globe, that allows for the recording of inter-regional transactions where either the source or destination are not identified. Examples of such transactions include trade and transportation margins and data on remittances. The Globe construct provides a general method for dealing with any transactions data where full bilateral data are missing.

The GLOBE_CC model includes a nested production structure with aggregate value added and aggregate intermediate inputs as imperfect substitutions. The elasticity of substitution between aggregate intermediates and aggregate value added allows limited substitution between aggregate intermediates and aggregate value added. There is substitution between three aggregate factors in value added – an aggregate of land and natural resources; an aggregate of capital and energy and an aggregate of skilled and unskilled labour. The elasticity of substitution among these aggregates ranges from 0.2 to 1.69 (See Annex Table A2.5.1 for a list of elasticity of substitution in value added for all activities). The energy input to value added is an aggregate of electricity and a fossil fuels aggregate; the fossil fuels aggregate consists of coal, oil extraction, gas extraction, petroleum, and gas distribution. For

23 For instance, the GTAP and GTAPinGAMS models, and, apparently, the LINKAGE model does not contain explicit nominal exchange rates. In fact, all these models contain (r + 1) numéraire, where r is the number of regions and the numéraire for each region is the fixed exchange rate, although appearing to contain only a single global numéraire.

each factor aggregate, the elasticity of substitution is 4, except for the fossil fuels aggregate where the elasticity of substitution is 2.

Imports and the domestic variety of commodities are imperfect substitutes in consumption and imports by partner are also imperfect substitutes.[24] Elasticities of substitution range from 0.4 to 8.6[25] (See Annex Table A2.5.2 for a list of the elasticity of substitution between imports and the domestic good for all commodities and regions). There is substitution among imports by trade partner and these range from 0.9 to 17.0 (See Annex Table A2.5.3 for a list of the elasticity of substation among imports by trade partner for all commodities and regions). Domestic production is sold on the export and domestic market and it is assumed that there is an elasticity of transformation between the domestic and export variety for all commodities and regions. Exports to partners are also not perfect substitutes and there is an elasticity of transformation among exports to different partners, for all commodities and regions.

The tax instruments include taxes on energy inputs and/or carbon emissions; these taxes enter the determination of the costs of production and the cost of commodities purchased by domestic institutions.

Simulations and closure settings

This study illustrates the use of a four policy instruments to reduce **global** carbon emissions by 20%: two taxes, quantity restrictions, and technology changes.[26] The shocks and model closure settings used for this study are summarized in Table 2.5. In each simulation, the low-income regions are exempted from reducing emissions.[27] The model allows market forces to determine optimal carbon reductions by region. As a result, regions that have already reduced carbon emissions will be required to make smaller changes. In the base data, regions have

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24 For example, an imported vehicle is not identical to a domestic vehicle. Likewise, imports are differentiated by region – a vehicle from Japan is different from a vehicle from Germany.

25 Armington elasticities of substitution from GTAP v10 are divided by 2. The values from GTAP are high because the GTAP model does not have a constant elasticity of transformation (CET) on the export side. The high elasticities of substitution to reduce the terms of trade effects from the GTAP model.

26 Note, in a comparative static model, technology changes are like a "magic bullet." The model does not account for research and development expenditures so there is no opportunity cost. The results are illustrative because the model does not account for the cost of technology changes. A better approach would be to use a recursive dynamic model to allow a reduction in current consumption to increase savings to pay for the new technologies. For this reason, results from simulation D1: technology change, are not passed to the single country models.

27 In this study, low-income regions are West Africa, North Africa, East Africa, Other Asia, Other South Asia, Central America and Other Latin America.

different initial taxes on fossil fuels – for example, taxes on fossil fuels are higher in the EU_27 than in NAFTA (see Figure A2.3.1): this suggests that the EU_27 has made more effort than NAFTA to reduce carbon emissions. Regions also have different emission rates of carbon by production activities due to different production technologies (for example, SACU has a high dependence on coal in electricity production).

The 20% reduction in **global** carbon emissions is based on the IPCC's pathways. This is below the target of 45% (IPCC, 2018b); however, according to the IPCC, not all the reduction in carbon emissions will come from market interventions. Instead, some will come from measures to capture and reduce carbon emissions via methods such as planting more trees.

The model closure conditions reflect assumptions about macroeconomic behaviour. With a fixed current account balance, it is assumed that changes in economic activity will not lead to a change in foreign borrowing. Instead, the exchange rate will adjust in each region. A balanced macroeconomic closure ensures that any changes in final demand are shared equiproportionately across households, government, and investment. The internal balance is held constant and changes in tax revenues collected are redistributed to households as changes in income tax rates. When the internal balance is held constant, economies can realise a "double dividend" effect of environmental tax policy – tax revenue generated can reduce taxes elsewhere in the economy. Adjusting income taxes has the advantage of being a less economically distorting change; but some of the costs of reducing emissions may be offset by increased efficiency in tax systems. Other tax replacement options such as a reduction in sales taxes work through the price system and affect decisions at the margin.

Table 2.5 Simulation summary

Shock	Description	Model Closure
A1	***Carbon Tax*** Reduce global carbon emissions 20% Endogenous tax on carbon emissions, low-income regions exempt	• Exchange rate (ER) flexible, trade account balance fixed • Share of government spending in final demand fixed • Share of investment spending in final demand fixed • Internal balance fixed and income taxes adjust • CPI numeraire
B1	***Energy Input Tax*** Reduce global carbon emissions 20% Endogenous tax on fossil fuels, low-income regions exempt	• Exchange rate (ER) flexible, trade account balance fixed • Share of government spending in final demand fixed • Share of investment spending in final demand fixed

		• Internal balance fixed and income taxes adjust
C1	***Quantity Restriction*** Reduce carbon emissions in each region to the levels found in A1 (Global carbon emission reduction of 20%, uneven by countries)[28] Quantity constraints: Total factor productivity (TFP) adjusts in each region – an equiproportionate change in TFP by each activity.	• Exchange rate (ER) flexible, trade account balance fixed • Share of government spending in final demand fixed • Share of investment spending in final demand fixed • Internal balance fixed and income taxes adjust • CPI numeraire
D1	***Technology Change*** Reduce global carbon emissions 20% Endogenous efficiency parameter for fossil fuel aggregate used in electricity production by region except low-income regions	• Exchange rate (ER) flexible, trade account balance fixed • Share of government spending in final demand fixed • Share of investment spending in final demand fixed • Internal balance fixed and income taxes adjust • CPI numeraire

Results

The presentation and discussion of the results from these simulations is limited because the objective of these simulations was the derivation of estimates of the changes in world prices and exchange rates that could then be used to examine the impacts of different response measures on two pilot study countries: Senegal and Kenya. If the objective of these simulations had been an evaluation of different response measures, which could be relatively easily undertaken the simulations and the presentation and discussion of the results may have been markedly different.

The results begin with details of the changes in CO_2 emissions by each region in the model under each of the four simulations, noting that the allocation of reductions by each region was determined by market mechanisms. Then some summary measures of the economic impacts are considered before presenting the results for world price changes for the two regions that provide the estimates for the individual country studies.

The achievement of a 20 percent reduction of global carbon emissions by different instruments produces markedly different changes in absolute (Table 2.6) and percentage (Figure 2.3) changes in emissions. As expected, regions with high carbon emissions before

[28] This calibration option can be perceived as also providing an indicator of the economic benefits from a carbon tax (A1) with market mechanisms determining the adjustments required.

applying the response measures, e.g., China and NAFTA, experience large absolute reductions, while regions with high fossil fuel taxes before applying the response measures, e.g., EU_27 and Other Europe, experience smaller absolute reductions. Notably, SACU experiences high absolute and relative reductions in carbon emissions, despite accounting for a relatively low share of global carbon emissions: this reflects SACU's dependence on coal that accounts for over 70 percent of its total emission (see Table 2.3). There are minor changes in carbon emissions for the regions exempt from the response measures slightly (the regions in italics in Table 2.6), with some, e.g., Central America and Other South Asia, increasing carbon emissions.

Table 2.6 Absolute change in carbon emission

	A1: Carbon tax	B1: Energy input tax	C1: Quantity restriction	D1: Technology change
China_HK	-28.76	-22.84	-28.76	-26.97
NAFTA	-11.81	-13.97	-11.81	-11.74
India	-4.46	-3.77	-4.46	-3.81
EU_27	-3.17	-4.27	-3.17	-4.17
Mid_East	-2.29	-3.51	-2.29	-1.84
Russ	-2.12	-3.80	-2.12	-2.89
Fmr_SU	-1.89	-1.74	-1.89	-1.45
H_Asia	-1.83	-3.02	-1.83	-3.26
SACU	-1.75	-1.32	-1.75	-1.95
Aus_Nzl	-0.51	-0.38	-0.51	-0.55
Othr_Eur	-0.49	-0.62	-0.49	-0.58
Othr_Asia	*-0.48*	*-0.18*	*-0.48*	*-0.37*
Brazil	-0.31	-0.60	-0.31	-0.30
Othr_L_Amer	*-0.04*	*-0.03*	*-0.04*	*-0.05*
N_Afr	*-0.03*	*0.00*	*-0.03*	*-0.04*
E_Afr	*-0.02*	*-0.01*	*-0.02*	*-0.02*
Othr_S_Asia	*-0.02*	*0.04*	*-0.02*	*-0.02*
W_Afr	*-0.01*	*-0.01*	*-0.01*	*0.00*
C_Amer	*0.01*	*0.04*	*0.01*	*0.02*

Source: Model simulations

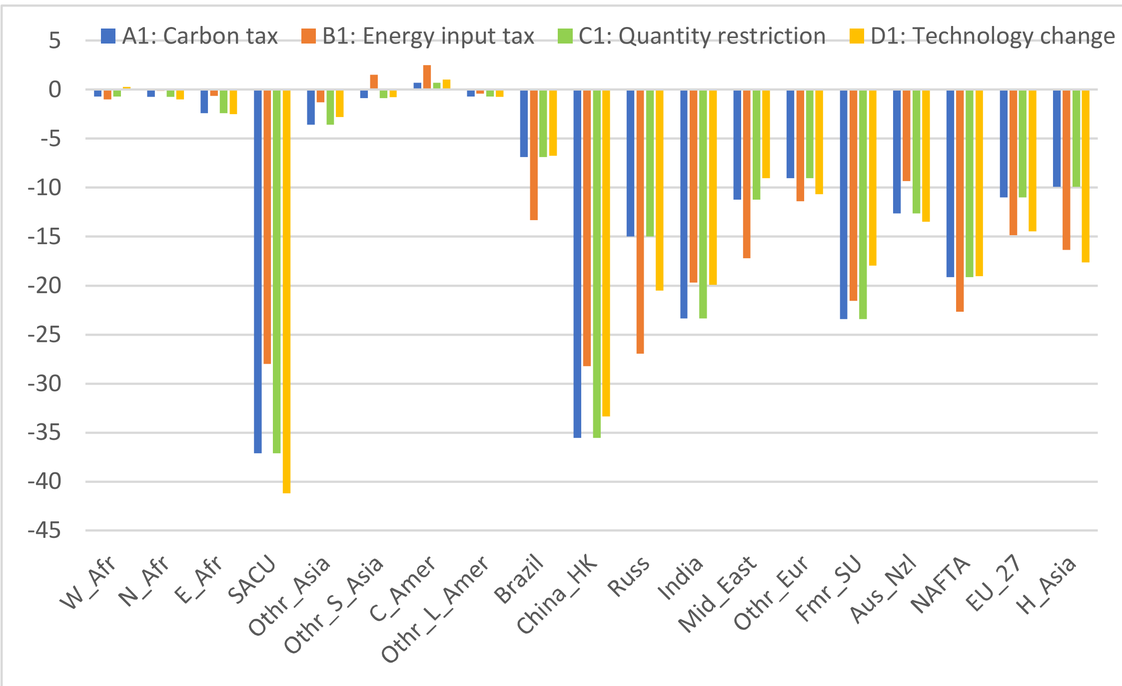
The presumption that the contributions by regions to the global reduction in emissions is determined by market mechanisms results in appreciable differences in the absolute and percent change reductions of emissions by regions.[29] With China and NAFTA accounting for

[29] Note that by design the emission reductions by regions for C1 (quantity restrictions) are those from A1 (carbon taxes). This is because the reduction in emissions in simulation A1 vary by region. Given the region emission reductions, quantity restrictions, by region, are determined.

between 60 and 70 percent of the required reductions in emissions, the results confirm the expectation that the response measures by these regions are critical. It is also evident that response measures by low-income and small island economies may make limited contributions to reducing global emissions.

The absolute reductions by China and NAFTA are highest in all simulations, whereas China is second highest in proportionate terms and NAFTA is fourth highest. This is consistent with an expectation that the burdens associated with emissions reductions will fall more evenly, in proportionate terms, across regions than the absolute changes may imply; nevertheless, the range of proportionate reductions is substantial.

Figure 2.3 Regional percent changes in carbon emissions



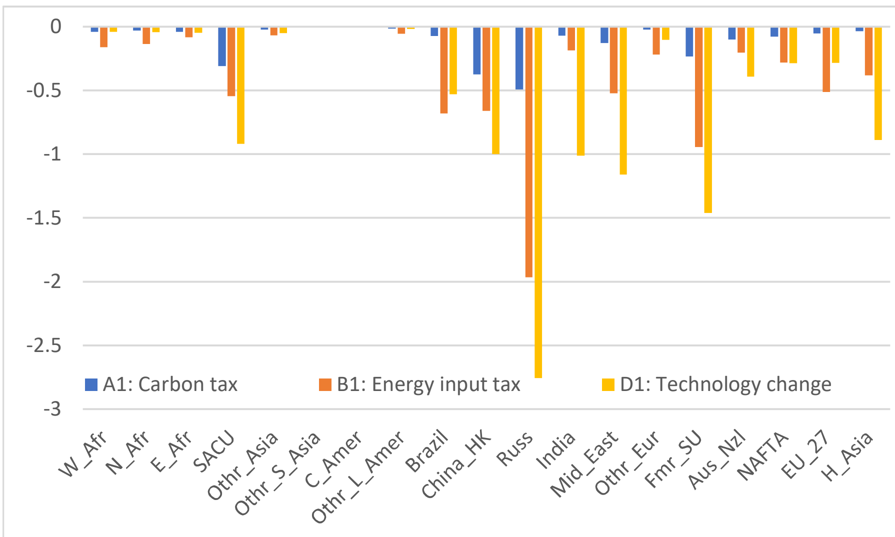
Source: Model simulations

Real GDP declines for most regions (Figure 2.4), with marginal increases for Central America in all simulations and for the regions exempt from the response measure in simulation C1 (quantity restrictions) (see Figure A2.4.1)[30] With the exception of Russia, and the crude instrument of quantity restrictions (C1), the impacts on GDP are more muted than might have been expected given the regional reductions in emissions. The reductions in GDP are not trivial, but they reflect how, given time, economic systems may adjust to changes. The

30 The real GDP results for C1 are reported in Annex 4 due to the vastly different scales.

results are consistent with economic theory: a tax on carbon is a more efficient tax instrument for all regions because it accounts for differences in carbon intensity of emissions by users of fossil fuels and the intensities can vary by production activity. In most instances the D1: technology change simulations have a larger negative impact on real GDP than either tax instrument. It is notable that the EU_27 and Other_Eur(ope) are exceptions, which reflects their high level of energy taxation before the response measures and hence the greater potential benefits from technology changes. Despite the tax efficiency arguments for directly taxing carbon, it may be a more difficult tax to introduce because of the data and infrastructure requirements; these may be important considerations for low-income economies. Instead, it may be more cost effective to reform existing taxes on fossil fuels.[31]

Figure 2.4 Real GDP (% change)



Source: Model simulations

The negative impacts on GDP reflect outcomes that will emerge when additional constraints are added in a CGE model. It is important to appreciate why this happens with these simulations. Initially the databases and model do not include any costs associated with CO_2 emissions and therefore there are no constraints on the system associated with CO_2 emissions; when emissions are reduced the system faces a new set of tighter constraints and must contract and then measured economic activity declines. As the policy instrument used to reduce CO_2 emissions becomes less efficient, the real GDP declines more: the real GDP

31 This can be accommodated in the model by customising the closure settings for tax replacement instruments by region, e.g., by using a GST rather than income tax instrument or using a mix of tax instruments.

declines are smallest when a tax on carbon is used to achieve a 20% reduction in CO_2 emissions, while technological change results in the biggest decline in real GDP.

Both tax instruments produce decreases in demand for fossil fuel inputs and a reduction in output of fossil fuels but have different effects on production structures. In China & Hong Kong, the region which must reduce carbon emissions the most (see Table A2.4.1 for output changes in China), the production of energy commodities declines from 8.5 percent in petroleum with a tax on fossil fuels to 62 percent for gas extraction with a tax on fossil fuels. Production of electricity, a clean energy source, declines because it uses a lot of coal in production. For other commodities, the output decline ranges from 0.1 percent (other food) to 2.5 percent (other manufacturing). All regions experience marked changes in the structure of production.

Table 2.7 Exchange rate, percent change

	A1: Carbon Tax	B1: Energy Input Tax	C1: Quantity Restriction	D1: Technology Change
West Africa	1.99	7.57	5.86	1.83
North Africa	1.26	4.51	2.09	1.29
East Africa	0.83	2.58	4.47	0.60
SACU	0.77	2.61	-0.26	0.20
Other Asia	0.88	1.51	0.06	1.49
Other South Asia	0.15	0.75	-0.72	0.30
Central America	0.37	0.94	0.88	0.64
Other Latin America	1.43	3.84	2.70	1.53
Brazil	-0.01	-0.75	0.57	-0.23
China & Hong Kong	-0.59	-1.19	1.44	-0.02
Russia	2.92	9.87	5.63	2.37
India	-1.29	-2.41	-3.53	-0.95
Middle East	0.86	3.95	3.57	-0.79
Other Europe	-0.06	-0.15	-0.27	0.02
Former Soviet Union	-0.08	0.78	-1.29	-1.27
Australia & New Zealand	3.35	4.29	3.85	5.11
NAFTA	-0.21	-0.75	-1.74	-0.01
EU_27	-0.26	-0.81	-1.10	-0.13
High-income Asia	-0.77	-2.92	-0.75	-1.43

Note: the exchange rate is local currency units per 'world dollar', so an increase is a depreciation; it takes more local currency units to buy a 'world dollar' so the local currency unit has become less valuable.
Source: Model simulations

In all countries required to reduce CO_2 emissions, there is a decrease in export supply. Low-income countries do not pay the taxes so there is little change in the import demand for fossil fuels and the net effect is an increase in the price of imported fossil fuels in low-income countries.[32] Since the trade account balance is held constant in all regions, this has general equilibrium effects. The increased cost of energy products means the prices of imports increase and to maintain the external balance the nominal exchange rate depreciates (Table 2.7) to increase the value of exports (the depreciations also reduces by raising the border prices).[33] For West Africa, there is a slight depreciation when there is a tax on carbon (2%), and a bigger depreciation (7.6%) when taxes are on fossil fuels (7.6 percent) or quantity restrictions (5.9 percent) are used to reduce global carbon emissions. This is because the later instruments are less direct so lead to bigger structural changes in the high-income and middle-income countries who must reduce emissions. For East Africa, the same pattern holds, but the magnitude is smaller. When there is a tax on carbon, depreciation is 0.8%; when there is a tax on fossil fuels, the depreciation is 2.6 percent; and when there is a reduction in output, the depreciation is 4.5 percent.

As a result of the changes in the patterns of production and consumption and associated changes in the exchange rate, the world prices of imports in West Africa and East Africa decline except for coal and gas manufacture and distribution.[34] There is a decrease in import demand due to the appreciation (See Table 2.8 for world price changes in West Africa and Table 2.9 for world price changes in East Africa). On the export side, the depreciation encourages sales to the export market – the supply of exports of non-energy commodities increases and world price of exports decline.

The net effect is a decline in real imports for West Africa and East Africa. There is an increase in real exports for West Africa and a slight increase in real exports for East Africa. The difference between the two regions is consistent with the different magnitudes of the exchange rate effects: there is a bigger depreciation in West Africa than in East Africa. This difference relates back to differences in import shares and the importance of different partners. (See Figures A2.4.2a, A2.4.2b, and A2.4.2c for real export and real import changes for all regions.)

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32 World prices are bilateral by commodity and trade partners. For example, the market for coal exported from China to West Africa consists of China's export supply of coal to West Africa and West Africa's import demand for coal from China.

33 In a dynamic model declining demand for fossil fuels would be expected to reduce investment in extraction activities, e.g., mines and oil/gas wells, with a commensurate reduction in supply. In a comparative static model this is proxied by reductions in the quantities of factors employed.

34 Coal and gas manufacture and distribution have the highest CO_2 coefficients, which means they are the dirtiest fossil fuels used. When there is a tax on carbon emission, output declines so exports decline, this supply shock increases the world price. The output changes are less dramatic for the other energy inputs because they are less dirty.

Table 2.8 World prices changes for West Africa (%)

	World price of imports *cif* (PWM) percent change			World price of exports *fob* (PWE) percent change		
	A1: Carbon Tax	**B1: Energy Input Tax**	**C1: Quantity Restriction**	**'A1: Carbon Tax**	**B1: Energy Input Tax**	**C1: Quantity Restriction**
Grain	-1.40	-4.29	-0.59	-1.61	-5.74	-6.93
Other Agriculture	-1.70	-4.80	-0.92	-1.14	-2.85	-6.14
Oilseed	-1.64	-5.56	-4.93	-0.85	-2.74	-7.02
Livestock	-1.33	-4.29	-2.33	-2.04	-7.55	-7.47
Coal	10.19	2.30	10.30	N/A	N/A	N/A
Extraction of crude petroleum	-2.51	-9.17	-8.12	-2.81	-10.99	-10.16
Extraction of natural gas	-3.06	-9.93	-4.57	-5.52	-17.78	-7.98
Other mining extraction	0.07	1.23	5.75	-2.70	-6.60	-11.69
Cattle meat and other meat	-1.24	-4.36	0.37	-1.17	-6.53	-19.63
Vegetable oils and fats	-1.56	-4.62	-3.67	-1.40	-4.71	-5.27
Other Food	-1.17	-3.81	1.15	-0.86	-3.13	-4.94
Textiles and wearing apparel	-0.61	-2.77	5.68	-1.48	-5.33	-6.12
Leather products	-0.64	-3.13	5.69	-0.67	-2.75	-2.99
Wood and paper	-0.87	-3.53	0.87	-0.58	-2.09	-2.38
Petroleum	-2.02	-6.65	1.98	-3.57	-11.72	-13.57
Chemicals	-0.82	-2.09	3.18	-1.12	-3.45	-3.58
Basic pharmaceutical products	-0.44	-2.27	4.35	-1.61	-5.93	-6.14
Other manufacturing	-0.38	-2.21	6.34	-2.25	-7.99	-13.23
Metals	-0.28	-1.90	6.07	-1.31	-5.19	-5.01
Transport equipment	-0.57	-2.44	6.08	-2.06	-7.35	-13.99
Electricity	-0.69	-2.43	-2.00	-1.41	-9.14	-7.04
Gas manufacture and distribution	8.34	7.15	6.55	-3.68	-9.63	-9.11
Construction	-0.93	-3.43	2.73	-0.97	-4.12	-16.45
Transport services	-0.70	-2.53	1.40	-1.02	-2.94	-5.99
Services for delivery of goods	-0.65	-2.59	1.10	-0.50	-2.10	-6.44
Other services	-0.90	-3.36	0.92	-0.42	-1.62	-6.62
Financial services	-0.64	-2.62	0.84	-1.04	-4.00	-10.67

Source: Model simulations

An important result is the extent of the differences in the changes in world prices of imports and exports consequent upon the different response measures, not only is there a mix in the signs there are also substantial differences in magnitudes across commodities. Moreover, the import and export price changes differ markedly between regions for the same response measures. These differences reflect the differences in the transactions between regions in the model and differences in the transactions within regions in the model. These differences mean that the shocks transferred from the results of the global model to the single country models will differ for different countries. This means that generic policy advice relevant to all regions is unlikely to be robust.

Table 2.9 World prices changes for East Africa (%)

	World price of imports *cif* (PWM) percent change			World price of exports *fob* (PWE) percent change		
	A1: Carbon Tax	**B1: Energy Input Tax**	**C1: Quantity Restriction**	**A1: Carbon Tax**	**B1: Energy Input Tax**	**C1: Quantity Restriction**
Grain	-1.27	-3.16	0.01	-1.07	-2.86	-3.61
Other Agriculture	-1.10	-2.66	-3.44	-1.00	-2.47	-6.89
Oilseed	-0.88	-2.58	-6.09	-0.66	-1.86	-9.05
Livestock	-0.83	-2.15	-3.36	-1.22	-4.32	-9.92
Coal	15.04	5.14	18.35	-8.28	-11.68	-12.18
Extraction of crude petroleum	-1.81	-6.29	-4.28	-2.97	-10.93	-15.67
Extraction of natural gas	N/A	N/A	N/A	-7.58	-5.57	-19.18
Other mining extraction	-0.04	0.36	10.19	-1.64	-3.67	-12.59
Cattle meat and other meat	-0.90	-2.23	2.62	-1.01	-3.99	-8.04
Vegetable oils and fats	-0.98	-2.32	0.09	-0.89	-2.58	-8.55
Other Food	-0.66	-1.81	4.82	-0.43	-1.35	-6.29
Textiles and wearing apparel	-0.11	-0.62	6.39	-0.27	-0.89	-4.03
Leather products	-0.05	-0.68	6.83	-0.17	-0.74	-6.60
Wood and paper	-0.30	-1.10	2.59	-0.51	-1.66	-4.24
Petroleum	-1.09	-3.96	7.38	-1.99	-7.28	-10.00
Chemicals	-0.41	-0.99	5.25	-0.83	-2.45	-7.02
Basic pharmaceutical products	0.11	-0.21	7.11	-0.47	-1.71	-2.63
Other manufacturing	0.12	-0.31	8.95	-0.46	-1.61	-9.19
Metals	0.11	-0.55	6.43	-0.39	-1.49	-5.11
Transport equipment	0.07	-0.07	12.74	-0.63	-2.08	-6.03
Electricity	7.79	12.92	13.38	-3.19	-17.70	-21.72
Gas manufacture and distribution	N/A	N/A	N/A	-3.11	-7.12	-9.07
Construction	-0.38	-1.15	5.10	-0.42	-1.97	-18.26
Transport services	-0.24	-0.48	3.96	-0.59	-1.69	-6.45
Services for delivery of goods	-0.13	-0.49	3.63	-0.21	-0.95	-6.86
Other services	-0.47	-1.49	2.55	-0.25	-0.97	-7.84
Financial services	-0.19	-0.66	2.54	-0.20	-1.00	-6.79

Source: Model simulations

The use of a tax policy to reduce carbon emissions generates a "double dividend" – the tax revenue can be used to reduce other taxes. In this study, the tax revenue from either a tax on carbon or an increased tax on fossil fuels replaces taxes on households. There is a reduction in household income taxes for either tax instrument (See Table A2.4.2). When there is a tax on carbon, household income taxes are reduced between 4 percent and 15 percent. The reduction is substantially larger when there is a tax on fossil fuels with the reduction as high as 55 percent in India, 26 percent in the Middle East and 17 percent in China & Hong Kong. A tax on fossil fuels is less efficient, meaning that a larger tax is needed, and the economy adjusts more with a tax on fossil fuels rather than a tax on carbon to achieve a 20 percent reduction in global carbon emissions. A tax on carbon generates smaller changes in tax collections because it is a more efficient tax instrument. The tax on carbon by region ranges from 6.2 (Brazil) to 49 (SACU), measured in local currency units. (See Table A2.4.3). However, in terms of the double dividend effect, the tax on fossil fuels generates more tax income and therefore can lead to a larger reduction in household income taxes when that is the tax replacement instrument used.

Sensitivity Analyses

In all CGE models, results are sensitive to the elasticities used in the functions that describe behaviour. When elasticities are lower, the model is less responsive in terms of quantity changes and instead, prices adjust more. When elasticities are higher, the model is more responsive in terms of quantity changes and prices adjust less. To evaluate the sensitivity of the Globe results to elasticities, two alternates are considered: a high case in which all model elasticities are increased 50% and a low case in which all model elasticities are reduced 25%. Results for sensitivity analysis of world prices and the exchange rate, the information passed from the Globe model to the single country models, are provided in Tables A2.6.1 to A2.6.5.

The results of the sensitivity analyses demonstrate that the changes in world prices do vary, as expected, but that the signs are unchanged. This indicates that the changes in incentives occasioned by the response measures are robust although the absolute magnitudes may vary.

Concluding Comments

The results in this study describe the links between global strategies to reduce carbon emissions and low-income countries. Even if low-income countries are exempt from reducing emissions, they are impacted through global market linkages and experience world price and exchange rate changes. Policies to reduce carbon emissions increase the costs of production in high-income and middle-income countries: producers shift away from using fossil fuels in production and consumers adjust their expenditure patterns. As a result, outputs of fossil fuels decline, and the output of electricity, a clean energy input, also declines because of the use fossil fuels, especially coal, in its generation. For low-income regions such as West Africa and East Africa, world prices for all commodities, except energy commodities, decline and the exchange rate depreciates.

The impact of response measures on low-income countries differs according to the policy instruments used to reduce carbon emissions, even when low-income countries are exempt from the policies imposed on other regions A tax on carbon is the most efficient instrument, with the smallest impact on world prices and the exchange rates of low-income regions. Furthermore, low-income countries have different trade shares and different dependencies on imports from carbon emitting regions. For example, in West Africa, mitigation strategies in high-income and middle-income regions result in a decline in the import price of electricity; East Africa has the opposite experience – the price of electricity increases. The differences in price results arise because the regions have different trade partners who experience different structural changes because of the different response measures.

For this study the primary purpose of the global analyses has been to demonstrate the differential impacts of different response measures across regions, and to provide estimates of these impacts to examine their implications at the level of individual countries. The results demonstrate that the impacts of different response measures are country/region specific; and hence achieve an objective of the study. The potential of global CGE models to provide information that can be important to countries seeking to understand the impacts of different response measures has not been exploited.

Annex

A2.1 Policy Instruments

<u>A1: Carbon Taxes</u>

A carbon tax is the main policy instrument advocated for climate change mitigation. A carbon tax is a tax levied on the carbon emissions from the use, or burning, of fossil fuels (coal, oil products, and natural gas). If the tax is applied to producers, they will pass the cost increase onto consumers in the form of higher prices: this ensures that both producers and consumers have incentives to reduce GHG-emitting energy use. Producers will change input mixes to minimize costs and consumers will change consumption patterns to optimize welfare. Carbon taxes are also intended to induce changes towards technologies with lower emissions, e.g., renewable energies.

The reasons why carbon taxes are advocated include the following:

1. taxes can raise large government revenues that may be used to finance new energy investments, response measures to climate change, and various action policies to address impacts of response measures for current and future generations;
2. in the presence of pre-existing tax distortions in factor markets (as is the case in most economies), implementing a carbon tax may reduce emissions and existing tax distortions, and provide a "double dividend" (reduce emissions and tax distortions);
3. price instruments (such as carbon tax or carbon prices) may, under certain circumstances (see below), be more effective that quantity instruments (such as caps on emissions);
4. carbon taxes may be significantly more efficient, relative to a carbon quota policy and other mitigation policies; and
5. carbon tax may be the best mitigation policy since it directly targets the pollutant.

The IMF Climate Change Report (2019) argues that a substantial carbon tax would be the most efficient way of tackling climate change because it is the only policy that can yield large enough reductions in emissions to meet the required climate targets. Similarly, various other studies posit that carbon tax can be an effective way in reducing emissions in developing countries.

