

The SEEA-Based Integrated Economic-Environmental Modelling Framework: An Illustration with Guatemala's Forest and Fuelwood Sector

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Abstract

This paper develops and operationalizes the Integrated Economic-Environmental Modelling (IEEM) platform which integrates environmental data organized under the first international System of Environmental Economic Accounting with powerful economy-wide modelling approaches. IEEM enables the ex-ante economic analysis of policies on the economy and the environment in a quantitative, comprehensive and consistent framework. IEEM elucidates the two-way interrelationships between the economy and environment, considering how economic activities depend on the environment as a source of inputs and as a sink for its outputs. The indicators generated by IEEM describe how depletion and degradation of the environmental resource base affect underlying wealth and future prospects for economic growth. To illustrate the analytical capacity of IEEM, the model is calibrated with Guatemala's SEEA and applied to analysis of its forest and fuelwood sector where negative health and environmental impacts arise from inefficient fuelwood use.

Keywords: ex-ante economic impact evaluation; system of environmental-economic accounting; computable general equilibrium model; wealth; natural capital; ecosystem services.

1. Introduction

Computable General Equilibrium (CGE) Models are powerful tools that provide insights on policy impacts on economic indicators. With the recent publication of the first international standard for environmental-economic accounting, the System of Environmental-Economic Accounting Central Framework (SEEA CF; UN et al., 2014), the analytical strengths of this approach are significantly enhanced. This paper builds on and operationalizes Banerjee et al's (2016) conceptual framework for integrating data organized under the SEEA into CGE models to construct an Integrated Economic-Environmental Modelling (IEEM) platform. IEEM enables the analysis of policy impacts on the economy and the environment in a quantitative, comprehensive and consistent framework (Banerjee, Cicowiez, Horridge, & Vargas, 2016).

IEEM reduces the need for making strong assumptions in reconciling environmental and economic data; it reduces analytical start-up costs and increases the timeliness of evidence-based policy advice. IEEM considers quantitatively how economic activities critically depend on the environment both as a source of inputs in the form of environmental resources, and as a sink for outputs in the form of emissions and effluents. For the first time in an ex-ante economic analytical framework, IEEM captures how depletion and degradation of the natural resource base and emissions affects national wealth and prospects for future economic growth, which is reflected in the indicators generated by IEEM.

Wealth may be understood as the aggregate value of manufactured capital, natural capital, and human and social capital. Nobel Laureate Joseph Stiglitz argued that a firm's health and potential are assessed based on its income and balance sheets. Before the SEEA, countries reported income flows, while information on natural resource stocks and thus the national balance sheet was seldom reported. The SEEA introduces the environmental dimension of the national balance sheet, which integrated into IEEM, enables the ex-ante assessment of the impacts of public policies, investments and exogenous shocks on wealth.

This paper describes the development of IEEM. To illustrate the analytical capacity of IEEM, Guatemala's SEEA is used to calibrate the model which is applied to Guatemala's fuelwood and forestry sector where negative health and environmental impacts arise from inefficient fuelwood use. This paper is structured as follows. Following this introduction, a brief overview of the

SEEA is provided. Next, the basic steps involved in transforming data organized under the SEEA into environmentally extended supply and use tables and social accounting matrices (SAM) are presented. Then, IEEM's mathematical approach to modelling natural resource input into the economy and output back to the environment is described. The scenario design section describes the application to Guatemala's fuelwood and forestry sector, followed by results and analysis. The paper concludes with a brief look at the frontier of integrated modelling of regulating and cultural and aesthetic ecosystem service supply and use.

2.1. The System of Environmental Economic Accounts

Over the last 20 years, efforts to measure the interactions between the economy and the environment have increased with progress demonstrated with the 2012 United Nations Statistical Commission adoption of the SEEA Central Framework as the first international standard for environmental-economic accounting (Obst & Eigengaam, 2016). To understand SEEA's contribution to advancing environmental statistics, the concept of the production boundary is fundamental. The System of National Accounts (SNA) states that:

“Economic production may be defined as an activity carried out under the control and responsibility of an institutional unit that uses inputs of labour, capital, and goods and services to produce outputs of goods or services. There must be an institutional unit that assumes responsibility for the process of production and owns any resulting goods or knowledge-capturing products or is entitled to be paid, or otherwise compensated, for the change-effecting or margin services provided.” With regard to environmental resources, it is added that: “A purely natural process without any human involvement or direction is not production in an economic sense” (EC, IMF, OECD, UN, & WB, 2009).

Thus, in order to account for environmental resources, the production boundary must be expanded to account for environmental processes that do not have a defined owner or receive compensation. In monetary terms, the asset boundaries of the SEEA Central Framework and the SNA are the same; in physical terms, however, the boundary of the SEEA is broader and includes all natural resources and areas of land of an economic territory, not limited to only those resources with a market value. In the ecosystem services literature, SEEA captures data on provisioning ecosystem services ([MA], 2005; TEEB, 2010). Furthermore, the SEEA encourages

the recording of the production and use of all goods and services in physical and where possible, monetary units, on own account within enterprises, whereas the SNA only favors some of these transactions which are relevant to capital formation or ancillary activities. This last step allows for the clear recording of the supply and use of environmental resources by economic units; for example, the production of energy from the burning of bagasse in the sugar milling industry, or the abstraction of water for livestock rearing.

The SEEA makes it possible to track natural capital inputs to the economy, the output of residuals in the form of emissions and effluents from the economy back to the environment, and changes to natural capital stocks. One of the most useful features of the SEEA is the ability to combine in single framework physical and monetary quantities. Banerjee et al. (2016) describes in detail the main elements of the SEEA which are relevant for integrated economic-environmental modelling.

2.2. Construction of an Environmentally Extended Supply and Use Table

The first step toward developing the database that underpins IEEM is the production of an Environmentally Extended Supply and Use table (hereafter EE SUT) based on the SEEA. From Guatemala's various environmental and economic accounts, a single consistent framework was constructed that combines natural economic and physical information, extending the monetary supply and use tables of the SNA with extensions to incorporate a column for the environment, and rows for natural inputs and residuals as proposed by the SEEA.

Although aggregated Guatemalan SEEA tables published by the statistical authorities were individually consistent with the relevant SEEA and other international classifications, in the specific case of Guatemala, it was discovered that an underlying series of unique identifiers was needed in order to account for all data and the nuances present at the most disaggregated level of data. These identifiers were required to achieve consistency between the different information domains, the international standard classifications, the local adaptations made by Guatemala's Central Bank, and different identification choices made by environmental accountants and statisticians working on developing Guatemala's SEEA. Steps like this are not uncommon when bringing together information from various sources and workflows.

For example, statisticians working on developing Guatemala's SEEA used various ways of representing the classification of the same product, mixing various levels of aggregation to create unique identifiers for their work, such as 01.002.99, or 01-002-99, or 0100299 or three columns, each with 01, 002, and 99, respectively. In other cases, the locally adapted classifications mixed levels of disaggregation, making it impossible to find unique correspondence with international classifications at some levels. In the case of monetary supply and use tables from the SNA, both columns and rows contained transactions. This feature was convenient for making necessary adjustments to national accounts for the calculation of some indicators like GDP, but resulted in an ambiguous database practice that mixed dimensions of the data (i.e. mixing products with transactions), and had to be resolved.

In order to address this challenge, an ad-hoc unique identifier classification approach was used to account for every data item from various sources, whether it clearly belonged to one of the standard international classifications or there were ambiguities that made this distinction difficult. At the same time, this resulted in the acknowledgement that national accounts tables are an eclectic combined presentation of a series of accounting steps, while retaining the way these are ordered and making them compatible with the environmental extensions that were derived from them.

The resulting EE SUT starts with the basic structure of SUT as defined by the SNA (EC et al., 2009) and adapted locally to the Guatemalan economy. Information on environmental interactions of those economic agents in the basic SUT is then added, extending it in order to account for environmental inputs to the economy, as well as emissions and effluents returned back from the economy to the environment. Although conceptually, the EE SUT follows the tables in the SEEA manual, some rearrangement along thematic lines is beneficial in order to group similar interactions and facilitate future modelling applications and interpretation. For example, rows explaining water used for irrigation were rearranged such that they sit adjacent to rows that describe water returns from that same form of irrigation. In the tables proposed by the SEEA, one environmental input (e.g. water) would be found above all transactions within the economy, with water returned to the environment below all economic transactions and in a residual outputs section.

The EE SUT is a double entry framework that shows socioeconomic and environmental interactions on the rows, which correspond to four basic data domains and 26 sections within them, as well as 21 different types of transactions on the columns. Table 1 depicts an EE SUT, with data cells that are typically populated, blackened.

Table 1. Basic structure of the Environmentally Extended Supply and Use Table; authors' own elaboration.

	T01	T02	T03	T04	T05	T06	T07	T08	T09	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	T21
01. Supply (Monetary)																					
02. Use (Monetary)																					
03. Value Added (Monetary)																					
04. Employment																					
05. Water supply (Registered/Unregistered)																					
06. Water use (Registered/Unregistered)																					
07. Cultivated Area (Ha)																					
08. Rainfed irrigation use (m3)																					
09. Sprinkler irrigation use (m3)																					
10. Drip irrigation use (m3)																					
11. Gravity use (m3)																					
12. Other use (m3)																					
13. All irrigation (m3)																					
14. Sprinkler irrigation return (m3)																					
15. Drip irrigation return (m3)																					
16. Gravity return (m3)																					
17. Other return (m3)																					
18. Energy supply (terajoule)																					
19. Energy use (terajoule)																					
20. Carbon Dioxide supply (CO2 tonnes)																					
21. Nitrous Oxide supply (CO2 tonnes equivalent)																					
22. Methane supply (CO2 tonnes equivalent)																					
23. Forest products supply (m3)																					
24. Forest products use (m3)																					
25. Animal species supply (number of individuals)																					
26. Animal species use (number of individuals)																					
27. Residuals supply (tonnes)																					
28. Residuals use (tonnes)																					
29. Subsoil resource supply (tonnes)																					
30. Subsoil resource use (tonnes)																					
31. Fishery supply (tonnes)																					
32. Fishery use (tonnes)																					

Note: Column names correspond to: T01 Output / Intermediate consumption , T02 Environment , T03 Imports of goods , T04 Imports of services , T05 CIF/FOB adjustment on imports , T06 Value added tax (VAT) , T07 Tariffs exc. VAT on imports , T08 Taxes on products, excluding VAT and Tariffs , T09 Subsidies on products , T10 Trade margins , T11 Transportation margins , T12 Electricity, gas, water margins, T13 Exports of goods , T14 Exports of services , T15 Household final consumption , T16 NFPI final consumption , T17 Individual government final

consumption , T18 Collective government final consumption , T19 Gross capital formation , T20 Stock variation , T21 Valuable objects.

The majority of columns correspond to transactions that are mostly relevant for the monetary and socio economic data domain; row sections 01 Supply (Monetary) and 02 Use (Monetary). Black cells represent not single values but, either commodity by industry matrices (T01) or commodity by transaction column vectors (T02-T021). Commodities further disaggregate each section on the rows according to the Central Product Classification (CPC), and industries disaggregate the T01 (Output/Intermediate consumption) column according to the International Standard Industry Classification (ISIC). Both classifications were locally adapted by the Central Bank of Guatemala to better reflect the country's economy.

With regard to data domains, the EE SUT is divided in 32 different sections of either supply, use, or complementary socioeconomic information for: (i) National Accounts monetary and socioeconomic information (sections 01 through 04); (ii) water accounting information (sections 05 through 17); (iii) energy accounting and greenhouse gas emissions information (sections 18 through 22); (iv) forest accounts information (sections 23 through 26); (v) residuals accounting information (sections 27 and 28); (vi) subsoil resources information (sections 29 and 30); and (vii) fisheries information (sections 31 and 32).

