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A Conceptual Framework for Integrated Economic–Environmental Modeling

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Abstract

Economy-wide models such as computable general equilibrium (CGE) models are powerful tools that provide insights on policy impacts on standard economic indicators. With the recent publication of the System of Environmental-Economic Accounting (SEEA), the power of this approach is amplified. This article addresses an important gap in economy-wide policy modeling applications and literature by developing a conceptual framework for the integration of the SEEA in the CGE framework, enabling for the first time the analysis of policy impacts on the economy and the environment in a quantitative, comprehensive, and consistent framework. Previous integrated modeling efforts have generally focused on the interaction between the economy and one environmental resource in isolation, requiring significant data reconciliation. Integration of SEEA into a CGE circumvents this resource intense process, enhancing analytical power, obviating the need for strong assumptions in reconciling economic–environmental data, reducing start-up costs, and increasing the timeliness of evidence-based policy advice.

Keywords

United Nations system of environmental–economic accounts, computable general equilibrium, environmental accounting, integrated modeling, evidence-based policy, experimental ecosystem accounting

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A country's system of national accounts (SNA) is used to derive key indicators of economic performance. Gross domestic product is one such indicator that is widely used to simultaneously summarize the state of a nation, its level of development, and rate of growth. However, while gross domestic product measures the value of transactions in an economy, it does not capture the depletion or degradation of the environmental resource base, which is one basis for the economic development of future generations. The Rio +20 Report (2012) emphasized the following:

> We recognize the need for broader measures of progress to complement gross domestic product in order to better inform policy decisions, and in this regard we request the United Nations Statistical Commission, in consultation with relevant United Nations system entities and other relevant organizations, to launch a programme of work in this area, building on existing initiatives.

Integrated economic and environmental data provide a more robust evidence base for policy makers to make better decisions (United Nations et al., 2014). For over two decades, international efforts have been underway to develop a framework for accounting for interactions between the economy and the environment. These efforts have culminated with the 2014 publication of The System of Environmental-Economic Accounting (SEEA) Central Framework, the first International Standard for Environmental–Economic Accounting, and the SEEA Experimental Ecosystem Accounting framework, which provides guidance on accounting for ecosystem goods and services (European Commission, Organisation for Economic Co-operation and Development, United Nations, & World Bank, 2013).

This article develops a conceptual framework for the integration of economic and environmental data for use in applied policy modeling within an economy-wide, computable general equilibrium (CGE) modeling framework. The following section provides an overview of the CGE framework, which is considered the workhorse of policy analysis (Jones, 1965). In the third section, the literature on modeling economic and environmental interactions in a CGE framework is reviewed. The fourth section provides an introduction to the SEEA including details of its origin and basic accounting structure. The fifth section offers a snapshot of Guatemala's SEEA, a leader in Latin America and the Caribbean in environmental accounting under SEEA, and an example of how the SEEA has been used to inform policy. The sixth section develops the conceptual framework for integrating SEEA data into a CGE framework for applied policy modeling and highlights some of the interesting interactions between the economy and environment in modeling of the mining, fisheries, and water sectors. The article concludes with a discussion on next steps in advancing the frontier of integrated economic–environmental modeling.

The Basic Structure of a CGE Model

Input–output modeling (I-O), pioneered by the work of Wassily Leontief, is a common approach for assessing the economy-wide impacts of a policy or program. I-O models are a representation of the productive sectors of an economy and their interlinkages (Dixon, Parmenter, Powell, & Wilcoxen, 1992; Shoven & Whalley, 1992). CGE models build on I-O modeling by overcoming some of their unrealistic assumptions, such as fixed prices and input shares, no input or factor supply constraints, and exogenous final demand. CGE models endogenize the price and demand system; enable substitution of goods and services in production and demand; provide a more realistic treatment of factor scarcity, institutions, and the macroeconomic environment; and allow for the optimization of agent behavior where producers compete for scarce resources and consumer expenditures (Banerjee & Alavalapati, 2010, 2014).[1]

A CGE model is a theoretically consistent mathematical representation of an economy, formalized by a system of equations describing demand for commodities, intermediate and factor inputs, equations that relate prices and costs, and market-clearing equations for factors and commodities (Dixon et al., 1992). Behavior of agents, such as utility-maximizing consumers and cost-minimizing producers, is represented by first-order optimality conditions, and the economic environment is described as a series of equilibrium constraints for factors, commodities, savings and investment, the government, and rest of the world accounts (Lofgren, Harris, Robinson, Thomas, & El-Said, 2002). The data platform upon which a CGE model is built is a social accounting matrix (SAM), a table of transaction values and transfers (flows) that describes the structure of production and final demands, and the circular flow of income between all agents in the economy including industries, institutions, and factors of production for a reference year (King, 1985).

Figure 1 depicts the transactions between all economic agents in a typical CGE model. Activities are industries that both demand (as intermediate inputs) and supply goods and services. Goods and services are consumed by households and governments and are supplied to export markets and foreign tourists. Activities also demand factors of production (labor, capital, land, and natural resources) and make payments to these factors. These payments are transferred to households in the form of wages and rents. Households may also receive income from transfers from the government or from the rest of the world (migrant labor, remittances, government subsidies, gifts, etc.). Households pay taxes, consume, and save by investing in the capital account.

A CGE model may be constructed to represent many countries linked through trade and transfers, national and subnational. They may also be constructed to represent various regions. Multinational and multiregional models are particularly relevant where transboundary environmental issues are concerned. In bottom-up regional models such as the The Enormous Regional

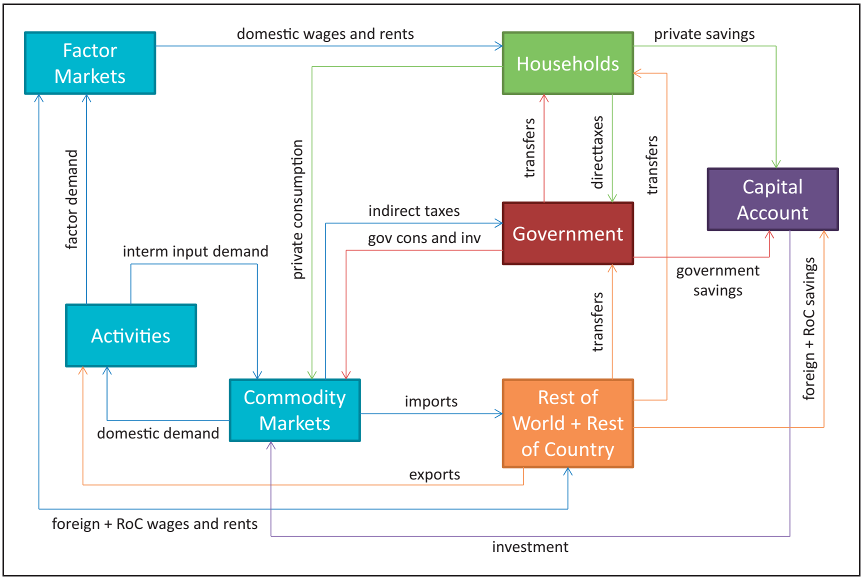

Figure 1. Flow of payments in a standard CGE model.
Source: Authors' own elaboration.