It has also been argued (Weitzman, 1974) that price instruments are more effective than quantity instruments, and, if there is uncertainty about abatement costs, price instruments are more effective than quantity instruments. Some studies argue that the choice of instrument (price versus quantity) must consider uncertainty over business cycles due to the possibility that carbon tax revenues fluctuate more (or less) than GHG emissions in different business cycles. Furthermore, a fixed price instrument may be more advantageous than a fixed quantity instrument owing to the procyclical behaviour of abatement costs (Grodecka & Kuralbayeva, 2015).

B1: Energy (input) Taxes

Fossil fuels, in their various forms, are the main source of GHG emissions. A viable market policy instrument is therefore increased taxes and/or reduced subsidies on fossil fuels that seek to reduce fossil fuel consumption and thereby reduce emissions. Fossil fuel taxes are mostly applied on producers, while subsidies are mostly applied on consumers, both intermediate and final.

Fossil fuel taxes are more prevalent among developed countries, and common in Europe. Developing countries, on the other hand, tend to have energy subsidies (rather than energy taxes) for, variously, socio-economic, development and energy poverty purposes.

The reasons why energy taxes may be advocated include the following:

1. energy inputs are more easily measured than emissions;
2. in the presence of pre-existing tax distortions in factor markets (as is the case in many economies), implementing an energy tax may reduce emissions and existing tax distortions, and provide a “double dividend” (reduce emissions and tax distortions);
3. price instruments may, under certain circumstances (see below), be more effective that quantity instruments; and
4. energy taxes may reduce the distortions due to energy subsidies.

C1: Quantity Constraints

Quantity constraints can target the level of emissions and/or energy input use; these can be applied at the level of the economy and/or the producers and consumers. They are appealing because they seem simple and easy to understand.

The reasons why quantity constraints may be advocated include the following:

1. emission output constraints are easy to understand but may be difficult measure;
2. input quantity constraints are easy to understand and measure;
3. input quantity constraints do not require efficient tax systems; and
4. input quantity constraints avoid the need to quantify emission rates.

These reasons suggest that quantity constraints may have a role to play in low-income economies where there are more binding information constraints, and the tax systems are less comprehensive.

Controlling the quantities of fossil fuels used can be a crude mechanism for limiting emissions, e.g., restricting the total use of coal. At the level of an activity, e.g., electricity generation, they can be a proxy instrument for government-imposed constraints, e.g., constraints of the quantities of electricity generated using different fossil fuels.

D1: Technology Change

Technology choices are typically influenced by the extent of knowledge about energy generation and the costs associated with different technologies. Extending the knowledge about energy generation requires investments in research and development (R&D) about new technologies, e.g., carbon scrubbing, wind turbine design, etc., and subsequently capital investment to install new technologies. In a market context there is a need to define why activities/industries will invest in R&D and new capital investments unless they are so incentivised, i.e., the concept of induced technology changes. Carbon taxes, energy input taxes and quantity constraints are all reasons why industries may be incentivised to develop new technologies.

In the current context technology changes can be categorised under four headings:

1. shifts from technologies with higher emission to those with lower emissions, e.g., from fossil fuel electricity generation to wind powered generation;

2. shifts from fossil fuels with higher emissions to those with lower emissions, e.g., from coal to gas; and
3. reductions in the quantity of emissions per unit of output from existing systems, e.g., reduced emissions from fossil fuel generation systems and carbon capture schemes;
4. the development of new, and currently unknown, technologies for power generation

The first two classes of technology changes are readily evaluated using standard economic tools and limited exogenous information, while the third can be evaluated with external information about the costs and benefits of existing technologies to reduce emissions. The fourth, is problematic since neither the technologies nor the costs and benefits are known, and the mode of analyses needs to change.

In all four classes of technology change there are strong arguments for the adoption of recursive dynamic models. Technology changes take time: the outcomes from R&D lag the expenditures, while new technologies require investment in new capital goods, e.g., replacing coal-fired power stations with renewable technologies, and may involve premature retirement of existing capital goods, e.g., coal-fired power stations. For analyses over short time horizons (up to say 30 years) the first the classes of technology change can be relatively straightforward. But for the fourth class, this method may be better used to estimate the value of investment in R&D and new capital that can be justified to achieve given outcomes, i.e., reductions in emissions.

A2.2 Aggregation of GTAP 10 data for UNFCCC project

This annex details the aggregation of the GTAP 10 database used for the global CGE analyses. Nearly all implementations of global CGE use aggregations of the GTAP database to ensure (i) the analyses focus on the appropriate sectors, regions and factors for the issues addressed and (ii) computational tractability. The following principles guided this aggregation schema.

<u>Sectors</u>

The following considerations guided the sectoral aggregation:

1. Energy and emission intensive sectors left unaggregated;
2. Sectors important to developing country economies left unaggregated;
3. Trade intensive sectors left unaggregated.

<u>Regions</u>

The following considerations guided the regional aggregation:

1. Developing, emerging and developed economies should be segmented;
2. The within regions transactions data are not robust, especially for developing regions;
3. Energy exporting countries should be, as far as sensible, be grouped;
4. Energy intensive regions should be, as far as sensible, be grouped

<u>Factors</u>

The following considerations guided the factor aggregation:

1. Land and natural resources should be kept separate;
2. Some aggregation of labour types was appropriate.

Table A2.2.1a Regions and Aggregation

UNFCCC Regions	GTAP Regions
North Africa	Egypt, Morocco, Tunisia, Rest of North Africa
West Africa	Benin, Burkina Faso, Cameroon, Cote d'Ivoire, Ghana, Guinea, Nigeria, Senegal, Togo, Rest of Western Africa
East Africa	Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Rwanda, Tanzania, Uganda, Zambia, Zimbabwe, Rest of Eastern Africa
SACU	Botswana, Namibia, South Africa, Rest of South African Customs, Central Africa, South Central Africa,
Other Asia	Rest of East Asia, Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Philippines, Thailand, Viet Nam, Rest of Southeast Asia, Rest of Oceania
India	India
Other South Asia	Bangladesh, Nepal, Pakistan, Sri Lanka, Rest of South Asia
Brazil	Brazil
Other Latin America	Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela, Rest of South America, Argentina, Bolivia, Rest of South America
Central America	Costa Rica, Guatemala, Honduras, Nicaragua, Panama, El Salvador, Rest of Central America, Dominican Republic, Jamaica, Trinidad and Tobago, Dominican Republic, Caribbean
Russian federation	Russian Federation
Former Soviet Union	Ukraine, Rest of Eastern Europe, Kazakhstan, Kyrgyzstan, Tajikistan, Rest of Former Soviet Union, Armenia, Azerbaijan, Georgia, Belarus, Rest of the World, Rest of North America, Rest of Europe, Albania
Middle East	Bahrain, Iran Islamic Republic of, Israel, Jordan, Kuwait, Oman, Qatar, Saudi Arabia, Turkey, United Arab Emirates, Rest of Western Asia
China and Hong Kong	China
High-income Asia	Japan, Korea, Taiwan, Singapore
NAFTA	Canada, United States of America, Mexico, Puerto Rico
Australia and New Zealand	Australia, New Zealand
EU_27	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Germany, Estonia, Greece, France, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden
Other Europe	United Kingdom, Switzerland, Norway, Rest of EFTA

Table A2.2.1b Factors and Aggregation

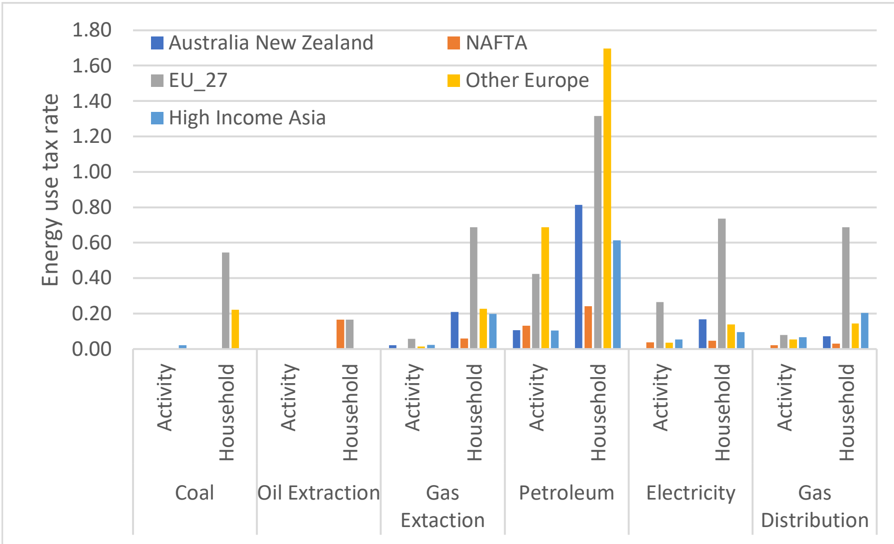
UNFCCC Factors	GTAP Factors
Capital	Capital
Land	Land
Natural Resources	Natural Resources
Skilled labour	Technicians and Skilled, Clerks, Office Managerial and Professional
Unskilled labour	Service and shop, Agriculture and Other workers

Table A2.2.1c Sectors and Aggregation

UNFCCC Sectors	GTAP Sectors
Grain	Paddy rice, Wheat, Cereal grains nec
Other agriculture	Vegetables fruit nuts, Sugar cane sugar beet, Plant based fibres, Crops nec, Raw milk, Wool silkworm cocoons, Forestry, Fishing
Oilseed	Oil seeds
Livestock	Bovine cattle sheep and goats, Animal products nec
Coal	Coal
Extraction of crude petroleum	Oil
Extraction of natural gas	Gas
Other mining extraction	Minerals nec
Cattle meat and other meat	Bovine meat products, Meat products nec
Vegetable oils and fats	Vegetable oils and fats
Other food	Dairy products, Processed rice, Sugar, Food products nec, Beverage and tobacco products
Textiles and wearing apparel	Textiles, Wearing apparel
Leather products	Leather products
Wood and Paper	Wood products, Paper products publishing
Coke and refined petroleum	Petroleum coal products
Chemicals	Chemical products
Basic pharmaceutical products	Basic pharmaceutical products
Other manufacturing	Rubber and plastic products, Mineral products nec, Computer electronic and optic, Electrical equipment, Machinery nec
Metals	Ferrous metals, Metals nec, Metal products
Autos parts & transport equip	Motor vehicles and parts, Transport equipment nec
Electricity	Electricity
Gas manufacture	Gas manufacture distribution
Construction	Construction
Trade services	Trade, Accommodation Food, Warehousing and support, Communication,
Transport services	Air transport, Water transport, Transport nec
Other services	Water, Public administration and defence, Education, Human health
Financial services	Financial services, Insurance, Real estate, Business services nec, Recreational service, Dwellings

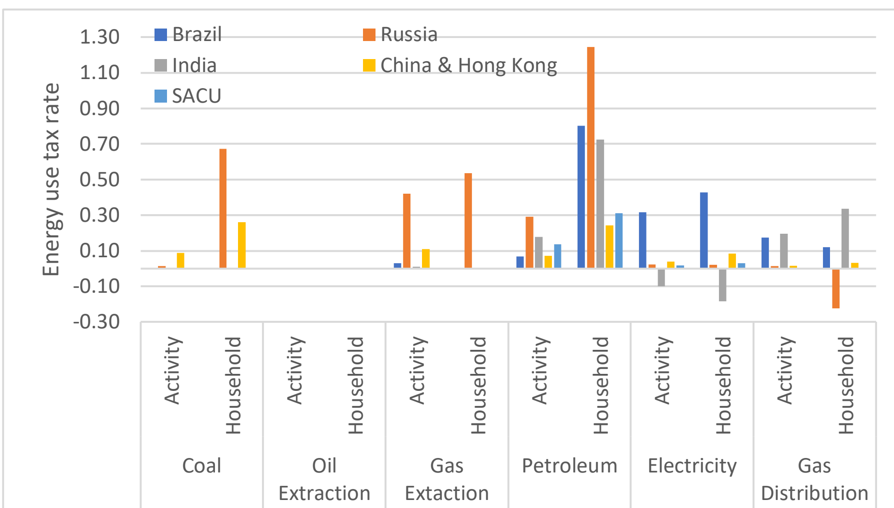
A2.3 Additional Background Data

Figure A2.3.1 Average Fossil fuel taxes (*ad valorem*), high-income regions



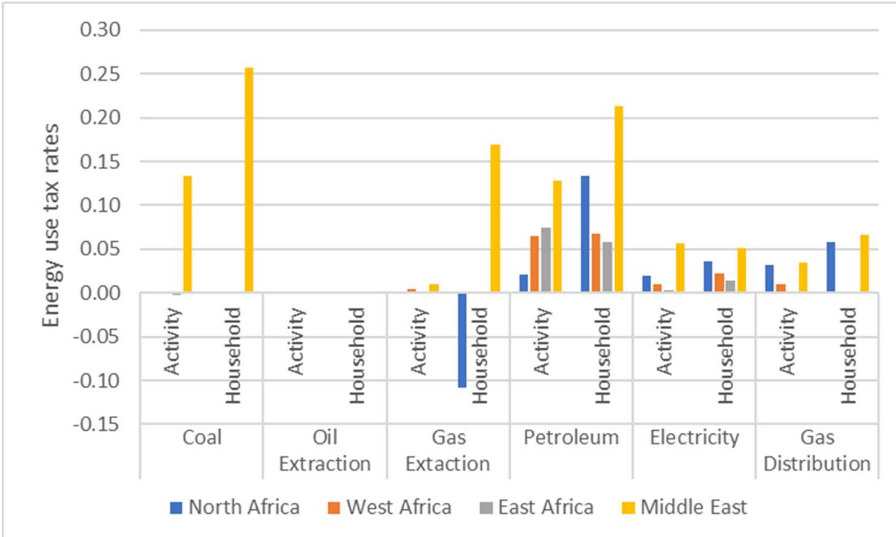
Note: Weighted averages by activity.

Figure A2.3.2 Average Fossil fuel taxes (*ad valorem*), middle-income regions



Note: Weighted averages by activity.

Figure A2.3.3 Average Fossil fuel taxes (*ad valorem*), Africa regions and Middle East



Note: Weighted averages by activity.

Table A2.3.1 Household income tax, percent of total government tax revenue

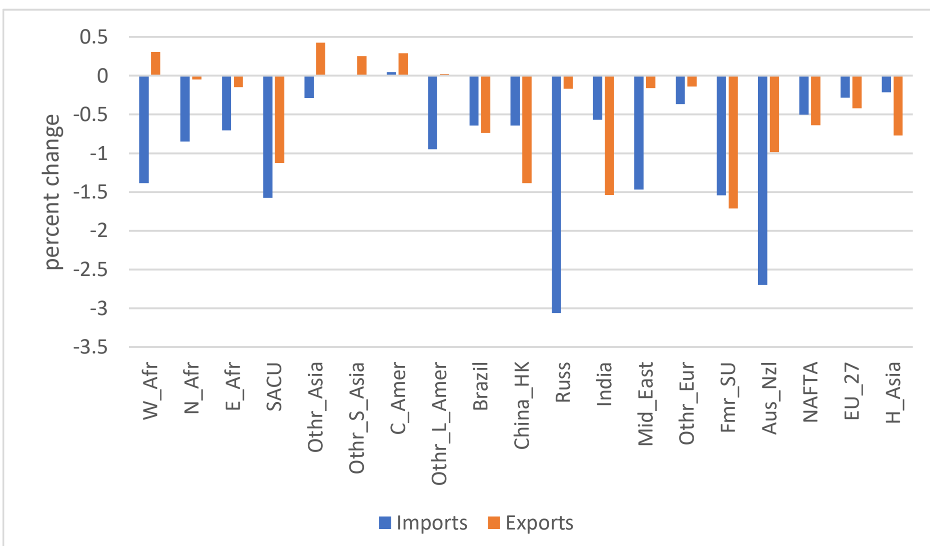
Region	Percent
West Africa	49.5
North Africa	45.4
East Africa	26.7
SACU	44.1
Other Asia	41.4
Other South Asia	38.9
Central America	30.0
Other Latin Amerinca	25.9
Brazil	20.3
China & Hong Kong	22.8
Russia	21.7
India	40.6
Middle East	33.5
Other Europe	37.6
Former Soviet Union	29.6
Australia New Zealand	50.7
NAFTA	41.6
EU_27	27.3
High-income Asia	26.2

A2.4 Additional Simulation Results

Figure A2.4.1 Real GDP for C1 Quantity Restrictions (% change)

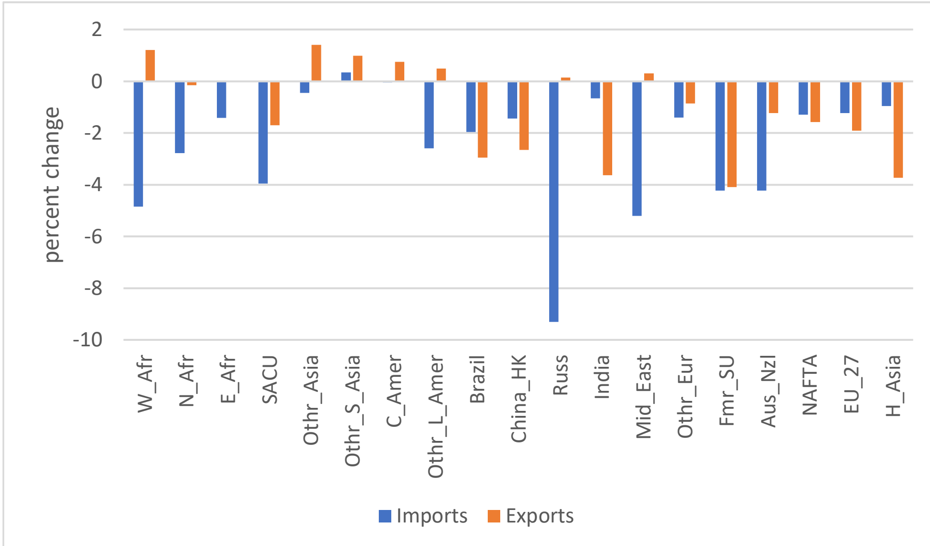
Source: Model simulations

Figure A2.4.2a Real imports & exports with A1: Carbon Tax (% change)



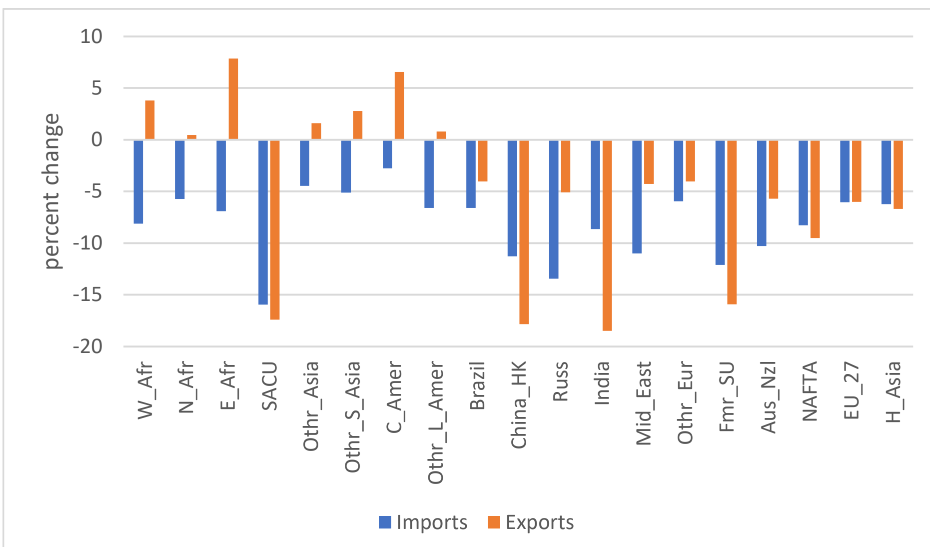
Source: Model simulations

Figure A2.4.2b Real imports & exports with B1: Energy Input Tax (% change)



Source: Model simulations

Figure A2.4.2c Real imports & exports with C1: Quantity Restrictions (% change)



Source: Model simulations

Table A2.4.1 Output in China (% change)

	A1: Carbon Tax	B1: Energy Input Tax	C1: Quantity Restriction	D1: Technology Change
Grain	-0.08	-0.51	-11.23	-11.23
Other Agriculture	0.61	0.37	-11.83	-11.83
Oilseed	0.12	-0.18	-6.53	-6.53
Livestock	0.12	0.04	-14.67	-14.67
Coal	-35.43	-29.68	-35.77	-35.77
Extraction of crude petroleum	5.55	-6.31	-25.71	-25.71
Extraction of natural gas	-47.32	-62.03	-65.14	-65.14
Other mining extraction	-1.36	-2.47	-11.68	-11.68
Cattle meat and other meat	0.05	0.00	-18.80	-18.80
Vegetable oils and fats	0.07	-0.15	-15.08	-15.08
Other Food	0.10	-0.14	-17.28	-17.28
Textiles and wearing apparel	-0.86	-1.88	-14.61	-14.61
Leather products	-0.92	-1.94	-15.48	-15.48
Wood and paper	-1.38	-2.28	-14.57	-14.57
Petroleum	-0.81	-8.51	-32.72	-32.72
Chemicals	-1.37	-2.23	-12.98	-12.98
Basic pharmaceutical products	-0.42	-0.62	-16.59	-16.59
Other manufacturing	-1.37	-2.48	-20.42	-20.42
Metals	-1.26	-2.15	-15.37	-15.37
Transport equipment	-0.65	-1.10	-22.99	-22.99
Electricity	-16.19	-46.00	-42.52	-42.52
Gas manufacture and distribution	-39.80	-19.33	-32.29	-32.29
Construction	-0.34	-0.66	-25.12	-25.12
Transport services	-1.18	-2.21	-15.64	-15.64
Services for delivery of goods	-0.87	-1.61	-16.37	-16.37
Other services	-0.29	-0.27	-17.26	-17.26
Financial services	-1.12	-2.10	-16.42	-16.42

Source: Model simulations

Table A2.4.2 Household income tax revenue (% change)

	A1: Carbon Tax	B1: Energy Input Tax	C1: Quantity Restriction	D1: Technology Change
West Africa	-0.13	-0.54	-0.34	-0.15
North Africa	-0.31	-1.17	-1.13	-0.37
East Africa	0.03	-0.29	-1.96	0.01
SACU	-3.89	-9.01	-11.14	0.83
Other Asia	-0.54	-1.26	-1.92	-0.86
Other South Asia	-0.15	-0.52	-0.29	-0.22
Central America	-0.23	-0.67	-1.28	-0.33
Other Latin America	-0.27	-0.97	-0.79	-0.24
Brazil	-1.93	-6.76	2.65	3.42
China & Hong Kong	-7.02	-17.30	-0.43	4.32
Russia	-2.93	-10.72	10.43	14.31
India	-15.17	-54.48	-18.30	-2.75
Middle East	-8.14	-25.76	-8.17	-0.53
Other Europe	-0.64	-2.56	1.18	-0.02
Former Soviet Union	-8.74	-21.60	8.83	3.03
Australia & New Zealand	-1.66	-3.44	-2.72	-0.23
NAFTA	-1.63	-5.10	1.14	0.52
EU_27	-0.77	-2.18	6.29	0.91
High-income Asia	-2.17	-11.35	3.81	2.89

Source: Model simulations

Table A2.4.3 Tax on carbon

Region	tonne of CO2 (LCU)
SACU	49.69
Brazil	6.20
China_HK	46.48
Russ	14.88
India	25.65
Mid_East	10.68
Othr_Eur	8.36
Fmr_SU	25.74
Aus_Nzl	12.17
NAFTA	19.98
EU_27	10.42
H_Asia	9.27

Source: Model simulations

Table A2.4.4 Reduction in carbon emission coefficients in aggregate fossil fuels (D1)

Region	% change
SACU	-65.20
Brazil	-41.00
China_HK	-59.43
Russ	-31.92
India	-43.83
Mid_East	-34.29
Othr_Eur	-42.86
Fmr_SU	-40.98
Aus_Nzl	-37.49
NAFTA	-38.31
EU_27	-36.05
H_Asia	-41.67

Source: Model simulations

Table A2.4.5 Original CO_2 coefficients for fossil fuels used in electricity

	Aus_Nzl	NAFTA	EU_27	H_Asia
ccoal	0.239	0.265	0.213	0.170
coil_ext	0.042	0.046	0.053	0.041
cgas_ext	0.075	0.066	0.045	0.039
cpetro	0.022	0.019	0.024	0.023
cgas_dst	0.076	0.126	0.050	0.041

	India	Mid_East	Othr_Eur	Fmr_SU
ccoal	0.241	0.192	0.188	0.243
coil_ext		0.051	0.043	0.014
cgas_ext	0.041	0.066	0.045	0.073
cpetro	0.019	0.037	0.014	0.016
cgas_dst	0.057	0.135	0.075	0.173

	SACU	Brazil	China_HK	Russ
ccoal	0.347	0.209	0.324	0.291
coil_ext		0.040	0.051	0.051
cgas_ext		0.053	0.127	0.085
cpetro	0.021	0.026	0.023	0.028
cgas_dst	0.062	0.060	0.245	0.084

Note: CO_2 coefficient is the amount of carbon emitted per unit of energy commodity used in production; measured as tonnes CO_2 per tonne oil equivalent

Table A2.4.6 CO_2 coefficients after technology adjustment

	Aus_Nzl	NAFTA	EU_27	H_Asia
ccoal	0.149	0.163	0.136	0.099
coil_ext	0.027	0.028	0.034	0.024
cgas_ext	0.047	0.041	0.029	0.023
cpetro	0.014	0.011	0.015	0.013
cgas_dst	0.048	0.078	0.032	0.024

	India	Mid_East	Othr_Eur	Fmr_SU
ccoal	0.136	0.126	0.108	0.144
coil_ext	0.000	0.034	0.024	0.008
cgas_ext	0.023	0.043	0.026	0.043
cpetro	0.011	0.024	0.008	0.010
cgas_dst	0.032	0.088	0.043	0.102

	SACU	Brazil	China_HK	Russ
ccoal	0.121	0.123	0.132	0.198
coil_ext	0.000	0.024	0.021	0.035
cgas_ext	0.000	0.031	0.052	0.058
cpetro	0.007	0.016	0.009	0.019
cgas_dst	0.022	0.035	0.099	0.057

Source: Model simulations

A2.5 Model Elasticities

Table A2.5.1 Elasticity of substitution in value added

	All regions
Grain	0.26
Other Agriculture	0.25
Oilseed	0.26
Livestock	0.26
Coal	0.20
Extraction of crude petroleum	0.20
Extraction of natural gas	0.20
Other mining extraction	0.20
Cattle meat and other meat	1.12
Vegetable oils and fats	1.12
Other Food	1.12
Textiles and wearing apparel	1.26
Leather products	1.26
Wood and paper	1.26
Petroleum	1.26
Chemicals	1.26
Basic pharmaceutical products	1.26
Other manufacturing	1.26
Metals	1.26
Transport equipment	1.26
Electricity	1.26
Gas manufacture and distribution	1.26
Construction	1.40
Transport services	1.68
Services for delivery of goods	1.63
Other services	1.26
Financial services	1.26

Note, in the GTAP data base, all regions have the same elasticity of substitution in value added, as reported in Table A2.5.1. There are minor differences by region for the sector "services for the delivery of goods" at the second decimal place.

Table A2.5.2 Elasticity of substitution between aggregate import and domestic variety

	West Africa	North Africa	East Africa	SACU	Other Asia	Other S Asia	Central America	Latin America	Brazil	China & HK	Russia	India	Middle East	Other Europe	F Soviet Union	Australia & NZ	NAFTA	EU_27	High-inc Asia
Grain	1.32	1.78	1.15	1.59	2.23	2.34	1.35	1.42	1.29	1.61	1.51	2.08	1.68	1.69	1.57	1.75	1.04	1.39	1.89
Other Agriculture	1.01	1.21	1.17	1.07	1.02	1.26	1.19	1.22	1.29	1.01	1.20	1.34	1.23	1.23	1.31	1.46	1.26	1.32	1.08
Oilseed	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23
Livestock	0.89	0.82	0.89	0.87	0.72	0.77	0.75	0.83	0.85	0.74	0.75	0.80	0.82	0.84	0.83	0.92	0.82	0.76	0.72
Coal	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52
Extraction of crude petroleum	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60
Extraction of natural gas	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60	8.60
Other mining extraction	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Cattle meat and other meat	1.97	2.01	2.05	2.06	2.11	2.01	2.10	2.06	2.02	2.15	1.98	1.98	2.05	2.08	2.06	1.99	2.05	2.10	2.09
Vegetable oils and fats	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
Other Food	1.01	1.11	0.96	0.96	1.04	1.27	1.04	1.02	1.08	0.96	1.17	1.16	1.14	0.97	1.22	1.05	1.01	1.02	1.00
Textiles and wearing apparel	1.86	1.86	1.86	1.86	1.87	1.87	1.86	1.86	1.86	1.87	1.86	1.87	1.86	1.86	1.86	1.86	1.86	1.86	1.86
Leather products	2.03	2.03	2.03	2.03	2.03	2.03	2.03	2.03	2.03	2.03	2.03	2.03	2.03	2.03	2.03	2.03	2.03	2.03	2.03
Wood and paper	1.61	1.61	1.57	1.54	1.57	1.53	1.54	1.56	1.53	1.56	1.58	1.55	1.55	1.54	1.55	1.55	1.58	1.54	1.52
Petroleum	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Chemicals	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
Basic pharmaceutical products	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
Other manufacturing	1.95	1.88	1.90	1.93	2.00	1.86	1.92	1.88	1.94	1.96	1.94	1.93	1.92	1.99	1.94	1.94	2.00	1.98	2.03
Metals	1.87	1.79	1.84	1.81	1.80	1.81	1.76	1.81	1.73	1.76	1.76	1.78	1.78	1.94	1.74	1.87	1.82	1.80	1.70
Transport equipment	1.90	1.55	1.59	1.49	1.66	1.74	1.78	1.58	1.52	1.56	1.54	1.67	1.57	1.63	1.60	1.60	1.58	1.58	1.56
Electricity	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
Gas manufacture and distribution	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
Construction	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Transport services	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Services for delivery of goods	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Other services	0.98	1.00	1.00	0.99	0.98	1.01	0.98	0.98	0.99	0.99	0.99	1.01	1.00	0.99	0.99	0.98	0.98	0.98	0.98
Financial services	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95

Table A2.5.3 Elasticity of substitution among imports from different regions

	West Africa	North Africa	East Africa	SACU	Other Asia	Other S Asia	Central America	Latin America	Brazil	China & HK	Russia	India	Middle East	Other Europe	F Soviet Union	Australia & NZ	NAFTA	EU_27	High-inc Asia
Grain	2.63	3.57	2.30	3.17	4.46	4.67	2.71	2.84	2.58	3.22	3.03	4.16	3.35	3.39	3.14	3.51	2.09	2.79	3.77
Other Agriculture	2.02	2.42	2.33	2.13	2.05	2.53	2.38	2.44	2.58	2.03	2.39	2.67	2.45	2.46	2.62	2.92	2.51	2.64	2.16
Oilseed	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45
Livestock	1.78	1.64	1.77	1.73	1.44	1.55	1.49	1.66	1.70	1.47	1.49	1.60	1.63	1.67	1.66	1.85	1.64	1.52	1.44
Coal	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05
Extraction of crude petroleum	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20
Extraction of natural gas	17.20	17.20	17.20	17.20	17.20	17.20	17.20	17.20	17.20	17.20	17.20	17.20	17.20	17.20	17.20	17.20	17.20	17.20	17.20
Other mining extraction	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Cattle meat and other meat	3.95	4.02	4.09	4.11	4.22	4.03	4.19	4.13	4.05	4.31	3.95	3.96	4.11	4.16	4.11	3.98	4.10	4.21	4.18
Vegetable oils and fats	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30
Other Food	2.01	2.22	1.93	1.92	2.08	2.53	2.09	2.05	2.15	1.93	2.34	2.33	2.28	1.93	2.43	2.09	2.02	2.03	1.99
Textiles and wearing apparel	3.73	3.73	3.72	3.72	3.73	3.73	3.72	3.72	3.73	3.73	3.72	3.74	3.73	3.72	3.72	3.72	3.72	3.72	3.72
Leather products	4.05	4.05	4.05	4.05	4.05	4.05	4.05	4.05	4.05	4.05	4.05	4.05	4.05	4.05	4.05	4.05	4.05	4.05	4.05
Wood and paper	3.22	3.22	3.14	3.07	3.14	3.06	3.08	3.12	3.06	3.13	3.15	3.09	3.09	3.08	3.11	3.10	3.15	3.07	3.04
Petroleum	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10
Chemicals	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30
Basic pharmaceutical products	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30
Other manufacturing	3.90	3.75	3.81	3.86	4.01	3.72	3.83	3.75	3.89	3.92	3.89	3.86	3.84	3.98	3.87	3.88	4.00	3.96	4.05
Metals	3.74	3.58	3.69	3.62	3.60	3.61	3.53	3.63	3.46	3.52	3.51	3.56	3.55	3.88	3.48	3.74	3.65	3.59	3.39
Transport equipment	3.80	3.10	3.19	2.99	3.33	3.47	3.56	3.15	3.03	3.11	3.08	3.33	3.15	3.25	3.20	3.20	3.16	3.15	3.12
Electricity	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80
Gas manufacture and distribution	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80
Construction	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90
Transport services	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90
Services for delivery of goods	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90
Other services	1.96	1.99	2.00	1.98	1.96	2.02	1.96	1.96	1.97	1.98	1.98	2.01	2.00	1.98	1.97	1.96	1.96	1.96	1.96
Financial services	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90

A2.6 Sensitivity Analysis

The tables in this section provide sensitivity analysis for the world import prices *cif,* world export prices *fob,* and exchange rates. These are the results that are passed from the Globe model to the single country models.