2.3 From an Environmentally-Extended Supply and Use Table to Social Accounting Matrix

A SAM is a matrix representation of the interrelationships existent on an economy at the level of individual production sectors, factors, and institutions. As stated in Round (2003), “it is a comprehensive, flexible, and disaggregated framework which elaborates and articulates the generation of income by activities of production and the distribution and redistribution of income between social and institutional groups”. A SAM is the core database for CGE models and is constructed based on SNA SUTs, integrated economic accounts, balance of payments, government accounts data and other ancillary data sources. The literature offers many general descriptions of what a SAM is and its key features (Breisinger, Thomas, & Thurlow, 2009; King, 1985; Round, 2003). What follows are some of the basic steps required to build an Environmentally Extended SAM (ESAM) as well as the satellite matrices required to track stocks and flows of environmental resources in physical units.

A SAM is composed of accounts. For each of these, a cell represents a payment column-wise and a receipt row-wise. Hence, columns represent expenditures for each account whereas rows record the matching incomes. Due to the accounting consistency of a SAM, total expenditure of every account must be equal to its total income. In other words, the total of every row must be equal to the corresponding total of the column. In our case, the standard SAM was extended in order to capture the two-way interrelations between the economic system and the environment. The basic structure of the ESAM is presented in stylized form in Table 2 where the first eight accounts are those found in a standard SAM.

Table 2. A stylized environmentally-extended social accounting matrix; source: authors' own elaboration.

receipts\spending

	act	com	factors	hhd	gov	RoW	sav-inv	total mon	enviro	water-reg	water-unreg	other resources	waste	emissions
act		dom-prod						inc firms		supply		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	source			
water-reg	int-dem			fin-dem										
water-unreg	int-dem													
other resources	int-dem			fin-dem		E	fin-dem							
waste	int-dem						fin-dem		sink					
emissions									sink					

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, water-reg = water registered, water-unreg = water unregistered, 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, and fin-dem = final demand. Source: author's own elaboration.

The logic behind the SAM transactions is the following. Activities buy intermediate inputs; pay for factors of production, thus generating the value added at factor prices; and pay indirect taxes. All these expenditures are financed with the payments that each activity receives for the sale of its output. Aggregate supply and demand are both recorded in the commodities accounts. For each commodity, the corresponding account records the sales of aggregate supply (domestic output plus imports from the rest of the country and the rest of the world, and related taxes) as follows: to activities as these demand intermediate goods; to households, government and investment as these demand final goods; and to the rest of the world as this demands the country's exports.

Factors earn returns from their involvement in domestic and foreign production, and they distribute them, net of taxes, to their owners (generally, households and enterprises). Institutions (households, enterprises, government, and rest of the world) receive incomes from production factors and (net) transfers that can be either spent in purchasing commodities or saved. Savings from household, the government (that is, the current account balance), and the rest of the world (that is, the current account balance with opposite sign) add to aggregate savings and these, in turn, are equal to the level of investment of the economy. Gross domestic product (GDP) at factor cost builds as activities remunerate factors of production (that is, value added). GDP at market prices equals GDP at factor cost plus indirect taxes and tariffs, which should also be equal to total final demand plus exports minus imports.

In an ESAM, the basic SAM framework is extended by incorporating environment-related accounts. Specifically, accounts are added which represent the environment as the source of natural capital and as a sink for by-products generated through economic activity (UN et al., 2014). For illustration, in the ESAM of table 2, three natural inputs are singled out: registered water, un-registered water, and other resources. As shown in cell [act,water-reg], registered water is supplied by the industries, using unregistered water (i.e. from the environment) as an input; specifically, the water utility company. On the other hand, unregistered water is obtained directly from the environment, and used for irrigation in the agricultural sector, among other things. In the case of other environmental resources, such as mining products, can also be exported and/or imported; see cells [other-resources,row] and [row,other-resources], respectively. In addition, industries and households can generate waste and emissions (i.e. cells [act,waste], [act,emissions], [hhd,emissions]) which can in turn be used as intermediate inputs (i.e. cell [waste,act]) and/or absorbed by the environment (i.e. cells [waste,environment] and [emissions,environment]). Certainly, it should be noted that cells in the basic SAM are measured in local currency units, while the extra cells needed for the ESAM are measured in physical units.

Not all environmental data is amenable or practical to integrate in an ESAM. These data are housed in satellite matrices linked to the ESAM through model equations. Specifically, data on stocks are stored in satellite matrices. Typically, these include opening stocks, change in stocks, and closing stocks, expressed in physical and/or monetary units depending on the particular

sector. In general, the change in the stocks will be consistent with the corresponding information in the ESAM. However, in some instances that is not the case. For example, if new extractive resources are discovered in a given period, the change in stocks for that period will not be the same in the ESAM and in the satellite stocks account.

In the case of Guatemala, satellite accounts were developed for: (i) stocks of extractive resources, expressed in physical units; (ii) stocks of forest resources, expressed both in physical and monetary units, and; (iii) land use by activity/commodity. In the case of extractive resources, the data on stocks contains estimates for a subset of the resources identified in the ESAM (i.e., the flows). Specifically, data on stocks for 11 extractive resources and data on flows of 52 extractive resources are available in the Guatemala SEEA. However, given that SUT data singles out four mining activities, the disaggregation in the SEEA is adequate for IEEM applications. In the case of fisheries, the SEEA of Guatemala does not provide data on stocks, though this could be integrated into the IEEM for Guatemala relatively easily, based on data from FAO.

In addition, we should note that, due to an accounting decision, there is a mismatch between the forest asset account and the flow account (BANGUAT/URL, IARNA, 2009). Essentially, reductions in stock of forests due to removals from the asset accounts differ from their counterpart in the supply of products coming from the forest in the flow account. The latter are called “forest products” and “felling residues”. The explanation given by the SEEA compilation team is that “the production of fuelwood that is generated as a by-product of the sawmill, furniture, and other manufacturing industries is added to the extractions of the forest.”¹ This unfortunately mixes primary extraction with reuse of residuals in the tables.

With regard to land use, a satellite account is used to store information related to what activities use land for producing commodities. Specifically, this account records the number of hectares destined to each agricultural crop commodity, forestry and fuelwood production in the ESAM. In the current application of IEEM, this information is not used, though in future agriculture-focused applications, this information would be highly relevant.

¹ Personal communication.

2.3.1 Building a MacroSAM

In the first step of building a SAM, a schematic representation of the economy is generated, using macroeconomic aggregates from the National Accounts. Specifically, data from the integrated economics accounts and the SUT are combined to build a MacroSAM as shown in Table 3. For Guatemala, the complete set of National Accounts was made available. Thus, no additional information was required to build the MacroSAM. When this is not the case, additional data on the balance of payments and government accounts/fiscal data needs to be obtained from other sources to construct the MacroSAM.

Table 3. MacroSAM for Guatemala 2010 (GDP share, percent); source: authors' own elaboration.

	act	com	f-lab	f-cap	cssoc	tax-act	tax-imp	tax-com	tax-dir	hhd	gov	row	sav	invng	invg	dstk	total
act		160.6															160.6
com	66.9									86.1	10.5	25.1		11.9	2.9	-0.9	202.5
f-lab	50.0											0.2					50.2
f-cap	40.6																40.6
cssoc	2.5																2.5
tax-act	0.6																0.6
tax-imp		0.7															0.7
tax-com		5.6															5.6
tax-dir										3.3		0.3					3.5
hhd			50.2	40.6	2.5						3.2	12.0					108.5
gov				0.0		0.6	0.7	5.6	3.5	4.1		0.2					14.6
row		35.6	0.0							3.0	0.7						39.3
sav										12.1	0.3	1.5					13.9
invng													11.9				11.9
invg													2.9				2.9
dstk													-0.9				-0.9
total	160.6	202.5	50.2	40.6	2.5	0.6	0.7	5.6	3.5	108.5	14.6	39.3	13.9	11.9	2.9	-0.9	657.1

Notes: the following abbreviations are used: act = activities; com = commodities; f-lab = labor; f-cap = gross operating surplus + mixed income; tax-act = activity taxes; tax-com = commodity taxes; sub-com = commodity subsidies; tax-imp = import tariffs; tax-dir = direct taxes; hhd = households; gov = government; row = rest of the world; sav = savings; invng = non-government investment; invg = government investment; dstk = stock change.

Additionally, our MacroSAM further disaggregates labor payments into gross operating surplus and mixed income as separate accounts. In other words, the MacroSAM provides information on the labor income of salaried and non-salaried (i.e., self-employed and income from

unincorporated enterprises owned by households) workers. Also, the activity and commodity taxes accounts are further split in order to single out activity and commodity subsidies, as present in the SUT. Finally, the MacroSAM further disaggregates the household account into households more narrowly defined, non-profit institutions serving households (NPISH), and enterprises (i.e., non-financial and financial corporations). SEEA data is not required for the construction of the MacroSAM.

2.3.2 A MicroSAM

Once a MacroSAM has been constructed, the aim then becomes to disaggregate it to provide greater sectoral and later, institutional detail (disaggregating types of labor and households, for example), according to the data available as well as the intended application of the SAM. Specifically, sectoral information from the SUTs is used as the main input to disaggregating activities and commodities. In the case of Guatemala, a highly disaggregated MicroSAM was produced with 122 activities and 219 commodities for the base year of 2010. Due to space limitations, an aggregate version of this MicroSAM is reproduced in Table 4 (panel a). Panel b of Table 4 lists the environment-related accounts in the extended SAM.

Some additional adjustments were required in constructing the ESAM, including treatment of export sectors with no domestic production (i.e. re-exports); splitting of sectoral gross operating surplus among payments to capital, land used in agriculture and forestry, and other natural resources used in fishing and mining based on SEEA and data from the Global Trade Analysis Project (GTAP) database (Narayanan, Aguiar, & McDougall, 2015). The splitting of trade and transport margins between domestic products, imports, and exports, assuming that the distribution of margins are proportional to the corresponding size of each transaction, and; stock variation as a component of total gross investment is expressed in the SAM as a payment from the savings-investment account (“sav”, in table 3) to the stock variation account (“dstk”, in table 3).

In practice, the presence of a specific, or fixed, natural resource factor (e.g., land, minerals, fish) dampens the supply response of the sector in question. In short, the indirect approach based on Narayanan et al. (2015) to estimate the natural resource cost shares can be explained as followed. Firstly, a value for the sectoral (partial equilibrium) supply elasticity is estimated, or obtained from the existing literature as in our case. Then, based on the functional forms used to model

sectoral production functions (i.e., CES functional form), we compute the natural resource cost shares implied by the said target elasticities.

Specifically, using the notation in Narayanan et al. (2015), it can be shown that the natural resource cost share can be computed from

$$\eta_s = \sigma_{VA} (\theta_R^{-1} - \theta_{VA}^{-1})$$

where η_s = elasticity of supply; σ_{VA} = elasticity of substitution between primary factors; θ_R = share of natural resources in total cost; and θ_{VA} = share of value added in total cost.

In Guatemala (and elsewhere) the SEEA does not provide estimates on the relevant cost shares.

Table 4: Accounts in the aggregated Guatemala 2010 ESAM; Source: Authors' elaboration.

