Environ Resource Econ (2019) 72:539–558
https://doi.org/10.1007/s10640-017-0205-9

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

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Accepted: 18 December 2017 / Published online: 29 December 2017

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 a powerful dynamic economy-wide modelling approach. 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 their outputs. In addition to standard economic impact indicators such as gross domestic product, income and employment, IEEM generates indicators that describe policy impacts on the use of environmental resources, wealth and environmental quality which together determine prospects for future economic growth and well-being. To illustrate the analytical capabilities of IEEM, the model is calibrated with Guatemala's

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10640-017-0205-9) contains supplementary material, which is available to authorized users.

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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 · Evidence-based policy design · System of environmental-economic accounting · Dynamic computable general equilibrium model · System of national accounting · Economic and environmental indicators · 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 strength of this approach is significantly enhanced. This paper builds on and operationalizes Banerjee et al's (2016a; 2016b) conceptual framework for integrating data organized under the SEEA into a dynamic CGE modelling framework to produce the integrated economic-environmental modelling (IEEM) Platform[1]. The IEEM Platform is an evidence-based policy and investment decision making framework which enables the analysis of policy impacts on the economy and the environment in a quantitative, comprehensive and consistent framework (Banerjee et al. 2016b).

There are three main features that distinguish the IEEM Platform from other economy-wide analytical frameworks. First, IEEM integrates data derived from the System of National Accounts, the core source of data for a CGE model, with the environmental accounts organized under the SEEA. This feature alone carries with it numerous advantages. With the SEEA and the System of National Accounting data underpinning IEEM, the Platform 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.

While there is a cost involved in implementing the SEEA and IEEM, once in place they can support analysis across sectors and policy issues. In terms of evidence-based policy design, the cost of developing an IEEM Platform based on the SEEA are much lower than if data collection were required to construct the underlying database on an application-specific basis, as is often the case with cost benefit analysis. With lower start-up costs of analysis and IEEM's applicability across economic and environmental policy issues, IEEM can generate more timely evidence-based policy advice which is a critical demand from policy and decision makers. The quality, consistency and compatibility of data organized under the SEEA with economy-wide frameworks is also a significant advantage which reduces the need for strong assumptions in reconciling environmental and economic data. Finally, with an increasing number of countries implementing the SEEA, cross-country and temporal analysis will soon become possible.

The second main feature that distinguishes the IEEM Platform from other economy-wide frameworks relates to the indicators it generates. For the first time in a forward-looking general equilibrium framework, IEEM captures how policies can affect current and future national wealth and economic growth. Wealth may be understood as the aggregate value of

[1] See Banerjee et al. (2016a, 2016b) for a review of the literature on previous efforts to integrate environmental data into an economy-wide framework, and the advantages of SEEA for economy-wide modelling.

manufactured capital, natural capital, and human and social capital. Indicators of wealth such as the inclusive wealth index measure changes to current and future well-being and are indicative of the sustainability of the development trajectory of an economy and society (Polasky et al. 2015; Stiglitz et al. 2010). 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, accounting for changes in stocks of environmental resources, which when integrated into IEEM, enables forward looking assessment of the impacts of public policies, investments and exogenous shocks on wealth.

Also related to indicators, the language of IEEM and the indicators it generates are fundamentally economic in nature. Decision makers in Central Banks, Ministries of Finance and other government institutions responsible for national budget allocations, are concerned with indicators that speak to impacts on employment, regional product, income, consumption and savings. All of these indicators are reported when undertaking policy analysis with the IEEM Platform.

The third main distinguishing feature of IEEM is its treatment of the environmental resources represented in the SEEA. Environmental resource-related sectors behave differently from traditional sectors such as the manufacturing and service sectors. For example, forests grow over time and can be harvested, degraded, or cleared to produce new agricultural land. As another example, the stocks of mining resources vary through time with extractions through mining activities and additions through new discoveries. The effective availability of mining resources for extraction depends to a degree on costs of extraction which are temporally dynamic as technology and demand vary. There is a well-established environmental economics literature that describes these dynamics and how they may be modelled.

