PAGE PARTNERSHIP FOR ACTION ON GREEN ECONOMY

THE INTEGRATED GREEN ECONOMY MODELLING FRAMEWORK

TECHNICAL DOCUMENT

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A farmer from Kipilat village planting a tree in Anabkoi. © UN Environment/Riccardo Gangale/2012

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LIST OF ACRONYMS

ANPA	Agenzia Nationale per la Protezione dell'Ambiente
CGE	Computable General Equilibrium model
EGSS	Environmental Goods and Services Sector
GE	Green Economy
GEPAs	Green Economy Policy Assessments
GER	Green Economy Report
GTAP	Global Trade Analysis Project
HS	Harmonized System
IDE-JETRO	Institute of Developing Economics, Japan External Trade Organization
IGEM	Integrated Green Economy Modelling framework
INEGI	Instituto National de Estadistica y Geografia
IO	Input-Output model
ISIC	International Standard Industrial Classification System
NSIC	National Standard Industrial Classification System
MRIO	Multi-Regional Input-Output model
OECD	Organisation for Economic Co-operation and Development
PAGE	Partnership for Action on Green Economy
PRODESEN	Programa de Desarrollo del Sistema Eléctrico Nacional
SAM	Social-Accounting Matrix
SD	Systemic Dynamics model
SEMARNAT	Secretaria de Medio Ambiente y Recursos Naturales
UNDP	United Nations Development Programme
UN ENVIRONMENT	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organization
WIOD	World Input-Output Database
WIOT	World Input-Output Table

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EXECUTIVE SUMMARY

Under the Partnership for Action on Green Economy (PAGE), UN Environment collaborated with modelling experts from around the globe to develop the Integrated Green Economy Modelling (IGEM) framework that aims to better respond to countries' needs in terms of analysing the cross- sectoral impacts of Green Economy (GE) policies, so as to incorporate some of the lessons learned from the application of existent modelling tools, such as the T21 model. Therefore, the IGEM framework is designed to serve three purposes: (1) it builds on UN ENVIRONMENT's past country experience with modelling green economy policies to answer increasingly complex requests from governments; (2) it supports the endowment of countries with solid quantitative tools to inform the design and implementation of green economy policies; and (3) it advances the process of implementing and monitoring some of the Sustainable Development Goals (SDGs), adopted in September 2015.

The IGEM framework presents a methodology on how to integrate three of the main modelling techniques used for green economy policy assessment to refine impact analysis of green policies and investments in the economy. It presents the linkages between a system dynamics (SD) model and a computable general equilibrium (CGE) model, building on input- output and social accounting matrix (IO-SAM) models. The goal of the first version of the IGEM framework is two-fold. First, it will test a concept of integrating three "greened" modelling approaches (SD, CGE and IO-SAM) to improve on the use of a single modelling tool for green economy policy assessment. Second, it will conduct specific evaluations of potential impacts of green economy policies.

Conventional versions of the IO-SAM, the CGE and the SD model need to be "greened" to answer GE policy questions. "Greening" includes modifications to the conventional models to analyse the impact on sectors that are related to the production and use of environmentally friendly goods and services, and it also includes the use of disaggregated data on these sectors. This implies making green sectors explicit and distinguishing them from other sectors which are defined based on conventional technologies and practices, as well as modifying some of the main interrelations of the model variables to better capture the impacts of green economy policies (policies inducing low carbon and resource efficient outcomes, among others).

In particular, a green IO-SAM model is featured by explicitly distinguishing the green sectors from other sectors which utilize conventional (high-carbon, less resource efficient) technologies and practices. A standard CGE model may be transformed into a "green" CGE model either by using input data on green sectors coming from the expanded IO-SAM; and/or by making specific modifications to the conventional CGE model to reflect the use of environmentally efficient technologies. These two approaches can be integrated. The System Dynamics (SD) model component of the IGEM framework can be best thought of as a SD model designed to focus on green policy analysis and to work in concert with the green CGE and green IO-SAM models. To do so, a green version of the SD model will develop the sector structure necessary to address the green economy policies under consideration while keeping the model tractable for interlinking with the CGE and IO components of the IGEM framework.

One of the main advantages of the IGEM is the linking between the green CGE model and the green SD model. In particular, CGE brings rigorous economic analysis as well as the ability to handle great detail across economic sectors. On the other hand, SD offers flexibility in modelling feedbacks between and within environmental and social sectors. Therefore, the IGEM approach offers an opportunity to combine the strengths of the two methods, which allows decision makers to address broader policy questions that go beyond the economic and environmental spheres to also incorporate social aspects.

The application of the IGEM framework is based on the case of Mexico. In 2012, Mexico became the first developing country to pass comprehensive climate change legislation. In 2014, Mexico introduced a carbon tax on fossil fuel production as part of a fiscal reform package and to support the achievement of GHG emissions mitigation targets. Based on different carbon tax rates, the IGEM is used to simulate two scenarios. One scenario explores the welfare impacts of redistributing the revenues of the tax as a lump sum to the population (rebate scenario). In the second scenario, revenues are reinvested into clean energy (feebate scenario), such as wind and solar. These scenarios are also compared to the business as usual case.

After simulating the impacts of the carbon tax in the CGE and SD models alone, the IGEM considers the effects of increased longevity on aggregate and sectoral outcomes by coupling the CGE with the SD model. Results show that GDP grows up to 0.33 percentage points more when longevity is taken into account in the rebate scenario. This growth reaches up to 1.3 percentage points when the feebate scenario is considered. Second, the gains are more or less evenly distributed over all consumers, with a slight bias towards the richest agents in the economy. However, since productivity increases, there is an increase in government revenues, and these added gains could, in principle, be redistributed to further increase the gains of the 20 per cent poorest consuming agents. Longevity is only one aspect of labour productivity and the positive externalities induced by reduced fossil fuel use will also reduce other negative productivity indicators, such as morbidity and days lost due to illness. Thus, the positive impacts found by applying the IGEM framework should be considered as a lower bound to the welfare and growth increases that may be expected from a generally healthier population.

The application of the IGEM highlights the importance of combining a carbon tax with policies which stimulate investments in the renewable energy sector and the importance of taking into account "hidden" benefits from reduced environmental impacts on welfare and productivity. It will provide policymakers with a sense of the integrated impact that green economy policies can achieve and how these can support the transition to an inclusive green economy.

However, it is important to recognize that this version of the IGEM framework should be considered as a first step to integrate three different modelling techniques. Additional work would be required to collect the necessary data to expand and adapt this first version of the IGEM to: (a) better combine the CGE and SD models; (b) conduct simulation-based testing of carbon taxes and other GE policies; and (c) conduct spatial analysis for the assessment of the impacts associated either directly or indirectly with trade and investments at subnational or supranational levels.

1 INTRODUCTION

Since the launch of the Green Economy Report (GER) in 2011, UN Environment has supported countries in developing Green Economy Policy Assessments (GEPAs). These studies (UNEP, 2012; UNEP, 2014a, b;) are a critical part of the decision-making process of policymakers to develop and adopt GE policies to achieve sustainable development targets. A typical GEPA includes five activities: (a) establishing priority sustainable development targets based on countries' overall development plans; (b) estimating the amount of investment required to achieve the targets; (c) identifying the policies or policy reforms that are essential for enabling the required investments; (d) assessing the impacts of the required investments as well as the enabling policies using a range of economic, social and environmental indicators and comparing the results with the business-as-usual scenario; and (e) presenting the assessment results to inform decision making.

Modelling is used in activity d) of the GEPA process and is an important tool for: (a) establishing the relationship of policy targets and relevant factors from different dimensions; (b) projecting the impacts of policy measures in advance; (c) analysing the effects of existing policies; and (d) identifying synergies and cross-sector impacts among policy choices.

An obstacle that remains in this respect is resistance to new modelling tools as think-tanks, independent research institutes, and international agencies are more likely to use modelling techniques they are most familiar with. However, these tools usually cannot undertake multi-dimensional analyses that account for the different time horizons and spatial implications of a GE transformation.

Therefore, to improve GE[1] modelling and to help countries better understand the cross-sector impacts of GE policies in order to develop and implement effective strategies, UN Environment has been working, under the Partnership for Action on Green Economy (PAGE), with modelling experts from around the globe to develop an Integrated Green Economy Modelling (IGEM) framework that will better respond to countries' needs in terms of analysing the impacts of GE policies. The IGEM combines elements of System Dynamics (SD), Computable General Equilibrium (CGE) and Input-Output and Social Accounting Matrix (IO-SAM) models.[2] It is an open-source modelling tool that countries can use and adapt to their specific country context.

This report is intended for an audience of policymakers with technical expertise in modelling frameworks, and who are interested in assessing the effects of green policies on the economy, environment and society within their national context.

The structure of this report is as follows: Section 1 introduces the modelling tools that have been used to date for GEPA and highlights the need for a new integrated model; Section 2 details the added value of the IGEM framework; Section 3 presents an application of the IGEM framework to the case of Mexico; and Section 4 draws conclusions.

1.1 UN ENVIRONMENT COUNTRY EXPERIENCE WITH THE MODELLING OF GE POLICIES

Following a similar approach to the GER (UNEP, 2011), GEPAs have been carried out in South Africa (UNEP, 2013); Kenya (UNEP, 2014c); Rwanda (UNEP, 2014d); Senegal (UNEP, 2014e); Burkina Faso (UNEP, 2014f); Uruguay (PNUMA, 2015); Ghana (UNEP, 2015); Mauritius (PAGE, 2015); Mozambique (UNEP, 2016); Peru (UNEP, forthcoming) and Mongolia (UNEP, forthcoming). With the exceptions of Mauritius and Mozambique, the Threshold 21 (T21) model[3] was employed.

Two approaches[4] have been used so far in country GE assessments for guiding simulations. The first approach sets investment targets as the driver of the simulations. A set of possible green interventions associated with the amount of investments and enabling conditions are proposed for supporting the transition to a GE. For instance, in the Kenya study (UNEP, 2014c), the GE scenario assumes an additional 2 per cent of GDP per annum (Kenya Economy GDP) as green investments compared to the baseline. Total investment of approximately KES 1.2 trillion (USD 14.9 billion) between 2012 and 2030 is analysed in a variety of interventions for greening the agriculture and energy sectors. The T21 modelling assesses the impact of the GE transition on society, economy and the environment. The report concludes by providing an overview of regulations, standards; fiscal policy instruments; institutional and policy processes needed to support a transition to a GE in the country.

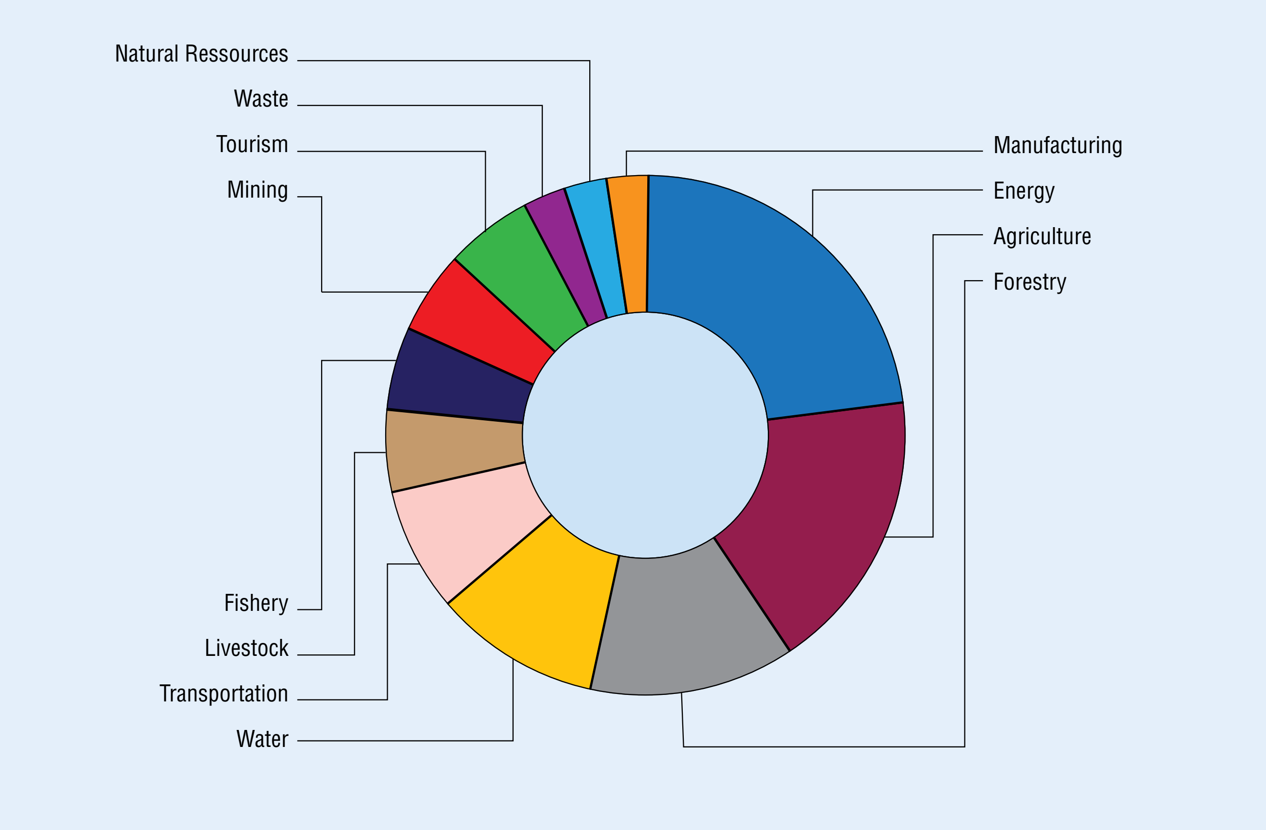
The second approach sets GE targets aligned with national sustainable development goals as the key driver for estimating the required investments and running policy target simulations. Specific enabling policies are proposed for spurring the identified green investments. For example, in Uruguay (PNUMA, 2015) green targets were simulated for four key sectors, namely, agriculture, livestock, tourism, and land transportation (private and public). One of the enabling policies considered by stakeholders for greening the agriculture sector was the use of tax exemptions to promote efficient farm irrigation (40,000 ha by 2030). This policy would enhance country resilience to climate change, which is viewed as a key challenge for transitioning towards sustainable development. The implementation of this target was associated with an investment cost of USD 488/ha. The T21 model was able to inform on the multiple benefits of implementing this fiscal policy.

While the first approach helps to create evidence of the GE transition, it has, however, received some criticism because the amount and origin of investments appear to be estimated without considering the realities of the country in terms of access to finance and domestic revenues. The second approach, although better received by national stakeholders, is more data intensive for building the model since estimations of required green investments result in a challenging process that goes beyond modellers' capacity. It is important to note that the models used in UN Environment's studies so far – apart from some exceptions - are not designed to provide investment estimates needed to achieve green targets.

UN Environment also provided guidance to Mexico on the GEPA development (SEMARNAT-INECC, 2014).[5] This consisted of employing sectoral System Dynamic (SD) models to assess the impact of greening the economy in four relevant sectors: forestry, transport, water, and fishery. The Computable General Equilibrium (CGE) model served as the macroeconomic engine to estimate the savings obtained from removing subsidies to energy consumption and welfare impacts of GE policies on the households. The savings were then used as investments by the SD model for achieving green targets in selected sectors. The sectoral models assess the impact of greening the four sectors mentioned above. As described by Ibarrarán et al., (2015), integrating the SD and CGE methodologies was helpful to consider their respective strengths. For instance, the SD model considered stocks, changes in natural resources and environmental quality; forestry, fishery, water and air quality were also specifically addressed. In contrast, the CGE model used tracked adjustments in demand because of different price and income elasticities for different goods and services and different consumption bundles for each of the four agents. The CGE model was also able to address stylized facts, such as unemployment in Mexico, as well as informality in the labour market.

Based on the review of ten country modelling studies supported by UN Environment,[6] some general conclusions can be drawn. First, the initial studies were focused on simulating scenarios using investments targets as a percentage of national GDP, while more recent studies consider green targets aligned with national sustainable development targets. The latter may be due to the discussions on the SDGs started in Rio+20 which rapidly gained momentum at national level as countries were committed to develop national SDGs. Second, energy, agriculture, and forestry have been selected in most of the cases as the priority sectors for a GE transition in the country (see Figure 1). Third, under both modelling approaches discussed above, investments are either associated to a GE target (e.g. cutting emissions by a certain level by 2030; reducing poverty by a certain rate by 2040, etc.), or to GE interventions (e.g. a carbon tax of USD X per tonne; investing USD X million on renewable energy) – a key input information for running the models. However, the SD models were not able to inform on the enabling policies required to spur the simulated investments.

Figure 1: *Priority sectors selected as key for a GE transition*



Source: Figure created by the authors.

Finally, while most of the countries used the T21 model which is a comprehensive SD model, some country studies show the viability of using simplified SD sectoral models (Mozambique, Mauritius and Mexico) and one country study already used as a core model a CGE model "coupled" to SD sectoral models (Mexico). The GEPA study for Mexico may be considered a pioneer effort towards developing a standardized integrated modelling tool as the IGEM framework presented in this report, since, as explained by Ibarrarán et al., (2015), at the outset Mexico's GEPA project focused on sectoral green policies aimed at being run jointly with a CGE model. However, such an approach was not able to capture internal dynamics within each sector and did not allow determining changes in flows and stocks of natural capital as well as their quality. Thus, including a SD analysis allowed for detailed sectoral analysis with feedback loops across and within sectors and in time, showing true inter-sectoral dynamics, and providing a better understanding of the impact of green policies on specific types of natural capital.

1.2 BENEFITS AND LIMITATIONS OF THE T21 MODEL

The T21 model, developed by the Millennium Institute, is a unique system dynamics model that encompasses the three dimensions of sustainable development (economic, social and environmental) and comprises several sectors for each dimension. The boundaries of the model separate its variables into endogenous and exogenous variables, depending on whether they are within or outside the control of governments.[7]

To support GE policy assessments, the T21 model shows how investments affect the system in terms of a wide range of indicators such as economic growth, employment and poverty alleviation. Further, it assesses not only whether targets are met, but also why they are not met. In doing so, it is important to revise the assumptions of the model. The model's main purpose is to motivate governments to assess adopt GE policies. The main tasks of a GE policy assessment are to: (a) specify what are the key goals for a GE transition in each country, to check the practicality of goals; (b) validate and inform goal setting; and (c) to base targets on a quantitative analysis

In this connection, the T21 has benefits in terms of supporting many aspects of the GE assessment process, such as the quantification of targets, the data collection, the model development (by a description of the causal structure), the policy analysis (by analysing direct and indirect impacts of policy interventions) and the facilitation of stakeholder involvement.

However, the T21 also has some limitations. In terms of time horizon, the T21 model looks at the impact of policy change over a mid- to long-term period but policy cycles are normally anchored in the short term for which the T21 is not particularly appropriate. The T21 is also not very well suited for sub-national analyses: data are aggregated at the national level and do not always allow a multi-country analysis. Another limitation of the T21 model is that it is not consistent when calculating income distribution, because in many cases, income distribution (to calculate poverty) is not endogenously determined within the model. The T21 focuses on the supply side, which limits the scope to capture some of the main inter-sectoral linkages in the economy, which are critical for labour and industrial policies. Although it is possible to analyse some aspects of trade policy in system dynamics, the T21 model is not appropriate for this analysis. Finally, the difficulty of building a consistent data system of national accounts is a general challenge to any modelling exercise.

In September 2014, PAGE held a workshop entitled "A Technical Workshop on Improving the T21 Model".[8] During the workshop some important areas for improving UN Environment's modelling tools were identified: (a) the need for more environmental indicators, particularly regarding the environmental footprints of different policy options; (b) the need to capture multi-country dynamics such as trade; (c) the need to appropriately address short-term impacts; (d) the need to better track inequality and other important inclusiveness variables.

1.3 THE IGEM FRAMEWORK PROJECT

Taking into account the recommendations from the September 2014 workshop and given the lessons learned from the country applications, PAGE, under UN Environment's leadership, initiated an "Integrated Green Economy Modelling framework" (IGEM framework) project in December 2014 to better integrate current IGE modelling tools. The IGEM framework presents a methodology on how to integrate three modelling techniques to refine impact analysis of green policies and investments in the economy. It explains the linkages between a system dynamics (SD) model and a computable general equilibrium (CGE) model, building on input-output and social accounting matrix (IO-SAM) models.

The integrated approach, in particular, offers an opportunity to combine the strengths of the SD model and the CGE model. The latter model brings rigorous economic analysis as well as the ability to handle great detail across economic sectors. On the other hand, the SD model offers flexibility in modelling feedbacks between and within environmental and social sectors. The strengths of the two methods integrated are precisely why the combined approach can be valuable for GE policy assessments.

The IGEM framework is designed to serve three purposes: it builds on UN Environment's past country experience with modelling GE policies to answer increasingly complex requests from governments; it supports the endowment of countries with solid quantitative tools to inform the design and implementation of GE policies; and it advances the process of implementing and monitoring some of the Sustainable Development Goals (SDGs), adopted in September 2015.

Answer increasingly complex requests from governments: The IGEM framework offers an opportunity to enhance the simulation of an inclusive green economy (IGE). Until recently, studies only focused on simulating investments. Developing models capable of additionally incorporating GE enabling policies that support investments would provide more information to policy and decision makers. The IGEM framework creates an interface between a SD model that describes the main social, demographic and environmental causal loops, and a CGE model that describes the potential economic effects of policies taking into account their general equilibrium impact, including the role of trade and fiscal policies. In order to analyse GE policies, the conventional CGE model needs to be adapted to use IO and SAM extensions that cover green activities, such as renewable energy production or resource efficient inputs. In this regard, the IO model and SAM extensions can play a key role in the IGEM framework by providing the basic dataset on the green components of the priority sectors and the linkages between the green sectors and other sectors in the economy. To construct these extensions, coordination with local authorities in charge of national statistics will be critical, given the significant data requirements that these extensions require.

Support the endowment of countries with solid quantitative tools: The IGEM can address the increasing need to provide methodological and analytical support to countries that strive to drive their medium- and long-term development plans towards GE pathways. The IGEM framework is a double effort to combine the best characteristics of three existing models into one modelling tool and to "green" these conventional models to provide the needed support to countries for their policymaking assessment in their transitions towards an IGE. The IGEM framework will also help countries that already have one or more of these modelling tools (SD, CGE, IO-SAM) to integrate these in a way that is better tailored to the type of policy assessment that an IGE policy agenda requires.

Support the process of implementing and monitoring some of the SDGs: The IGEM framework can provide a framework for a GE target approach – instead of an investment target approach - that could also contribute to support countries in implementing and monitoring selected SDG targets. The integrated approach of development implied by the SDGs requires existing modelling tools to be adjusted to capture these goals and their interrelation with other targets and development objectives. Currently available modelling tools, when taken in isolation, only analyse some of the increasing concerns of integrating the environmental and social dimensions in economic policy planning. The combination of the best characteristics of the SD, CGE and IO-SAM, as contained in the IGEM framework, offers a more integrated development agenda calls for a more integrated approach to modelling.

The first step of the IGEM project was to agree to a common list of policy questions that new modelling tools should help to answer.[9] From the list of policy questions, UN Environment ambitions the IGEM framework to be able to answer as many as possible, but particularly the following eight questions:

1) How can the impact of investments (new and shifted) and policies be assessed?

2) What benefits might investments and policies generate across sectors in terms of economic opportunities, inclusiveness and environmental sustainability?

3) Are the impacts likely to be long or short-term?

4) How will green subsidy reforms (e.g. feed-in tariffs) likely impact productivity in GE sectors?

5) How will green tax reforms and removing fossil fuel subsidies mobilize domestic revenues for green investment? What will be the implications of such reforms on environmental, economic/fiscal and social fronts?

6) How do trade policies and regulations enhance investments in GE sectors?

7) Which labour interventions deliver more (quantity) and better (quality including decency) green jobs? Which approaches create better access for the unemployed and underemployed?

8) What types of industrial policy measures are in place to support the transition towards a GE?

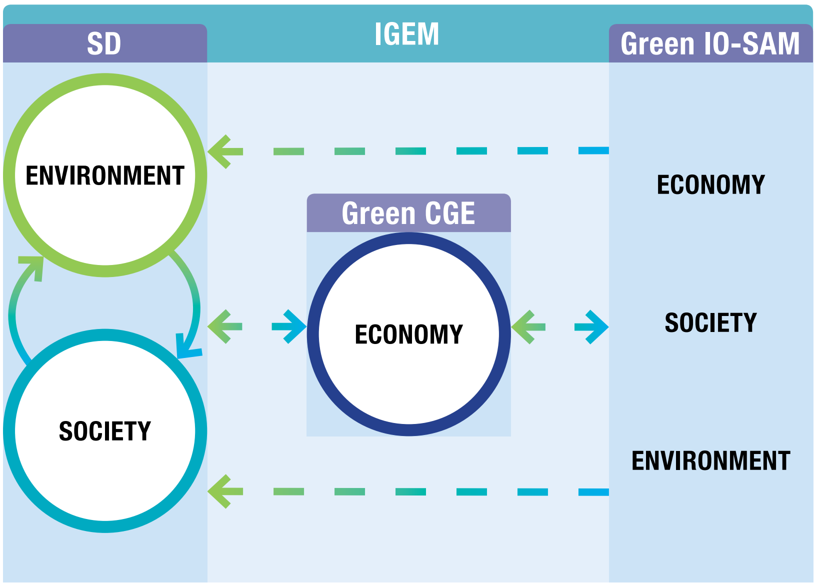
The goal of the first version of the IGEM is two-fold. First, it is to test a concept of integrating three "greened" modelling approaches (SD, CGE and IO-SAM) to improve on the use of a single modelling tool for GE policy assessment. Second, it is to conduct specific evaluations of potential impacts of GE policies. The energy sector of Mexico has been selected for this application and for the policy analysis.[10, 11]

1.3.1 How can the CGE and IO-SAM complement a single SD model analysis?

The IGEM framework methodology explores how the CGE model can remedy some of the limitations of the T21, by using IO-SAM extensions. The typical structure of a CGE model is calibrated with IO and SAM as well as with some econometric techniques to estimate parameters. The model is dynamic and is mostly focused on economic interrelations. In terms of GE policies, this type of model has been used in the analysis of the impacts of eliminating energy subsidies or imposing a carbon tax, among others. It can also analyse trade policy impacts, as well as impacts on the allocation of labour across sectors. The effect on broad environmental issues cannot be directly modelled (as opposed to the SD model), but some analysis of depletion of natural resources can be undertaken. The CGE model also allows simulating non-linearity between input and output, given the existing non-linearity in the production and utility functions. The CGE could thus complement the SD model, by modelling the economic impacts of a given policy and by providing this information as an input to the SD model for further modelling of environmental and social impacts.

In conjunction with the CGE model, green extensions of the IO model and SAM can be used to provide information on green sectors to the CGE model. The IO model is especially suitable for short-term projections on the economy-wide impact of sectoral investments through the intersectoral linkages in the economy. In the IO model, inputs are linearly linked to outputs (thus non-linearity is not included). The IO model can easily be decomposed into different levels of labour skills (including skilled and unskilled or formal and informal), which is particularly relevant for understanding labour market dynamics in developing countries. The SAM model focuses on circular flows with interactions between institutional agents within the economy. The SAM and IO models are both static ones and are limited to analyse the dynamics of medium to long-term investments. Further, these models cannot take lags into account, but the SAM model can handle non-linearity. Figure 2 summarizes the main linkages between the three models.

Figure 2: *Diagram of the IGEM framework showing the linkages between the SD, CGE and IO-SAM models*



Source: Figure created by the authors.

Finally, it is important to recognize that any integration of different modelling techniques will be a challenging exercise, because of each model's singularities. It is therefore crucial to be able to discern what a particular modelling approach can and cannot do. Experts at the September 2014 workshop warned against the potential danger of nesting completely different approaches, in particular the T21 model with other approaches, and recommended making improvements only in particular areas of the T21. However, based on the list of key GE policy questions, it soon became clear that improvements to the T21 model alone would not be sufficient to answer these questions. An integrated strategy was therefore adopted to create the IGEM framework in which the three types of modelling tools complement each other. An important aspect to achieve this integration of modelling tools is to ensure consistency between models. Consistency of tools, modelling approaches and messages is a key issue, since low consistency will lead to significantly different or contradicting results. This will be further discussed in Section 3, in which the application of the IGEM is presented.

2 ENHANCING THE ABILITY OF MODELLING TOOLS TO SUPPORT GE POLICY-MAKING: THE IGEM FRAMEWORK

The two main added values of the IGEM framework project are to develop some general guidelines on how to "green" the IO-SAM, the CGE and the SD (section 2.1) models, and to develop a methodology on how to link these greened models (section 2.2). Section 2.3 then discusses how the IGEM and its sub-components can help to answer GE policy questions.

2.1 "GREENING" THE MODELS

Conventional versions of the IO-SAM, the CGE and the SD model need to be "greened" to address GE policy questions. "Greening" includes any modifications to the conventional models to analyse the impact on sectors that are related to the production and use of environmentally friendly goods and services, and includes the use of data on these sectors. This implies making green sectors explicit and distinguishing them from other sectors which are defined by their reliance on conventional technologies and practices, as well as modifying some of the main interrelations of the model variables to better capture the impacts of GE policies (e.g. policies inducing low carbon and resource efficient outcomes).

2.1.1 Green extensions from the IO-SAM

To create a generic IGEM framework, a green version of the IO-SAM model is essential to provide the fundamental database and accounting framework on which a green CGE will be built. A green IO-SAM model distinguishes the green sectors it incorporates from similar sectors reliant upon conventional technologies and practices.

A conventional IO model aggregates different industries/services into sectors, and is built upon the statistical data of national accounts and inter-industry transactions at sectoral levels. For the compilation of sectors based on industry classification (either based on domestic or international standards), both green industry and conventional industry (either producing similar products to the green industry or different products) are combined to form one sector. For example, an electricity generation sector is usually an aggregate sector, including electricity generated from different fossil fuels (coal, oil and gas), nuclear power, hydro and others (including renewable energy, such as solar, wind, geothermal, wave, and biomass, etc.). The production recipe indicated by the technical coefficients of the IO model therefore presents the average level of the aggregate sector. Such aggregation disguises the unique characteristics of the green subsectors in question, in particular their environmentally-friendly nature in terms of low emissions, cleaner production and less intensity in material use. Using the conventional IO model for analysing green sectors will therefore be either misleading or even wrong. For example, it will be wrong to use the IO model with the aggregate electricity generation sector for assessing the impacts of investment in renewable energy, because there should be no inputs from fossil fuels for electricity generation from renewable energy. It is also not convincing that an expected simulation of investment in the green sectors is modelled as a simulation in the aggregate conventional (more carbon intensive) sectors.

In this context, to construct a green IO-SAM model, the green sectors need to be separated from the conventional aggregate sector, or need to be presented as new sectors if they are not originally covered by the statistics or industrial surveys. The benefit of separating green sectors from conventional sectors is to enable the comparison of investments in green and conventional sectors, and their respective impacts on the economy, employment and the environment.

Disaggregation or creation of new green sectors may require specific data and IO techniques, depending on the request for resolution at the sector, process or technology levels. First, disaggregating green subsectors from their conventional sectors, e.g. organic farming from the agricultural sector, renewable energy from electricity generation, sustainable forest practices from forests, and green building from buildings, etc., requires a clear definition of the green subsectors (what kind of activities are included), and of their corresponding sectors in the national standard industrial classification system (NSIC) or the international standard industrial classification system (ISIC code). Second, defining these sectors will also depend on how the available national IO-SAM is classified in terms of sectors and how these sectors correspond to the NSIC or ISIC. Finally, since statistics for most of the green sectors are lacking in national surveys, the availability of data required for the disaggregation of green sectors is quite challenging.

2.1.1.1 Steps towards constructing a green IO- SAM

This section explains the process of sector disaggregation related to green sectors using renewable energy (solar PV) as an example. First, a conventional IO model with aggregation of green and non-green sectors will be disaggregated to present detailed green sectors. Second, a green SAM will be constructed based on the built-up green IO model.

Step 1: Create an expanded (or green) IO.

Based on the IO model described in Table A3.1 of Annex 3,[12] Table 1 shows an expanded IO model by disaggregating the original sector, n, into two sectors, a `green sector' $(n+1)$ and `others' (n) .[13] Such disaggregation will make changes to the original IO model by adding a new column and a new row related to the `green sector', $(n+1)$, and relevant adjustments to the row and column related to `others' (sector n - see the two columns and two rows highlighted in Table 1).

Table1: *Disaggregating an IO table with a green sector*

		PURCHASING SECTORS						FINAL DEMAND				TOTAL OUTPUTS (X)
		1	…	j	…	n	$n+1$					
PRODUCING SECTORS	1	x_{11}	…	x_{1j}	…	x'_{1n}	$x'_{1,n+1}$	c_1	i_1	g_1	e_1	X_1
	⋮	⋮		⋮		⋮	⋮	⋮	⋮	⋮	⋮	⋮
	i	x_{i1}	…	x_{ij}	…	x'_{in}	$x'_{i,n+1}$	c_i	i_i	g_i	e_i	X_i
	⋮	⋮		⋮		⋮	⋮	⋮	⋮	⋮	⋮	⋮
	n	$x'_{n,1}$	…	$x'_{n,j}$	…	$x'_{n,n}$	$x'_{n,n+1}$	c'_n	i'_n	g'_n	e'_n	X'_n
	$n+1$	$x'_{n+1,1}$	…	$x'_{n+1,j}$	…	$x'_{n+1,n}$	$x'_{n+1,n+1}$	c'_{n+1}	i'_{n+1}	g'_{n+1}	e'_{n+1}	X'_{n+1}
VALUE-ADDED (v')		v_1	…	v_j	…	v'_n	v'_{n+1}	v_c	v_i	v_g	v_e	V
IMPORTS (m)		m_1	…	m_j	…	m'_n	m'_{n+1}	m_c	m_i	m_g		M
TOTAL INPUTS (X)		X_1	…	X_i	…	X'_n	X'_{n+1}	C	I	G	E	

Source: Zhou et al., 2015.

The relation between the disaggregated model and the original model can be explained as follows (Equations 1-10):

$$x_{n,j} = x'_{n,j} + x'_{n+1,j} \qquad (j = 1, \ldots, n-1) \qquad (Eq.1)$$

$$x_{i,n} = x'_{i,n} + x'_{i,n+1} \qquad (i = 1, \ldots, n-1) \qquad (Eq.2)$$

$$x_{n,n} = x'_{n,n} + x'_{n,n+1} + x'_{n+1,n} + x'_{n+1,n+1} \qquad (Eq.3)$$

$$v_n = v'_n + v'_{n+1} \qquad (Eq.4)$$

$$m_n = m'_n + m'_{n+1} \qquad (Eq.5)$$

$$c_n = c'_n + c'_{n+1} \qquad (Eq.6)$$

$$i_n = i'_n + i'_{n+1} \qquad (Eq.7)$$

$$g_n = g'_n + g'_{n+1} \qquad (Eq.8)$$

$$e_n = e'_n + e'_{n+1} \qquad (Eq.9)$$

$$X_n = X'_n + X'_{n+1} \qquad (Eq.10)$$

where the variables without a prime indicate values in the original model and those with a prime indicate transactions in the disaggregated model which needs to be solved.

This system of equations (Eqs.1-10) cannot be solved without additional information/data to identify the variables. Ideally, if information was available for all the variables with a prime in the new sector, $(n+1)$, through Eqs. 1-10, those variables with a prime for sector n could be easily calculated, except for the four variables at the intersect of the two columns and two rows, i.e. $x'_{n,n}$, $x'_{n+1,n}$, $x'_{n+1,n}$ and $x'_{n+1,n+1}$ However, if the share of the new sector $n+1$ in the total output of the original sector is known, indicated by w, one way to calculate these variables is by solving

$x'_{n,n} = (1-w)^2 x_{n,n}$, $x'_{n+1,n} = w(1-w)\, x_{n,n}$, $x'_{n,n+1} = w(1-w)\, x_{n,n}$, and $x'_{n+1,n+1} = w^2 x_{n,n}$.

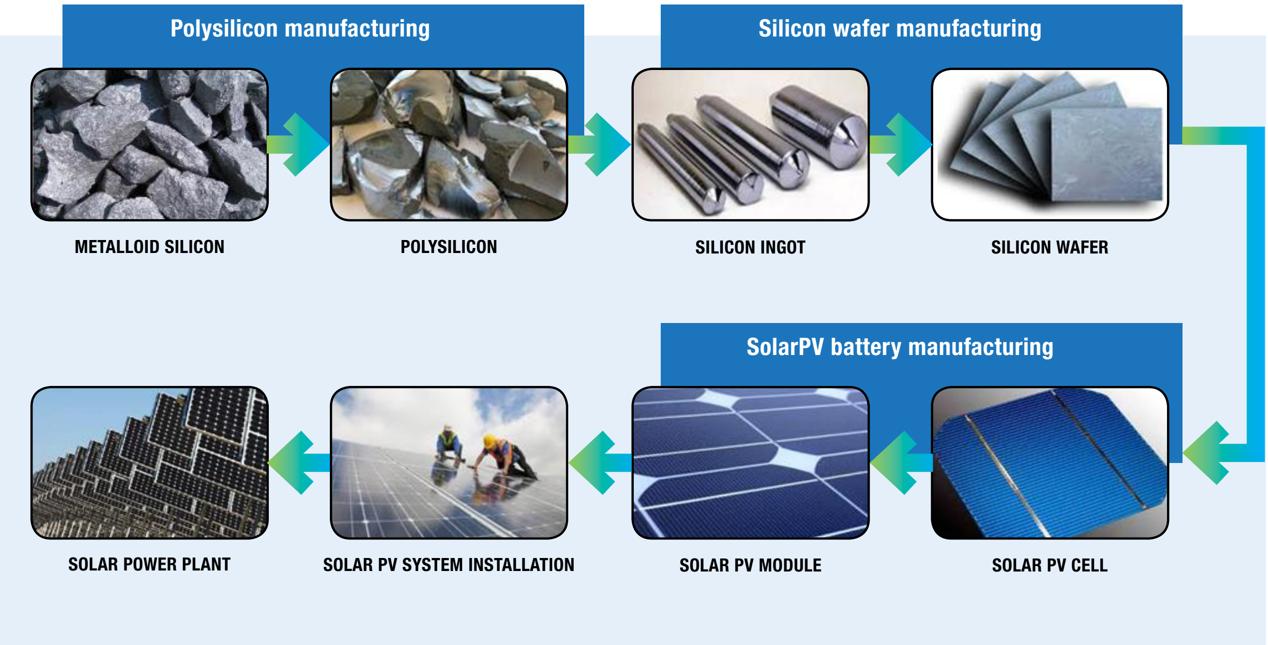
A few academic papers discuss the disaggregation methods, either in a more general way (Wolsky, 1984; Suh and Huppes, 2009; Lindner, et al., 2012a), or specifically targeting a particular sector (Lindberg and Hansson, 2009, on livestock; Lindner et al., 2012b, on electricity sector).