Panel A: Economic Accounts

Category - #		Item	Category - #	Item
Sectors- activities and commodities (29)	Primary (9)	Coffee	Factors (8)	Labor, salaried unskilled
		Banana		Labor, salaried skilled
		Cereals		Labor, non-salaried unskilled
		Other agriculture		Labor, non-salaried skilled
		Livestock		Capital
		Other forestry		Land
		Fuelwood		Nat res, fishing
		Fishing		Nat res, mining
		Mining	Trade and transport margins (3)	Dist marg, domestic
	Manufacturing (13)	Food prod		Dist marg, imports
		Beverages and tobacco prod		Dist marg, exports
		Textiles and wearing apparel	Taxes and subsidies (8)	Social contributions, unskilled
		Wood and wood prod		Social contributions, skilled
		Paper and paper prod		Tax, activities
		Refined petroleum prod		Subsidy, activities
		Chemicals		Tax, value added (VAT)
		Rubber and plastics		Tax, imports (tariffs)
		Non-metallic mineral prod		Tax, commodities
		Basic metals and metal prod		Subsidy, commodities
		Machinery and equipment		Tax, income
		Other manufactures	Institutions (13)	Households, rural, quintiles 1-5
		Recycling		Households, urban, quintiles 1-5
	Services (7)	Electricity		Enterprises
		Water		Government
		Construction		Rest of world
		Trade	Savings-Investment (4)	Savings
		Hotels and restaurants		Investment, private
		Transport		Investment, government
		Other services		Stock change

Panel B: Environmental accounts

Category - #	Item	Category - #	Item
Water (11)	Registered, supply	Energy (10) (*)	Supply, Fuelwood
	Registered, use		Supply, Mining
	Non-registered, rainfed		Supply, Refined petroleum prod
	Non-registered, sprinkler irrigation		Supply, Recycling
	Non-registered, drip irrigation		Supply, Electricity
	Non-registered, gravity use		Use, Fuelwood
	Non-registered, other use		Use, Mining
	Return, sprinkler irrigation		Use, Refined petroleum prod
	Return, drip irrigation		Use, Recycling
	Return, gravity use		Use, Electricity
	Return, other use		
Forestry Res (14)	Supply by commodity, 7	Emissions (12)	Carbon-Diox (CO ₂), by comm, 4
	Use by commodity, 7		Nitrous Oxide (N ₂ O), by comm, 4
Fishing Res (4) (*)	Supply, Fishing		Methane (CH ₄), by comm, 4
	Supply, Food prod	Waste (2) (*)	Total supply
	Use, Fishing		Total use
	Use, Food prod	Land use (8)	Agriculture, 4
Mining Res (4) (*)	Total supply		Bushes
	Total use		Pastures
	Initial stock		Forest
	Final stock		Other

(*) more disaggregated information is available in Guatemala SEEA

3.1 The IEEM Platform

IEEM takes a standard CGE modelling framework as its starting point. The mathematical formulation of the core CGE model is presented in Appendix A. This model has been well documented and tested in a variety of applications (Banerjee, Cicowiez, & Cotta, in review; Banerjee, Cicowiez, & Gachot, 2015). Banerjee et al (2016) reviews the literature on the integration of environmental issues into the CGE framework. This literature has provided a basis for how environmental resources are modelled in IEEM.

The SEEA was designed to enable a flexible and modular implementation according to implementing country priorities. Similarly, the (Banerjee et al., in review; Banerjee et al., 2015)IEEM platform was developed with a modular structure such that the water, energy and emissions and forest, aquatic and mineral resource modules may be switched on or off depending on whether or not SEEA data are available for the country in question. For the case of Guatemala, all environmental modules are included and the sections that follow describe each environmental module in IEEM.

3.2. Forest Resources Module

For the forest sector, IEEM uses monetary unit values for model calibration, specifically, quetzales per m³ of forest products. In this particular case, both the forest account and the SUT use the same product classification. As will be shown in a later section, this is not the case for the mineral resources. IEEM tracks the commodity flows in physical units, at commodity-specific, observed unit values. In terms of modeling, the production function of the forestry sector singles out the logged land area as a factor of production. Specifically, a Constant Elasticity of Substitution (CES) function is used to combined labor and capital factors (equation F1), while a fixed coefficient assumption (i.e., Leontief) is used for the logged land area (equation F2) -- (see also land market module below. In turn, also under the assumption of fixed coefficients, intermediate inputs are exogenous quantities per unit of the activity (not shown here). Equation F3 tracks the evolution of the forestry stock, interpreted as the amount of hectares of forest. Recalling the discussion presented in section 2.3 on the small mismatch between the forest asset and forest flow accounts in the case of the Guatemalan SEEA, the adjustment parameter $forstkadj_t$ is used to reconcile this incongruence and assumes that the relative size of the mismatch is constant. In equation F4, the deforested area is computed, as the (negative of the) difference between forest land area in period t and forest land area in period t-1. Thus, equation F3 and F4 together show that deforestation occurs when logging, $QFOR_t$, is higher than the natural growth rate of the forest resources, $QFORSTK_t(1 + forgrw_t)$.

$$(F1) \quad QVA_{a,t} = \phi_a^{va} TFP_{a,t} \left(\sum_{a \in A} \delta_a^{va} QF_{a,t}^{-\rho_a^{va}} \right)^{\frac{-1}{\rho_a^{va}}} \quad f \in F$$

$$(F2) \quad QFOR_t = ifora_a QA_{a,t} \quad a \in A$$

$$(F3) \quad QFORSTK_t = QFORSTK_{t-1} (1 + forgrw_{t-1}) - forstkadj_t QFOR_{t-1}$$

$$(F4) \quad QDEFOR_t = -(QFORSTK_t - QFORSTK_{t-1})$$

where

$QA_{a,t}$ = level of activity a

$QF_{f,a,t}$ = quantity demanded of factor f from activity a

$QDEFOR_{a,t}$ = land deforestation

$QFOR_{a,t}$ = forest area logged in a given period

$QFORSTK_t$ = stock of forestry resources

$QVA_{a,t}$ = quantity of aggregate value added

$TFP_{a,t}$ = sectoral TFP index

$forgrw_t$ = growth rate of forest resources

$forstkadj_t$ = adjustment factor for FORSTK

$ifora_{a,t}$ = area logged per unit of forestry output

Upper bound on deforestation

IEEM allows imposing an exogenous (e.g., regulated) upper bound on deforestation (equation F5). To that end, an endogenous indirect tax at rate $GAMMADEFOR_t$ is levied on the forestry activity (equation F6). Thus, when imposing an upper bound on deforestation, one of the following two equilibrium situations will be observed: (i) deforestation is less than the specified upper bound and the tax rate is zero, or (ii) deforestation is equal to the upper bound and the tax

rate is positive. In turn, in order to mimic a regulatory mechanism, tax collection is transferred in full to the owners of the capital factor used in forestry.

$$(F5) \quad QDEFOR_t \leq qmaxdefor_t$$

$$(F6) \quad GAMMADEFOR_t \geq 0$$

$$(F7) \quad (QDEFOR_t - qmaxdefor_t) GAMMADEFOR_t = 0$$

where

$qmaxdefor_t$ = maximum level for deforestation

$GAMMADEFOR_t$ = rate of tax on forestry activity used to impose an upper bound on deforestation

3.3. Land Market Module

Sectoral demand for agricultural land

On the demand side, the treatment of agricultural land is similar to that of other factors.² Land demand in equations L1 to L2 is derived from the first order conditions of the optimization problem (i.e., cost minimization/profit maximization) solved by the representative firm in each activity that uses land, namely agriculture. Equation L2 defines the user price of land as the supplier price of land plus the tax on land use minus the endogenous subsidy on land use.

$$(L1) \quad QF_{f,a,t} = \left(\frac{PVA_{a,t}}{WFA_{f,a,t}} \right)^{\sigma_a^{va}} \left(\delta_{f,a}^{va} \right)^{\sigma_a^{va}} \left(\phi_a^{va} TFP_{a,t} \right)^{\sigma_a^{va}-1} QVA_{a,t} \quad f \in F \wedge a \in A$$

$$(L2) \quad WFA_{f,a,t} = \overline{WF}_f WFDIST_{f,a,t} (1 + tfact_{f,a,t} - GAMMAFA_{f,a,t}) \quad f \in F \wedge a \in A$$

where

$QF_{f,a,t}$ = quantity demanded of factor f from activity a

$PVA_{a,t}$ = value-added price for activity a

² In other contexts, this treatment can also be applied to land used in managed forests.

$WF_{f,a,t}$ = average price of factor f

$WFA_{f,a,t}$ = wage for factor f in activity a

$TFP_{a,t}$ = sectoral TFP index

$QVA_{a,t}$ = level of activity a

$WFDIST_{f,a,t}$ = wage distortion factor for factor f in activity a

$tfact_{f,a,t}$ = rate of factor use tax

$GAMMAFA_{f,a,t}$ = rate of factor return subsidy to f from private capital

Lower bound on sectoral land use

To enable the option of modelling land use incentive policies, IEEM allows the imposition of a lower bound to the land used by a given sector. To that end, an endogenous subsidy is introduced in equation L2 above. In turn, equations L3 to L5 are used to endogenously compute the subsidy rate on the corresponding land rent. Specifically, one of the following two equilibrium situations will be observed: (i) land use in selected sector (e.g., managed forestry) is larger than the specified lower bound and the subsidy rate is zero, or (ii) land use selected sector (e.g., managed forestry) is greater than or equal to the lower bound and the subsidy rate is positive. This same mechanism can be used to impose minimum factor use in other sectors should an application warrant this treatment.

$$(L3) \quad QF_{land,a,t} \geq qmin_{land,a,t}$$

$$(L4) \quad GAMMAFA_{land,a,t} \geq 0$$

$$(L5) \quad (QF_{land,a,t} - qmin_{land,a,t})GAMMAFA_{land,a,t} = 0$$

where

$qfmin_{f,a,t}$ = minimum level of employment of factor f in activity a

Sectoral land supply

On the supply side, IEEM allows two alternatives: (i) an upward-slopping land supply curve as formulated in equations L6a and L7, or; (ii) a vertical supply curve with total land fixed as formulated in equations L6b and L7.³ In equations L6a and L6b deforested land (see equation F4) is added to the supply of agricultural land – see last term on the right-hand side. Equation L7 defines the total national land endowment. Next, total land supply is allocated to each sector under the assumption of perfect or imperfect mobility. In the case of perfect mobility, the return to land is uniform across sectors. In the case of imperfect mobility, the return to land in each sector is related to some extent to sectoral conditions and thus becomes sector-specific. Equation L9 computes total land supply. Equation L8, derived from the first order condition of a Constant Elasticity of Transformation (CET) function that preserves physical additivity, determines sectoral land supply.⁴ Equation L9 defines the national return to land. Equation L10 is the equilibrium condition where supply is equal to demand for the sectoral land markets.

$$(L6a) \quad \begin{aligned} ENDOW_{i,f,t} &= \overline{endow}_{i,f,t} \overline{ENDOWADJ}_{f,t} \left(\frac{WFS_{f,t}}{CPI} \right)^{\eta_f^s} \\ &+ \sum_{\substack{t' \leq t \in T \\ f \in FLAND}} SHIF_{i,f,t'-1} QDEFOR_{t'-1} \end{aligned} \quad f \in F$$

$$(L6b) \quad \begin{aligned} ENDOW_{i,f,t} &= \overline{endow}_{i,f,t} \overline{ENDOWADJ}_{f,t} \\ &+ \sum_{\substack{t' \leq t \in T \\ f \in FLAND}} SHIF_{i,f,t'-1} QDEFOR_{t'-1} \end{aligned} \quad f \in F$$

$$(L7) \quad QFS_{f,t} = \sum_{i \in INS} ENDOW_{i,f,t} \quad f \in F$$

$$(L8) \quad QFSA_{f,a,t} = QFS_{f,t} (\delta_{f,a}^f)^{\sigma_f^f + 1} \left(\frac{\overline{WF}_{f,t} WFDIST_{f,t}}{WFS_{f,t}} \right)^{\sigma_f^f} \quad f \in F \wedge a \in A$$

$$(L9) \quad WFS_{f,t} = \left[\sum_a (\delta_{f,a}^f)^{\sigma_f^f + 1} (\overline{WF}_{f,t} WFDIST_{f,t})^{\sigma_f^f} \right]^{\frac{1}{\sigma_f^f}} \quad f \in F$$

$$(L10) \quad QFSA_{f,a,t} = QF_{f,a,t} \quad f \in F \wedge a \in A$$

³ For related modeling of land use, see among others, Hertel et al. (2010).