The IEEM Platform contains environmental modelling modules to capture these environmental resource-specific dynamics for each environmental resource represented in the SEEA. This feature provides a more realistic representation of economy-environment interactions. It also enables the application of the IEEM Platform across various economic and environmental issues where in the past it would be necessary to develop a specific model for each environmental issue explored, and costly to collect the data required to calibrate the model (Banerjee et al. 2016a, 2016b).

This paper describes the development and operationalization of the IEEM Platform. To illustrate the analytical capabilities of IEEM, Guatemala's SEEA is used to calibrate an IEEM for Guatemala (IEEM-GUA) which is then applied to the analysis of 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, an overview of the SEEA and the IEEM database development process is provided. Next, the environmental modelling modules are described. Section 4 describes the application of the IEEM Platform to Guatemala's fuelwood and forestry sector, followed by results and analysis. Section 5 concludes the paper with the key findings of the application and a discussion of the frontier of integrated economic-environmental modelling for evidence-based policy analysis.

2 The System of Environmental Economic Accounts and the IEEM Database

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's adoption of the SEEA Central Framework as the first international standard for environmental-economic accounting (Obst and Eigengraam 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 all environmental resources, the production boundary must be expanded to account for environmental processes that do not have a defined owner or exchange value. 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)[2]. In the context of Guatemala, one provisioning ecosystem service that is not accounted for in the SNA but is represented in the SEEA is water provisioning services used for irrigated agriculture. Guatemala's SEEA records the supply and use of irrigation water in physical units. Since irrigation water does not have an exchange value in Guatemala, it is not recorded in monetary units in the country's SEEA.

Another advantage of the SEEA is that it encourages the recording of the production and use of all goods and services in physical and monetary units (where possible), on own account within enterprises. This feature implies that the supply and use of all environmental resources by economic units are recorded, including those environmental resources which do not have an exchange value. For example, bagasse is an input in the sugar milling industry's energy production process. The bagasse used in the process, while it does not have an exchange value, is accounted for in the SEEA supply and use tables, where it is recorded in physical units.

Thus, the SEEA makes it possible to track environmental 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 environmental resource stocks. The recording of data in both physical and monetary units is a particularly useful for IEEM and is an important way in which indicators estimated to capture semi-inclusive wealth can be supplemented with biophysical indicators (Stiglitz et al. 2010). Banerjee et al. (2016a, 2016b) describe the main elements of the SEEA, focusing on those relevant for IEEM and integrated economic-environmental modelling.

[2] The concept of ecosystem services is relevant for IEEM since while the IEEM Platform operationalized here integrates data on provisioning ecosystem services, one of the goals of the IEEM project is to move beyond provisioning services to represent regulating and maintenance services such as climate regulation and erosion mitigation, as well as cultural ecosystem services. This frontier area is discussed in the concluding remarks section.

Based on the SEEA, the first step toward developing the database that underpins IEEM is the production of an Environmentally Extended Supply and Use Table (hereafter EESUT). From Guatemala's SEEA, a single consistent framework was constructed that extends the monetary supply and use tables (SUT) of the SNA with extensions to incorporate a column for the environment, and rows for environmental inputs and residuals as proposed by the SEEA. The procedures for constructing the EESUT and its basic structure are presented in Appendix A (available online).

Once an EESUT has been developed, the next step in constructing the IEEM database is to construct a social accounting matrix (SAM) for the country in question. A SAM is a matrix representation of the interrelationships existent in an economy at the level of individual economic 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 a CGE model and is constructed based on the SNA SUTs, integrated economic accounts, balance of payments accounts, government accounts data and other ancillary data sources. Detailed descriptions of a SAM and its key features may be found in the literature, see for example: Breisinger et al. (2009), King (1985) and Round (2003). Appendix B provides detail on the construction of the SAM for Guatemala. Appendix C demonstrates the integration of data derived from the EESUT with the SAM to produce the final Environmentally Extended SAM (Appendix B and C are available online).