If the new sector $n+1$ has similar technical coefficients as its original sector and has similar usage across sectors, by using the output share of $n+1$ in its original sector, w, it is straightforward to calculate all variables in the two columns and two rows. However, this is not very useful since the very purpose of disaggregation is to distinguish the new sector $n+1$ from others in terms of its unique features related to different products, functions, production technology, process or method, etc. Therefore, to build an expanded IO model with green sectors, the task is to make use of available information to achieve a disaggregation of the IO model.

For this task, the proposed method is based on previous research on resource flow accounting using the multi-region input-output model by disaggregating the steel and iron sector based on two technologies, blast furnace steel making and electric arc furnace steel making, and disaggregating relevant upstream sectors such as iron or mining from other mining, and steel recycling from other recycling, etc. (Zhou, Yano & Kojima, 2013).

One way to start is to collect data/information on the cost composition or the production recipe of the new sector from a supply chain viewpoint. For example, if the aim is to disaggregate the electricity generated from solar PV from the aggregate sector of electricity, the supply chain and major components of solar power generation needs to be known. The following chart is an example of the supply chain of solar power generation (Figure 3). Understanding the supply chain and production process of solar power generation is important because it allows modellers to distinguish electricity that is generated from renewable sources from the aggregate electricity sector. A disaggregated IO will be the basic dataset for the construction of the SAM, which is the base year data set and the starting point of the CGE modelling.

Figure 3: *The supply chain of solar power generation*



Source: Zhou et al., 2015.

Figure 4: *Diagram on how to prepare a green SAM based on a green IO*

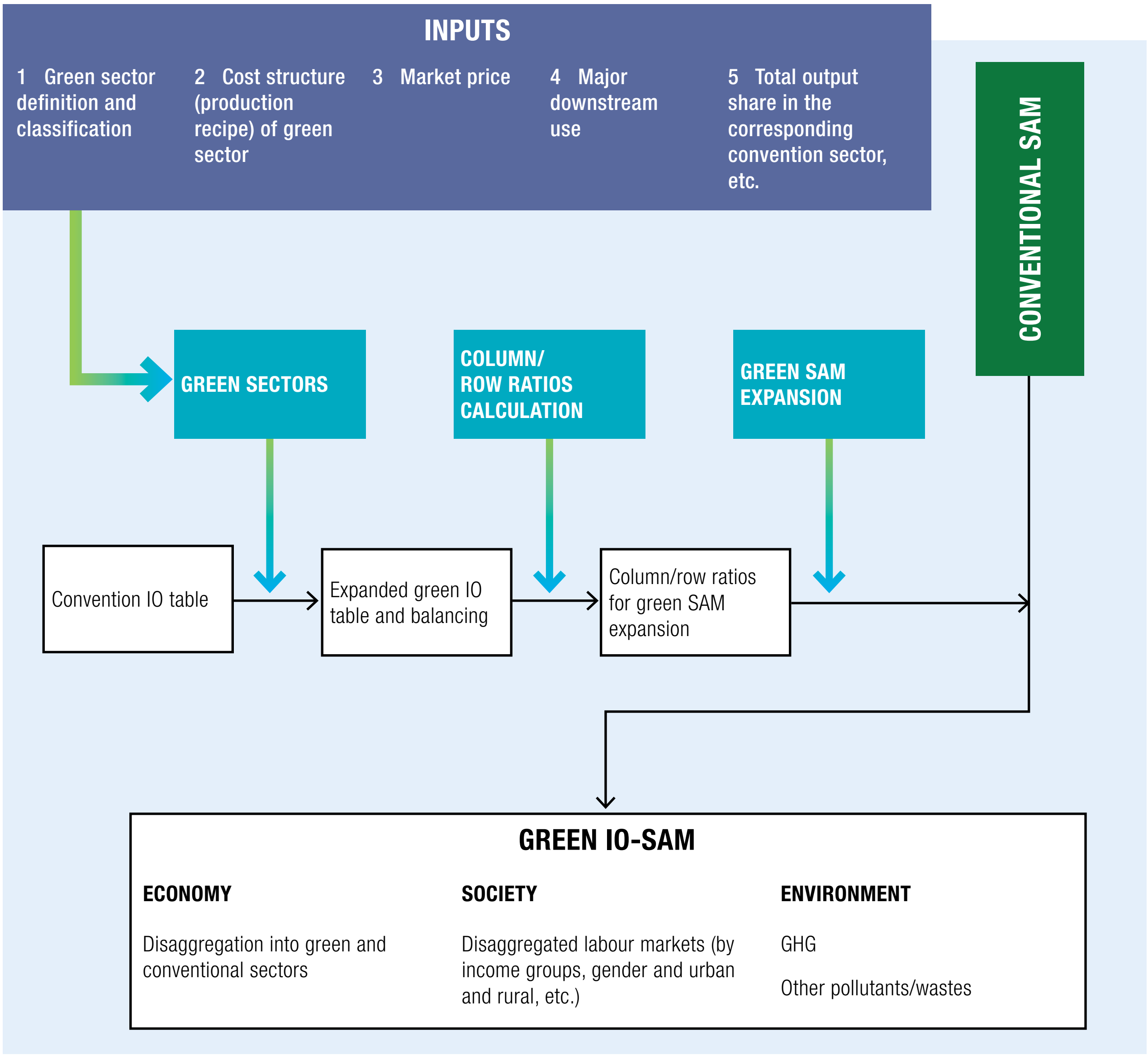


Figure created by Zhou X and adapted by authors.

If the quantity of electricity generated from solar PV (e.g. in kWh) is known in the reference year, as well as the price of electricity generated from solar power, the total output (in monetary terms) from solar power generation can be determined. By multiplying the total output by the cost composition, and by mapping the upstream components with corresponding IO sectors (see next section), all the variables in the column related to the new sector, solar PV, can be calculated.

$$x'_{i,solar} = a'_{i,solar} \times X'_{solar} \qquad \text{(Eq.11)}$$

where $a'_{i,solar}$ is the technical coefficient or the production recipe of solar power generation.

For the variables in the new row, electricity generated from solar power can be assumed to be used in the same way as electricity generated from other energy carriers, such as fossil fuels, nuclear and hydro, since it is connected with the transmission grid through which electricity is used by end-users, who cannot distinguish how it was generated. By using the ratio of the total output of solar power generation in the electricity sector (calculated as $w_{solar} = X'_{solar}/X_{ele}$), variables in the new row can be calculated.

In intersecting rows and columns, it is assumed that no electricity (either generated from solar power or generated from other sources) is used in the solar power generation.[14] However, electricity (both from solar power and other sources based on their relative ratio in terms of total output) is used for electricity generation from other sources (see Eq.12).

$$\begin{aligned} x'_{other,solar} &= 0 \\ x'_{solar,solar} &= 0 \\ x'_{other,other} &= (1 - w_{solar})x_{ele,ele} \qquad \text{(Eq.12)} \\ x'_{solar,other} &= w_{solar}x_{ele,ele} \end{aligned}$$

So far, the variables in both the new column and the new row related to solar power generation can be calculated. A similar approach can be used for wind power generation.

Step 2: Create an expanded (or green) SAM.

After an expanded (or green) IO table is established, a corresponding expansion for the SAM can be conducted using the process depicted in Figure 4.

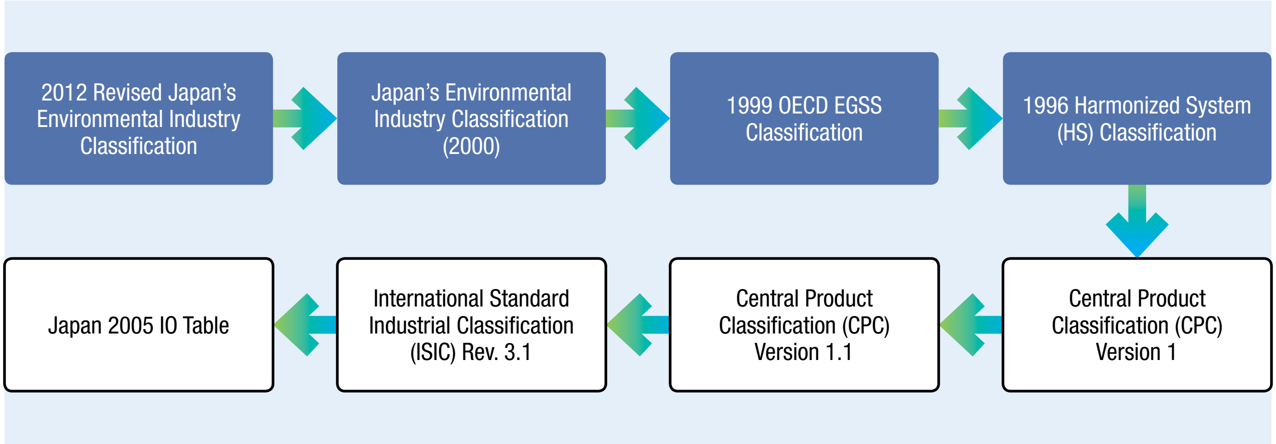
Step 3: Mapping green sectors with corresponding IO-SAM sectors: The example of renewable energy in Japan.

As indicated in the previous steps, to construct an expanded green-sector IO-SAM model, it is necessary to map the upstream component sectors and downstream use sectors of the new sector, as well as the new sector itself, with corresponding sectors classified in the IO-SAM model. Many national IO-SAM models use sector classification based either on a national standard industrial classification (NSIC) system or the International Standard Industrial Classification (ISIC). For illustration purposes, an example based on the definition of renewable energy in Japan's classification of Environmental Goods and Services Sector (EGSS)15 and their correspondence sectors in Japan's 2005 IO model is introduced in the following paragraphs (Zhou and Mustafa, 2015). The EGSS framework was developed in 2000 and is now being used in many EU countries and several developing countries. Japan's statistics on environmental industry, date from 2000 and are based on the OECD definition and methodology of EGSS (OECD, 1999), and include three broad categories, i.e. pollution management, cleaner technologies and production, and resource management. An important characteristic of this approach is that classifications, as formulated by the OECD (1999), can also be used in the analysis of green trade flows. This is particularly useful because it allows the analysis to not only inform about potential impacts of green policies on the production side, but also on the trade side. In addition, the work on disaggregating sectors to analyse EGSS using the Harmonized System (HS) trade classification will open the door to future analyses of the impact of green trade policies.[16]

In 2012, Japan revised the classification on environmental industry to reflect recent trends in combating climate change and special characteristics of solid waste management, in particular the 3Rs (Reduce, Re-use and Recycle) (MOEJ, 2012). Statistics were also updated accordingly for the period from 2000 to 2012 in terms of the market size, employment, value added, imports and exports (MOEJ, 2014).

Since there is no direct correspondence between EGSS and IO sectors for Japan which can be readily

Figure 5: *Preparation of the correspondence table for EGSS and IO sectors*



Source: Zhou and Mustafa (2015).

used for the IO analysis, different sector/product classifications and their correspondence were used as a means to map EGSS sector classification with IO sector classification. Figure 5 presents the linkages of these different sector classifications.

The four categories of Japan's revised Environmental Industry Classification (2012) are: (a) Pollution prevention and control; (b) Measures combating climate change; (c) Solid waste management; and (d) Effective resource utilization and conservation of the natural environment. The correspondence between the 2012 Japan's revised Environmental Industry Classification and the 2000 Japan's Environmental Industry Classification is provided by the MOEJ (MOEJ, 2012). This latter classification is based on the OECD 1999 manual for data collection and analysis of the environmental goods and services industry (OECD, 1999), in which the correspondence between EGSS classification and the Harmonized Commodity Description and Coding System (HS) commodity code is provided. On the other hand, the correspondence between the Japanese 2005 IO table (190 sectors) and the International Standard Industrial Classification Revised Version 3.1 (ISIC Rev. 3.1) is provided by the Japanese government (Ministry of General Affairs of Japan, 2002). ISIC Rev. 3.1 has the correspondence with the Central Product Classification Version 1.1 (CPC V1.1) which links with CPC V1. Finally, CPC V1 links with the 1996 HS classification. The correspondence table between the 2012 Revised Japan's Environmental Industry Classification and the 2005 IO sector classification can then be established.

In particular, Table 2 shows the classification of renewable energy in the 2012 Revised Japan's Environmental Industry Classification, and its correspondence sector code in Japanese 2005 IO table and correspondence ISIC code.

Once the green IO-SAM has been constructed and the green sectors have been mapped accordingly, this information will serve as a primary input to the CGE.[17]

Table 2: *Classification of renewable energy in Japan's EGSS and correspondence in ISIC and the IO model*

CLASSIFICATION BY EGSS						CORRESPONDENCE ISIC CODE	CORRESPONDENCE SECTORS IN THE 2005 IO MODEL
B MEASURES COMBATING CLIMATE CHANGE							
Level 2		Level 3		Level 4			
b1	Renewable energy use	**b11**	Renewable energy power generation systems	**b11-1**	Solar PV power system	3190. Manufacture of other electrical equipment (n.e.c.)	3241-09. Other electrical devices and parts
				b11-2	Installation of solar PV power system	4510. Site preparation 4520. Building of complete constructions or parts thereof; civil engineering; 4530. Building installation; 4540. Building completion	4132-02. Electric power facilities construction
				b11-3	Residential solar PV system	2930. Manufacture of domestic appliances n.e.c.	3251-02. Household electric appliances (excl. air-conditioners)
				b11-4	Installation of residential solar PV system	4510. Site preparation; 4520. Building of complete constructions or parts thereof; civil engineering; 4530. Building installation; 4540. Building completion	4132-02. Electric power facilities construction
				b11-5	Wind power generation facilities	3110. Manufacture of electric motors, generators and transformers	3211-01. Rotating electrical equipment
				b11-6	Biomass energy utilization facilities	3110. Manufacture of electric motors, generators and transformers	3211-01. Rotating electrical equipment
				b11-7	Small and medium hydro power	3110. Manufacture of electric motors, generators and transformers	3211-01. Rotating electrical equipment
				b11-8	Geothermal power generation	3110. Manufacture of electric motors, generators and transformers	3211-01. Rotating electrical equipment
				b11-9	Measures for power system stability	3130. Manufacture of insulated wire and cable	2721-0. Electric wires and cables
				b11-10	Wood stove	2731. Casting of iron and steel	2631-031. Cast materials
		b12	Renewable energy electricity sales	**b12-1**	New energy power generation business	4010. Production, collection and distribution of electricity	5111-03. Electricity (water power, etc.)
		b13	Operation and maintenance of renewable energy power generation facilities	**b13-1**	Operation and maintenance of wind power generation facilities	7499. Other business activities n.e.c.	8519-09. Other business services
				b13-2	Operation and maintenance of non-residential solar PV power generation system	7499. Other business activities n.e.c.	8519-09. Other business services

Source: Zhou and Mustafa (2015). Note: n.e.c. stands for "not elsewhere classified".

2.1.1.2 Spatial extensions of the IO-SAM

A national economy, and particularly a regional (or sub-national) economy within a country, is often an open system which interacts with other countries or regions through imports/exports or inflows/outflows of energy, materials, natural resources, capital resources and human resources. Through international trade or interregional trade within a country, policies implemented in one place can extend influence beyond the geographical boundaries. For example, a carbon-pricing policy implemented in one country may have an adverse impact on the industrial competitiveness of domestic energy-intensive sectors due to the changes in the terms of trade, which may benefit the competing sectors in other countries. In addition, goods produced in one region/country can be consumed by the people located in other regions/countries via transportation and trade. Although the consumption stage might be clean, off-site pollution and emissions, or the degradation of the natural environment during the production stage may be left to the producing country. Furthermore, there are also substantial economic and environmental impacts associated with the relocation of the polluting industries from one region/country with stricter environmental standards to a region/country with less stringent environmental requirements and often the impacts to different regions/countries are different. A country/region that accepts the relocation of a polluting industry is often referred to as a pollution haven.

To capture the above-mentioned spatial impacts associated either directly or indirectly with trade, a MRIO model can adequately present the locations of the origin and destination of individual trade flows related to the inter-sectoral transactions. In a MRIO model, not only the producing sectors and the consuming sectors for the intermediate demand and the final consumers (e.g. the households, the government and investment, etc.), but also their locations will be traced. Table 3 is a simplified framework of a two-sector and two-region MRIO, where all the entries are presented in a bivariate by indicating the sectors (both producing and consuming sectors) in subscripts and regions (both the origin and the destination) in superscripts. For example, x_{12}^{21} indicates the transaction or trade from Sector 1 located in Region 2 to Sector 2 located in Region 1.

Table 3: *Preparation of the correspondence table for EGSS and IO sectors*

		INTERMEDIATE DEMAND				**FINAL DEMAND**		**EXPORT TO** (ROW)	**TOTAL OUTPUT** (x)
		$s1r1$	$s2r1$	$s1r2$	$s2r2$				
SUPPLY (s)	$s1r1$	x_{11}^{11}	x_{12}^{11}	x_{11}^{12}	x_{12}^{12}	f_1^{11}	f_1^{12}	e_1^{1ROW}	x_1^1
	$s2r1$	x_{21}^{11}	x_{22}^{11}	x_{21}^{12}	x_{22}^{12}	f_2^{11}	f_2^{12}	e_2^{1ROW}	x_2^1
	$s1r2$	x_{11}^{21}	x_{12}^{21}	x_{11}^{22}	x_{12}^{22}	f_1^{21}	f_1^{22}	e_1^{2ROW}	x_1^2
	$s2r2$	x_{21}^{21}	x_{22}^{21}	x_{21}^{22}	x_{22}^{22}	f_2^{21}	f_2^{22}	e_2^{2ROW}	x_2^2
IMPORT FROM (ROW)		m_1^{ROW1}	m_2^{ROW1}	m_1^{ROW2}	m_2^{ROW2}				
VALUE-ADDED (v)		v_1^1	v_2^1	v_1^2	v_2^2				
TOTAL INPUT (x)		x_1^1	x_2^1	x_1^2	x_2^2				

Source: Zhou, et al., 2010.

Depending on the geographical levels under consideration (either a province, a city or the northern and southern parts within a country or a multi-country region, e.g. North America, Europe, and Asia and the Pacific, etc.), a MRIO model can take the forms of modelling multiple regions at subnational levels, or modelling multiple countries at supranational levels. By presenting the spatial locations of all the variables and parameters included in a national IO model, an MRIO model can therefore analyse the spatial impacts of production, consumption, investment, and other policy shocks. For example, in the area of sustainable consumption and production, there have been debates on production-based vs. consumption-based responsibility for the emissions embodied in international trade. MRIO models can be easily used to account for both production-based (the so-called territorial approach) and consumption-based (such as carbon footprints) emissions or other environmental impacts (such as water footprint or ecological footprints) that are embodied in tradable goods (Lenzen, et al., 2004; Peters and Hertwich, 2008; Wiedmann, 2009; Zhou, 2010; Zhou and Imura, 2011).

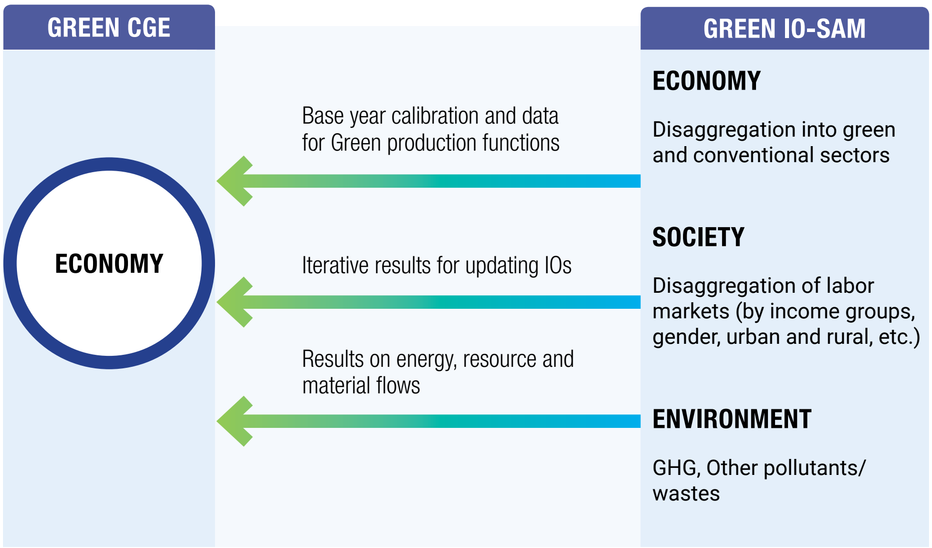
A multi-region CGE model built upon a MRIO/multi-region SAM can function the same way as a single-country CGE model however with the power of conducting spatial analysis.[18] For example, a multi-region CGE model is often used to analyse trade-related policies, such as the impacts of free-trade agreement in a specific region, or the impacts of carbon pricing policy on the industrial competitiveness of domestic industries and the implementation of border carbon adjustment policies (Zhou, Yano & Kojima, 2013).

From the data availability viewpoint, many countries already established the MRIO model at the subnational levels. For example, a MRIO model for China's eight regions was constructed for 2000 (IDE-JETRO, 2003). In Japan, a MRIO model for 47 prefectures was constructed to analyse carbon leakage and economic leakage across regions within Japan (Hasegawa et al., 2015). A MRIO model was constructed covering the US at the state level and 100 countries. It was used to track consumption-based CO_2 emissions across US regions (Caron, et al., 2014). An interregional IO model was constructed for five regions in Indonesia, which was then used for building an interregional SAM and eventually the construction of an interregional CGE model. There have also been efforts devoted to establishing the database and construction of multi-country IO models. For example, the Institute of Developing Economics, Japan External Trade Organization (IDE-JETRO), compiled Asian International Input-Output Tables for 1985, 1990, 1995, 2000 and 2005 and several bilateral IO tables for Japan and other Asian countries such as China, Republic of Korea, the Philippines, Thailand, Malaysia and Singapore, etc. The Global Trade Analysis Project (GTAP) database and the GTAP model were constructed through the coordination of Purdue University and have been widely used by academia and policy researchers for assessing trade-related issues. The World Input-Output Database (WIOD), a public database funded initially by the European Commission as part of its seventh Framework Programme, provides world input-output tables (WIOT) covering 27 EU countries and 13 other major countries in the world for the period from 1995 to 2011 (WIOD website).

2.1.2 The green CGE model

A standard CGE may be transformed into a "green" CGE either by using input data on green sectors coming from the expanded IO-SAM; or by making specific modifications to the conventional CGE model to reflect the use of environmentally efficient technologies. These two approaches can be integrated (Figure 6). The construction of a green CGE at the country level will also very much benefit from the existing modelling work already available in many countries.

Figure 6: *Diagram of the linkages between the CGE model and the IO-SAM model*



Source: Figure created by the authors.

The presentation of the Green CGE has two levels. First, it presents a generic discussion of the main changes that a standard CGE should undergo to become "green". Second, the specific discussion on how to undertake those changes to obtain a "green" CGE model will be largely based on the present CGE model for Mexico (Ibarrarán and Boyd, 2006).

2.1.2.1 Technical changes to the CGE to make it green

Using the Mexican model as an example, the standard CGE would be modified in three important ways in order to be more conducive to modelling and simulating the economic, social, and environmental effects of a host of policies enacted to promote green growth.

1) The first modification of the model implies incorporating the latest data available in the SAM used in the simulations. This data includes IO tables, consumption data by household income, "green" accounting matrices, government spending and taxation data, data on GDP growth, data on depreciation, and data on the country´s international accounts. In the case of Mexico, such data will come from a number of sources, including INEGI, Banco de México, World Bank, SEMARNAT, and the Mexican Finance Ministry (SHCP).

2) The second major modification of the model deals with its treatment of water. Currently, water is only treated insofar as it is a consumer good and, as such, is a part of the typical consumer's budget (for each income group). Water, however, serves as a major input to the agricultural and manufacturing sectors, and thus has a major role as both a primary input to production and as a recipient of both point and non-point pollution.[19] To account for this increased role of water in the model, "green" accounting matrices mentioned above will be used and treated as a primary input in the modified CGE model.

3) Finally, the sectors in the model – agriculture, livestock, forestry, manufacturing, chemicals and plastics, mining, oil and gas, transport, electricity, services, and refining – will be re-aggregated from

the new IO tables and (in addition to the present production sectors) a special "green" production sector will be constructed consisting of those manufacturing, refining, and chemical subsectors where environmentally efficient technologies (such as wind turbines, solar panels, efficient lights, etc.) can be expected to occur. Then using a methodology, first theoretically developed by Dixit and Stiglitz, and computationally implemented by Rutherford et al. (1997), this sector will be modelled as a monopolistically competitive industry capable of generating endogenous (as opposed to exogenous) economic growth.

At this point, and notwithstanding the three changes discussed above, GE policies may be reflected in the Boyd-Ibarrarán model through changes in sectoral investment into different sectors that may in turn, for example, produce capital goods for the energy sector. In this sense, a large part of the investment goes into manufacturing. The productivity of labour can also be exogenously changed based on parameters that can be found or calculated. The model distinguished between formal and informal labour per sector, and these are taxed accordingly. After policies change (e.g. by changing the tax structure by sector or any of the discussed GE policies), worker migration between formal and informal sectors can be tracked. Capital and education, as well as training may have an effect on labour productivity, which in turn may affect the economy as a whole. Changes in water availability also changes productivity, particularly in primary sectors (agriculture, livestock, and forestry) and in hydropower.

For policymakers to understand the multidimensional impacts of investing in green sectors, the economic forecasts of the green CGE model must be coupled with forecasts on the social and environmental dimensions, through a linkage with a green system dynamics model (see section 2.2).

2.1.3 The SD model and how it is "greened"

The System Dynamics (SD) model component of the IGEM framework can be best thought of as an SD model designed to focus on green policy analysis and to work in concert with the green CGE and green IO-SAM models. To do so, a green version of the SD model will develop the sector structure necessary to address the GE policies under consideration, while keeping the model tractable for interlinking with the CGE and IO components of the IGEM framework. As a first step, the core SD model will be presented and, as a second step, the presentation will describe how the core SD model is greened and linked with the green CGE.

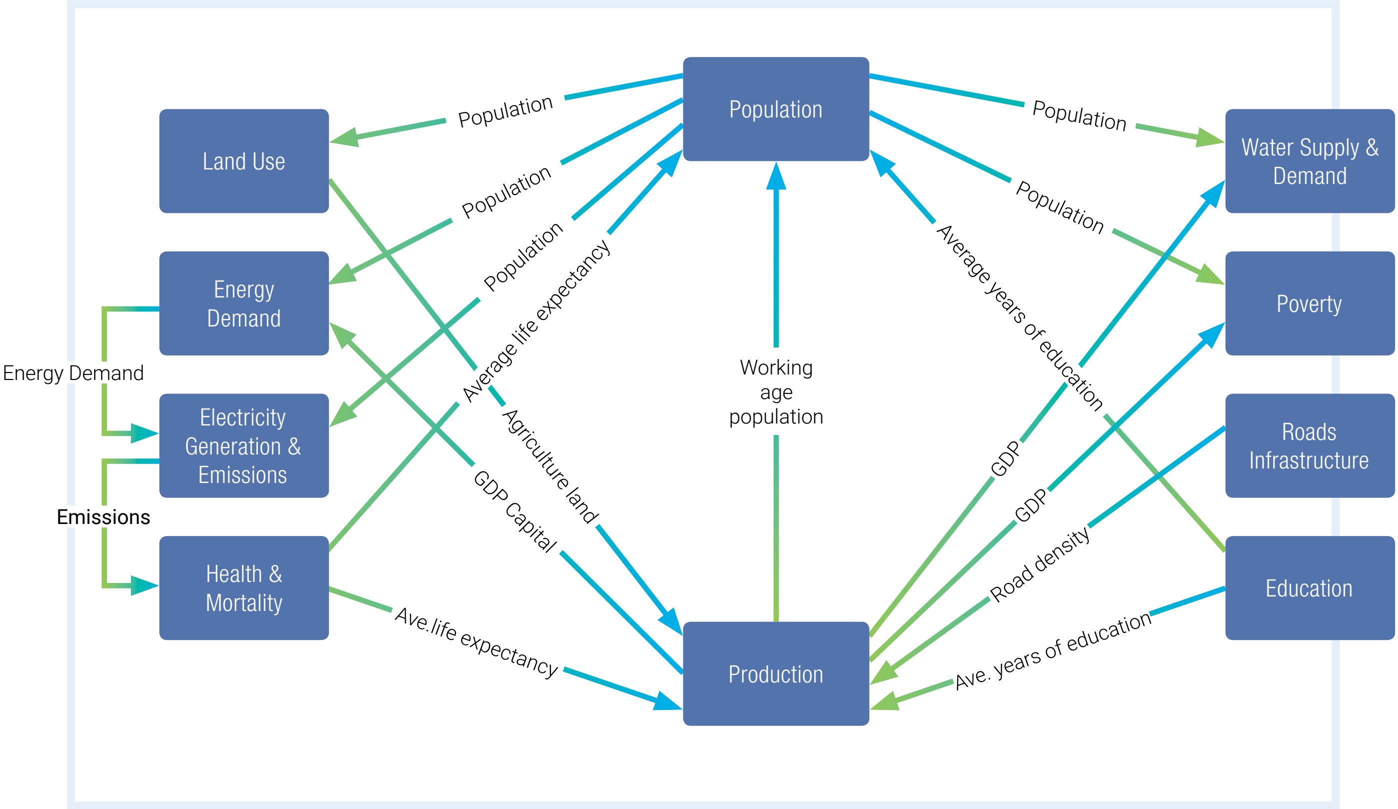
2.1.3.1 The core SD model

The core SD model contains 10 sectors,[20] which could also be called 'modules' or 'sub-models'. These are: (a) population and fertility; (b) education;(c) health and mortality; (d) poverty; (e) production; (f) land-use; (g) water demand & supply; (h) energy demand; (i) electricity generation and emissions; and (j) roads infrastructure. An additional sector is currently being developed to account for Fossil Fuel Resources. The number of sectors in the SD model is fewer than in a T21 model, which can contain 50 or more modules.[21] Nevertheless, all three dimensions of sustainable development are addressed: economic (production and energy demand sectors), social (population and fertility, education, roads infrastructure, health and mortality, and poverty sectors), and environmental (land-use, water demand and supply, and electricity generation and emissions sectors). These sectors are interconnected by a web of feedback loops and there are overlaps between dimensions in some sectors: for example, there are both environmental and economic aspects to the electricity generation and emissions sector.

Figure 7 shows the core structure of the SD model. Model sectors, or 'modules,' are indicated by hexagons. Key information transfers between the SD sectors are indicated by labelled arrows. The sectors contain distinct decision-making processes. During simulation, the sectors receive information cues from other sectors; they then process this information and transmit it to other sectors and update various indicators of the system state.

The education and health sectors exert important influences on the production and population sectors. These latter two directly influence the remaining sectors. Note that the land sector influences the Production sector, which includes industry agriculture and services, through the availability of agricultural land.

Figure 7: *Macro structure of the core SD model*

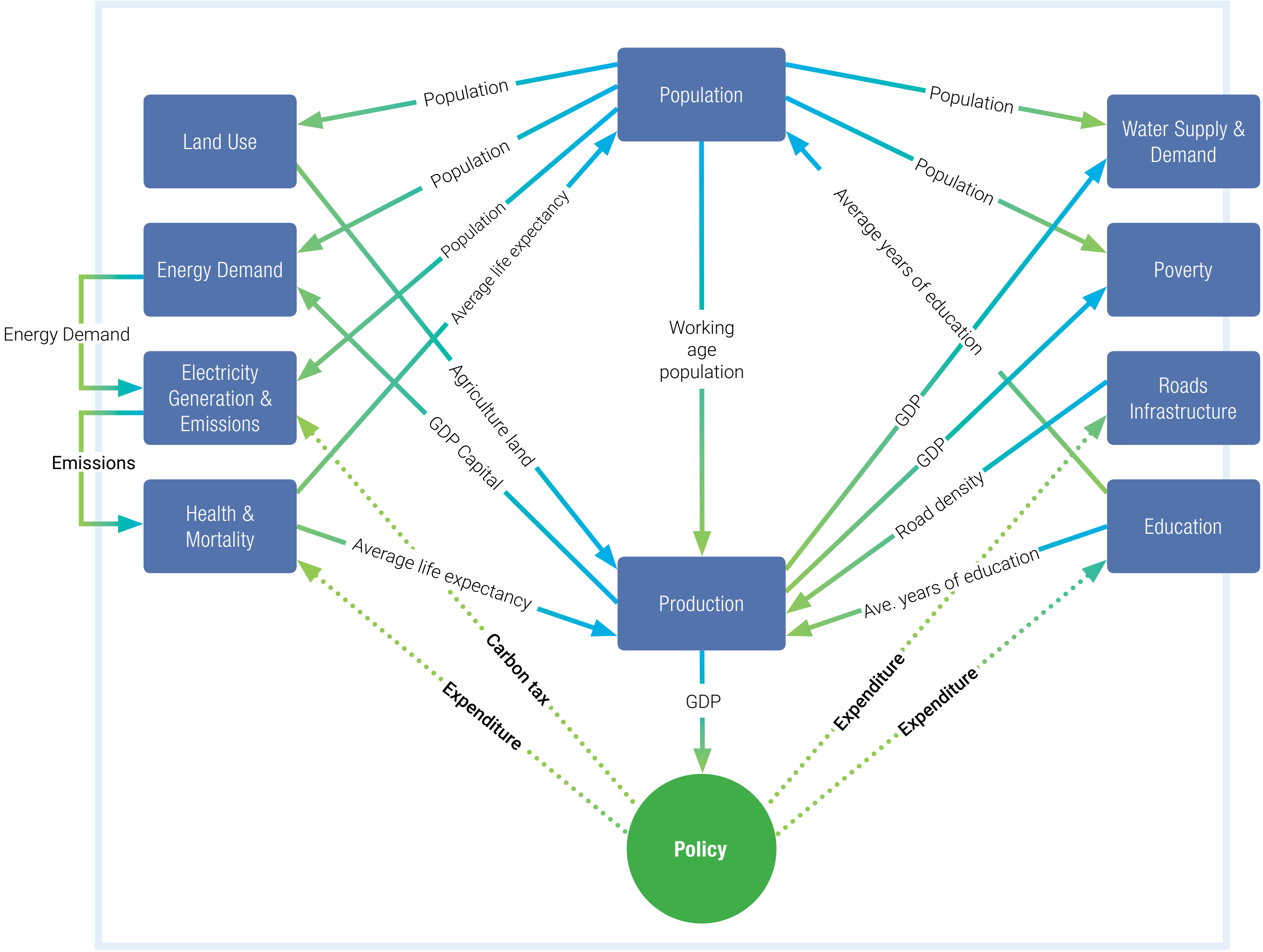


Source: the Millennium Institute

Figure 8 shows the SD model structure with policy elements in place. The policy information linkages are indicated by dashed arrows. The policy shown is a carbon tax policy that influences energy demand, and government expenditures for health and education.

The model structure described on Figure 8, simulates as a stand-alone SD model. For hard-linked simulation with the green CGE and IO-SAM models, the production sector will be disconnected and the associated information linkages will couple the CGE, IO-SAM and SD models.

Figure 8: *Macro structure including policy elements*



Source: the Millennium Institute

2.1.3.2 The green SD model

To understand how the SD model can be made compatible to analyse GE policies, the model must be "greened". For the purpose of the IGEM framework, the energy sector has been chosen as the green sector to be presented in more detail. A green SD will thus be the core SD with a disaggregated sector to help analyse a specific GE policy question. In the energy demand sector, the following types of energy sources are explicitly modelled: electricity, oil, coal, gas, renewables, providing the policy space for shifts from more polluting to less polluting energy types. Prices for each energy type are included and may be adjusted to account for carbon tax with resulting gradual demand shifts. In the electricity generation & emissions sector energy types are disaggregated for electricity generation, upstream carbon taxes may then cause shifts over time in energy technology.