⁴ In the modified CET, the sum of the volume components is equal to the total volume; this specification has been used for land supply allocations in Giesecke et al. (2013).

where

$ENDOW_{i,f,t}$ = real endowment of factor f for institution i

$QFS_{f,t}$ = total supply of factor f

$QFSA_{f,a,t}$ = supply of factor f to activity a

$SHIF_{i,f,t}$ = share for institution i in the income of factor f

$WFS_{f,t}$ = supply price of factor f

η_f^s = land supply elasticity

3.4. Water Module

This section describes how non-registered water, in other words, water not supplied by the water utility company used in agricultural activities is modeled. 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 W1 to W6 summarize the agricultural water use module of the IEEM platform.⁵

Equation W1 states that, within a given period, water demand in agricultural sectors is proportional to the corresponding output in agricultural sectors. Equation W2 allows for adjustments in water demand per unit of agricultural output. Specifically, we assume a negative relation between water use per hectare of a given crop and the price of water. In turn, water demand by the households is proportional to the respective population sizes (equation W3). Equations W4 to W6 represent the equilibrium conditions in the market for agricultural water. In modelling agricultural water, one of the following two situations can be observed: (i) water supply is larger than water demand and the price of water is zero, or; (ii) water demand is equal to water supply and the price of water is positive.

⁵ In its full version, IEEM can handle various water categories. In the case of Guatemala, registered and non-registered water is distinguished, while non-registered water could be further split between agriculture and non-agriculture uses.

In the case of Guatemala, given the available information in the SEEA, we assume that water supply is initially larger than water demand and the price of non-registered water is zero. Then, as water demand increases in a non-base simulation, restriction (W4) becomes binding and the price of non-registered water becomes positive, generating a cost for producers (equation W5) and an income for water owners (equation W7). In the model calibration, it is assumed that water income is allocated across institutions in proportion to their ownership of land ($SHIWAT_{i,t}$ in equation W7).

$$(W1) \quad WATD_{a,t} = IWAT_{a,t} QA_{a,t} \quad a \in A$$

$$(W2) \quad IWAT_{a,t} = \overline{iwat}_{a,t} \left(\frac{PWAT_t}{PWAT_t^0} \right)^{\eta_a^{wat}} \quad a \in A$$

$$(W3) \quad WATD_{h,t} = \overline{iwat}_{h,t} pop_{h,t} \quad h \in H$$

$$(W4) \quad \sum_{a \in AAGR} WATD_{a,t} \leq \overline{WATS}_t$$

$$(W5) \quad PWAT_t \geq 0$$

$$(W6) \quad \left(\sum_{a \in AAGR} WATD_{a,t} - \overline{WATS}_t \right) PWAT_t = 0$$

$$(W7) \quad YIWAT_{i,t} = SHIWAT_{i,t} PWAT_t \sum_{a \in AAGR} WATD_{a,t} \quad i \in INS$$

where

A = set of activities

AAGR = set of agricultural activities

$WATD_{a,t}$ = water demand

$WATS_t$ = water supply

$PWAT_t$ = water price

$YIWAT_{i,t}$ = institutional income from water

$SHIWAT_{i,t}$ = share of institution ins in total water income

η_a^{wat} = price elasticity of water demand

In addition, we also consider water categories that record monetary and physical information in the SUT and the SEEA, respectively; more specifically, registered water supplied by the water company. In those cases, water is treated as a “standard” commodity but model calibration is conducting using value (quetzales) and volume (m^3) data. In so doing, we found that unit values for registered water demand differ among water demanders. Thus, we introduce an implicit water tax rate or distortion factor that allows modeling water prices that (exogenously) differ across demanders, relative to an economy-wide average water price.

3.5. Energy and Emissions Module

Following the SEEA, IEEM is structured so as to include any number of emissions (indexed by *emi*) generated through production processes and by final users of goods and services, for example, household use of fuelwood and the resulting emissions. In the Guatemalan SEEA, emissions from the following pollutants are singled out: carbon dioxide (in CO_2 tons), nitrous oxide (in CO_2 tons equivalent), and methane (CO_2 tons equivalent). In IEEM, equations EM1 and EM2 determine the level of emissions from intermediate and final demand, respectively. In equation EM3, the basic coefficient is *iemibar*, which represents the initial level of emissions per unit of consumption, for example, tons of CO_2 emitted per m^3 of fuelwood consumed. In turn, changes in IEMIADJ would reflect exogenous changes in the emissions coefficients that could be brought about by autonomous improvements in the level of emissions per unit of use.

Equation EM4 determines the level of emissions generated by emitter, which in the Guatemalan SEEA are industries and households. This information can be used, for example, to track the level of emissions from certain sectors. Equation EM5 determines the total level of emissions, for emission *emi*. Finally, equation EM6 calculates the total of greenhouse gas emissions where the individual gases are weighted by the so-called global warming potential (GWP). In our case, all emissions in the Guatemalan SEEA are greenhouse gases. IEEM enables limits to be imposed on the level of emissions. To that end, an endogenous tax on emissions may be introduced, for example, a carbon tax, at the same time that emissions are capped at $EMITOT(emi,t)$.

$$(EM1) \quad EMIS_{emi,c,a,t} = IEMI_{emi,c,a,t} QINT_{c,a,t} \quad emi \in EMI \wedge c \in C \wedge a \in A$$

$$(EM2) \quad EMIS_{emi,c,h,t} = IEMI_{emi,c,h,t} QH_{c,h,t} \quad emi \in EMI \wedge c \in C \wedge h \in H$$

$$(EM3) \quad IEMI_{emi,c,ac,t} = \overline{iem_i}_{emi,c,ac,t} IEMIADJ_{emi,c,ac,t} \quad emi \in EMI \wedge c \in C \wedge ac \in (A \cup H)$$

$$(EM4) \quad EMISAC_{ac,t} = \sum_{emi \in EMI, c \in C} EMI_{emi,c,ac,t}$$

$$(EM5) \quad EMISTOT_{emi,t} = \sum_{c \in C, ac \in A \cup H} EMIS_{emi,c,ac,t}$$

$$(EM6) \quad EMISGHG_t = \sum_{emi} gwpwts_{emi} EMISTOT_{emi,t}$$

where

EMI = set of emission categories

A = set of activities

C = set of commodities

H = set of households

$EMIS_{emi,c,ac,t}$ = emissions of emi from commodity c by emitter ac

$QINT_{c,a,t}$ = quantity of commodity c as intermediate input to activity a

$QH_{c,h,t}$ = quantity consumed of commodity c by household h

$IEMI_{emi,c,ac,t}$ = emissions of emi per unit demanded of commodity c by emitter ac

$EMISAC_{ac,t}$ = total emissions by emitter ac

$EMITOT_{emi,t}$ = total emission by pollutant emi

$EMISGHG_t$ = total of GHG emissions

$gwpwts_{emi}$ = global warming potential weights

3.6. Mineral Resources Module

In the case of the mining sector, it is relevant to consider that mineral extraction over time is limited by the size of recoverable reserves. Minerals are nonrenewable resources and extraction costs are a function of the stock of recoverable reserves; the smaller the remaining stock, the higher is the marginal cost of extraction (Ghadimi, 2007). Mathematically, we expand the total factor productivity (TFP) definition of equation PF7 as shown in equation MN1, relating productivity to mineral resource stock. Equation MN2, due to different classification of commodities and extractive resources, determines the extraction of resource type *ext* through a fixed coefficient of the level of output of the corresponding mining sector. For example, the extractive resources are classified as oil, natural gas, silica sand, attapulgite, chromite, quartz, and others. On the other hand, the SUT follows the CPC classification with less sectoral detail. Of course, the information in the extractive resources account can be aggregated to match the commodities in the SUT, particularly at the aggregate level such as “non-metallic minerals”.

In equation MN3, the stock of mineral resources is updated, based on the stock remaining from the previous period, extraction, and recoverable discoveries. In this formulation, where new discoveries do not make up for extraction, TFP in mining activities decreases over time as the stock of minerals is depleted, reflecting the increase in the marginal cost of extraction. Considering that the baseline scenario is generated under the assumption of a balanced growth path, to avoid changes in sectoral TFP in the baseline, it is assumed that new discoveries are equal to current extraction as indicated in equation MN4. Thus, sectoral TFP, which is a function of the remaining stock, does not change in the baseline. This assumption in IEEM can be calibrated according to the particular resource and country context that is the subject of analysis.

$$(MN1) \quad TFP_{a,t} = tfp_{exog,a,t} \prod_{inv \in INVGINF} \left(\frac{KG_{inv,t}}{KG_{inv}^{00}} \right)^{tfpelas_{a,inv}} \prod_{ext \in EXT} \left(\frac{EXTSTK_{ext,t}}{EXTSTK_{ext}^{00}} \right)^{fpelas_{a,ext}} \quad a \in AMIN$$

$$(MN2) \quad EXTS_{ext,a,t} = iext_{ext,a,t} QA_{a,t} \quad ext \in EXT \wedge a \in AMIN$$

$$(MN3) \quad EXTSTK_{ext,t} = EXTSTK_{ext,t-1} - \sum_{a \in A} EXTS_{ext,a,t-1} + EXTDISC_{ext,t-1} \quad ext \in EXT$$

$$(MN4) \quad EXTDISC_{ext,t} = \sum_{a \in A} EXTS_{ext,a,t}^0 \quad ext \in EXT$$

where

EXT = set of extractive resources

$AMIN$ = set of mining activities

$INGINF$ = set of government investment in public infrastructure

$QA_{a,t}$ = level of activity a

$TFP_{a,t}$ = sectoral TFP index

$KG_{inv,g,t}$ = government capital stock

$EXTS_{ext,ac,t}$ = supply of extractive resource ext by supplier ac

$EXTSTK_{ext,t}$ = stock of extractive resource ext

$EXTDISC_{ext,t}$ = discovery of extractive resource ext

$tfpexog_{a,t}$ = exogenous component of sectoral TFP

$iext_{ext,a}$ = supply of extractive resource ext per unit of output from act a

$tfpelas_{a,ext}$ = elasticity of the resource output with respect to the available resource stock

3.7. Aquatic Resources Module

A CGE approach has not been widely applied to exploring fisheries issues, though there is significant unexplored potential for extending a standard CGE framework to take into account fish population dynamics (Banerjee et al., 2016). The approach developed in this module follows guidance from the literature related to ecosystem-based management of fisheries, which is an integrated approach to management that considers the entire ecosystem, including humans (Pikitch et al., 2004). An extension to this approach involves incorporating a biology module representing the biological processes that affect fisheries productivity. Mathematically, a biological logistic production function for fisheries may be written in two steps as

$$(FS1) \quad B_t = B_{t-1} + \left[rB_{t-1} \left(1 - \frac{B_{t-1}}{k} \right) \right] - QA_t$$

where

B_t = resource stock (biomass; marine population) in time t

QA_t = quantity of fish harvested; level of activity a

r = intrinsic growth rate of the resource stock

k = carrying capacity of the environment

Then, equation (FS2) is the classical harvest function often used in bio-economic analysis. Equation (FS2) is frequently referred to as the catch-per-unit-effort production function (Conrad, 2010), because it assumes that catch per-unit of effort QA_t/E_t is proportional to the stock B_t with $q > 0$ being the constant of proportionality.

$$(FS2) \quad QA_t = qB_tE_t$$

where

E_t = fishing effort as function of labor and capital

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 the CGE model. Specifically, equation FS2 is replaced with

$$(FS3) \quad QA_a = A_a \phi_a^{va} TFP_a \left(\sum_f \delta_{f,a}^{va} QF_{f,a}^{-\rho_a^{va}} \right)^{\frac{-1}{\rho_a^{va}}}$$

where alternative ecosystem states and associated stock levels B_t are incorporated into the shift parameter A_t ($=qB_t$). Thus, when B_t increases, $A_t > 1$, this in turn leads to an adjustment in fishing effort, which is a function of capital and labor inputs in the CGE model. Typically, partial equilibrium models of fisheries use "effort" as the single human factor of production. On the other hand, IEEM considers both capital and labor at the same time that the fishing sector interacts with other sectors and competing factor demand. In contrast to conventional partial equilibrium formulations, IEEM captures the economy-wide effects of stock variation.