Table A2.6.1 Exchange rates, percent change, sensitivity analysis

	Low		High	
	A1: Carbon Tax	B1: Energy Input Tax	A1: Carbon Tax	B1: Energy Input Tax
West Africa	3.09	11.47	1.04	4.09
North Africa	1.89	6.47	0.70	2.62
East Africa	1.24	3.67	0.46	1.51
SACU	1.10	3.83	0.47	1.50
Other Asia	1.26	2.17	0.54	0.93
Other South Asia	0.21	0.96	0.10	0.52
Central America	0.51	1.29	0.24	0.59
Other Latin America	2.16	5.81	0.80	2.11
Brazil	0.01	-1.02	-0.02	-0.46
China & Hong Kong	-1.02	-1.98	-0.25	-0.55
Russia	4.37	14.51	1.66	5.66
India	-1.90	-3.75	-0.74	-1.24
Middle East	1.47	6.44	0.38	1.87
Other Europe	-0.03	-0.14	-0.07	-0.13
Former Soviet Union	-0.04	1.22	-0.10	0.36
Australia & New Zealand	4.84	6.36	1.97	2.42
NAFTA	-0.28	-1.00	-0.13	-0.48
EU_27	-0.38	-1.24	-0.16	-0.44
High-income Asia	-1.18	-4.43	-0.43	-1.59

Source: Model simulations

Table A2.6.2 World price, percent change, West Africa, low elasticity

	World price of imports, *cif*, percent change		World price of exports, *fob*, percent change	
	A1: Carbon Tax	B1: Energy Input Tax	A1: Carbon Tax	B1: Energy Input Tax
Grain	-2.00	-5.90	-2.33	-7.95
Other Agriculture	-2.42	-6.53	-1.48	-3.82
Oilseed	-2.43	-7.94	-1.17	-3.79
Livestock	-1.97	-6.20	-3.11	-10.95
Coal	13.25	2.13		
Extraction of crude petroleum	-3.63	-12.60	-3.76	-13.98
Extraction of natural gas	-4.34	-13.47	-7.36	-22.43
Other mining extraction	0.05	1.50	-3.83	-9.17
Cattle meat and other meat	-1.89	-6.35	-1.90	-9.65
Vegetable oils and fats	-2.36	-6.91	-2.13	-6.88
Other Food	-1.73	-5.43	-1.25	-4.29
Textiles and wearing apparel	-1.00	-4.32	-2.20	-7.66
Leather products	-0.99	-4.74	-0.97	-3.84
Wood and paper	-1.39	-5.33	-0.88	-3.04
Petroleum	-2.90	-9.21	-4.94	-15.39
Chemicals	-1.34	-3.54	-1.68	-5.04
Basic pharmaceutical products	-0.88	-3.81	-2.46	-8.63
Other manufacturing	-0.73	-3.60	-3.34	-11.32
Metals	-0.59	-3.20	-2.05	-7.67
Transport equipment	-0.99	-3.85	-3.04	-10.37
Electricity	-1.29	-4.15	-2.23	-12.72
Gas manufacture and distributi	10.78	8.45	-5.46	-13.33
Construction	-1.57	-5.46	-1.31	-5.47
Transport services	-1.16	-4.02	-1.49	-4.22
Services for delivery of goods	-1.12	-4.16	-0.76	-2.95
Other services	-1.49	-5.27	-0.64	-2.29
Financial services	-1.12	-4.23	-1.58	-5.73

Source: Model simulations

Table A2.6.3 World price, percent change, East Africa, low elasticity

	World price of imports, *cif*, percent change		World price of exports, *fob*, percent change	
	A1: Carbon Tax	B1: Energy Input Tax	A1: Carbon Tax	B1: Energy Input Tax
Grain	-1.82	-4.43	-1.53	-3.98
Other Agriculture	-1.53	-3.60	-1.30	-3.22
Oilseed	-1.26	-3.56	-0.86	-2.50
Livestock	-1.19	-3.02	-1.83	-6.33
Coal	20.12	6.81	-10.83	-14.97
Extraction of crude petroleum	-2.49	-8.19	-3.90	-13.72
Extraction of natural gas			-9.99	-7.59
Other mining extraction	-0.10	0.10	-2.27	-4.90
Cattle meat and other meat	-1.32	-3.13	-1.55	-5.96
Vegetable oils and fats	-1.41	-3.30	-1.29	-3.66
Other Food	-0.97	-2.58	-0.60	-1.86
Textiles and wearing apparel	-0.14	-0.80	-0.36	-1.19
Leather products	0.00	-0.80	-0.19	-0.85
Wood and paper	-0.47	-1.61	-0.74	-2.31
Petroleum	-1.53	-5.24	-2.77	-9.54
Chemicals	-0.67	-1.63	-1.21	-3.48
Basic pharmaceutical products	0.05	-0.44	-0.74	-2.43
Other manufacturing	0.11	-0.52	-0.63	-2.13
Metals	0.09	-0.89	-0.62	-2.20
Transport equipment	0.06	-0.10	-0.92	-2.92
Electricity	10.35	16.94	-4.09	-22.22
Gas manufacture and distribution			-4.49	-9.79
Construction	-0.63	-1.74	-0.50	-2.47
Transport services	-0.39	-0.81	-0.82	-2.30
Services for delivery of goods	-0.26	-0.81	-0.30	-1.20
Other services	-0.67	-2.01	-0.36	-1.26
Financial services	-0.35	-1.06	-0.29	-1.30

Source: Model simulations

Table A2.6.4 World price, percent change, West Africa, high elasticity

	World price of imports, *cif*, percent change		World price of exports, *fob*, percent change	
	A1: Carbon Tax	B1: Energy Input Tax	A1: Carbon Tax	B1: Energy Input Tax
Grain	-0.78	-2.44	0.99	-3.28
Other Agriculture	-0.99	-2.76	0.99	-1.83
Oilseed	-0.91	-3.16	0.99	-1.66
Livestock	-0.77	-2.52	0.99	-4.30
Coal	7.00	2.16		
Extraction of crude petroleum	-1.50	-5.79	0.98	-7.67
Extraction of natural gas	-1.88	-6.35	0.96	-12.55
Other mining extraction	0.05	0.86	1.05	-3.92
Cattle meat and other meat	-0.66	-2.44	0.99	-3.59
Vegetable oils and fats	-0.87	-2.55	0.99	-2.65
Other Food	-0.61	-2.00	1.00	-1.74
Textiles and wearing apparel	-0.29	-1.42	1.00	-3.05
Leather products	-0.34	-1.69	1.00	-1.64
Wood and paper	-0.43	-1.86	1.02	-1.17
Petroleum	-1.21	-4.07	1.05	-7.81
Chemicals	-0.40	-0.90	1.01	-1.93
Basic pharmaceutical products	-0.14	-1.02	0.99	-3.34
Other manufacturing	-0.13	-1.03	1.00	-4.67
Metals	-0.05	-0.80	1.02	-2.87
Transport equipment	-0.25	-1.22	1.00	-4.31
Electricity	-0.27	-1.10	0.99	-5.76
Gas manufacture and distributi	5.42	4.97	0.98	-6.08
Construction	-0.47	-1.87	0.99	-2.66
Transport services	-0.39	-1.48	0.99	-1.73
Services for delivery of goods	-0.35	-1.50	1.00	-1.25
Other services	-0.49	-1.93	1.00	-0.95
Financial services	-0.33	-1.48	0.99	-2.41

Source: Model simulations

Table A2.6.5 World price, percent change, East Africa, high elasticity

	World price of imports, *cif*, percent change		World price of exports, *fob*, percent change	
	A1: Carbon Tax	B1: Energy Input Tax	A1: Carbon Tax	B1: Energy Input Tax
Grain	-0.76	-1.90	0.99	-1.74
Other Agriculture	-0.68	-1.67	0.99	-1.64
Oilseed	-0.52	-1.56	1.00	-1.19
Livestock	-0.49	-1.28	0.99	-2.43
Coal	10.03	3.54	0.94	-8.10
Extraction of crude petroleum	-1.14	-4.22	0.98	-7.77
Extraction of natural gas			0.95	-3.55
Other mining extraction	0.01	0.51	0.99	-2.33
Cattle meat and other meat	-0.52	-1.33	0.99	-2.18
Vegetable oils and fats	-0.59	-1.38	0.99	-1.52
Other Food	-0.39	-1.12	1.00	-0.87
Textiles and wearing apparel	-0.07	-0.39	1.04	-0.57
Leather products	-0.06	-0.49	1.03	-0.55
Wood and paper	-0.15	-0.60	1.02	-1.00
Petroleum	-0.67	-2.57	0.99	-4.84
Chemicals	-0.20	-0.42	1.04	-1.44
Basic pharmaceutical products	0.13	-0.04	1.04	-0.98
Other manufacturing	0.11	-0.10	1.06	-1.04
Metals	0.12	-0.22	1.01	-0.81
Transport equipment	0.07	-0.02	1.03	-1.24
Electricity	5.07	8.54	0.98	-12.09
Gas manufacture and distribution			0.98	-4.54
Construction	-0.20	-0.68	1.00	-1.34
Transport services	-0.14	-0.33	1.00	-1.05
Services for delivery of goods	-0.07	-0.32	1.00	-0.64
Other services	-0.24	-0.82	1.00	-0.61
Financial services	-0.10	-0.42	1.00	-0.67

Source: Model simulations

3. Impact of response measures in Senegal

Summary

This chapter reports the results from analyses of the potential implications for Senegal of 20% reductions in global CO_2 emissions achieved by three different mechanisms: carbon taxes (A1), energy input taxes (B1) and global economic contractions (C1). Low-income regions, including Senegal, are exempt from reducing emissions by assumption, but are impacted through changes in global trade patterns and prices derived from simulations implemented in a global model (see Chapter 2). The changes in emissions for the broader West African region are shown in Table 2.6. The results confirm that GDP and welfare will decline in Senegal under all three simulations but that the impacts on Senegal are dependent on the global responses measure that are adopted. Typically, the negative impacts are greater for urban than rural households because the agricultural, and food activities experience relative expansions. The main driver of the results is that the decline in returns to labour increase with level of skill; mainly driven by the relative contraction of service activities. The impacts are least marked for the carbon tax (A1) simulation and most marked for the quantity restrictions (C1), but the distributional consequences are greatest for input taxes (B1); this information may be important when Senegal evaluates the implications of global responses instruments. Similarly, the distributional and mixed SDG results may be important guides when Senegal decides on its mitigation policies.

Introduction

Global warming, caused mostly by human activities, has been shown to be a key contributor to global climate change, which has threatened natural ecosystems as well as human and economic systems. Importantly, global warming is arguably the largest environmental externality facing economies, international organizations, citizens, and the world's ecosystems. As such, remedying existing effects of global climate change and even preventing future effects requires the implementation of various response measures to climate change and actions to address their (particularly negative) impacts.

It is recognized in the 2015 Paris Climate Change Agreement that Parties may be affected not only by climate change, but also by the impacts of the measures taken in response. To this effect, in Katowice, Parties also agreed to four work programme areas for its established mechanisms to address the impacts of the implementation of response measures viz. “the forum on the impacts of the implementation of response measures” and “the Katowice Committee of Experts on the impacts of the implementation of response measures”. The agreed four work programme areas are:

a. Economic diversification and transformation.
b. Just transition of the workforce and the creation of decent work and quality jobs.
c. Assessing and analysing the impacts of the implementation of response measures.
d. Facilitating the development of tools and methodologies to assess the impacts of the implementation of response measures.

Over the years, developing country Parties have expressed the need for the development, enhancement and use of methodologies and tools for the assessment, as well as capacity building to undertake national and sub-national level assessments and analyses of the impacts of the implementation of response measures, (both in-country, but particularly, cross-border impacts), which are manifested within the environment, social and economic dimensions of their economy. For this purpose, a study was initiated for two pilot countries, Kenya and Senegal, with a view to understanding the challenges of development and use of computable general equilibrium (CGE) modelling tools and methods, that can be adopted, adapted and used by low-income and small island economies to assess the impacts of the implementation of response measures both in-country and cross-border.

The process of implementing a CGE assessment of the impact of selected response measures on the economy of Senegal is described in this chapter together with the results of the analysis. The assessment makes use of a linked system of two CGE models: a global model, GLOBE_CC (McDonald & Thierfelder, 2020b), which is used to simulate reductions in emissions via different response measures, and a single country model, STAGE_CC (McDonald & Thierfelder, 2020a), which uses the changes in international prices and the exchange rate from GLOBE model simulations to evaluate the impact of response measures in Kenya and Senegal.

Data & economic structure

<u>Data</u>

The assessment uses a CGE model, STAGE_CC, which is calibrated on a Social Accounting Matrix (SAM) for Senegal (Boulanger *et al.*, 2017). The SAM provides a snapshot of income and expenditure flows in the Senegalese economy in 2014. These data are augmented with household population data (Mainar Causape, 2020) to allow for the computation of per capita results.

The accounts of the SAM are aggregated in line with the coverage of the GLOBE_CC model to provide a model of a size that is both tractable and readily understood for purposes of the pilot project. The STAGE_CC Senegal model runs with 23 activities (including 4 regional agricultural activities) producing 20 commodities using 19 factors (land, labour, and capital) that provide income to 10 household groups. Details about the aggregation are available in Table A3.1.1.

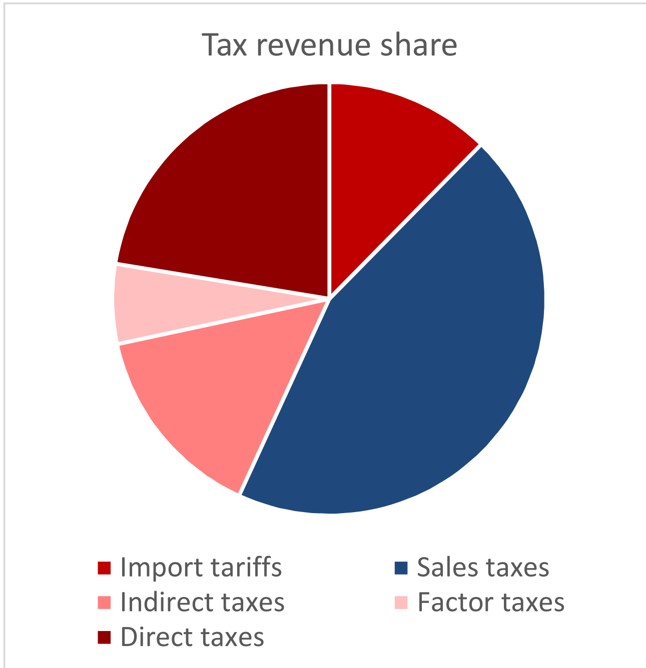
Economic structure

The impacts of the response measures (such as the introduction of a carbon tax) are transmitted through changes in international prices that affect the costs of imports and prices received for exports. The transmission of these global changes to the local economy affects terms of trade as well as real exchange rates, which, in turn, cause domestic changes in real incomes, consumption, carbon emissions, and household welfare. Thus, understanding the economic structure of a country, including trade relationships, is an important step in understanding the likely effects of global response measures on individual countries.

Private consumption demand forms the largest share of GDP[35] in the base year (77%). Government demand stands at 17%, while investment demand is 15% of GDP. Exports form 27% of GDP and imports 49%; domestic production that is not exported completes the commodity balances. The excess of imports over exports reflects the trading position of Senegal and external balance deficit. In addition to the macroeconomic structure of the economy, the structure of tax revenue is of interest as it informs the choice of tax replacement policy in the model's closure settings when conducting the simulations. The share of revenue derived from each tax is shown in Figure 3.1.

35 Throughout GDP is calculated from the expenditure side: consumption (private (C), government (G) and investment (I)), plus exports (X) minus imports (M).

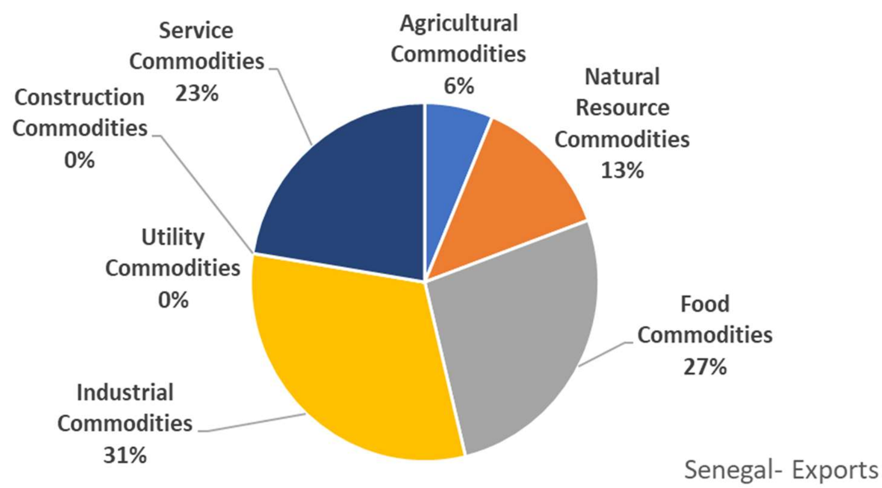
Figure 3.1 Tax Revenue Structure in Senegal



Data source: Senegal Social Accounting Matrix 2014.

Regarding the structure of trade, there is no single commodity that dominates Senegal's exports. The four highest export commodities contribute almost equal shares, namely mining (oil and minerals) (13%), other manufactured goods (11%), chemicals (10%), and processed fish (9%). Across broad commodity groups as shown in Figure 3.2, industrial commodities produce around a third of exports (31%), followed by food commodities (27%), and other services (22%). Natural resources and agricultural commodities contribute only 13% and 6% of exports, respectively.

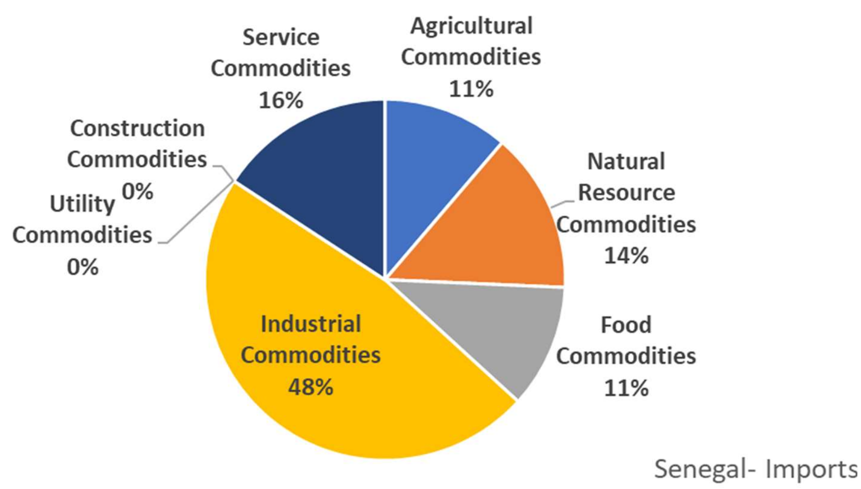
Figure 3.2 Sectoral shares of Senegal's exports, 2014



Data source: Authors' elaboration using Senegal Social Accounting Matrix 2014.

In contrast, over 47% of Senegal's imports are dominated by industrial commodities as shown in Figure 3, primarily energy-intensive petroleum products (14%), mining (oil and minerals) (11%), and chemicals (10%). The second highest imported commodity group is services (16%).

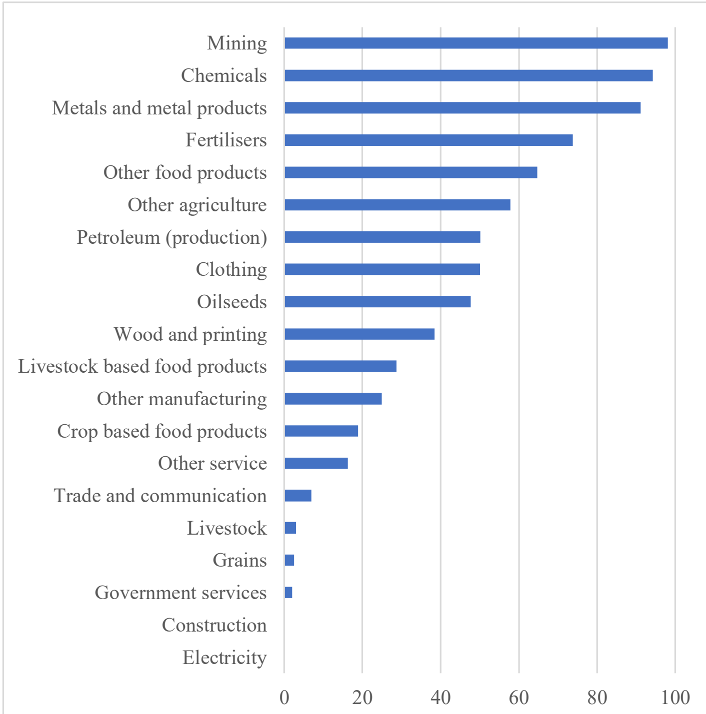
Figure 3.3 Sectoral shares of Senegal's imports, 2014



Data source: Authors' elaboration using Senegal Social Accounting Matrix 2014.

Senegal's import dependence, as shares of total supply, is evident and important in energy-intensive industries, namely mining (oil and minerals) (98%), chemicals (94%), fertilisers (74%), and petroleum products (50%) as shown in Figure 3.4. Import dependence in agricultural products varies ranges from 60% (in other agricultural products) to 17% in other crops. Notably, Senegal was self-sufficient in electricity production in 2014.

Figure 3.4 Import dependency ratio by commodity, 2014



Calculation: Import dependency ratio = value of imports*100/ (value of domestic production + value of imports – value of exports).

Data source: Authors' elaboration using Senegal Social Accounting Matrix 2014.

Senegal is linked into global energy markets through a high dependency on oil and petroleum imports. The use of these products within the domestic economy is reported in Table 3.1.

The use of the mining product as an input into the petrol (47%) and construction (12%) industries reflects its composition of oil and minerals. Exports form one third of the demand for mining despite its high import dependency. It is this commodity to which changes in international oil prices will be linked. The structure of demand for petrol differs from that of the mining commodity. Intermediate demand for petrol is dominated by electricity demand (15%) showing the importance of oil in electricity production in Senegal, followed by demand from the trade and communications sector (13%). In terms of final demand, households demand 15% of total petrol for private consumption, 32% of total petrol is used in the formation of capital goods and 10% goes to export.

Table 3.1 Energy use in Senegal (share of total demand)

	Intermediate demand					Final demand		
	Petrol	Electricity	Construction	Trade and comm'n	Other	Hhld	Invt	Exports
Mining (oil, minerals)	47%	0%	12%	0%	6%	0%	2%	34%
Petrol	1%	15%	2%	13%	12%	15%	32%	10%

Data source: Authors' elaboration using Senegal Social Accounting Matrix 2014.

Model[36]

This assessment makes use of linked global and single country CGE models. CGE models are typically deterministic in nature without a stochastic component. The results produced by the model are therefore determined by four elements:

1. the linkages in the economy as captured in the initial database;
2. the 'behaviour' of the model as specified in the model's equations; determined by the functional forms and parameter values including elasticities;
3. the closure settings for the model which depicts the assumed functioning of the economy; and
4. the location and magnitude of the shock(s).

To complement the description of the linkages in the economy in the section above, this section includes a short description of the model's behaviour and parameter values, along with the 'closure' settings for the model. The location and magnitude of the shock(s) are defined in the simulations section below.

<u>Model behaviour</u>

The single country model used in the pilot study is the STAGE_CC single-country computable general equilibrium (CGE) model (McDonald & Thierfelder (2020a); McDonald (2020)) used in its comparative static mode: it is a variant/development of the STAGE 3 single country CGE model. This model is characterised by several distinctive features. First, the model allows for a generalised treatment of trade relationships by incorporating provisions for non-traded exports and imports, i.e., commodities that are neither imported nor exported, competitive imports, i.e., commodities that are imported and domestically produced, non-competitive imports, i.e., commodities that are imported but not domestically produced,

[36] A comprehensive technical document for STAGE_CC is available (McDonald & Thierfelder, 2020a).

commodities that are exported and consumed domestically and commodities that are exported but not consumed domestically. Second, the model allows for modelling of multi-product activities using various assumptions; fixed proportions of commodity outputs by activities with commodities differentiated by the activities that produce them, varying output mixes by activities in response to changes in the (basic) prices of commodities, and domestically produced commodities that are differentiated by source activity or are homogeneous, i.e., undifferentiated by source activity. Hence the numbers of commodity and activity accounts are not necessarily the same. Third, the (value added) production technologies can be specified as generalised nested Constant Elasticity of Substitution (CES) functions.[37] Fourth, trade and transport margins between factory and dock gate and the consumer are levied on domestic consumption. Fifth, consumption expenditure by each representative household group (RHG) is represented by nested CES and Stone-Geary (linear expenditure system – LES) utility functions. And sixth, the functional distribution of income is endogenously determined through the specification of the ownership (domestic and foreign) of factors used within the economy being defined as a series of variables.

Elasticity values

In addition to the transactional data contained in the SAM, a CGE model requires other data to enable its application and to link the data with the behavioural relationships represented in the mathematical representation of the economy, i.e., the model. The starting parameter values, e.g., for trade shares, are calculated from the initial database. The paucity of elasticity estimates for Senegal is highlighted in the review of available elasticity values in Annex 3.2. Given the dearth of elasticity estimates for Senegal and the use of the model in soft-linked model system with the global model, the values of elasticities are harmonized, where possible, with those used in the West Africa region in the global model, GLOBE_CC. An overview of the elasticity values for the Senegal model is provided in Table A3.2.1. Note that sensitivity analyses, which assess the robustness of the model results with respect to the assumed elasticity values, is included towards the end of the results section.

Market clearing and model closure

The closure of the model has economic and operational purposes. From an economic perspective, the closure defines the functioning of the economy. Operationally, the closure addresses the constraint that the number of variables must equal the number of equations in

[37] The nesting system for production is flexible and is configured by the user by set definitions that encompass both primary and intermediate inputs, i.e., there is no requirement to change the behavioural relationships or calibration code.

the model. The ‘fixing’ of excess variables to equate the number of variables and equations is the process of model closure.

The model closure for Senegal includes the following specification: the exchange rate is fixed (to allow for the passing down of exchange rate changes from the global model) with a varying external balance; the economy is assumed to be investment driven with the value of investment fixed; Government borrowing is fixed to prevent additional expenditure being financed by debt, the income tax rates vary to fix the value of government expenditure and savings/borrowings; technology is fixed at all production levels; the Consumer Price Index (CPI) is fixed as the numéraire against which changes in prices are benchmarked.

The choice of tax replacement instrument is motivated by the presence of income tax in the current tax system (initially making up 22% of government income) and the advantage of being a lump sum and therefore less-distorting tax. Other tax replacement options such as a sales taxes work through the price system, affecting decisions at the margin.

All factors are assumed to be fully employed, recognising the role of labour in providing non-market services including home and caring duties which are not captured in the standard definition of the labour force. Some sectoral rigidities are introduced into the model, specifically, a fixed supply of land in regional agricultural production and a fixed supply of capital in mining and chemicals. This factor market specification results in economy-wide returns for labour and sector specific returns for land and capital (in selected sectors).

Simulations

A range of response measures to reduce global carbon emissions are considered in the pilot study including taxes and quantity restrictions[38]. Three simulations are considered:

A1: Reduce global carbon emissions by 20% via an endogenous tax on carbon with low-income regions exempt

B1: Reduce global carbon emissions 20% via an endogenous tax on fossil fuels with low-income regions exempt

[38] In addition to the three simulations in GLOBE_CC, a fourth simulation, D1: Technology change was implemented. It derived estimates of the efficiency gains in fossil fuel use in the electricity sector by region (except low-income regions) required to achieve a 20% reduction in global carbon emissions achieved. This simulation is not passed on to the single country models for two reasons. First, it is exploratory in nature only. Second, the Pilot Study excludes developing countries, including Senegal, from implementing measures in GLOBE_CC to reduce carbon emissions, partly owing to the large economic costs of reducing carbon emissions and to the low contribution of those economies to global carbon emissions.

C1: Reduce carbon emissions in each region to the levels found in A1 (global carbon emission reduction of 20%, uneven by countries) via quantity constraints in which Total factor productivity (TFP) adjusts in each region by an equiproportionate change in TFP to each activity

The impact of each response measure is passed through to the pilot country model using 'soft' linking between the global CGE model, GLOBE_CC, and the single country model, STAGE_CC as shown in Figure 3.5. A mapping between the commodities of the global and single-country model is constructed to allow the shocks to be passed across. The mapping is made by matching the commodities in the global model to those in the country models according to the definitions of the commodity accounts. A full list of the mapping between global and Senegal traded commodities is included in Table A3.1.1.

Specifically, the percentage change in the world price of imports and exports and the exchange rate are passed from the global to the single country models. As the global model contains bilateral trade flows and the single country has a single composite trading partner, world prices are aggregated using the value share of each trading partner's imports or exports in the base. Note that there is no feedback from the single country to global model due to small country assumption under which changes in trade at the country level have no significant influence on world markets.

The direction and magnitude of the changes in world prices and exports resulting from the three response measures are shown in Table 3.2. World prices for imports to, and exports from, West Africa fall for all commodities except selected energy and primary commodities. The effect is larger for emissions reduction via energy input taxes (B1) than via a carbon tax (A1) and via quantity restrictions (C1) than energy input taxes (B1). West Africa experiences a depreciation in all simulations due to pressures to export more to maintain the external balance (fixed in GLOBE_CC). The depreciation is largest for emissions reduction via input taxes, followed by input restrictions, then a carbon tax. It is these changes in world prices and the exchange rate that are passed down to the Senegal CGE model.

Figure 3.5 Linking the global and country level CGE models

The lower section of Table 3.2 indicates the sign and magnitude of the changes to local prices when world prices have been adjusted by the change in exchange rates. In all simulations, the sign of the change in prices changes except for selected energy, primary, transport and manufacturing commodities and most exports in C1. The size of the depreciation is sufficient to reverse falling world import and export prices in the region. Notably, the import price of oil falls in all simulations as the falling demand for fossil fuels in response to climate change mitigation leads to lower prices (the rebound effect). Given the importance of oil (included alongside minerals in Senegal's mining commodity) in Senegal's energy supply, this effect will be significant in the impact of response measures on the Senegalese economy. Note also, that the world import price of coal rises significantly in the global model as the most carbon intensive fossil fuel. An economy which relies on imported coal for its energy supply would therefore see different impacts of global response measures than an economy, such as Senegal, that is reliant on oil imports.