Model (TERM) CGE model (Horridge, Madden, & Wittwer, 2005), each region is modeled as a separate economy connected to other regions by interregional flows of goods and inputs (Giesecke & Madden, 2013). Top-down models begin with national data and disaggregate regions based on the regional data available such as regional employment by sector (Miller & Blair, 2009). Simulations conducted with CGE models produce results in terms of impacts on key economic indicators including gross regional production, sector output, prices, household income and employment, and welfare indicators.

The SAM

The basic accounting structure and the underlying data required to implement a CGE model is derived from a SAM. A SAM is a comprehensive statistical representation of an economy at a particular point in time (Figure 2). It is a square matrix with matching row and column accounts, where each cell in the matrix shows a payment from its column account to its row account. Major accounts in a standard SAM are the following: activities that carry out production; commodities (goods and services) that are produced or imported and sold domestically or exported; factors used in production, which include labor, capital, land, and other natural resources; and institutions such as households, government, and the rest of the world.

	Activities	Commodities	Factors	Households	Government	Savings-Investment	Rest of World	Total
Act		Production						
Com	Intermediate consumption			Consumption	Consumption	Investment	Exports	
Fac	Value added						Investment	
HH			Value added				Transfers	
Gov	Transfers	Transfers		Transfers			Transfers	
S-I							Savings	
RoW		Imports	Income					
Tot								

Figure 2. Basic accounts in an aggregate SAM.
Note. SAM: social accounting matrix.
Source: Authors' own elaboration.

The main data source in the construction of a SAM is the country's national accounts, in particular, supply and use tables (SUTs) and integrated economic accounts. In addition to the national accounts, other key data sources are information on a country's balance of payments, government accounts, and household survey data. Other industry-specific survey data may be of importance depending on the intended analytical application of the SAM.

Economy-Wide Modeling of Economic–Environmental Interactions

There is growing experience in the modeling of economic–environmental interactions with CGE models, with some emphasis on energy and climate change issues. Burniaux and Truong (2002) developed an energy–environmental extension to the Global Trade Analysis Project (GTAP) model; GTAP is a widely used multiregion, multisector model used since 1993 for quantitative analysis of international policy issues.[2] Burniaux and Truong's (2002) approach introduces substitutability between energy types in the GTAP model. In addition to substitutability, GTAP-E incorporates emissions as well as emissions trade. Medvedev and van der Mensbrugghe (2012) evaluate impacts and mitigation policies of climate change in Latin America. The authors build on the World Bank's global ENVISAGE model, introducing a high degree of disaggregation for Latin American and Caribbean countries and linking this model to household survey data for examining within-country climate change impacts on households.

Banerjee et al. (2015) modeled climate change impacts on household caloric intake by developing a linked CGE and food security model for Bangladesh. Böhringer and Rutherford (2013) examined how transitioning from coal to cleaner energies could be facilitiated through flexibility of emissions abatement, revenue recyclying, and technology in Poland. Bosello et al. (2011) developed an approach for assessing climate change impacts on ecosystems, especially with regard to carbon sequestration services. Bosello, Roson, and Tol (2006) examined how climate change may affect human health, leading to impacts on labor productivity and demand for health-care services.

As water scarcity issues have seemed to increase in recent years, examining these issues in a CGE framework is a growing area of inquiry (Brouwer, Hofkes, & Linderhof, 2008; Smajgl et al., 2012). One of the earlier experiences with modeling water in an economy-wide framework is that of Berck, Robinson, and Goldman (1990), which considered water supply constraints in the San Joaquin Valley in the United States. In this work, water is disaggregated as a factor of production and combined with land in fixed proportions to create irrigated land.

Berrittella, Hoekstra, Rehdanz, Roson, and Tol (2007) developed an extension to the GTAP model to evaluate groundwater scarcity in the context of international trade. The theory underlying the extension is that reductions in water supply would be expected to increase the relative price of water-intensive goods, thus shifting the competitiveness of some industries and terms of trade (Berrittella et al., 2007). Further work with this model investigates the economics of water pricing (Berrittella, Rehdanz, Roson, & Tol, 2006) and the impact of improvements in irrigation efficiency (Calzadilla, Rehdanz, & Tol, 2011).

Australia's Center of Policy Studies has investigated issues related to water scarcity, allocation, and pricing. Horridge et al. (2005) developed the TERM CGE model to consider the economic impact of drought. Further advances with this modeling framework led to the development of TERM-H2O. This model has considerable irrigation sector detail to explain how changes in relative prices affect water trade and the reallocation of farm factors of production (Dixon, Rimmer, & Wittwer, 2011; G. Wittwer, 2012; G. Wittwer & Griffith, 2011). Recent analysis by Wittwer and Banerjee (2015) explored the viability of investment in irrigated agricultural development in Australia's North West Queensland. Banerjee (2015) investigated the returns to investing in irrigation efficiency to return water to the environment for enhanced ecosystem services supply.

Economy-wide frameworks have also been used to analyze forest-related issues. Some of these experiences are reviewed in Banerjee and Alavalapati (2014) and include analysis of changes in stumpage fees and related policies (Alavalapati, Percy, & Luckert, 1997; Dee, 1991; Stenberg & Sirwardana, 2009). Forest-product trade-related issues have also been explored by Dufournaud, Jerrett, Quinn, and Maclaren (2000) and Gan (2004, 2005). Land-use dynamics between forestry, agriculture, and deforestation has emerged as an important area of inquiry (Banerjee & Alavalapati, 2009, 2010; Cattaneo, 2001, 2002; Persson & Munasinghe, 1995) and more recently including consideration of biofuel crops (Banerjee, MacPherson, & Alavalapati, 2012; Huang, Alavalapati, & Banerjee, 2012).