In the dynamic implementation of IEEM, when the capital stock grows at the same rate as the effective labor force, the economy is on a balanced growth path. However, balanced growth cannot be a feature of the aquatic resource module, because species populations cannot grow continually. In fact, unlike the growth of the effective labor force and capital stock, ecosystem populations are limited by photosynthesis and converge to steady states, with zero net growth. Thus, the sectors reliant on ecosystem inputs will not be expected to grow at the rate of the (effective) labor and capital stocks.

Usually, a common objective of renewable resource management such as fisheries is to maintain a standing (per capita) stock $B_t \equiv B$, so as to attain a maximum sustainable yield or MSY. Note that steady-state equilibrium means that corresponding to each biomass level B is a certain rate of harvest Q that just balances the natural rate of growth and thus maintains an intertemporal equilibrium situation. This rate of harvest, at which $Q_t = [rB_{t-1}(1 - B_{t-1}/k)]$, is the sustainable yield, and MSY is simply the maximum sustainable yield. Of course, there is a level of fishing effort (E_{MSY}) and quantity of fish harvested (Q_{MSY}) that corresponds to the maximum sustainable yield. In turn, the modeling of an upper bound to the amount of fishing permitted in a given year (i.e., a quota) can be introduced as follows, using a mixed complementarity formulation.

$$(Q_t - \bar{Q}_{MSY})\gamma = 0$$

$$Q_t \leq \bar{Q}_{MSY}$$

$$Q_t \geq 0$$

$$\gamma \geq 0$$

where gamma the (endogenously determined) rent per unit of fish harvested. Thus, one of the following two situations can occur:

$$(i) \quad Q_t < \bar{Q}_{MSY} \text{ and } \gamma = 0$$

$$(ii) \quad Q_t = \bar{Q}_{MSY} \text{ and } \gamma > 0$$

In case (ii), when the fishing quota is binding, the owner of the fishing rights would collect the rents.

3.8. Waste and Residuals Module

For waste and residuals, the Guatemalan SEEA provides information on physical units (tons) of the supply and use, by activities, households, and the rest of the world through imports and exports, respectively, of products such as hospital waste, paper waste, glass waste and rubber waste, among others. In the accounts, waste and residuals accounts follow a specific classification, however these are currently not linked to the commodities classification of the SAM. In the SEEA, the supply of waste and residuals is greater than that which is used or demanded. The supply of waste and residuals is therefore equal to the sum of the amount demanded and the amount dumped into the environment. The fact that the number of residuals supplied (23) is larger than the number of residuals used (8) is illustrative of this feature of the Guatemalan SEEA.

In terms of modeling, we assume that the supply (see equations W1 to W3) and use (see equations W4 and W5) of waste and residuals is a fixed proportion of the corresponding volume variable in the model. In other words, IEEM is able to track the supply and use of waste residuals. For example, the supply of paper waste by the households is a fixed proportion of total household consumption (equation W2). However, due to the specific classification of waste and residuals, we cannot link their supply and use to the supply and use of specific commodities in the SAM.

$$(W1) \quad RESIDS_{resid,a,t} = iresids_{resid,a,t} QA_{a,t} \quad resid \in RESID \wedge a \in A$$

$$(W2) \quad RESIDS_{resid,h,t} = iresids_{resid,h,t} \sum_c PQD_{c,h}^{00} QH_{c,h,t} \quad resid \in RESID \wedge h \in H$$

$$(W3) \quad RESIDS_{resid,row,t} = iresids_{resid,row,t} \sum_c pwm_{c,h}^{00} EXR^{00} QM_{c,t} \quad resid \in RESID$$

$$(W4) \quad RESIDD_{resid,a,t} = iresidd_{resid,a,t} QA_{a,t} \quad resid \in RESID \wedge a \in A$$

$$(W5) \quad RESIDD_{resid,h,t} = iresidd_{resid,h,t} \sum_c PQD_{c,h}^{00} QH_{c,h,t} \quad resid \in RESID \wedge h \in H$$

where

$RESID$ = set of waste and residuals categories

$RESIDS_{resid,ac,t}$ = supply of waste of residual resid by supplier ac

$RESIDD_{resid,ac,t}$ = demand of waste of residual resid by demander ac

$iresids_{resid,ac,t}$ = waste and residuals per unit supplied by supplier ac

$iresidd_{resid,ac,t}$ = waste and residuals per unit demanded by demander ac

3.9. Household Consumption Module

Firstly, household consumption expenditure is distributed across composite commodities according to a Stone-Geary utility function, from which a linear expenditure system is derived (equation H1). Secondly, household decide on the composition of the commodities bundle (equation H2) through a CES “production” function. Alternatively, the model allows for a different classification of consumer and producer goods and services. In fact, a “make matrix” of three dimensions (i.e., c [produced commodities], v [consumed commodities], and h [households]) is used where each consumed good can be composed of one or more supplied goods, combined using a CES function.

For example, households can consume the good “energy” composed by the produced goods fuelwood, petroleum goods, and electricity; in other words, “energy” is not produced by one individual activity in the model. Equation (H3) defines the price of the composite commodities. Equation (H4) is the corresponding “production function” of the composite commodities. In Section 4, we simulate autonomous improvements in energy efficiency in the household consumption of fuelwood through an increase in the $qheff_{c,h,t}$ parameter in equation (H2).

$$(H1) \quad QH_{v,h,t} = qhmin_{v,h,t} + \frac{\delta_{v,h}^{les}}{PCV_{v,h,t}} \left(EH_{h,t} - \sum_{v' \in CH} PCV_{v',h,t} qhmin_{v',h,t} \right) \quad v \in V \wedge h \in H$$

$$(H2) \quad QCV_{c,v,h,t} = \left(\frac{PCV_{v,h,t}}{PQD_{c,h,t}} \right)^{\sigma_{v,h}^c} \left(\delta_{c,v,h}^c \right)^{\sigma_{v,h}^c} \left(qheff_{c,h,t} \phi_{v,h}^c \right)^{\sigma_{v,h}^c - 1} QH_{v,h,t} \quad c \in C \wedge v \in V$$

$$(H3) \quad PCV_{v,h,t} QH_{v,h,t} = \sum_{c \in C} PQD_{c,h,t} QCV_{c,v,h,t} \quad c \in C \wedge h \in H$$

$$(H4) \quad QH_{v,h,t} = \phi_{v,h}^c \left(\sum_{c \in C} \delta_{c,v,h}^c QCV_{c,v,h,t}^{-\rho_{v,h}^c} \right)^{\frac{-1}{\rho_{v,h}^c}} \quad v \in V \wedge h \in H$$

where

V = set of composite consumption commodities

$PCV_{v,h,t}$ = price of (household-specific) composite commodity v (e.g., energy)

$PQD_{c,h,t}$ = composite commodity demand price for c demanded by h

$QH_{v,h,t}$ = quantity consumed of composite commodity v by household h

$QCV_{c,v,h,t}$ = quantity consumed of commodity c by household h through composite commodity v

$qheff_{c,h,t}$ = commodity- and household-specific consumption efficiency parameter

4.1. An Illustrative Application of IEEM to Guatemala's Fuelwood Sector

Sixty-seven percent, approximately 2.1 million of Guatemalan households use fuelwood as a primary source of energy with fuelwood constituting 57% of the country's overall energy use. Fuelwood is primarily used in cookstoves for cooking food and heating homes, as well as serving cultural purposes (Banco de Guatemala & IARNA-URL, 2009; Bielecki & Wingenbach, 2014; INAB, 2015). With population growth and the expansion of the agricultural frontier, fuelwood is becoming scarcer, requiring more time for its collection which is often the responsibility of women and children, taking an increasing share of their time from other important activities such as education. Furthermore, the use of open cookstoves is well known to have detrimental health effects, increasing the probability of households' contraction of respiratory illness by 31% (SEGEPLAN, 2010), the premature death of over 5,000 people per year, and productivity losses of around 1% of Gross Domestic Product (Global Alliance for Clean Cookstoves, 2014). Finally, extraction of fuelwood is in excess of what natural forests produce with a national fuelwood deficit of over 10 million m³ leading to increasing deforestation and forest degradation (INAB, IARNA-URL, & FAO, 2012).

To address this critical issue, more efficient use of fuelwood is one of 5 specific objectives of Guatemala's National Energy Policy 2013-2027 and is the overall goal of The National Strategy for Sustainable Production and Efficient Use of Fuelwood 2013-2024 (INAB, 2015; MEM, 2013). This National Strategy will: (i) establish 48,000 ha of forest plantations to produce 1.2 million m³ of fuelwood/per year; (ii) promote efficient fuelwood use by providing technical and financial support for the use of efficient fuelwood cookstoves. The strategy will reduce the fuelwood deficit by 25% and benefit over 200,000 or 13% of the households that currently use open cookstoves.

The IEEM framework is applied to explore the economic, environmental and social impacts of implementation of Guatemala's fuelwood strategy. In addition to this being a critical policy issue for the Guatemalan government, this issue was chosen for exploration due to its multidimensional nature with regard to economic-environmental interactions to illustrate the analytical power of the IEEM framework. IEEM's ability to track land use and forest resources will capture how the fuelwood strategy affect forest stocks. The creation of forestry and agroforestry plantations, and the fabrication and adoption of more efficient cookstoves may

lower costs of fuelwood and have employment generating implications. Less pressure on standing natural forests for fuelwood will ensure these forests are retained as important carbon sinks. Reduction of effort expended to collect fuelwood and more efficient fuelwood use in the home will have both productivity and health impacts, freeing up labor for more productive activities. Finally, more efficient fuelwood use will have implications for the country's energy-emissions profile. All of these interactions are captured in the IEEM framework.

4.2. Scenario Design

Four scenarios were developed to explore the impacts of Guatemala's fuelwood strategy. All four scenarios are compared to the baseline scenario. Most results are described as the percent difference with respect to the baseline scenario. In the baseline and simulations, IEEM updates the underlying data to 2016 with the relevant period of analysis beginning in 2016 until 2025. The following four scenarios were simulated:

- **Baseline.** The baseline or reference scenario is “business-as-usual” scenario; this first simulation is designed to replicate observed trends during 2010-2015 at the macro and sectoral levels. From 2016 on, this first simulation assumes that past trends will continue into the period from 2016 to 2025. In the simulations that follow, all shocks are introduced during the period 2016-2025; i.e., the non-base simulations deviate from the base for the period 2016-2025.
- **Efficiency:** The efficiency simulation imposes a 25% increase in fuelwood consumption efficiency for households, following a logistic implementation pathway from 2016 and 2020.
- **Efficiency + health:** The efficiency + health simulation links increased household fuelwood efficiency with improvements in household health which in turn have implications for the productivity of working household members. Various studies in Guatemala and in other countries have measured improvements in household air quality arising from the more efficient use of fuelwood, primarily through the use of efficient cookstoves (Ahmed, Awe, Barnes, Cropper, & Kojima, 2005; Duflo, Greenstone, & Hanna, 2008; Jagger & Shively, 2014; Lambe & Ochieng, 2015; McCracken & Smith, 1998; Smith et al., 2011; Smith et al., 2013; Smith-Sivertsen et al., 2009). There are a handful of studies that have used this information to estimate the economic benefits that improved fuelwood use efficiency can

generate. For example, García-Frapolli et al (2010), using data from Habermehl (2007), account for the number of work hours lost attributable to sickness arising from open cookstoves. The types of sickness include acute respiratory diseases, eye disease and burns that result from the use of open cookstoves. In this scenario, figures from Garcia-Frapolli et al (2010) are used to estimate the number of hours saved due to improved efficiency of household fuelwood use. The hours saved translate into the equivalent of 0.5% of labor value added in the baseline. Given that a large proportion of fuelwood use occurs in rural areas (51% of the population), a conservative approach is taken in this scenario and a 0.125% productivity shock is implemented on rural household labor productivity.