Table 3.2 Global impacts on West Africa

	A1: 20%↓ emissions, endogenous carbon tax		B1: 20%↓ emissions, endogenous energy input taxes		C1: 20%↓ emissions, endogenous reduction in input quantities	
	Imports	Exports	Imports	Exports	Imports	Exports
World prices	↓ except, coal, mining & gas	↓	↓↓ except coal, mine, gas	↓↓	↑↑ except agriculture, oil, gas	↓↓↓
Exchange rate	2% depreciation		7.6% depreciation		5.9% depreciation	
Local prices	↑ except oil, gas, petroleum	↑ except energy, livestock, transport, other manufacturing	↑↑ except oil, gas	↑↑ except energy, livestock, transport, other manufacturing, electricity	↑↑↑ except oil	↓↓ except other food, leather, wood, chemicals, and metals

Simulation results: the impact of response measures

The impacts of three global response measures on the Senegal economy are discussed in this section. As a low-income country, Senegal is exempt from implementing the response measures by assumption. Therefore, all impacts are a result of the implementation of response measures in other (developed) countries.

The impact on illustrative SDG indicators

The results are presented through the lens of the Sustainable Development Goals (SDGs). A set of illustrative indicators covering three SDGs have been developed in the pilot study for use in reporting assessments (Shutes, 2021):

GOAL 8: Decent Work and Economic Growth

GOAL 9: Industry, Innovation and Infrastructure

GOAL 10: Reduced Inequality

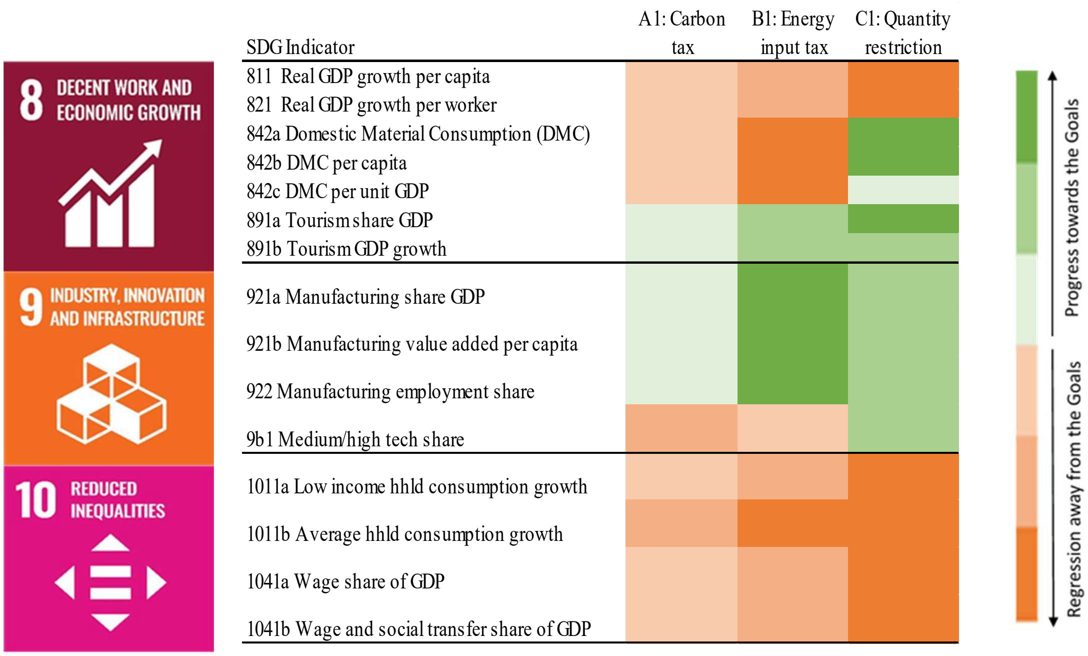
The illustrative indicators are selected to provide a broad evaluation of the social, economic, and environmental impacts of response measures. The reporting of average growth in Goal 8 is an important and known indicator to policy advisors which is complemented with Goal 9 indicators on structural change and Goal 10 indicators on the distributional impacts on households.

An overview of the indicative impact on selected SDG indicators is shown in Figure 3.6. (Deeper) shades of green indicate (increased) progress towards SDG targets and (deeper) shades of orange indicate regression away from Goal targets. The specific application of the SDG illustrative indicators (Shutes, 2021) to Senegal is detailed in Table A3.3.1.

The extent to which policies are coherent can also be evaluated by comparing the direction of change of the indicators across the Goals. Synergies occur when multiple indicators improve and trade-offs occur when some indicators improve, and others worsen. Note however, that while the direction of change is comparable across Goals, the shading only indicates relative differences within each indicator. Note also that any movement towards or away from the SDGs is a result of mitigation and policy responses; rather than any endogenous targeting of the Goals within the model itself.

The impact of response measures appears to have a mixed impact on the economy of Senegal. But a closer look reveals that although there appears to be some progress towards SDG8 and 9, the improvements in the indicators arise from structural changes in a shrinking economy that has negative effects on household for all response measures. There is no response measure option which leads to progress in all three Goals and the results indicate that carbon tax, as the more efficient instrument, has a milder negative effect than the energy input taxes (B1) and quantity restrictions (C1).

Figure 3.6 Impact of response measures on SDGs in Senegal



Source: simulation results.

For SDG8, decent work and economic growth, the indicators show a reduction in real GDP growth per capita and per worker under all response measures. Domestic Material Consumption (DMC) – an indicator of environmental pressure on the use of materials including biomass (plants, wild fish, hunting, forestry, and traded livestock), fossil fuels, metal ores and non-metallic minerals – increases under simulations A1 and B1 by all measures. DMC falls in simulation C1, due to the reduced demand for materials under the quantity restrictions imposed to achieve emissions reductions. Indicator 891 on tourism impacts is included for completeness but is a proxy measure that should be viewed with caution as tourism activities are included in other services in the database. Separating hotels and restaurants into a separate activity would improve the informational value of this indicator to the extent that the economic linkages with tourism differ from services.

For SDG9, industry, innovation and infrastructure, changes in the illustrative indicators provide insights into the impact of response measures on structural changes and manufacturing. Progress towards Goal 9 is achieved through an increasing role of manufacturing in developing countries coupled with an increase in medium and high-tech industry. The results indicate that response measures lead to an increase in the share of manufacturing by all measures, with the impact being greatest when energy input taxes are used as the policy instrument (B1) and smallest when carbon taxes are used (A1). Although this progress towards SDG9 is indicated by the results, the result must be held alongside the SDG8 results: desirable structural change occurs but in a contracting economy with lower real GDP per capita. The impact on the share of medium and high- tech industries in total manufacturing differs across the three response measures. The share of medium and high-tech industries (see Table A3.3.1 for a list), falls when emissions reductions are achieved through a carbon tax (A1) and energy input taxes (B1), but increases when quantity restrictions are used.

For SDG10, reduced inequality, the picture is clear: response measures in developed countries are likely to worsen inequality in Senegal. Consumption falls for both poor and average households and wages form a smaller share of GDP. In line with the general picture, the effect is mildest for A1 and strongest for C1. It should be noted that consumption falls faster for the average household than households in the lowest 40% of the income distribution. This suggests there are dynamics at play that are buffering the incomes of the poor: these are examined further below.

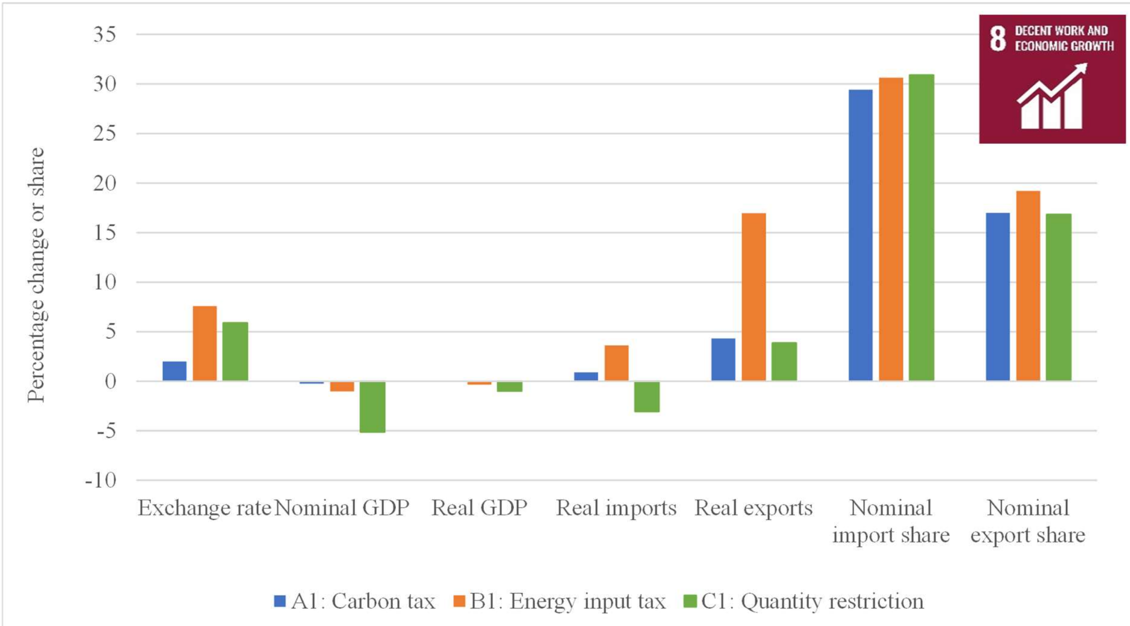
The overall picture is clear: none of the response measures considered here allow progress towards all three SDGs in Senegal. Clear trade-offs are at play as any progress towards structural change (SDG9) happens in a context of a smaller economy (SDG8) with reduced household consumption (SDG10). The impact of the trade-offs is smallest when emissions reductions are achieved via the less distorting carbon tax (A1), followed by energy use taxes (B1) and finally, quantity restrictions (C1). Extending the coverage of the SDG indicators to other Goals would broaden the picture of synergies and trade-offs arising from the impact of response measures.

Furthermore, grouping the indicators along the dimensions of People, Planet and Profit reveals additional insights. With carbon tax and energy input taxes, the impacts on people (SDG10) and planet (DMC) are negative, with mixed effects on profit (SDG8, SDG9) as the manufacturing and tourism shares increase but in a smaller economy. Under quantity restrictions, the negative impact on people is stronger but with reduced environmental pressure on the planet (DMC) and, again, mixed impacts on profits as the share of manufacturing and tourism increase but in a smaller economy.

The impact on the macroeconomy

The following discussion of results drills deeper into the drivers of the observed changes in SDG indicators. In each case, the results relate to SDG8, 9 or 10 as indicated.

Figure 3.7 Macroeconomic impacts



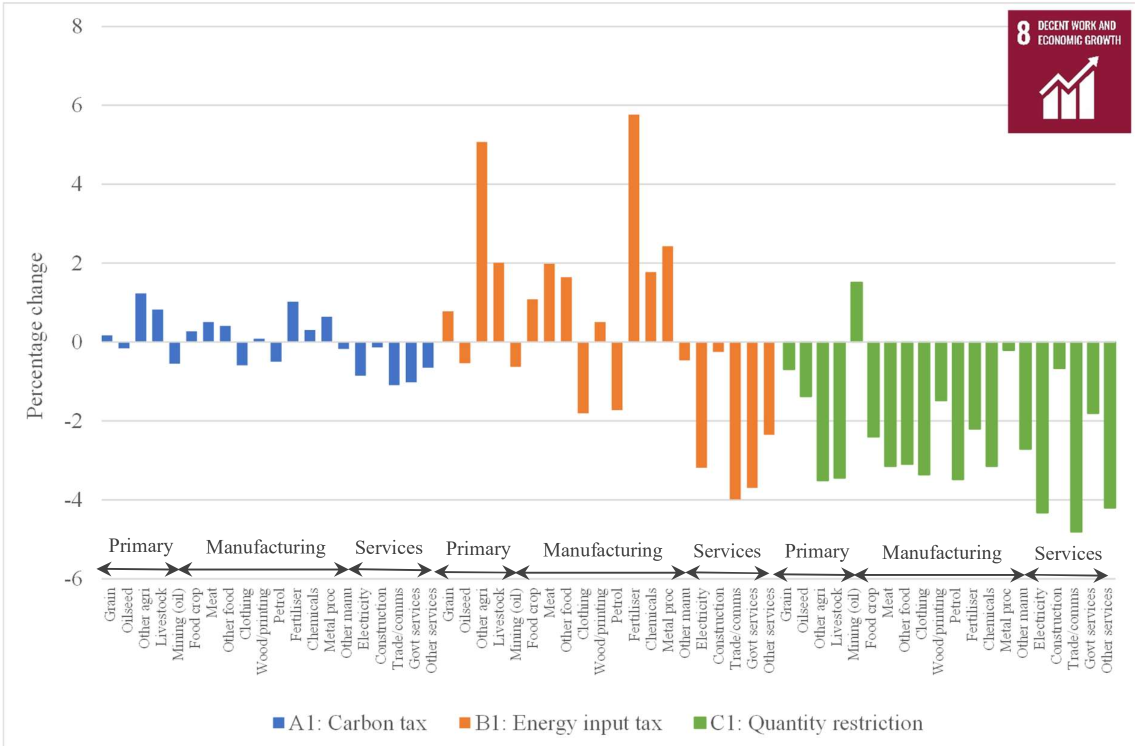
Source: simulation results.

The macroeconomic effects of the three response measures are shown in Figure 3.7. The percentage change in the exchange rate is the change imposed from the global model as shown in Table 3.2. Together with the changes in world import and export prices, the exchange rate changes lead to lower levels of nominal and real GDP, with larger effects with the energy input tax and quantity restriction measures. The changes in global and regional economic conditions increase exports and imports (except for C1), which lead the economy to become more trade orientated with an increased share of imports in total domestic supply and exports in total domestic production. Under the quantity restriction response measure (C1), real imports fall but the nominal import share rises due to the large increase in import prices.

<u>The impact on commodity demand</u>

The headline indicator of falling real GDP in SDG8 belies a more nuanced picture at the commodity level as shown in Figure 3.8.

Figure 3.8 Commodity demand (percentage change)



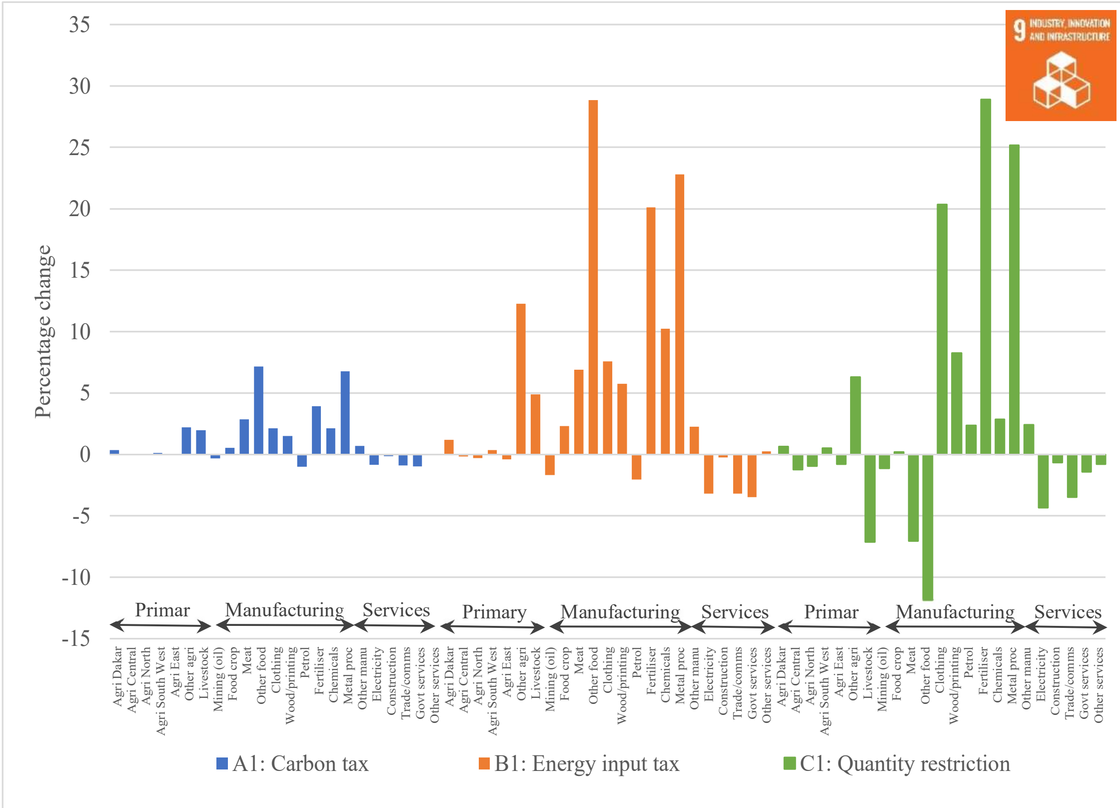
Source: simulation results.

Within the overall fall in demand, there are winners and losers. Although the general increase in import prices reduces overall demand, this is countered by the exchange rate depreciation which boosts export demand for some products. In general, demand for some primary and most manufacturing commodities increases and demand for services falls as a result of the carbon tax (A1) and energy input tax (B1) response measures. A closer look reveals that the pattern of impact on demand at the commodity level is similar for the carbon and energy input tax measures but with greater impacts under emissions reductions achieved by energy input taxes. The impact of emissions reductions achieved by quantity restrictions (C1) is a different story. The large increase in import prices for all commodities except oil is reflected in lower demand in line with the greater fall in GDP growth shown in SDG8.

<u>The impact on production</u>

The illustrative indicators for SDG9 suggest an increase in the role of manufacturing under all response measures. The changes in production by activity shown in Figure 3.9 show that production increases most for manufacturing compared to primary and service sectors which bears out the headline change in the SDG9 indicators.

Figure 3.9 Production quantities (percentage change)



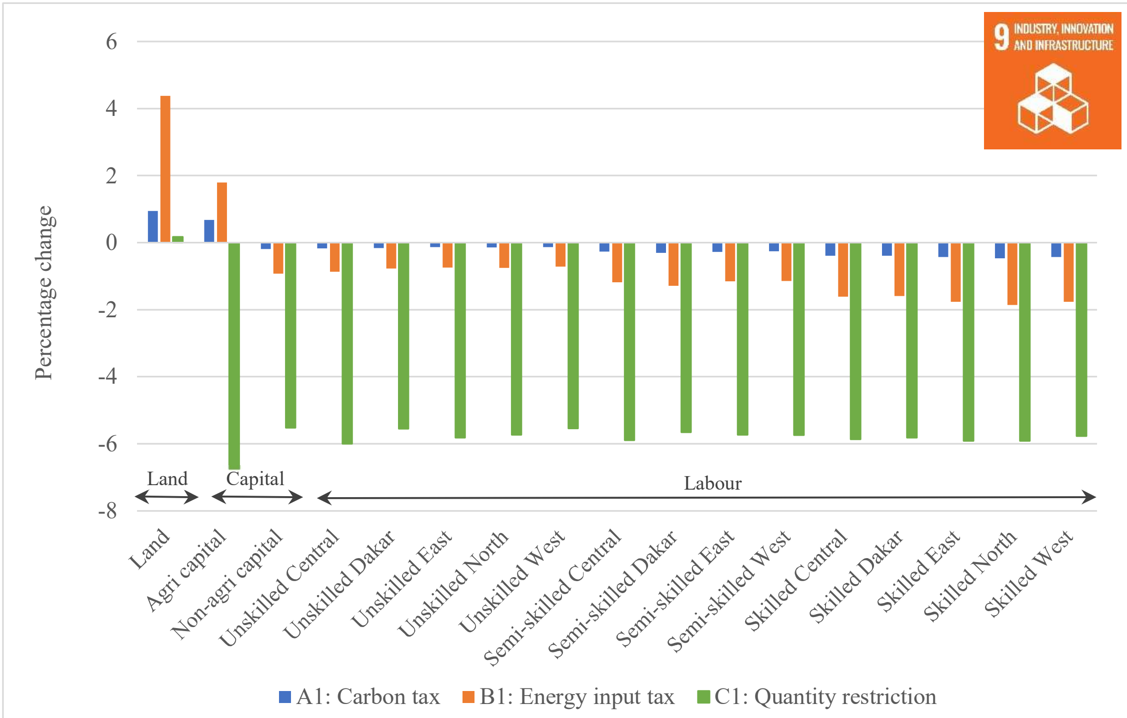
Source: simulation results.

Rising exports, as seen in the macroeconomic changes in the SDG8 analysis, are predominantly fuelled by the manufacturing sector. The production increases, see Figure 3.9, are larger than the changes in demand reported in Figure 3.8; highlighting the role of export demand in changing production patterns in Senegal. Again, the impacts are more muted when emission reductions are achieved through a carbon tax rather than energy input use taxes or quantity restrictions.

<u>The impact on factor markets</u>

The changes in production lead to changes in demand for land, capital, and labour. As all factors are assumed to be fully employed, changing demands are reflected in the returns to land and capital and wage rates as shown in Figure 3.10. Overall, response measures to reduce global emissions reduce the demand and therefore the wages of labour and non-agricultural capital and increase the demand, and therefore the returns, to land and agricultural capital with the exception of quantity restrictions (C1).

Figure 3.10 Factor returns (percentage change)



Source: simulation results.

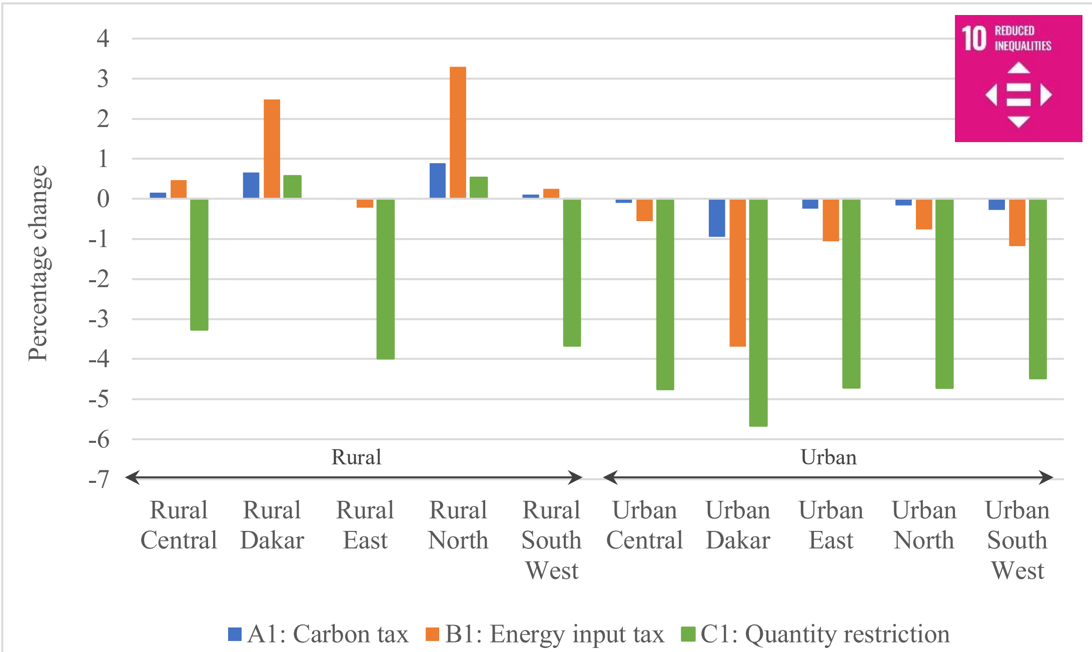
The changes in factor returns are consistent with the reduction in the size of the economy seen in SDG8. Labour is assumed to be mobile – able to move between sectors – which results in economy-wide determination of wage rates. The reduction in aggregate demand leads to a reduction in the demand for labour and lower wage rates. This effect is mildest when emissions are reduced via a carbon tax (A1) and strongest when quantity restrictions are used (C1) driven by the impacts on the service sector which employs 70% of labour in Senegal.

In contrast, land, which is tied to regional agricultural production, and agricultural capital, which is segmented by pattern of use rather than by assumption, are insulated from the economy-wide effect; responding only to changes in the agricultural sector. There is a particularly strong increase in the demand for land when energy input tax instruments are used to reduce emissions (B1) driven by export demand for Other agricultural commodities. Conversely, the demand for agricultural capital falls strongly when quantity restrictions are used (C1) due to the contraction in the livestock sector which uses 19% of agricultural capital.

The impact on households

As the mainstay of household income, returns to factors, especially labour, drive changes in household income and therefore inequality (SDG10). The percentage changes in household income are shown in Figure 3.11 and provide household level insights to complement the SDG10 indicators shown in Figure 3.6. As seen in the SDG10 results, real incomes fall for poor and average households under all response measures, with the rate of decrease being faster for the average household than poorer households.

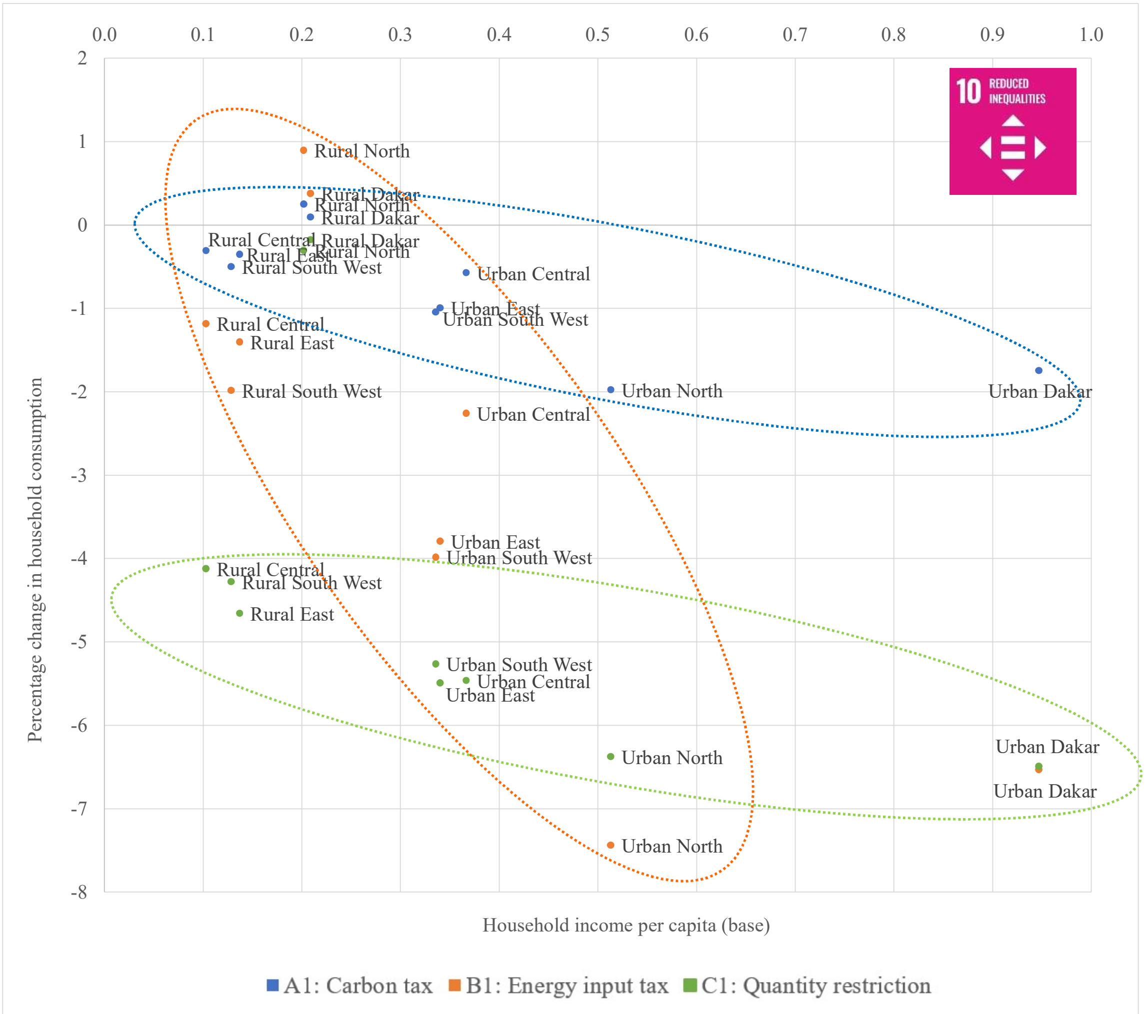
Figure 3.11 Household income (percentage change)



Source: simulation results.

Rural households in Senegal are systematically poorer than their urban counterparts in Senegal. Yet, incomes fall for urban households under all response measures due to the fall in returns to the factors they supply to the market (largely labour and non-agricultural capital). In contrast, incomes to rural (poorer) households rise under the carbon tax and energy input tax response measures due to the impact on land and non-agricultural capital returns and their reliance on remittances from abroad. Reliance on remittances and increases in the returns to land and agricultural capital buffer the negative wage and non-agricultural capital effects for poorer rural households. The impact of quantity restrictions is negative on household incomes for almost all households as reflected in the strength of the effect in the SDG10 indicator results.

Figure 3.12 Household income per capita vs. percent change in consumption



Source: simulation results.

Plotting a household's income per capita in the base against the change in household consumption by simulation, see Figure 3.12, highlights how response measures impact households differently and allows for the identification of vulnerable households. The reduction in household incomes translates into lower household consumption for all households in all simulations except Rural North and Rural Dakar in the carbon tax (A1) and energy input tax simulations (B1). As with the other results, household consumption falls least when a carbon tax is used to reduce global emissions and most when quantity restrictions are introduced as shown by the dashed lines that group most households in each simulation.

Although rural (poorer) households are less affected as seen in the SDG10 results, their lower initial income status puts them more at risk, particularly when energy input taxes and quantity restrictions are used as response measures to reduce global emissions. Rural Central, Rural South West and Rural East households are particularly vulnerable. In contrast, urban households have a higher initial income status yet experience a greater reduction in consumption. The results highlight that household vulnerability is a combination of both the initial income status of the household and the magnitude of the impact of the response measure.

Sensitivity analysis

In all CGE models, results are sensitive to the elasticities used in functions that describe behaviour. When elasticities are lower, the model is less responsive in terms of quantity changes and instead, prices adjust more. When elasticities are higher, the model is more responsive in terms of quantity changes and prices adjust less. Two alternatives were considered to assess the sensitivity of the simulations results to the choice of elasticities values. A high case in which model elasticities are increased 50% and a low case in which elasticities are reduced 25%. Results of the sensitivity analyses for selected SDG indicators are provided in Table A3.4.1. In no cases did the change in the elasticities change the sign of the results: lower elasticities result in slightly smaller SDG impacts while higher elasticities lead to slightly larger effects. Some exceptions occur when quantity restrictions are used, and lower (higher) elasticities lead to larger (smaller) effects. The conclusions presented in this report are robust to the choice of elasticity values under the range considered in the sensitivity analysis.

In addition to the parameter sensitivity analysis described above, further sensitivity analyses may also be conducted including changes in household elasticities, closures, factor market assumptions and shock values passed down from the global model.

Conclusions

The results from this pilot study illustrate the insights that can be derived using this method, even with a simplified model and truncated database (SAM) for Senegal. Global carbon reductions, achieved by carbon taxes (A1), energy input taxes (B1) or quantity restrictions (C1), produce contractions in measured global economic activity; contractions that may be offset by technological change, e.g., transitioning to energy producing technologies with lower carbon emissions. Such contractions in measured global economic activity are not necessarily synonymous with a reduction in global welfare: environmental benefits, e.g., reductions in heat stress, may be deemed more valuable than the foregone material economic benefits.