3 The IEEM Platform

IEEM takes a dynamic CGE modelling framework as its starting point and integrates environmental resource-specific modules whose design follows the IEEM conceptual framework developed in Banerjee et al. (2016a, 2016b). The SEEA was formulated to enable flexible and modular implementation according to implementing country priorities. Similarly, the IEEM Platform was developed with a modular structure such that the environmental modules, namely the forest and deforestation, land, water, energy and emissions, mineral resources, aquatic/fisheries resources, waste and residuals modules may be switched on or off depending on whether or not SEEA data are available for the country in question. In the case of the IEEM-GUA Platform, all environmental modules are included.

In the forestry and deforestation module, IEEM tracks forest commodity flows in physical units, at commodity-specific, observed unit values. In this module, 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 combine labor and capital factors, while a fixed coefficient, Leontief assumption is used for the logged land area. In turn, also under the Leontief assumption, intermediate inputs are specified as exogenous quantities per unit of the activity.

The forestry and deforestation module accounts for the natural growth rate of the forest resource. Deforestation occurs when the rate of timber extraction is higher than the growth rate of the forest resources. For the purposes of policy simulations, the forestry and deforestation module enables that an upper bound for deforestation be set to simulate the imposition of a mechanism to regulate deforestation and land conversion.

In the land module, the treatment of agricultural land is similar to that of other factors.[3] The demand for land is derived from the first order conditions of the cost minimization optimization problem solved by the representative firm in each activity that uses land. In terms of land supply, total land supply may be fixed or demand driven with an upward sloping supply curve. The land module enables the option of modeling land use incentive policies through imposing a lower bound on the area of land used by a given economic activity.

The water module models unregistered water used in agricultural activities; unregistered water is water not supplied by the water utility company.[4] In the case of Guatemala, given the available information in Guatemala's SEEA, it is assumed that water supply is initially larger than water demand and the price of unregistered water is zero. If water demand increases in a non-baseline or policy simulation, the price of unregistered water becomes positive, generating a cost for producers and an income for the owners of the resource. In the model calibration, it is assumed that water income is allocated across households in proportion to their ownership share of land.

The energy and emissions module is structured to include any number of types of emissions generated through production processes and emissions generated by final users of goods and services, such as households. In the Guatemalan SEEA, carbon dioxide, nitrous oxide and methane are accounted for, all in CO_2 equivalent tons. For the purposes of policy simulations, the energy and emissions module enables the imposition of exogenous changes in the emissions coefficients that could be brought about by technological improvements in production processes that reduce the level of emissions per unit of output. IEEM also enables limits to be imposed on the level of emissions. To that end, an endogenous emissions tax such as a carbon tax may be introduced, while emissions may be capped at a user-specified level.

In the case of the mining resource module, 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). This resource dynamic is captured by expanding the definition of total factor productivity as it relates to the productivity of mineral resource extraction. The stock of mineral resources is updated each period, based on the stock remaining from the previous period, extraction, and new recoverable mineral discoveries. In this formulation, where new discoveries do not make up for extraction, the total factor productivity in mining activities decreases over time as the stock of minerals is depleted. This declining total factor productivity increases the marginal cost of extraction and lowers the productivity of the mining sector as mineral stocks become depleted.

An economy-wide approach has not been widely applied to exploring fisheries policies, though it has been shown that there is significant potential for extending a standard CGE framework to take into account fish population and management dynamics (Banerjee et al. 2016a, 2016b). The approach developed in the fisheries module follows guidance from the literature related to the integrated ecosystem-based management of fisheries, which considers the entire ecosystem, including human-ecosystem interactions (Pikitch et al. 2004). An

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

[4] In its full version, IEEM can include 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.

extension to this approach involves incorporating a biological systems module to represent the processes that affect fisheries' productivity.