- **Efficiency + zero deforestation:** This simulation imposes the same shock as the efficiency shock together with an upper bound on deforestation; for illustrative purposes, a policy of zero deforestation is imposed. This upper bound is enforced through an endogenous incentive. This scenario represents the joint implementation of the fuel wood strategy, and Guatemala's PROBOSQUE program which provides incentives for reforestation and sustainable forest management.

At the macro level, IEEM as any other CGE model, requires the specification of the equilibrating mechanism for three macroeconomic balances. For the non-baseline scenarios: (i) changes in income tax rates on households clear the government budget which implies that there is no domestic and/or foreign financing beyond baseline values ensuring the budget neutrality of simulations; (ii) the model is savings-driven where private investment is the clearing variable in the savings-investment balance, adjusting to make use of available financing, and; (iii) the real exchange rate equilibrates inflows and outflows of foreign exchange, by influencing export and import quantities implying that the simulations are neutral in terms of changes in net foreign assets. The non-trade related payments of the balance of payments, specifically, transfers and foreign investment follow exogenously imposed paths.

In these simulations, the household expenditure elasticity on components of the energy bundle is an important driver of simulation results. To obtain the best estimate possible, expenditure elasticities for both rural and urban households were estimated with a Tobit model, based on data from the National Living Conditions Survey (INE, 2011). For rural households, expenditure elasticities for electricity, fuelwood and petroleum products were estimated as 0.688, 0.530 and

1.191, respectively while for urban households, these were estimated as 0.813, 0.431 and 1.159, respectively.

4.3. Results and Analysis

First, in the baseline, Table 5 shows households disaggregated by income quintile, their share of fuelwood in their consumption bundle, and the household's share of total household income. For rural households, the lower quintiles have the greatest fuelwood expenditure share while for urban households, the highest income quintile, with over 27% of total household income, spends the least on fuelwood.

Table 5. Household fuelwood consumption.

	Household quintile	Fuelwood expenditure share	Share of total income
Rural	HH q1	13.1	3.3
	HH q2	15.2	4.6
	HH q3	14.1	5.5
	HH q4	13.9	6.8
	HH q5	11.3	10.0
Urban	HH q1	12.4	6.3
	HH q2	9.0	8.8
	HH q3	5.4	11.9
	HH q4	4.0	15.2
	HH q5	1.6	27.7
Total		100.0	100.0

The increase in fuelwood efficiency is introduced as shown in figure 1. The efficiency shock begins in 2016 and increases in intensity following a logistic curve up until 2020 after which it remains constant at 25%. The forest incentive implemented in the model is equivalent to a 15% tax on the forestry activity in 2016, 3.4% in 2020 and 15.5% in 2025. As a percentage of GDP, the incentive is equivalent to 0.17% a significant figure given that forestry value added represents about 0.80% of GDP.

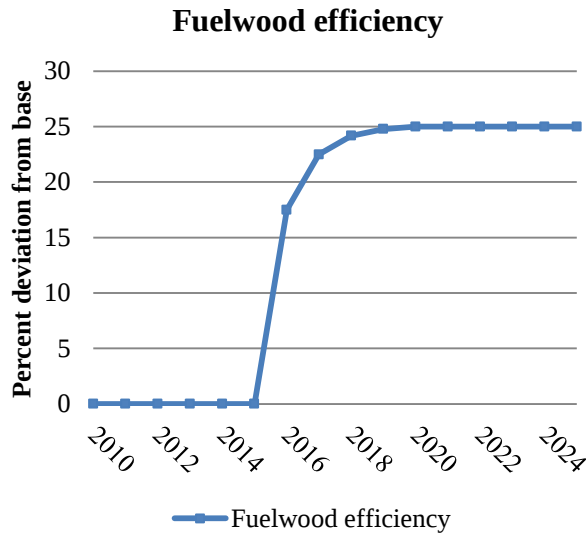


Figure 1. Implementation of fuelwood efficiency shock. Source: Authors' own elaboration.

Figure 2, Panel A, shows household consumption as a proxy for well-being. The improvement in fuelwood efficiency has a positive impact on well-being on the order of around 0.20% with respect to the baseline by 2025. The efficiency + zero deforestation scenario also has a positive impact though to a slightly lesser degree than in the efficiency scenario alone. This less pronounced impact in the efficiency + zero deforestation scenario is driven by a decrease in wages that the upper bound on deforestation brings about, given the decrease in the output of agriculture, a labor-intensive sector. The efficiency + health scenario which accounts for the improved productivity arising from health benefits has the greatest positive impact of the three scenarios equivalent to 0.30% with respect to the baseline in 2025.

In terms of unemployment impacts, there are small differences across scenarios with unemployment slightly lower by 2025 in the efficiency + health scenario compared with efficiency and efficiency + zero deforestation scenarios. Impacts on GDP are positive for the efficiency, efficiency + zero deforestation and the efficiency + health scenario; by 2025, as a percent deviation with respect the baseline they are 0.18%, 0.16% and 0.31%, respectively.

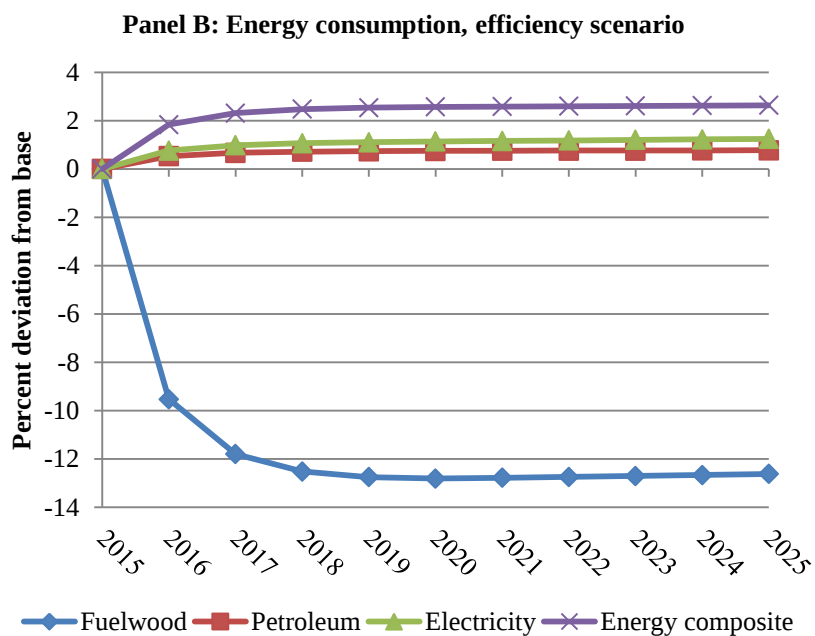
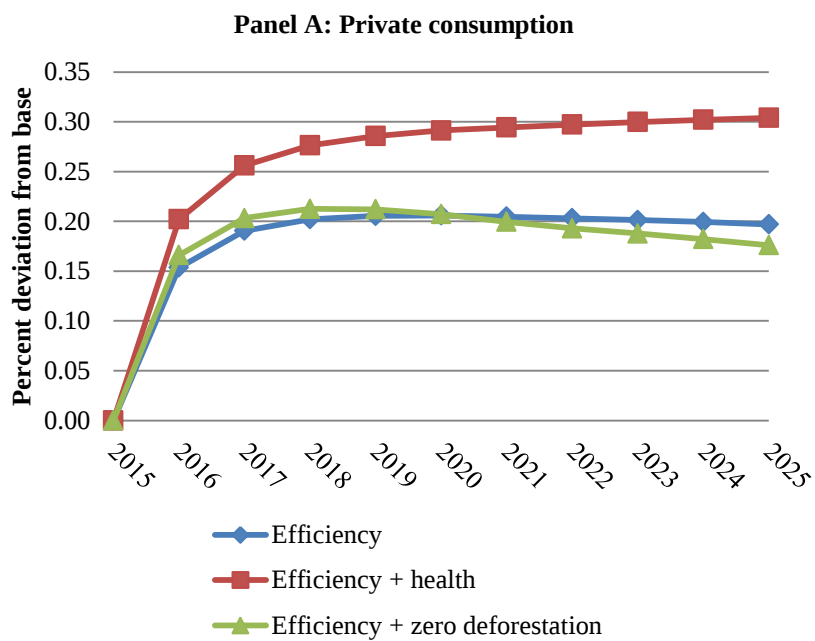


Figure 2. Panel A: Household private consumption. Panel B: Household energy consumption.
Source: Authors' own elaboration.

Figure 2, Panel B, depicts household energy consumption. There is a 12% decline in the value of fuelwood consumption which remains relatively steady after the full implementation of the

shock. This 12% decline is less than the 25% increase in fuelwood use efficiency since in terms of Tera joules of energy from fuelwood used, the increase in efficiency also induces an increase in the number of Tera joules consumed. In a practical sense, this implies that households are changing their behavior in response to increased fuelwood efficiency by one or a combination of the following: consuming more food that is cooked; cooking food longer; allowing food to reach a higher temperature; heating homes to a higher temperature, and/or; heating homes for a longer period of time. There are small increases in the consumption of other forms of energy and a larger positive impact on the overall energy consumption bundle. This effect is driven by the decrease in the cost of the energy bundle as well as an income effect due to the savings on fuelwood consumption arising from the fuelwood efficiency shock.

While not shown here, household fuelwood consumption in the efficiency + zero deforestation scenario is slightly lower than in the efficiency scenario, though the difference is small. Output from the fuelwood sector is still lower in the efficiency + zero deforestation scenario, given the limit imposed on deforestation. Of course, this decrease in fuelwood output is also related to a decrease in the use of non-land factors of production. Impacts on energy consumption in the efficiency + health scenario are very similar in trend and magnitude to those presented in Panel B.

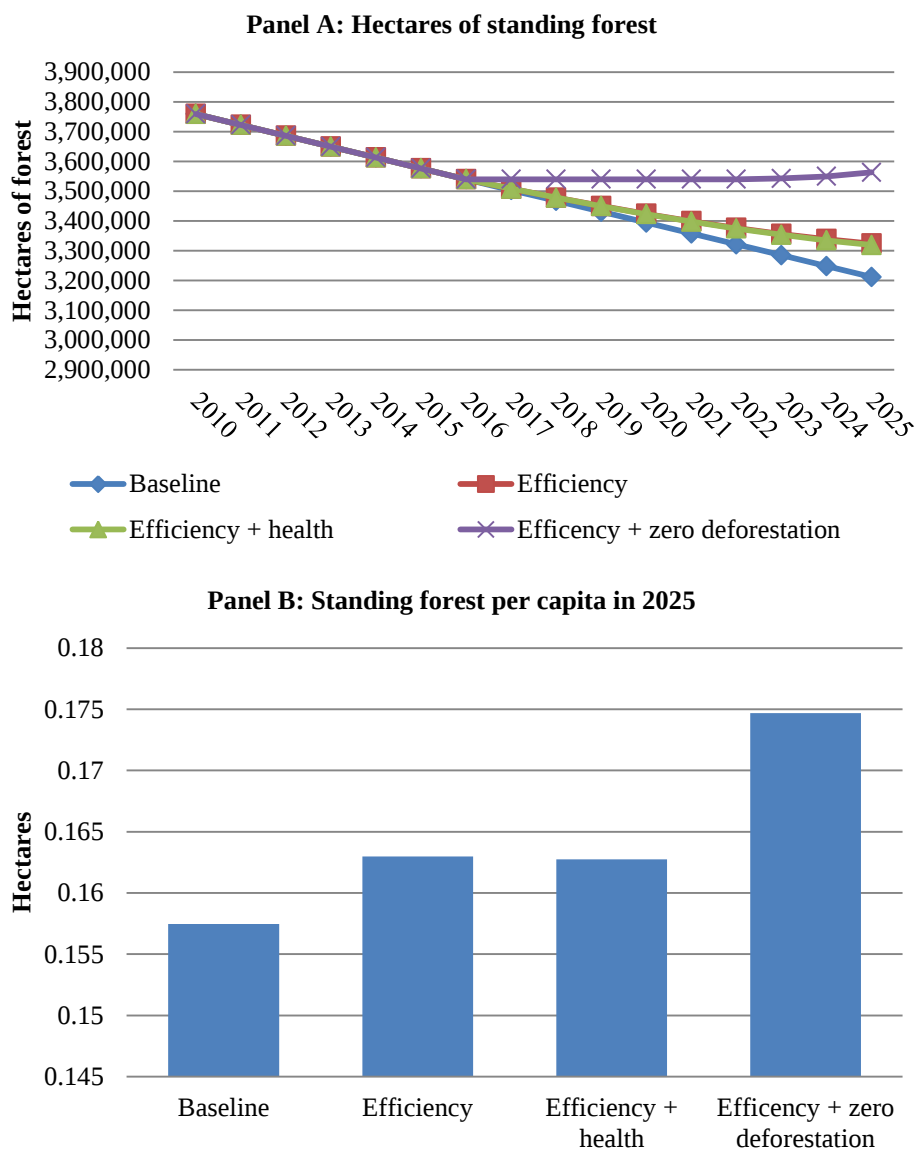


Figure 3. Panel A: Hectares of standing forest. Panel B: Hectares of forest per capita in 2025.