The results demonstrate that all three global response measures reduce measured GDP in Senegal through the impacts of changes in world prices for imports and exports and a depreciation of the exchange rate: domestic import and export prices increase except for some energy products including oil. The negative impacts of the response measures are least for carbon taxes (A1), and most for quantity restrictions (C1) with energy input taxes (B1) in between; these results are consistent with the expectation that carbon taxes will be the least distorting of the three instruments.

The reductions in GDP are mitigated by changes in the structure of production as Senegal adjusts to new patterns of international prices. These production changes cause reductions in the wage rates, with the reductions increasing with the skill levels. The rate of return to non-agricultural capital also declines but returns to agricultural capital and land typically increase. This pattern of factor price changes reflects two key factors: first, a relative increase in the share of production accounted for by agriculture, and second, the fact that the prices for land and agricultural capital are determined by the demand for inputs by agricultural activities while the price of labour, which is determined across the whole economy, declines.[39]

The decline in the price of labour is expected to impact negatively on all households particularly those who are more dependent on labour income. This is so for most households in all simulations, and the magnitudes of the negative impacts on some households, through combinations of reduced incomes and increases in commodity prices, indicate that poverty levels are likely to increase. This is especially so for the energy tax and quantity restriction simulations. However, the Rural North and Rural Dakar households are better off under carbon tax and energy input tax due to their income and consumption patterns. This is a consequence of the increases in the prices of land and agricultural capital, which are important sources of income for these households, alongside remittances. More generally, the increases in the prices of land and agricultural capital buffer, to some extent, the negative impacts on poorer (rural) households.

The patterns of the negative impacts of the different response measures are relatively the similar across the simulations; simply, urban households suffer more than rural households. The carbon tax (A1) and quantity restrictions (C1) simulations results in similar relative impacts but with those for quantity restrictions being relatively more negative. On the other hand, the energy input taxes (B1) result in greater relative negative impacts for the urban households, which, while making all households less well off, reduces urban-rural welfare differences; this reflects the differences in the impact of returns to labour.

The implications for the priorities identified by respondents to the questionnaire (see Annex 3.5) are clear. Along the economic dimension, economic growth and rural incomes fall across the simulations and government borrowing is maintained by assumption. Along the social dimension, poverty is likely to increase although the consumption of poorer households falls slower than the average household. Along the environmental dimension, reductions in

[39] In a recursive dynamic model, the returns to agricultural and non-agricultural capital will tend to converge as investment in new capital shifts towards agricultural capital.

global carbon emissions are coupled with increased domestic material consumption when the reduction is achieved through carbon and energy input taxes and decreased domestic material consumption when quantity restrictions are used.

The impacts on SDG measures are mixed. In all simulations some SDG measures improve while others worsen. The extent of the differences is greatest for quantity restrictions (C1) and least for carbon taxes (A1). Governments may be prepared to accept trade-offs between different SDG measures, but may be concerned if the negative impacts on some SDG measures are large. These results are indicative of how different response measures may impact on Senegal and can provide information that guides policy choices. For instance, the results may induce the government to adopt different mitigation policies according to the response measures adopted to reduce global emissions. The impacts of different mitigation policies have not been explored for this study but will be important considerations for governments.

Annex

A3.1 Model Aggregation

Table A3.1.1 Model aggregation and mapping to GLOBE commodities

GLOBE_CC mapping	**Commodities**	**Activities**
Grain	Grains	Dakar region agriculture
Oilseed	Oilseeds	Central region agriculture
Other agriculture	Other agriculture	North Region agriculture
Livestock	Livestock	South West region agriculture
Crude oil extraction	Mining	East region agriculture
Other food	Crop based food products	Crop agriculture
Meat	Livestock based food products	Livestock agriculture
Other food	Other food products	Mining
Textiles	Clothing	Crop based food products
Wood	Wood and printing	Livestock based food products
Petroleum	Petroleum (production)	Other food products
Chemicals	Fertilisers	Clothing
Chemicals	Chemicals	Wood and printing
Metals	Metals and metal products	Petroleum (production)
Other manufacturing	Other manufacturing	Fertilisers
Electricity	Electricity	Chemicals
Construction	Construction	Metals and metal products
Trade services, Transport	Trade and communication	Other manufacturing
Other services	Government services	Electricity
Other services	Other services	Construction
		Trade and communication
Factors of production	**Households**	Government services
Land	Rural Household - Dakar region	Other services
Agricultural capital	Rural Household - Central region	
Non-agricultural capital	Rural Household - North Region	
Unskilled labour - Dakar	Rural Household - South West regions	
Unskilled labour - Central region	Rural Household - East region	
Unskilled labour - North region	Urban Household - Dakar region	
Unskilled labour -South West regions	Urban Household - Central region	
Unskilled labour - East	Urban Household - North Region	
Semi-skilled labour - Dakar	Urban Household - South West regions	
Semi-skilled labour - Central region	Urban Household - East region	
Semi-skilled labour - North Region	Household (Rest of the world)	
Semi-skilled labour - South West regions		
Semi-skilled labour - East region		
Skilled labour - Dakar		
Skilled labour - Central region		
Skilled labour - North Region		
Skilled labour - South West regions		
Skilled labour - East region		
Labour - rest of the world		

A3.2 Model elasticities

Review of available elasticity values

Various sources can be used to derive the values of elasticities that are used in CGE models. In an ideal world, econometric regressions would be used to estimate the values of given elasticities applicable to a given country or region. But there is a dearth of the requisite data and quantitatively derived elasticity values in the economics literature and, consequently, a dearth of studies that focus on calculating the elasticities of substitution in all economies, and especially in developing countries, including Kenya and Senegal. Hence, CGE models apply a wide range of elasticities, some based on studies of other regions or countries with potentially similar characteristics, and many based on educated value judgements: hence the need for sensitivity analyses.

The single country STAGE_CC models for each of Kenya and Senegal along with their database are set up with given sets of elasticities estimated as reasonable estimates; however, the models have the option of using elasticities from other databases or of other values. This section provides a summary of the elasticities used in different CGE analyses of Kenya and Senegal, as applicable to the single country model, STAGE_CC, for each country.

Similarly, various CGE models of the Senegalese economy use elasticity estimates without calculations or quantitative support or are dated, and country-specific models of Senegal are also far and few in between. Using a two-sector model, Devarajan & de Melo (1987) assess the response of the three members of the African Financial Community (namely Cameroon, Côte d'Ivoire, and Senegal) to the commodity and oil price shocks in the 1970s in light of their fixed exchange rate regimes and other institutional constraints. The analyses do not have elasticity estimates specifically for any of the three countries. Similarly, Annabi *et al*. (2005) employ a CGE model based on a SAM for Senegal, using elasticities that are assumed without estimation or value justification.

Sartori *et al*. (2018) assess the structural consequences of water availability scenarios in Senegal, following a multidisciplinary approach and a sequential integrated modelling method including general equilibrium analyses of changes in agricultural productivity: the elasticity of water demand with respect to the industrial output volume was 0.46, based on Reynaud (2003). Reynaud's (2003) values were based on econometric estimates of industrial water demand in France; the values may be applicable to Senegal. The estimation results show that industrial firms are sensitive to water price inputs, with varying ranges of water elasticity[40].

[40] Network water elasticity is estimated at −0.29 (ranging from −0.10 to −0.79, varying by the type of industry); autonomous water price elasticity is not significant; while elasticity for treated water is evaluated at −1.42 (ranging from −0.90 to −2.21 according to the industry considered).

Relevant studies for Africa

Beyond Senegal, there are few estimates for elasticities in developing countries at large and Africa, specifically. The most prominent studies are for South Africa. Ntombela *et al*. (2018) estimate the Armington and export supply elasticities for individual and aggregate agricultural commodities for South Africa using time-series data from 1980 to 2016. Their results show that estimates for an aggregate agriculture commodity tend to be inelastic relative to estimates for an individual product, suggesting higher sensitivity of products to changes in relative prices. The study also finds Armington estimates to be closer to unity for the majority of agricultural products, suggesting that agricultural imports are imperfect substitutes for domestically-produced agricultural products. Finally, for export supply elasticities, the study results find grains to be more elastic than fruit and meat. This result would suggest that domestic grain production is relatively more responsive to price changes in the export markets than domestically. Finally, long-run estimates for the two sets of elasticities were found to be larger than the short-run estimates for all agricultural products.

At a more regional level, Sahn *et al*. (1996) and Maio *et al*. (1999) examine the impact of structural adjustment policies on the poor in Africa using CGE models. Sahn *et al*., (1996) concluded that in Madagascar and Tanzania, the poor benefited from adjustments. Meanwhile, Maio *et al*. (1999) concluded that the effects on the poor are dependent on the assumptions made about parameters such as elasticities (as well as relationships, and closure in the models). Neither study estimated the elasticity values but used ranges of values. There is some evidence of low total agricultural production price elasticity in sub-Saharan Africa, even if the elasticity for individual crops may be high. As such, the total "agricultural production is not likely to rise much in response to improved incentives, especially if infrastructure and the supply of inputs does not improve" (Maio *et al*., 1999).

These results can be indicative for Senegal as a starting point but need to be adjusted to reflect each economy's economic, trade structure, and consumer preferences. Nevertheless, as a result of data deficiencies, parameters can be estimated from elasticities for commodities and industries, but the definitions used might not always be consistent with those adopted in the model. Due to the lack of data, if elasticities cannot be derived based on empirical work or references to elasticities of countries with similar structures, elasticity values will often be estimated based on calibration methods. The models are then implemented using ranges of low and high elasticities for sensitivity analyses.

Table A3.2.1 Elasticity values used in the STAGE_CC Senegal model

Production structure	Intermediates/ aggregate value added (0.5) Intermediate inputs Aggregate value added

	Value added (sigmava1) Land-fertiliser Aggregate labour Aggregate capital 1sigmava: primary (0.25-0.26), mining (0.2), food processing (1.12), manufacturing and services (1.26), construction (1.4), trade and communications (1.68) Aggregate land and fertiliser (elastf: 1.2) Land Fertiliser Aggregate labour (elastf: 4) Aggregate skilled labour Aggregate semi-skilled labour Aggregate unskilled labour Labour from Rest of World Aggregate capital (elastf: 4) Capital (agricultural) Capital (non-agricultural) Aggregate skilled labour (elastf: 4) Skilled labour by region Aggregate semi-skilled labour (elastf: 4) Semi-skilled labour by region Aggregate unskilled labour (elastf: 4) Unskilled labour by region
Commodity elasticities	Sigma: 1.75 Omega: 2 Exdem: 0 Sigmaxc: 4
Activity elasticities	Sigmax: 0.9 except agriculture in Central and East regions, crop agriculture, mining, crop and livestock-based food products (0.5) and livestock and clothing (0.65) Sigmava: 1.6 except agriculture in Central and East regions, crop agriculture, mining, crop and livestock-based food products (0.8), clothing (1.2), livestock (1.25) and agriculture in Dakar and South West regions and other food (1.5) Omegaout: 4
Household elasticities	Frisch: Rural Central, Rural South West, Rural East (-3.5); Rural Dakar, Rural North (-3); all Urban except Urban Dakar (-2.5); Urban Dakar (-2) Incelast: agriculture and processed food (0.4), manufacturing, utilities, and construction (1.5), trade, communications, and services (2.2) Comelasth: 0

A3.3 Illustrative SDG indicators

Table A3.3.1 Groupings used in calculating Senegal SDG indicators

Grouping	Members
Material commodities	Grains, Oilseeds, Other agriculture, Livestock, Mining
Manufacturing	Crop-based food products, Livestock-based food products, Other food products, Clothing, Wood and printing, Petroleum, Fertilisers, Chemicals, Metals and metal products, Other manufacturing
Medium/high tech activities	Fertilisers, chemicals, metals and metal products, other manufacturing

A3.4 Sensitivity analysis

The results of a parameter sensitivity analysis in which selected model elasticities are increased 50% (high) and reduced 25% (low) are presented below.

Table A3.4.1 Results of sensitivity analysis for selected SDG indicators

	A1: Carbon tax			B1: Energy input tax			C1: Quantity restriction		
	Low	Base	High	Low	Base	High	Low	Base	High
811 Real GDP growth per capita	-0.08	-0.09	-0.09	-0.34	-0.35	-0.36	-1.01	-1.01	-1.03
921a Manufacturing share GDP	10.66	10.66	10.67	11.25	11.27	11.30	11.07	11.03	10.94
9b1 Medium/high tech share	41.46	41.44	41.39	41.41	41.34	41.20	43.30	43.32	43.37
1011a Low income hhld consumption growth	-0.08	-0.10	-0.14	-0.37	-0.44	-0.60	-2.54	-2.48	-2.37
1011b Average hhld consumption growth	-1.29	-1.34	-1.43	-4.84	-5.01	-5.36	-5.53	-5.39	-5.13

A3.5 Insights from the questionnaire for stakeholders

The purpose of the questionnaire was to collect information to understand the relevant indicators and parameters associated with the impacts of implementation both temporally and spatially in the pilot countries. The collected information may be used for calibrating the models and methodologies being developed or tested for the purpose.

The questionnaire had the following five sections: (1) Stakeholder information; (2) Priorities and objectives; (3) Policy impacts and action policies; (4) Commitments; and (5) Allowable trade-offs. In the first section (Stakeholder information), the questionnaire collects various information of each stakeholder, including the organization with which the stakeholder is associated along with their role in affecting climate change and/or climate change policy. The questionnaire also requested a confirmation of a consent to retain respondents' email addresses in this study database only for purposes of the analysis for the duration of this pilot study with the UNFCCC, at the end of which the email address would be removed from the study database. All respondents gave such consent. For the subsequent sections (2 through 5), the questions separate the section into three focus areas:

1. Economic, which includes primarily effects on the economy, mostly at the macroeconomic level;
2. Social, which includes primarily effects at the socioeconomic level and household levels pertaining to but not limited to education, health, socioeconomic wellbeing, and wages; and
3. Environmental, which includes primarily effects on the various environmental and agricultural resources as well as emissions and climate change indicators.

The questionnaire was sent to people from various organizations involving climate change and the environment. A total of four completed responses were submitted. Analysing the results from said respondents, various common themes emerge in some areas only. Notably, the low number of responses per question renders the likelihood of a common theme emerging low, especially for questions with a high number of possible responses. As such, this section analyses the responses by reporting, first, the responses that were selected by at least half (50% or more) of the respondents as a common theme. If no response was not selected by 50% or more of the respondents, the analysis lists all responses.

First, in terms of the economic, social, and environmental priorities, important common themes emerged in the first two but not the latter. The three highest-ranked priorities along with the corresponding share of responses are presented in the following table.

Table A3.5.1 Rankings of priorities according to questionnaire respondents in Senegal

Priority rank	Economic priorities	Social priorities	Environmental priorities
First	Economic growth (75%)	Poverty alleviation (75%)	Water preservation (25%) Soil preservation (25%) Climate change (25%) Coastal erosion (25%)
Second	Reducing government borrowing (75%)	Income distribution (50%)	Water preservation (25%) Soil preservation (25%) Air pollution (25%) Climate change (25%)
Third	Increasing rural incomes (50%)	Access to clean affordable energy (50%)	Climate change (50%)

Second, among the 17 possible SDGs, the respondents ranked in a descending order, the SDGs selected for the Pilot Project as follows:

Goal 8 (Decent Work and Economic Growth): 3rd, 5th, 6th, 13th.

Goal 9 (Industry, Innovation and Infrastructure): 8th, 8th, 12th, 14th.

Goal 10 (Reduced Inequality): 6th, 7th, 9th, 15th.

These results show that each of the three selected SDGs is ranked in the top half of the SDG at least half of the respondents, which justifies the SDG selection in the Pilot Project.

Third, the effects of the impact of response measures in each of the economic, social, and environmental responses are consistent with the ranking of the priorities and SDGs. The following table summarizes the responses corresponding to the indicators that would worsen, improve, or not change because of the implementation of a given response measure in developed countries.

Table A3.5.2 The effects of the implementation of response measures on various indicators in Senegal, per questionnaire responses

Worsening (% of responses)	Improving (% of responses)	No change (% of responses)
Actual impacts of response measures to date		
Government borrowing (75%)	Economic growth (50%)	Adult morbidity (100%)
Trade deficit (75%)	Access to clean energy (75%)	Income inequality (75%)
	Gender equality (50%)	Rural income (75%)
	Poverty (50%)	Share of manufacturing in GDP (75%)
	Air pollution (50%)	Soil preservation, water preservation (75%)
Expected impacts of future response measures		

Worsening (% of responses)	Improving (% of responses)	No change (% of responses)
Government borrowing (50%)	Economic growth (70%)	Adult morbidity (75%)
Income inequality (50%)	Environmental: Air pollution; water preservation; soil preservation; access to clean energy; wildlife protection; and climate change (100%)	Child mortality (75%)
	Gender equality (50%)	Gender equality (50%)
	Socio-economic: Poverty (75%) Rural income (100%)	Share of manufacturing in GDP (75%)

Fourth, common action policies were selected by the responses as policies that have been or are to be adopted in Kenya in response to the aforementioned (actual and expected) impacts of response measures. The leading action policies identified by the respondents are:

1. The adoption of renewable energy projects;
2. New projects and development programs;
3. Economic diversification and transformation; and
4. Green employment opportunities (which is not yet available and, thus, pertains to future policies).

Furthermore, the respondents agree that the most likely funding source for the adoption of such policies is by way of increasing donor funding.

Fifth, the allowable trade-offs pertaining to the implementation of action policies in response to response measures are another important area in which common themes emerge in the responses. The following tables lists the trade-offs that were considered not allowed by the majority (75% of more) of the respondents.

Table A3.5.3 Not allowable trade-offs of action policies adopted in response to response measures in Senegal, per questionnaire responses

Economic indicators (% of responses)	Social indicators (% of responses)	Environmental (% of responses)
Economic growth (100%)	Income inequality (75%)	Rate of climate change (100%)
Rural incomes (75%)	Poverty (75%)	Water preservation (75%)
Trade balance deficit (75%)	Gender inequality (75%)	Air pollution (75%)
	Access to clean energy (75%)	

These results show that there is clear agreement among the respondents about the indicators that should not worsen because of the implementation of action policies. Importantly, these indicators are also consistent with the indicators ranked as the top three priorities for Senegal by the respondents.

In contrast, for the trade-offs considered allowable in Senegal by the questionnaire respondents, there is almost no agreement among them. Importantly, the allowable indicators are also consistent with indicators marked as having low priorities for the respondents. The following graph depicts these allowable trade-offs along with the corresponding number of responses.

Figure A3.5.1 Allowable economic trade offs

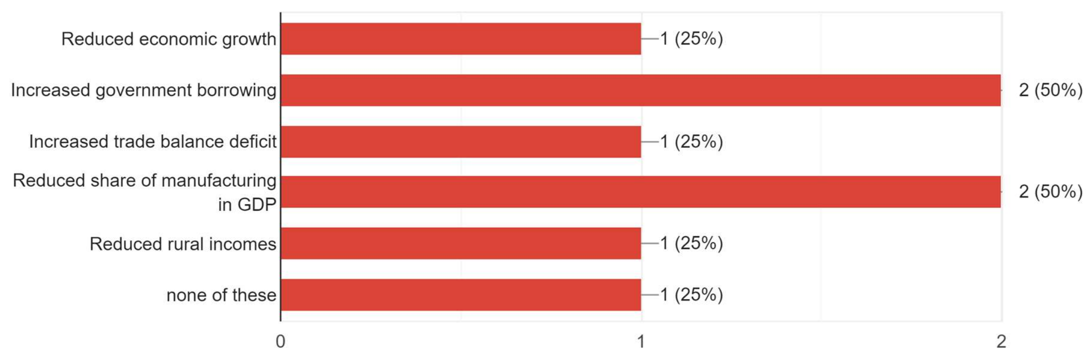


Figure A3.5.2 Allowable social trade offs

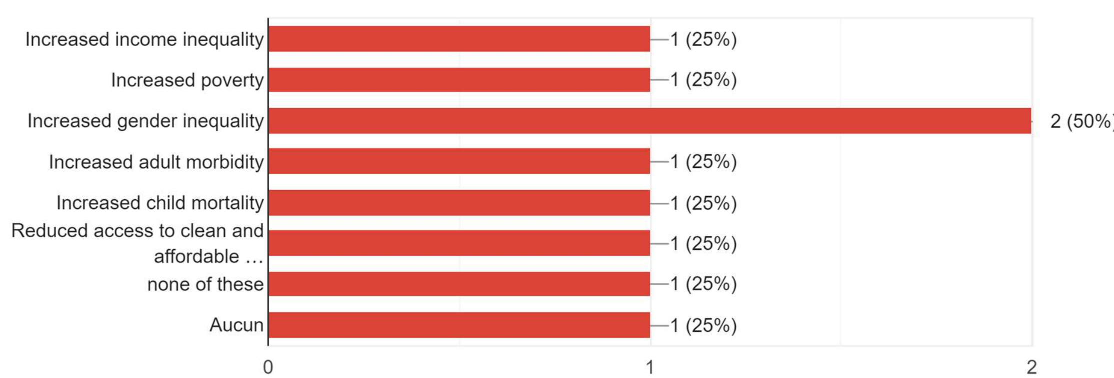
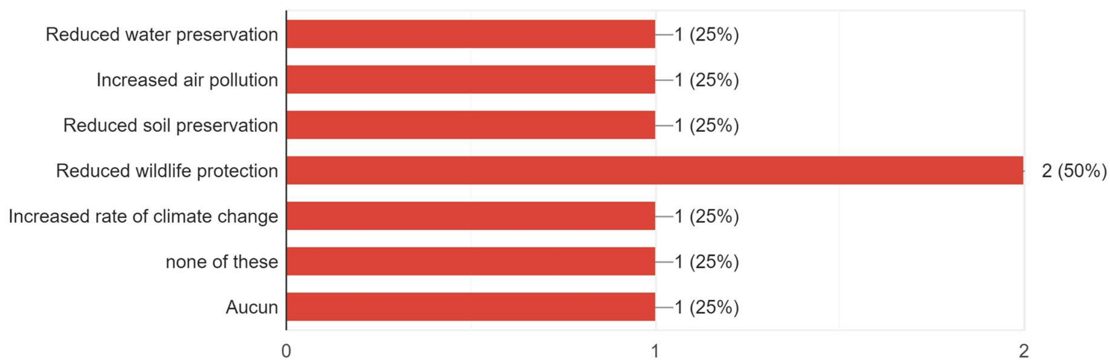


Figure A3.5.3 Allowable environmental trade offs



4. Impact of Response Measures in Kenya

Summary

The results from this study of Kenya illustrate how a computable general equilibrium (CGE) model for a country can provide useful information to guide policy formulation in a low-income country confronted by changes in its economic environment occasioned by response measures to climate change. The results illustrate how different response measures produce different changes in the economic environment and therefore in the changes in the patterns of production, consumption and household incomes and welfare. A comparison of the implications for Kenya with those for Senegal consequent upon common global response measures, illustrates how common global response measures produce different changes in the external environment faced by countries, while differences in domestic relationships and structures exacerbate the difference in impacts. As such domestic mitigation strategies will vary across countries.

The simulations implemented for this study are designed to illustrate the information that can be gleaned from this class of economic model. The simulations are not designed to provide specific policy advice, but rather to demonstrate how different changes in the global economic environment will have different implications for individual countries.

Introduction

The Government of Kenya has acknowledged that climate change is a major driving factor in its economic activities (Government of Kenya, 2010) and has taken steps towards meeting its international obligations and ensuring that climate change is considered in the country's policies, activities, and investment plans (Government of Kenya, 2015). Key challenges include designing and implementing those policies; understanding the effects on the Kenyan economy of global response measures implemented by the Conference of Parties to reduce global CO_2 emissions; and evaluating the effects of alternative policy options on the Kenyan economy and environment.

Economy-wide computable general equilibrium (CGE) models are a useful quantitative method for assessing the effects of various shocks and/or alternative policy solutions in an economy and, accordingly, designing policy. This chapter reports an application of a single country CGE model, STAGE_CC, to evaluate the implications for the Kenyan economy of (stylised) global response measures derived from a global CGE model, GLOBE_CC

(McDonald & Thierfelder, 2020b).[41] The global model is calibrated with data from the Global Trade Analysis Project (GTAP), while the Kenya CGE model is calibrated from a SAM for Kenya. The shocks implemented in both the global and single country models are illustrative of the insights that can be realised from CGE models: they are not intended to inform Kenyan policy decisions, although the models are capable, given appropriate parameterisation of the shocks, of providing information for Kenyan policy makers.

The results demonstrate the extent to which different response measures impact differentially on the Kenyan economy. Global response measures will have negative measured economic implications because response measures increase the constraints imposed on economic agents. It is evident that economically efficient response measures, e.g., carbon taxes, have lesser negative implications for Kenya than less economically efficient response measures; although it is not evident that economically efficient response measures can necessarily be realised. In addition to conventional economic measures of the impacts, the results also include measures of the impacts based on Sustainable Development Goals (SDG) indicators (Shutes, 2021).

The rest of the chapter is organised as follows. The next section, two, reviews the data used to calibrate the CGE model outlined in the third section. The simulations used for this illustrative study are detailed in the fourth section with the fifth section given over to analyses and discussion of the results. The sensitivity of the results to changes in exogenous parameters and model settings are evaluated in the sixth section. The final section provides some concluding comments. There are a series of Annexes that provide supporting information and data.

Data

The first few steps in implementing any CGE model involve the identification and collection of data that guide the model design and calibration as well as the type of insights that the model provides.

Background information on national priorities

The first step undertaken as part of this study was gathering necessary information to understand the leading national policy priorities by the various stakeholders in Kenya and to guide the calibration of the STAGE_CC model for Kennya; the development of the methodologies tested to examine response measures; the analysis of the effects of response

[41] The global simulations presume that low-income economies are excluded from making emission reductions: this does not mean that the low-income economies are immune from the consequences of response measures.

measures; and the choice of mitigation policies in response to them. To that end, an online questionnaire was prepared and sent to various stakeholders in Kenya, to collect information that would aid in understanding the relevant indicators and parameters associated with the impacts of response measures implementation, both temporally and spatially, in Kenya. Details of the questionnaire are provided in Annex 4.1.

The questionnaire was sent to 10 people from various organizations involving climate change and the environment. No responses were received from Kenya. Therefore, to fill the gap in understanding, regard was given to Kenya's *Second National* Communication to the United Nations Framework Convention on *Climate Change* (Government of Kenya, 2015). Nevertheless, this documentation lacked information on the expected current and future effects of response measures on the economic, social, and environmental indicators in Kenya.

<u>Database: SAM and ancillary data</u>

The STAGE_CC model for Kenya was calibrated using a Social Accounting Matrix (SAM). Specifically, the SAM data are sourced from Social Accounting Matrix of Kenya 2014 (Mainar-Causape *et al*, 2018), which used 2014 as the base year. It details current account transactions (remittances, international transfers, and factor earnings), value added split between factors, direct and indirect tax information, and trade (import and exports) for each commodity. The population information of each household in Kenya is sourced from the Integrated Household Budget Survey, 2005/2006 for Kenya.

The structure of the data in the SAM is also reflected in the model and summarized as follows. In the model, the economy has various households that purchase commodities, both from domestic markets as imports, final consumption. They also supply labour and own capital. Similarly, the government also consumes commodities, from domestic markets and imports. Activities also consumes those commodities as part of their intermediate consumption, and rent capital and hire workers, to supply products and services to meet the different demand sources. In the model, agents purchase commodities, both from domestic markets as imports, either for final consumption (by households and governments) or intermediate consumption (by activities). The production factors are employed by the different activities which produce goods consumed domestically or in export markets. The activities pay (as wages and capital rent) the owners of the factors of production, namely households, enterprises, and the government, and the rest of the world. Agents also receive income from factors on the domestic market, from government transfers, and from transfers from the rest of the world.

The structure of the SAM is illustrated by a macro-SAM in Table 4.1, where the active sub matrices are identified by *X,* and the inactive sub matrices are identified by *0*. Importantly, the STAGE_CC model is designed to run not only for a SAM for Kenya or Senegal, but any SAM for other economies, so long as this SAM does not contain information in the inactive sub matrices and conforms to the rules of a SAM. This is because the inactive submatrices relate to transactions that are not accounted for by behavioural relationships in the model.

In addition to the SAM, two additional databases were used by the model. The first are two satellite accounts that record the 'quantities' of primary inputs used by each activity and the quantities of factors owned by each institution. If such quantity data are not available, then the entries in the factor use and ownership matrices are calculated from the corresponding sub matrices of the SAM. Pending data availability, satellite accounts for other data can be also used, with data for CO_2 or GHG emissions being the most relevant for this study. Nevertheless, there are not sufficient data available at the country level to be included in the STAGE_CC model. Further, while the focus of this study is on global emission reductions, Kenya's emissions are a small part of those emissions. Accordingly, for this study the satellite accounts for GHG carbon emissions by Kenya is void. The changes in emissions for the broader East African region are shown in Table 2.6.

Table 4.1 Macro SAM for the Standard STAGE Model

	Commodities	**Activities**	**Factors**	**Households**	**Enterprises**	**Government**	**Capital Accounts**	**Rest of the World (RoW)**
Commodities	0	X	0	X	X	X	X	X
Activities	X	0	0	0	0	0	0	0
Factors	0	X	0	0	0	0	0	X
Households	0	0	X	0	X	X	0	X
Enterprises	0	0	X	0	0	X	0	X
Government	X	X	X	X	X	0	0	X
Capital Accounts	0	0	X	X	X	X	0	X
Rest of the World (RoW)	X	0	X	X	X	X	X	0
Total	X	X	X	X	X	X	X	X

The second series of additional data are the elasticities of substitution for imports and exports relative to domestic commodities, the elasticities of substitution for the constant elasticity of substitution (CES) production functions, the income elasticities of demand for the linear expenditure system and the Frisch (marginal utility of income) parameters for each household, and factor mobility and household migration elasticities. All the data are accessed by the model from data recorded in Excel and GDX (GAMS data exchange) files.

<u>Aggregation and production structure</u>

The data from the Kenya SAM included 71 commodities, 54 activities, and 32 factors (27 labour, 3 capital, and 2 land factors). For purposes of this study the data were aggregated to include 43 commodities, 41 activities, and 30 factors. The 22 households in the SAM database remained in the model's database (see Annex 4.2 for details).

<u>Key features of the Kenyan economic structure</u>

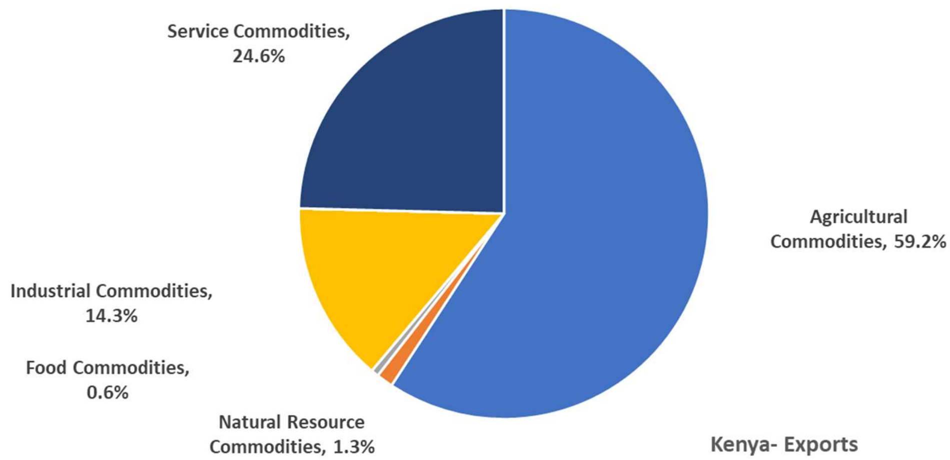
The SAM reveals important features of the Kenyan economy. The economic structure of an economy is one of the key determinants of the effects of response measures and mitigation policies on countries responses, with the others being the shocks themselves. Therefore, understanding the economic structure is key to interpreting model results.