Economy-wide applications in the mining sector are scarcer. Higgs (1986) is one example of considering a range of shocks to Australia's mining sector in terms of wage, demand, tariff, tax, and foreign exchange using the ORANI model.[3] Lofgren, Robinson, and Thurlow (2002) explored Zambia's dependence on copper mining and how it may respond to fluctuations in world copper prices using the IFPRI model.[4] The research group, Tourism Research Australia (2013), studied the effect of Australia's mining boom on the tourism sector at the local level. Finally, Wiebelt (2001) considered the short- and long-run impacts of an environmental tax on waste from the mining sector in South Africa.

There are some examples of CGE applications to the fisheries sector. Jin (2012) incorporates an aquaculture sector in a CGE for New England to examine interactions between aquaculture and capture fisheries. Kiyama (2012) developed a two-country model linked with a clam stock model to examine predator prey interactions to inform resource recovery and sustainable management of the fishery. Narayan and Prasad (2006) examined the economic impact of export development strategies based on fisheries exports relative to other sectoral development strategies. Seung and Waters (2010) developed a CGE model to examine the impact on the Alaskan economy of reductions in allowable catch, increases in fuel prices, and reductions in demand for seafood.

As this literature review indicates, much of the previous analyses has focused on investigating the interactions between the economy and one environmental resource or negative environmental externality in the case of climate change or pollution. Sourcing the environmental data for integration in a SAM is a time-consuming process, requiring strong assumptions for data reconciliation. The following sections demonstrate how the SEEA facilitates data integration and reduces the need for strong assumptions for reconciling data from different sources. Furthermore, the SEEA captures data on stocks of some environmental resources, and it is now possible to track how economic–environmental interactions affect these stocks; measure the contribution of stocks to the wealth of a region or nation; and assess how trends in stocks of environmental resources affect prospects for economic growth and human well-being.

The SEEA: The New International Statistical Standard

The SEEA Central Framework was developed to combine economic data with environmental information in a common accounting framework consistent with the United Nations SNA (Obst & Vardon, 2014). This unifying framework enables the measurement of the contribution of the environment to the economy and the measurement of the impact of economic activity on the environment and stocks of environmental resources (Dube & Schmithusen, 2003). The core strength of the SEEA is its consistent application of accounting rules and principles in the representation of the environment in both monetary and physical terms (United Nations et al., 2014).

Environmental–economic accounting under the SEEA overcomes two core limitations of the SNA with regard to the environment. First, the depletion of environmental resource stocks is accounted for only in terms of its positive contribution to economic output, and second, the condition of a nation's environmental resources is not accounted for thereby enabling natural resource degradation to proceed undetected. In addition to SEEA's compatibility with the SNA (2008), it is compatible with the Balance of Payments and International Investment Position framework, the International Standard Industrial Classification of All Economic Activities, the Central Product Classification system, and the Framework for the Development of Environment Statistics. This international consistency of the SEEA further enables cross-country and temporal analysis.

The development of the SEEA and its compatibility with the SNA offers an unprecedented opportunity to advance the field of integrated economic–environmental modeling. With the SNA as the primary data source for a SAM, which in turn is the main source of data for a CGE, integration of SEEA into a SAM framework enables a robust and consistent representation of the environment in economy-wide policy modeling. An important finding from the literature review is that strong assumptions are required to reconcile environmental and economic data for use in an economy-wide framework. With the SEEA, data reconciliation and strong assumptions are no longer required to the extent they were previously, and its integration into a CGE reduces start-up costs and the timeliness of policy advice.

Origins of the SEEA

The origins of the standardization of environmental accounting may be traced at least as far back as the 1991 Special Conference on Environmental Accounting in Baden, Austria. One year later, the 1992 United Nations (UN) Conference on Environment and Development launched Agenda 21, which emphasized the importance of environmental accounting and called for a program to develop national systems of integrated economic and environmental accounts for all nations (United Nations et al., 2014, Chapter 8.41). Agenda 21 stated the following:

> A first step towards the integration of sustainability into economic management is the establishment of better measurement of the crucial role of the environment as a source of natural capital and as a sink for by-products generated during the production of man-made capital and other human activities . . . A common framework needs to be developed whereby the contributions made by all sectors and activities of society, that are not included in the conventional national accounts, are

> included . . . A programme to develop national systems of integrated environmental and economic accounting in all countries is proposed.

In 1994, the UN Statistical Commission established the London Group on Environmental Accounting as a forum for sharing experiences in the development of frameworks for environmental accounting. The London Group was instrumental in revisions of the 1993 SEEA and producing the 2003 SEEA. The 2003 SEEA was published by the United Nations, the European Commission, the International Monetary Fund, the Organisation for Economic Co-operation and Development, and the World Bank (Edens & Haan, 2010; United Nations et al., 2014). This early version of the SEEA was a compilation of best practices for environmental accounting. As experience with environmental accounting increased, international institutions set a course toward developing an international environmental statistical standard.

To oversee the development of the statistical standard, the UN Statistical Commission established the UN Committee of Experts on Environmental-Economic Accounting in 2005 (Edens & Haan, 2010). At the Statistical Commission's 43rd Session in March of 2012, the SEEA Central Framework was adopted as the International Standard for Environmental-Economic Accounting, and in 2014, the SEEA 2012 Central Framework was published (Obst, Hein, & Edens, 2015; United Nations et al., 2014).

Consistent and compatible with SEEA, guidance on resource-specific accounting includes the following: (a) SEEA Water, a SEEA subsystem that provides a conceptual framework for organizing hydrological and economic data; (b) SEEA Energy, also a SEEA subsystem, defines agreed concepts and classifications for energy and energy-related emissions accounts; (c) SEEA Land and Ecosystems is currently developing a framework and defining the scope of experimental ecosystem accounting; and (d) SEEA Agriculture, Forestry, and Fisheries, which concluded its Second Global Consultation in January 2016 and is now under revision. In addition to guidance on resource-specific accounting, the report, SEEA Applications and Extensions, provides a demonstration of how SEEA may be used in research, policy, and decision making. This report includes an introduction to environmentally extended I-O modeling and mentions CGE modeling as a particularly powerful application of the accounts (European Commission, Food and Agriculture Organisation of the United Nations, Organisation for Economic Co-operation and Development, United Nations, & World Bank, 2014).