Panel A of figure 3 shows the policy impacts on stocks of forest resources. The baseline represents declining forest stock due to illegal deforestation and logging. In the baseline, over the period of analysis Guatemala loses half a million hectares of forest. The efficiency and efficiency + health scenarios reduce the loss by 100,000 hectares. The efficiency + zero deforestation scenario maintains forest cover at its 2016 level. In terms of standing forest per capita, in 2025 there are 0.157 ha/capita in the baseline, 0.163 ha/capita in both the efficiency and efficiency + health scenarios, and in the efficiency + zero deforestation scenario, forest stock per capita increases to 0.175 ha/capita.

Table 6. Impacts on sectoral output, percent deviation from baseline in 2025. Source: Authors' own elaboration.

Commodity	Base value added	Efficiency	Efficiency + health	Efficiency + zero deforestation
Coffee	5,554	-0.43	-0.17	-1.57
Banana	3,506	-0.66	-0.55	-2.21
Cereals	4,048	0.18	0.28	0.25
Other agriculture	19,728	0.04	0.16	-0.18
Livestock	11,930	0.09	0.19	0.02
Other forestry	2,612	0.81	1.05	-1.47
Fuelwood	1,424	-12.52	-12.48	-12.40
Fishing	882	0.07	0.12	0.15
Mining	7,879	0.05	0.11	0.14
Food prod	66,421	0.15	0.26	0.19
Beverages and tobacco prod	8,160	0.13	0.22	0.20
Textiles and wearing apparel	23,433	0.35	0.54	0.80
Wood and wood prod	2,393	0.13	0.30	0.03
Paper and paper prod	4,613	0.15	0.30	0.32
Refined petroleum prod	178	0.05	0.14	0.17
Chemicals	12,467	0.15	0.30	0.37
Rubber and plastics	6,161	0.10	0.24	0.22
Non-metallic mineral prod	7,228	0.09	0.28	0.15
Basic metals and metal prod	8,050	0.05	0.23	0.19
Machinery and equipment	1,582	0.32	0.56	0.87
Other manufactures	6,425	0.14	0.29	0.15
Recycling	146	0.39	0.66	1.17
Electricity	10,985	0.33	0.45	0.35
Water	2,252	0.09	0.20	0.15
Construction	35,013	0.05	0.26	0.07
Trade	73,909	-0.13	-0.01	-0.20
Hotels and restaurants	20,398	0.20	0.40	0.43
Transport	18,586	-0.09	0.05	-0.08
Other services	169,064	0.06	0.18	0.10

Impacts on sectoral output are shown in Table 6. In the efficiency scenario, other forestry, textiles and electricity sectors show the greatest positive impact while the fuelwood, export-oriented agriculture (i.e., coffee and banana), trade and transport sectors are most negatively impacted. The efficiency + zero deforestation scenario has overall more positive impacts on

sectoral output, with the exception of the fuelwood sector. The impact on the agricultural sector is considerably more negative than in the efficiency scenario, however. Magnitudes of these positive impacts are amplified across sectors in the efficiency + health scenario.

Figure 4, Panel A shows the greenhouse gas emissions captured in the Guatemalan SEEA, namely carbon dioxide, nitrous oxide and methane, and their decline as a result of the efficiency scenario; the efficiency + zero deforestation scenario and efficiency + health scenarios, with similar levels of fuelwood consumption, generate a similar result in terms of emissions. Figure 4, Panel B demonstrates that those households consuming a greater share of fuelwood, particularly the poorer rural households, have the greatest change in their emissions profile and therefore benefit the most from the fuelwood strategy in terms of savings and the potential health benefits.

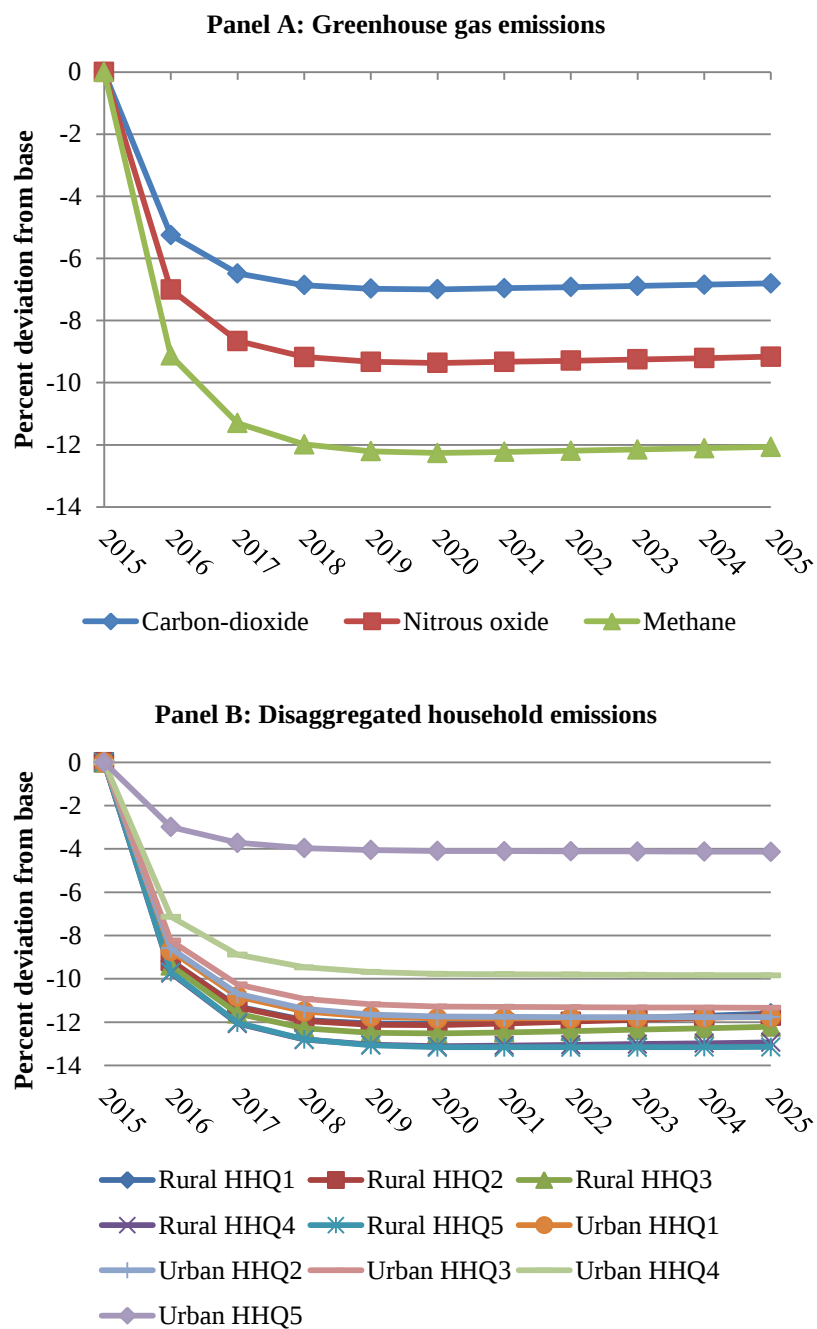


Figure 4. Panel A: Greenhouse gas emissions. Panel B: Disaggregated household emissions.
Source: Authors' own elaboration.

Figure 5 shows baseline levels of emissions, showing that the electricity sector and food processing sectors are the greatest emitters of greenhouse gases, followed by non-metallic mineral production and transportation services.

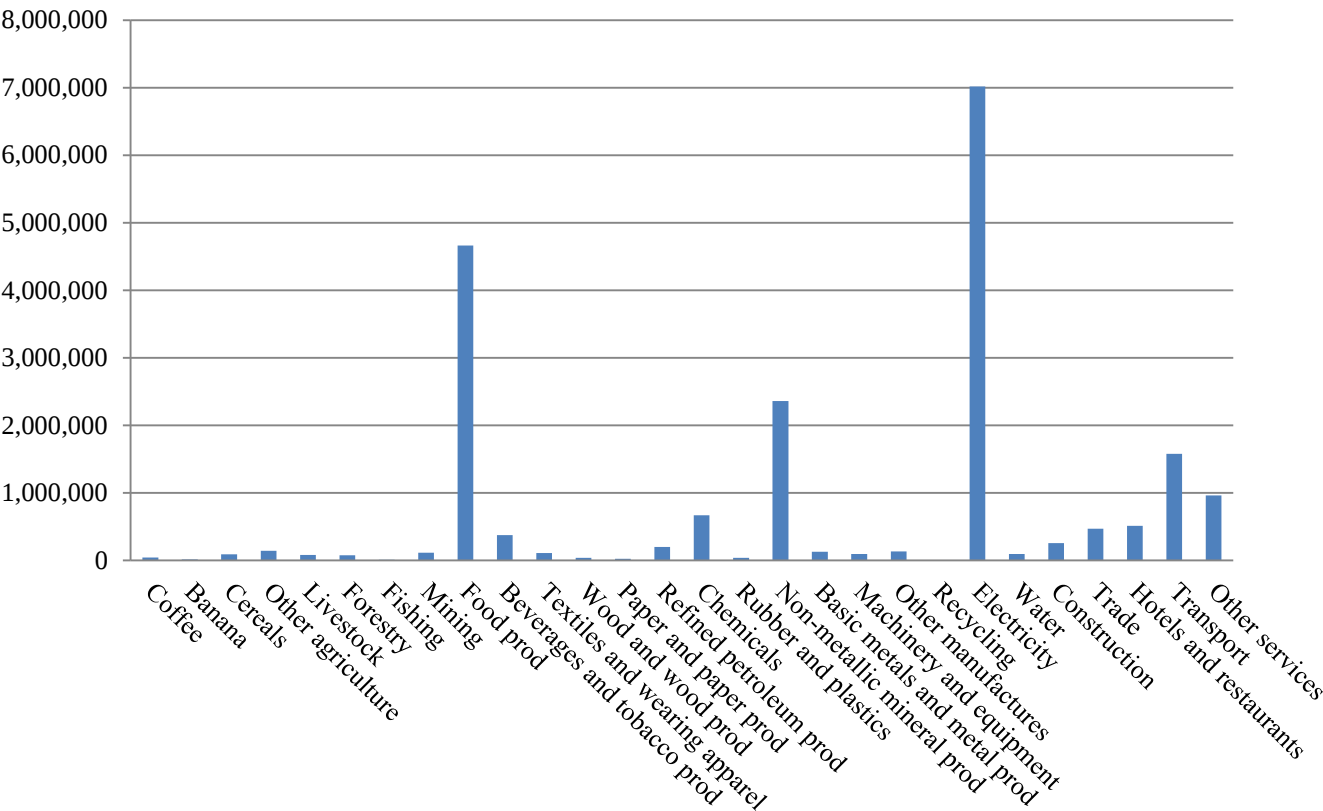


Figure 5. Baseline emissions. Source: Authors’ own elaboration.