Energy demand

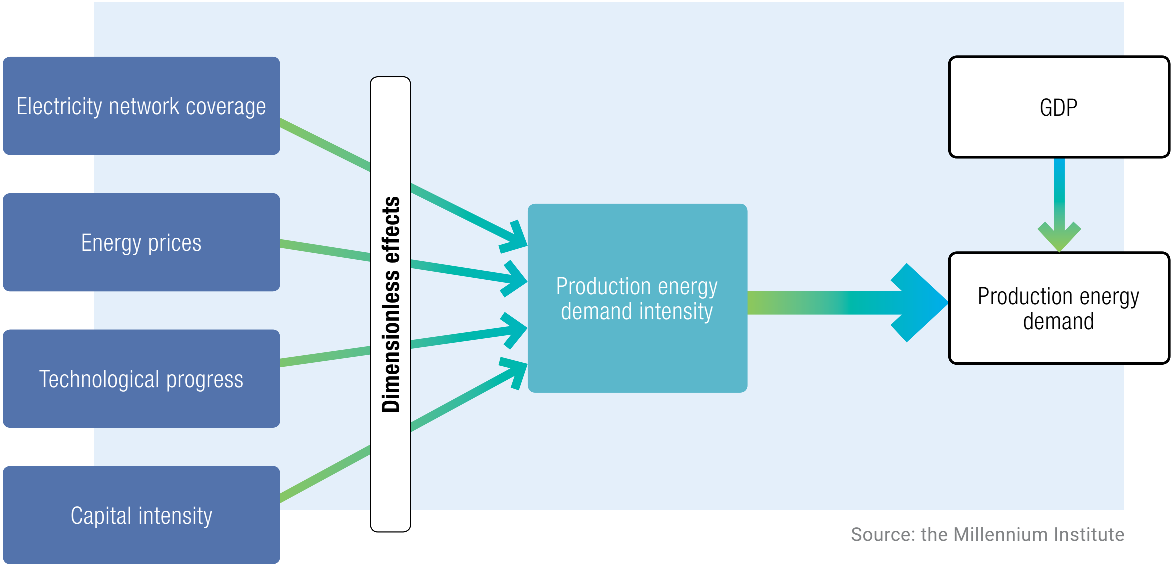
In the green SD model, the energy demand sector focuses on final energy consumption. The electricity generation and emissions sector addresses primary energy consumed to produce electricity (in addition to GHG emissions).

Final energy demand

Four categories of energy demand are modelled: (a) production energy demand; (b) Residential energy demand; (c) transportation energy demand; and (d) 'Other' energy demand. For each of these demand categories, energy types (electricity, oil, coal, gas, and renewable) are explicitly modelled using arrayed variables. Energy prices (for each energy type) are defined exogenously, but normalized against their initial values. The figures below are simplified causal diagrams of the model structure.

Figure 9 shows a simplified causal structure for production energy demand (this is final energy demand). Production energy demand (for the five energy types) is the product of production energy demand intensity (for each energy type) and real GDP at factor cost. Production energy demand intensity is influenced by changes in electricity network coverage, energy prices, technological progress, and capital intensity; this is shown on the left in Figure 9. As electricity network coverage increases, electricity demand intensity will also tend to increase, while final use of other energy types will decrease.

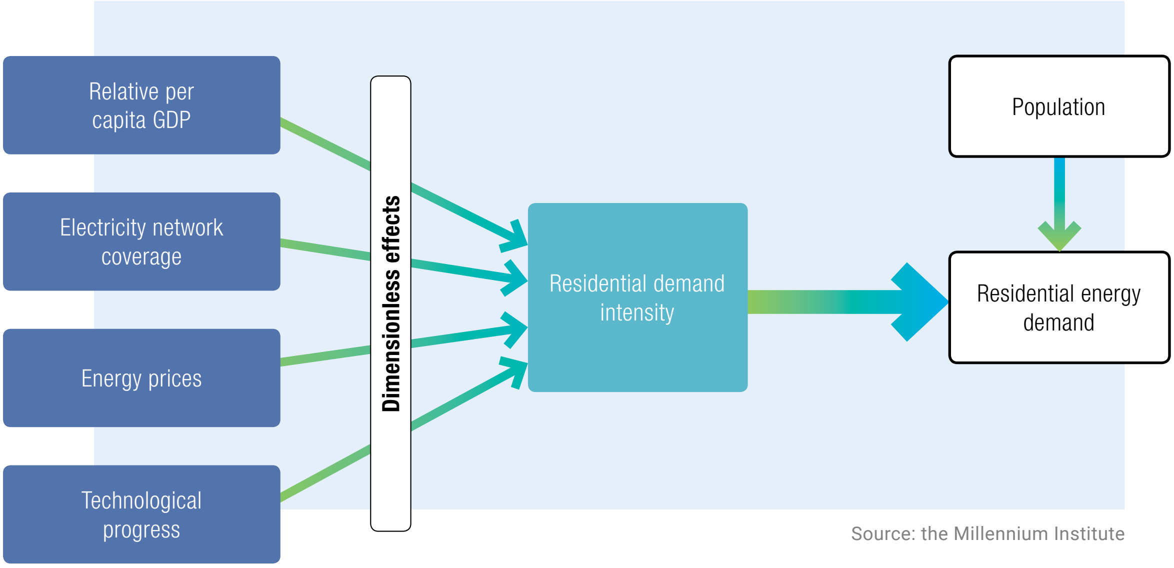
Figure 9: *Causal structure for production energy demand*



Source: the Millennium Institute

Figure 10 shows a simplified causal structure of Residential energy demand. Residential energy demand is the product of Residential energy demand intensity and Population. There are some differences in the influencing variables from the Production energy demand case: Energy intensity is influenced by relative per capita GDP (current per capita GDP divided by initial per capital GDP), while Residential demand intensity is not influenced by capital intensity.

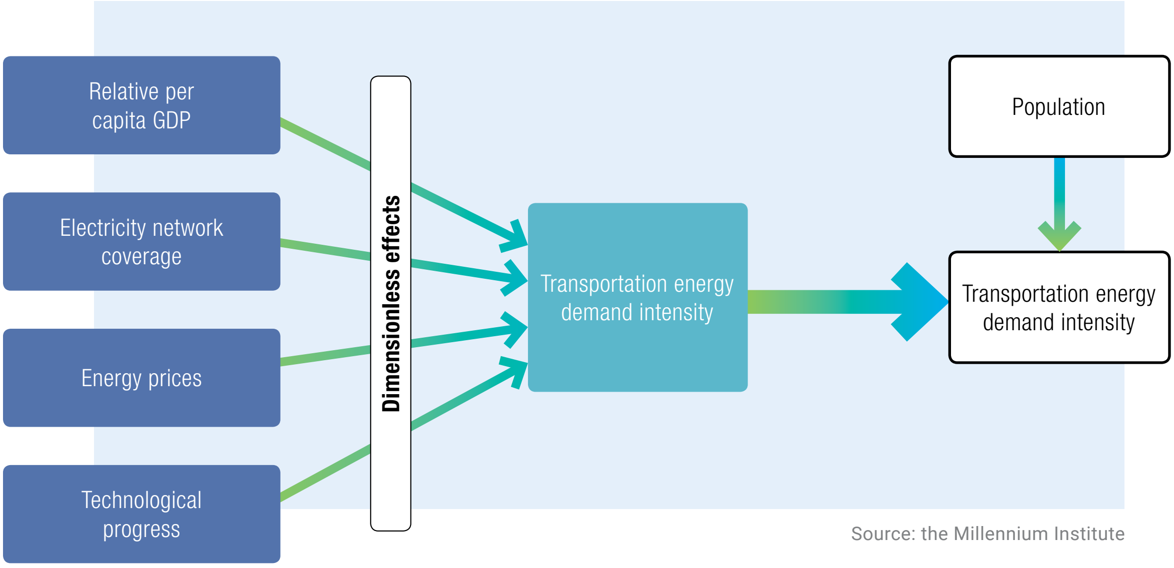
Figure 10: *Simplified causal structure of residential energy demand*



Source: the Millennium Institute

Figure 11 shows a simplified causal structure for transportation energy demand. Transportation energy demand is the product of population and transportation energy demand intensity.

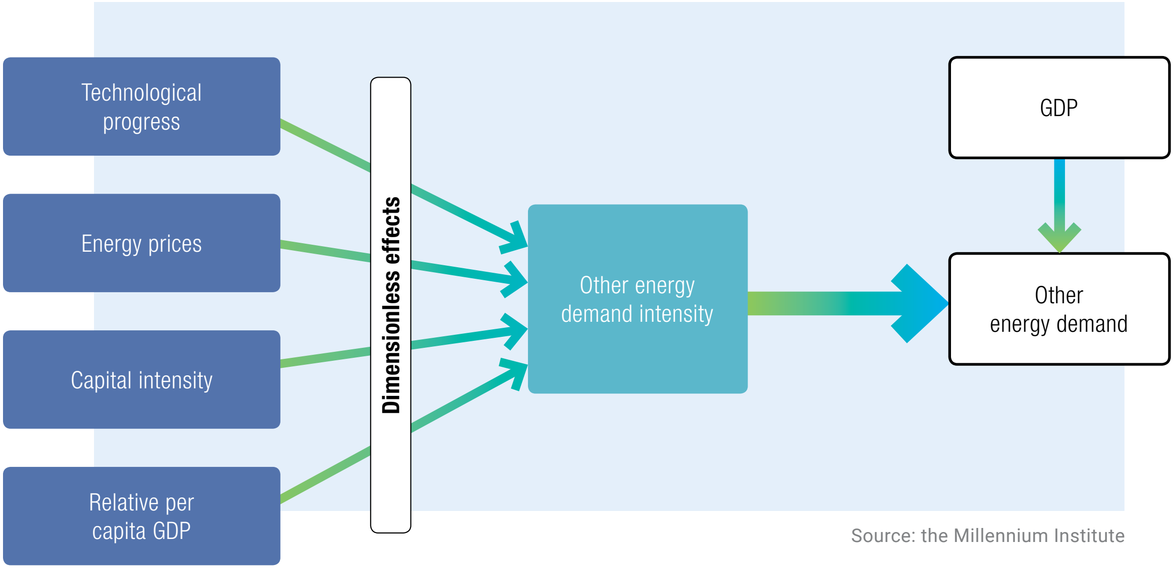
Figure 11: *Simplified causal structure of transportation energy demand intensity*



Source: the Millennium Institute

Figure 12 shows a simplified causal structure of Other energy demand. 'Other' represents energy demand not into the production, residential, or transportation categories described above. Similar to production energy demand, other energy demand is the product of other energy demand intensity and real GDP at factor cost. The influencing variables include Technological progress and Energy prices as with all the categories of energy demand. However, what is different from the structure for production energy demand is the use of relative per capita GDP, reflecting an assumption that much of other demand is artisanal in nature.

Figure 12: *Simplified causal structure of 'other' energy demand*

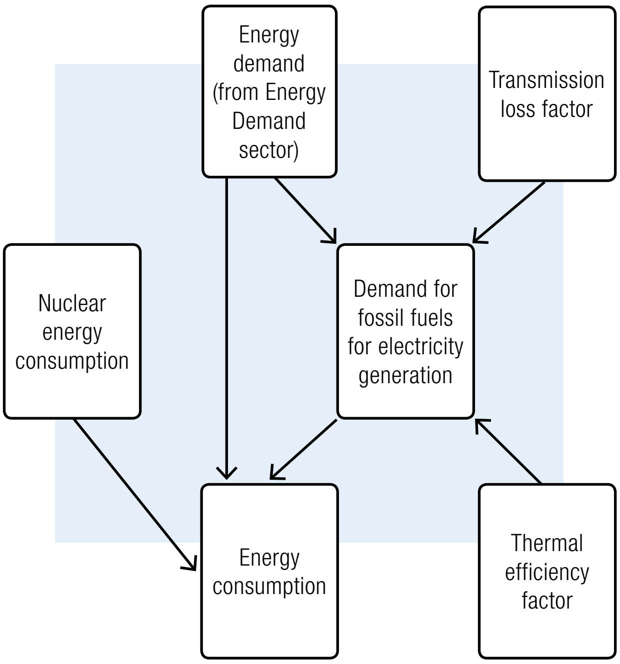


Source: the Millennium Institute

Primary energy demand and related emissions

Figure 13 shows a simplified causal structure for primary energy consumption. Energy demand is developed from the Energy Demand sector and is the sum of the four categories of energy demand described above (production, residential, transportation and other). Energy demand includes demand for each of the five energy types (electricity, oil, coal, gas, renewables). Energy consumption includes all the demand for the five energy types plus additional consumption for the generation of electricity, which is shared between three types of fossil fuel generation (oil, coal, gas), and nuclear (defined exogenously). Transmission losses and thermal efficiency are accounted into the demand for fossil fuels for electricity generation.

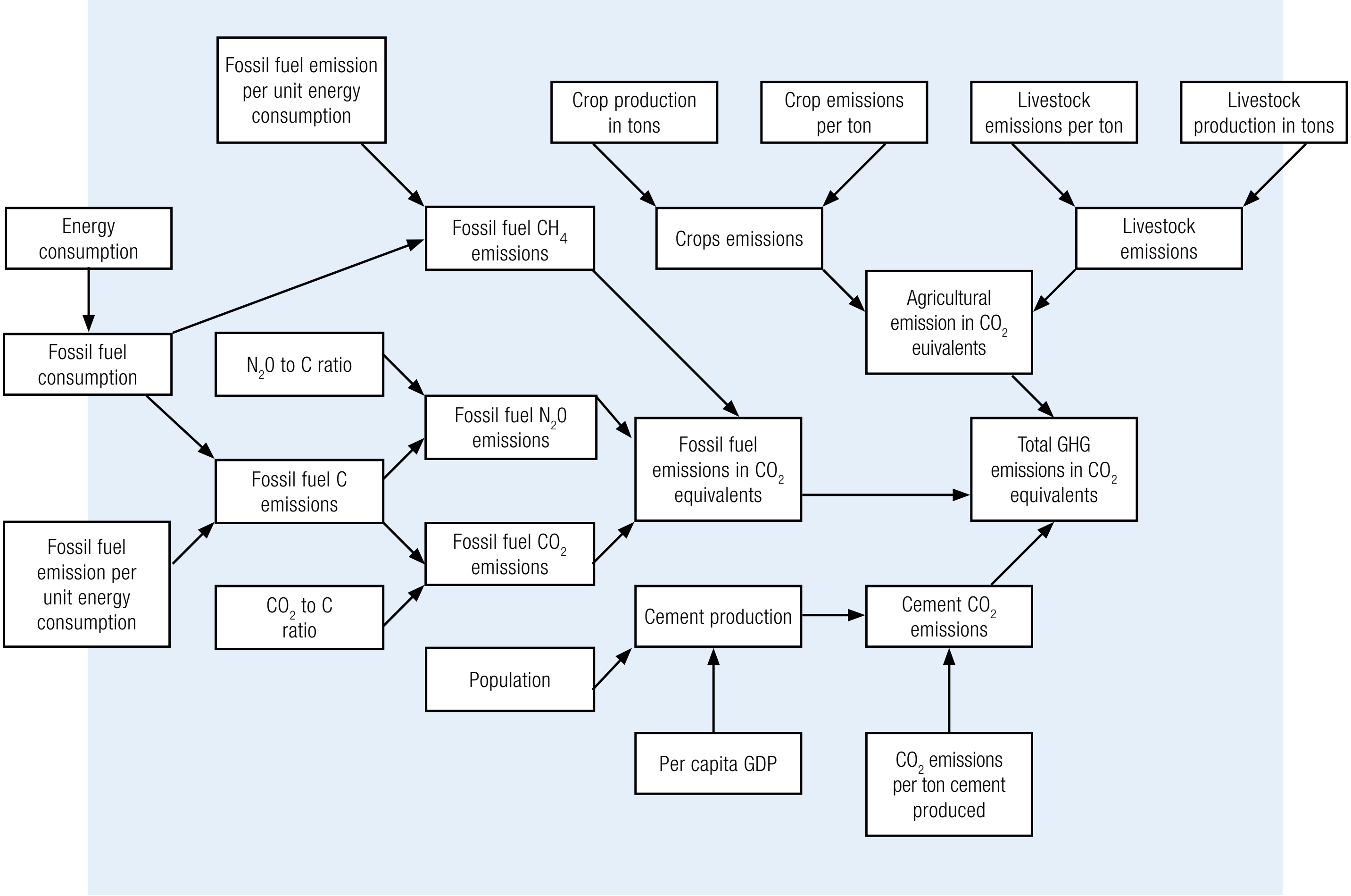
Figure 13: *Simplified causal structure of primary energy consumption (in electricity generation & emissions sector)*



Source: the Millennium Institute

Figure 14 shows the causal structure for GHG emissions. GHG emissions from fossil fuel consumption, cement production, and agriculture are accounted for. Fossil fuels emissions of carbon (C) and methane (CH_4) are calculated by multiplying energy consumption (of each fossil fuel type) by its respective conversion factor (obtained from IPCC 2006. Conversion factors for CH_4 and nitrogen (N_2O) to CO_2 equivalents are from the ANPA-Italy.[22] Crops and livestock emissions (in CO_2 equivalents) are the product of production (metric tonnes/year) and respective emissions factors (FAO[23]). Non-energy CO_2 emissions from cement manufacture are the product of cement production (metric tonnes/year) and an emissions factor (metric tonnes CO_2 per metric tonne cement produced).

Figure 14: *Simplified causal structure for GHG emissions*



Source: the Millennium Institute

The following is a list of the initial conditions for each sector. It is important that the initial values used in the SD and CGE models closely match each other. In the case of a soft linkage, discrepancies in behaviour between the models can be attributed to parametric or structural assumptions. For hard linkage matching initial values will be required for coherent simulation.

Population and fertility

- Initial population – available for five year cohorts from UN Population Division.
- Initial desired number of children per woman
- Initial contraceptive prevalence

Education

- Initial average years of schooling
- Initial target years of schooling
- Health and mortality
- Initial average life expectancy

Production

- Initial capital (combining industry, services, agriculture)
- Initial agricultural land
- Initial labour force
- Initial production (aggregate for industry, services, agriculture)
- Initial real GDP
- Initial real per capita GDP
- Initial propensity to invest

Land use

- Initial agricultural land
- Initial settlement land
- Initial forest land

Water demand and supply

- Initial per capita water demand
- Initial industry water demand per unit of output

Energy demand

- Initial capital intensity
- Initial electricity network coverage
- Initial production energy demand intensity
- Initial residential energy demand intensity
- Initial transportation energy demand intensity
- Initial other energy demand intensity

Electricity generation and emissions

- Initial per capita cement production

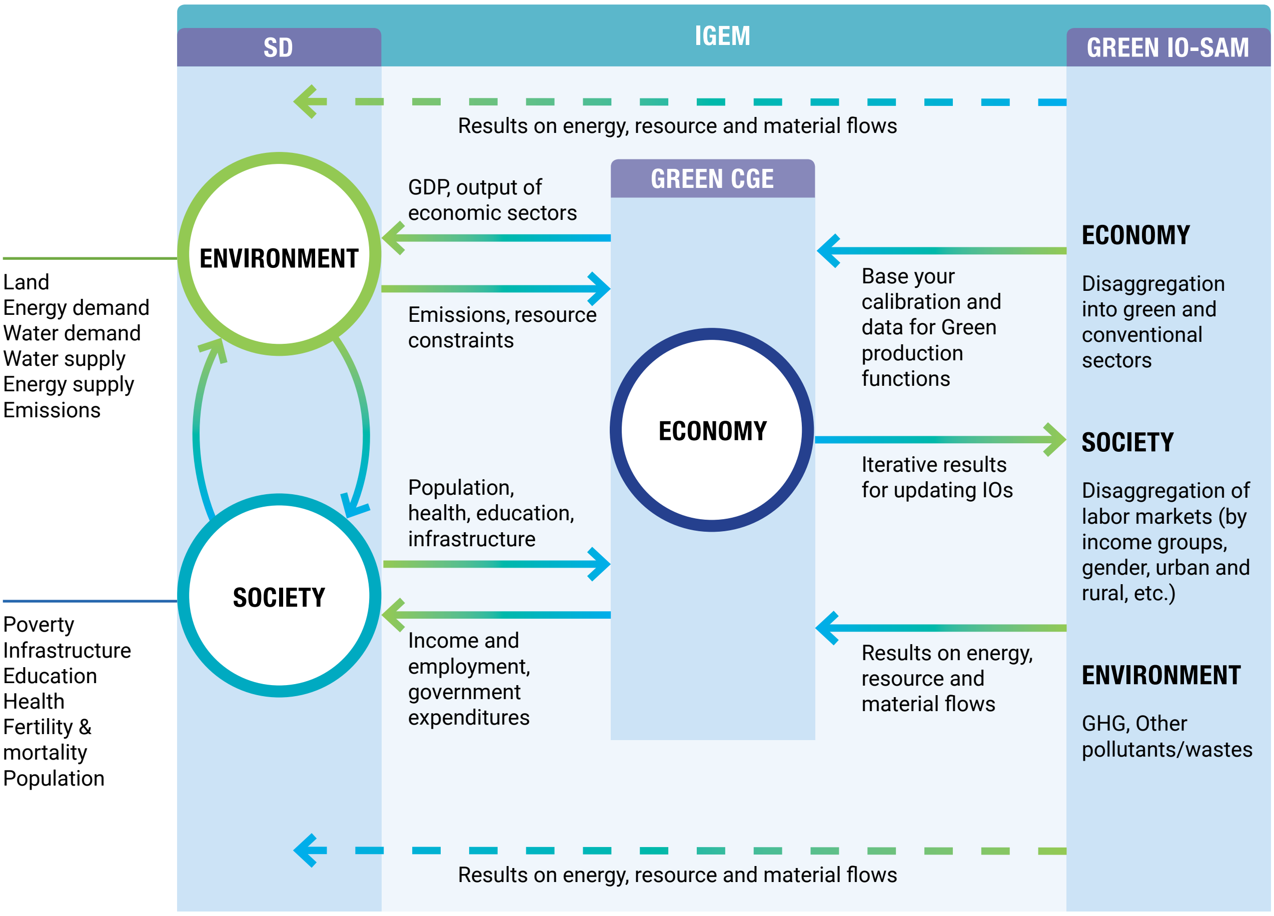
To summarize, the SD component complements the green CGE in assessing the impacts of investments by facilitating scenario analysis. The SD model accounts for information linkages and feedback loops between sectors, showing how benefits and trade-offs of investments propagate across sectors, impacting, for example, the growth and distribution of income, health, and environmental sustainability[24] (Figure 15).

2.2 LINKAGES BETWEEN MODELS: THE GENERIC IGEM FRAMEWORK

This section presents the generic IGEM framework, i.e. the linkages between the core SD model, the CGE model and the IO-SAM models. Figure 15 illustrates the information and decision-making structure of the IGEM.

Information transfers (or linkages) between the three component models are indicated by arrows. The solid line arrows indicate more explicit linkages in the IGEM framework, while the dashed line arrows between the IO-SAM and SD indicate indirect linkages that occur through the CGE model. Rectangles indicate model boundaries. In addition to the indicated external linkages between modelling approaches, the SD model features internal feedback between model sectors within and across the Society and Environment dimensions (as already shown in Figure 8). A more complete list of variables allowing exchanges between the three models is included in Table 4.

Figure 15: *Diagram of the IGEM framework information structure*



Source: Figure created by the authors.

Table 4: *Input variables for the three component models*

SD	CGE	IO-SAM
— Real Gross Domestic Product at factor cost — Real Gross Domestic product at market prices — Real agriculture production (value added) — Real crops production (value added) — Real livestock production (value added) — Real industry production (value added) — Real services production (value added) — Investment by sector (agriculture, industry, services) — Initial capital by sector (agriculture, industry, services) — Depreciation by sector (agriculture, industry, services) — Employment by sector (agriculture, industry, services) — Real household disposable income — Real household disposable income in PPP — Real government expenditure for education — Real government expenditure for health care — Real government expenditure for infrastructure	— Population growth — Initial GDP growth by sector and the aggregate economy — Technological change by sector — Subsidies, taxes, tariffs to apply — Depletion of oil — Depletion of natural gas	— Data on disaggregated green and conventional sectors (technical coefficients, etc.); — Data on disaggregated labour markets (by income groups, gender and urban and rural, etc.).

Source: Table compiled by the authors.

One of the main advantages of the IGEM is the linking between the green CGE model and the green SD model, because the SD model is able to connect the economic forces that impose pressure on the environment with other important dimensions of sustainable development like health, which is clearly an advantage of the integrated approach (as discussed in the previous sections). The CGE can provide information about the environment, as well as poverty and inequality, but it will be limited in terms of what it can predict about the implications for health outcomes. The IGEM framework allows the models to address broader policy questions that go beyond the economic and environmental spheres to also incorporate social aspects.[25]

In addition, although CGE models do incorporate environmental effects into their analysis, these models are, by their very nature, models to look at economic welfare and competitive markets (which presents significant challenges to address the existence of public goods or externalities).[26] Furthermore, physical quantities in CGE models are usually defined in terms of economic units, while SD models can also keep track of biophysical quantities. Hence, another advantage of the IGEM framework is to use two self-contained models and use the results of each of the models to complement each other rather than adding sectors to either model in an "ad-hoc" way.

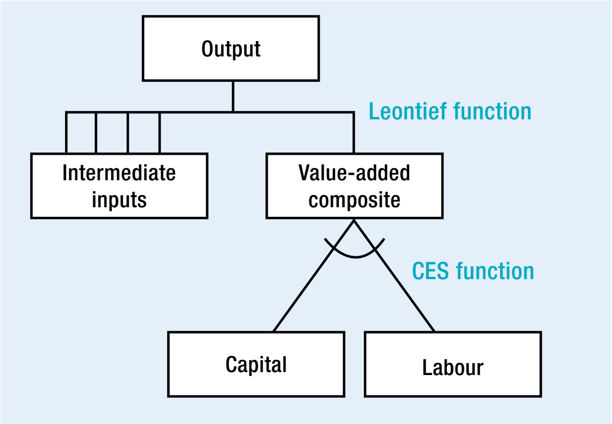
The three models connected through the IGEM were not originally conceived for this purpose. One of the main challenges of the generic IGEM framework is to identify entry points in each of the models to create a consistent interface. The next sections present more explicitly how the IGEM framework makes linkages between the different modelling tools.

2.2.1 Linking the IO-SAM with the CGE

The primary linkage of the IGEM framework is between the IO-SAM and the CGE. This linkage is important because it later determines how green sectors are taken into account in the green version of the models. The IO table and the SAM[27] are the fundamental database and building blocks of an empirical CGE model. An IO table is usually used to build the production function for the intermediate inputs and value-added composite at the top level of the nesting approach (see Figure 16). In addition, the base-year SAM is usually used for the calibration of a CGE model. Therefore, a green IO-SAM can provide a good foundation for the green CGE to have a better resolution for the green sectors through its mechanisms of optimization and responses to the price changes based on factors such as the elasticity of substitution.

In addition, since the IO-SAM models have the unique characteristic of accounting for income, employment, resource and material flows in a tractable and transparent way, the IO-SAM can also be used as a model serving these particular accounting purposes. Lacking the dynamic mechanisms for mid- and long-term simulation of the standard IO model, it is beneficial to link the IO-SAM with the CGE model using the iterative results of policy simulation, e.g. price index change, output change, etc., on a 5-year interval, for example, as inputs to update the base-year IO which can be used for the accounting purpose.

Figure 16: *Classic production functions*



Source: Zhou X.(2015).

2.2.2 Linking the CGE with the SD model

The secondary linkage is between the CGE and the core SD model. CGE models are only capable of calculating market values. Physical impacts, changes in natural capital, and impacts on health or air pollution are not accounted for in the CGE. To be able to answer GE policy questions, the CGE model needs to be linked with other models, such as the core SD model, because the SD is capable of including sectors, such as water use, waste, buildings, tourism and human and environmental health in its modelling.

The CGE model requires the following input information (listed in Table 4): population growth, initial GDP growth by sector and for the aggregate economy, technological change by sector, depletion of oil and depletion of natural gas. To ensure consistency between the CGE and the SD models, the following conditions need to be fulfilled:

1) Parameter selection: A common set of carefully chosen parameters for the two models needs to be selected to guarantee consistency;

2) Variable trends: The input variables must be compared to check whether they follow the same trend, even before introducing any GE policies;

3) Other common variables, such as initial growth rates and policy variables (taxes and subsidies), must be as consistent as possible in the two models;

4) Model calibration: Caution should be used to select the same values of parameters for labour growth, labour and capital productivity, and economic growth in the two models;

5) Initial conditions: The two models should share the same initial conditions.

These conditions will ensure that the policies studied are introduced and interpreted into each model in a similar fashion (i.e. their interpretation across models is consistent). The simulation time horizon for this exercise will be 1990-2036, but can be adjusted according to need.

The IGEM framework integrates two types of linkages between the CGE and the SD model:

A soft linkage. In the soft linkage approach the models are run independently. The entire scenario is run on one model (either the SD or the CGE), the results are fed into the other model, and vice versa. This iterative loop of behaviour assessment and model revision continues until the model behaviours converge to an acceptable level. In this non-coupled approach, the SD model will contain its own internal economic sectors, to be able to run independently.

In the case of the soft linkage, each model runs on its own without direct input from the others. The idea is that comparison of the simulation results and structures of different models can lead to insights to the real-world system. For example, comparing the SD and CGE models, some differences in simulation outcomes may be due to the explicit time lags in the SD model (strength of SD modelling). Other differences may be due to the greater degree of disaggregation in the CGE model (strength of the CGE model). Both these differences may contribute to a better understanding of the behaviour of the real world system.

A hard linkage. In the hard linkage approach, the CGE and SD models are manually coupled. Each model is run for 2-year iterations. After each iteration, designated output values from each model are transferred as inputs to the other model. A series of 2-year iterations are thus run over the entire time horizon to simulate the system behaviour. The information structure in Figure 13 shows the paths of information exchange. In the coupled approach the CGE and IO-SAM models will account for the economic decision-making, the internal economic sectors of the SD model will be disconnected.

In the case of the hard linkage, the models are more directly linked, such as, for example, in the case of the "one-way" linkage in which the SD model is run with exogenous time-series data produced by the CGE model. It was not possible to run a "full" hard linkage between the SD and the CGE because the models run differently. The SD model runs recursively; all dynamic variables are updated at each time step. However, the CGE model makes use of a solver to find an instantaneous solution across the time horizon. Devising recursive interactions between the CGE and SD models through the time horizon is a key area for future research. A "one-way" hard linkage was run instead, whose main value is that the SD model is able to provide biophysical outputs such as CO_2 emissions and particulate pollution and their effects on health in direct non-monetary units that the CGE is currently unable to provide. However, the "one-way" linkage effects of increased longevity on aggregate and sectoral outcomes are used in the green CGE model. This result does not currently feed back into the SD model (this is why it is a "one-way" linkage).

It may be important to note that there is no strict demarcation between "soft" linkages and "hard" linkages since both models are self-contained. They might be viewed as a continuum where soft linkages look at one or two variables (e.g. higher productivity due to a better environment) and running the two models with each other's inputs, and a situation where the models are run multiple times with multiple re calibrations.

Another advantage of the SD linkage is that SD is not limited to expressing variables in monetary terms. Any biophysical, social, or economic units can be expressed. For example, carbon emissions can be expressed in metric tonnes per year. Therefore, the SD component can add a great deal of flexibility in the types of variables it embodies. Such variables can be readily compared to available data.

2.2.3 Linking the IO-SAM with the SD model

An additional linkage can be found between the IO model and the SD model. The accounting results as the outputs of IO analysis can be possibly linked with the environment module in the SD model. A linkage can be made to connect fossil fuel consumption to human health, for example by linking consumption of fossil fuels to particulate air pollution, and by formulating effects on human health based on WHO health standards for particulates. While the sectoral consumption and final consumption of fossil fuels can be estimated through the IO model, the linkages with the impacts on human health can be fulfilled by the SD model. With more detailed regional models or a MRIO model, it is also possible to trace where the pollution is generated and how it influences the health of the local people, even though the final consumers of the goods may not suffer from these impacts through off-site consumption attributable to interregional or international trade. It can also help analyse similar issues, such as payment for eco-system services related to international trade.

On the other hand, the SD model can generate as an output the proportion of the population below the poverty line. For the hard-linked simulation, the SD will require data on the average per capita income from the SAM or the CGE to calculate this proportion. In addition, the poverty line, or a range of poverty lines, is needed from the published data to complete this exercise.[28]

2.3 HOW CAN THE IGEM FRAMEWORK HELP TO ANSWER DIFFERENT GREEN ECONOMY POLICY QUESTIONS?

One of the main advantages of the IGEM is to help policymakers find answers to a wide set of policy questions. This section reviews some of the main policy questions[29] that can be answered with the different models included in the IGEM framework.

Table 5 presents the GE policy questions presented in the introduction and lists how the different subcomponents of the IGEM can help address these.

Table 5: *Illustrative list of GE policy questions and how the IGEM framework can address them*

GE POLICY QUESTIONS	IGEM FRAMEWORK		
	CGE	SD	IO-SAM
1. How can the impact of investments (new and shifted) and policies be assessed?	X	X	
2. What benefits might investments and policies generate across sectors in terms of economic opportunities, inclusiveness and environmental sustainability?	X	X	X
3. Are the impacts likely to be long or short-term?	X	X	X
4. How will green subsidy reforms (e.g. feed-in tariffs) likely impact productivity in GE sectors?	X	X	
5. How will green tax reforms and removing fossil fuel subsidies mobilize domestic revenues for green investment? What will be the implications of such reforms on environmental, economic/fiscal and social fronts?	X	X	X
6. How do trade policies and regulations enhance investments in GE sectors?	X		X
7. Which labour interventions deliver more (quantity) and better (quality and decent) green jobs? Which approaches create better access for the unemployed and underemployed?	X		X
8. What types of industrial policy measures are in place to support the transition towards a GE?	X		X

Source: Table compiled by the authors.

1. How can the impact of investments (new and shifted) and policies be assessed?

- The CGE is able to model the general equilibrium implications of comprehensive policies, like many of the GE investment policies. The CGE illustrates important repercussions throughout the economy given that this is an economy-wide model that shows the interactions across sectors and groups of consumers.

- The SD model allows the user to visualize how influences of investments or policies propagate throughout the system's interlinked feedback structure to generate interlinked impacts. Through the action of self-reinforcing feedback loops a relatively small investment can sometimes pay large dividends over time. For example, increased government expenditure in education, after a time lag, improves total factor productivity, which in turn increases GDP and releases funding for education. Higher levels of education of women can lead to a lower birth rate, increasing availability of basic health care, increasing productivity and GDP, making more funds available for education or health programmes. The effects of such interlinked feedback loops, coupled with time delays and cumulative effects are impossible to intuit. The SD model helps to make sense of these interconnections, to assess the system-wide influences of policies and investment, and helps to foresee undesirable unforeseen consequences.

2. What benefits might investments and policies generate across sectors in terms of economic opportunities, inclusiveness and environmental sustainability?

Economic:

- The SD model can simulate a wide range of impacts in the economy. It can be disaggregated in some economic sectors (typically agriculture, manufacturing and services), as well as in some other specific sectors, depending on the country application. The main strength of the SD tool is to create integration between sectors rather than capturing highly disaggregated detail. The policy discussed in Section 3 is a carbon tax to decrease emissions by incentivizing shifts to less carbon intensive energy production. The structure of the SD model implies that lower emissions will improve human health and consequently productivity and GDP, which in turn will result in more funds becoming available for investment in education, health, and infrastructure. Environmental sustainability is furthered by reduced carbon emissions. Economic opportunities accompany increased GDP as citizens benefit from improved education and health status, and access to markets through improved transportation infrastructure.

- The CGE model can be disaggregated in sectors, such as agriculture, livestock, fisheries and forestry, mining, refining, oil and natural gas, chemicals and plastics, transport, electricity, manufacturing and services. This is one of the most important strengths of the CGE, which allows analysing cross-sectoral and general equilibrium effects of policies. The green CGE could evaluate investment impacts in terms of economic opportunities by looking at the growth generated in different sectors, and impacts in terms of inclusiveness through the impact of investment on different income groups. In terms of environmental sustainability, the CGE can only consider impacts through energy use or sectors affected, but not with greater detail.

- The IO-SAM model is critical for the greening of either the SD or the CGE model. For GE policy assessment and sectoral impact analysis, IO-SAM extensions are needed for the greening of the other models.

Social:

- The SD model can trace population dynamics and human capital accumulation (via education and health), and at an aggregated level, impacts on poverty and inequality.

- The CGE model, with the use of disaggregated SAM extensions, depending on policy assessment needs, can assess the policy impacts on the income of different agents by income quartile. Depending on data availability and the specific country application, the CGE can also keep track of the evolution of workers' status by level of skills (their income and employment status), gender (women and men), location (urban or rural) and whether they are working in the formal or informal sector.

Environmental:

- The SD model is able to present biophysical impacts on land use, water, and emissions and their connection to social and economic aspects.

- Other models, such as CGE and IO-SAM, cannot do this biophysical impact assessment, although they have linkages for policy analysis in sectors like energy, transportation and agriculture.

3. Are the impacts likely to be long or short-term?

- The SD model is more appropriate for presenting long-term impacts. It has the ability to handle delayed impacts and complex causal relationships, which typically require time to unfold. The feedback structure of the SD model ensures that the implementation of a particular intervention at a given time creates a direct, local impact on the target sector, and that such an impact spreads over time throughout the system.

- The CGE model can be more informative on some short-run impacts, although it is not a business cycle model (e.g. quarterly data). The CGE model is designed to give information at the yearly frequency, but most applications typically present results on intervals of five to six years.

- The IO-SAM model is designed to provide short-run impacts, given the nature of the assumptions made about the stability of the coefficients of the current production function.

4. How will green subsidy reforms (e.g. feed-in tariffs) likely impact productivity in GE sectors?

- CGE: This question can be answered by the CGE, although further development (with IO-SAM extensions) of the CGE model is needed to actually capture the richness of policy instruments in this area.

- SD: Green subsidy reforms are best implemented in the CGE model. If coupled with the SD model, the SD model can mimic influences on overall productivity through the pathways described in answers to questions 1 and 2 above.