Basic SEEA Structure

The SEEA Central Framework uses a systems approach to organizing information, covering both stocks and flows relevant to environmental resources. For compatibility, the accounting concepts, structures, rules, and principles of the

SNA are used. The SEEA is designed to allow individual environmental account modules to be developed to address a country's most urgent policy needs without the need for all environmental accounts to be developed at once (United Nations et al., 2014).

While the SNA provides a structure for accounting for environmental assets, the SEEA extends this treatment in three critical ways: (a) Environmental assets in the SEEA are quantified in both biophysical and economic terms that enable accounting for environmental assets that do not currently have an economic value. Within the broader UN accounting framework, this implies dropping the SNA's requirement that for an environmental asset to be counted, it must have an owner and generate a future income stream; (b) the SEEA recognizes the contribution of individual resources to ecosystem function and the ecosystem services they provide. The SEEA Experimental Ecosystem Accounting (EC et al., 2013) document outlines basic concepts for ecosystem accounting, extending the production boundary beyond provisioning services to include regulating and cultural and aesthetic services, and (c) degradation and depletion is based on physical change to environmental assets and includes changes in quality of ecosystem services (Obst & Vardon, 2014).

The SEEA organizes data on economic–environmental interactions in three categories: (a) It describes the physical flows of materials and energy within the economy and between the economy and the environment, (b) it accounts for environmental resource stocks and changes to stocks, and (c) it accounts for transactions between economic units that are considered environmental (e.g., environmental protection and preservation) in monetary terms.

The accounts themselves are made up of four types of tables: (a) SUTs represent flows of environmental inputs, products, and residuals in physical and monetary units. Three subsystems were developed for SUTs since not all physical flows should be recorded similarly or aggregated. The subsystems are material flow accounts, water accounts (cubic meters), and energy accounts (joules); (b) environmental asset accounts represent opening and closing stocks in physical and monetary terms. The monetary revaluation of stocks at the end of the accounting period serves to account for changes in asset pricing; (c) economic accounts with depletion-adjusted economic indicators; and (d) transactional accounts represent economic activities for transactions related to environmental management, mitigation, and other environmental expenditures. While these environmental transactions are recorded in the SNA, they may be difficult to identify or disaggregate depending on the classifications used. In the subsections that follow, a brief description of the first two types of tables (flow and asset accounts) that are of special importance for integrated economic–environmental modeling is provided.

Physical flow accounts. While monetary flows are recorded in SUTs, the physical flows that underpin them are recorded in physical SUTs (PSUTs). The I-O accounting identity that describes the physical flows of materials from the environment to the economy is the sum of natural inputs, imports, and residuals received from the rest of the world. This equates to materials exiting the economy as the sum of residual flows to the environment, exports and residuals sent to the rest of the world, plus net additions to stocks. The physical inputs considered in the context of PSUTs are natural resource inputs, renewable energy sources, and other natural inputs.

Of the natural resource inputs in PSUTs, there are mineral and energy resources, soil resources, natural timber resources,[5] natural aquatic resources, other natural biological resources, and water resources. Natural resource inputs that are not transformed into products are returned to the environment as natural resource residuals, which are losses incurred during extraction, unused extraction, or reinjections of natural resource inputs (United Nations et al., 2014). Inputs of energy from renewable sources are nonfuel energy sources from the environment. Other natural inputs are inputs from soil, which include nutrients and other elements in the soil absorbed by the economy in productive processes, and inputs from air in the form of compounds and elements (nitrogen and oxygen among others) used in production and combustion.

Physical flow accounts for energy describe energy flow from extraction or capture from the environment to the economy, and its use by industries and households, and then back to the environment. Physical flow accounts for water describe the initial abstraction of water from the environment, its flow into the economy to supply industry and households, and the flow of water back to the environment. Physical flow accounts for materials refer to various natural inputs, products, and residuals. The main areas where physical flow accounting has been used are product flow, air emissions, emissions to water, solid waste, and economy-wide material flow accounting (United Nations et al., 2014).

Environmental assets in the SEEA. There are seven environmental assets considered in the SEEA, namely, mineral and energy resources, land accounts, soil resources, timber resources, aquatic resources, other biological resources (excluding timber and aquatic resources), and water resources. A brief overview of each of these accounts follows.

Mineral and energy resource asset accounts. Mineral and energy resources can be extracted from the environment but are nonrenewable. Asset accounts contain information on quantities and values of stocks and changes over the accounting period through extraction, depletion, and discoveries. Mineral and energy assets include oil, natural gas, coal and peat, and nonmetallic and metallic minerals. Known deposits are classified as commercially recoverable, potentially commercially recoverable, noncommercial, and other deposits. Units of measure depend on the resource and include number of barrels, cubic meters, and tons. Monetary asset accounts are underpinned by the physical stock of the resource and the net present value approach to valuation (United Nations et al., 2014).

Land asset accounts. Land is where economic and environmental processes occur. The SEEA provides a framework for classification of land use and land cover. Land use comprises land and inland water with subcategories for each. Land is disaggregated as agriculture, forestry, land used for aquaculture, use of built-up areas, land used for maintenance and restoration of environmental functions, other uses of land not included, and land not in use. Land cover classes, on the other hand, represent physical and biological land cover, which includes both biotic and abiotic surfaces. The UN Food and Agriculture Organisation's Land Cover Classification System (Version 3) provides the theoretical basis for land cover classification in any country (FAO Global Land Cover Network, 2009).

Land asset accounts in physical terms are valuable for describing land use and land use change, as well as ownership. Monetary asset accounts for land show the value of land, with changes in the total value of land reflecting revaluations, while at a finer scale, changes in value may be due to changes in land use and reclassification. Land valuation can be complex due to the physical assets located on the land.

Soil resource asset accounts. Soil resources support production of biological resources, provide nutrients and water for agriculture and forestry, provide habitat, play a role in carbon sequestration, and serve as the foundation for infrastructure. Accounting for soil resources has many applications, including quantifying soil lost to erosion and other changes, as well as accounting for the resource in terms of its nutrient content, health, and its role in agriculture and forestry production. Soil resources are measured through soil surveys that generate maps representing suitability, threats, hazards, and various other soil properties.

Soil accounting focuses on the area of soil types at the beginning and closing of the accounting period and changes in availability for different uses. Soil volumes may also be measured to account for changes resulting from erosion or natural disasters, as well as soil depletion. Soil asset accounts show opening and closing volumes with additions through soil formation to be considered to be very slow, and therefore, the view is that soil is a nonrenewable resource from an accounting perspective. Soil movement is accounted for as it is transported by wind and water; soil may be transported *from* the accounting unit and recorded as a loss or *to* the accounting unit and recorded as a gain. In addition to asset accounts, soil resources are accounted for in PSUTs. Movement of soil for construction, land reclamation, landscaping, and other uses is recorded as natural resource input from the environment to the economy. The movement of mineral elements of soil can be accounted for through material flow accounting. The value of soil resources, as in the case of physical assets, is tied to the value of the land.