Trade

Kenya's trade structure is key in determining the effects of response measures on its economy. The impacts of response measures to reduce carbon emissions are transmitted to the individual countries through trade changes, affecting the exchange rate (which, in turn, affects real incomes and real measures of economic activity) as well as changes in international prices which, in turn, affect costs of a country's imports and exports.

Kenya's exports, Figure 4.1, are dominated by agricultural products, which account for 59% of total exports. One commodity, tea, contributes over 40% of the country's exports, and is the backbone of the Kenyan economy, contributing around 25% of the country's GDP and employing over 70% of its labour. It is also one of the country's largest contributors to GHG emissions. The services commodities group has the second highest export share of approximately 25% (dominated 13% by trade and 8% by hotels), representing both domestic services and tourism. Finally, industrial commodities sector has a 14% share of total exports.

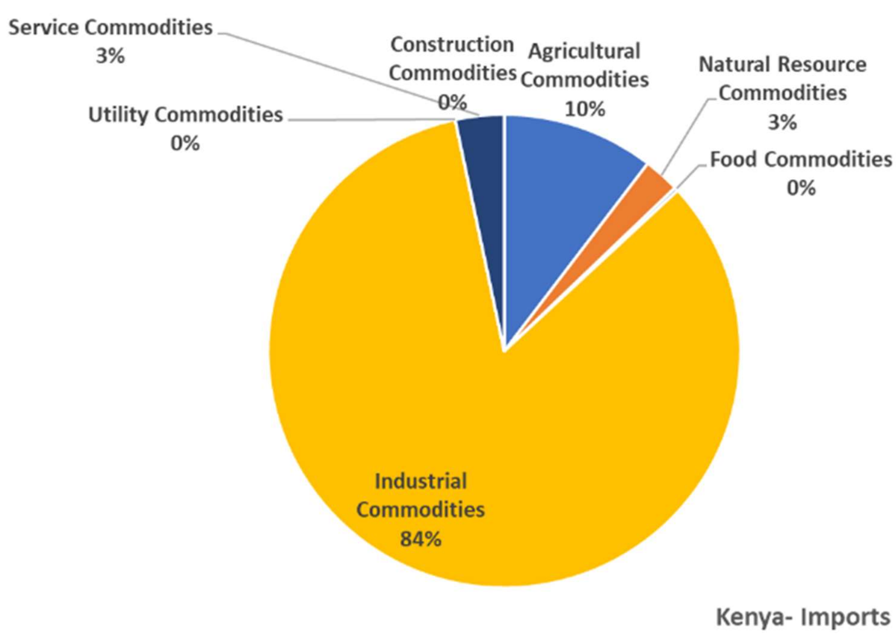
Figure 4.1 Sectoral shares of Kenya's exports (2014)



Data source: Authors' elaboration using Kenya Social Accounting Matrix 2014.

Imports of industrial commodities, Figure 4.2, account for approximately 85% of imports, with the main products being petroleum (21%) chemicals (20%), machinery (18%), and textile (6%). The fifth highest imported product are pulses & oil seeds (6%) within the agricultural commodities group. Import dependence in Kenya is evident in both petroleum and mining (69.6%) as well as manufactured and industrial products (38%), and less so in agriculture (8%).

Figure 4.2 Sectoral shares of Kenya's imports (2014)



Data source: Authors' elaboration using Kenya Social Accounting Matrix 2014 (2018).

In the energy sector specifically, where import dependence is high (69.6%), imported petroleum and mining products are consumed by various demand sources, as explained in the following Table 4.2.

Table 4.2 Energy use in Kenya (share of total demand)

	Intermediate demand				Final demand			
	Construction	Electricity	Petroleum	Other	Household	Government	Investment	Export
Mining	73%	0%	0%	21%	0%	0%	0%	6%
Petroleum	8%	2%	2%	43%	43%	0%	0%	2%

Data source: Authors' elaboration using Kenya Social Accounting Matrix 2014 (2018).

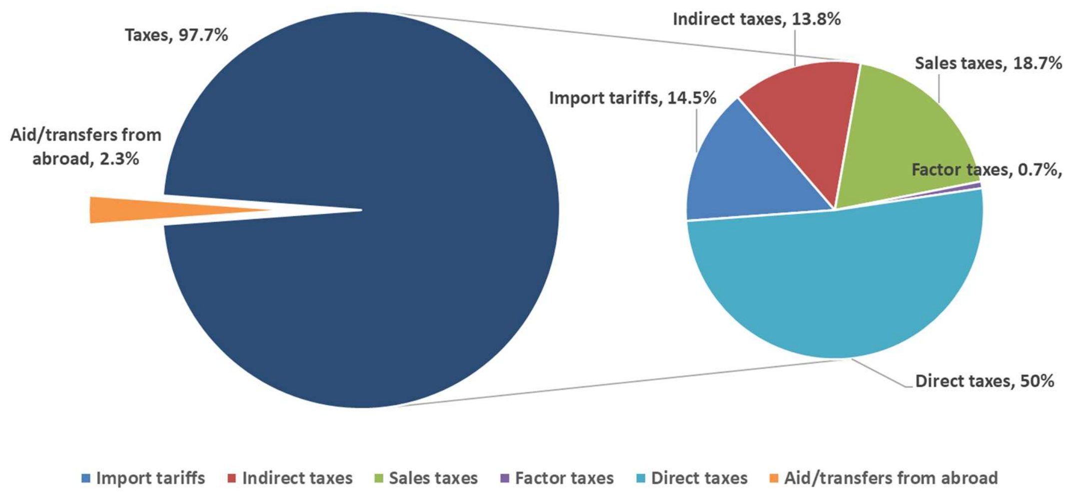
Mining product is used almost entirely by intermediate demand, most of which is from the construction industry (73%). Similarly, petroleum is an input demanded by intermediate demand (51%), followed by household demand (43%). Exports from both mining and petroleum are minimal, which reflects the energy-import dependence of Kenya. As such, when global energy prices change, e.g., following a global shock, they are transmitted to the Kenyan economy through the costs faced by industries, especially those that energy input intensive.

Government income

The Kenyan government earns income from transfers (aid) from abroad as well as taxes from 5 sources—namely direct, indirect, sales, factor and import taxes. Most of government income is generated from taxes and that the government's reliance on foreign aid is negligible, Figure 4.3. Direct taxes on households generate more than half of the government's income, while the remaining half is divided sources from import tariffs, indirect taxes, and sales taxes in similar shares.

The sources of government income are important determinants of how the government can design mitigation policies that can be used to maximize the positive or minimize the negative impacts of response measures. If responses to global warming reduce overall economic activity and thereby government revenue, the government can respond by reducing expenditures and/or increasing taxes, except in so far as reductions in government revenue are not offset by increases in aid transfers.

Figure 4.3 Government income share by source in Kenya (2014)



Data source: Authors' elaboration using Kenya Social Accounting Matrix 2014.

The dominant source of tax revenue is direct taxes, which suggests that direct taxes may be the best tax (revenue) replacement instrument. Nevertheless, it transpires that nearly 70% of direct tax revenue is contributed by three household groups (Table 4.3), which implies that changes in direct tax rates will disproportionately impact those three households, despite the incomes per capita of those households not being markedly greater than the other households.

Table 4.3 Share of direct income tax, population, and income per capita

Household	Population	Income per capita	Share of direct tax
Nairobi - Quintile 1 (richest)	915,281	6.89	1.0%
Nairobi - Quintile 2	732,083	2.96	20.2%
High Rainfall - Urban	2,430,715	2.77	0.2%
Nairobi - Quintile 3	544,416	2.50	0.9%
Semi-Arid South - Urban	187,689	2.43	0.1%
Mombasa - Quintile 2	189,977	2.24	0.6%
Semi-Arid North - Urban	204,785	2.22	0.9%
Nairobi - Quintile 4	408,044	2.17	5.4%
Mombasa - Quintile 1 (richest)	399,381	1.89	33.5%
Nairobi - Quintile 5 (poorest)	163,241	1.65	0.9%
Coast - Urban	262,011	1.58	0.4%
Mombasa - Quintile 3	152,224	1.48	1.8%
Mombasa - Quintile 4	88,028	1.46	1.0%
Arid North - Urban	252,201	1.27	2.0%
High Rainfall - Rural	18,657,913	1.01	0.2%
Semi-Arid South - Rural	2,910,643	0.99	15.3%
Mombasa - Quintile 5 (poorest)	46,033	0.96	5.5%
Semi-Arid North - Rural	2,793,598	0.93	4.7%
Arid South - Urban	116,527	0.91	0.6%
Coast - Rural	1,545,289	0.52	1.4%
Arid South - Rural	555,988	0.41	0.4%
Arid North - Rural	1,908,788	0.28	3.1%

Data source: Authors' elaboration using Kenya Social Accounting Matrix 2014 and population data 2005/2006.

Savings

Savings in Kenya are mainly sourced from (capital) transfers from the rest of the world, and local enterprises, with direct savings by households being relatively unimportant and the government running a marked deficit (Table 4.4).

Table 4.4 Sources and values of general investment savings in Kenya (2014)

	Households	Enterprises	Government	Transfers from Rest of the World	Total
Investment saving	51,284	715,764	(213,904)	778,195	**1,331,339**

Data source: Authors' elaboration using Kenya Social Accounting Matrix 2014 and population data 2005/2006.

Model[42]

The STAGE_CC model used for Kenya is a variant of the STAGE 3 model, adapted for the pilot studies commissioned by the UNFCCC and calibrated with a SAM of the Kenyan economy and associated data accounts. STAGE is a 'STandard' Applied General Equilibrium model and is implemented in the General Equilibrium Model System (GAMS) programming

[42] A comprehensive technical document for STAGE_CC is available (McDonald & Thierfelder, 2020a).

language. The use of the model is presented in the "*STAGE: A User Guide*" document delivered to the UNFCCC as part of this pilot project. Further, the model code, relevant equations, theoretical underpinnings, and model genealogy are documented in STAGE_CC technical documentation (McDonald & Thierfelder, 2020a). This section summarizes the STAGE_CC model.

Model summary

The single country model used in the pilot study is the STAGE_CC single-country computable general equilibrium (CGE) model (McDonald & Thierfelder, 2020a) operated in its comparative static mode. It is a simplified variant of the STAGE 3 single country CGE model. This model is characterised by several distinctive features. First, the model allows for a generalised treatment of trade relationships by incorporating provisions for non-traded exports and imports, i.e., commodities that are neither imported nor exported, competitive imports, i.e., commodities that are imported and domestically produced, non-competitive imports, i.e., commodities that are imported but not domestically produced, commodities that are exported and consumed domestically and commodities that are exported but not consumed domestically. Second, the model allows for modelling of multi-product activities using various assumptions; fixed proportions of commodity outputs by activities with commodities differentiated by the activities that produce them, varying output mixes by activities in response to changes in the (basic) prices of commodities, and domestically produced commodities that are differentiated by source activity or are homogeneous, i.e., undifferentiated by source activity. Therefore, the numbers of commodity and activity accounts are not necessarily the same. Third, the (value added) production technologies can be specified as generalized nested Constant Elasticity of Substitution (CES)[43]; the nesting used is reported in Annex 4.4. Fourth, trade and transport margins between factory and dock gate and the consumer are levied on domestic consumption. Fifth, consumption expenditure by each representative household group (RHG) is represented by nested CES and Stone-Geary (LES) utility functions. And sixth, the functional distribution of income is endogenously determined through the specification of the ownership (domestic and foreign) of factors used within the economy which is defined as a series of variables.

Elasticities

In addition to the data contained in the SAM, calibrating and implementing any CGE model also requires additional exogenous data, namely elasticities, which control, in part, the responsiveness of the behavioural relationships represented in the mathematical representation

[43] The nesting structure is controlled by set assignments and requires no changes to the model equations. The nesting structure can encompass both primary and intermediate inputs.

of the economy, i.e., the model. The model requires elasticities for the functions controlling consumption, production, and international trade. In applying the STAGE__CC model for Kenya, the following elasticities were chosen: elasticities of substitution for imports and exports relative to domestic commodities; the elasticities of substitution for the CES production functions; the income elasticities of demand for the linear expenditure system and the Frisch (marginal utility of income) parameters for each household; and factor mobility and household migration elasticities. In a perfect world, econometric regressions would be used to estimate the values of given elasticities applicable to a given country or region. Nevertheless, in reality, there is a dearth of quantitatively-derived elasticity values in the economics literature and a dearth of studies that focus on calculating the elasticities of substitution specifically in Kenya, for East Africa, and for countries in general.

Elasticities values have been selected to apply the STAGE_C C model for Kenya, and ranges of low and high elasticities have subsequently been implemented for sensitivity analyses to ensure the robustness of the results to the selected elasticities values (Annex 4.6 summarises the elasticities, the existing relevant literature on elasticities for Kenya, the method of determining elasticities for Kenya, and the selected values applied in the model.

Model closures

The STAGE_CC when run in comparative static mode can simulate results in both the short and long runs via different model closures. In simple terms, a model closure indicates the way in which it is set to solve, marking important and fundamental differences in how an economy is understood or perceived to function. Mathematically, it is implemented through the way different markets clear and the way in which certain variables are set to be either exogenous or endogenous. The model is designed to allow multiple macroeconomic closures, such as fixed exchange rates and government budget constraints, investment expenditure (versus savings), factor market clearing conditions, and structural rigidities that impose constraints on the range of solutions (responses) available to the modelled agents.

Various closures can be implemented based on country-specific circumstances, the selected policy question that is being examined, or the selected mitigation policies that may be implemented to address effects of response measures implementation. For purposes of this report, a set of closures were selected in applying the model to Kenya for illustration purposes only (see below and Annex 4.7).

Simulations

<u>Response measures</u>

This study evaluates the effects of the global implementation of three response measures to reduce global carbon emissions on the Kenyan economy: the response measures are implemented at a global level but their ensuing effects impact individual countries at a local level. First, the implementation of response measures at a global level is simulated in the GLOBE_CC model, to estimate of the impacts on the global economy. The three simulated response measures are:

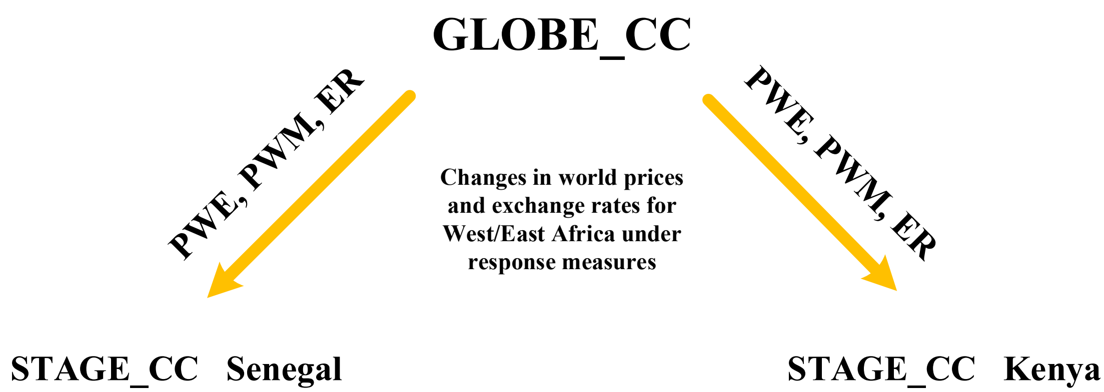
Table 4.5 Description of response measures implemented in the global model

Simulation	Description
A1: Carbon tax	A reduction of global carbon emissions by 20% via an endogenous tax on carbon with low-income regions exempt
B1: Energy input tax	A reduction of global carbon emissions 20% via an endogenous tax on fossil fuels with low-income regions exempt
C1: Quantity restriction	A reduction of carbon emissions in each region to the levels found in simulation A1 (global carbon emission reduction of 20%, uneven by countries) via quantity constraints, in which Total factor productivity (TFP) adjusts in each region by an equiproportionate change in TFP to each activity.

In addition to the three simulations in GLOBE_CC, a fourth simulation, D1: Technology change was implemented. It derived estimates of the efficiency gains in fossil fuel use in the electricity sector by region (except low-income regions) required to achieve a 20% reduction in global carbon emissions achieved. This simulation is not passed on to the single country models for two reasons. First, it is exploratory in nature only. Second, the Pilot Study excludes developing countries, including Kenya, from implementing measures in GLOBE_CC to reduce carbon emissions, partly owing to the large economic costs of reducing carbon emissions and to the low contribution of those economies to global carbon emissions.

The impact of each response measure is implemented in the STAGE_CC model through changing exogenous parameters equalling the values that are passed through from the global model to the local country model of Kenya using a soft linking between GLOBE_CC and the STAGE_CC for Kenya. Specifically, Kenya's connection to the world economy is largely determined through trade, the impacts that are passed to Kenya are the results of the global model pertaining to percentage changes in world prices of imports (*PWM*), world prices of exports (*PWE*), and the nominal exchange rate (*ER*). Figure 4.4 depicts this process for the two countries selected for the UNFCCC pilot study, namely Senegal and Kenya. Importantly, the process could be similar for any country for which the STAGE_CC is implemented.

Figure 4.4 Linking the global and country level CGE models



Source: Pilot project team.

The world price results per commodity from the global model are passed to a corresponding commodity in the single country model, based on a mapping of aggregated commodities used for each model. As the global model contains bilateral trade flows and the single country has a single composite trading partner, world prices are aggregated using the value share of each trading partner's imports or exports in the base. Given the "small open economy" assumption, changes in local country prices do not affect the global economy, so there is no feedback from the single country model to global model.

Similarly, for exchange rates, the country or regional results from the global model are passed to the single country that is the same or falls in the same region in the global model, based on a mapping for countries and regions. The exchange rate changes for the East Africa region resulting from the implementation of each of the response measures in GLOBE_CCC are passed on to Kenya as shocks in its nominal exchange rate. The mappings for commodities between GLOBE_CC and STAGE_CC for Kenya are reported in Annex 4.2.

<u>Shock values</u>

For each scenario (A1, B1, C1), three shocks are added to the STAGE_CC model: a percentage change in the world price of imports (*PWM*) per commodity per simulation; a percentage change the world price of exports (*PWE*) per commodity per simulation; and a percentage in the exchange rate (*ER*) per simulation.

All three response measure scenarios result in a depreciation of the exchange rate, a general decrease of the export price, and a general decrease in the import price for most commodities in scenarios A1 and B1, but an increase in C1. Annex 4.5 details the results of the three response measures (shocks) in GLOBE_CC for East Africa matched to the corresponding commodity in Kenya. The results from GLOBE_CC recorded world prices, as percentages changes, were converted to a multiplicative value with which to change, i.e., shock, the import and export prices in STAGE_CC: a percentage change decrease in world prices in GLOBE_CC results is translated to a shock of less than 1 in STAGE_CC; while a percentage change increase in GLOBE_CC is translated to a shock exceeding 1. Table 4.6 reports the values of the shocks imposed per response measure scenario.

The depreciation of the exchange rate is a particularly important result for economies, especially developing countries that depend on imports in their final and intermediate consumption. A depreciation of the exchange rate affects the economy in three main ways. First, it reduces the relative power of the currency, entailing that imports become relatively more expensive and, therefore, results in a reduction of imported goods for the same level of income. Second, a depreciating exchange rate entail that domestically-produced goods become relatively less expensive in the international market, so exports increase for the same level of income in the Rest of the World (where exports are sold). Third, by raising the price of imports, a depreciating exchange rate raises the relative prices of imports consumed as final goods as well as the price of domestic products that use imported intermediates. Therefore, these changes have raised prices overall and cause a rise in the consumer price index (CPI).

<u>Closures: Labour market specification and factor market clearing conditions</u>

To examine the effects of response measures on the Kenyan economy, the shocks are simulated using a long-run closure since the response measures are long-term actions. The closure assumes full employment and full factor mobility for all factors market clearing conditions, and a balanced macro closure whereby the burdens of adjustment a spread equiproportionately across households, government and investment/savings market, with tax replacement by means of flexible direct tax rates. government, and enterprises. The exchange rate is fixed and a flexible external balance. Further details of the closure are reported in Annex 4.7.

Table 4.6 Changes in exchange rates and world import and export prices

	A1: Carbon tax		B1: Energy input tax		C1: Quantity restriction	
Change in Exchange rate shocks (depreciation)						
Economy wide	0.80		2.6		4.5	
Changes in world prices shocks						
Commodity	**Import price**	**Export price**	**Import price**	**Export price**	**Import price**	**Export price**
Wheat	0.99	0.99	0.97	0.97	1.00	0.96
Maize	0.99	0.99	0.97	0.97	1.00	0.96
Rice	0.99	0.99	0.97	0.97	1.00	0.96
Other cereals	0.99	0.99	0.97	0.97	1.00	0.96
Pulses & oil seeds	0.99	0.99	0.97	0.98	0.94	0.91
Roots & tubers	0.99	0.99	0.97	0.98	0.97	0.93
Vegetables	0.99	0.99	0.97	0.98	0.97	0.93
Fruits	0.99	0.99	0.97	0.98	0.97	0.93
Tea	0.99	0.99	0.97	0.98	0.97	0.93
Others crops	0.99	0.99	0.97	0.98	0.97	0.93
Sheep, goat and lamb for slaughter	0.99	0.99	0.98	0.96	0.97	0.90
Beef	0.99	0.99	0.98	0.96	1.03	0.92
Poultry	0.99	0.99	0.98	0.96	0.97	0.90
Other livestock	0.99	0.99	0.98	0.96	0.97	0.90
Dairy	0.99	1.00	0.98	0.99	1.05	0.94
Sugar & bakery & confectionary	0.99	1.00	0.98	0.99	1.05	0.94
Beverages & tobacco	0.99	1.00	0.98	0.99	1.05	0.94
Other manufactured food	0.99	1.00	0.98	0.99	1.05	0.94
Water	1.00	1.00	0.99	0.99	1.03	0.92
Forestry	0.99	0.99	0.97	0.98	0.97	0.93
Fishing	0.99	0.99	0.97	0.98	0.97	0.93
Mining	1.00	0.98	1.00	0.96	1.10	0.87
Grain milling	0.99	1.00	0.98	0.99	1.05	0.94
Meat & dairy	0.99	1.00	0.98	0.99	1.05	0.94
Textile & clothing	1.00	1.00	0.99	0.99	1.06	0.96
Leather & footwear	1.00	1.00	0.99	0.99	1.07	0.93
Wood & paper	1.00	0.99	0.99	0.98	1.03	0.96
Printing and publishing	1.00	0.99	0.99	0.98	1.03	0.96
Petroleum	0.99	0.98	0.96	0.93	1.07	0.90
Fertilizers	1.00	0.99	0.99	0.98	1.05	0.93
Chemicals	1.00	0.99	0.99	0.98	1.05	0.93
Metals and machines	1.00	1.00	0.99	0.99	1.06	0.95
Non metallic products	1.00	1.00	1.00	0.98	1.09	0.91
Other manufacturers	1.00	1.00	1.00	0.98	1.09	0.91
Electricity	1.08	0.97	1.13	0.82	1.13	0.78
Construction	1.00	1.00	0.99	0.98	1.05	0.82
Trade	1.00	1.00	1.00	0.99	1.04	0.93
Transport	1.00	0.99	1.00	0.98	1.04	0.94
Communication	1.00	1.00	1.00	0.99	1.04	0.93
Hotels	1.00	1.00	1.00	0.99	1.04	0.93
Health	1.00	1.00	1.00	0.99	1.03	0.92
Education	1.00	1.00	0.99	0.99	1.03	0.92
Other services	1.00	1.00	0.99	0.99	1.03	0.92

Source: Model simulations.

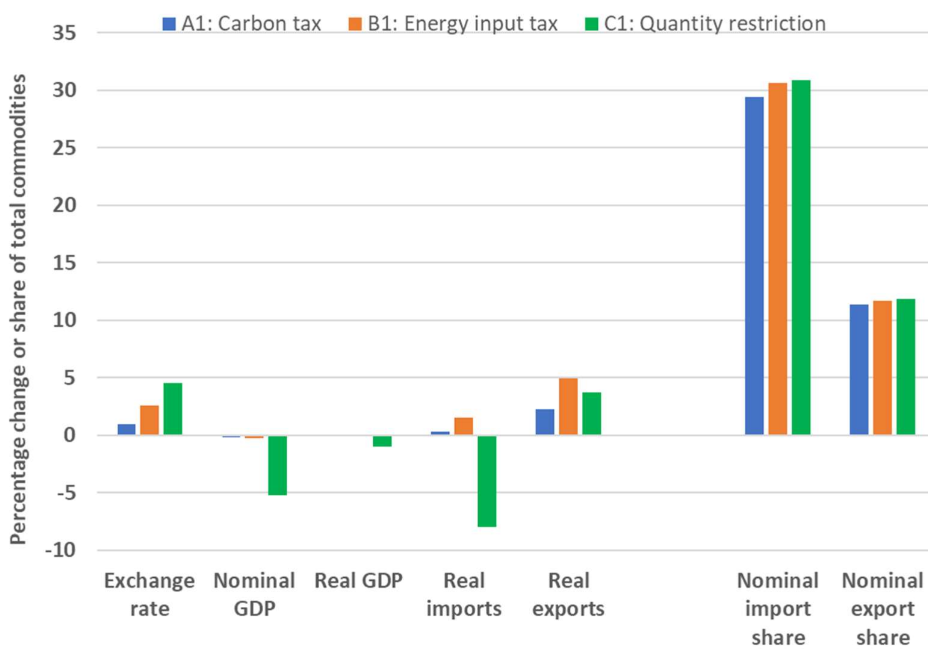
Simulation Results and Discussion

This report summarises model results for the macroeconomic aggregates, factor markets, and household incomes: the results are selected and summarized through the lens of Kenya's Sustainable Development Goals (SDGs). Specifically, the results assess the implications on Kenya's progress towards three SDGs to highlight the economic, social, and environmental results of the selected response measures.

Effects of response measures on macroeconomic aggregates

Macroeconomic aggregates are summary measures of the effects of the shocks and key indicators of Kenya's progress towards SDG 8. Figure 4.5 summarises the effects of the simulated response measures on selected macroeconomic variables for Kenya.

Figure 4.5 Percentage change in selected macroeconomic aggregates



Source: Model simulation results.

The impacts on the reported aggregates are least for the carbon tax measures and greatest for the quantity restriction measures (except for real imports and real exports). The changes in world import and export prices coupled with the depreciating exchange rate led to lower levels of nominal and, to lesser degrees, real GDP, with larger effects under quantity restriction measures. Similar trends are evident for real imports, where only minor improvements occur under the carbon tax and energy input tax measures, compared with large negative effects under the quantity restriction measures. These negatives are driven by both the size of the shocks passed from the global model, specifically the larger magnitude of the exchange rate depreciation, as well as the declines in import prices especially for mining and industrial commodities which are Kenya's major imports. Even with the decline of import prices, a larger depreciation of the exchange rates renders imports more expensive, so their quantity declines. Nominal import shares rise, however, owing to the larger increase in import prices. By contrast, real exports increase, with the lowest increase under carbon tax measures, and the highest increase under energy input tax measures. Most of Kenya's exports are agricultural goods, primarily tea, which increase owing to the changes in world prices of agricultural exports and the depreciating exchange rate which make Kenya's exports relatively less expensive.

Finally, the increased share of nominal imports in total domestic supply and the increased share of nominal exports in total domestic production indicate that the response measures render Kenya more trade oriented.

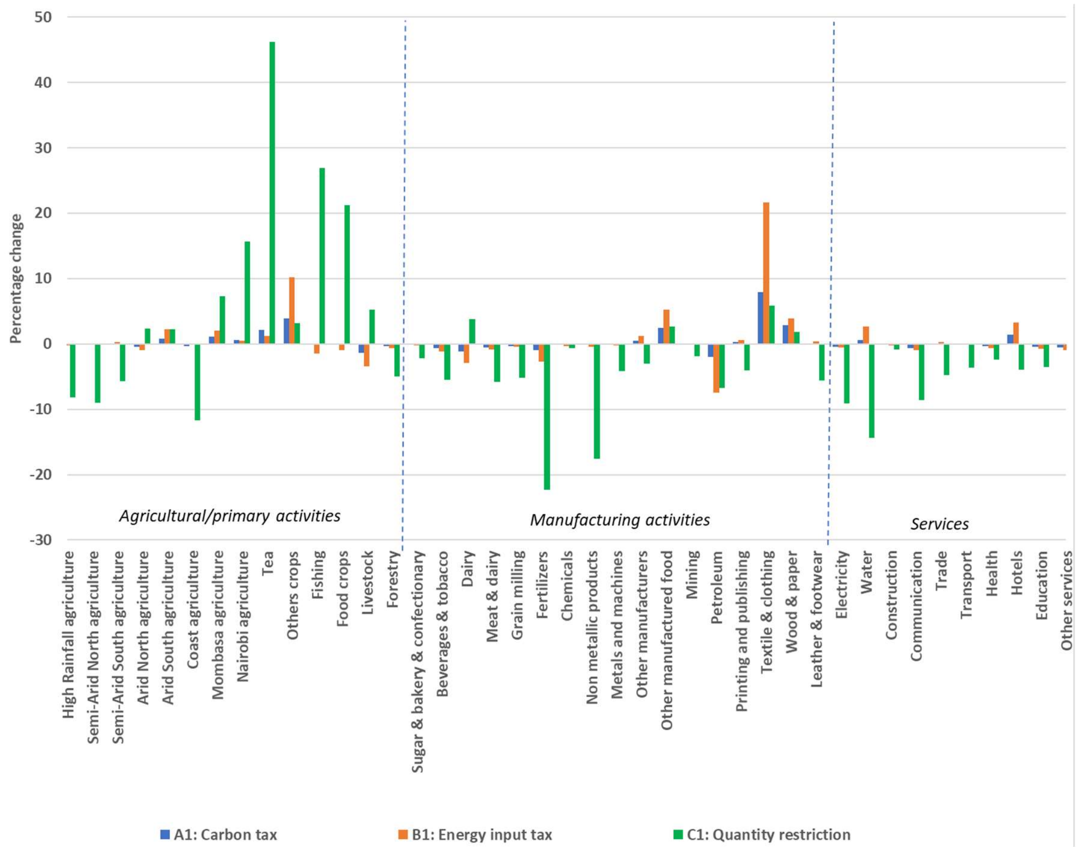
Effects of response measures on domestic production

The changes in the patterns of domestic productions vary, Figure 4.6. The results demonstrate how different response measures impact on Kenya. Overall agricultural/primary production increases, with an emphasis on the export products driven by the increase in export demand for these products. Quantity restrictions expand primary production the most for tea, fishing, and other agriculture.

The impact on manufacturing production is mixed, contracting for food agriculture but expanding in light and heavy manufacturing to varying degrees, with the largest increase occurring when energy input tax measures are implemented. The increase is particularly notable for textile and clothing, which is partly driven by increased export demand. The increase is limited under carbon tax measures but declines when quantity restrictions are implemented. There is also a notable decrease in fertilizer production, particularly when quantity restrictions are implemented, owing to the increased relative price of fertilizers, which sees the expansion of agricultural production being met by increased demand for other production factors (land, capital, and labour) and away from fertilizers.

Finally, services production, on balance, deteriorates under all scenarios in line with an increased emphasis on the production of tradeable products. The exceptions are hotels, owing to increased export demand when energy input tax measures are implemented; and water, the production of which increases when energy input tax measures are implemented, due to increased demand from agriculture.