In the IEEM fisheries module, the resource stock is a function of the quantity of fish harvested, the intrinsic growth rate of the fish population and the carrying capacity of the environment. The module includes a catch-per-unit-effort production function which assumes that catch per-unit-effort is proportional to the existing stock (Conrad 2010). Typically, partial equilibrium fisheries models use effort as the single human factor of production. The IEEM Platform, as an economy-wide framework, expands on this specification and considers both capital and labor at the same time that the fisheries sector interacts with other sectors and competes for factors of production. In contrast to conventional partial equilibrium formulations, IEEM captures the economy-wide effects of stock variation. For policy simulation purposes, the fisheries module enables simulation of maximum sustainable yield assumptions as well as simulations related to fishing quotas which are operationalized through upper bounds for allowable volumes of fish catch in a given year.

In the waste and residuals module, the Guatemalan SEEA provides information in physical units on the supply and use of residuals such as hospital waste, paper waste, glass waste and rubber waste, among others. Users and suppliers of this waste and residuals are economic activities, households, and the rest of the world. The waste and residuals module tracks the supply and use of these residuals.

Appendix D (available online) provides considerable detail on each of the environmental modules described above including their mathematical formulation. IEEM is currently programmed in the General Algebraic Modelling System (GAMS 2013) and GEMPACK (Harrison and Pearson 1996). To demonstrate the analytical capabilities of IEEM, the sections that follow apply IEEM-GUA to the issue of fuelwood and forestry in Guatemala.

4 An Illustrative Application of IEEM-GUA to Forestry and Fuelwood in Guatemala

Over two million (67%) households in Guatemala, use fuelwood as a primary source of energy while fuelwood constitutes 57% of the country's overall energy use. Fuelwood is primarily used in stoves for cooking food and heating homes, and also serves important cultural functions (Banco de Guatemala & IARNA-URL 2009; Bielecki and Wingenbach 2014; INAB 2015).

Population growth and the expansion of Guatemala's agricultural frontier are in part responsible for forest degradation, deforestation and fuelwood scarcity where there is a national fuelwood deficit of over 10 million m^3 (INAB, IARNA-URL, & FAO 2012). Fuelwood collection is often the responsibility of women and children which as the resource becomes scarcer, takes an increasing share of their time from other important activities such as education. The use of open cook stoves is well known to have detrimental health impacts, increasing the probability of household members' contraction of respiratory illness by 31% (SEGEPLAN 2010), the premature death of over 5000 people per year, and productivity losses of around 1% of Gross Domestic Product (Global Alliance for Clean Cookstoves 2014).

To address this critical issue, more efficient use of fuelwood is one of the core 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 Fuelwood Strategy sets out to establish 48,000 ha of forest plantations to produce 1.2 million m^3 of fuelwood/per year and promote efficient fuelwood use through technical and financial support for the use of efficient fuelwood cook stoves. The strategy aims to reduce the fuelwood deficit by 25% and benefit over 200,000 or 13% of the households that currently use open cook stoves.

The IEEM-GUA Platform is applied to explore the economic, environmental and social impacts of implementation of Guatemala's fuelwood strategy, and the parallel policy PROBOSQUE. PROBOSQUE provides incentives for both reforestation and sustainable forest management and is one of the largest forest incentive programs in the Latin American and Caribbean region. In addition to these being critical policy issues for the Guatemalan Government, the IEEM Platform was applied to these issues to demonstrate the analytical power of IEEM in highlighting the multiple dimensions and trade-offs inherent in economic-environmental interactions.

IEEM's ability to track land use and forest resources will capture how the fuelwood strategy affects forest stocks. The creation of forestry and agroforestry plantations, and the fabrication and adoption of more efficient cook stoves 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 sources of ecosystem services. Reduction in the effort required to collect fuelwood and more efficient fuelwood use in the home will have both productivity and health impacts, freeing up time for household members to pursue 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 analysis with the IEEM Platform.