Timber resource asset accounts. Timber is an input into the production of paper, furniture, and other products. It is used in construction and as a source of fuel and provides a medium for the storage of carbon. Timber resources are defined in the SEEA as the volume of trees, living or dead, and include all trees regardless of diameter, tops of stems, large branches, and dead trees lying on the ground that can still be used for timber or fuel. The distinction between natural timber resources or cultivated timber resources is important. The growth of natural timber resources does not occur within the production boundary and only enters this boundary once it is removed from its original location (e.g., harvested from the forest). In the case of cultivated forests, growth is considered as an increase in inventories of the enterprise responsible for cultivation of the forest.

Physical asset accounts for timber record opening and closing volumes over the accounting period where changes to volumes are due to both growth and removal of timber. The monetary asset accounts reflect changes to stocks recorded in the physical asset account as well as the revaluation of timber resources due to changes in prices. Since not all timber resources are available for harvest in a given year due to legislation or other reasons, the value of timber resources that are not eligible for harvest should be identified separately. The SNA records net changes in inventories, whereas the SEEA records changes in inventories on a gross basis. Resource rents for timber resources may be estimated, but this also would include a rent attributable to land. The actual stumpage price can also provide an estimate of the resource rent.

While not described in the SEEA Central Framework, flow accounts for timber resources may be useful for many applications. These accounts register the movement of forest goods between the forest and the economy in physical and monetary units. Flow accounts include output, intermediate consumption, and final consumption of forest products. Carbon accounts for timber resources may also be developed based on the structure of the physical asset accounts for timber resources.

Aquatic resource asset accounts. Aquatic resources include fish, crustaceans, molluscs, shellfish, other aquatic organisms, and aquatic mammals such as whales. Aquatic resources consider both coastal and inland fisheries. Aquatic resources can be harvested for commercial purposes, used for subsistence, or used for recreation. Asset accounts represent stocks and changes to stocks of aquatic resources within a country's economic territory and over the high seas for which a country has ownership rights. While all aquatic resources are within the scope of the SEEA asset accounts, in practice, the scope is limited to those resources that may be used commercially. Aquatic resources may be naturally occurring or cultivated. The Aquatic Sciences and Fisheries Information System maintains a list of over 11,500 species and is linked to the Food and Agriculture

Organization of the United Nations International Standard Classification for Aquatic Animals and Plants, categorizing commercial species into 50 groups. Aquaculture is defined as aquatic resources produced within aquaculture facilities.

Physical asset accounts represent the total biomass of all species subject to harvesting or cultivated within the national boundary and exclusive economic zone as well as the portion of resources that a country has access to through international agreement. For natural aquatic resources, different types of stocks may be accounted for including exploitable stock, sexually mature stock, and the absolute size of natural aquatic stock. Monetary accounts reflect the physical flows and revaluations applied between the opening and closing of the accounting period. With cultivated aquatic resources, market prices can be used to estimate the value of the resource and resource flow. In the case of valuing natural aquatic resources, there are two approaches. The first is to use the value of long-term fishing licenses and quotas where markets are functioning well. The second approach is to estimate the value based on the net present value of the rent to the resource. The resource rent may be based on information on annual licenses or using information from the SNA using the residual value method.

Other biological resource asset accounts. Other biological resources are cultivated animals and plants which includes livestock and annual and perennial crops, which are grown for food. In the case of cultivated biological resources, these are accounted for with considerable detail in the SNA. As for natural biological resources, the SEEA does not provide specific tables for the accounting for these resources, as the organization of information depends on the specific resource and intended application of the accounts. Accounting for naturally occurring biological resources, asides from aquatic and timber resources, is challenging; it is usually only possible to measure and register these accounts where access rights are controlled or management and conservation activities occur.

Water asset accounts. Water asset accounts present data on the stock of water at the beginning and end of the accounting period and includes artificial reservoirs, lakes and rivers, or stored ground and soil water. In addition, the accounts measure flows of water as it is harvested, consumed, and added to in the form of precipitation, and flows to and from other countries and flows to the sea. In the SEEA, water is accounted for as a component of *land and other areas* as in situ and passively used water and as a component of *water resources* where it is the volume of water in the environment and harvested for use. The three types of water considered in the SEEA are soil water, superficial water (rivers and lakes), and groundwater.

Water flow accounts quantify the abstraction of water from the environment to the economy, the water flow within the economy in terms of supply and use by industries and households, and water flow back to the environment. These flows are represented in the SEEA in the PSUTs, which organizes data in five sections: (a) abstraction of water from the environment, (b) distribution and use of water by enterprises and households, (c) flow of wastewater and reused water, (d) return flow of water to the environment, and (e) evaporation, transpiration, and water that is incorporated in products (United Nations et al., 2014).

Guatemala's Integrated Environment and Economic Accounts: Preliminary Analysis and Policy Impact

Guatemala began to implement the SEEA in 2006 and is a leader in the Latin American and Caribbean region with the full suite of SEEA accounts compiled from 2001 through 2010 (see Instituto de Agricultura, Recursos Naturales y Ambiente-Universidad Rafael Landívar [IARNA-URL], 2007; Instituto Nacional de Estadística, Banco Central de Guatemala y Instituto de Agricultura, & Recursos Naturales y Ambiente de la Universidad Rafael Landívar, 2013). Guatemala's accounts were constructed using as a reference the guidelines detailed in IARNA-URL (2007). These guidelines contributed to the early exercises in environmental accounting conducted in developing countries and economies in transition such as India, Indonesia, China, the Philippines, Thailand, Mexico, Brazil, Colombia, Botswana, Namibia, and Cote d'Ivoire. Having realized their value, all of these nations have been working toward more systematic and regular compilation of environmental accounts.

The Guatemalan experience offers findings on the interactions between the economy and the environment for 130 economic sectors of the national economy. Once compiled, the accounts themselves shed light on interesting interactions between the economy and the environment and temporal dynamics between 2001 and 2010. Key issues related to water, energy, and forest resources emerged, enabling for the first time analysis of these issues and policy alternatives in an integrated framework (Galvez, Tuy, & Carrera, 2014a). The accounts showed that in the case of Guatemala, the most important flows from the environment to the economy were those of water, energy and mineral resources, and timber.