5. How will green tax reforms and removing fossil fuel subsidies mobilize domestic revenues for green investments? What will be the implications of such reforms on environmental, economic/fiscal and social dimensions?

- The CGE model can provide the impact of green tax reforms in terms of fiscal revenues, and keep track of economy-wide impacts across sectors and agents. It can also explore the impact of green fiscal policies in which the resources from a carbon tax are either rebated to the public or to a specific economic sector, such as renewable energy. The CGE model can give information about the potential impacts of green tax reforms on economic growth, sectoral output, agents' consumption, income distribution, employment status, and trade.

- The SD model can give similar (although less detailed) information on the economic and social impacts of green tax reform, but in addition it can also provide information on the environmental impact of these policies (e.g. GHG emissions, particulates).

- The IO model can provide additional information on the linkages between the production levels of the economic sectors and the biophysical impacts on water, land use and emissions depending on the data availability for resource use intensity or emissions intensity of relevant economic sectors. Linkages could also be established in a geographical detailed manner, such as through regional IO models (e.g. for a province, a state or a city) or a multi-region input-output (MRIO) model, if data is available. The critical challenge for this geographical representation is that it requires that all relevant information in a national model to be available for the target geographical levels (either at subnational levels, e.g. a province, a city or northern part of a country, or at supranational levels, e.g. North America, Europe, Asia and the Pacific, etc.). This imposes significant constraints on data availability, because it requires economic, social and environmental data to be available at the given geographical levels.

6. How do trade policies and regulations enhance investments in GE sectors?

- Computable General Equilibrium (CGE) model: This question can be answered by the CGE, although further development (with IO-SAM extensions) of the CGE model is needed to actually capture the richness of policy instruments in this area. Depending on the type of analysis done, the CGE model will need IO-SAM extensions for greening the sectors as well as international disaggregation like those used by the Global Trade Analysis Project (GTAP), in case the policy questions require a multi-country/region analysis (see Burniaux, 2002). International trade within the CGE model is handled by means of a foreign agent. Output in each of the producing sectors is exported to the foreign agent in exchange for foreign-produced imports. Under this set-up the aggregate level of imports is set and grows at the steady state level, but the level of individual imports may change in response to changes in relative prices and the elasticity of substitution between domestically produced and imported like products. Exports are exogenous as well and are assumed to follow a constant growth path. They are, however, responsive to changing prices, and can change as individual sectors' prices are affected. Transfer payments, on the other hand, are endogenous and serve to clear the model. The exchange rate is then determined by the interaction of capital made available for external uses, goods supplied for export, and the exogenous level of imports. This model can present trade results for all the sectors in which the model is disaggregated.

- The SD model is not particularly well suited to present trade results, although some aggregate information about overall trade is presented (calculated mostly at the aggregate level and as a residual). The SD model does not currently contain the policy space to directly assess trade policies and regulations. This is best implemented in the CGE model. As described above, the feedback structure of the SD model, if run in conjunction with the CGE model, can yield insights on influences on a wide range of variables, including emissions, human health, productivity and changes in government investments in human capacity and infrastructure.

- An IO model can accommodate detailed trade information in various ways. For example, both imports and exports can be aggregated as individual vectors aligning together with the final demand and the investment columns in the IO table. In this way, the origin of the imports and how they are used in domestic production, or by the final demand sectors will not be explicit, nor will the destination of exports be traceable. Alternative ways to make these details transparent include, for example, a detailed import matrix accounting for the origin country and usage by domestic sectors aligning below domestic inter-sectoral transaction matrix or a detailed export matrix indicating destination countries, or both depending on the need of trade policy assessment. With these details on trade, an IO model can analyse the impacts of the changes in final demand (either domestic demand or overseas demand through exports) or investment in domestic production and imports. Again, it is more appropriate to use CGE models with proper trade representations to similar trade policy measures, such as change in the tariff rate (Zhou, Yano & Kojima, 2013). In addition to the ability for economic impact assessment, MRIO models are often used to account for consumption-based emissions (such as carbon footprint) or other environmental impacts (such as water footprint or ecological footprints) that are embodied in international trade of goods (Lenzen, et al., 2004; Peters and Hertwich, 2008; Wiedmann, 2009; Zhou, 2010; Zhou and Imura, 2011).

7. Which labour interventions deliver more (quantity) and better (quality including decency) green jobs?

Which approaches create better access for the unemployed and underemployed?

- The IO-SAM model provides short-run impacts of policies affecting the final demand or investments on the sectoral allocation of factors of production, in this particular case labour, according to fixed intersectoral transaction coefficients. It can give a good idea of the short-run direct and indirect job effects of GE policies. With proper disaggregation of the labour force, e.g. skilled vs. unskilled workers, woman vs. man, urban vs. rural labour, etc., the IO-SAM can assess the short-term impacts on different groups of labour. If the information on total labour force is available, the unemployment rate or the employment rate can be estimated. However, it might be difficult to estimate underemployment using IO-SAM techniques.

- The CGE can only assess jobs, not their quality. It can tell if they are green depending on the type of sector, but not more precisely. The CGE can be broken-up into formal and informal labour per sector. By introducing GE policies, it can follow workers' migration from formal to informal labour by sector. In addition, exogenous changes to labour productivity, which may have economy-wide effects, can also be introduced in the CGE model.

- The SD model can only provide limited information about employment, because of its limited level of sectoral disaggregation. The current SD model does not directly examine labour interventions, other than considering influences of health, education, and infrastructure improvements on productivity and employment. The SD model does not explicitly model green jobs or decency of jobs.

8. What types of industrial policy measures are in place to support the transition towards a GE?

- The CGE model can present the impact of policies having a differentiated sectoral effect, according to the different sectors already described. In this type of model, green policies are included through changes in investment in different sectors that may, for example, in turn produce capital goods for the energy sector, with a large part of the investment going into manufacturing.

- The IO model can either on its own or by facilitating the greening of the CGE model present a very detailed analysis of the linkages across economic sectors. From the IO perspective, disaggregating green subsectors from their conventional sector (e.g. organic farming from agriculture, renewable energy from electricity generation, sustainable forest practice from forests and green building from buildings, etc.) can be carried out at the conceptual level. However, it requires a clear definition of the green subsectors (what kind of activities are included), and of their corresponding sectors in the national standard industrial classification system (NSIC), or the international standard industrial classification system (ISIC). In addition, the main limitation is not conceptual but of data availability. With green extensions of the IO-SAM, the impacts of the investments in the green sectors can easily be analysed. However, for assessing the impacts of other types of industrial policies, such as tax or subsidies implemented in particular sectors, the CGE might be a more appropriate modelling approach.

- The SD model has a limited response to this type of analysis as it is constrained by the relatively low degree of sectoral disaggregation in the industry sector.

3 TESTING THE IGEM FRAMEWORK: SCENARIOS FOR A GREEN AND LOW CARBON ECONOMY IN MEXICO

This section presents the application of the IGEM framework. It first presents two theoretical approaches that illustrate how the IGEM can help answer different policy questions from different angles. It then presents background on Mexico's energy transition to introduce the application of the IGEM framework to model the introduction of a carbon tax.[30]

3.1 DIFFERENT APPROACHES TO APPLY THE IGEM FRAMEWORK: THE CASE OF A CARBON TAX

In reference to the review of previous UN Environment country studies in Section 1.1, the IGEM can be applied in two ways to analyse GE policies, following either a target-driven approach or an investment-driven approach. For illustration purposes, these approaches are discussed with the case of a carbon tax . These two approaches are meant to provide the reader with an idea of the implementation steps (or mechanism) associated with the IGEM framework in order to answer a GE policy question, and to evaluate what are the impacts of a target or investment-driven approach on the different sectors of the economy.

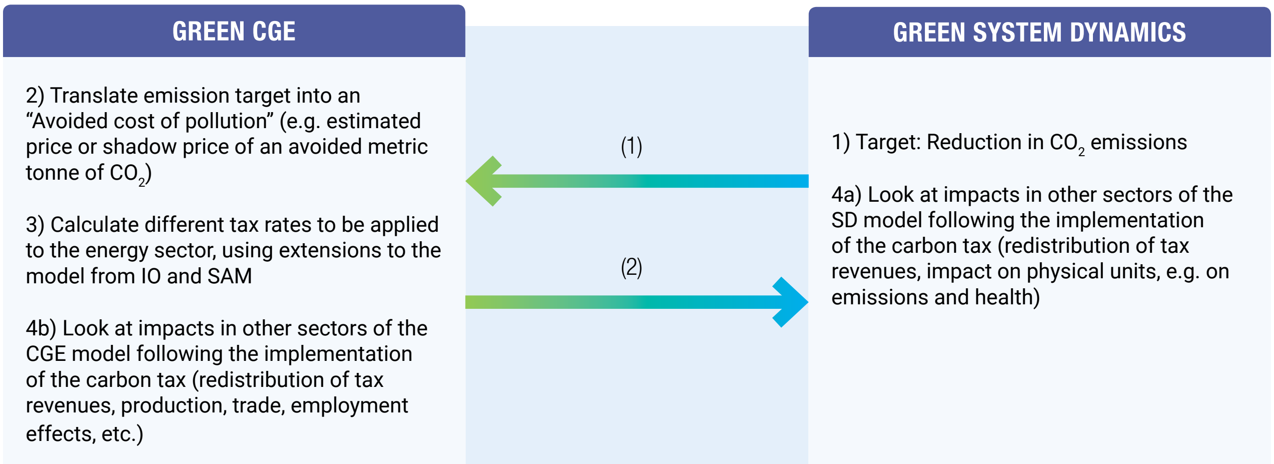
It is important to note that this illustration abstracts from the very important discussion on the timing of the policy (e.g. one-time change, progressive and steady change, change biased towards the end), and that these are important considerations that will need to be taken into account when the application is tested.

A target-driven approach, as its name indicates, focuses on the outcome of a policy. The desired outcome will serve to simulate what are the required investments to achieve it. In other words, the modelling constraint is set by the end or objective of the policy, which will determine the means of implementation. In contrast, an investment (or price)-driven approach focuses on the costs of implementing a (not necessarily quantified) policy outcome. The modelling constraint in this case is set by a financial constraint or revenue generation target.

A target-driven approach could be the following: "Achieve a target of a X per cent reduction of CO_2 emissions by 2030 (compared to baseline year of 2015)". This constraint can then be used to calibrate the green CGE model and the green SD model, along with other assumptions. However, as many modelling techniques can easily handle pricing tools, a target-driven approach could also be perfectly implemented by trying different investment or price levels and by analysing how the simulated results come closer to the specific target. In some cases, the modeller is asked what will be the impact of a specific policy, what we have called the investment-driven approach. However, in other cases the modeller is asked what policy mix could achieve a certain target (e.g. the volume of investment, the level of a tax or a combination that is required to achieve the target). Either approach is useful for policy analysis and it will depend on the type of specific question the modeller is facing, and they should be able to use the IGEM framework and interpret the results for either approach.

One of the policy questions related to this target could be "What are the effects of different tax rates to achieve this target?". Figure 17 describes a target- driven approach for this example.

Figure 17: *Target-driven approach*



1) Target: Reduction in CO_2 emissions

2) Translate emission target into an "Avoided cost of pollution" (e.g. estimated price or shadow price of an avoided metric tonne of CO_2)

3) Calculate different tax rates to be applied to the energy sector, using extensions to the model from IO and SAM

4a) Look at impacts in other sectors of the SD model following the implementation of the carbon tax (redistribution of tax revenues, impact on physical units, e.g. on emissions and health)

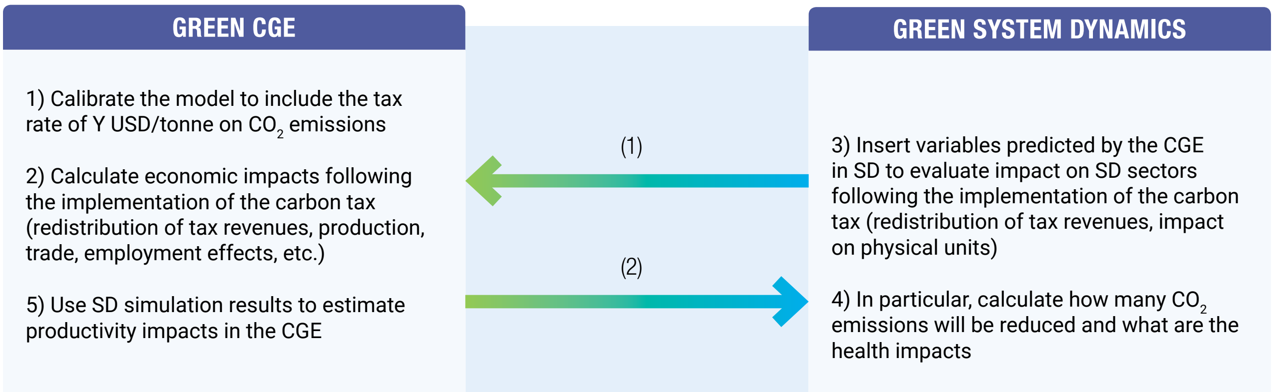
4b) Look at impacts in other sectors of the CGE model following the implementation of the carbon tax (redistribution of tax revenues, production, trade, employment effects, etc.)

Source: Figure created by the authors.

An investment (or price)-driven approach could instead consider the following objective: "A tax rate of USD Y/tonne of CO2 will be implemented to reduce national CO2 emissions" and related policy questions would thus be "How much revenue can be generated from the tax, how many CO2 emissions can be mitigated and what would be the induced impacts (e.g. on sectoral and aggregate production and employment, income distribution, emissions, health and productivity)?". Figure 18 illustrates this other mechanism within the IGEM framework.other mechanism within the IGEM framework.

In these two examples, it is important to note that the forecasting mechanism will be different, because although the CGE and SD will share common initial conditions, the initial calibration related to the policy question will be initiated either in the CGE or the SD model, depending on the chosen approach.

Figure 18: *Investment (or price)-driven approach*



1) Calibrate the model to include the tax rate of Y USD/tonne on CO_2 emissions

2) Calculate economic impacts following the implementation of the carbon tax (redistribution of tax revenues, production, trade, employment effects, etc.)

3) Insert variables predicted by the CGE in SD to evaluate impact on SD sectors following the implementation of the carbon tax (redistribution of tax revenues, impact on physical units)

4) In particular, calculate how many CO_2 emissions will be reduced and what are the health impacts

5) Use SD simulation results to estimate productivity impacts in the CGE

Source: Figure created by the authors.

In terms of policy applications, it seems that both approaches may have significant similarities. Most of the models are designed to have exogenous changes in policies (e.g. investments), which will serve as the key shock driving results. However, the difference between the two approaches is about the policy question. On the one hand, it may be the case that policymakers have a certain amount of resources available for policy implementation and wish to know the potential impact of using these resources among competing alternatives. Here the investment-driven approach will be most useful. On the other hand, it may be the case that policymakers set some policy targets and are interested to know what would be the amount of resources required to reach these targets. In this case the target-driven approach will be more useful. Notice that in terms of modelling, it could be the case that the target-driven approach requires running the model with the investment-driven approach many times until targets are reached. In the next sections, the application of the IGEM framework is tested using an investment (or price)-driven approach.

3.2 APPLICATION OF THE IGEM FRAMEWORK TO MODEL A CARBON TAX IN MEXICO

3.2.1 Policy framework: Mexico's energy transition

Mexico is the world's thirteenth-largest emitter of CO_2 emissions[32] and is projected to be the world's fifth-largest economy in 2050[33]. In 2012, Mexico became the first developing country to pass comprehensive climate change legislation, including a mandate to reduce emissions of carbon dioxide by 30 per cent below business-as-usual levels by 2020, and by 50 per cent below 2000 levels by 2050.[34] Furthermore, the legislation stipulates that 35 per cent of the country's electricity should come from "clean" sources (see below) by 2024, and requires mandatory emissions reporting by the country's largest polluters.

In March 2015, before the Paris climate conference, Mexico became the first developing country to submit its Intended Nationally Determined Contribution (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC). Mexico's INDC includes an unconditional target of 22 per cent greenhouse gas (GHG) reductions below baseline in 2030, starting to decrease emissions in 2026. If Mexico receives further international support and specific elements included in a global agreement (e.g. technical cooperation and access to financial resources and technology), the pledged reduction could go up to 36 per cent below baseline.[35] Emission reductions will mainly come from the energy, industrial, agriculture, waste and land-use and forestry sectors and will be based on a baseline year of 2013.[36]

To support the achievement of GHG emissions mitigation targets put forth in its INDC,[37] Mexico introduced a carbon tax on fossil fuel production in 2014 as part of a fiscal reform package. The carbon tax applies only to the use of fossil fuels (except natural gas – see Table 6). It aims to create awareness of CO_2 emissions, to put a price to carbon and to promote the use of cleaner fuels. The legal framework also includes an option for covered entities to use Kyoto's Certified Emissions Reduction (CER) credits from Mexican Clean Development Mechanism projects for compliance. The approximate price of carbon was set at USD 3.5/tCO_2eq.[38]

The tax rate was capped at 3 per cent of the sales price of fuel, and is expected to collect approximately USD 1 billion a year.[39] Compliance began in January 2014, but the rules to use CERs had not yet been developed at the moment this paper was finalized.

Table 6: *The carbon tax – rates and revenues*

FUEL	CO_2 POTENTIAL (CO_2 PER UNIT)	TAX (USD CENTS* PER UNIT OF INPUT)	TAX AS % OF PRICE	REVENUE 2014 (*USD MILLION)
Natural gas	1.94 kg per m^3	0.000 per m^3	0.0	0.0
LPG	1.69 tons per m^3	0.415 per litre	1.02	58.7
Gasoline	2.27 tons per m^3	0.708 per litre	0.80	278.4
Kerosene	2.60 tons per m^3	0.846 per litre	1.10	28.4
Diesel	2.64 tons per m^3	0.859 per litre	0.95	170.4
Fuel Oil	3.05 tons per m^3	0.917 per litre	1.71	58.6
Coal	2.37 tons per ton	0.1881per kg	2.85	0.6
Petrol Coke	3.27 tons per ton	0.1061 per kg	1.65	24.9
Total (+others)				620.1

Source: Estimations by SHCP, C02 potentials from CMM, Revenue from SAT.

(*Exchange rate for May 2015)

3.2.2 Carbon tax scenarios

Based on different carbon tax rates, the IGEM framework explores the welfare impacts of reinvesting the carbon revenue into clean energy ("feebate" scenario). Feebates are funds or "fees" that have been collected from carbon taxes and that are invested into green energy alternatives, such as wind and solar. Results are compared to the business-as-usual (BAU) case and to the revenue neutral case (rebate scenario) reached by lump sum returns (reallocating payments to the population). The simulated time horizon is until 2036. Table 7 provides more detail on these scenarios.

Individual results for the CGE and SD model simulations (no linkage) are first presented and then for the coupling between the two models (one-way hard linkage).

Table 7: *Summary of carbon tax scenarios tested by the IGEM framework*

SCENARIO	TAX RATE	CGE	SYSTEM DYNAMICS
Scenario 1 - Feebate scenario with low tax rate (FBL)	3.5 USD/tCO_2eq (current carbon tax rate in Mexico)	1) Estimate the economic effects of feebate scenarios compared to a revenue neutral carbon tax (lump-sum) and a business-as-usual scenario 3) Use results from the SD to estimate effects of increased longevity on productivity	2) Estimate the social and environmental impacts resulting from the CGE simulation (health and emissions)
Scenario 2 - Feebate scenario with high tax rate (FBH)	25 USD/tCO_2eq[40]		
The two feebate scenarios will be compared to:			
Rebate scenario (lump sum) with high (RH) and low (RL) tax rates	3.5 and 25 USD/tCO_2eq		
Business-as-usual scenario (BAU)	No carbon tax[41]		

Source: Table compiled by the authors.

3.2.3 Results from the CGE model

This section presents the results of simulating, using an investment (or price)-driven approach (as highlighted in Figure 16), the two carbon tax rates (3.5 USD and 25 USD/tCO_2eq.) with the CGE model. Although the CGE model does not calculate emissions directly, when a tax is set on carbon, output falls and so do emissions.

3.2.3.1 Scenario 1: Low carbon tax combined with an investment in clean energy (FBL)

Table 8 shows the impact of a "modest" (i.e. 3.5 USD/tCO_2eq) carbon tax levied against all fossil fuels in Mexico with the receipts going to finance "clean" energy sources, such as wind and solar in the electricity sector (FBL scenario),[42] compared with the BAU case and with a “low carbon tax revenue neutral” (RL scenario), which is a similar scenario but in which the receipts of the tax are returned directly to consumers in the form of a lump sum distribution instead of funnelled into clean energy investment. Since the aim is to quantify the impacts of such a scheme as clearly and transparently as possible, Column 1 (Table 8) presents the percentage changes of this simulation (FBL) compared to the BAU case, while Column 2 presents the changes of this simulation (FBL) with reference to the "low carbon tax scenario with lump sum redistributions” (RL). In both cases, either BAU or the revenue neutral approach are the initial points. The aggregate results for FBL show that with a small carbon tax, the numbers do not differ greatly from the BAU case. Gross Domestic Product (GDP), aggregate welfare, government consumption, and the level of the capital stock all go down slightly (given that the policy explored is a tax that is supposed to reduce the production of the carbon intensive sectors). Compared to the RL scenario (Column 2, Table 8), however, values for GDP and investment are slightly higher than before as the revenues are used for purposes of green investment (showing that additional investments in green sectors will generate positive effects on the economy). Overall, welfare is higher than in the RL scenario as well since new investment has stimulated overall growth, but its distribution is slightly less progressive (affecting slightly negatively the agents at the bottom of the distribution) compared to the RL scenario because the subsidy of capital investment has been beneficial to the capital owners in the higher income groups (agent 3 and agent 4).[47]

Table 8: *Aggregate and sectoral effects of a revenue-neutral carbon tax (feebate policy), in 2036*

	COLUMN 1	COLUMN 2
Aggregate results	FBL vs. BAU (%)	FBL vs. RL (%)
GDP	-0.1670	0.2652[43]
Investment	0.4514	1.0984
Government[44]	-0.2072	-0.0125
Capital Stock	-0.3253[45]	0.0078
Welfare		
Agent 1 (20% poorest)	-0.1174	-0.0364
Agent 2 (3-5 deciles)	-0.1119	0.0097
Agent 3 (6-8 deciles)	-0.1192	0.0167
Agent 4 (20% richest)	-0.1407	0.0321
Aggregate welfare agents 1-4	-0.1279	0.0078[46]
Government welfare	0.0000	0.0000
Selected sectors		
Agriculture	-0.7599	-0.3504
Manufacturing	-1.0087	-0.3915
Oil	-5.1713	-1.5797
Natural gas	-4.7644	-1.3594
Mining	-6.2312	0.2144
Refining	-4.1215	-1.1295
Electricity	5.6699	6.2579

Source: Modellers’ calculations.

Results for the production sectors show that the subsidy to green investment has the intended effects of stimulating electricity production and stemming fossil fuel use (Columns 1 and 2, Table 8, lower section). By 2036 electricity production[48] goes up by over 6 per cent, while petroleum extraction and refinery output both go down by over 1 per cent. Results in other production sectors show modest changes (see Annex 7).[49]

3.2.3.2 Scenario 2: High Carbon Tax combined with investment in Clean Energy (FBH)

The following scenario (FBH) extends the scope of the previous simulation by introducing a high carbon tax rate of 25 USD/tCO_2eq designed to curb carbon emissions in a significant manner. As before, the scenario pairs this tax with investment in clean energy and results are compared both to a BAU case and to a rebate scenario (the revenues from the high carbon tax are re-distributed to consuming agents in the form of a lump sum payment - RH scenario).[50] The results are qualitatively similar to the FBL scenario but the magnitudes are much larger and correspond to what would occur if Mexico took significant steps to simultaneously curb fossil fuel use and invest in renewable energy alternatives.

Table 9: *Aggregate and sectoral effects of a revenue-neutral carbon tax (feebate policy), in 2036*

	COLUMN 1	COLUMN 2
Aggregate results	FBL vs. BAU (%)	FBL vs. RL (%)
GDP	-1.9318	1.0186
Investment	-0.2010	3.4304
Government[51]	-1.4058	0.1768
Capital Stock	-1.3240	1.0674
Welfare		
Agent 1 (20% poorest)	-0.8717	-0.2434
Agent 2 (3-5 deciles)	-0.8511	0.0231
Agent 3 (6-8 deciles)	-0.8936	0.0792
Agent 4 (20% richest)	-1.0541	0.1780
Aggregate welfare agents 1-4	-0.9601	0.0951
Government welfare	0.0000	0.0000
Selected sectors		
Agriculture	-5.1320	-2.1984
Manufacturing	-7.4112	-2.9469
Oil	-28.5069	-3.1453
Natural gas	-28.6476	-4.0895
Mining	-94.1274	-0.1850
Refining	-25.2683	-3.7044
Electricity	13.3272	23.1085

Source: Modellers' calculations.

Looking first at the aggregate results, these show that such a tax/subsidy policy would entail small losses with regards to consumer welfare, GDP, and the size of the capital stock with respect to the BAU case (Column 1, Table 9). The investment in clean energy technology, however, would result in higher aggregate indicators than when the tax revenues were returned directly to consumers (Column 2, Table 9). The distribution of welfare would however again be biased towards capital owners and penalize the lowest 20 per cent in the population. Furthermore, as already pointed out, these results do not include external benefits, such as improved health and overall quality of life that would accompany a reduction in fossil fuel use and, to the extent that these positive externalities are not included, the results for welfare should be regarded as a lower estimate.

The results for production are qualitatively similar to the previous run with the low tax rate. A high carbon tax combined with investment in renewable energy would lead to decreases in fossil fuel use from BAU conditions. Furthermore, the investment in renewable energy sources would further cut into carbon use as these fuels were, in effect, "crowded out" as inputs into electricity. Elsewhere in the economy, sectors will experience gains or losses depending on the strength of their linkages to fossil fuels. Hence, it can be seen that energy intensive sectors, such as chemicals, decline while livestock and forestry experience modest gains over most of the period relative to the BAU case.[52]

3.2.4 Results from the SD model

This section presents the results of simulating the two carbon tax rates (3.5 USD and 25 USD/tCO_2eq.) with the SD model on the full amount of carbon equivalent emissions from fossil fuel use across all economic sectors. Potential impacts on a mix of electrical energy generation types and greenhouse gas (GHG) emissions under different carbon tax regimes are shown in the diagrams below.[53] In the simulations, the carbon taxes are implemented in 2016 and run through 2050. The SD model here is run without any direct linkage with the CGE or the IO-SAM models.

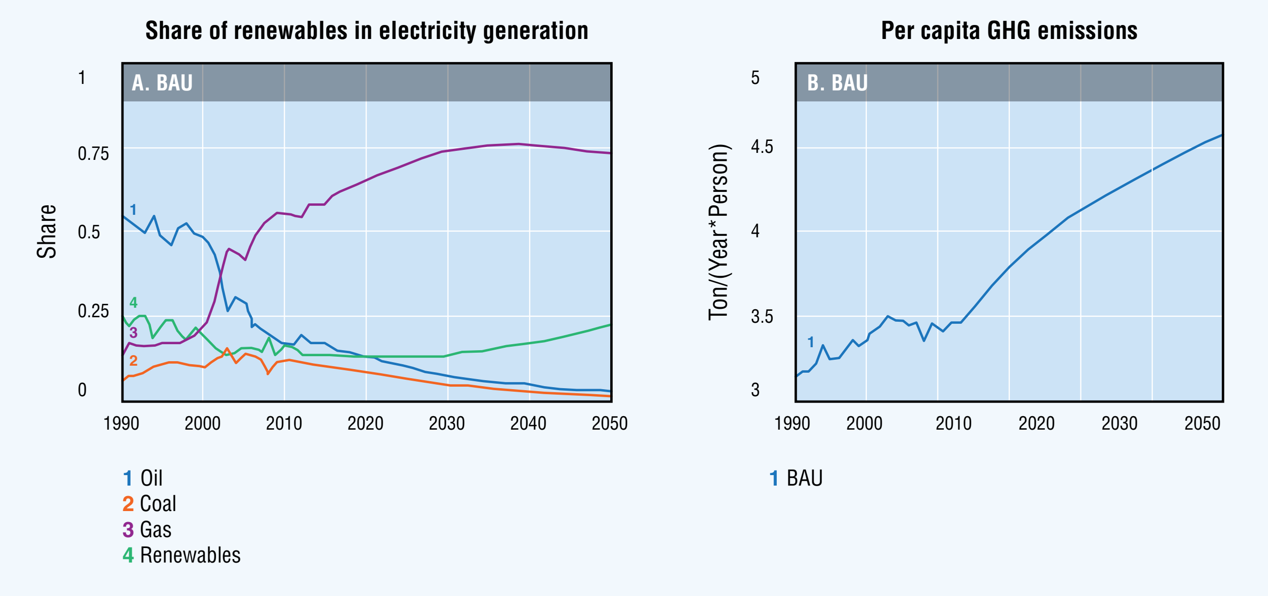
To capture lags associated with planning, constructing, and decommissioning power plants of all types, a supply chain structure is included in the model. Desired aggregate power generation capacity is based on simulated forecasts of energy demand. Investment decisions to select one or another type of electricity generation are based on the relative costs of electricity (US EIA 2015). These simulations should be considered as experimental "what if" scenarios to explore likely carbon emission outcomes under a range of different carbon tax policies. The analysis focuses on the patterns of the simulated time paths and should not be considered as point predictions.

3.2.4.1 Business-as-usual (BAU) simulation – no carbon tax

In the business as usual (BAU) simulation no carbon tax is implemented. This provides a base of comparison for the simulated carbon tax policies.

Figure 19.A shows a mix of electrical energy generation categories consisting of oil, coal, gas, and renewables. The mix of electrical energy sources is displayed as shares of the total mix. Figure 19.B shows per capita CO_2eq emission in metric tonnes per person per year. Before 2016, the threshold year for the carbon tax intervention, a transition in the electricity generation technology mix has occurred, showing a decline in oil-based generation and an increase in gas-based electricity generation spurred by low cost natural gas imports. Coal-fired electricity generation is stagnant through the historical period and declines over the future horizon under the assumption of higher fuel costs compared to gas. Renewables decline slightly over the historical horizon but gradually increase over the future horizon due to accumulating learning curve effects that lower cost.

Figure 19: *Business-as-usual (BAU) simulation*



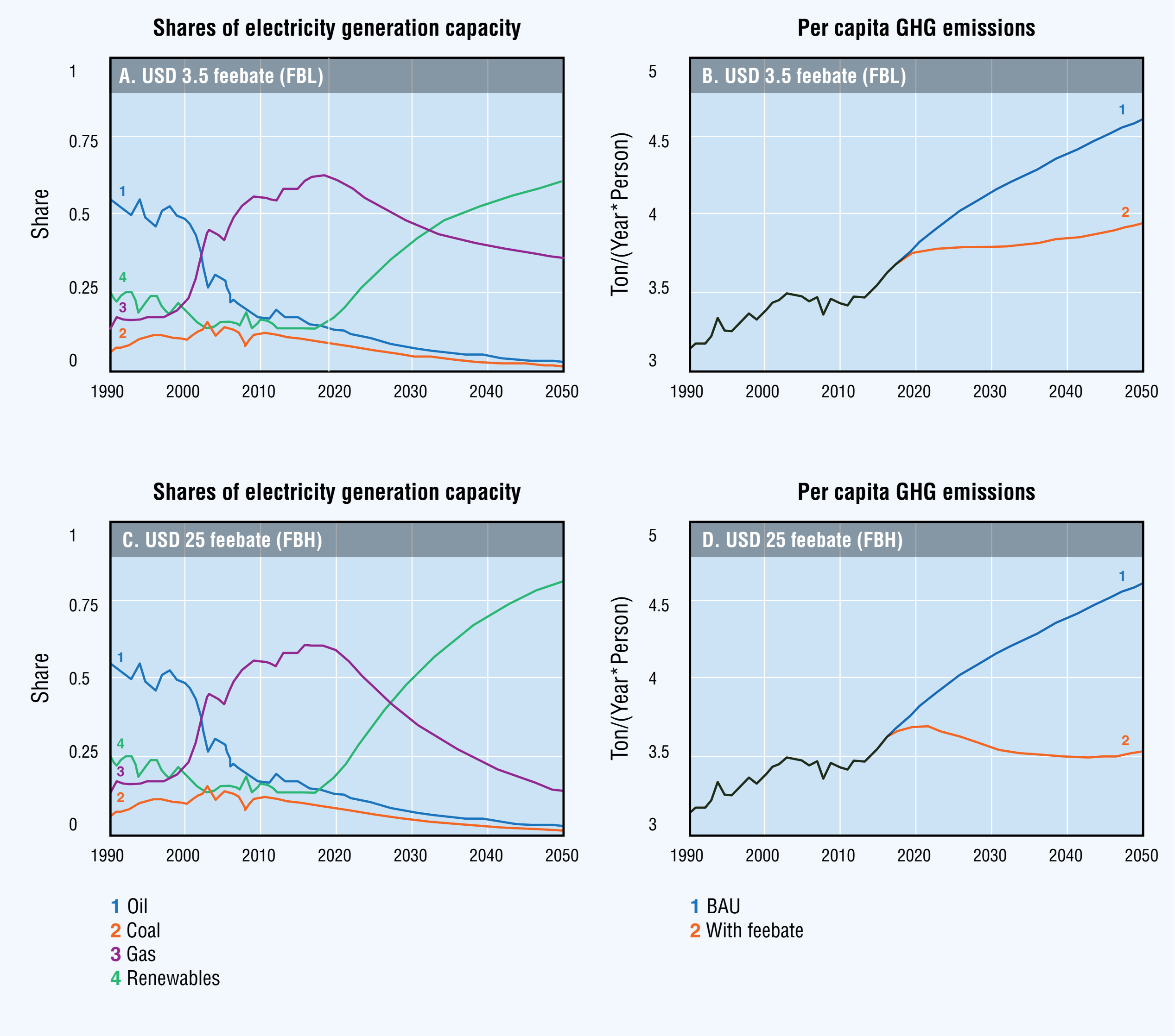
Source: the Millennium Institute.

3.2.4.2 Carbon tax rebated to renewables (feebate scenario) compared to BAU

In this simulation the feebate policy described in Section 3.2.2 is enacted on carbon equivalent emissions from fossil fuel burning across all economic sectors.

When the feebate scenario is enacted, a shift in the trajectory patterns of electricity sources is seen with renewables gradually overtaking gas-fired generation. As expected, the simulation results for both electricity generation mix and CO_2eq emissions are sensitive to the tax amount. At the USD 3.5 rate renewables surpass gas-fired around 2033, with renewables approximately 60 per cent in 2050. At USD 25, the pattern shift occurs more quickly, with renewables surpassing gas-fired generation around 2026. By 2050 renewables are over 80 per cent of the total energy generation mix.

Figure 20: *Simulation of carbon taxes on CO2eq emissions rebated to renewables (FBL/FBH compared to BAU)*



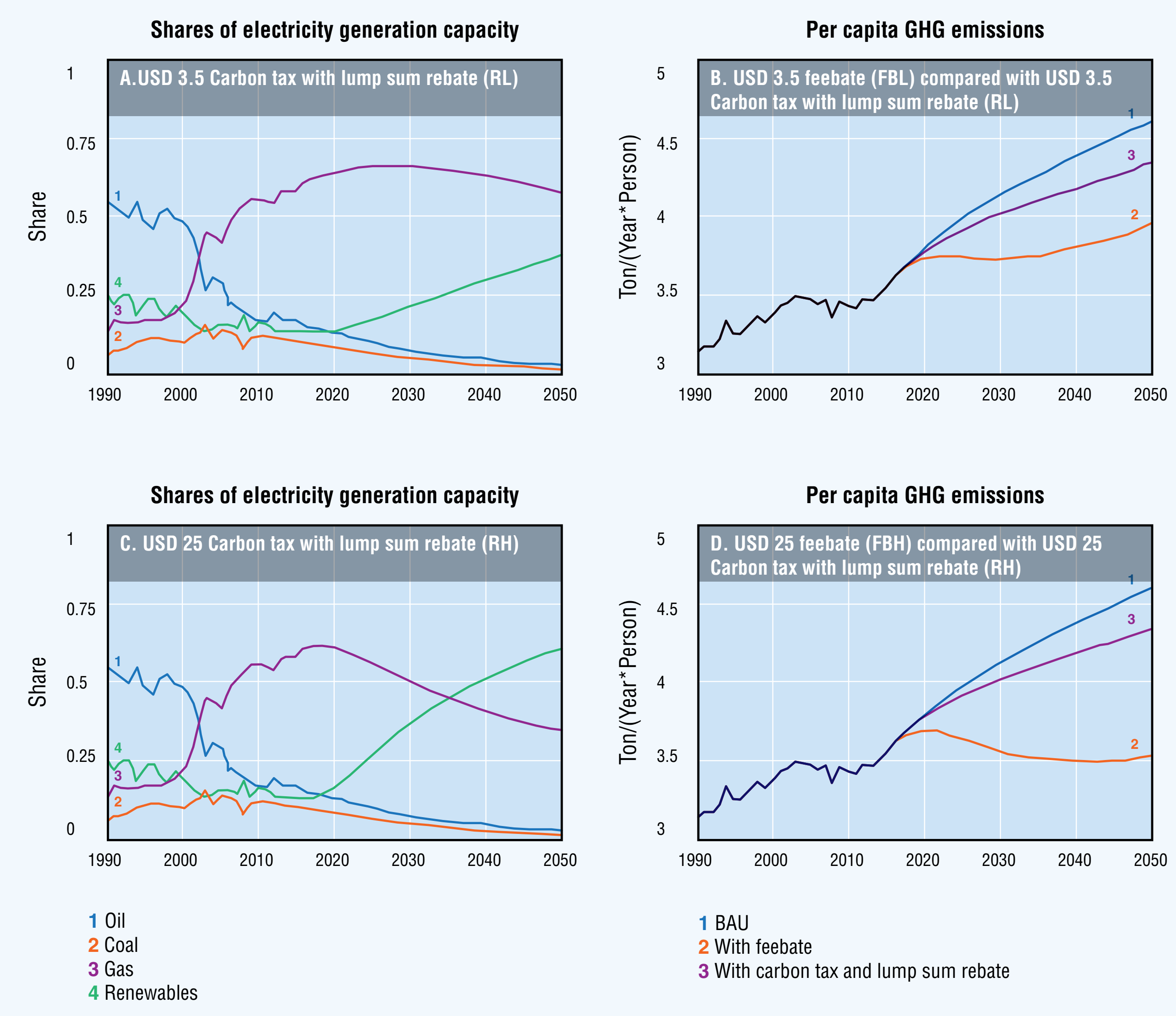
Source: the Millennium Institute.