Figure 4.6 Percentage change in domestic production (quantities)



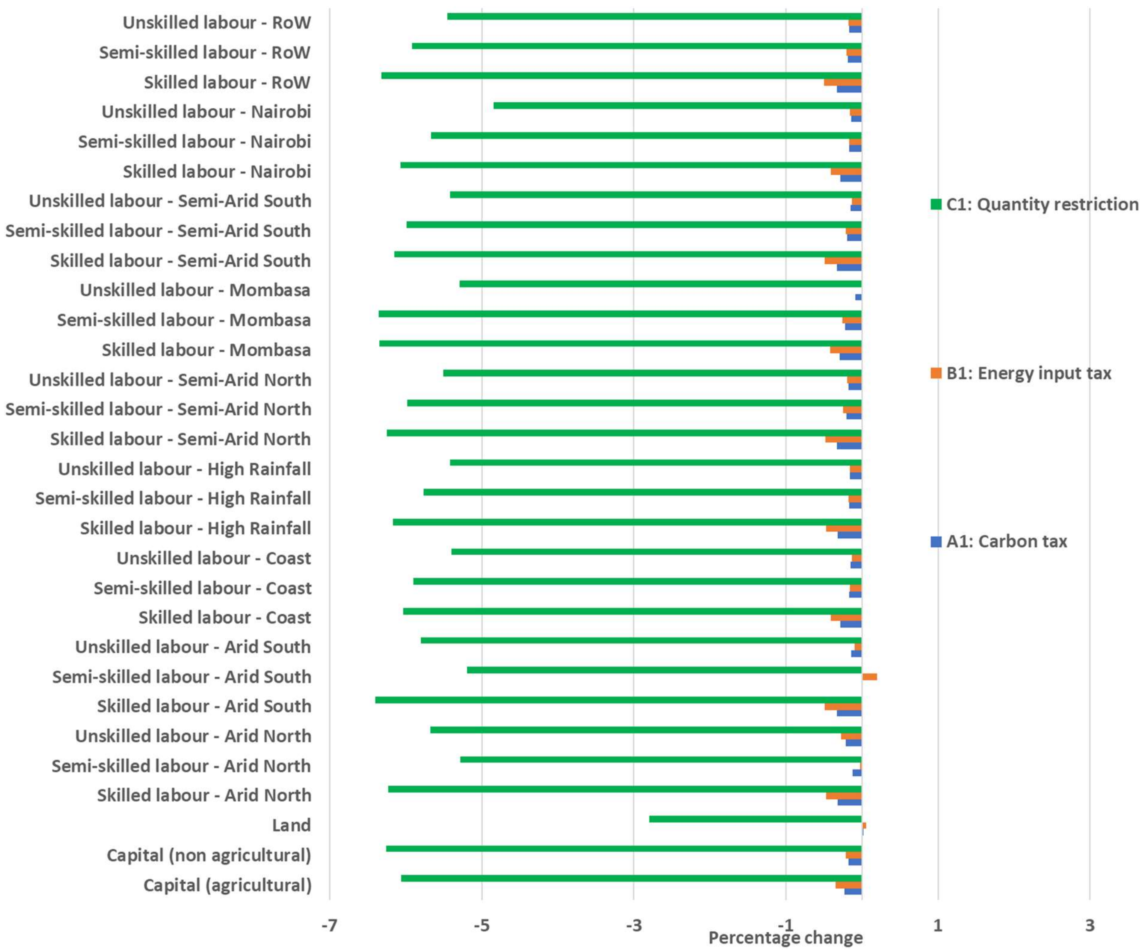
Source: Model simulation results.

Overall, the shocks drive increases in primary production but do so at the expense of manufacturing production. The decline in services production may be a cause for concern because the services sector employs a substantial share of the labour force.

<u>Effects of response measures on factor markets</u>

As the graph shows (Figure 4.7), incomes for all factors decline under all scenarios, except for land and semi-skilled labour in the Arid South area under the energy input tax measures. Notably, incomes for land and agricultural capital generally decreasing at lower rather than labour reducing under the carbon tax and energy input tax measures (Figure 4.7). These changes are consistent with the overall contractionary effect of the response measures. They also reflect increased demand for factors by agricultural products, especially land and agricultural capital relative to labour in some activities, owing to the expanded agricultural sectors, which grow to accommodate additional export demand. The growth in textile and agricultural export demand attracts labour from the contracting sectors to the expanding agricultural export sectors. The increased demand of land and agricultural capital relative to labour, coupled with the mobility of labour, reduce the overall wage rate for labour across the economy.

Figure 4.7 Percentage change in factor returns



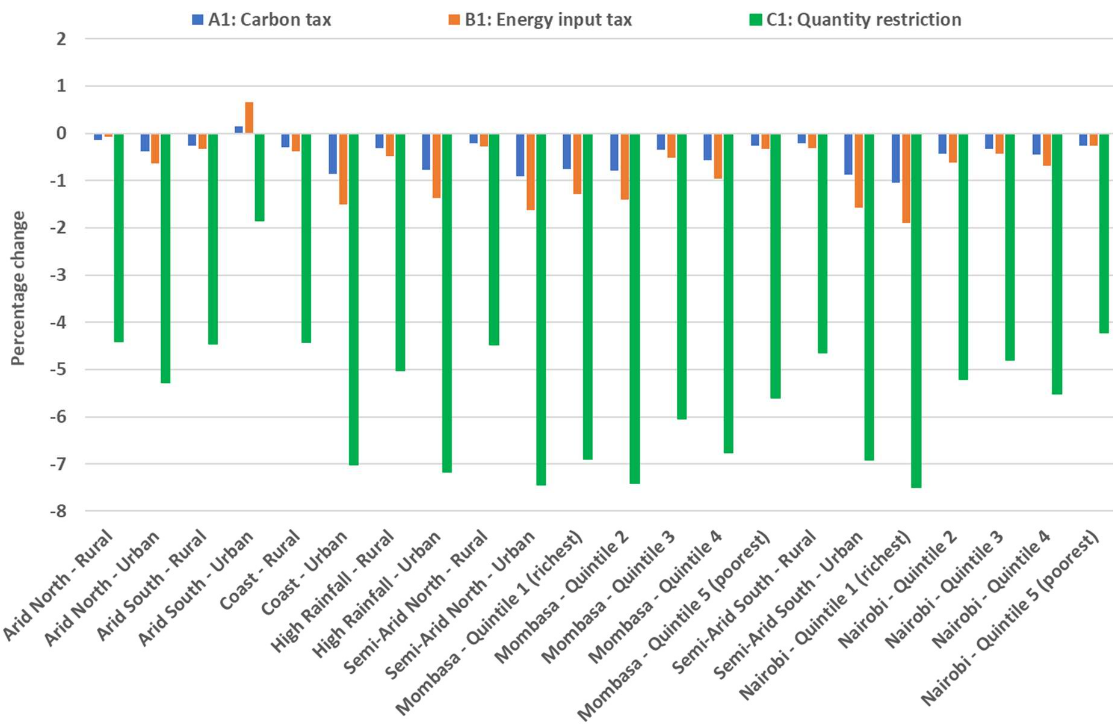
Source: Model simulation results.

The magnitudes of these changes indicate that wage rates decline least when carbon tax measures are implemented, while the largest losses occur under quantity restriction measures. These results reflect the magnitudes of the changes in the trade prices and exchange rate depreciation as they interact with the structure of the Kenyan economy.

<u>Effects of response measures on Household income</u>

The impacts on households are arguably the most important concern when framing policy options. Household income changes are important to the assessment of any response measures (see Figure 4.8), but poverty and inequality considerations are also important. In all three scenarios, response measures unequivocally and negatively impact household incomes in Kenya, causing a decline in income of every household in the country, except for the urban Arid South region under energy input tax. These results are consistent with the contractionary effects of response measures on the Kenyan economy as well as the effects on factor incomes, described previously.

Figure 4.8 Percentage change in household incomes in Kenya



Source: Model simulation results.

Carbon tax is the response measure with the least negative effects on household income. By contrast, quantity restriction measures have the most negative effects on the 22 households. The magnitude of declines resulting from the three response measures are higher for urban than rural households, except for the Arid South-Urban household.

The rural households are employed largely in agriculture, despite increased returns to land and agricultural capital. These results are consistent with income from the sale of labour services being the dominant determinant of rural household incomes.

Effects of response measures on Kenya's selected SDGs

The results from STAGE_CC for Kenya have been used to evaluate the changes on various summary measures that represent selected SDGs.[44] To illustrate this capability, three SDGs were selected as illustrative indicators to provide insights into the impact of response measures: GOAL 8: Decent Work and Economic Growth; GOAL 9: Industry, Innovation and Infrastructure; and GOAL 10: Reduced Inequality.

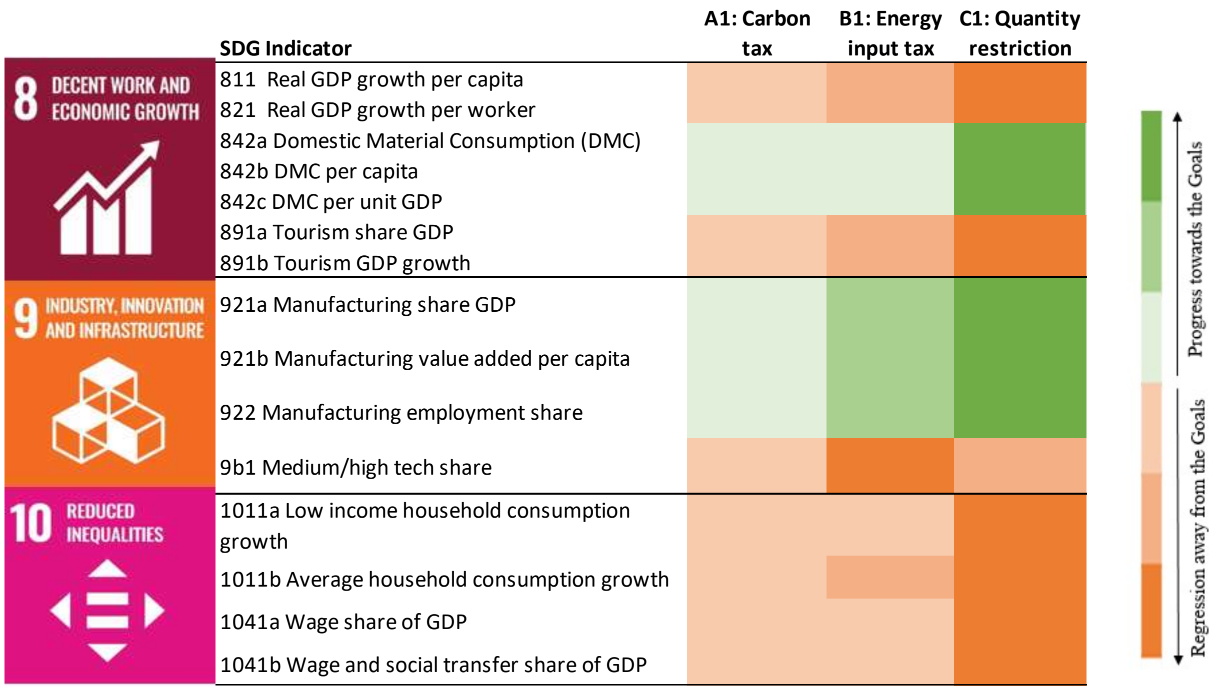
The impacts of the selected response measures on the selected SDGs and their indicators are summarised in Figure 4.9. The effects are reported in relative terms, with green shades

44 Details about the estimation of the SDG indicators are provided in the document "*Development of toolkit for assessment of impacts of implementation of response measures: Illustrative SDG indicators*". Details on the grouping of activities for SDG indicators are reported in Annex 4.8.

indicating progress towards SDG targets, and orange shades indicating regression away from SDG targets. The darker the shade indicates the larger movements towards or away from the SDG targets. The results only reflect the effects of the simulated response measures, holding everything else constant in Kenya's SDG target policy and economic conditions, whereas the overall progress towards SDG targets would be the net effect of multiple actions.

The effects of each response measure are mixed, with none of the response measures providing mostly progression towards or regression away from the indicators. For example, carbon tax has mixed yet minimal effects on GOAL 8 indicators, while energy input tax and quantity restriction improve certain indicators and deteriorate others. GOAL 9 indicators show similar mixed trends, with quantity restriction having the most improvement on all indicators, except for indicator 9B1 on which deteriorates under all measures with the most under energy input tax. Finally, the three selected response measures have negative effects on GOAL 10, with carbon tax achieving the least deterioration, while quantity restriction achieving the most deterioration.

Figure 4.9 Impacts of selected response measure simulations on selected SDGs



Source: Author's assessments based on model simulation results.

Two key insights emerge from these results. First, carbon tax is the response measure with the least distortions that causes the least regression away from selected SDGs, but it has limited effects on enabling Kenya to progress towards the selected SDGs. Second, all response measures have mixed effects on the SDGs, which means that when assessing the impacts of different response measures on progress towards its SDGs there are trade-offs. Nevertheless, exceptions can be warranted pertaining to specific national priorities that ought to be given more consideration in the evaluation of the effects of response measures on their relevant SDG. In those cases, policy makers might accept different trade-offs between the policies. For example, all three response measures improve manufacturing employment, with carbon tax resulting in the least improvements, while quantity restrictions resulting in the most improvements. Therefore, if the local policy priority is employment, then more emphasis should be placed on the results for SDGs influenced by employment and, subsequently, to use that to influence mitigation policies for just transitions of the labour force. If the impacts of response measures on poverty, income distribution and inequality are important, all of which are elements in SDG 10, then carbon tax would emerge as the least unfavourable response measure. Subsequently, this information could be used to guide the design of mitigation policies that counter the effects of response measures.

Sensitivity Analyses

The sensitivity and reliability of the model results were assessed with respect to the selected parameters values and assumptions. Generally, sensitivity analyses with respect to elasticity values are implemented, but equally important are sensitivity analyses to changes in factor market assumptions, closure settings, and shock values.

For purposes of this study for Kenya, the sensitivity analyses undertaken with respect to the closure settings and the values of various world price shocks and the industries on which they are imposed, indicate that the patterns in the results are robust.

The sensitivity analyses with respect to elasticities included: first, elasticity values were increased by 50%; second, elasticity values were decreased by 25%; and third, variations in the Frisch elasticity parameters for households were evaluated, while maintaining relatively higher values for richer and urban households than rural and poorer households. The results of the sensitivity analyses show that while there are changes in the magnitudes of the model results, the signs on the results do not change, which is the most important consideration when evaluating the robustness of the insights provided.

It is concluded, therefore, that the results are robust across a range of elasticity values and the ensuing conclusions are robust to the selected elasticity values that fall within the tested range.

Conclusions

This study demonstrates the policy insights that can be produced from whole-economy analyses of policy options. In this study, the implications of climate change response measures upon a single low-income economy were explored using illustrative shocks to produce illustrative results. Notwithstanding their illustrative nature, the results have various important policy implications.

Climate change response measures will, other things being equal, negatively impact on measured economic well-being both globally and within individual countries. These negative impacts may, over time, be offset by changes in technologies that allow the production of ‘green’ energy, but such changes will require time and resources. In the shorter term, the results demonstrate that there will be appreciable changes in incentives and associated changes in patterns of production and consumption. These will be accompanied by changes in factor returns and household incomes, even in a country exempt from implementing response measures to reduce carbon emissions. CGE analyses can, therefore, provide policymakers with information that will allow them to analyse the impacts on their economies of different global response measures, and assess the implications of different (domestic) mitigation policies. And, accordingly, it enables them to adjust domestic policies to maximize the positives and minimize the negatives of applied response measures on their citizens, fiscal positions, environment, and economies. The scope of policies that can be examined in this class of model is large and has the potential to conduct a multitude of studies and fulfil a multitude of objectives.

A comparison of the implications for Kenya with those for Senegal, consequent upon common global response measures, clearly demonstrates that simple ‘rule of thumb’ mitigation strategies are unlikely to be robust. Common global response measures produce different changes in the external environment faced by countries, while differences in domestic relationships and structures exacerbate the in-country impacts. As such, domestic mitigation strategies are likely to vary appreciably across countries.

Annex

A4.1 Questionnaire to Stakeholders

The first step undertaken as part of this study is gathering necessary information to understand the leading national priorities by the various stakeholders in Kenya and to guide the calibration of the STAGE_CC model for Kennya and the development of the methodologies tested to examine response measures. To that end, an online questionnaire was prepared and sent to various stakeholders in Kenya. It aimed to collect information that would aid in understanding the relevant indicators and parameters associated with the impacts of response measures implementation, both temporally and spatially, in Kenya.

The questionnaire had the following five sections: (1) Stakeholder information; (2) Priorities and objectives; (3) Policy impacts and action policies; (4) Commitments; and (5) Allowable trade-offs. In the first section (Stakeholder information), the questionnaire collects various information of each stakeholder, including the organization with which the stakeholder is associated along with their role in affecting climate change and/or climate change policy. The questionnaire also requested a confirmation of a consent to retain respondents' email addresses in this study database only for purposes of the analysis for the duration of this pilot study with the UNFCCC, at the end of which the email address would be removed from the study database. All respondents gave such consent. For the subsequent sections (2 through 5), the questions separate the section into three focus areas:

1. Economic, which includes primarily effects on the economy, mostly at the macroeconomic level;
2. Social, which includes primarily effects at the socioeconomic level and household levels pertaining to but not limited to education, health, socioeconomic wellbeing, and wages; and
3. Environmental, which includes primarily effects on the various environmental and agricultural resources as well as emissions and climate change indicators.

The questionnaire was sent to approximately 10 people from various organizations involving climate change and the environment. No responses were received from Kenya.

A4.2 Model Data Aggregation and Mapping with GLOBE_CC

Table A4.2.1 Commodities aggregation, descriptions, and mapping from GLOBE_CC

List of aggregated commodities in the SAM			Mapping to data from GLOBE_CC	
No.	Commodity code (c)	Commodity description (c)	Mapped commodity code in GLOBE_CC	Commodity description
1	c_whea	Wheat	cgrain	Grain
2	c_maiz	Maize	cgrain	Grain
3	c_rice	Rice	cgrain	Grain
4	c_ogrn	Other cereals	cgrain	Grain
5	c_oils	Pulses & oil seeds	coilseed	Oilseed
6	c_root	Roots & tubers	cothr_ag	Other agriculture
7	c_vege	Vegetables	cothr_ag	Other agriculture
8	c_frui	Fruits	cothr_ag	Other agriculture
9	c_tea	Tea	cothr_ag	Other agriculture
10	c_ocrp	Others crops	cothr_ag	Other agriculture
11	c_goat	Sheep, goat and lamb for slaughter	clvstk	Livestock
12	c_beef	Beef	cmeat	Cattle meat and other meat
13	c_poul	Poultry	clvstk	Extraction of crude petroleum
14	c_oliv	Other livestock	clvstk	Extraction of natural gas
15	c_dair	Dairy	cothr_food	Other food
16	c_bake	Sugar & bakery & confectionary	cothr_food	Other food
17	c_bevt	Beverages & tobacco	cothr_food	Other food
18	c_omfd	Other manufactured food	cothr_food	Other food
19	c_watr	Water	cothr_svc	Other services
20	c_fore	Forestry	cothr_ag	Other agriculture
21	c_fish	Fishing	cothr_ag	Other agriculture
22	c_mine	Mining	cmine	Other mining extraction
23	c_gmil	Grain milling	cothr_food	Other food
24	c_meat	Meat & dairy	cothr_food	Other food
25	c_text	Textile & clothing	ctext	Textiles and wearing apparel
26	c_foot	Leather & footwear	cleath	Leather products
27	c_wood	Wood & paper	cwood	Wood and Paper
28	c_prnt	Printing and publishing	cwood	Wood and Paper
29	c_petr	Petroleum	cpetro	Coke and refined petroleum
30	c_fert	Fertilizers	cchem	Chemicals
31	c_chem	Chemicals	cchem	Chemicals
32	c_nmet	Metals and machines	cmetal	Metals
33	c_mach	Non-metallic products	cothr_mfg	Other manufacturing
34	c_oman	Other manufacturers	cothr_mfg	Other manufacturing
35	c_elec	Electricity	celec	Electricity
36	c_cons	Construction	cconstr	Construction
37	c_trad	Trade	ctrd_svc	Trade services
38	c_tran	Transport	ctrnsp	Transport services
39	c_comm	Communication	ctrd_svc	Trade services
40	c_hotl	Hotels	ctrd_svc	Trade services

41	c_heal	Health	cothr_svc	Other services
42	c_educ	Education	cothr_svc	Other services
43	c_osrv	Other services	cothr_svc	Other services

Source: Compilation from SAM aggregated for Kenya for the STAGE_CC model for Kenya.

Table A4.2.2 Activities aggregation, description, and mapping from GLOBE_CC

List of aggregated activities in the SAM			Mapping to data from GLOBE_CC	
No.	Activity code in GAMS (a)	Activity description (c)	Mapped activity code in GLOBE_CC	Activity description
1	ah_HR	High Rainfall	agrain	Grain
2	ah_MN	Semi-Arid North	agrain	Grain
3	ah_MS	Semi-Arid South	agrain	Grain
4	ahf_AN	Arid North	agrain	Grain
5	ahf_AS	Arid South	agrain	Grain
6	ahf_CO	Coast	agrain	Grain
7	ahf_MO	Mombasa	agrain	Grain
8	ahf_NA	Nairobi	agrain	Grain
9	a_teas	Tea	aothr_ag	Other agriculture
10	a_food	Food crops	aothr_ag	Other agriculture
11	a_ocrp	Others crops	aothr_ag	Other agriculture
12	a_livs	Livestock	alvstk	Livestock
13	a_fore	Forestry	aothr_ag	Other agriculture
14	a_fish	Fishing	aothr_ag	Other agriculture
15	a_mine	Mining	amine	Other mining extraction
16	a_mill	Grain milling	aothr_food	Other food
17	a_bake	Sugar & bakery & confectionary	aothr_food	Other food
18	a_meat	Meat & dairy	aothr_food	Other food
19	a_dair	Dairy	aothr_food	Other services
20	a_omfd	Other manufactured food	aothr_food	Other agriculture
21	a_bevt	Beverages & tobacco	aothr_food	Other agriculture
22	a_text	Textile & clothing	atext	Textiles and wearing apparel
23	a_foot	Leather & footwear	cleath	Leather products
24	a_wood	Wood & paper	awood	Wood and Paper
25	a_prnt	Printing and publishing	awood	Wood and Paper
26	a_petr	Petroleum	apetro	Coke and refined petroleum
27	a_fert	Fertilizers	achem	Chemicals
28	a_chem	Chemicals	achem	Chemicals
29	a_nmet	Metals and machines	ametal	Metals
30	a_mach	Non-metallic products	aothr_mfg	Other manufacturing
31	a_oman	Other manufacturers	aothr_mfg	Other manufacturing
32	a_elec	Electricity	aelec	Electricity
33	a_watr	Water	aothr_svc	Other manufacturing
34	a_cons	Construction	aconstr	Construction
35	a_trad	Trade	atrd_svc	Trade services
36	a_tran	Transport	atrnsp	Transport services
37	a_comm	Communication	atrd_svc	Trade services
38	a_hotl	Hotels	atrd_svc	Trade services
41	a_educ	Education	aothr_svc	Other services
42	a_heal	Health	aothr_svc	Other services
43	a_osrv	Other services	aothr_svc	Other services

Source: Compilation from SAM aggregated for Kenya for the STAGE_CC model for Kenya.

Table A4.2.3 Factors aggregation and description

No.	Factors (f) code in GAMS	Factors (f) description
1	fland	Land
2	flb_ANsk	Skilled labour - Arid North
3	flb_ANss	Semi-skilled labour - Arid North
4	flb_ANus	Unskilled labour - Arid North
5	flb_ASsk	Skilled labour - Arid South
6	flb_ASss	Semi-skilled labour - Arid South
7	flb_ASus	Unskilled labour - Arid South
8	flb_COsk	Skilled labour - Coast
9	flb_COss	Semi-skilled labour - Coast
10	flb_COus	Unskilled labour - Coast
11	flb_HRsk	Skilled labour - High Rainfall
12	flb_HRss	Semi-skilled labour - High Rainfall
13	flb_HRus	Unskilled labour - High Rainfall
14	flb_MNsk	Skilled labour - Semi-Arid North
15	flb_MNss	Semi-skilled labour - Semi-Arid North
16	flb_MNus	Unskilled labour - Semi-Arid North
17	flb_MOsk	Skilled labour - Mombasa
18	flb_MOss	Semi-skilled labour - Mombasa
19	flb_MOus	Unskilled labour - Mombasa
20	flb_MSsk	Skilled labour - Semi-Arid South
21	flb_MSss	Semi-skilled labour - Semi-Arid South
22	flb_MSus	Unskilled labour - Semi-Arid South
23	flb_NAsk	Skilled labour - Nairobi
24	flb_NAss	Semi-skilled labour - Nairobi
25	flb_NAus	Unskilled labour - Nairobi
26	flb_RWsk	Skilled labour - RoW
27	flb_RWss	Semi-skilled labour - RoW
28	flb_RWus	Unskilled labour - RoW
29	fcp_ag	Capital (agricultural)
30	fcp_na	Capital (non-agricultural)
31	f_fert	Fertiliser
Aggregate factors		
32	flab	Aggregate labour
33	f_lnd_fert	Land fertiliser aggregate

Source: Compilation from SAM aggregated for Kenya for the STAGE_CC model for Kenya.

Table A4.2.4 **Households** description

No.	Households (h) code in GAMS	Households (f) description
1	hAN_RU	Arid North - Rural
2	hAN_UR	Arid North - Urban
3	hAS_RU	Arid South - Rural
4	hAS_UR	Arid South - Urban
5	hCO_RU	Coast - Rural
6	hCO_UR	Coast - Urban
7	hHR_RU	High Rainfall - Rural
8	hHR_UR	High Rainfall - Urban
9	hMN_RU	Semi-Arid North - Rural
10	hMN_UR	Semi-Arid North - Urban
11	hMO_Q1	Mombasa - Quintile 1 (richest)
12	hMO_Q2	Mombasa - Quintile 2
13	hMO_Q3	Mombasa - Quintile 3
14	hMO_Q4	Mombasa - Quintile 4
15	hMO_Q5	Mombasa - Quintile 5 (poorest)
16	hMS_RU	Semi-Arid South - Rural
17	hMS_UR	Semi-Arid South - Urban
18	hNA_Q1	Nairobi - Quintile 1 (richest)
19	hNA_Q2	Nairobi - Quintile 2
20	hNA_Q3	Nairobi - Quintile 3
21	hNA_Q4	Nairobi - Quintile 4
22	hNA_Q5	Nairobi - Quintile 5 (poorest)

Source: Compilation from SAM aggregated for Kenya for the STAGE_CC model for Kenya.

Table A4.2.5 Factor use and other taxes

No.	Taxes (t) code in GAMS	Taxes (t) description
1	tfland	Factors tax use on Land
2	tflb_ANsk	Factors tax use on Skilled labour - Arid North
3	tflb_ANss	Factors tax use on Semi-skilled labour - Arid North
4	tflb_ANus	Factors tax use on Unskilled labour - Arid North
5	tflb_ASsk	Factors tax use on Skilled labour - Arid South
6	tflb_ASss	Factors tax use on Semi-skilled labour - Arid South
7	tflb_ASus	Factors tax use on Unskilled labour - Arid South
8	tflb_COsk	Factors tax use on Skilled labour - Coast
9	tflb_COss	Factors tax use on Semi-skilled labour - Coast
10	tflb_COus	Factors tax use on Unskilled labour - Coast
11	tflb_HRsk	Factors tax use on Skilled labour - High Rainfall
12	tflb_HRss	Factors tax use on Semi-skilled labour - High Rainfall
13	tflb_HRus	Factors tax use on Unskilled labour - High Rainfall
14	tflb_MNsk	Factors tax use on Skilled labour - Semi-Arid North
15	tflb_MNss	Factors tax use on Semi-skilled labour - Semi-Arid North
16	tflb_MNus	Factors tax use on Unskilled labour - Semi-Arid North
17	tflb_MOsk	Factors tax use on Skilled labour - Mombasa
18	tflb_MOss	Factors tax use on Semi-skilled labour - Mombasa
19	tflb_MOus	Factors tax use on Unskilled labour - Mombasa
20	tflb_MSsk	Factors tax use on Skilled labour - Semi-Arid South
21	tflb_MSss	Factors tax use on Semi-skilled labour - Semi-Arid South
22	tflb_MSus	Factors tax use on Unskilled labour - Semi-Arid South
23	tflb_NAsk	Factors tax use on Skilled labour - Nairobi
24	tflb_NAss	Factors tax use on Semi-skilled labour - Nairobi
25	tflb_NAus	Factors tax use on Unskilled labour - Nairobi
26	tflb_RWsk	Skilled labour - RoW
27	tflb_RWss	Semi-skilled labour - RoW
28	tflb_RWus	Factors tax use on Unskilled labour - RoW
29	tfcp_ag	Factors tax use on Capital (agricultural)
30	tfcp_na	Factors tax use on Capital (non-agricultural)
31	tflab	Factors tax use on Aggregate labour
32	tf_fert	Factors tax use on Fertiliser
33	tf_lnd_fert	Factors tax use on Land fertiliser aggregate
34	imptax	Import tariffs
35	exptax	Export taxes
36	indtax	Indirect taxes
37	vattax	Value added taxes (TAX)
38	saltax	Sales taxes
39	ssaltax	Sales taxes quantity
40	ectax	Excise taxes
41	facttax	Factor taxes
42	dirtax	Direct taxes

Source: Compilation from SAM aggregated for Kenya for the STAGE_CC model for Kenya.