Figure 6 shows the multidimensional impacts of the efficiency scenario. The figure shows a decline in agricultural land use with a concomitant increase in the stock of forestland as deforestation is slowed as a result of the fuelwood strategy. Forestry output declines as would be expected, as fuelwood prices fall. Water use remains similar to baseline consumption despite the small decline in agricultural output. Total greenhouse gas emissions fall as a result of the improvements in efficiency.

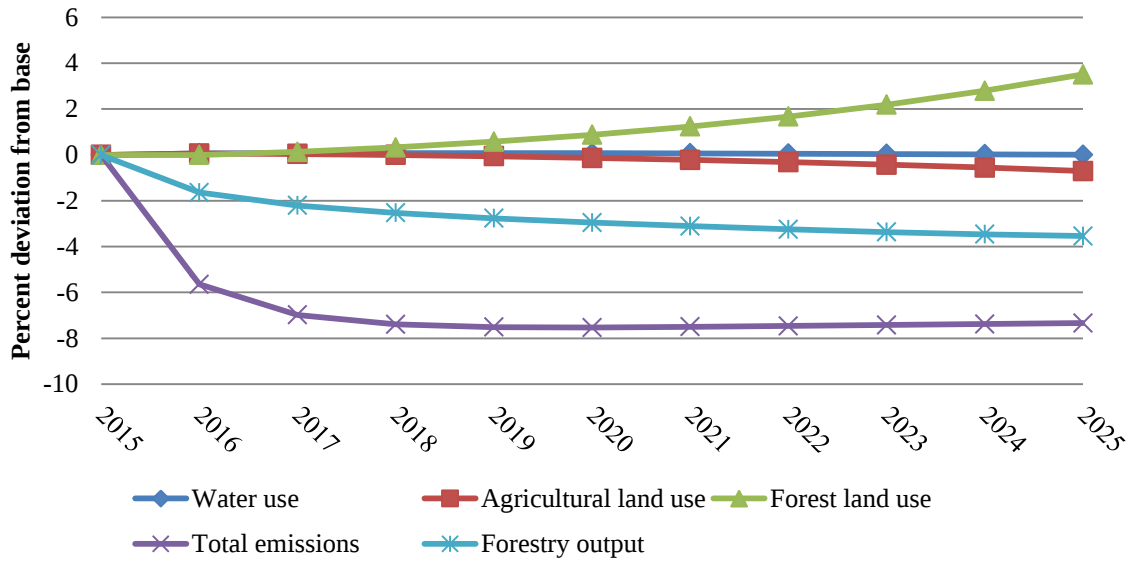


Figure 6. Multiple impacts of household fuelwood efficiency shock. Source: Authors' own elaboration.

A key indicator generated by IEEM that reflects policy impacts on wealth and the national balance sheet is genuine savings. Genuine savings is national savings adjusted for depletion of the underlying environmental resource base and pollution damages, with the addition of expenditure on education as a proxy for investment in human capital (UN et al., 2005). What follows is the estimation of a variation of genuine savings which emphasizes IEEM's environmental dimension, without the estimation of investment in education.

Depreciation is the reduction in the value of an asset through time due to wear and tear. Depreciation of the stock of forests is calculated using IEEM results as the product of the annual volume of deforestation and the output price of logs in that year. Similarly, depreciation of mining stocks is calculated using IEEM results as the product of the annual volume of mineral extraction and the output price. Emissions damages are calculated based on IEEM results as the product of annual greenhouse gas emission and the value used by the World Bank in its estimation of adjusted net savings which is equal to US\$20/ton of carbon dioxide equivalent (World Bank, 2011). Adjusted genuine savings is therefore calculated as Gross National Savings less forest depreciation, mineral depreciation and the cost of emissions.

Figure 7, Panel A shows the scenario impacts on genuine savings until 2025. In the efficiency and efficiency + health scenario, there is a steady increase in genuine savings following

implementation of the fuelwood strategy, with health impacts resulting in greater savings than the efficiency scenario alone. The efficiency + zero deforestation scenario has the most wealth enhancing impact. Once both fuelwood and zero deforestation strategies are implemented, there is a sudden increase in adjusted genuine savings which is greater than the efficiency + health scenario as a result of the full detention of deforestation. While always above baseline levels, the increased savings slowly falls to USD76 million in 2022 from its peak of USD130 million following implementation of the strategies. After 2022, savings begins to rise again. This trend is explained by the sudden increase in forest stock following implementation of the zero deforestation strategy. The small decline between 2016 and 2022 and then the stabilization that follows are explained by movement toward equilibrium between the natural rate of forest growth and the legal forest harvest.

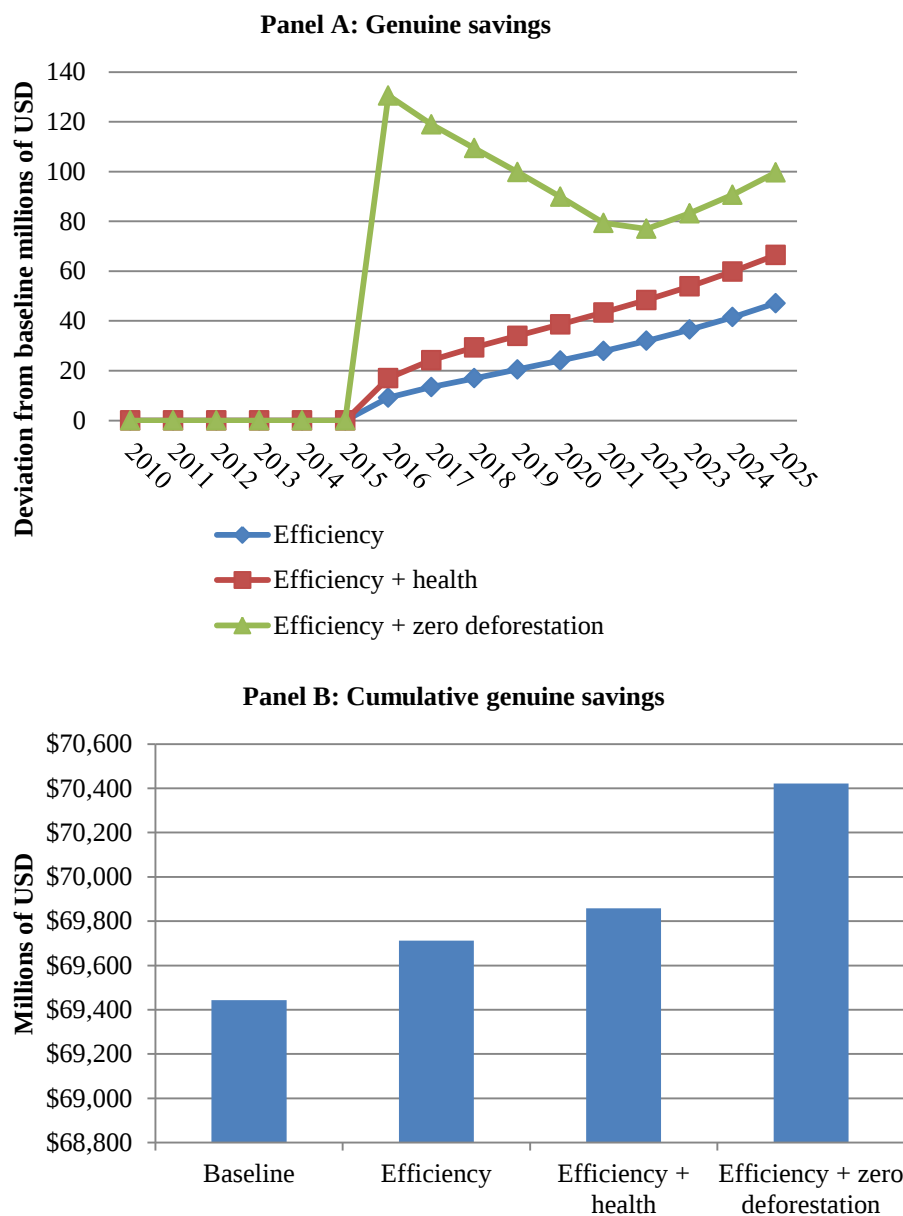


Figure 7. Panel A: Scenario impacts on genuine savings until 2025. Panel B: Cumulative impact on genuine savings in 2025, real 2010 USD. Source: Authors' own elaboration.

Panel B of figure 7 shows cumulative genuine savings in 2025 with the efficiency + zero deforestation scenario generating an additional USD978 million in savings above baseline business as usual levels.

5. Concluding Remarks and the Way Forward

This paper develops the IEEM platform which enables the analysis of policy impacts on the economy and the environment in a quantitative, comprehensive and consistent framework. With the SEEA database underlying, IEEM, explicitly considers how economic activities critically depend on the environment both as a source of inputs and as a sink. While most previous economy-wide analysis of environmental issues has tended toward the study of one environmental issue in isolation, the SEEA underpinnings of the platform provides a more robust representation of the environment, facilitating the detection of unexpected impacts. The ability to track impacts on stocks of some environmental resources and land use, as well as environmental inputs and outputs in physical units are all new features that comprise IEEM. IEEM complements the comprehensive data of the SEEA with modeling approaches that are not found in standard CGE models, such as the customized production functions for individual natural resource sectors.

To illustrate the analytical capabilities of IEEM, the model is calibrated based on Guatemala's SEEA and used to examine the country's fuelwood strategy coupled with PROBOSQUE, one of the largest forest incentive programs in the Latin American and Caribbean region. Implementation of the strategy results in a reduction in fuelwood consumption and emissions, though a small increase overall in household consumption of the energy bundle. With a reduction in fuelwood production and consumption, there is a decrease in deforestation. This shift, while resulting in decreased export-oriented agricultural production, also tends to increase water consumption and emissions from the expanding sectors. Overall, the effect is positive with increased household income and consumption contributing to enhanced well-being.

Coupling of the fuelwood strategy with Guatemala's forestry incentive program, the combined effect is generally in the same direction, though of a lesser magnitude. When the impact of reduced household emissions on household labor productivity is taken into account, the positive impacts on household well-being are amplified. The primary channel of impact is the increase in household income which generally results in greater consumption of most goods and services. This greater consumption of course has implications for rates of consumption of environmental resources as well as levels of emissions and effluents returning to the economy.

Prior to development and implementation of the SEEA, national accounting focused on national income flows. The SEEA now makes it possible for countries to report on the status of the

national balance sheet. In the illustration of Guatemala's fuelwood and forest incentive policies, analysis with IEEM shows generally positive environmental impacts in terms of a reduction in fuelwood use, deforestation and harmful greenhouse gas emissions. The reduction in greenhouse gas emissions in turn has positive health impacts, particularly on rural poor households which induces improvements in labor productivity and higher income. For the first time in an ex-ante economic analytical framework, IEEM estimates the impact of these policies in terms of national wealth in the form of genuine savings. From this perspective both the fuelwood strategy and fuelwood incentive policy enhance Guatemala's underlying wealth and thus prospects for future economic growth.

In ecosystem services terminology, the SEEA extends the production boundary of the SNA to include ecosystem provisioning services for which there may be no owner and there is no market transaction. In the Guatemalan SEEA, for example, water used for irrigation is not subject to a market transaction, though it is accounted for in the SEEA. We view the next step in advancing IEEM is in the accounting for regulating and cultural and aesthetic services, such as sediment control and recreational values, respectively. While part of the challenge lies in how these services may be valued and structured for use in an economy-wide model, a greater challenge is in how to accurately represent the biophysical processes that underpin the supply of these other services. This is a ripe area for future research that is contemplated in advancing the IEEM framework to account for how ecosystems are critical in underpinning national wealth and well-being, and future prospects for economic development.

Acknowledgements

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