It is noteworthy that even at the high tax rate of USD 25, the phasing out of coal and oil technologies does not accelerate. A real-world problem in electrical power generation is the inertia of the power generation sector. This is one reason why it is important to use a supply chain approach to capture lags in the system associated with planning, construction and decommissioning. The model assumes that existing power generation capacities of all types have a constant useful life (after which individual plants are decommissioned). This means that even if new construction ceases, there will still be a lag before existing plants are decommissioned, therefore the oil and coal capacity in aggregate decay gradually.

3.2.4.3 Carbon tax rebated to renewables (feebate scenario) compared with rebate scenario

Figure 21.A shows the electricity generation mix under a carbon tax policy that rebates tax receipts as lump sum payments to the general population. Figure 21.B compares CO_2eq emissions under BAU, feebate, and lump sum rebate policies.Comparing Figures 21.A and C with Figures 20.A and C shows that the feebate policy causes a much faster transition to renewables. This is particularly the case at the USD 3.5 tax rate, but at USD 25 the feebate policy causes renewables to exceed gas-fired generation approximately 10 years earlier than the tax plus lump sum rebate policy.

Figure 21: *Comparison of carbon tax with feebate and carbon tax with lump sum rebate (FBL compared to RL and FBH compared to RH)*



Source: the Millennium Institute.

Lastly, Figure 22 shows the shares of renewable energy capacity, comparing the BAU, the feebate and the rebate scenario with low and high tax.

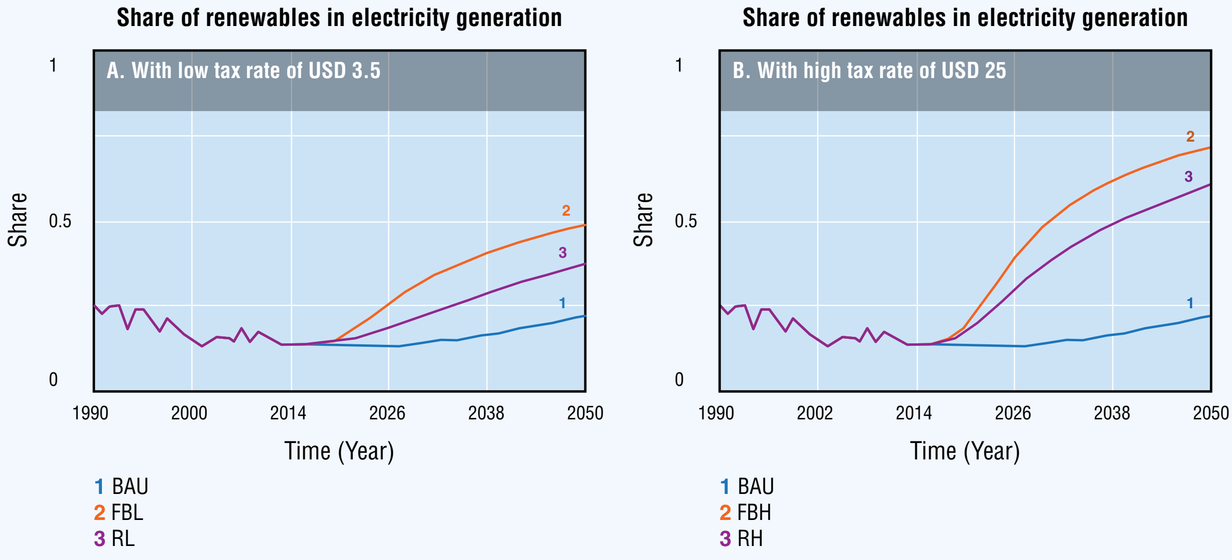
As can be seen, under RL or RH, the share of renewable energy generation increases, because the relative cost of renewables decreases. This effect is amplified in the feebate scenario because of the re-investment in the renewable energy sector.

To summarize, the carbon tax simulation exercises only consider shifts in electricity sources due to relative financial cost. For the sake of experimentation other factors, such as regulation or technological breakthroughs (other than learning curve cost reduction for renewables) are not taken into consideration.

The simulations suggest that low tax levels, such as the USD 3.5 per metric tonne carbon equivalents, are of limited value in effecting a transformation of the electricity generation mix.

The simulations demonstrate that the feebate policy, with the high carbon tax on full emissions, achieves the greatest carbon emission reduction.

Figure 22: *Evolution of the share of renewable energy capacity following BAU, FBL, RL, FBH and RH scenarios*



Source: the Millennium Institute.

3.2.5 Evaluating green policies in the IGEM: Effects of increased longevity of Mexican workers using both the CGE and the SD models

This section presents the simulation results when running the dynamic CGE model in conjunction with the SD model and using output gathered from the SD model to supplement and adjust the CGE input parameters. Section 3.2.3 and Annexes 7 and 8[54] presented the results for the impacts of a high carbon tax (i.e. USD 25 tCO_2eq tax on sectoral growth and consumer welfare in the Mexican economy feebate and rebate scenarios compared to BAU with no longevity) using the CGE only. In order to concentrate strictly on economic growth and allocation issues, proceeds of the tax were redistributed back to the various consuming agents in a revenue-neutral manner. Results showed that such a tax had a small negative impact on growth and income but these stand-alone CGE simulations did not quantify all of the external benefits of such a tax. Since the burning of fossil fuels generates particulates and other harmful waste, a carbon tax would have positive impacts on the health of the population, which in turn should increase productivity as healthier individuals typically work more and produce more (Adedayo & Anthony, 2016; Swift, 2011; Aghion et al., 2010). Based on these assumptions, the IGEM framework was applied considering any increase in longevity equal to an increase in productivity, and using the average longevity of Mexican workers as one metric of the health impacts described above.

3.2.5.1 The impact of a high revenue neutral carbon tax with a lump-sum redistribution and increased longevity[55]

The SD model was run assuming a USD 25/ tCO_2eq carbon tax on emissions of all sectors (for consistency purposes) and generated, as part of its output, population longevity for each year covered in the analysis. This data was then used to augment the level of labour productivity as an input into the dynamic CGE model. The CGE model was subsequently re-ran assuming the same level of tax rates on fossil fuel (as well as the same level of redistribution payments to consuming agents) as before, and the detailed results of this exercise are given in Table 10 and in Annex 9.[56]

In Column 1 of Table 10, simulation results of the RH scenario with longevity are compared with the BAU to show the impact of the carbon tax, including longevity. These results are qualitatively very similar to the comparison of the RH scenario with no longevity with the BAU (see Annex 8) and thus give little in the way of any new insights. Hence, in Column 2 the RH scenario with longevity is compared to the RH scenario with no longevity in order to concentrate on the impact of the higher longevity figures inputted from the SD model.

Turning first to the aggregate numbers in Column 2, Table 10, several things become readily apparent. First, in keeping with the inputs obtained from the SD model itself, the changes in longevity are small but positive and increasing throughout the period of the analysis (see Annex 9 for more detail). Thus, for example, GDP grows slightly, but the positive changes grow until, in the final year of the analysis, the level of GDP is 0.33 percentage points greater than in the case in which longevity was not taken into account. Second, the gains seem to be evenly distributed over all consumers and the low-income agents experience about the same (small) percentage gains as the wealthiest agents due to the effects of redistribution to all agents of the carbon tax revenues. Third, since productivity increases, there is an increase in government revenues, and these added gains could, in principle, be redistributed to further increase the gains of the consuming agents.

Table 10: *Aggregate and sectoral effects of a revenue-neutral carbon tax (rebate policy) and a feebate scenarios (FBH), in 2036*

	COLUMN 1	COLUMN 2	COLUMN 3
	RH with longevity vs BAU (%)	RH with longevity vs RH no longevity (%)	RH with longevity vs RH with no longevity (%)
GDP	-2.5608	0.3332	1.2949
Investment	-2.7583	0.7796	3.8981
Government[57]	-1.3718	0.1916	0.3705
Capital Stock	-2.0615	0.2945	1.7113
Welfare			
Agent 1 (20% poorest)	-0.5612	0.0614	0.0709
Agent 2 (3-5 deciles)	-0.8088	0.0585	0.0938
Agent 3 (6-8 deciles)	0.0525	0.0525	0.1438
Agent 4 (20% richest)	-1.1663	0.0533	0.2468
Aggregate welfare agents 1-4	-0.9912	0.0545	0.1786
Government welfare	0.0583	0.0542	0.0471
Selected sectors			
Agriculture	-2.2540	0.5032	0.4238
Manufacturing	-3.3250	0.7797	0.5180
Oil	-19.4086	0.3080	-1.4591
Natural gas	-18.6950	0.3195	-1.2141
Mining	-48.2412	0.2921	0.0974
Refining	-16.7771	0.3899	-0.1950
Electricity	-5.8425	0.4676	23.7461

Source: Modellers' calculations.

Turning next to the results for the individual producing sectors, not surprisingly, the gains there are also small but positive and increasing. Furthermore, since labour productivity was increased (and not capital) the sectors (such as manufacturing and agriculture) that are the most labour intensive are the ones that experience the largest gains. It is also noteworthy that since productivity and demand increase for all goods, fossil fuel extraction and refining increases relative to the case with lower expected longevity (RH with no longevity). Hence, policymakers may be inclined to further increase carbon taxes to stem fossil fuel use and encourage the use of renewable energy sources.

Finally, one should note that longevity is only one aspect of labour productivity and the positive externalities induced by reduced fossil fuel use will also reduce other productivity indicators such as morbidity and days lost due to illness. Thus, the positive impacts seen here should be seen as a lower bound to the welfare and growth increases that may be expected from a generally healthier population.

3.2.5.2 The Impact of a large revenue neutral carbon tax with "feebate" and increased longevity[58]

The SD model was also run with the feebate scenarios whereby a USD 25/tCO_2eq tax was levied on Mexican emissions. The funds were used to invest in clean energy, and the impact on longevity was calculated. In the final CGE model run these SD longevity numbers were used as inputs to the CGE productivity parameters and the model was run under the assumption of a USD 25/tCO_2eq feebate scenario. As in the preceding section, FBH simulations were then compared both to the BAU case and the feebate scenario with no assumption of a worker's longevity increase (Columns 1 and 3, Table 10, respectively, and detailed results in Annex 10).

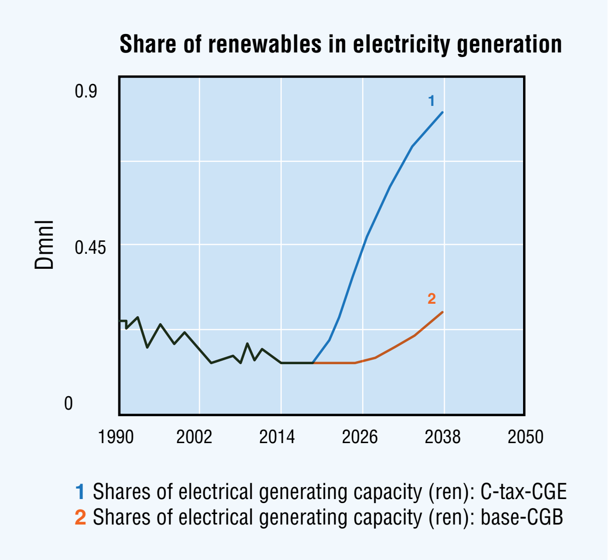
As in the RH scenario with longevity the impact of higher population longevity is small but positive and persistent. Column 2 shows the results for the FBH scenario with longevity compared to the FBH scenario with no longevity adjustments. These results are fairly similar to the results in Column 2 of Table 10 (RH with longevity compared to RH with no longevity), but there are some important differences.

Here again GDP increases more significantly, although not by an enormous margin than in the previous scenario (GDP rises by about 1.3 percentage points relative to when longevity gains were not taken into account). Most of this rise in GDP can be attributed to increased investment and this is consistent with the fact that under a feebate policy, carbon tax revenues would be directly invested in renewable energy sources.[59] Here again, all consumers would experience welfare gains but the percentage gains would be slightly higher for higher income agents with capital income (agents 3 and 4). Most production sectors experience slight gains when longevity is considered with the highest gains occurring in the electricity sector (where most carbon tax funds are re-invested). Indeed, the only production sectors that show any production declines are those related to the extraction and refining of fossil fuels. This drop is fairly small, but it does indicate that in the feebate case, the productivity gains due to higher longevity may not justify continued higher carbon taxes to maintain the intended level of emissions reductions.

Finally, Figure 23 shows the trajectory of the share of renewables in electricity generation following the coupled CGE+SD simulation. The red line represents the BAU case and the blue line represents the FBH case (USD 25/tCO_2eq on all fossil fuel emissions). Compared to Figure 20.B (SD simulation only), the share of renewables in total electricity generation reached in 2036 is much higher (approximately 0.85). This last result highlights that productivity gains following increased longevity in the high tax feebate scenario result in the greatest impact for renewable energy development.

A synthesis of the main results obtained from the different simulations (CGE; SD; SD-CGE) is provided in Table 11.

Figure 23: *Share of renewables in total electricity generation following the coupled SD-CGE simulation*



Source: the Millennium Institute.

Table 11: *Main simulations' results for the different scenarios*

SCENARIO	MAIN RESULTS FROM CGE SIMULATION	MAIN RESULTS FROM SD SIMULATION	MAIN RESULTS FROM IGEM SIMULATION (SD-CGE)
— Scenario 1 – Feebate scenario with low tax rate (FBL) — Scenario 2 – Feebate scenario with high tax rate (FBH) The two feebate scenarios will be compared to: — Rebate scenario (lump sum) with high (RH) and low (RL) tax rates — Business-as-usual scenario (BAU) = no carbon tax	Scenario 1: FBL-BAU — Introducing a carbon tax on emissions of fossil fuels will entail small losses with regards to consumer welfare, GDP, and the size of the capital stock. Scenario 2: FBH-RH — Feebate scenario will result in higher values for aggregate indicators (e.g. GDP, Investment, etc.) up to 2036 than rebate scenario. Both scenarios — A carbon tax paired with "green" investment will have positive environmental impacts, while improving the energy mix by increasing the share of renewables with minimal impact on overall production (GDP).	Scenario 1: FBL-BAU/RL — Low tax levels are of limited capacity in inducing a transformation of the electricity generation mix. Scenario 2: FBH-BAU/RH — Feebate policy, with the high carbon tax on full emissions, achieves the greatest carbon emission reduction.	— GDP grows up to 1.3 percentage points (0.33 percentage points) when the effect of lower emissions on longevity and later on labour productivity is taken into account in the feebate (rebate) scenario. — The gains are more or less evenly distributed over all consumers, with a slight bias towards the richest agents in the economy. — Government revenues also increase.

Source: Table compiled by the authors.

4 CONCLUSIONS

The IGEM framework offers two main added-values to policymakers and academic researchers. First, it details a methodology to “green” conventional modelling tools, the CGE, SD and IO-SAM models, and, second, it presents a methodology to link these three types of modelling tools to better answer GE policy questions.

First, on greening, the paper presents a comprehensive methodology to green IO and SAM models, based on the example of Japan for the renewable energy sector. It details how the CGE can be greened through the inclusion of additional sectors (e.g. water) and/or by using a green IO-SAM as input, and how the SD model can be greened by disaggregating a particular sector to address environmental and social questions of interest to policymakers.

Second, on the coupling, the paper presents a methodology on how to link the three types of modelling tools (the IGEM framework) by identifying the main entry points between the models and how this linkage can be reinforced following different rounds of integration. It also discusses each model's strengths and weaknesses and how, through their combination in the IGEM framework, they can help to answer a broader range of key GE policy questions.

The theoretical aspects are complemented by an application of the IGEM to simulate the impacts of different carbon tax rates on emissions, inspired by the experience of Mexico. The results from the CGE simulations alone show that, compared to business as usual, introducing a carbon tax on emissions of fossil fuels would entail small losses with regards to consumer welfare, GDP, and the size of the capital stock. However, if Mexico were to take significant steps to simultaneously curb fossil fuel use and invest in renewable energy alternatives (feebate scenario), this could result in higher values for aggregate indicators (e.g. GDP, investment, etc.) up to 2036 than when the tax revenues are returned directly to consumers (rebate scenario). The feebate scenario shows a biased distributive effect towards capital owners in the economy, which could indicate that in the actual policy implementation, a mix of investments policies and some transfers to the poorest may be needed. Taken as a whole these results imply that a carbon tax paired with "green" investment will have positive environmental impacts, while improving the energy mix by increasing the share of renewables with minimal impact on overall production (GDP). Looking at the SD simulations alone suggest that low tax levels are of limited value in effecting a transformation of the electricity generation mix. The simulations demonstrate that the feebate policy, with the high carbon tax on full emissions, achieves the greatest carbon emission reduction.

Welfare effects in the stand-alone CGE should be taken as lower bound estimates, as the CGE does not include external benefits such as improved health and overall quality of life induced by a reduction in fossil fuel use. However, the IGEM framework is able to consider the effects of increased longevity on aggregate and sectoral outcomes by coupling the CGE with the SD model. The results from the Mexico case study are interesting. First, GDP grows up to 0.33 percentage points more when the effect of lower emissions on longevity and later on labour productivity is taken into account in the rebate scenario. This growth reaches up to 1.3 additional percentage points when the feebate scenario is considered. Second, the gains are more or less evenly distributed over all consumers, with a slight bias towards the richest agents in the economy. However, since productivity increases, there is an increase in government revenues, and these added gains could, in principle, be redistributed to further increase the gains of the 20 per cent poorest consuming agents. Longevity is only one aspect of labour productivity and the positive externalities induced by reduced fossil fuel use will also reduce other negative productivity indicators such as morbidity and days lost due to illness. Thus, the positive impacts found by applying the IGEM should be considered as a lower bound to the welfare and growth increases that may be expected from a generally healthier population.

To conclude the application of the IGEM framework highlights the importance of combining a carbon tax with policies which stimulate investments in the renewable energy sector and the importance of taking into account "hidden" benefits from reduced environmental impacts on welfare and productivity. GE policies have the potential to generate positive impacts on the economic, social and environmental fronts. The results from the IGEM show that the positive externalities of increased longevity of Mexican workers resulting from the introduction of a carbon tax achieve the highest growth stimulus until 2036 if a feebate policy is adopted. As an integrated framework, the IGEM is therefore able to depict a more complete picture of the GE by taking into account not only direct economic effects following the introduction of a carbon tax, but also indirect ones, resulting in health and productivity improvements, induced by lower emissions. This example of the application of the IGEM, inspired by the case of Mexico, will provide policymakers with a sense of the integrated impact that GE policies can achieve and how these can support the transition to an IGE.

Finally, it is important to recognize that this version of the IGEM framework should be considered a first step in the process of integrating three of the main modelling techniques frequently used to assess the potential impacts of GE policies. This work offers a framework to understand policy implications through the calculation and analysis of a series of “what if” scenarios, but it is not meant to be predictive. Additional work (including sensitivity analysis) is needed to better combine the CGE and SD models and conduct simulation-based testing of carbon taxes and other GE policies. Furthermore, the limited availability of data (within the relative short period of time of this project) represented a challenge for "greening” the models (e.g. disaggregating of green sectors, regional disaggregation, etc.) as well as for capturing the spatial impacts associated with trade and investments. Therefore, additional work would be required to collect the necessary data to expand and adapt this first version of the IGEM when applied to other countries.

5 REFERENCES

Adedayo, O. A. & Anthony, E. A. (2016). *"Threshold Effects between Longevity, Labour Productivity and Economic Growth in sub-Saharan Africa (SSA): A Non-dynamic Panel Data Analysis"*, 3rd International Conference on African Development Issues (CUI-ICADI 2016).

Aghion, P., Howitt, P. & Murtin, F. (2010). *"The relationship between health and growth: when Lucas meets Nelson-Phelps (No. w15813)"*, National Bureau of Economic Research.

Armington, P. (1969), *"A Theory of Demand for Products Distinguished by Place of Production"*, International Monetary Fund Staff Papers 16: 159 -178, Washington D.C.: IMF.

Ballard, C. L., Fullerton, D., Shoven, J. B. & Whalley, J. (1985). *A general equilibrium model for tax policy evaluation*, Chicago: University of Chicago Press.

Bergman, L. (2005). *"CGE modeling of environmental policy and resource management"*, Handbook of environmental economics 3, 1273-1306.

Boyd, R. & Ibarrarán, M. E. (2002). *"Cost of compliance with the Kyoto Protocol: a developing country´s perspective"*, Energy Economics 24, 21-39.

Boyd, R. & Ibarrarán, M. E. (2009). *"Extreme climate events and adaptation: an exploratory analysis of drought in Mexico"*, Environmental and Development Economics 14, 371-395.

Boyd, R. & Ibarrarán, M. E. (2009). *"Extreme climate events and adaptation: an exploratory analysis of drought in Mexico"*, Environmental and Development Economics 14, 371-395.

Burniaux J., Truong T. (2002). *"GTAP – E: an energy – environmental version of the GTAP E model"*. GTAP Technical Paper No. 16. Available at: https://www.gtap.agecon.purdue.edu/resources/download/1203.pdf

Caron, J., Metcalf, G. & Reilly, J. (2014). *The CO2 Content of Consumption Across US Regions: A Multi-Regional Input-Output (MRIO) Approach.* MIT Joint Program on the Science and Policy of Global Change Report No. 266. Cambridge: Massachusetts Institute of Technology (MIT).

Consejo Nacional de Evaluación de la Política de Desarrollo Social (2014). *Metodología para la medición multidimensional de la pobreza en México (segunda edición)*. México, DF: CONEVAL.

Hasegawa, R., Kagawa, S. & Tsukui M. (2015). *Carbon footprint analysis through constructing a multi-region input–output table: A case study of Japan*. Journal of Economic Structures, 2015 4:5.

Hosoe, N., Gasawa, K. & Hashimoto, H. (2010). *Textbook of Computable General Equilibrium Modelling: Programming and Simulation*. England: Palgrave Macmillan.

Ibarrarán, M. E. & Boyd, R. (2006). *Hacia el Futuro: Energy, Economics and the Environment in 21st Century Mexico.* The Netherlands: Springer.

Ibarrarán, M. E., Boyd, R. & Moreno L. (2011). *"Costly commitments: climate change policy in Mexico"*, Latin American Policy 2 (2), 222–233.

Ibarrarán, M. E., Bassi, A. M. & Boyd R. (2015). *Analyzing green growth: integrating models to assess green economy – methods and applications to Mexico. In M. Ruth (Ed.), Handbook of Research methods and Applications in Environmental Studies (pp. 375-395)*. Cheltenham: Edward Elgar Publishing Limited

Institute of Developing Economics, Japan External Trade Organization (IDE-JETRO) (2003). *Multi-regional Input-Output Model for China 2000*. IDE Statistical Data Series, No. 86.

Instituto Nacional de Estadistica y Geografia (2003). *Input-Output Matrix for Mexico 2003*, Mexico.

International Panel on Climate Change. (2006). *IPCC Guidelines for National Greenhouse Gas Inventories*. IPCC: Geneva. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/

Lenzen, M., Pade, L.L. & Munksgaard, J.(2004). *CO2 Multipliers in Multi-region Input-Output Models. Economic Systems Research* 16, 391-412.

Leontief, W. (1936). *Quantitative input-output relations in the economic system of the United States.* Review of Economics and Statistics, 18, 105-125.

Leontief, W. (1941). *The Structure of American Economy 1919-1939*. New York: Oxford University Press.

Lindberg, G. & Hansson, H. (2009). E*conomic impacts of livestock production in Sweden: An input-output approach.* Department of Economics, Swedish University of Agricultural Sciences, Working Paper Series 2009/1.

Lindner, S., Legault, J. & Guan, D.B. (2012a). *Disaggregating input–output models with incomplete information.* Economic System Research, 24 (4), 329-347.

Lindner, S., Legault, J. & Guan, D.B. (2012b). *Disaggregating the electricity sector of China's input output table: Application to environmental-economic life cycle analysis*. Paper presented at the 20th International Input-Output Conference, Bratislava, Slovakia, June 24-29, 2012. Available at: https://www.iioa.org/conferences/20th/papers/files/989_20120229060_Lindner_etal_IIIOAConference.pdf**Lofgren, H., Harris,**

R.L. & Robinson, S. (2002). *A Standard Computable General Equilibrium (CGE) Model in GAMS.* International Food Policy Research Institute.

Miller, R. E. & Blair, P.D. (2009). *Input-Output Analysis: Foundations and Extensions (Second Edition)*. New York: Cambridge University Press.

Ministry of General Affairs of Japan (2002). *Chapter VI: Concept, definition and scope by sector.* Available at: http://www.soumu.go.jp/main_content/000327482.pdf

Ministry of the Environment of Japan (2012). *Regarding the Revision of Environmental Industry Classifications.* MOEJ: Tokyo. Available at: http://www.env.go.jp/policy/keizai_portal/B_industry/1-1.bunruikaitei.pdf

Ministry of the Environment of Japan (2014). *Estimation of the Market Size of the Environment Industry and Examination of Environmental Business Promotion Measures Made on a Commission Basis in Fiscal 2013*. MOEJ: Tokyo. Available at: http://www.env.go.jp/policy/keizai_portal/B_industry/b.houkoku2.pdf

Organization of Economic Co-operation and Development (1999). *The Environmental Goods and Services Industry: Manual for Data Collection and Analysis.* OECD: Paris Available at: http://www.oecd-ilibrary.org/industry-and-services/the-environmental-goods-and-services-industry_9789264173651-en

PAGE (2015), *"Green Economy Assessment Mauritius"*, Geneva: UNEP.

Peters, G.P. & Hertwich, E.G.(2008). *CO2 embodied in international trade with implications for global climate policy.* Environmental Science & Technology 42(5), 1401-1407.

PNUMA (2015). *"Hacia una economía verde en Uruguay: Condiciones favorables y oportunidades"*, Geneva: UNEP.

Quesnay, F. (1758). Tableau Économique.

Ramsey, F. (1928). *"A mathematical theory of saving"*, Economic Journal 38, 543-559.

Rutherford, T. F., Montgomery W.D. & Bernstein P.M. (1997). *"CETM: a dynamic general equilibrium model of global energy markets, carbon dioxide emissions and international trade"*, University of Colorado Discussion Paper in Economics 97-3.

Sheng, F. (2016). *"An Emerging Theory of an Inclusive Green Economy"* , Web log post. 26 Jan. 2016. Available at: http://web.unep.org/greeneconomy/blogs/emerging-theory-inclusive-green-economy

Suh, S. & Huppes, G. (2009). *Methods in the Life Cycle Inventory of a Product. In: Suh, S. (Ed.)*, Handbook of Input-Output Economics in Industrial Ecology, Eco-Efficiency in Industry and Science 23. Springer.

Swift, R. (2011). *"The relationship between health and GDP in OECD countries in the very long run"*, Health economics 20(3), 306-322.

UNEP (2011). *"Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication"*, Geneva: UNEP.

UNEP (2012), *"Measuring Progress towards an Inclusive Green Economy"*, Geneva: UNEP.

UNEP (2013), *"Green Economy Scoping Study: South African Green Economy Modelling Report (SAGEM) – Focus on Natural Resource Management, Agriculture, Transport and Energy Sectors"*, Geneva: UNEP.

UNEP (2014a), *"A Guidance Manual for Green Economy Policy Assessment"*, Geneva: UNEP.

UNEP (2014b), *"Using Indicators for Green Economy Policymaking"*, Geneva: UNEP.

UNEP (2014c), *"Green Economy Assessment Report – Kenya"*, Geneva: UNEP.

UNEP (2014d), *"Green Economy Sectoral Study on Energy –Rwanda"*, Geneva: UNEP.

UNEP (2014e), *"Green Economy Assessment Study - Senegal"*, Geneva: UNEP.

UNEP (2014f), *"Green Economy Assessment Study – Burkina Faso"*, Geneva: UNEP.

UNEP (2015), *"Indicators for Green Economy Policymaking – A Synthesis Report of Studies in Ghana, Mauritius and Uruguay"*, Geneva: UNEP.

UNEP (2016), *"Economia Verde Relatório De Modelação – Moçambique"*, Geneva: UNEP.

U.S. Energy Information Administration (EIA) (2015). *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2015*. https://www.eia.gov/forecasts/aeo/pdf/electricity_generation.pdf

Wiedmann, T. (2009).*"A review of recent multi-region input–output models used for consumption-based emission and resource accounting"*, Ecological Economics 69, 211-222.

WIOD website: http://www.wiod.org/new_site/database/wiots.htm

Wissema, W. & Dellink, R. (2007). *"AGE analysis of the impact of a carbon energy tax on the Irish economy"*, Ecological Economics 61.4, 671-683.

Wolsky, A.M. (1984). *"Disaggregating Input-Output Models"*, The Review of Economics and Statistics 66 (2), 283-291.

Zhou, X. (2010). *Environmentally Extended Multi-Region Input-Output Model: Sharing Responsibility Across the Globe.* In Murray, J., Wood, R. (Eds.): The Sustainability Practitioner's Guide to Input-Output Analysis. Chapter 14. Common Ground Publishing LLC., Champaign, Illinois, 165-176.

Zhou, X., Liu, X.B. & Kojima, S., (2010). *Carbon Emissions Embodied in International Trade: An assessment from the Asian perspective. IGES Research Report 2010.* Hayama: Institute for Global Environmental Strategies (IGES).

Zhou, X. & Imura, H., (2011). *"How does consumer behavior influence regional ecological footprints? An empirical analysis for Chinese regions based on the multi-region input-output model"*, Ecological economics 71, 171-179.

Zhou, X., Ambiyah, A., Kojima, S. & Shirakawa, H. (2013). *"Accounting for the carbon footprints and embodied primary resources using multi-region input-output analysis"*. Full paper presentation at the 21st International Input-Output Conference, 9-12 July 2013, Kitakyushu, Japan. Available at: http://pub.iges.or.jp/modules/envirolib/upload/4529/attach/Section_2.2_MRIO_20130130.pdf

Zhou, X., Yano, T. & Kojima, S., (2013). *"Proposal for a national inventory adjustment for trade in the presence of border carbon adjustment: Assessing carbon tax policy in Japan"*, Energy Policy 63, 1098-1110.

Zhou, X. (2015). *"Construction of a Generic Integrated Green Economy Model. Role of the input-output model and social accounting matrix in IGEM"*, Institute for Global Environment Strategies (IGES), 1 December 2015.

Zhou, X., Li, D.W. & Chang, M. (2015). *"Renewable Energy in China: Life cycle impact assessment based on firm-level survey"*, IGES Working Paper July 2015. Hayama: Institute for Global Environmental Strategies (IGES).

Zhou, X. & Moinuddin, M., (2015). *"Economic and Employment Impact Assessment of Green Investment: A case study on Environmental Goods and Services Sector (EGSS) in Japan"*, IGES Working Paper, July, 2015. IGES: Hayama. Accessed at: http://pub.iges.or.jp/modules/envirolib/view.php?docid=6541

Zhou, X. & Mustafa, M. (2015). *"Economic and Employment Impact Assessment of Green Investment: A case study on Environmental Goods and Services Sector (EGSS) in Japan"*, IGES Working Paper July 2015. IGES: Hayama.

NOTES

[1] An inclusive green economy (IGE) contributes to the overarching goal of poverty eradication and shared prosperity in an intergenerational context by safeguarding planetary boundaries, some of which (e.g. climate, freshwater, ocean and land) are mirrored in the SDGs. The planetary boundaries are, however, not to be considered passively in an IGE; instead, they should serve as drivers for innovative solutions that not only respect ecological thresholds but also contribute to reduced poverty and shared prosperity (Sheng, 2016).

[2] See Annexes 3, 5 and 6 for a detailed description of the models. All Annexes will be made available upon request.

[3] The T21 model is a system dynamics model developed by the Millennium Institute (MI) that includes endogenous links within and across the economic, social and environmental sectors through various feedback loops to simulate especially medium- and long-term impacts of green investment scenarios against business as usual (BAU) or baseline scenarios.

[4] See also Section 3.1 for a discussion of these two approaches.

[5] Not published at the moment this article is being written but an article on the modelling methodology followed is found in Ibarrarán et al. (2015).

[6] A summary of the 10 green economy country studies is provided in Annex 2 . All Annexes will be made available upon request.

[7] Visit the Millennium Institute website for a more detailed description of the T21 model: http://www.millennium-institute.org/integrated_planning/tools/T21/

[8] Participants at the workshop included researchers from the Millennium Institute, the Institute for Global Environmental Strategies (IGES), the Institute for Sustainable Development and International Relations (IDDRI), the Centro Studi sul Federalismo (Italy), the University Iberoamericana Puebla (Mexico), the United Nations Environment Programme, the United Nations Industrial Development Organization (UNIDO), the International Labour Organization (ILO), the University of Bergen and Shanghai University.

[9] See Annex 1 for the complete list of questions, provided upon request.

[10] A workshop was organized in April 2016 to present the first results of the IGEM framework. A summary of the main outcomes can be found in Annex 11, provided upon request.

[11] The application of the IGEM framework to the case of Mexico should be considered experimental in nature, but it offers insights of general applicability to other cases. The exploratory simulations are not necessarily predictive for the case of Mexico (or any other application), but they offer a framework to understand policy implications throughout the calculation and analysis of a series of what if scenarios. Additional work is needed to combine CGE/SD, and conduct simulation-based testing of carbon taxes and other GE policies.

[12] This Annex will be made available upon request.

[13] This is a generalization of a more complex and detailed process in which for many specific sectors the green components can be subdivided from other less sustainable production practices.

[14] In case the quantity of renewable energy used in the solar power generation is significant, then that electricity should be taken into account.

[15] EGSS can adequately represent many green products/sectors.

[16] See UNEP (2016): "Trade on Environmental Goods at a Glance: Technical note", March 2016.

[17] A suggestion for the renewables sector in Mexico, using Japan's previous experience in this sector is presented in Annex 4, provided upon request.

[18] This allows us to calibrate the model disaggregation not only at the sectoral and agent level but also at the regional spatial level. This is very data demanding and unfortunately for the current application of this report such data was not available.

[19] See http://www.epa.vic.gov.au/your-environment/water/protecting-victorias-waters/point-and-nonpoint-sources-of-water-pollution for the distinction between point and non-point water pollution.

[20] See Annex 6 for a description of these sectors, provided upon request.

[21] In the SD model used in the IGEM framework, the structures of the sectors do, however, have a history in T21 applications, which provides an important element of their validation. These sector structures are amenable to modification, expansion, or disaggregation if necessary for the specific country analysis.

[22] Source: http://www.cnel.it/cnelstats/popupFonteSingola.asp?source=49

[23] Available at: http://faostat.fao.org

[24] See section 2.3 for further discussion.

[25] See section 2.3 for a discussion of how the IGEM framework can address green economy policy questions.

[26] See Bergman, (2005) for using CGE models with externalities for environmental policy analysis. Other works in this area include Wissema and Dellink, (2007).

[27] See Annex 3 for a description of the IO and SAM, provided upon request.

[28] In the case of Mexico, the measurement of poverty is multidimensional (including aspects of economic wellbeing and social rights). This application focus on the monetary aspects of poverty, but future applications could expand the notion of poverty measures used in the analysis. See Coneval, (2014).

[29] See Annex 1 for the complete list of questions, provided upon request.

[30] For a discussion on how CGE and SD models can be integrated in the case of Mexico with other policy applications, see Ibarrarán et al 2015.

[31] The role of IO-SAM is to disaggregate or to create new green sectors for the green CGE, and will therefore not be displayed.

[32] Data is for 2011. United Nations Statistics Division. "Carbon dioxide emissions (CO2), thousand metric tons of CO2 (CDIAC)." Millennium Development Goals Indicators. Available at: http://mdgs.un.org/unsd/mdg/SeriesDetail.aspx?srid=749&crid=

[33] https://www.gov.uk/government/publications/exporting-to-mexico/exporting-to-mexico

[34] http://www.nature.com/news/mexico-passes-climate-change-law-1.10496

[35] http://climateactiontracker.org/indcs.html

[36] http://switchboard.nrdc.org/blogs/cherrera/mexico_announces_ambitious_emi.html

[37] Mexico's INDC submission (as of March 2015) is available here: http://www4.unfccc.int/submissions/INDC/Published%20Documents/Mexico/1/MEXICO%20INDC%2003.30.2015.pdf

[38] SEMARNAT, 2014. Available at: https://www.thepmr.org/system/files/documents/Carbon%20Tax%20in%20Mexico.pdf

[39] OECD (2014). Mexican fiscal reform environmental taxes; Carbon tax and the Tax on Pesticides. June 2014. Available at: http://www.oecd.org/tax/tax-global/Session%203%20-%20LUNA.pdf

[40] This value is close to the weighted average for OECD countries (EUR 27). See "Climate and Carbon, Aligning prices and policies", OECD Environment Policy Paper, October 2013, no.1, p.23, for more detail.

[41] The BAU scenario assumes that no carbon tax is implemented. This assumption allows us to analyse the impacts of the carbon tax as it is.