Taking a closer look at the forest sector, the accounts revealed that demand for timber products increased by 17% between 2001 and 2010, growing from 29.6 million m^3 to 34.6 million m^3. A proportion of this demand served as a main input for primary and secondary industries which transform timber into value-added goods. Flows of forest goods within the economy show that sawn wood represents 90% of timber demand, while furniture manufacturing demanded only 3%. The rest of the domestic economy absorbed 2% of forest goods, while exports and gross capital formation accounted for 3% and 4%, respectively (Galvez, Tuy, & Carrera, 2014b).

Analysis of Guatemala's SEEA has begun to generate evidence-based policy advice, particularly in the case of the forest sector. Guatemala's forest accounts distinguish licensed (legal) and unlicensed (illegal logging). Results of the analysis show that over the past 60 years, Guatemala has lost approximately half of its forest cover due to agricultural expansion, urban development, and timber and fuelwood harvesting. Remarkably, these accounts revealed that over 95% of commercial logging operations were conducted outside of legal oversight (Banco de Guatemala & IARNA-URL, 2009; Vargas, 2015). While it was well known that some illegal logging was taking place, it was not until Guatemala's SEEA was developed that the magnitude of the problem became apparent. The SEEA clearly showed that current regulation was inadequate and that enforcement was severely lacking due to capacity constraints. These findings catalyzed high-level political discussion within Guatemala's National Institute of Forests and has subsequently resulted in a number of substantive changes.

The initial response has led to the National Institute of Forests commissioning analytical work to provide additional inputs to the policy debate about the governance capacity in the forest sector (IARNA-URL, 2009; El Instituto Nacional de Bosques, Instituto de Agricultura, Recursos Naturales y Ambiente- Universidad Rafael Landivar, & Food and Agriculture Organization of the United Nations, 2012). The SEEA findings and the additional analytical work have served as critical inputs into an array of national strategies to address the core issues identified and include the following: a National Strategy for the Control of Illegal Logging, a National Strategy for Production and Efficient use of Fuelwood, a National Strategy for the Restoration of Forest Landscapes, and a new National Forest Policy.

Another significant impact of the SEAA has been the changes implemented by the National Institute of Forests, in terms of its governance and accountability structure, as well as the broadening of its monitoring and enforcement capacity throughout the country. One important change implemented to reduce forest sector illegality was a new forest licensing system; operational since 2012, this system enables the tracking of shipments of timber products from forest to market. To encourage legal forestry and improved land use and management, a new Forest Incentives Law (PROBOSQUE) was approved, which lengthens the period over which forestry incentives are provided and establishes new incentives for reforestation, agroforestry, and energy-producing forests (Vargas, 2015). Future analysis of the SEEA will enable assessment of the effectiveness of these programs in reducing illegality and promoting improved land use.

Conceptual Framework for Integrating SEEA in an Economy-Wide Framework for Applied Policy Modeling

The integration of SEEA into a CGE framework and the development of the Integrated Economic–Environmental Modelling (IEEM) platform enables comprehensive analysis of the two-way interrelationships between the economy and the environment. Specifically, the proposed modeling approach recognizes that economic activities critically depend on the environment both as a source of inputs in the form of environmental resources and as a sink for its outputs in the form of emissions and waste.

Figure 3 elaborates on this interrelationship, where land, subsoil, timber, aquatic, and water resources provide inputs into productive processes. In IEEM, these are the raw materials used by firms, in addition to labor and capital, to produce the goods and services consumed by households. IEEM captures this contribution from the environment to economic processes in quantitative terms and in both monetary and physical units. In addition to the goods and services generated by the economy, emissions, waste, and other residuals are produced and returned to the environment which are also quantified and captured in IEEM, including the costs that these negative externalities imply. Another important advance in IEEM is its ability to track changes in stocks of environmental assets. In this way, IEEM can generate adjusted measures of economic growth and development such as adjusted net income and savings. These indicators take into account the depletion and degradation of environmental assets, which represent a nation's underlying wealth and are foundational for human well-being.

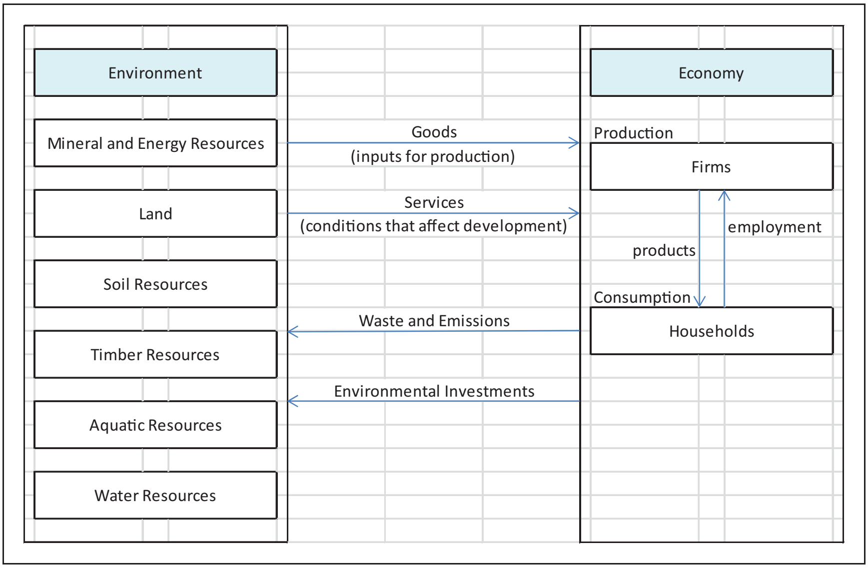

Figure 3. Interactions between the environment and the economic system as captured in IEEM.
Source: Authors' own elaboration.

Figure 4 depicts IEEM's environmentally extended SAM (ESAM) which singles-out transactions between the economy and the environment. With IEEM's ability to track stocks of some environmental resources, the initial stocks of, for example, mineral resources are used to initialize the submodel represented by Equations (1) and (2). In turn, cell (act, natural resource) in Figure 4 would provide the base-year change in the stock or reserves of mineral resources. For non-base-year periods, the evolution of the mineral stock is an endogenous variable in IEEM.

Within a CGE framework, environmental resources are considered as nonproduced assets, meaning they do not require labor or capital inputs for them to be produced. The services that environmental resources provide are considered as rent payments or flows of economic resources. Thus, in IEEM, environmental resources such as forests, aquatic resources, mineral and energy resources, and water are treated as factors of production employed in specific economic activities.