4.1 Scenario Design

Three scenarios were developed to explore the impacts of Guatemala's fuelwood and forest incentive strategies. All three scenarios are compared to the baseline forecast. Most results are described as the percent difference with respect to the baseline scenario. The period of analysis in this study is from 2016 to 2025. Following the description of the baseline forecast, the three scenarios are described.

Baseline The baseline or reference scenario is the "business-as-usual" scenario. This first simulation is designed to replicate observed trends during 2010–2015 at the macro and sectoral levels. The year 2010 is the base year for the data that underpins IEEM-GUA. From 2016 on, this baseline forecast assumes that past trends will continue from 2016 to 2025. In the simulations that follow, all shocks are introduced beginning in 2016.

Efficiency The efficiency simulation imposes a 25% increase in household fuelwood consumption efficiency following a logistic implementation pathway from 2016 to 2020. This scenario simulates the introduction of more efficient fuelwood household cooking technology, such as the Patsari cookstove.[5]

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 (Ahmed et al. 2005; Duflo et al. 2008; Jagger and Shively 2014; Lambe and Ochieng 2015; McCracken and Smith 1998; Smith et al. 2011, 2013; Smith-Sivertsen et al. 2009). Some studies have used this information to estimate the economic benefits that improved fuelwood use efficiency can generate. For example, García-Frapolli et al. (2010),

[5] See for example: http://www.appropedia.org/Patsari_Cookstove.

using data from Habermehl (2007), account for the number of work hours lost attributable to sickness arising from open cook stoves.

In this scenario, figures from García-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 + Health The efficiency + health simulation links increased household fuelwood efficiency with improvements in household health which in turn have implications for the productivity of the members of rural households.

Efficiency + Zero Deforestation This simulation imposes the same shock as the efficiency shock together with the restriction of zero deforestation. This constraint is enforced through an endogenous incentive. This scenario represents the joint implementation of the fuel wood strategy, and the PROBOSQUE program. In this scenario, forest incentives in IEEM are implemented as a tax on the forest management sector. Revenues from this tax are then transferred to the owners of capital used by the forest management sector, thus generating incentive for reducing levels of deforestation. The rate applied to the sector is 15.3% in 2016, 3.7% in 2020, and 1.2% in 2021. This declining rate is due to the observation that increased fuelwood efficiency over time reduces the extent to which an incentive is required to deter deforestation.

At the macro level, IEEM as with other CGE models, 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 most robust 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.

4.2 Results and Analysis

First, to provide a picture of baseline household fuelwood consumption, Table 1 shows: households disaggregated by income quintile; each household income quintile's share of fuelwood in their consumption bundle, and; the share of total income that each household income quintile spends on fuelwood. For rural households, the lower quintiles have the greatest fuelwood expenditure share while urban households in the highest income quintile with over 27% of total household income, spend the least on fuelwood.

Table 1 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

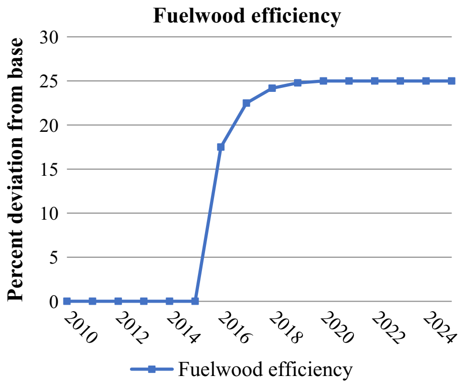

Fig. 1 Implementation of fuelwood efficiency shock
Source: Authors' own elaboration

The increase in fuelwood efficiency is introduced as shown in Fig. 1. The efficiency shock begins in 2016 and increases in intensity following a logistic functional form up until 2020 after which it remains constant at 25%.