[42] See Annex 7 for detailed results, provided upon request.

[43] The positive impact of additional green investments can be seen on the higher GDP, investment and capital stock of the feebate scenario compare with the lumps sum transfer scenario. The negative impacts seem on column one, just reflect the fact that for positive effects of green policies, carbon taxes must be complemented by additional investments policies that stimulate green activities in a larger scale. The same applies to Table 9.

[44] Government refers to the total expenditure that, under a balanced budget, we assume here it is equal to total income from tax revenue and sales of publicly provided goods and services. Since the idea here is to see how this concept changes when different policies are simulated, it is of little interest to this paper to include how the overall deficit will behave once policies are enacted in terms of its long terms sustainability. What we want to show here is how this balance in government revenues (or expenditure) changes under different policies.

[45] The capital stock decreases because it is assumed that electric generators that use fossil fuels would close after the introduction of the carbon tax.

[46] The overall aggregate welfare agents result is positive because consumers are better served by renewables and the impact on prices than by the transfer they received as a lump sum of tax collections.

[47] This could indicate that in the actual implementation of the policy, a mix of investments policies and some transfers to the poorest may be needed.

[48] Including renewable energy.

[49] This Annex will be provided upon request.

[50] Results comparing the rebate scenario with a high tax rate (RH) compared to BAU in the CGE model are presented in Annex 8, provided upon request.

[51] Government refers to the total expenditure that, under a balanced budget, we assume here it is equal to total income from tax revenue and sales of publicly provided goods and services. Since the

idea here is to see how this concept changes when different policies are simulated, it is of little interest to this paper to include how the overall deficit will behave once policies are enacted in terms of its long terms sustainability. What we want to show here is how this balance in government revenues (or expenditure) changes under different policies.

[52] See Annex 7, Tables A7.11-15 (BAU) and Tables A7.16-20 (RH) for more detail, provided upon request.

[53] The model has been calibrated with data from the World Bank, UN Population Division, FAO, International Energy Agency (IEA), and other international sources.

[54] Provided upon request.

[55] For full results, see Annex 9, Tables A9.1-A9.5 (changes due to longevity with respect to the original BAU)and Tables A9.6-A9.10 (changes due to longevity with respect to RH scenario with no longevity).

[56] Provided upon request.

[57] Government refers to the total expenditure that, under a balanced budget, we assume here it is equal to total income from tax revenue and sales of publicly provided goods and services. Since the idea here is to see how this concept changes when different policies are simulated, it is of little interest to this paper to include how the overall deficit will behave once policies are enacted in terms of its long terms sustainability. What we want to show here is how this balance in government revenues (or expenditure) changes under different policies.

[58] For full results, see Annex 10, Tables A10.1-5 (changes due to longevity compared to original BAU) and Tables A10.6-10 (changes due to longevity with respect to the FBH with no longevity). Provided upon request.

[59] The comparison of these results with those of column 2, Table 10 illustrate that when the carbon tax is just rebated to the public and it is not channeled to new investments on renewable (feebate), the impact on investment will be limited (only marginally positive when labor productivity increases, because of the positive effect of the reduction of emissions on labour productivity).

ANNEXES

ANNEXES CONTENTS

ANNEX I – MODELLING TOOLS AND GREEN ECONOMY POLICY QUESTIONS

The aim of this annex is to try to identify green economy (GE) policy questions that modelling tools, and in particular the IGEM, can help answer. The underlying objective is to enhance the ability of modelling tools to help advise countries willing to implement GE policies.

Within the integrated policymaking process, the focus is on the policy assessment stage, in which modelling plays a more prominent role.

It is assumed that stakeholder meetings will result in the identification and agreement of development priorities, which set the stage for the following questions addressed to modellers.

I. INVESTMENTS

The previous stages of the integrated policymaking process identified issues and priorities, and the key targets and policy instruments to address the most relevant issues. This implies the identification of potential large-scale green investments in GE sectors and their role in achieving the identified targets. This would also include the choice of an outcome measure (e.g. impact on gender ratio, number of jobs, sectoral productivity, gross fixed capital formation, etc.). Some of the main policy questions that we have when analysing investments are:

1) What are the underlying financing options (debt, equity, domestic, external, public, private, mixed, etc.) to achieve these investments?

2) How do these investment options compare in terms of cost/risk?

3) Which criteria should be used to select and prioritize investment options?

4) How can the impact of these investments (new and shifted) and policies be assessed?

5) What benefits might investments and policies generate across sectors and in terms of economic opportunities, inclusiveness and environmental sustainability?

6) Are the impacts likely to be long or short-term?

II. ENABLING POLICIES

Which policies could enable these investments? These include fiscal (taxes, subsidies, public spending/investments), industrial (specific sectors and types of supportive measures), trade (tariff and non-tariff), labour, and social protection policies, and regulations/standards.

1) Which type of public spending and investments help achieve green innovations and how can they increase access to and affordability of green technologies

2) How can regulations for resource and energy efficiency be implemented?

3) How do certification requirements relate to productivity in GE sectors?

4) Which labour interventions deliver more (quantity) and better (quality including decency) green jobs? Which approaches create better access for the unemployed and underemployed?

5) Are there social protection instruments which focus on any or a combination of factors like supporting, mitigating or enabling?, which instruments can generate green public goods?

6) What types of industrial policy measures are in place to support the transition towards a green economy?

7) How will green subsidy reforms (e.g. FITs) likely impact productivity in GE sectors?

8) How will green tax reforms and removing fossil fuel subsidies mobilize domestic revenues for green investment? What will be the implications of such reforms on environmental, economic/fiscal and social fronts?

9) Which industrial policies generate the most co-benefits across multiple sectors (e.g. the biggest forward and backward linkages in GDP, productivity, employment, etc.) and across social (gender) and environmental dimensions (vulnerability to climate change)?

10) How do trade policies and regulations enhance investments in GE sectors?

11) To what extent do international markets represent a factor of vulnerability or opportunity for low income countries in their transition towards a GE?

12) How to compare the different policy instruments available?

13) How can public policies support awareness be raised of environmental and social issues?

III. IMPACTS OF INVESTMENTS AND POLICIES ON INDICATORS

What are the impacts of investments and enabling policies on indicators that capture the key policy targets, including:

- GDP and economic growth
- GDP (sectoral distribution)
- Energy intensity of (sectoral) GDP
- Emission intensity of (sectoral) GDP
- % of renewables in total energy
- % renewables to non-renewables by sector
- Relative prices
- Green/decent jobs (total and by sectors)/real wages
- Fiscal revenue/macroeconomic stability
- Import/export/competitiveness
- Productivity/sectoral spillovers
- Access to "green" credit and investment
- Health
- Access to and affordability of water and sanitation
- Access to and affordability of modern energy
- Poverty
- Equity/inclusiveness
- Greenhouse gas emissions (CO2, HFC, CH4, etc.)
- Biodiversity/ecosystems
- Natural capital (land, water, forests, fisheries)
- Etc.

IV. CROSS CUTTING ISSUES

Policy assessment is influenced by the contest in which it is done. Here are some of the most critical issues that affect the type of policy questions that models need to contribute answering:

- Level of information available for assessment (data rich vs data short countries): the quantity and quality of data available affects the type of questions that could be asked and potentially answered (e.g. disaggregated sectoral impact, distributional issues across economic agents, gender, regions, communities, urban/rural, etc.);

- Time horizon most relevant for key stakeholders: for some stakeholders, the long run is the most critical time horizon, while for others it is the medium and short run (information at different levels of time horizon are critical to inform the integrated policymaking); Degree of consensus on national targets (e.g. some countries have already reached consensus on national/ sectoral priorities and targets, while others haven't);

- Choice of policy instrument to achieve targets (macroeconomic and enabling policies vs. sectoral policies) and;

- Social preferences about the weights assigned to different dimensions of green economy (this will be country specific priorities, but it is critical for green economy that no particular dimension gets a particularly low weight).

V. MODELS

How will models, such as a system dynamics model, CGE, I/O, SAM, GIS, etc., help to assess investments and policies identified in I and II over the range of impacts identified in III?

Which models can deal better with the issues highlighted in IV?; which models depend more on certain types of data that it are difficult to find in some countries?; which models are the best to provide relevant information at different time horizons?; how can models help to improve the target setting efforts made in a country/sector?; can they support the target setting process in those country/sectors in which consensus has not been reached?; how can models inform on the extent of conflicting policy targets?; how can models incorporate the social weights assigned to the different dimension of green economy?; which models are able to present such weights in a more transparent way?

What types of aspects/questions can CGE, I/O, SAM and GIS help address for which a system dynamics model is not/less suited for and vice-versa?

If a particular system dynamics model is used as a main tool due to its economic, social and environmental interconnectedness, how would it be possible to link CGE, I/O, SAM and GIS models to it to have a big picture of the tool box?

ANNEX II – REVIEW OF COUNTRY STUDIES

Table 1: *Summary of 10 green economy country studies supported by UNEP*

COUNTRY STUDY	GREEN SECTORS (SUB-SECTORS)	GREEN ECONOMY INTERVENTIONS
1) SOUTH AFRICA	Agriculture	- Investments in organic fertilisers.
	Natural Resource Management[1]	- Investments in the clearing of the invasive alien species.
	Transportation	- investments to improve transport sector efficiency.
	Energy	- Investments in the expansion of renewable power generation.
2) KENYA	Agriculture	- Investments in agro-forestry; - Investments in sustainable water management practices such as rainwater harvesting, irrigation and use of less water-intensive crop varieties; - Capacity building, training on agroforestry and sustainable livestock management; - Research & Development (R&D) programmes on international environmental standards and more efficient agricultural technologies (less energy, chemicals).
	Energy	- Investments in clean energy solutions for households (e.g. solar lanterns, LPG-improved, cook stoves, and energy-efficient lighting and appliances); - Capacity building and funding to support upfront costs of exploration, appraisal and production drilling for large-scale geothermal generation to provide base load electricity; - Investments in off-grid alternatives, such as hybrid systems diesel - wind, solar or small-hydro, in the short-term for isolated communities and in on-grid renewable energy, including small-hydro, wind and solar.
3) RWANDA	Energy (RE)	- Investments (including capital cost, operation and maintenance costs) in additional grid-electricity capacity from renewable energies (i.e., hydro, methane, solar, geothermal and peat) for reaching established targets under the country's 2020 vision document.
4) URUGUAY	Agriculture	- Tax exemptions to promote water saving irrigation systems; - Mandatory implementation of responsible soil use and management plans.
	Livestock (cattle)	- Capacity building, technical assistance, and technological transfer to enhance adequate livestock density management; - Subsidies for the constructions of dams, irrigation systems and drinking troughs.
	Tourism (coastal tourism)	- Implementation of land use regulation plans in the coastal departments; - Subsidy for energy audits and a guarantee fund for implementing energy efficiency measures in hotels and restaurants.
	Transportation (land transportation)	- Implementation of traffic regulations in favour of the public transport in Montevideo; - Energy efficiency standard label for private vehicles; - Rehabilitation of rail transport.
5) MEXICO	Energy	- Phasing out all existing subsidies on gasoline, diesel, LPG, and electricity as a means of decreasing their use and promoting conservation of fossil fuels.
	Forestry	- Investments in reforestation programmes for secondary forests and secondary rainforests.
	Fishery	- Investments in controlling capacity and in supporting fish reproduction as a measure to gradually reduce fish catch.
	Transportation	- Investments in policy interventions on Transit Oriented Development (TOD); energy efficient vehicles; optimization and expansion of public transport networks; promotion of non-motorized transportation (e.g. system of public bicycles); along with transport demand management policies such as removal of harmful fuel subsidies, fuel saving standards for heavy-duty vehicles and freight optimization policies.
	Water	- Investments to increase water efficiency for the northern and central regions.

6) SENEGAL	Agriculture	- Investments to reduce salinization/desertification; - Investments in the substitution of chemical fertilizers and pesticides.
	Forestry	- Investments in sustainable forest management; - Investments in reforestation; - Investments in the substitution of wood energy with gas energy.
	Water resources	- Investments in building reservoirs for controlling rainwater; - Investments in water reuse; - Investments in increased water productivity.
	Energy production	- Investments in renewable energy (solar, wind and hydroelectric); - Investments in the substitution of wood energy with gas energy; - Investments in bioenergy production: biofuel and biogas.
	Energy efficiency	- Investments in increased energy efficiency (in industry, construction and transport).
	Waste management	- Investments in waste collection systems.
7) BURKINA FASO	Agriculture (crop cultivation)	- Investments in the substitution of chemical fertilizers and pesticides with natural fertilizers and bio-pesticides, to promote agricultural extension services, and to reduce agricultural land degradation.
	Livestock	- Investments in the intensification of livestock, and reduction of grazing land degradation.
	Forestry	- Investments in reforestation, and valorisation of non-timber forest products, and reducing the use of wood energy, as direct effect of energy sector policies.
	Water (infrastructure)	- Investments in the construction of dams and irrigation infrastructure.
	Energy	- Investments in renewable electricity: solar PV and hydropower, in reducing consumption of traditional combustibles by installing solar cookers or improved cookers, or using gas for cooking; - Investments in energy efficient buildings that save electricity for air conditioning.
	Mining	- Contribution to promote renewable electricity.
8) GHANA	Agriculture (crop cultivation)	- Investments to increase irrigated harvested areas.
	Energy	- Investments in the promotion of electricity generation from renewable sources (solar, wind, hydropower); - Investments in the installation of energy efficient light bulbs and refrigerators.
	Forestry	- Investments to increase reforestation.
9) MOZAMBIQUE	Energy	- Investments to increase access to electricity through the expansion of natural gas generation capacity; - Investments to improve energy efficiency.
	Fisheries	- Reducing fishing capacity and interventions to support fish spawning and regeneration.
	Forestry	- Investments in reforestation programmes and in forest plantation for production purposes.
	Mining	- Investments in waste reuse technologies and processes to reduce toxic waste production and groundwater pollution; - Investments to improve water efficiency in populated areas around mining sites.
10) MAURITIUS	Agriculture	- Investments to increase the land area under sustainable cultivation; - Investments to reach self-sufficiency in certain strategic crops.
	Energy	- Investments to increase electricity from renewable energy, and in energy efficiency improvements in residential, industrial and domestic sectors.
	Manufacturing	- Investments to improve water and energy efficiency.
	Tourism	- Investments to improve water and energy efficiency.
	Water	- Investments to improve water efficiency and reduce water losses; - Investments in waste recycling in the residential, commercial and industrial sectors.

Source: Table compiled by the authors.

ANNEX III – THE FUNDAMENTALS OF THE IO AND SAM

III.1 Input-output model (IO)

The initial input-output model originated in the eighteenth century owing to the work of François Quesnay on the *"Tableau Économique"* (Quesnay, 1758). It was then in 1936 when an analytical framework named as input-output analysis (IOA) was developed by Wassily Leontief to present the economic system of the United States (Leontief, 1936, 1941). Professor Wassily Leontief received the Nobel Prize in Economic Science in 1973 in recognition of his contributions to modern economics.

Basic data and framework of an IO model

IOA, often used interchangeably as an IO model, is generally constructed from observed economic data in monetary terms for a specific geographic region (a country, a state or a county, etc.) and for a particular time period (usually a year) (Miller and Blair, 2009). One essential set of data for an IO model are the monetary values of the flows of products from each of the producing sectors (as a seller) to each of the purchasing sectors (as a buyer), the so called inter-industry transactions. Often the set of producing sectors is the same as the set of purchasing sectors. The magnitudes of these inter-industry transactions can be presented in a table, namely an input-output table, with producing sectors listed on the left and the same sectors, the purchasing sectors, listed on the top. A schematic framework of a basic IO table is presented in Table A3.1.

The mathematical structure of an IO model consists of a set of n linear equations with a given set of f_i s and n unknown variables $X_i (i = 1, \dots n)$ which is often presented in matrix format. Reading by rows in the table, we can have the following relations:

$$\begin{aligned} X_1 &= x_{11} + \cdots + x_{1j} + \cdots + x_{1n} + f_1 \\ &\vdots \\ X_i &= x_{i1} + \cdots + x_{ij} + \cdots + x_{in} + f_i \qquad (Eq.A1) \\ &\vdots \\ X_n &= x_{n1} + \cdots + x_{nj} + \cdots + x_{nn} + f_n \end{aligned}$$

where

X_i : total output of sector i;
x_{ij}: output of sector i used by sector j;
f_i : total final demand for sector.

Or in a compact format as:

$$X_i = \sum_{j=1}^{n} x_{ij} + f_i \qquad (Eq.A2)$$

While reading by columns, one can find the following relations:

$$\begin{aligned} X_1 &= x_{11} + \cdots + x_{i1} + \cdots + x_{n1} + v_1 \\ &\vdots \\ X_j &= x_{1j} + \cdots + x_{ij} + \cdots + x_{nj} + v_j \qquad (Eq.A3) \\ &\vdots \\ X_n &= x_{1n} + \cdots + x_{in} + \cdots + x_{nn} + v_n \end{aligned}$$

Where v_j: total value-added for sector j.

In a compact format, this can be re-written as:

$$X_j = \sum_{j=1}^{n} x_{ij} + v_j \qquad (Eq.A4)$$

A fundamental assumption in an IO model is that the inter-industry flows x_{ij} depend solely on the total output of sector j which uses inputs from sector is in fixed proportions. Therefore, unlike a classical production function such as those used in a CGE model, the Leontief production function assumes a linear production function without considering the economies of scale in production and no substitution

Table A3.1: *Schematic framework of an IO table*

		PURCHASING SECTORS					FINAL DEMAND				TOTAL OUTPUT (X)
PRODUCING SECTORS	1	x_{11}	…	x_{1j}	…	x_{1n}	c_1	i_1	g_1	e_1	X_1
	⋮	⋮		⋮		⋮	⋮	⋮	⋮	⋮	⋮
	i	x_{i1}	…	x_{ij}	…	x_{in}	c_i	i_i	g_i	e_i	X_i
	⋮	⋮		⋮		⋮	⋮	⋮	⋮	⋮	⋮
	n	x_{n1}	…	x_{nj}	…	x_{nn}	c_n	i_n	g_n	e_n	X_n
VALUE-ADDED (v')		v_1	…	v_j	…	v_n	v_c	v_i	v_g	v_e	V
IMPORTS (m)		m_1	…	m_j	…	m_n	m_c	m_i	m_g		M
TOTAL INPUT (x)		X_1	…	X_i	…	X_n	C	I	G	E	

Source: Xin Zhou.

between factors of production. Based on these assumptions, a set of technical coefficients, or input- output coefficients, are defined:

$$a_{ij} = x_{ij}/x_j \qquad (Eq.A5)$$

Using Eq.5, Eq.1 can then be written in a matrix form as:

$$\begin{bmatrix} x_1 \\ \vdots \\ x_i \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ a_{i1} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nj} & \cdots & a_{nn} \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_i \\ \vdots \\ x_n \end{bmatrix} + \begin{bmatrix} f_1 \\ \vdots \\ f_i \\ \vdots \\ f_n \end{bmatrix} \qquad (Eq.A6)$$

or in a compact format as:

$$X = AX + F \text{ or } (I - A)X = F \qquad (Eq.A7)$$

where A matrix is called technical coefficients matrix.

If $(I - A)$ is singular, $(I - A)^{-1}$ exists. Given the set of f_is, the n unknown variables $x_i(i = 1, \dots n)$ can then be solved:

$$X = (I - A)^{-1}F = BF \qquad (Eq.A8)$$

Where $B = (I - A)^{-1}$ is known as the Leontief invers or total requirement matrix with each element b_{ij} indicating how much will be produced by sector i for one unit final demand in sector j. In Eq.8, X are endogenous variables and A matrix and F vector are exogenous variables. Due to its static nature, an IO model is often used for near-term projections (e.g. five years). By updating the IO tables using additional data (such as GDP projection) and various techniques (such as RAS among others), an IO model can also be used for mid-term projections (e.g. 10 years).

IO table and national accounts

The information presented in an IO table can be well linked with a system of national accounts. First, the inter-industry transaction table (the one located in the quadrant surrounded by the dark-black frame) constitutes part of a complete set of income and product accounts of an economy. The components of the final demand column, including household purchases, investment, government purchases and exports, are often grouped into domestic final demand (*C+I+G*) and external find demand (exports, *E*).

Value added row is the payments by industrial sectors and final demand sectors for labour services and other value-added items such as government tax, interest payments to capital, rental payments to land and company profits, etc. Finally, the import row records the expenditure in imports by industrial sectors and the final demand sectors.

Summing up across the total output column and across the total input rows throughout the economy, we can find:

$$X = X_1 + X_2 + V + M \qquad (Eq.A9)$$

$$X = X_1 + X_2 + C + I + G + E \qquad (Eq.A10)$$

Equating the two equations for X and subtracting x_1 and x_2, we can have:

$$V + M = C + I + G + E \qquad (Eq.A11)$$

or

$$V = C + I + G + (E - M) \qquad (Eq.A12)$$

The left side represents gross national income and the right side represents gross national product (GNP).

III.2 Social accounting matrix

A social accounting matrix is a comprehensive and economy-wide data framework representing the economy of a nation (Lofgren, et al., 2002). Similar to an IO table, a SAM is often structured in a square matrix in which the same agent (categorized as Activity, Fact, Indirect Tax, Final Demand and Externa, etc.) is represented by a row and a column. The entries indicate flows of goods and services from the agents listed in the rows to the counterpart agents listed in the columns (Hosoe, et al., 2010). In other words, the incomes of an account are located along its row and the expenditures along its column. The underlying principle of a double-entry accounting framework requires that for each account in the SAM, total revenue (row total) equals total expenditure (column total).

A SAM is often used as a fundamental database for building an empirical CGE model. To be specific, the data provided in a SAM is used to estimate the coefficients and exogenous variables of a CGE model which is usually called calibration. The structure of a simple SAM for a standard CGE model can be shown in Table A3.2, in which each entry is explicitly explained in text. Depending on the function and requirement of a specific CGE model, the structure of the SAM can vary. For example, an Activity by Commodity matrix can be used instead of the Activity by Activity matrix indicated in Table A3.2. In addition, an Enterprise agent can be added and the Indirect Tax account can be merged with the Government, etc. (such as an example on p.5 in Lofgren, et al., 2002). Furthermore, if international trade is of particular interest, the External agent can then be disaggregated into origin countries for imports and destination countries for exports. Again, if different households are of special focus of the empirical study, households can also be disaggregated into different categories in terms of, for example, rural and urban households and different income levels, etc.

Almost all the data in a SAM can be obtained directly or derived by a corresponding IO table. In particular, the shadowed cells in grey colour in Table A3.2 can be directly obtained from an IO table. The column sum and row sum entries in grey are simply calculated by summing across row entries or across column entries for each relevant agent. The challenge left for the construction of a SAM for an empirical CGE model is how to make the data for those entries that cannot be derived from an IO table.

By using the row-sum and column-sum equality rule for each agent, the entries shaded in blue can be calculated directly. For example, factor income equals Factor expenditure, based on which factor income to households can be easily calculated. Those entries shaded in green can also be derived based on the rule of row-sum equals column sum. For example, foreign outflow equals foreign inflow, subtracting exports from which the external savings can be derived. The left work is how to estimate the entries coloured in orange. Knowing one of the three entries tough, for example other national statistics, can help calculate the other two.

Table A3.2: *Structure of a SAM for the standard CGE model*

		ACTIVITY	FACTOR		INDIRECT TAX		FINAL DEMAND			EXTERNAL	TOTAL
		1 ⋯ n	Capital	Labor	Domestic indirect tax	Import tariffs	Household	Government	Investment		
ACTIVITY	1 ⋮ n	Intermediate inputs					Household consumption	Government consumption	Investment	Exports	Activity costs (gross input)
FACTOR	Capital	Value-added from capital services									Factor income
	Labor	Value-added from labor services									
INDIRECT TAX	Domestic indirect tax	Production tax									Tax revenue
	Import tariffs	Import tariffs									
FINAL DEMAND	Household		Factor income to households								Household income
	Government				Government revenue from production taxes	Government revenue from import tariffs	Government revenue from direct taxes on households				Government income
	Investment						Household savings	Government savings		External savings	Savings
EXTERNAL		Imports									Foreign outflow
TOTAL		Activity costs (gross input)	Factor expenditures		Tax expenditure		Household expenditures	Government expenditures	Investment	Foreign inflow	

Source: Modified by the author based on Hosoe, et al. (2010), p.45.

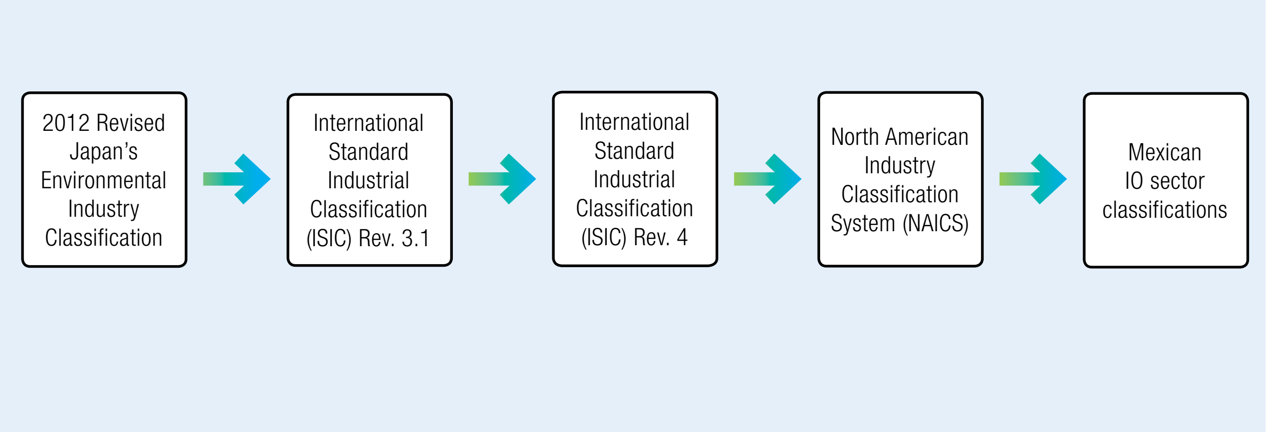
ANNEX IV – CONSTRUCTION OF A GREEN IO-SAM MODEL FOR RENEWABLE ENERGY SIMULATION

One way to simulate renewable energy scenarios is to construct a renewable energy-expanded IO-SAM, based on which the CGE model can build the production function based on the nesting of renewable energies and conventional fossil fuel-based energies in an explicit way to examine the impacts of policy interventions, such as a Feed-in-Tariff (FIT) or Renewable Portfolio Standards (RPS), on energy supply and demand as well as on the economy-wide responses.

As mentioned in Section 2.1.1.1, to construct a renewable energy-expanded IO-SAM, it is important to present renewable energies and their associated production chains explicitly in relevant IO sector classification. One key element to do so is to know the sector classification of the existing Mexican IO table which may correspond to the renewable energy generation. Due to lacking of existing literature, a preliminary sector mapping exercise (see Figure A4.1) was conducted under this project based on a similar study conducted for Japan (Zhou and Mustafa, 2015). Sector classification in the Mexican IO table follows the North American Industry Classification System (NAICS). To use similar sector mapping approach in the Japanese study, the following steps are conducted to have a correspondence between the EGSS classification and the NAISC sector classification. A preliminary mapping results is presented in Table A4.1.

The established renewable energy-expanded IO-SAM can then be used to construct the nesting of the electricity in the CGE model which can simulate the impacts of policy interventions, such as a FIT scheme or a RPS scheme, on energy supply and demand. An example nesting is shown in Figure A4.2. On top of the nesting, electricity (E) is produced from fossil fuels (EFF) and renewable energy (ERE) based on a CES function. The elasticity of substitution between EFF and ERE is σ_E. EFF is produced from natural gas (NG) and coal (CO) based on a CES function with the elasticity of substitution between NG and CO, σ_{EFF}. Similarly, ERE is produced from various renewable energy, including e.g. wind (WD), solar PV (SP), hydro (HD), geothermal (GE) and biomass (BM). Based on

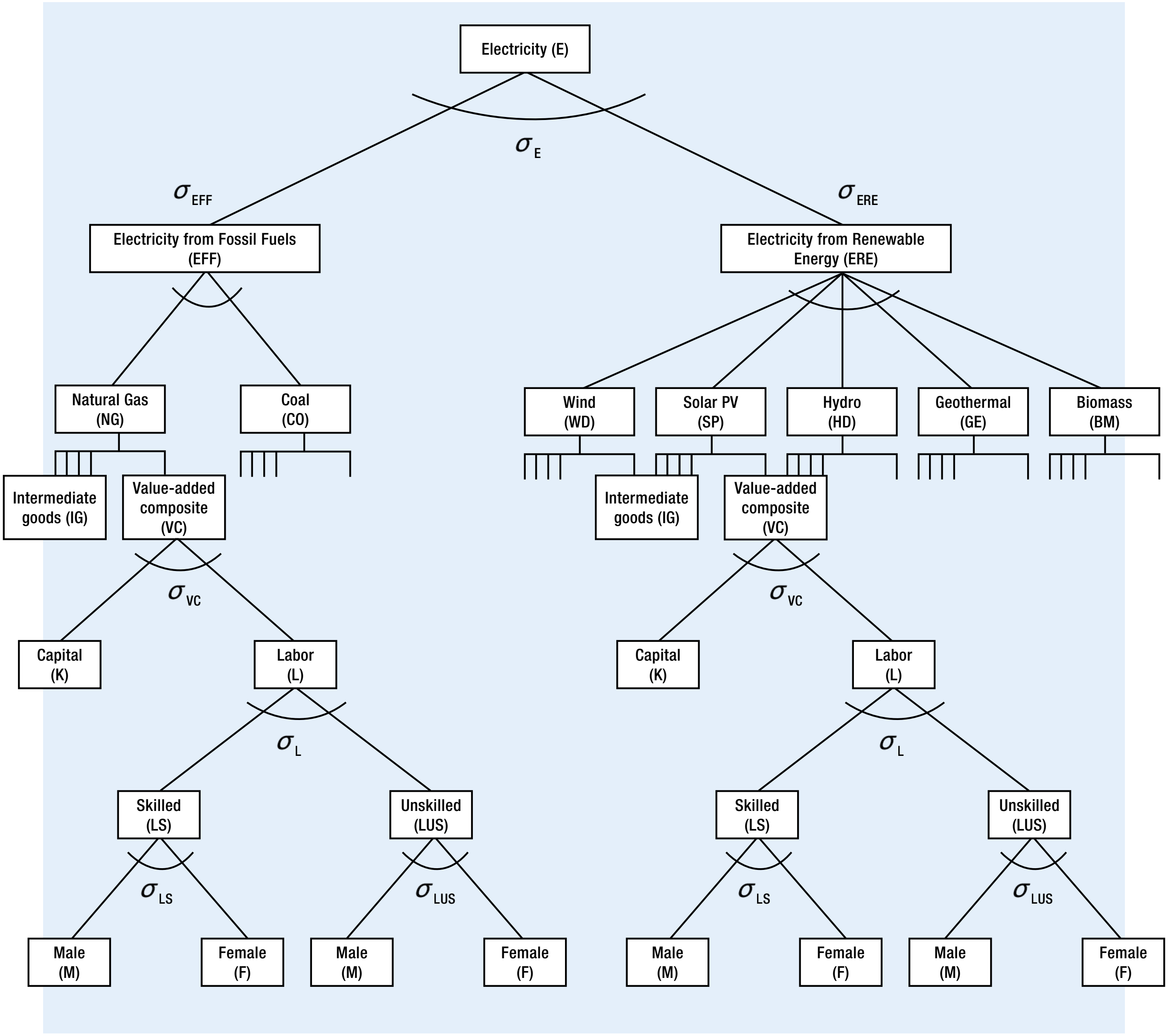
Figure A4.1: *Mapping renewable energy sectors/EGSS with Mexican IO sector classifications*



Source: Compiled by Xin Zhou based on Zhou and Moinuddin (2015) and sector classification by the North American Industry Classification System (NAICS).

the energy-expanded IO-SAM, both fossil fuels (NG and CO) and renewable energy (WD, SP, HD, GE and BM) are produced from intermediate goods and value-added composite based on the Leontief production function. The value-added is then composed of capital and labour. In particular, for the assessment of job creation impacts, labour can further be disaggregated into skilled workers and unskilled workers and both can be further disaggregated into different gender groups.

Figure A4.2: *Nesting of electricity for the CGE model based on the renewable energy-expanded IO-SAM*



Source: Xin Zhou.

Table A4.1: *Results of mapping renewable energy sectors/EGSS with NAISC sector classification*

2012 REVISED JAPAN'S ENVIRONMENTAL INDUSTRY CLASSIFICATION			CORRESPONDENCE ISIC REV.3.1		CORRESPONDENCE ISIC REV. 4		2007 NAISC	
B MEASURES COMBATING CLIMATE CHANGE			**CODE**	**EXPLANATION**	**CODE**	**EXPLANATION**	**CODE**	**EXPLANATION**
Level 2	Level 3	Level 4						
b1 Renewable energy use	b11 Renewable energy power generation systems	b11-1 Solar PV power system	3190	Manufacture of other electrical equipment n.e.c.	2790	Manufacture of other electrical equipment	335999	All Other Miscellaneous Electrical Equipment and Component Manufacturing
		b11-2 Installation of solar PV power system	4510	Site preparation	3900	Remediation activities and other waste management services	562910	Remediation Services
			4520	Building of complete constructions or parts	4390	Other specialized construction activities	238160	Roofing Contractors
							238170	Siding Contractors
							238190	Other Foundation, Structure, and Building Exterior Contractors
			4530	Building installation	4329	Other construction installation	238290	Other Building Equipment Contractors
			4540	Building completion	4330	Building completion and finishing	238390	Other Building Finishing Contractors
		b11-3 Residential solar PV system	2930	Manufacture of domestic appliances n.e.c.	2819	Manufacture of other general- purpose machinery	333319	Other Commercial and Service Industry Machinery Manufacturing
							333999	All Other Miscellaneous General Purpose Machinery Manufacturing
					2750	Manufacture of domestic appliances	335228	Other Major Household Appliance Manufacturing
					3312	Repair of machinery	811310	Commercial and Industrial Machinery and Equipment (except Automotive and Electronic) Repair and Maintenance
		b11-4 Installation of residential solar PV system	4510	Site preparation	3900	Remediation activities and other waste management services	238160	Remediation Services
			4520	Building of complete constructions or parts	4390	Other specialized construction activities	238170	Roofing Contractors
							238170	Siding Contractors
							238190	Other Foundation, Structure, and Building Exterior Contractors
			4530	Building installation	4329	Other construction installation	238290	Other Building Equipment Contractors
			4540	Building completion	4330	Building completion and finishing	238390	Other Building Finishing Contractors

			b11-5	Wind power generation facilities	3110	Manufacture of electric motors, generators and transformers	2811	Manufacture of engines and turbines, except aircraft, vehicle and cycle engines	333611	Turbine and Turbine Generator Set Units Manufacturing
			b11-6	Biomass energy utilization facilities	3110	Manufacture of electric motors, generators and transformers				
			b11-7	Small and medium hydro power	3110	Manufacture of electric motors, generators and transformers				
			b11-8	Geothermal power generation	3110	Manufacture of electric motors, generators and transformers				
			b11-9	Measures for power system stability	3130	Manufacture of insulated wire and cable				
			b11-10	Wood stove	2731	Casting of iron and steel	2431	Casting of iron and steel	331210	Iron and Steel Pipe and Tube Manufacturing from Purchased Steel
	b12	Renewable energy electricity sales	b12-1	New energy power generation business	4010	Production, collection and distribution of electricity	3510	Electric power generation, transmission and distribution	221111	Hydroelectric Power Generation
									221119	Other Electric Power Generation
									221121	Electric Bulk Power Transmission and Control
									221122	Electric Power Distribution
	b13	Operation and maintenance of renewable energy power generation facilities	b13-1	Operation and maintenance of wind power generation facilities	7499	Other business activities n.e.c.	8299	Other business support activities n.e.c.	561499	All Other Business Support Services
									561990	All Other Support Services
			b13-2	Operation and maintenance of non-residential solar PV power generation system	7499	Other business activities n.e.c.	8299	Other business support activities n.e.c.	561499	All Other Business Support Services
									561990	All Other Support Services

Source: Compiled by Xin Zhou based on Zhou and Moinuddin (2015) and sector classification by the North American Industry Classification System (NAICS).