A4.4 Production Structure

Table A4.4.1 Production structure

Structure	Details
Production structure	Value added: - Land-fertiliser - Aggregate labour - Aggregate capital Land-fertilizer: - Land - Fertilizer Labour aggregate: - Skilled labour aggregate - Semi-skilled labour aggregate - Unskilled labour aggregate Capital aggregate: - Capital (agricultural) - Capital (non-agricultural) Skilled labour aggregate: - Skilled labour by region Semi-skilled labour aggregate: - Semi-skilled labour by region Unskilled labour aggregate: - Unskilled labour by region

A4.5 Results from GLOBE_CC Shocks for East Africa

Table A4.5.1 Results of the GLOBE__CC shocks (response measure implementation) for East Africa that correspond to commodities in Kenya

	A1: Carbon tax		B1: Energy input tax		C1: Quantity restriction	
Change in Exchange rate shocks (depreciation)						
Economy wide	0.80		2.6		4.5	
Results of percent changes in world prices shocks from GLOBE_CC for East Africa						
Commodity	**Import price**	**Export price**	**Import price**	**Export price**	**Import price**	**Export price**
Wheat	-1.27	-1.07	-3.16	-2.86	0.01	-3.61
Maize	-1.27	-1.07	-3.16	-2.86	0.01	-3.61
Rice	-1.27	-1.07	-3.16	-2.86	0.01	-3.61
Other cereals	-1.27	-1.07	-3.16	-2.86	0.01	-3.61
Pulses & oil seeds	-0.88	-0.66	-2.58	-1.86	-6.09	-9.05
Roots & tubers	-1.10	-1.00	-2.66	-2.47	-3.44	-6.89
Vegetables	-1.10	-1.00	-2.66	-2.47	-3.44	-6.89
Fruits	-1.10	-1.00	-2.66	-2.47	-3.44	-6.89
Tea	-1.10	-1.00	-2.66	-2.47	-3.44	-6.89
Others crops	-1.10	-1.00	-2.66	-2.47	-3.44	-6.89
Sheep, goat and lamb for slaughter	-0.83	-1.22	-2.15	-4.32	-3.36	-9.92
Beef	-0.90	-1.01	-2.23	-3.99	2.62	-8.04
Poultry	-0.83	-1.22	-2.15	-4.32	-3.36	-9.92
Other livestock	-0.83	-1.22	-2.15	-4.32	-3.36	-9.92
Dairy	-0.66	-0.43	-1.81	-1.35	4.82	-6.29
Sugar & bakery & confectionary	-0.66	-0.43	-1.81	-1.35	4.82	-6.29
Beverages & tobacco	-0.66	-0.43	-1.81	-1.35	4.82	-6.29
Other manufactured food	-0.66	-0.43	-1.81	-1.35	4.82	-6.29
Water	-0.47	-0.25	-1.49	-0.97	2.55	-7.84
Forestry	-1.10	-1.00	-2.66	-2.47	-3.44	-6.89
Fishing	-1.10	-1.00	-2.66	-2.47	-3.44	-6.89
Mining	-0.04	-1.64	0.36	-3.67	10.19	-12.59
Grain milling	-0.66	-0.43	-1.81	-1.35	4.82	-6.29
Meat & dairy	-0.66	-0.43	-1.81	-1.35	4.82	-6.29
Textile & clothing	-0.11	-0.27	-0.62	-0.89	6.39	-4.03
Leather & footwear	-0.05	-0.17	-0.68	-0.74	6.83	-6.60
Wood & paper	-0.30	-0.51	-1.10	-1.66	2.59	-4.24
Printing and publishing	-0.30	-0.51	-1.10	-1.66	2.59	-4.24
Petroleum	-1.09	-1.99	-3.96	-7.28	7.38	-10.00
Fertilizers	-0.41	-0.83	-0.99	-2.45	5.25	-7.02
Chemicals	-0.41	-0.83	-0.99	-2.45	5.25	-7.02
Metals and machines	0.11	-0.39	-0.55	-1.49	6.43	-5.11
Non metallic products	0.12	-0.46	-0.31	-1.61	8.95	-9.19
Other manufacturers	0.12	-0.46	-0.31	-1.61	8.95	-9.19
Electricity	7.79	-3.19	12.92	-17.70	13.38	-21.72
Construction	-0.38	-0.42	-1.15	-1.97	5.10	-18.26
Trade	-0.13	-0.21	-0.49	-0.95	3.63	-6.86
Transport	-0.24	-0.59	-0.48	-1.69	3.96	-6.45
Communication	-0.13	-0.21	-0.49	-0.95	3.63	-6.86
Hotels	-0.13	-0.21	-0.49	-0.95	3.63	-6.86
Health	-0.18	-0.40	-0.48	-1.32	2.55	-7.84
Education	-0.47	-0.25	-1.49	-0.97	2.55	-7.84
Other services	-0.47	-0.25	-1.49	-0.97	2.55	-7.84

A4.6 Elasticities

A CGE model is calibrated to a database in the structure of a Social Accounting Matrix (SAM) for the country or region(s) modelled. In addition to the transactional and inter-industrial data contained in the SAM, a CGE model requires other data to enable its application and to link the data with the behavioural relationships represented in the mathematical representation of the economy, i.e., the model. The results of various policy, or other, shocks in a CGE model depend on not only the underlying database, but also on the magnitude of the shocks and the values of the elasticities used. Elasticities are among the most important data for employing a CGE model. Trade elasticities specifically are important as they determine the demand substitution between commodities from different sources (locally produced and imported bundles) resulting from changes in their relative prices. Model results in terms of both of price and quantity (such as import) changes can be substantially affected by using varying elasticity values. As such, the results of a CGE model depend on the values of elasticities used, and it is important for modellers to use correct elasticity estimates.

As applicable to models, of this pilot project, various elasticities are used, including:

1. Commodity elasticities of substitution, which are commodity, regions group and region specific, including
    a. Elasticity of substitution between the domestic variety and aggregate imports;
    b. Elasticity of substitution among imports from different trade partners;
    c. Elasticity of substitution between domestic and aggregate exports; and
    d. Elasticity of substitution among trade partners.
2. Activity elasticity of substitution between aggregate intermediates and value added;
3. Household elasticities
    a. Frisch; and
    b. Income elasticities.

Literature review on potentially applicable elasticities

Various sources can be used to derive the values of elasticities that can be used in a model. In an ideal world, econometric regressions would be used to estimate the values of given elasticities applicable to a given country or region. But there is a dearth of quantitatively derived elasticity values in the economics literature and a dearth of studies that focus on calculating the elasticities of substitution specifically in Kenya and Senegal and other countries. To that end, most single country CGE models apply a wide range of elasticities based on studies of other regions or countries with potentially similar characteristics. Some elasticities are also based on educated value judgement.

The single country STAGE_CC model for Kenya (as well as for Senegal, as the other pilot study country) along with its database are set up with given sets of elasticities estimated as reasonable estimates; however, the modelers have the option of using elasticities from other databases or of other values. This section provides a summary of the elasticities used in different CGE analyses for Kenya, as applicable to the single country model, STAGE_CC.

Elasticity estimates for Kenya

Various CGE models of the Kenyan economy use elasticity values without calculations or quantitative estimates for them. For example, Karingi and Siriwardana (2003) estimate in a CGE framework of the effects of adjustment to terms of trade shocks in 1970s (owing to oil price changes) on agriculture and income distribution in Kenya. While relevant, this study relies on a dated structure of Kenya's economy that might not accurately correspond to Kenya's economic structure under the pilot study. Araceli and Ferrari (2011) analyse the effects of reducing obstacles to trade on Kenya's agro-food sector but rely on elasticity values from the GTAP database.

Similar trends are shown in more recent CGE studies of Kenya (such as World Bank, 2018, Scandizzo *et al.*, 2018). For example, the World Bank (2018) assesses the effects of Kenya's safari tourism on herd population using a CGE model, which is also calibrated using elasticity values without estimate sources or calculations. This study uses elasticities of substitution of CES production functions ranging from 0.6 (agriculture) to 1 (industry). While the CET functions for Armington hypothesis are also calibrated with a higher elasticity range (0.5 to 2) and elasticity of foreign tourism demand with respect to wildlife ranging from 0.3 to 1.5.

Relevant studies for Africa

Beyond Kenya and Senegal, there are few estimates for elasticities in developing countries at large and Africa, specifically. The most prominent studies are for South Africa. Ntombela *et al*. (2018) estimate the Armington and export supply elasticities for individual and aggregate agricultural commodities for South Africa using time-series data from 1980to 2016. Their results show that estimates for an aggregate agriculture commodity tend to be inelastic relative to estimates for an individual product, suggesting higher sensitivity of products to changes in relative prices. The study also finds Armington estimates to be closer to unity for the majority of agricultural products, suggesting that agricultural imports are imperfect substitutes for domestically-produced agricultural products. Finally, for export supply elasticities, the study results find grains to be more elastic than fruit and meat. This result would suggest that domestic grain production is relatively more responsive to price changes in the export markets than domestically. Finally, long-run estimates for the two sets of elasticities were found to be larger than the short-run estimates for all agricultural products.

At a more regional level, Sahn *et al*. (1996) and Maio *et al*. (1999) examine the impact of adjustment policies on the poor in Africa using CGE) models and show that, in Madagascar and Tanzania, the poor benefited from adjustments. Meanwhile, Maio *et al*. (1999) show that the effects on the poor are dependent on the assumptions made about parameters such as elasticities (as well as relationships, and closure in the models). Neither study estimates the elasticity values but use a range of values. Further, there is some evidence of low total agricultural production price elasticity in sub-Saharan Africa, even if the elasticity for crops may be high. As such, the total "agricultural production is not likely to rise much in response to improved incentives, especially if infrastructure and the supply of inputs does not improve" (Maio *et al*., 1999).

These results can be indicative for Kenya and Senegal as a starting point but need to be adjusted to reflect each economy's economic, trade structure, and consumer preferences. Nevertheless, because of data deficiencies, parameters can be estimated from elasticities for commodities and industries, but the definitions used might not always be consistent with those adopted in the model. Due to the lack of data, if elasticities cannot be derived based on empirical work or references to elasticities of countries with similar structures, elasticity values will often be estimated based on calibration methods. The models are then implemented using ranges of low and high elasticities for sensitivity analyses.

<u>Elasticities applied to the STAGE_CC for Kenya</u>

Due to the lack of data, elasticities cannot be derived based on empirical work or references to elasticities of countries with similar structures. As such, for STAGE__CC for Kenya, a wide range of elasticities has been determined based on the economic structure, calibration methods, and an understanding of the economic dynamics in Kenya. Elasticities ranges of low and high elasticities have also been implemented for sensitivity analyses to ensure the robustness of the results in line of the selected elasticities values.

The following tables depict the values of elasticities used in the model.

Table A4.6.1 Model elasticities

Elasticity type	Description and values
Production structure elasticities	Factor elasticity (*Elastf)* at all levels = 4 Values added Sigmava1: - 0.25-0.25 for all agricultural products and livestock/primary; - 0.2 for mining; - 1.2 for food processing; - 1.26 manufacturing, chemicals, mining and petroleum, other services (health, education, and other), and network services (water); - 1.4 for construction; and - 1.63-1.68 for trade, communications, transportation, and hotels.
Commodity elasticities	Sigma: 1.75 Omega: 2 Exdem: 0 Sigmaxc: 4
Activity elasticities	Sigmax: - 0.65 for activities: *ahf_MO* *a_livs* *a_fore* *a_fish* *a_mine* *a_mill* *a_bake* *a_meat* *a_dair* *a_omfd* *a_bevt* *a_text* - 0.5 for activities: *ah_MN* *ahf_AS* *ahf_CO* *ahf_NA* *a_teas* *a_food* - 0.9 for all remaining activities Sigmava: 1.5

Elasticity type	Description and values
	Omegaout: 0
Household elasticities	**Elasticity of the marginal utility of income *(Frisch)* per household**: - - 3 for households: *hAN_RU* *hAS_RU* *hCO_RU* *hHR_RU* *hMN_RU* *hMO_Q5* *hMS_RU* - -2.5 for households: *hAN_UR* *hAS_UR* *hCO_UR* *hHR_UR* *hMN_UR* *hMO_Q3* *hMO_Q4* *hMS_UR* *hNA_Q3* *hNA_Q4* - -2 for households: *hMO_Q1* *hMO_Q2* *hNA_Q1* *hNA_Q2* **Income elasticity** *(Incelast)*: - 0.4 for agricultural products (vegetables and fruits); - 1.5 for agricultural products (tea, meats & dairy), food, utilities, trade & services, industrial commodities, construction; - 2.2 for water, forestry, other manufactured goods, and other services. **Commodity elasticity for CES utility functions** (*Comelasth*): 0

A4.7 Model Closures

The following table details the selection of the closures as implemented in model simulations.

Table A4.7.1 Closure and market functioning

Closure	Adopted setting
Foreign exchange	Exchange rate fixed External balance flexible
Investment/savings	Investments value fixed Savings vary equiproportionate for households and enterprises
Enterprise	Volume of final demand fixed Enterprises transfers to households fixed
Government	Direct tax on households flexible All other tax rates fixed Government’s consumption share in total final domestic demand fixed Government transfers fixed Government savings flexible
Factor markets	Supply of factors by institution fixed Labour is mobile across sectors Wage rates flexible Capital fixed in some activities such as mining (base closure)
Technology	Fixed at all production levels
Numéraire	Consumer price index fixed

A4.8 SDG Indicators Analysis

In undertaking the analysis for the selected SDGs for Kenya, various activities were grouped for purposes of calculating Kenya's SDG indicators, as shown in the following table.

Table A4.8.1 SDG groupings and group members

Grouping	Material commodities *(cdmc)*	Manufacturing activities (*amanu*)	Medium and high tech activities (amanumht)	Activity containing tourism (atour)
Members	Wheat	Dairy	Fertilisers	Hotels
	Maize	Sugar & bakery & confectionary	Chemicals	Other services
	Rice	Beverages & tobacco	Metals and machines	
	Other cereals	Other manufactured food	Other manufacturers	
	Pulses & oil seeds	Textile & clothing		
	Roots & tubers	Leather & footwear		
	Vegetables	Wood & paper		
	Fruits	Printing and publishing		
	Tea	Petroleum		
	Others crops	Fertilisers		
	Forestry	Chemicals		
	Fishing	Metals and machines		
	Mining	Other manufacturers		
	Sheep, goat and lamb for slaughter			

5. Lessons Learnt and A Way Forward

Introduction

This pilot project for the ‘Development of toolkit for assessment of impacts of implementation of response measures’ encompassed a series of aims, which were defined as a series of tasks, and four generic objectives. There were defined with respect to a demonstration of the “capability of the (CGE) toolkit to contribute to the evaluation of policy options that mitigate the impacts of climate change in developing and small island economies.” The focus of this chapter is on the lessons learnt during the pilot project and suggestions for a way forward organised by reference to the four generic objectives in the Terms of Reference (ToR), namely

- demonstrate how to assess the impacts of the implementation of response measures especially cross-border impacts;
- demonstrate how the tools and methods can be used to assess and analyse the social, economic and environmental impacts arising from the implementation of climate policies and actions;
- identify the technical and policy analyses and data requirements needed to support effective assessments and analyses of response measures using the identified tools and methods; and
- demonstrate how the results from the tools and methods can be reported to communicate the impacts with policy makers and to inform the formulation of ameliorating measures.”

This pilot project was designed to illustrate the insights that can be derived with the designated analytical method using simplified models and truncated databases (Social Accounting Matrices (SAMs)). The truncated SAMs reduced the richness of information about economic transactions, while retaining the information necessary for the results to demonstrate the insights that can be acquired using the method. Similarly, using slightly simplified models improved the accessibility of the results and policy implications to non-experts. Future studies can extend the analyses by exploiting the full richness of the SAMs, e.g., home production for home consumption (HPHC), other emissions, etc., including a broader representation of the Sustainable Development Goals and restoring behavioural relationships to the models, e.g., non-separable decisions by peasant households, extended utility functions and a richer labour market specification.

The objectives of the pilot project have been met by global and single country CGE models that demonstrate the impacts of response measures both cross-border and within country; there are three separate reports for the global and (two) single country applications. The implementation of these models has served to demonstrate the data requirements and methods required to analyse the impacts. The analyses have been augmented by including selected illustrative SDG indicators to extend the assessment of the impacts beyond standard economic measures. Finally, the reporting of the results has demonstrated methods by which the insights can be communicated to policymakers through presentations and final reports for the model simulations.

In this chapter, the second section is concerned with lessons learnt, while a way forward, given the outcomes of the pilot project and the lessons learnt, is covered in the third section. The fourth, and final section, is given over to some recommendations.

Lessons Learnt

The commentaries on 'lessons' learnt are written from the perspective of the information that may have been acquired from the outcomes of the pilot projected given the starting point implied by the ToR. Experts in global and single country CGE analyses may reasonably argue that, given experience, some of these 'lessons' may have been expected.

Data

The data requirements of whole-economy models are often cited as being a substantial constraint upon their use and value. However, whole-economy models only require detailed data relating to a single year[45], and the data required to augment the national accounts data detailed in the System of National Accounts (SNA) are arguably not excessive. Arguably, national accounts data comprising Supply and Use Tables (SUT) combined with a series of 'complete and consistent'[46] T-accounts for domestic institutions (households, (incorporated

[45] Even in wealthy and data rich countries the capacity to run all the surveys, and/or censuses, required for the national accounts in one year rarely exists. Hence the data are likely to rely on surveys and censuses taken over a few years close to a 'single' year.

[46] 'Complete' in the sense that they cover the whole economy and 'consistent' in the sense that they are reconciled, i.e., the income received by one agent 1 from agent 2 is equal to the expenditure by agent 2 on items from agent 1.

business) enterprises, government and investment), details of current account transactions (remittances, international transfers, factor earnings, etc.), value added split between labour, capital and land,[47] and some detail about tax revenues are enough to create a basic Social Accounting Matrix (SAM). If these data are complemented by detailed household income and expenditure and labour force surveys, the construction of a SAM capable of providing substantial information about the economy and its social and distributional relationships is relatively straightforward.

The survey data requirements for a SAM undoubtedly require the commitment of skilled labour resources to the collection and processing of data. In countries with limited resources and conflicting demand on government expenditures this may be problematic.

Greater difficulties are associated with the data requirements for macroeconomic and macro econometric models; typically, these models require consistent and reliable time series (historical) data that may or may not be available. Moreover, one of the key roles of disaggregated national accounts data is to ensure the benchmarking of reliable macroeconomic data.

Single Country Data

An exploration of the available official SAMs and Supply and Uses Tables (SUT) that were publicly available for low-income and small island economies, produced extremely limited results: Ethiopia was a notable exception. The limited availability of high-quality data constrained the choice of countries for the case studies. Other sources of SAMs were found, e.g., the ‘nexus’ SAMs by IFPRI, but an examination of these SAMs raised concerns about their appropriateness for the country specific studies. Three detailed SAMs had been produced by the Joint Research Centre (JRC) of the European Commission (EC) for Senegal, Kenya, and Ethiopia; these SAMs were deemed to provide adequate databases.

The lessons learnt include:

1. the absence of comprehensive and detailed national accounts data is a substantial limitation on the
    i. quality of analyses that can be generated, and
    ii. the countries that can be so analysed;
2. differences in economic structure are important;

[47] A ‘mixed income’ category is often used in official data to represent factor payments to owner operators of enterprise.

3. reliable data that are ‘complete and consistent’ may be more valuable than highly disaggregated data that are less reliable; and
4. high quality national data may help ensure that the low-income and small economies are more accurately represented in global databases.

Global Data

The Global Trade Analysis Project’s (GTAP) database is the only ‘consistent’ global database, and hence is currently the only readily available option for calibrating a global CGE model. An examination of the GTAP SAMs for low income and small island economies raised some doubts as to the appropriateness of using individual country data in the global model.[48] The decision was taken to use aggregate regions representing groups of low-income economies from the same geographic regions derived from the GTAP database v10 for 2014 (Aguiar *et al*., 2019).

The lessons learnt include:

1. without comprehensive national account data for low-income and small island economies the reliability of the GTAP database, and the ability of users to evaluate the representation of those countries in the GTAP database, will be impaired;
2. the GTAP database is ‘consistent’ but not ‘complete’, e.g., international transactions in the current account are absent and transactions between domestic institutions are missing;
3. the recording of transactions in the GTAP database at the level of a single dollar can present database and model problems; and
4. the representation of within country transactions in the GTAP database may not be adequate for the analyses of policy options dependent on within country data.

Models

The models defined for use in this project were limited to remain viable within the scope of this project. This involved some customisation of the GLOBE 3 and STAGE 3 models to produce the GLOBE_CC and STAGE_CC models. In addition, the models were run in the comparative static mode; again, to be consistent with the scope of this project.

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48 The Center for Global Trade Analysis notes that “the objective of the GTAP Data Base is not to provide I-O tables, but to facilitate the operation of economic simulation models ensuring users a consistent set of economic facts. ….. Users building I-O tables based on this information do that under their own risk, and are assumed to understand the limitations imposed by the process of data base construction.” (https://www.gtap.agecon.purdue.edu/databases/v10/index.aspx)

The objectives of the project were concerned with demonstrating the capacity of this class of model to fulfil the needs of the UNFCCC to facilitate "the development of tools and methodologies to assess the impacts of the implementation of response measures", and the models were deemed sufficient for the project's objectives.

The lessons learnt include:

1. increases in model (behavioural) complexity may provide additional insights but may compromise the ability of non-specialists to access insights from the results;
2. large global models, c 200,000 variables, may experience difficulties finding solutions to large shocks and/or complex simulations (mainly attributable to data issues and the very large differences in the scale of transactions across countries);
3. complex single country models, c 50,000 to 100,000 variables, should present few difficulties finding solutions to large shocks and/or complex simulations, but model complexity in some dimensions of the model may obscure relationships in some other dimensions of the model;
4. linking global and single country models will always involve a degree of compromise;
5. enhanced data handling methods for accessing the results will be important, especially for inexperienced model users;
6. models containing complex behavioural relationships can, and should, be accessible and readily usable.[49]

Analysis

Implementing policy scenarios in CGE models is not the objective of such exercises: the objectives are the insights and policy options that can be elucidated from analyses of the results. Each simulation will typically produce between two and half and three times the number of results as there are variables in the model, i.e., the volume of data generated will be large for any comprehensive analysis of a scenario. This places a substantial premium upon ensuring the results are accessible and that training supports learning how to filter the results to extract the insights.

The lessons learnt include:

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49 All too often it is implied that model complexity necessarily makes a model difficult to use. The GAMS software was designed to make complex mathematical models accessible, concise, portable, and general (Brooke *et al*., 1992, pp 3-5).

1. routines that report results for all model variables, and percentage changes in variables, are required;
2. routines that generate summary results, e.g., GDP, welfare, SDGs, are required; and
3. results need to be accessible via software that inexperienced users find accessible.

Training[50]

CGE models are not commonly taught in universities and therefore many well-trained and experienced economists have had no exposure to CGE models. Moreover, it takes time for individuals to gain the experience and skills necessary to use CGE models and interpret the results.

The lessons learnt include:

1. CGE training programmes are necessary;
2. CGE training programmes should be linked to the chosen CGE models;
3. post-training support for use and extension of CGE models is essential; and
4. developing the necessary experience and skills takes time and that needs recognizing before embarking on a training programme.

A Way Forward

Data

It is axiomatic that high quality databases that are 'complete and consistent' for individual economies are crucial requirements for all economic models. Some models require detailed long period time series data, e.g., aggregate data for macro econometric models, while others require detailed cross section data, e.g., household income and expenditure data for micro simulation models. The CGE models used for this study require detailed cross section data from several surveys/censuses, e.g., household income and expenditure data, surveys manufacturing, agriculture, etc., and labour force surveys, if 'complete and consistent' databases are to be developed. It is the necessity of gathering detail about the whole economy that can be daunting and the costs of surveys that discourages statistical agencies.

CGE models are all calibrated using data that can be presented in a Social Accounting Matrix (SAM) format with satellite accounts, which are, at their simplest, matrix-based representations of national accounts.

[50] A separate report on training in CGE methods was provided to the UNFCCC (cgemod, 2020a).

Single Country Data

The data for single countries are the only databases that can be compiled solely at the discretion of decision makers in individual countries. The compilation of high-quality databases that are 'complete and consistent' provides governments with information that can guide domestic policy decisions and ensure that the country's economy is correctly represented internationally. Domestic control over the data generation process is more likely to produce data that accurately portray the economy and ensure that data priorities are defined domestically. If national statistical agencies do not control the data generation process government's risk ceding control over the data generation process to third parties whose priorities may differ, in which case the results from economic models may consequently poorly represent the economy and induce poor policy advice. This has been implicitly recognised through the 'African Project on the 2008 System of National Accounts'.[51]

The recommended way forward is for low-income economies and small island economies to prioritise the development of national accounts data consistent with the System of National Accounts (SNA)[52][53] by domestic agencies. The key building blocks are

1. supply and use tables (SUT) (based on requisite survey data);
2. segmentation of taxes on products/commodity and industries/activities in the SUT;
3. household income and expenditure surveys;
4. labour force surveys;
5. international transactions - trade data and other current account transactions; and
6. reconciled institutional accounts (households, government, etc.).

A policy of open data is recommended. Open data will maximise the use of the data for economic analysis and research and extend the information available for the analyses of policy options and decision-making. Open data will reduce the costs to governments of commissioned economic analyses[54] and induce the production of independent research and economic analyses. Moreover, open data will, typically, increase the quality of economic analysis and research by facilitating the comparison of information from multiple studies.

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51 "National accounts statistics are key indicators for describing the national economy and its interactions with the rest of the world and thus, fundamental for economic analysis and research, monitoring and evaluating the performance of an economy, policy formulation, decision-making, and good economic governance." (https://www.uneca.org/foucusareaesna/pages/economic-statistics-and-national-accounts)

52 In an ideal world the national accounts would be based on the 2008 version of the SNA.

53 An emphasis here is on the SNA, but it should be noted that economic accounts are a core part of the System of Environmental-Economic Accounting 2012.

54 Data compilation is often the most expensive component of economic analyses by consultants.

The combination of SUT and reconciled institutional and national accounts can often be used to produce a simple SAM. But it is not recommended that the construction of SAMs should be a priority of national statistical agencies. However, the adoption of an organisational framework that identifies aggregate data requirements that satisfy 'complete and consistent' criteria is recommended, i.e., a SAM. Such a framework will help to reduce the existence of 'gaps' in the national accounts.

Resource constraints will typically ensure that the key building blocks will not be compiled for a single year; hence the compilation of a SAM will require the reconciliation of data from several years and will, at best, be a periodic exercise. The processes involved, and available mathematical methods, are well understood and relatively straightforward if the requisite national accounts data have been collected and reconciled. Thereafter the compilation of SAMs can be delegated to other agents; the information content of such a SAM will be greatly increased if the compilers have access to the underlying survey data.[55] It is probable that the cost to the national accounts office of compiling a SAM could be minimal, e.g., the time taken to supply databases, if compilers are required to publish the SAM as part of a government's open data programme.[56]

Global Data

The GTAP database is the only globally consistent database available and is, for the foreseeable future, the only viable option for global models. The non-trade accounts in GTAP, especially for low-income economies, are arguably the least reliable part of the GTAP database. The best short-term option for improving the representation of economies in the GTAP database is the compilation of SUT by national statistical agencies although ultimately governments cannot mandate how their published data are used by GTAP.[57]

It is recommended that

1. countries publish official SUT at regular intervals, less than every 5 years, to encourage the use of official data by GTAP;

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55 Subject to confidentiality conditions.

56 If the SAM is built on the official SUT assessments of quality of the data in the SAM is straightforward. In addition, the compilation of a SAM may help identify aspects of the national accounts data that may benefit from improvement.

57 It is important to note "the limitations imposed by the process of data base construction." (https://www.gtap.agecon.purdue.edu/databases/v10/index.aspx)

2. the GTAP database's 'power' sector extension[58] is used;
3. the GTAP database's non-CO_2 emissions data[59] is used;
4. the GTAP database is augmented with international transactions in the current account other than goods and services; and
5. the GTAP database is augmented with data on transactions between domestic institutions.

Models

Model developments will need to involve compromises between complexity and accessibility. If the objective is that all analyses would be contracted out to teams of 'experts' the need for compromises may be reduced, but not eliminated, provided any added complexity does not compromise the ability of the 'experts' to present and explain the results and identify and justify policy recommendations. But if 'ownership' of the analyses, along with the interpretation of, and policy implications from, the results is to be held by individual countries some compromises will be necessary.

None of these should impair the usability of the models; even complex models should be user friendly.[60]

Global

The development of global model is, to a greater or lesser extent, dependent on the data available from the GTAP databases and any data available to augment the GTAP database. Given the relatively rigid structure of the GTAP database the opportunities for developments are somewhat limited and will probably need to track developments of globally consistent databases. Many, if not all, of the recommended extensions to a global model are available in existing global CGE models, including GLOBE 3[61].

The constraints imposed by the data mean that a single model could be commissioned that would meet the practical needs of all low-income and small island economies.

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58 The 'power' extension disaggregates the electricity activity into 12 activities: transmission and distribution ('T&D'), seven base load technologies ('NuclearBL', 'CoalBL', 'GasBL', 'HydroBL', 'OilBL', 'WindBL' and 'OtherBL'1), and four peak load technologies ('GasP', 'OilP', 'HydroP', and 'SolarP').

59 Non-CO2 emissions data include CH4 (methane), N2O (nitrous oxide) and fluorinated gases (F-gases).

60 In this context 'user friendly' does mean implementing a model via a GUI; rather it means that the model's behavioural relationships are transparent and that simulations can be easily implemented and understood.

61 GLOBE_CC was a simplified variant of the GLOBE_CC model created for this pilot project.

It is recommended that future models include

1. electricity generation with multiple technologies, e.g., coal, gas, nuclear, renewables, etc;
2. emissions of GHG other than CO_2;
3. international current account transactions other than those in goods and services, e.g., aid, remittances, etc.;
4. transactions between domestic institutions, e.g., savings by households, government internal balances, etc.;
5. codes that allow the model to be implemented, simply, in both comparative static and recursive dynamic modes;
6. codes are available to summarise and extract results, including SDG estimates, in a user-friendly manner; and
7. programmes that provide dedicated training and post training support.

Single Country

The opportunities for developments of a single country model are more eclectic than those for a global model: country specific data can, and probably should, include diverse ranges of transactions. This means that while a 'standard', or 'template', model could be commissioned it is unlikely to meet fully the needs of all low-income and small island economies. Many, if not all, of the recommended extensions to a single country model are available in existing 'standard' CGE models, including STAGE 3[62] .

It is recommended that a 'standard' model should include

1. electricity generation with multiple technologies, e.g., coal, gas, nuclear, renewables, etc;
2. emissions of GHG;
3. support for the development of country specific variants of the model to encompass economy specific features and behaviours;
4. codes that allow the model to be implemented, simply, in both comparative static and recursive dynamic modes;
5. codes are available to summarise and extract results, including a broader range of SDG indicators, in a user-friendly manner; and
6. programmes to provide dedicated training and post training support.

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62 GLOBE_CC was a simplified variant of the GLOBE_3 model created for this pilot project.

Analyses

GAMS and GEMPACK provide utilities that can facilitate the collection of results from global and single country CGE models. While convenient these utilities are not comprehensive. But the extent of the information available from CGE analyses depends heavily on the ability of users to extract, examine and summarise the results.

It is recommended that CGE models should include codes/tools that

1. collect and collate the results;
2. compute summary results, e.g., GDP, welfare, etc;
3. compute summary SDG estimates; and
4. output the results in user friendly data formats.

Summary of Recommendations

This section collects the main recommendations.

Training

An understanding of CGE modelling is necessary for individuals to effectively engage with the approach. This gives rise to a key training recommendation:

1. Provide training programmes linked to the chosen CGE models and post training support with time allocated for trainees to practice and further develop skills.

Data

Quantitative analyses require data. Improving the quantity and quality of data will improve the quality of the analyses. Reducing cost of quantitative policy analyses is the aim of the general recommendation to:

1. Prioritise the development of national accounts data consistent with the System of National Accounts
2. Augment economic data with environmental accounts consistent with the System of Environmental-Economic Accounts
3. Adopt a policy of open data

Models

Finally, recommendations that cover both country and global models are:

1. Select user friendly models that summarise and extract results, including a range of SDG indicators;
2. Augment models with key features including electricity generation technologies, non-CO_2 emissions, international transactions and country specific behaviours;
3. Choose models with code that is open source and/or has been independently verified;
4. Choose models that can be implemented in both comparative static and recursive dynamic modes.

6. Concluding Comments

The analyses conducted for this pilot project demonstrate that global response measures will have negative economic implications at the economy level for all countries, even if they do not implement response measures. The costs will not be spread evenly between countries, or between consumers and producers within countries, and that the magnitudes of the negative consequences will be influenced by the instruments used as global response measures. These negative consequences may be, partially, offset by changes in technology and economic policies, but such changes may be costly; explorations of these changes were not part of this pilot project. The analyses also demonstrate that individual global response measures are likely to have markedly different economic impacts on different countries. This reflects the differences in the economic relationships within countries and between countries. This result indicates that detailed socio-economic analyses of the impacts of proposed and implemented global response measures on different low-income and small island economies is important for the development of country-specific mitigation strategies.

This conclusion is supported by the analyses of the impacts of global response measures at the level of individual economies. Using case studies for two African economies, Senegal and Kenya, it is demonstrated that the patterns of production, consumption and income distribution in a country are important determinants of how the economic impacts of global response measures are translated into domestic socio-economic outcomes. This result indicates that detailed country analyses of the impact of global response measures has the potential to provide information that can guide country specific mitigation policies. Importantly country specific analyses have the potential to identify household groups that are particularly vulnerable to the impacts and the impacts on selected SDG indicators.

The pilot study clarifies some of the constraints upon the analyses of global response measures and mitigation strategies facing low-income and small island economies. Quantitative socio-economic analyses require data, technical expertise, and an appreciation of the insights that quantitative analyses might provide. Shortfalls in technical expertise are relatively easily addressed, in the short run, by training programmes and/or the use of contracted specialists at relatively low cost. Filling shortfalls in data will take longer and cost more, but the benefits should have economic benefits well beyond those associated with climate change. Addressing both these shortfalls however will require that policy advisors have sufficient knowledge to instigate the appropriate analyses, evaluate the quality of the analyses and translate the insights into policy responses. An important conclusion from this pilot study is that valuable insights can be acquired without recourse to extraordinarily complex models that require large and complex databases. Consequently, this class of model can be used to provide usable insights within a relatively short time horizon.

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