The SEEA introduces a number of new dimensions to a standard SAM. First, while flows or rent payments of environmental resources may be treated in a

	act	com	factors	hhd	gov	RoW	sav-inv	total mon	enviro	natural resources	waste	emissions
act		dom-prod						inc firms		supply	by-prod	by-prod
com	IO			C	G	E	I	demand				
factors	VA							inc fac				
hhd			VA					inc hhd				by-prod
gov	T	T						inc gov				
RoW		M	INC-F	TR				out forex		M	imp	
sav-inv				SH	SG	SF		sav				
total mon	cost firms	supply	spnd fac	spnd hhd	spnd gov	in forex	inv					
enviro							enviro invest			source		
natural resources	int-dem			fin-dem		E	fin-dem					
waste	int-dem						fin-dem		sink			
emissions									sink			

Figure 4. Schematic environmentally extended social accounting matrix.

Note: Where act: activities; com: commodities; dom-prod: domestic production; gov: government; RoW: rest of the world; sav-inv: savings-investment; total-mon: total monetary; enviro: environment; IO: intermediate consumption; VA: value added; T: taxes; M: imports; INC-F: factor income to/from abroad; TR: transfers; C: private consumption; G: government consumption; E: exports; I: investment; SH: households savings; SG: government savings; SF: foreign savings; int-dem: intermediate demand; fin-dem: final demand. Source: Authors' own elaboration.

SAM as payments to factors of production, representation of the stocks of these resources requires a different approach. In IEEM, data on stocks of environmental resources are represented in satellite matrices linked to the SAM. In terms of dynamic CGE modeling, economic sectors use and make payments to environmental resources and other factors of production in their productive processes. While the transactions between productive sectors and factors of production are captured in the SAM, the payment to factors also implies the use and perhaps depletion of the underlying stock of the environmental resource. To capture changes to the underlying stock, a link must be created between the economic activity of 1 year and the stock of the environmental asset in the subsequent year.

Second, the SEEA introduces some environmental resources for which markets may not yet be developed. For example, in country without a market for water, water in its natural condition (unprocessed or undelivered) is not represented in a SAM since no transaction is recorded between the environmental resource and the water user or demander. In the absence of a payment being made to the factor of production, treatment of this resource must occur outside of the SAM. To address this challenge, IEEM creates linkages to a satellite account and module which represents the stock of water and an algorithm for estimating changes to stocks as a result of activities using water as an input. Similarly, the SEEA provides information on land use, land-use change, and energy and emissions, which may be tracked in parallel accounts. Tracking energy and emissions provides an indication of the emissions' intensity of economic activity in any given year.

Finally, the SEEA provides a detailed description of transactions related to environmental management and mitigation. In a standard SAM, these transactions form part of the payments made by the government account and relevant private sectors to economic sectors which undertake these environmental management activities on their behalf. The detail provided by SEEA enables a detailed disaggregation of these payments such that environmental expenditure may be assessed alongside other key indicators such as gross regional product, adjusted for environmental resource depletion and degradation, and emissions.

In terms of the mathematical modeling of economic–environmental interactions, three examples are provided to illustrate some of the innovative aspects of these interactions that are captured within IEEM. How IEEM models energy and mineral resources, aquatic resources, and water resources are discussed in turn.

Energy and Mineral Resources

In the case of energy and mineral resources, using the oil sector for illustrative purposes, it is relevant to consider that oil production over time is limited by the size of recoverable oil reserves. In fact, oil is an exhaustible resource, and its cost of production depends on the stock of reserves; the smaller the remaining stock, the higher is the marginal cost of extraction (Ghadimi, 2007). IEEM captures this dynamic relationship between stocks, marginal cost, and output. Mathematically, this relationship is captured through the production function of the oil sector and is written as

$$Q_t = A_t\left(\delta^K K_t^{-\rho} + \delta^L L_t^{-\rho}\right)^{\frac{-1}{\rho}}, \quad (1)$$

$$A_t = S_t^{\eta}\phi, \quad (2)$$

where

Q = output;
L = labor input;
K = capital stock;
A = scale factor;
S = stock of resource remaining in the ground at each period;
δ^K, δ^L, and ρ = parameters of the CES production function;
ϕ = parameter reflecting the technology; and
η = elasticity of the resource output with respect to the available resource stock.

Thus, in this formulation, $A(Z)$ decreases over time as the stock of oil is depleted, reflecting the increase in the marginal cost of extraction.

In the case of the energy and mineral sector, the SEEA for Guatemala provides detailed data on supply and use of 52 extractive resources by activities and foreign suppliers (imports) and users (exports), respectively. In addition, the SEEA for Guatemala also provides data on 11 extractive resource stocks; specifically, data on opening stocks, changes, and closing stocks are available. As an example, Table 1 shows the available information on flows (Panel A) and stocks (Panel B) for the cases of natural gas and gold, two extractive resources produced in Guatemala.

Aquatic Resources

In the case of Guatemala's SEEA, aquatic resource data are available in terms of supply and use; however, no information on stocks is currently available since these aquatic resource stocks go beyond national borders. Absent other sources of data, FAOSTAT can be used to estimate the initial stocks of the various aquatic resources identified in the Guatemalan SEEA.

An innovative aspect of IEEM is its modeling of fish population dynamics with a biological module that represents the biological processes that affect fisheries productivity and therefore output. Mathematically, a logistic biological

Table 1. Natural Gas and Gold Supply and Use, SEEA Guatemala 2010.

Panel A: Flows of natural gas and gold, Year 2010 (tons)

	Mineral	Industries	Imports	Exports	Stock change[a]	Total
Supply	Natural gas	35,087,081	0	0	0	35,087,081
	Gold	11	0	0	0	11
Use	Natural gas	1,247,940	0	34,060,363	−221,222	35,087,081
	Gold	0	0	10	0	11

Panel B: Stocks (reserves) of natural gas and gold, Year 2010

	Mineral	Tons
Opening stock	Natural gas	2,598,519,713
	Gold	40
Change in stock	Natural gas	−13,923,185
	Gold	−9
Closing stock	Natural gas	2,584,596,527
	Gold	31

[a]Stock change refers to changes in stocks of minerals previously extracted.

production function for fisheries may be described in two steps as

$$B_t = B_{t-1} + \left[rB_{t-1}\left(1 - \frac{B_{t-1}}{k}\right)\right] - Q_t, \tag{3}$$

where
B_t = resource stock (biomass; marine population) in time t,
Q_t = quantity of fish harvested,
r = intrinsic growth rate of the resource stock, and
k = carrying capacity of the environment.