ANNEX V – DESCRIPTION OF THE CGE MODEL

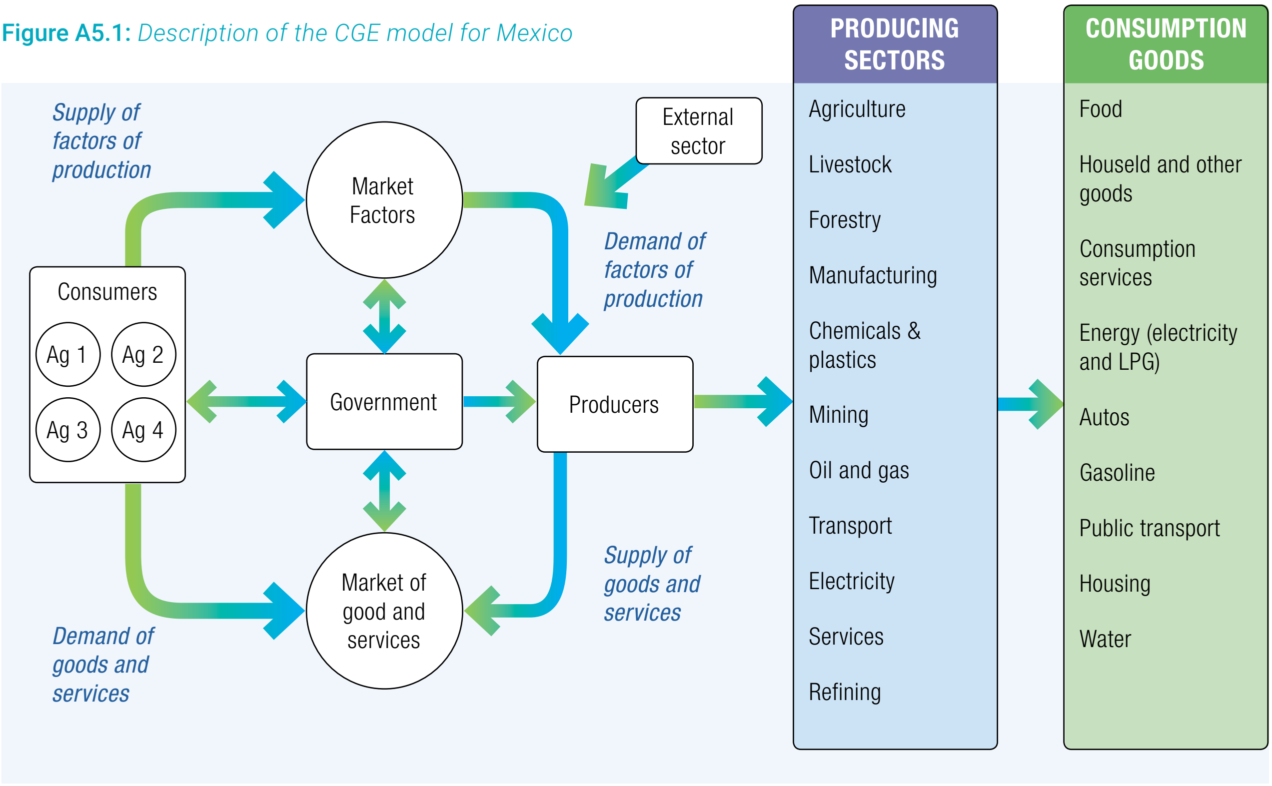
The base of the Green CGE model used in the IGEM is the dynamic computable general equilibrium (CGE) model of the Mexican economy developed by Boyd and Ibarrarán to address the effects of Green Economy policies, i.e., carbon taxes and a renewable energy policy. Due to the comprehensive nature of any policies these policies, they can have important repercussions throughout the economy so a broad analysis such as an economy-wide model that shows the interactions across sectors and groups of consumers is needed.

This model is based on earlier work by Ramsey (1928) and Ballard et al. (1985).[2] It has been used since the mid-1990s to address issues related to trade, and later to analyse energy policies (Ibarrarán and Boyd, 2002 and 2006). It has also been used to evaluate specific issues related to the effects of climate change such as drought (Boyd and Ibarrarán, 2009), and specific public policies such as the 2008-2012 Special Program on Climate Change (Ibarrarán et al., 2011). In all cases, it has addressed the macroeconomic and sectoral effects of policies.

It is a national model that has 12 producing sectors. The model is described in Figure A5.1. The primary sector is disaggregated into agriculture, livestock, fisheries, and forestry. There is also a disaggregated energy sector that includes mining, oil and natural gas, refining, and chemicals and plastics. It has manufacturing, electricity, transport, and services. This allows us to explicitly deal with and quantify the interaction of sector-specific policies with other sectors.

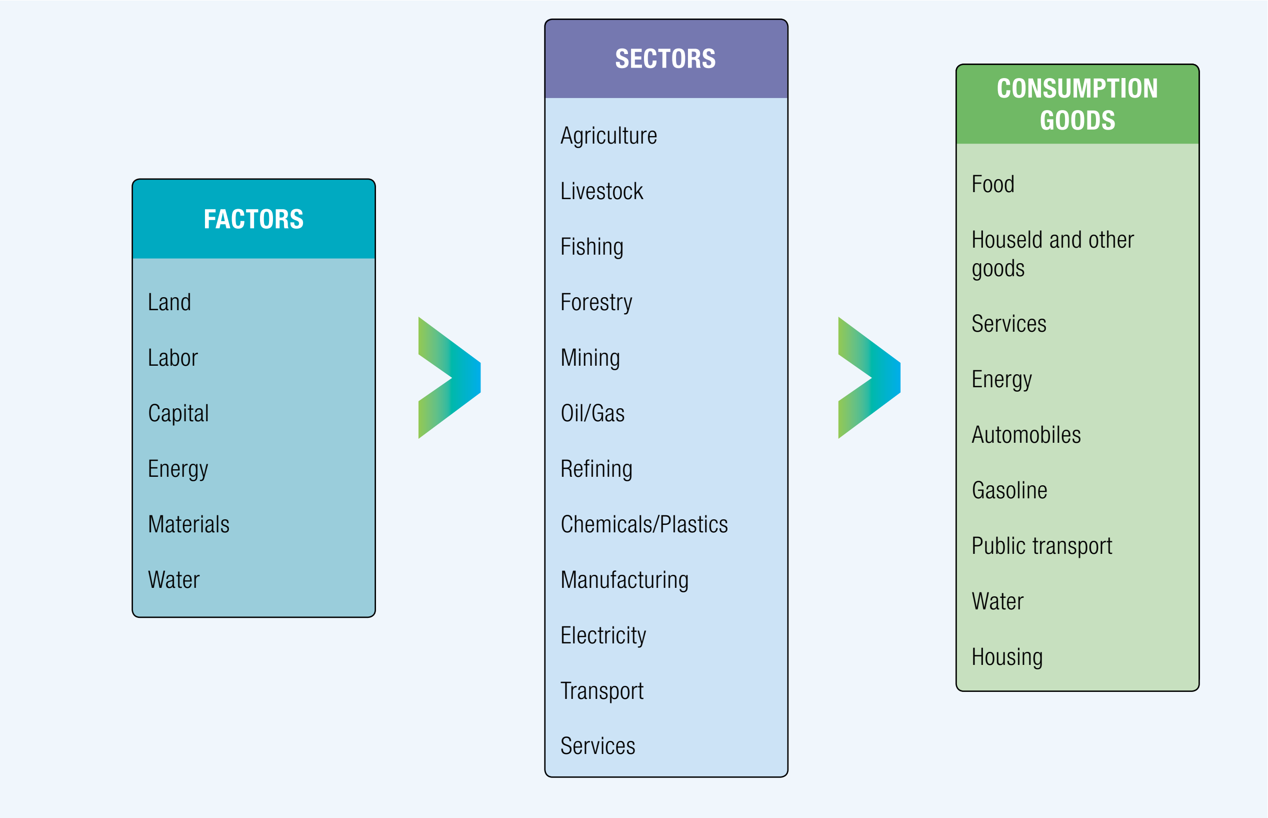
There are nine consumption goods: food, household goods, consumption services, energy (which includes electricity and liquid petroleum gas, or LPG), private and public transport, gasoline, housing and water. These are produced by combining the outputs of the producing sectors through a conversion matrix.

Figure A5.1: *Description of the CGE model for Mexico*



Source: Ibarrarán et al 2015.

Figure A5.2: *Production and consumption in the model*



Source: Ibarrarán et al 2015.

Production and consumption sectors are modelled using nested constant elasticity of substitution (CES) production functions for both production and final consumption goods and services. Figure A5.2 describes them. This allows for different degrees of substitution for the inputs considered, particularly between labour, capital, energy, and non-energy inputs. Technologies are represented by production functions that exhibit constant elasticities of substitution, and technical progress is taken as exogenous to the model. The model has been modified to differentiate between formal and informal workers, and the effect of this distinction on production sectors. The indirect utility function as a function of income, prices, and preferences parameters for the consumer is defined as V, where

$$V = I[\alpha P_H{}^{(1-\sigma_2)} + (1-\alpha)[\frac{P_S P}{P_K \gamma}]^{(1-\sigma_2)}]^{(1-\sigma_2)}$$

Here, I is the expanded income, P_H is the price of present consumption (leisure, goods and services), P is the price of composite consumption commodity, P_S is the price of saving, P_K is the return on capital, γ is the physical service flow per unit of capital goods purchased, α is a weighting parameter, and σ_2 is the elasticity of substitution between present and future consumption, following Ballard et al. (1985).

To capture the distinction between formal and informal workers, the model is slightly modified. In particular, we use a CES production function of the form

$$V_t = \phi_t\left[\delta_L L_t^{(\sigma-1)/\sigma} + \delta_K K_t^{(\sigma-1)/\sigma} + \delta_E E_t^{(\sigma-1)/\sigma} + \delta_M M_t^{(\sigma-1)/\sigma}\right]^{\frac{\sigma}{\sigma-1}}$$

where V_t is value added at time t, and L_t, K_t, E_t and M_t denote labour, capital, energy, and material inputs, respectively. Also, ϕ_t is a shift parameter, σ is the elasticity of substitution between inputs, and the δ 's are share parameters defined so that

$\delta_L, \delta_K, \delta_E, \delta_M > 0$ and $\delta_L + \delta_K + \delta_E + \delta_M = 1$

In addition, we assume that labour is a composite good consisting of formal (*F*) and informal (*I*) labour nested in the CES production function. In particular, the labour composite is given by

$$L_t = \Omega_t\left[\delta_F F_t^{(\varepsilon-1)/\varepsilon} + \delta_I I_t^{(\varepsilon-1)/\varepsilon}\right]^{\frac{\varepsilon}{\varepsilon-1}},$$

where Ω_t is a shift parameter, ε is the elasticity of substitution between formal and informal workers, and the δ's are share parameters defined so that $\delta_F, \delta_I > 0$ and $\delta_F + \delta_I = 1$. It is important to mention that this feature of the model may be turned off in case this is not relevant to the UNEP team.

The government agent is modelled with an expenditure function similar to the household expenditure functions (that is, based on a CES utility function). Revenues derived from all taxes and tariffs are spent according to an expenditure function. Each sector has its own tax rate according to the latest information available, so it can reflect the tax structure, especially the VAT rates associated with each consumption sector. The structure of the model is optimal to analyse tax changes, since it divides consumption and production sectors, and thus gives room to specify the type of tax. Producers receive their income according to prices defined before taxes, and consumers take decisions based on after tax prices. Within this expenditure function the government spends its revenues on goods and services from the various private production sectors discussed above.

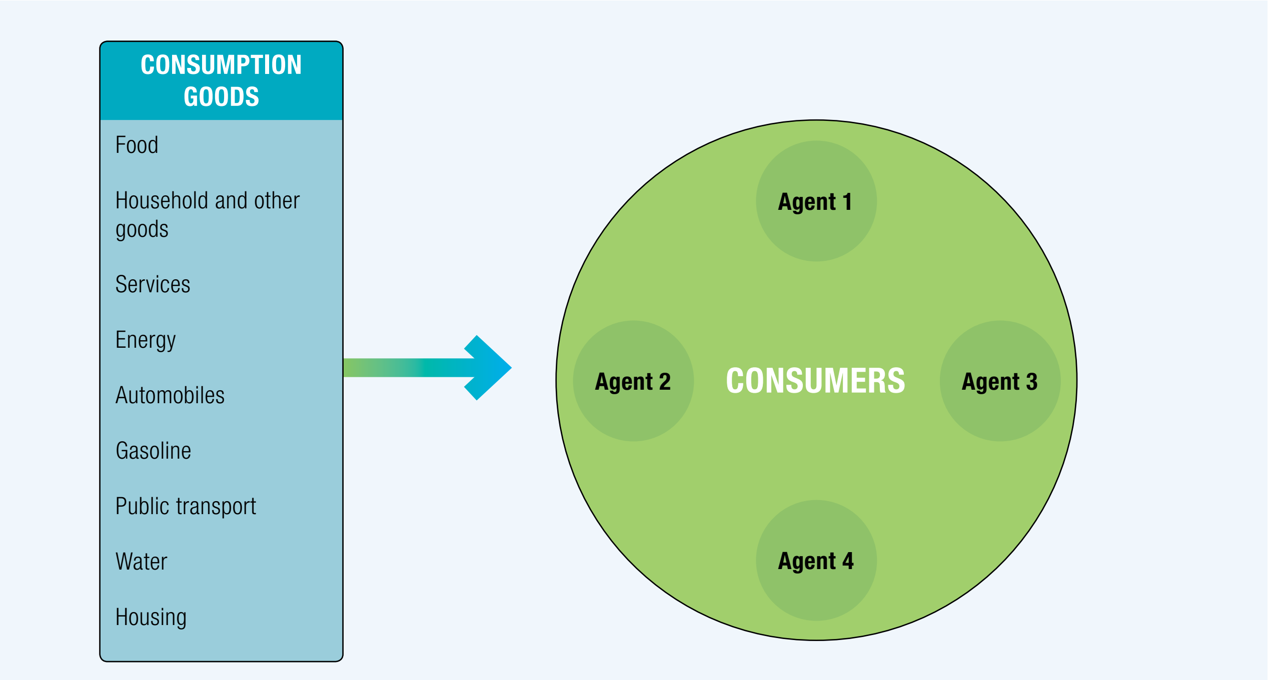
International trade within the model is handled by means of a foreign agent. Output in each of the producing sectors is exported to the foreign agent in exchange for foreign-produced imports. Under this setup the aggregate level of imports is set and grows at the steady state level, but the level of individual imports may change in response to changes in relative prices. Exports are exogenous as well and are assumed to follow a constant growth path. They are, however, responsive to changing prices, and can change as individual sectors are shocked. Transfer payments, on the other hand, are endogenous and act so as to clear the model. The exchange rate is determined then by the interaction of capital made available for external uses, goods supplied for export, and the exogenous level of imports. Price-dependent import supply schedules are derived from elasticity estimates found in the literature. In specifying the level of substitutability between goods we replace the classic Heckscher-Ohlin assumptions and rely instead on the Armington (1969) assumptions which allow for imperfect substitutability between foreign and domestically produced goods. One feature of this setup which is particularly important to our present analysis is that it incorporates flexible trade prices and thereby allows for adjustments in the balance of trade in the various simulations.[3]

The model also reflects unemployment in Mexico. For this exercise, initial unemployment rate has been set at 4.5%, and it may change as a result of the policies simulated. In the model, firms hiring formal workers pay payroll taxes (i. e., contributions to social insurance). In contrast, firms hiring informal workers do not pay payroll taxes. This creates a distortion in the cost of formal and informal salaried workers. In this setting, both formal and informal workers are demanded by firms, and the effect of a change in relative prices on the share of formal and informal workers is determined by the elasticity parameter ε. In keeping with the current situation, all payroll taxes are collected exclusively from formal workers. This featured may also be ignored if deemed necessary.

The model has four household (income) categories: agent 1 (the poorest consumers) includes deciles 1 and 2; agent 2 groups deciles 3, 4, and 5; agent 3 the next three deciles; and agent 4 the top 20% of the population. There is also a foreign sector and a government in this model. The model uses the input-output matrix produced by the National Statistics Office (INEGI, 2003), and data from both national and international sources.[4]

The economic variables determined by the model are investment, capital accumulation, production (aggregate and by sector), household consumption by sector and welfare by agents, imports and exports. The level of depreciation and the initial return to capital are taken as exogenous, as is the rate of labour force growth.

Figure A5.3: *Consumption goods and agents*



Source: Ibarraran and Boyd.

ANNEX VI – DESCRIPTION OF INDIVIDUAL SYSTEM DYNAMICS (SD) MODEL SECTORS

Systems Dynamics (SD) is usually considered a top-down method, i.e. a macro approach is taken rather than the characterization of individual agents, and is generally not used for optimization. Assumptions of perfect information and rational expectations are not employed. Rather, decision-making is assumed to take place with limited information and with time lags in adjusting perceptions and taking action. These assumptions are considered to be key causal factors underlying dynamic behaviours and offer insights into system inertia and policy resistance, for example in the adoption of clean energy technologies. Systems Dynamics policy design seeks to work within a realistic decision-making structure to offer practical solutions, which can be considered an advantage of the method. Additionally, SD emphasizes model comprehensibility and learning for improved decision-making. The learning process can be obscured when detail complexity is emphasized, this could be considered a limitation of the method.

There are ten sectors in the SD model.

1. Population and Fertility

The population sector includes 81 age cohorts, from less than one year to over 80. The population in each cohort shifts upward in age one year for each year of the simulation with the exception of the over 80 cohort. Each cohort is subject to a mortality rate. This is defined by a death rate distribution for the age groups and the average life expectancy at birth, which is formulated in the Health and Mortality sector.

Population is increased by births, a function of the population of women between 15 and 49, a fertility age distribution, and an average fertility rate. The average fertility rate is influenced by a desired fertility rate and contraceptive prevalence.

The Population sector is initialized and calibrated with data from the UN Population Division.

2. Health and Mortality

The Health and Mortality sector calculates a well-being index on the basis of perceived real per capita income and public health expenditure compared to reference values:

> *Well being index = (perceived real pc gdp/ reference saturation income)*income weight+*
>
> *(effective pc health expenditure/reference saturation pc health expenditure)*(1-income weight)*

Perceived real per capita income is used because it is assumed that the impacts on health of changes in income will come into effect after a time lag.

A logistic function is used to translate the well-being index to the indicated life expectancy at birth, which is a key input to the Population sector.

3. Education

In the education sector the average years of schooling is defined on the basis of an initial national target for years of schooling and the level of government expenditure per pupil on education. As the level of educational expenditure changes relative to its initial value, a power-law function modifies the initial target for years of schooling to yield a current target for years of schooling:

> *Relative education expenditure per pupil = education expenditure per pupil/initial education expenditure per pupil*

*target years of schooling = initial target years of schooling*relative education expenditure per pupil^elasticity of target years of schooling to education expenditure*

The average years of schooling then adjusts to the current target over a defined time lag. The Education sector is calibrated using data from the Barrow-Lee database (www.barrowlee.com).

4. Production

For simplicity the Production sector models aggregate national production, subsuming agriculture, industry and services.

Total factor productivity for the entire economy is modelled as the product of the effects of the population's education and health status. The effects of education and health are formulated in similar fashion (only the effect of education, i.e., literacy) is shown here:

effect of literacy rate on tfp = relative average years of schooling^elasticity of tfp to literacy rate

A value for relative production is modelled as the product of total factor productivity and power-law functions of labour, capital, and agricultural land:

*relative production = relative capital^capital elasticity*relative labour force^labour elasticity*relative agriculture land^(1-capital elasticity-labour elasticity)*total factor productivity*

Relative capital, relative labour force, and relative agricultural land in each case are the ratio of current values to initial values.

Relative production is then multiplied by the initial relative production to yield real GDP at factor cost. Real GDP at market prices is derived taking into account indirect taxes minus subsidies as a share of GDP (defined exogenously with World Bank data).

Capital investment is modelled as real GDP at market prices multiplied by the propensity to invest. Capital is represented by a stock variable (in real currency units) and is subject to depreciation. The Production sector is calibrated with World Bank data.

5. Poverty

The Poverty sector assumes a log normal distribution of income. The Gini coefficient and poverty line are taken as exogenous. Using these as inputs along with the average per capita real GDP, the proportion of the population with income below the poverty line is calculated as an indicator of the prevalence of poverty.

6. Land Use

There are 4 categories of land use in the Land Use sector: agricultural land, settlement land, forest land, and other land. Other land represents types of land not fitting into the settlement, agricultural, and forest categories as well as land undergoing transition from one type to another. Each category is modelled with a stock variable. Population is the principle driver of change in the sector. As population increases, settlement land increases based on an assumed settlement area per person and results in conversion of other land to settlement land. Agriculture land increases based on an assumed per capita average required area of agricultural land. Agriculture land increases through conversion of other land and forest land. Agriculture land decays to other land at an assumed fractional rate. Also there is an exogenously defined deforestation rate in addition to clearance for agriculture. The Land Use sector is initialized and calibrated with land use data from the FAO.

7. Water Demand and Supply

The Water Demand and Supply sector includes demand from household, agriculture, and industry. For agriculture water demand is based on area under irrigation and an assumed agricultural water consumption per hectare of irrigated land. Household demand is modelled as population multiplied by an assumed per capita use, modified by per capita income with water use increasing with per capita income. Industrial demand is based on real GDP at factor cost and an average industrial consumption per unit of GDP output. Industrial water consumption is assumed to become more efficient as national educational levels improve. The water resources vulnerability index is calculated as the ratio of total water demand to the level of renewable water resources (exogenously defined). The Water sector is calibrated with FAO Aquastat data.

8. Energy Demand

The Energy Demand sector models energy demand from production (industry, services, agriculture), residential, transportation and 'other' users. Energy demand for each category of users is calculated by electrical, oil, coal, gas, and renewable sources.

Production energy demand is the product of production energy intensity (in quadrillion btu per unit of real currency) for each energy type and real GDP at factor cost. Production intensity is influenced by energy price (for each of the energy sources), the extent of the electrical network, technological advancement (driving efficiency), and capital intensity.

Residential energy demand is the product of residential energy intensity (in qbtu per person-year) and population. Residential energy demand is modified by energy price, electrical network extent, technology, and per capita income.

Transportation energy demand is the product of transportation energy intensity (in qbtu per person-year) and population. Transportation energy demand is influenced by energy price, technology, per capital income, and changes in real GDP.

Other energy demand is the product of other energy demand intensity (qbtu per real currency units) and GDP. Influencing factors are energy price, capital intensity, and relative per capita GDP.

The influencing factors mentioned above are implemented with power-law functions with elasticities that vary for the energy types (i.e., electricity, oi, coal, gas, renewables). An exception is the influence of technology, which has an exogenously defined base value. Energy prices are set using exogenous data normalized against initial values for each energy type. The exception is the price for electricity, which is set in terms of normalized prices for oil, coal, and gas, i.e., energy sources for electricity generation. The Energy Demand sector is initialized and calibrated with data from the International Energy Agency.

9. Electricity Generation and Emissions

This sector accounts for electricity generation in terms of the fossil fuels consumed to generate electric power. Fossil fuel consumption for electricity generation is explicitly influenced by transmission loss and thermal efficiency in the electrical sector. The shares of fossil fuel types for electricity generation (oil, coal, gas) are assumed to transition from the current time (2015) to 2050, moving to less coal consumption and greater relative gas consumption.

For consumption of each type of fossil fuel (for electricity generation and direct use) greenhouse gas emissions are calculated, separately for CO_2, N_2O, and CH_4. N_2O and CH_4 are converted to CO_2 equivalents for total greenhouse gas emissions for fossil fuel burning in CO_2 equivalents. CO_2 from cement production is modelled with an assumed non-energy CO_2 emission per ton of cement produced. Crop and livestock GHG emissions are modelled in similar fashion; production in tons is multiplied by assumed CO_2 equivalents per ton of production.

10. Roads Infrastructure

The roads infrastructure considers only paved roads. The sector is developed around a supply chain for paved road infrastructure consisting of two stocks, Road Infrastructure and Roads Under Construction.

The policy entry point for the sector is expenditure for road infrastructure, taken as a fraction of real GDP. Road infrastructure expenditure is assumed as prioritized for maintenance. If allocated expenditure for road infrastructure exceeds the total amount required for maintenance then new road construction is initiated, increasing the stock of Roads Under Construction. The completion rate of road construction is modelled as the stock Roads Under Construction divided by an average construction completion time. The decay rate of existing road infrastructure is dependent on the extent to which infrastructure expenditure covers total maintenance cost. If road infrastructure expenditure is greater than or equal to total maintenance cost, there is then no decay. If expenditure is less than total maintenance cost decay, then occurs. The rate of road decay is modelled as:

Roads decay rate =

Road Infrastructure(1-implemented fraction of necessary maintenance)/average roads life without maintenance*

Where the implemented fraction of necessary maintenance is the ratio of total road infrastructure expenditure to the total required expenditure for maintenance.

Key indicators developed in the sector are Roads Kilometres Per 1000 People, and Relative Road Density, which is the ratio of the current value of road density (in kilometres of road per hectare of land) to its initial value. The World Bank is the primary data source for the sector.

ANNEX VII – RESULTS OF THE CGE STAND-ALONE MODEL COMPARING FBL TO BAU, FBL TO RL, FBH TO BAU AND FBH TO RH

Low tax scenario

Table A7.1: *Changes in aggregate results following FBL scenario, percentage change with respect to BAU*

CATEGORY	2016	2020	2026	2030	2036
GDP	0.0085%	0.0522%	0.0001%	-0.0869%	-0.1670%
Investment	0.2483%	0.3729%	0.1285%	0.0000%	0.4514%
Government[5]	0.0253%	0.0417%	0.0785%	0.0364%	-0.2072%
Capital Stock	-	-	-	-	-0.3253%
Aggregate welfare (∑Agent 1–4)					
Agent 1 (poorest 20%)	-	-	-	-	-0.1174%
Agent 3 (deciles 6-8)	-	-	-	-	-0.1119%
Agent 4 (richest 20%)	-	-	-	-	-0.1407%
Government welfare	-	-	-	-	0.0000%
Aggregate welfare	-	-	-	-	-0.1279%

Table A7.2: *Changes in production following FBL, percentage change with respect to BAU*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.1309%	0.1554%	0.1487%	0.0895%	-0.7599%
Livestock	0.1067%	0.1428%	0.1216%	0.0183%	-0.7721%
Forestry	0.2545%	0.2268%	0.1931%	0.0000%	-0.9036%
Fisheries	0.0000%	0.0000%	0.0000%	-0.2674%	-0.6928%
Oil	0.1336%	-0.3190%	-2.3019%	-3.9458%	-5.1713%
Natural gas	0.1121%	-0.2756%	-2.1575%	-3.6093%	-4.7644%
Mining	0.1649%	-0.9601%	-5.2632%	-5.3633%	-6.2312%
Refining	0.0765%	-0.2024%	-1.6783%	-2.9442%	-4.1215%
Transport	0.0057%	0.0153%	-0.0522%	-0.1806%	-0.6124%
Electricity	0.0215%	1.6887%	3.1135%	2.8171%	5.6699%
Chemicals & plastics	0.1720%	0.1030%	-0.9753%	-2.1527%	-4.0460%
Services	0.0093%	0.0453%	0.0505%	-0.0173%	-0.4098%
Manufacturing	0.1901%	0.2452%	0.1202%	-0.0060%	-1.0087%

Table A7.3: *Changes in consumption following FBL, percentage change with respect to BAU*

CATEGORY	2016	2020	2026	2030	2036
Food	-0.0728%	-0.0559%	-0.0348%	-0.0891%	-0.3201%
Household goods	-0.0737%	-0.0659%	-0.1604%	-0.3003%	-0.5142%
Consumer services	-0.0818%	-0.0436%	0.0000%	-0.0462%	-0.2517%
Autos	-0.0841%	-0.0937%	-0.1269%	-0.1996%	-0.4277%
Electricity and LPG	-0.0805%	0.3955%	0.7648%	0.6343%	1.2583%
Public transport	-0.0783%	-0.0838%	-0.1424%	-0.2457%	-0.5233%
Gasoline	-0.0832%	-0.1506%	-0.4559%	-0.7471%	-1.0660%
Water	-0.0912%	-0.0809%	0.0000%	-0.0611%	-0.3132%
Housing	-0.0606%	-0.0538%	-0.0227%	-0.0407%	-0.2777%

Table A7.4: *Change in exports following FBL, percentage change with respect to BAU*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.1610%	0.2865%	0.1209%	0.2172%	-0.0929%
Livestock	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Forestry	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Fisheries	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Oil	0.1774%	-0.3244%	-2.1437%	-3.5791%	-4.3839%
Natural gas	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Mining	0.0000%	-1.1236%	-3.8095%	-3.4483%	-4.4118%
Refining	0.0000%	0.0000%	-1.3514%	-2.3077%	-2.8436%
Transport	0.1563%	0.1394%	0.1182%	0.0532%	-0.2283%
Electricity	0.0000%	0.0000%	4.1667%	3.8462%	3.2258%
Chemicals & plastics	0.1644%	0.0998%	-0.3483%	-0.6778%	-1.0175%
Services	0.1813%	0.2012%	0.2544%	0.2128%	-0.0130%
Manufacturing	0.1804%	0.1902%	0.1333%	0.0499%	-0.1734%

Table A7.5: *Change in imports following FBL, percentage change with respect to BAU*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.0000%	0.0000%	-0.2116%	-0.3159%	-0.3210%
Livestock	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Forestry	0.0000%	0.0000%	0.0000%	0.0000%	-1.6393%
Fisheries	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Oil	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Natural gas	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Mining	0.0000%	1.1494%	3.8835%	4.0580%	3.6765%
Refining	0.0000%	0.2372%	1.2832%	2.1756%	2.4970%
Transport	0.0000%	0.0000%	0.0000%	-0.2597%	-0.2193%
Electricity	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Chemicals & plastics	0.0000%	0.0742%	0.3146%	0.5344%	0.6015%
Services	0.0000%	0.0000%	-0.2380%	-0.3733%	-0.4074%
Manufacturing	-0.0032%	-0.0284%	-0.1322%	-0.2150%	-0.2635%

Table A7.6: *Changes in aggregate results following FBL, percentage change with respect to RL*

CATEGORY	2016	2020	2026	2030	2036
GDP	0.0259%	0.0623%	0.1363%	0.1684%	0.2652%
Investment	0.1652%	0.2972%	0.5135%	0.5248%	1.0984%
Government	-0.0253%	-0.0353%	-0.0162%	0.0509%	-0.0125%
Capital Stock	-	-	-	-	0.0078%
Aggregate welfare (∑Agent 1–4)					
Agent 1 (poorest 20%)	-	-	-	-	-0.0364%
Agent 2 (deciles 3-5) w	-	-	-	-	0.0097%
Agent 3 (deciles 6-8)	-	-	-	-	0.0167%
Agent 4 (richest 20%)	-	-	-	-	0.0321%
Government welfare	-	-	-	-	0.0000%
Aggregate welfare	-	-	-	-	0.0078%

Table A7.7: *Change in production following FBL, percentage change with respect to RL scenario*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.0653%	0.0582%	0.1650%	0.2534%	-0.3504%
Livestock	0.0533%	0.0951%	0.2226%	0.2743%	-0.3176%
Forestry	0.2538%	0.2262%	0.1927%	0.1745%	-0.4559%
Fisheries	0.0000%	0.0000%	0.0000%	0.2681%	-0.2326%
Oil	0.0400%	0.0933%	0.2302%	-1.0270%	-1.5797%
Natural gas	0.0560%	0.1106%	0.2205%	-0.8811%	-1.3594%
Mining	0.0823%	0.3729%	0.6693%	0.7313%	0.2144%
Refining	0.0382%	0.1291%	0.3023%	-0.5927%	-1.1295%
Transport	0.0114%	0.0255%	0.0870%	0.0983%	-0.1260%
Electricity	0.0215%	1.7370%	3.5065%	3.3916%	6.2579%
Chemicals & plastics	0.0904%	0.2829%	0.6675%	0.0399%	-0.9562%
Services	0.0110%	0.0294%	0.0920%	0.1507%	-0.0490%
Manufacturing	0.0911%	0.1515%	0.3248%	0.3830%	-0.3915%

Table A7.8: *Change in consumption following FBL, percentage change with respect to RL scenario*

CATEGORY	2016	2020	2026	2030	2036
Food	-0.0132%	-0.0147%	0.0099%	0.0691%	0.0210%
Household goods	-0.0105%	0.0189%	0.0683%	0.0581%	0.0470%
Consumer services	-0.0065%	0.0087%	0.0417%	0.1078%	0.0829%
Autos	0.0000%	0.0000%	0.0476%	0.0857%	0.0491%
Electricity and LPG	0.0000%	0.4656%	0.9411%	0.9318%	1.7351%
Public transport	-0.0157%	-0.0280%	-0.0119%	0.0000%	-0.0738%
Gasoline	-0.0167%	-0.0151%	0.0000%	-0.1314%	-0.2197%
Water	-0.0912%	0.0000%	0.0000%	0.0612%	0.0000%
Housing	0.0000%	-0.0269%	0.0000%	0.0813%	0.0348%

Table A7.9: *Change in exports following FBL, percentage change with respect to RL scenario*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Livestock	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Forestry	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Fisheries	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Oil	0.0253%	0.0000%	0.0000%	-1.1383%	-1.3996%
Natural gas	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Mining	0.0000%	0.0000%	0.9901%	0.0000%	0.0000%
Refining	0.0000%	0.0000%	0.0000%	-0.7874%	-0.9756%
Transport	0.0000%	0.0000%	0.0000%	0.0532%	-0.0458%
Electricity	0.0000%	0.0000%	4.0000%	3.7037%	6.2500%
Chemicals & plastics	0.0000%	0.0000%	0.0437%	-0.1606%	-0.2481%
Services	0.0000%	0.0000%	0.0169%	0.0910%	0.0390%
Manufacturing	0.0000%	0.0131%	0.0444%	0.0774%	0.0450%

Table A7.10: *Change in imports following FBL, percentage change with respect to RL scenario*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.0000%	0.0000%	0.0000%	-0.0634%	0.0000%
Livestock	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Forestry	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Fisheries	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Oil	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Natural gas	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Mining	0.0000%	0.0000%	0.0000%	0.0000%	-0.2364%
Refining	0.0000%	0.0000%	0.0905%	0.7605%	0.8913%
Transport	0.0000%	0.0000%	0.2907%	0.0000%	0.0000%
Electricity	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Chemicals & plastics	0.0000%	0.0000%	-0.0101%	0.1772%	0.1969%
Services	0.0000%	0.0000%	0.0596%	-0.0535%	-0.0455%
Manufacturing	0.0000%	0.0000%	-0.0024%	-0.0668%	-0.0838%

Results for consumption show, as expected, that energy use goes up relative to both the BAU case (Table A7.3) and the RL scenario (Table A7.8). Gasoline use and transportation decrease in response to the curbing of fossil fuel extraction. Taken as a whole these results imply that a carbon tax paired with "green" investment will have positive environmental impacts with minimal impact on overall production (GDP).

Finally, since Mexico's energy supply comes primarily from domestic sources, there is minimal change in the foreign sector. Exports of petroleum decline as expected but all other trade sectors remain largely unaffected. Impacts with respect to BAU are shown in Tables A7.4 and changes with respect to the RL scenario are shown in Table A7.9, and for imports in Tables A7.5 and A7.10, respectively.