Then, Equation 4 is the classical harvest function used in bioeconomic analysis

$$Q_t = qB_tE_t, \tag{4}$$

where
E_t = fishing effort as a function of labor and capital and
q = catchability coefficient.

The effect of changing stock size (B_t) may then be modeled by modifying the production function for the fishing sector in IEEM. Specifically, Equation 4 is replaced with

$$Q_t = A_t\left(\delta^K K_t^{-\rho} + \delta^L L_t^{-\rho}\right)^{\frac{-1}{\rho}}, \tag{5}$$

where alternative ecosystem states and associated stock levels B_t are incorporated into the shift parameter, A_t ($=qB_t$). Thus, when B increases, $A_t > 1$, this in turn leads to an adjustment in fishing effort, which is a function of capital and labor inputs. The economy-wide effects of stock variation can then be estimated with IEEM.

Water Use

Modeling water in an economy-wide framework poses its own set of challenges, particularly in the case of nonregistered water, which is water not distributed by a water utility company, and is used primarily by the agricultural sector. In IEEM, it is assumed that water not supplied by the water utility company and not subject to an economic transaction has, initially, a price of zero. Then, depending on supply and demand condition, the price of water can become greater than zero. Mathematically, Equations 6 through 11 summarize the water-used-in-agriculture module of IEEM.[6]

Equation 6 states that, within a given period, water demand in agricultural sectors is proportional to the corresponding output from agricultural sectors. Equation 7 shows the zero profit condition for agricultural sectors, which includes payments for water used (see last term). Equations 8 to 10 represent the market equilibrium conditions in the agricultural water market. As shown, one of the following two situations can be observed: (a) water supply is larger than water demand and the price of water is zero, or (b) water demand is equal to water supply and the price of water is positive.

In the case of Guatemala, given the available information in the SEEA, it is assumed that water supply is initially larger than water demand and the price of water is zero. Then, as water demand increases in a counterfactual simulation, restriction (Equation 8) becomes binding and the price of water becomes positive. The positive price of water generates a cost for producers and income for water owners, as shown in Equation 11. In model calibration, IEEM is structured to allocate water-derived income across institutions in proportion to their ownership of land, which is determined by the *shiwat* parameter in Equation 11.

$$WATD_{j,t} = iwat_{j,t} Q_{j,t}, \tag{6}$$

$$P_{j,t}(1 - ta_{j,t})Q_j = w_t L_{j,t} + r_t K_{j,t} + \sum_i P_{i,t} QINT_{ij,t} + PWAT_t WATD_{j,t}, \quad (7)$$

$$\sum_{j \in jagr} WATD_{j,t} \leq \overline{WATS}_t, \quad (8)$$

$$PWAT_t \geq 0, \quad (9)$$

$$\left(\sum_{j \in jagr} WATD_{j,t} - \overline{WATS}_t \right) PWAT_t = 0, \quad (10)$$

$$YIWAT_{ins,t} = shiwat_{ins,t} PWAT_t \sum_{j \in jagr} WATD_{j,t}, \quad (11)$$

where
$i = j =$ activities or commodities,[7]
iagr = jagr = agricultural activities,
$t =$ time,
$WATD_{j,t} =$ water demand,
$WATS_t =$ water supply,
$PWAT_t =$ water price,
$YIWAT_{ins,t} =$ institutional income from water, and
$shiwat_{ins,t} =$ share of institution *ins* in total water income.

Concluding Remarks and the Way Forward

This article has developed a conceptual framework for integrated economic and environmental modeling which can assist policy and decision makers interested in understanding the potential economic and environmental impacts of policies before implementation. Integrating environmental features into CGE models in the past has required a resource-intensive data reconciliation process and strong underlying assumptions to model interactions between an environmental resource and the economy. The publication of the SEEA which is compatible with the United Nations SNA presents an attractive opportunity to advance the field of integrated economic–environmental modeling.

Data collected and organized under the SEEA enable the full suite of environmental accounts to be integrated into a CGE framework. This considerably increases analytical power, reduces start-up costs, and increases the timeliness of policy advice. Furthermore, with the core strength of a CGE being its ability to simulate how policies impact interlinked sectors and economic agents, the SEEA provides additional dimensions, revealing policy impacts not only on the economic system but also on the environmental resource base upon which the economic system is built and sustained.

This article is an output of an ongoing research program undertaken through the Inter-American Development Bank Biodiversity and Ecosystem Services Program. The IEEM modeling platform is currently being piloted after which it will be applied to explore critical policy issues in Guatemala including illegal logging, food security, and tourism development. Capacity building forms an integral part of the research program that will serve to generate awareness in policy makers of the analytical tools available to inform and substantiate their decisions, as well as build in-country capacity for model use. A key outcome of this research program will be achieved if a culture of evidence-based policy making is fostered in the region and data collection efforts under SEEA are further catalyzed.

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Notes

1. The interested reader can read more about the fundamentals and basic building blocks of CGE models in the following resources: Burfisher (2011); Dixon and Jorgenson (2013); Dixon, Parmenter, Powell, and Wilcoxen (1992); Lofgren, Harris, Robinson, Thomas, and El-Said (2002); and Shoven and Whalley (1992).
2. For more details on the GTAP model, database, and project, see https://www.gtap.agecon.purdue.edu/default.asp.
3. ORANI has a long history; it has been used for decades for quantitative policy analysis in Australia and has since been adapted to numerous countries. For more details, see http://www.copsmodels.com/oranig.htm.
4. The IFPRI Standard CGE model in GAMS was developed at IFPRI in early 2000s to analyze issues related to food policy in developing countries. Its use has expanded widely to include most sectors of interest; for more details, see https://www.ifpri.org/publication/standard-computable-general-equilibrium-cge-model-gams-0.
5. The use of the term *natural* distinguishes these resources from those that are cultivated.
6. In its full version, the developed IEEM can handle various water categories. In the case of Guatemala, we can distinguish between registered and nonregistered water. In addition, we can further split nonregistered water used between agriculture and non-agriculture uses.
7. To simplify, in this presentation, we are assuming that there is a one-to-one relationship between activities and commodities. However, the model allows for situations in which one activity produces more than one commodity, and one commodity is produced by more than one activity.

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