High tax scenario

Table A7.11: *Changes in aggregate results following FBH, percentage change with respect to BAU*

CATEGORY	2016	2020	2026	2030	2036
GDP	0.0097%	0.2020%	-0.0403%	-0.7547%	-1.9318%
Investment	1.3878%	1.9020%	1.3316%	-0.1752%	-0.2010%
Government[6]	0.2342%	0.3930%	0.4739%	0.2926%	-1.4058%
Capital Stock	-	-	-	-	-1.3240%
Aggregate welfare (∑Agent 1–4)					
Agent 1 (20% poorest)		-	-	-	-0.8717%
Agent 2 (3-5 deciles)	-	-	-	-	-0.8511%
Agent 3 (6-8 deciles)	-	-	-	-	-0.8936%
Agent 4 (20% richest)	-	-	-	-	-1.0541%
Government welfare	-	-	-	-	0.0000%
Aggregate welfare	-	-	-	-	-0.9601%

Table A7.12: *Changes in production following FBH, percentage change with respect to BAU*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.6716%	1.0573%	1.1755%	0.7405%	-5.1320%
Livestock	0.6096%	0.9430%	0.8040%	0.1096%	-5.4153%
Forestry	0.7576%	0.8989%	0.9560%	0.3478%	-5.5644%
Fisheries	0.0000%	0.0000%	-0.5970%	-1.9074%	-4.3373%
Oil	0.8871%	-2.7869%	-13.2944%	-28.9518%	-28.5069%
Natural gas	0.7786%	-2.5438%	-12.5000%	-27.8155%	-28.6476%
Mining	1.1410%	-7.0356%	-50.3337%	-78.7629%	-94.1274%
Refining	0.4760%	-1.9509%	-9.8099%	-22.7414%	-25.2683%
Transport	0.0000%	0.0561%	-0.3360%	-1.2600%	-3.9900%
Electricity	0.1076%	4.9446%	8.8913%	6.4663%	13.3272%
Chemicals & plastics	0.9862%	-0.1805%	-5.7089%	-17.0654%	-28.6101%
Services	0.0382%	0.2554%	0.2208%	-0.2248%	-2.9985%
Manufacturing	1.1017%	1.4236%	0.8749%	-0.2800%	-7.4112%

Table A7.13: *Changes in consumption following FBH, percentage change with respect to BAU*

CATEGORY	2016	2020	2026	2030	2036
Food	-0.5057%	-0.3721%	-0.4040%	-0.7023%	-2.3396%
Household goods	-0.5241%	-0.5827%	-1.2427%	-2.3513%	-3.5767%
Consumer services	-0.5460%	-0.3471%	-0.2655%	-0.4949%	-2.0785%
Autos	-0.5712%	-0.5653%	-0.9771%	-1.6080%	-3.1254%
Electricity and liquefied petroleum gas (LPG)	-0.4850%	0.8556%	1.9202%	0.8748%	2.3191%
Public transport	-0.4877%	-0.5339%	-0.8980%	-1.6397%	-3.1729%
Gasoline	-0.5187%	-1.0499%	-2.6749%	-5.0187%	-5.9198%
Water	-0.4579%	-0.3247%	-0.2051%	-0.3681%	-2.0778%
Housing	-0.5484%	-0.3511%	-0.2273%	-0.3672%	-2.0726%

Table A7.14: *Change in exports following FBH, percentage change with respect to BAU*

SECTOR	2016	2020	2026	2030	2036
Agriculture	1.2719%	1.4124%	1.3126%	1.0741%	-0.6542%
Livestock	1.0753%	0.9524%	0.8065%	0.7246%	-0.6289%
Forestry	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Fisheries	0.0000%	0.0000%	0.0000%	0.0000%	-2.4390%
Oil	1.1526%	-2.5070%	-12.0055%	-26.3491%	-23.3703%
Natural gas	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Mining	1.2500%	-5.9524%	-31.2500%	-43.2099%	-46.2366%
Refining	1.2121%	-0.8824%	-6.9364%	-15.7270%	-14.0541%
Transport	1.2346%	1.2388%	0.9368%	0.3710%	-1.1547%
Electricity	5.2632%	4.5455%	11.1111%	10.3448%	16.2162%
Chemicals & plastics	1.2446%	0.5456%	-1.5922%	-4.7182%	-5.3215%
Services	1.2755%	1.4478%	1.5693%	1.4384%	-0.2212%
Manufacturing	1.2757%	1.2759%	0.7991%	0.1297%	-1.3319%

Table A7.15: *Change in imports following FBH, percentage change with respect to BAU*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.0000%	-0.2502%	-1.3581%	-2.5259%	-2.1311%
Livestock	0.0000%	0.0000%	-1.9231%	-1.7241%	-2.9412%
Forestry	0.0000%	0.0000%	-2.2222%	-2.0000%	-3.3898%
Fisheries	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Oil	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Natural gas	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Mining	0.0000%	5.7762%	23.7037%	29.4479%	29.4118%
Refining	-0.1416%	1.9767%	6.5925%	12.3297%	10.0274%
Transport	0.0000%	0.0000%	-0.8798%	-1.8519%	-1.5590%
Electricity	0.0000%	0.0000%	0.0000%	0.0000%	-33.3333%
Chemicals & plastics	0.0283%	0.5415%	1.5583%	3.1568%	2.4753%
Services	0.0000%	-0.3514%	-1.5710%	-2.9089%	-2.5058%
Manufacturing	-0.0032%	-0.2023%	-0.7875%	-1.5698%	-1.3928%

Table A7.16: *Changes in aggregate results following FBH, percentage change with respect to RH scenario*

CATEGORY	2016	2020	2026	2030	2036
GDP	0.1320%	0.2703%	0.6493%	1.1049%	1.0186%
Investment	0.7401%	1.2593%	2.6693%	4.5177%	3.4304%
Government	-0.0792%	-0.1021%	-0.0538%	0.1502%	0.1768%
Capital Stock	-	-	-	-	1.0674%
Aggregate welfare (∑Agent 1–4)					
Agent 1 (20% poorest)	-	-	-	-	-0.2434%
Agent 2 (3-5 deciles)	-	-	-	-	0.0231%
Agent 3 (6-8 deciles)	-	-	-	-	0.0792%
Agent 4 (20% richest)	-	-	-	-	0.1780%
Government welfare	-	-	-	-	0.0000%
Aggregate welfare	-	-	-	-	0.0951%

Table A7.17: *Change in production following FBH, percentage change with respect to RH scenario*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.1954%	0.3085%	0.8065%	1.7480%	-2.1984%
Livestock	0.2391%	0.4261%	1.0152%	1.8991%	-2.1933%
Forestry	0.2532%	0.2252%	0.9653%	1.7699%	-2.1773%
Fisheries	0.0000%	0.0000%	0.2994%	0.5479%	-0.7177%
Oil	0.1060%	0.3427%	0.9838%	-0.5566%	-3.1453%
Natural gas	0.1114%	0.3973%	1.0423%	-1.1402%	-4.0895%
Mining	0.3271%	1.2000%	3.2480%	5.3203%	-0.1850%
Refining	0.1526%	0.5090%	1.3227%	-0.3312%	-3.7044%
Transport	0.0571%	0.1277%	0.3899%	0.6722%	-0.5842%
Electricity	0.0862%	5.7561%	12.9738%	12.8415%	23.1085%
Chemicals & plastics	0.3599%	1.1126%	2.9745%	2.9323%	-4.9550%
Services	0.0526%	0.1396%	0.4101%	0.7941%	-0.3512%
Manufacturing	0.3508%	0.6612%	1.5398%	2.6718%	-2.9469%

Table A7.18: *Change in consumption following FBH, percentage change with respect to RH scenario*

CATEGORY	2016	2020	2026	2030	2036
Food	-0.0499%	-0.0531%	0.0200%	0.2023%	0.2737%
Household goods	-0.0265%	0.0569%	0.2361%	0.2338%	0.4442%
Consumer services	0.0066%	0.0409%	0.1576%	0.3525%	0.4991%
Autos	0.0423%	0.0754%	0.1765%	0.2906%	0.3922%
Electricity and LPG	-0.0404%	1.4100%	3.2208%	3.1585%	6.1807%
Public transport	-0.0315%	-0.0842%	-0.0479%	0.0109%	0.0095%
Gasoline	0.0000%	-0.0152%	0.0401%	-0.2732%	-0.2515%
Water	0.0000%	0.0000%	0.0000%	0.1844%	0.2671%
Housing	0.0000%	-0.0270%	0.0682%	0.2659%	0.3199%

Table A7.19: *Change in exports following FBH, percentage change with respect to RH scenario*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.0000%	-0.1410%	-0.1192%	0.0000%	0.0000%
Livestock	0.0000%	0.0000%	0.0000%	0.0000%	0.6329%
Forestry	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Fisheries	0.0000%	0.0000%	0.0000%	0.0000%	-2.3810%
Oil	-0.0501%	-0.1022%	0.0000%	-2.6702%	-3.2764%
Natural gas	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Mining	0.0000%	0.0000%	1.2658%	1.2500%	1.0870%
Refining	-0.3021%	0.0000%	0.0000%	-2.0349%	-1.8568%
Transport	-0.0771%	-0.1375%	-0.1170%	0.0000%	0.0000%
Electricity	0.0000%	4.7619%	12.5000%	11.5385%	23.3333%
Chemicals & plastics	-0.1081%	-0.0496%	0.0885%	-0.3744%	-0.3682%
Services	-0.0894%	-0.0991%	-0.0334%	0.1952%	0.2478%
Manufacturing	-0.0726%	-0.0421%	0.0717%	0.1849%	0.3133%

Table A7.20: *Change in imports following FBH, percentage change with respect to RH scenario*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.0000%	0.0835%	0.2149%	-0.0647%	0.0547%
Livestock	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Forestry	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Fisheries	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Oil	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Natural gas	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Mining	0.0000%	-0.3597%	-0.4914%	-0.6098%	-0.8576%
Refining	0.0000%	0.1164%	0.2575%	1.9444%	2.0694%
Transport	0.0000%	0.0000%	0.2941%	0.0000%	0.0000%
Electricity	0.0000%	0.0000%	0.0000%	0.0000%	-25.0000%
Chemicals & plastics	0.0000%	-0.0123%	-0.0399%	0.3983%	0.4744%
Services	0.0000%	0.0703%	0.1210%	-0.1644%	-0.1390%
Manufacturing	0.0000%	-0.0057%	-0.0048%	-0.1787%	-0.2224%

The consumption figures, shown in Tables A7.13 and A7.18, indicate as expected, that gasoline use goes down relative to both the BAU and the RH scenario. Energy use goes up as consumers´ costs in that sector decline (increased supply of electricity from renewables drive prices down). Elsewhere the impact on consumer goods is relatively stable indicating that the principle impacts of this policy are largely confined to the energy-based sectors.

Finally, effects on exports, both with respect to the BAU case and with regard to the lump sum return are shown in Tables A7.14 and A7.19, and the case of imports are shown in Tables A7.15 and A7.20 respectively. Exports of fossil fuels goods decline while exports of electricity increase. Imports of oil and natural gas remain the same compared to BAU, while electricity imports decrease. Mining and refining imported goods increase due to the relative price increase of these goods following the introduction of the carbon tax.

ANNEX VIII – RESULTS OF THE CGE AND SD MODEL SIMULATIONS ALONE FOLLOWING THE INTRODUCTION OF A HIGH CARBON TAX ON ALL EMISSIONS OF ALL SECTORS (RH COMPARED TO BAU)

Table A8.1: *Results for the CGE model: RH scenario compared to BAU, changes in aggregate results*

CATEGORY	2016	2020	2026	2030	2036
GDP	-0.1221%	-0.0677%	-0.6851%	-1.8337%	-2.8844%
Investment	0.6623%	0.6711%	-1.2853%	-4.4898%	-3.5105%
Government	0.3142%	0.4972%	0.5302%	0.1431%	-1.5604%
Capital Stock	-	-	-	-	-0.02349
Aggregate welfare					
Agent 1 (20% poorest)	-	-	-	-	-0.6223%
Agent 2 (3-5 deciles)	-	-	-	-	-0.8668%
Agent 3 (6-8 deciles)	-	-	-	-	-0.9641%
Agent 4 (20% richest)	-	-	-	-	-1.2190%
Aggregate welfare	-	-	-	-	-1.0452%
Government welfare	-	-	-	-	0.0000%

Table A8.2: *Changes in production (RH vs. BAU)*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.4798%	0.7577%	0.3800%	-0.9848%	-2.7434%
Livestock	0.3733%	0.5236%	-0.2026%	-1.7560%	-3.0098%
Forestry	0.5089%	0.6803%	0.0000%	-1.3962%	-3.1627%
Fisheries	0.0000%	0.0000%	-0.8902%	-2.4064%	-3.4642%
Oil	0.7881%	-3.0436%	-12.5943%	-22.0176%	-19.6561%
Natural gas	0.6726%	-2.8666%	-12.0280%	-20.8599%	-18.9539%
Mining	0.8244%	-7.6809%	-35.5739%	-46.8858%	-48.3920%
Refining	0.3252%	-2.4103%	-10.1224%	-18.2572%	-17.1004%
Transport	-0.0571%	-0.0715%	-0.7220%	-1.9038%	-3.2719%
Electricity	0.0215%	-0.5241%	-2.8457%	-5.2535%	-6.2807%
Chemicals & plastics	0.6338%	-1.2785%	-8.1332%	-17.0112%	-18.1921%
Services	-0.0144%	0.1163%	-0.1880%	-1.0104%	-2.5690%
Manufacturing	0.7606%	0.7779%	-0.6472%	-2.8742%	-4.0730%

Table A8.3: *Changes in consumption (RH vs. BAU)*

CATEGORY	2016	2020	2026	2030	2036
Food	-0.4535%	-0.3178%	-0.4222%	-0.8979%	-2.5528%
Household goods	-0.4950%	-0.6359%	-1.4601%	-2.5252%	-3.8802%
Consumer services	-0.5496%	-0.3866%	-0.4217%	-0.8419%	-2.5226%
Autos	-0.6100%	-0.6371%	-1.1421%	-1.8677%	-3.4095%
Electricity and LPG	-0.4425%	-0.5394%	-1.2236%	-2.2063%	-3.5850%
Public transport	-0.4540%	-0.4472%	-0.8425%	-1.6239%	-3.0845%
Gasoline	-0.5161%	-1.0239%	-2.6443%	-4.5180%	-5.3509%
Water	-0.4558%	-0.3236%	-0.2046%	-0.5501%	-2.2965%
Housing	-0.5455%	-0.3229%	-0.2948%	-0.6301%	-2.3429%

Table A8.4: *Change in imports (RH vs. BAU)*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.0000%	-0.3328%	-1.5515%	-2.4005%	-2.1402%
Livestock	0.0000%	0.0000%	-1.8868%	-1.6949%	-2.8571%
Forestry	0.0000%	0.0000%	-2.1739%	-1.9608%	-3.2787%
Fisheries	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Oil	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Natural gas	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Mining	0.0000%	6.5134%	31.7152%	42.6087%	42.8922%
Refining	-0.1414%	1.8980%	6.7828%	11.8881%	8.8916%
Transport	0.0000%	0.0000%	-1.1628%	-1.8182%	-1.5351%
Electricity	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Chemicals & plastics	0.0283%	0.5568%	1.6235%	2.8500%	2.0540%
Services	0.0000%	-0.4202%	-1.6657%	-2.6667%	-2.3087%
Manufacturing	-0.0032%	-0.1962%	-0.7766%	-1.3692%	-1.1538%

Table A8.5: *Change in exports (RH vs. BAU)*

SECTOR	2016	2020	2026	2030	2036
Agriculture	1.2882%	1.5759%	1.4510%	1.0858%	-0.6500%
Livestock	1.0870%	0.9615%	0.8130%	0.7299%	-1.2500%
Forestry	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Fisheries	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Oil	1.2167%	-2.3459%	-10.7186%	-18.6829%	-16.1975%
Natural gas	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Mining	1.2658%	-5.6180%	-24.7619%	-31.0345%	-32.3529%
Refining	1.5337%	-0.8746%	-6.4865%	-11.7949%	-10.6635%
Transport	1.3281%	1.3937%	1.0638%	0.3723%	-1.1416%
Electricity	5.5556%	0.0000%	0.0000%	0.0000%	-3.2258%
Chemicals & plastics	1.3699%	0.5985%	-1.6543%	-4.1467%	-4.7018%
Services	1.3826%	1.5697%	1.6282%	1.2618%	-0.4674%
Manufacturing	1.3658%	1.3350%	0.7333%	-0.0549%	-1.6226%

ANNEX IX – DETAILED RESULTS: REBATE SCENARIOS WITH LONGEVITY

Table A9.1: *Changes in aggregate results, RH with longevity vs. BAU*

CATEGORY	2016	2020	2026	2030	2036
GDP	-0.1119%	-0.0586%	-0.6314%	-1.7127%	-2.5608%
Investment	0.6623%	0.6711%	-1.1568%	-4.1983%	-2.7583%
Government	0.3286%	0.5101%	0.5600%	0.2110%	-1.3718%
Capital Stock	-	-	-	-	-2.0615%
Aggregate welfare					
Agent 1 (20% richest)	-	-	-	-	-0.5612%
Agent 2 (3-5 deciles)	-	-	-	-	-0.8088%
Agent 3 (6-8 deciles)	-	-	-	-	-0.9121%
Agent 4 (20% richest)	-	-	-	-	-1.1663%
Aggregate welfare	-	-	-	-	-0.9912%
Government welfare	-	-	-	-	0.0583%

Table A9.2: *Changes in production, RH with longevity vs. BAU*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.4580%	0.7383%	0.4295%	-0.8207%	-2.2540%
Livestock	0.3733%	0.5236%	-0.1216%	-1.5548%	-2.4425%
Forestry	0.5089%	0.4535%	0.0000%	-1.2216%	-2.5602%
Fisheries	0.0000%	0.0000%	-0.8902%	-2.1390%	-3.2333%
Oil	0.7481%	-3.0702%	-12.5943%	-21.9650%	-19.4086%
Natural gas	0.6726%	-2.8666%	-12.0280%	-20.8068%	-18.6950%
Mining	0.7420%	-7.6809%	-35.5105%	-46.7128%	-48.2412%
Refining	0.3061%	-2.4287%	-10.1049%	-18.1726%	-16.7771%
Transport	-0.0571%	-0.0715%	-0.6785%	-1.7899%	-2.9403%
Electricity	0.0215%	-0.5241%	-2.7787%	-5.1013%	-5.8425%
Chemicals & plastics	0.6157%	-1.3043%	-7.9961%	-16.6758%	-17.8913%
Services	-0.0110%	0.1193%	-0.1349%	-0.8879%	-2.2140%
Manufacturing	0.7380%	0.7509%	-0.5467%	-2.6294%	-3.3250%

Table A9.3: *Changes in consumption, RH with longevity vs. BAU*

CATEGORY	2016	2020	2026	2030	2036
Food	-0.4369%	-0.3060%	-0.3875%	-0.8177%	-2.3337%
Household goods	-0.4792%	-0.6265%	-1.4160%	-2.4348%	-3.6309%
Consumer services	-0.5365%	-0.3750%	-0.3873%	-0.7650%	-2.3047%
Autos	-0.6100%	-0.6183%	-1.0945%	-1.7679%	-3.1529%
Electricity and LPG	-0.4425%	-0.5394%	-1.1930%	-2.1511%	-3.3951%
Public transport	-0.4383%	-0.4472%	-0.8188%	-1.5598%	-2.8918%
Gasoline	-0.5161%	-1.0089%	-2.6182%	-4.4587%	-5.1853%
Water	-0.4558%	-0.2427%	-0.1364%	-0.4890%	-2.0877%
Housing	-0.5152%	-0.3229%	-0.2494%	-0.5691%	-2.1347%

Table A9.4: *Change in imports, RH with longevity vs. BAU*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.0000%	-0.3328%	-1.4810%	-2.3373%	-1.9797%
Livestock	0.0000%	0.0000%	-1.8868%	-1.6949%	-1.4286%
Forestry	0.0000%	0.0000%	-2.1739%	-1.9608%	-3.2787%
Fisheries	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Oil	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Natural gas	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Mining	0.0000%	6.5134%	31.7152%	42.6087%	43.1373%
Refining	-0.1414%	1.8980%	6.8744%	12.0435%	9.1352%
Transport	0.0000%	0.0000%	-1.1628%	-1.8182%	-1.5351%
Electricity	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Chemicals & plastics	0.0283%	0.5568%	1.6337%	2.8678%	2.0980%
Services	0.0000%	-0.4202%	-1.6062%	-2.6667%	-2.2635%
Manufacturing	-0.0032%	-0.1962%	-0.7814%	-1.3800%	-1.1847%

Table A9.5: *Change in exports, RH with longevity vs. BAU*

SECTOR	2016	2020	2026	2030	2036
Agriculture	1.2882%	1.4327%	1.4510%	0.9772%	-0.5571%
Livestock	1.0870%	0.9615%	0.8130%	0.7299%	-0.6250%
Forestry	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Fisheries	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Oil	1.1660%	-2.3958%	-10.7674%	-18.7306%	-16.2206%
Natural gas	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Mining	1.2658%	-5.6180%	-24.7619%	-31.0345%	-31.6176%
Refining	1.2270%	-0.8746%	-6.4865%	-11.7949%	-10.6635%
Transport	1.3281%	1.3240%	1.0047%	0.3723%	-1.0046%
Electricity	5.5556%	0.0000%	0.0000%	0.0000%	-3.2258%
Chemicals & plastics	1.3151%	0.5486%	-1.6979%	-4.1467%	-4.5614%
Services	1.3146%	1.5094%	1.5773%	1.2770%	-0.3245%
Manufacturing	1.3069%	1.2792%	0.7111%	-0.0200%	-1.4064%

Table A9.6: *Changes in aggregate results, RH with longevity vs. RH no longevity*

CATEGORY	2016	2020	2026	2030	2036
GDP	0.0102%	0.0091%	0.0541%	0.1233%	0.3332%
Investment	0.0000%	0.0000%	0.1302%	0.3053%	0.7796%
Government	0.0144%	0.0128%	0.0296%	0.0678%	0.1916%
Capital Stock	-	-	-	-	0.2945%
Aggregate welfare					
Agent 1 (20% poorest)	-	-	-	-	0.0614%
Agent 2 (3-5 deciles)	-	-	-	-	0.0585%
Agent 3 (6-8 deciles)	-	-	-	-	0.0525%
Agent 4 (20% richest)	-	-	-	-	0.0533%
Aggregate welfare	-	-	-	-	0.0545%
Government welfare	-	-	-	-	0.0542%

Table A9.7: *Changes in production, RH with longevity vs. RH no longevity*

SECTOR	2016	2020	2026	2030	2036
Agriculture	-0.0217%	-0.0193%	0.0494%	0.1658%	0.5032%
Livestock	0.0000%	0.0000%	0.0812%	0.2048%	0.5849%
Forestry	0.0000%	-0.2252%	0.0000%	0.1770%	0.6221%
Fisheries	0.0000%	0.0000%	0.0000%	0.2740%	0.2392%
Oil	-0.0398%	-0.0274%	0.0000%	0.0675%	0.3080%
Natural gas	0.0000%	0.0000%	0.0000%	0.0671%	0.3195%
Mining	-0.0818%	0.0000%	0.0984%	0.3257%	0.2921%
Refining	-0.0191%	-0.0189%	0.0195%	0.1035%	0.3899%
Transport	0.0000%	0.0000%	0.0438%	0.1160%	0.3428%
Electricity	0.0000%	0.0000%	0.0689%	0.1607%	0.4676%
Chemicals & plastics	-0.0180%	-0.0261%	0.1492%	0.4041%	0.3677%
Services	0.0034%	0.0030%	0.0532%	0.1237%	0.3644%
Manufacturing	-0.0224%	-0.0267%	0.1011%	0.2521%	0.7797%

Table A9.8: *Changes in consumption, RH with longevity vs. RH no longevity*

CATEGORY	2016	2020	2026	2030	2036
Food	0.0166%	0.0118%	0.0349%	0.0809%	0.2248%
Household goods	0.0159%	0.0095%	0.0448%	0.0928%	0.2594%
Consumer services	0.0132%	0.0117%	0.0345%	0.0776%	0.2235%
Autos	0.0000%	0.0189%	0.0481%	0.1017%	0.2657%
Electricity and LPG	0.0000%	0.0000%	0.0310%	0.0564%	0.1970%
Public transport	0.0157%	0.0000%	0.0239%	0.0652%	0.1989%
Gasoline	0.0000%	0.0152%	0.0268%	0.0621%	0.1750%
Water	0.0000%	0.0812%	0.0684%	0.0615%	0.2137%
Housing	0.0305%	0.0000%	0.0455%	0.0614%	0.2133%

Table A9.9: *Change in imports, RH with longevity vs. RH no longevity*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.0000%	0.0000%	0.0716%	0.0647%	0.1640%
Livestock	0.0000%	0.0000%	0.0000%	0.0000%	1.4706%
Forestry	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Fisheries	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Oil	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Natural gas	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Mining	0.0000%	0.0000%	0.0000%	0.0000%	0.1715%
Refining	0.0000%	0.0000%	0.0858%	0.1389%	0.2237%
Transport	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Electricity	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Chemicals & plastics	0.0000%	0.0000%	0.0100%	0.0173%	0.0431%
Services	0.0000%	0.0000%	0.0605%	0.0000%	0.0463%
Manufacturing	0.0000%	0.0000%	-0.0048%	-0.0109%	-0.0313%

Table A9.10: *Change in exports, RH with longevity vs. RH no longevity*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.0000%	-0.1410%	0.0000%	-0.1074%	0.0935%
Livestock	0.0000%	0.0000%	0.0000%	0.0000%	0.6329%
Forestry	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Fisheries	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Oil	-0.0501%	-0.0511%	-0.0546%	-0.0587%	-0.0275%
Natural gas	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Mining	0.0000%	0.0000%	0.0000%	0.0000%	1.0870%
Refining	-0.3021%	0.0000%	0.0000%	0.0000%	0.0000%
Transport	0.0000%	-0.0687%	-0.0585%	0.0000%	0.1386%
Electricity	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Chemicals & plastics	-0.0541%	-0.0496%	-0.0443%	0.0000%	0.1473%
Services	-0.0671%	-0.0594%	-0.0501%	0.0150%	0.1435%
Manufacturing	-0.0581%	-0.0550%	-0.0221%	0.0350%	0.2198%

ANNEX X – DETAILED RESULTS: FEEBATE SCENARIOS WITH LONGEVITY

Table A10.1: *Changes in aggregate results, FBH with longevity vs. BAU*

CATEGORY	2016	2020	2026	2030	2036
GDP	0.0205%	0.2148%	0.0171%	-0.6367%	-1.6269%
Investment	1.4073%	1.9389%	1.4781%	0.0583%	0.2508%
Government	0.2456%	0.4042%	0.5059%	0.3590%	-1.1957%
Capital Stock	-	-	-	-	-0.6780%
Aggregate welfare					
Agent 1 (20% poorest)	-	-	-	-	-0.5518%
Agent 2 (3-5 deciles)	-	-	-	-	-0.7738%
Agent 3 (6-8 deciles)	-	-	-	-	-0.8217%
Agent 4 (20% richest)	-	-	-	-	-0.9752%
Aggregate welfare	-	-	-	-	-0.8685%
Government welfare	-	-	-	-	0.0512%

Table A10.2: *Changes in production, FBH with longevity vs. BAU*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.6761%	1.0686%	1.2556%	0.9102%	-2.3313%
Livestock	0.6133%	0.9519%	0.9119%	0.3110%	-1.4182%
Forestry	0.5089%	0.9070%	0.9653%	0.5236%	-1.6566%
Fisheries	0.0000%	0.0000%	-0.5935%	-1.8717%	-3.0023%
Oil	0.8549%	-2.7379%	-11.7344%	-23.1751%	-20.8284%
Natural gas	0.7848%	-2.5358%	-11.1111%	-21.7091%	-19.9379%
Mining	1.1542%	-6.5731%	-33.3545%	-43.8870%	-48.3417%
Refining	0.4592%	-1.9319%	-8.8986%	-18.4264%	-17.2620%
Transport	0.0000%	0.0664%	-0.2827%	-1.1266%	-3.5019%
Electricity	0.1077%	5.2019%	9.8427%	7.0961%	15.9740%
Chemicals & plastics	0.9779%	-0.1802%	-5.2475%	-14.2189%	-21.1476%
Services	0.0416%	0.2658%	0.2788%	-0.0949%	-2.5547%
Manufacturing	1.0904%	1.4384%	0.9930%	-0.0194%	-3.5761%

Table A10.3: *Changes in consumption, FBH with longevity vs. BAU*

CATEGORY	2016	2020	2026	2030	2036
Food	-0.4899%	-0.3531%	-0.3601%	-0.6127%	-2.0594%
Household goods	-0.5055%	-0.5605%	-1.1793%	-2.2032%	-3.1977%
Consumer services	-0.5300%	-0.3314%	-0.2231%	-0.4067%	-1.8089%
Autos	-0.5679%	-0.5434%	-0.9201%	-1.4827%	-2.7496%
Electricity and LPG	-0.4827%	0.8990%	1.9884%	0.9653%	2.6116%
Public transport	-0.4696%	-0.5170%	-0.8544%	-1.5385%	-2.8734%
Gasoline	-0.4994%	-1.0239%	-2.5791%	-4.7196%	-5.4130%
Water	-0.4558%	-0.3236%	-0.1364%	-0.2445%	-1.7745%
Housing	-0.5152%	-0.3229%	-0.2041%	-0.2846%	-1.8049%

Table A10.4: *Change in imports, FBH with longevity vs. BAU*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.0000%	-0.2496%	-1.3399%	-2.4005%	-1.9262%
Livestock	0.0000%	0.0000%	-1.8868%	-1.6949%	-2.8571%
Forestry	0.0000%	0.0000%	-2.1739%	-1.9608%	-3.2787%
Fisheries	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Oil	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Natural gas	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Mining	0.0000%	6.1303%	31.0680%	42.0290%	41.6667%
Refining	-0.1414%	2.0166%	7.1494%	14.2191%	11.3886%
Transport	0.0000%	0.0000%	-0.8721%	-1.8182%	-1.5351%
Electricity	0.0000%	0.0000%	0.0000%	0.0000%	-25.0000%
Chemicals & plastics	0.0141%	0.5444%	1.5931%	3.2686%	2.5822%
Services	0.0000%	-0.3501%	-1.5467%	-2.8267%	-2.3993%
Manufacturing	-0.0032%	-0.2019%	-0.7862%	-1.5584%	-1.4028%

Table A10.5: *Change in exports, FBH with longevity vs. BAU*

SECTOR	2016	2020	2026	2030	2036
Agriculture	1.2882%	1.4327%	1.3301%	1.0858%	-0.5571%
Livestock	1.0870%	0.9615%	0.8130%	0.7299%	-0.6250%
Forestry	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Fisheries	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Oil	1.1153%	-2.4956%	-10.7917%	-20.9019%	-18.9663%
Natural gas	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Mining	1.2658%	-5.6180%	-23.8095%	-30.1724%	-31.6176%
Refining	1.2270%	-0.8746%	-6.7568%	-13.5897%	-12.3223%
Transport	1.2500%	1.1847%	0.9456%	0.3723%	-1.0046%
Electricity	5.5556%	4.7619%	12.5000%	11.5385%	19.3548%
Chemicals & plastics	1.2055%	0.4988%	-1.6108%	-4.5056%	-4.9123%
Services	1.2466%	1.4087%	1.5604%	1.4746%	-0.0649%
Manufacturing	1.2296%	1.2366%	0.7861%	0.1673%	-1.0939%

Table A10.6: *Change in aggregate results, FBH with longevity vs FBH no longevity*

CATEGORY	2016	2020	2026	2030	2036
GDP	0.1428%	0.2827%	0.7071%	1.2194%	1.2949%
Investment	0.7401%	1.2593%	2.7995%	4.7619%	3.8981%
Government	-0.0684%	-0.0926%	-0.0242%	0.2156%	0.3705%
Capital Stock	-	-	-	-	1.7113%
Aggregate welfare					
Agent 1 (20% poorest)	-	-	-	-	0.0709%
Agent 2 (3-5 deciles)	-	-	-	-	0.0938%
Agent 3 (6-8 deciles)	-	-	-	-	0.1438%
Agent 4 (20% richest)	-	-	-	-	0.2468%
Aggregate welfare	-	-	-	-	0.1786%
Government welfare	-	-	-	-	0.0471%

Table A10.7: *Changes in production, FBH with longevity vs FBH no longevity*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.1954%	0.3085%	0.8723%	1.9138%	0.4238%
Livestock	0.2391%	0.4261%	1.1168%	2.1039%	1.6409%
Forestry	0.0000%	0.2252%	0.9653%	1.9469%	1.5552%
Fisheries	0.0000%	0.0000%	0.2994%	0.5479%	0.4785%
Oil	0.0663%	0.3153%	0.9838%	-1.4842%	-1.4591%
Natural gas	0.1114%	0.3405%	1.0423%	-1.0731%	-1.2141%
Mining	0.3271%	1.2000%	3.4449%	5.6460%	0.0974%
Refining	0.1335%	0.4902%	1.3616%	-0.2070%	-0.1950%
Transport	0.0571%	0.1379%	0.4425%	0.7923%	-0.2379%
Electricity	0.0862%	5.7561%	13.0600%	13.0344%	23.7461%
Chemicals & plastics	0.3419%	1.1126%	3.1412%	3.3647%	-3.6128%
Services	0.0560%	0.1494%	0.4677%	0.9248%	0.0147%
Manufacturing	0.3273%	0.6555%	1.6509%	2.9393%	0.5180%

Table A10.8: *Changes in consumption, FBH with longevity vs FBH no longevity*

CATEGORY	2016	2020	2026	2030	2036
Food	-0.0366%	-0.0354%	0.0624%	0.2878%	0.5063%
Household goods	-0.0106%	0.0758%	0.2849%	0.3303%	0.7101%
Consumer services	0.0197%	0.0554%	0.1994%	0.4390%	0.7322%
Autos	0.0423%	0.0943%	0.2246%	0.3923%	0.6832%
Electricity and LPG	-0.0404%	1.4461%	3.2518%	3.2431%	6.4270%
Public transport	-0.0157%	-0.0702%	-0.0120%	0.0869%	0.2179%
Gasoline	0.0167%	0.0000%	0.0669%	-0.2111%	-0.0656%
Water	0.0000%	0.0000%	0.0684%	0.3073%	0.5342%
Housing	0.0305%	0.0000%	0.0910%	0.3477%	0.5509%

Table A10.9: *Change in imports, FBH with longevity vs FBH no longevity*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.0000%	0.0835%	0.2149%	0.0000%	0.2187%
Livestock	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Forestry	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Fisheries	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Oil	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Natural gas	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Mining	0.0000%	-0.3597%	-0.4914%	-0.4065%	-0.8576%
Refining	0.0000%	0.1164%	0.3433%	2.0833%	2.2931%
Transport	0.0000%	0.0000%	0.2941%	0.0000%	0.0000%
Electricity	0.0000%	0.0000%	0.0000%	0.0000%	-25.0000%
Chemicals & plastics	-0.0141%	-0.0123%	-0.0300%	0.4070%	0.5175%
Services	0.0000%	0.0703%	0.1210%	-0.1644%	-0.0927%
Manufacturing	0.0000%	-0.0057%	-0.0097%	-0.1918%	-0.2518%

Table A10.10: *Change in exports, FBH with longevity vs FBH no longevity*

SECTOR	2016	2020	2026	2030	2036
Agriculture	0.0000%	-0.1410%	-0.1192%	0.0000%	0.0935%
Livestock	0.0000%	0.0000%	0.0000%	0.0000%	0.6329%
Forestry	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Fisheries	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Oil	-0.1002%	-0.1533%	-0.0819%	-2.7289%	-3.3040%
Natural gas	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Mining	0.0000%	0.0000%	1.2658%	1.2500%	1.0870%
Refining	-0.3021%	0.0000%	-0.2890%	-2.0349%	-1.8568%
Transport	-0.0771%	-0.2062%	-0.1170%	0.0000%	0.1386%
Electricity	0.0000%	4.7619%	12.5000%	11.5385%	23.3333%
Chemicals & plastics	-0.1622%	-0.0992%	0.0443%	-0.3744%	-0.2209%
Services	-0.1341%	-0.1585%	-0.0668%	0.2102%	0.4043%
Manufacturing	-0.1344%	-0.0971%	0.0524%	0.2223%	0.5375%

ANNEX XI – OUTCOMES OF THE WORKSHOP ON "DESIGNING AN INTEGRATED GREEN ECONOMY MODELLING (IGEM) TOOL FOR INFORMING GREEN ECONOMY POLICY MAKING PROCESSES"

In the framework of the Partnership for Action on Green Economy (PAGE), UNEP held a workshop in April 2016 on "Designing an Integrated Green Economy Modelling (IGEM) tool", bringing together researchers from PAGE agencies and PAGE country representatives from Mongolia (Ministry of Finance) and Peru (Universidad del Pacífico) with experts on modelling from the Millennium Institute, the Institute for Global Environmental Strategies (IGES), Ohio University, École Polytechnique Fédérale de Lausanne (EPFL), and the Department of National Planning of Colombia. The Global Green Growth Institute (GGGI), the Global Footprint Network and the Norwegian Agency for Development Cooperation (NORAD) also contributed to the success of the event.

During the workshop the conceptual framework of the IGEM tool and first country application results were presented. Participants showed great interest in the creation of the IGEM tool and provided a lot of useful feedback on the tool, its implementation and areas for improvement.

During the workshop three main topics were discussed:

1. How to expand the analysis of the IGEM framework. Other types of capital (e.g. natural capital) rather than only GDP should be considered in the construction of the model. Moreover, Geographical Information Systems (GIS) should also be linked to the IGEM tool in order to provide new findings in terms of spatial analysis and to identify low hanging fruit. It was also recognized that one critical factor for the success of these expansions is data availability (which, given the richness of the analysis requires economic, social and environmental information to be available and disaggregated in a similar way). Lastly, some participants recommended to put more focus on the assessment of the effects of opportunities rather than mainly modelling costs, but this depends specifically on the type of policy that is to be analysed.

2. How the IGEM tool can help support countries in implementing their priority SDGs. The workshop underlined the importance of supporting governments and development planners with a quantitative tool to help them develop and implement green economy policies to achieve sustainable development targets.

3. Country applications of the IGEM tool - opportunities and challenges. The availability of data (disaggregated data and time series data) represents a real issue for the construction of models and individual indicators. Furthermore, an additional challenge to the country application of the IGEM tool is represented by the ability of human capital to use it, therefore training human capital and building capacity should be considered as crucial for the correct use and dissemination of the tool. Moreover, during the workshop, a methodology to build a green IO-SAM model was presented but developing this is a lengthy process which is very data intensive, an important constraint in many developing countries.

Based on the workshop outcomes, and considering that this is one of the first international attempts to coordinate work between different modelling schools to construct an integrated modelling tool for assessing green economy policies, the PAGE researcher team of this project proposes to concentrate efforts on the following aspects as next steps:

1. Apply the IGEM framework at the country level to model green economy policies, based on the experience with the case of Mexico. The scenario presented at the workshop responded to the request by the government of Mexico to explore a carbon tax scenario. Based on two different tax rates, the final report will present results based on a rebate only and a feebate scenario.

New scenarios, kept for future research, will focus on investments (such as, i.e. diversifying the energy mix), to highlight how the IGEM framework can capture opportunities (including further analysis of biophysical and social impacts) coming from the implementation of green economy policies, in line with the SDGs.

2. Build on existing models at the country level, to expand the analysis of green economy policy questions. Based on the discussions at the workshop, there would be interest to link the Colombian CGE or the Peruvian T21 models, with other modelling tools, using the IGEM methodology.

3. Support PAGE countries in developing green versions of existing or new modelling tools, using the IGEM methodology. A concrete example would be to support a PAGE country to build a green IO- SAM, using the EGSS classification and its mapping with IO-SAM identified in the IGEM project.

NOTES

[1] Natural Resource Management refers to soil, water, ecosystems, etc., as well as extracted non- renewable (mineral and energy) resources.

[2] The model is solved via GAMS/MPSGE using the software developed by Rutherford as employed in Rutherford et al. (1997).

[3] For other CGE models introducing trade and environmental considerations see Burniaux J., Truong T. "GTAP – E: an energy – environmental version of the GTAP E model", GTAP Technical Paper No. 16 Revised January 2002. https://www.gtap.agecon.purdue.edu/resources/download/1203.pdf

[4] For a formal mathematical description of the model, see Ibarrarán and Boyd (2006, 114–126).

[5 - 6] Government refers to the total expenditure that, under a balanced budget, is assumed here to be equal to total income from tax revenue and sales of publicly provided goods and services. Since the idea here is to see how this concept changes when different policies are simulated, it is of little interest in this paper to include how the overall deficit will behave once policies are enacted in terms of its long terms sustainability. What is aimed to be shown here is how this balance in government revenues (or expenditure) changes under different policies.

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State Secretariat for Economic Affairs SECO

For further information:

PAGE Secretariat
UN Environment
Resources and Markets Branch
11-13 Chemin des Anémones
CH-1219 Chatelaine-Geneva
Switzerland
page@unep.org

www.un-page.org

@PAGExchange

@GreenEconomyUNEP

un-page.org/newsletter