Figure 2, Panel A, shows private consumption as a proxy for household well-being. The improvement in fuelwood efficiency has a positive impact on well-being on the order of 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 due to the decrease in wages that the upper bound on deforestation brings about, given the decrease in agricultural output which is 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 gross domestic product

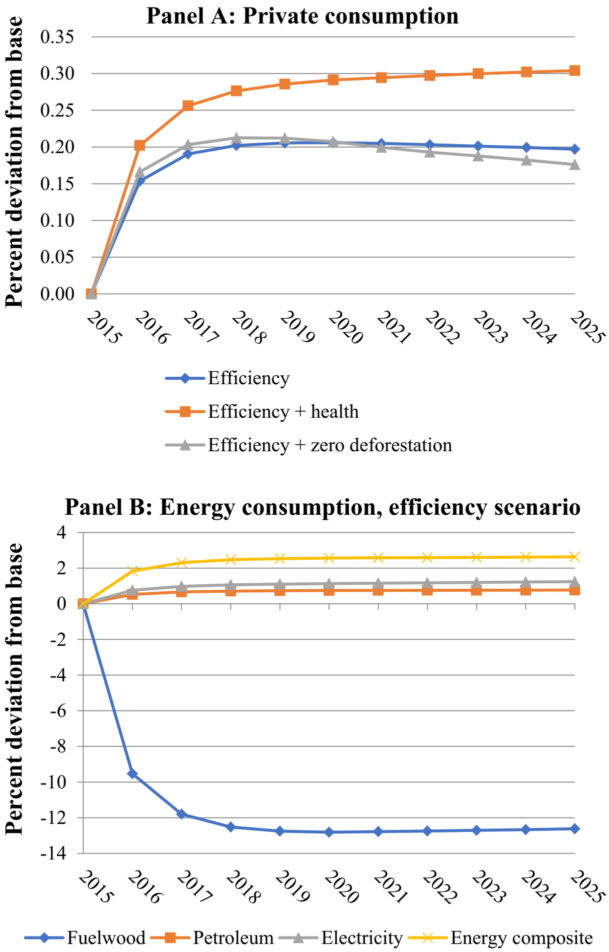

Fig. 2 Panel A: Household private consumption. Panel B: Household energy consumption *Source*: Authors' own elaboration

are positive for the efficiency (0.18% as a percent deviation from the baseline by 2025), efficiency + zero deforestation (0.16%) and the efficiency + health scenario (0.31%).

Figure 2, Panel B, depicts household energy consumption for the efficiency scenario and shows 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 of fuelwood used, the increase in efficiency also induces an increase in the number of Tera joules consumed. 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 increase in disposable income attributed to savings on fuelwood consumption.

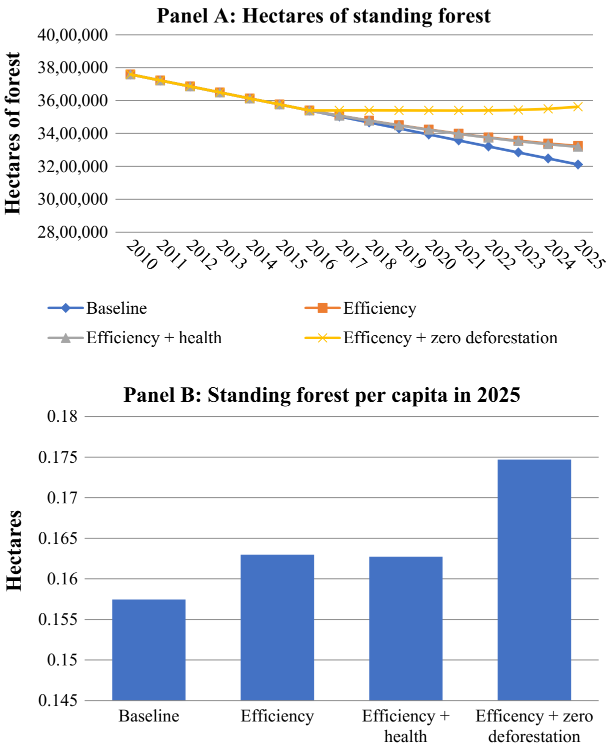

Fig. 3 Panel A: Hectares of standing forest. Panel B: Hectares of forest per capita in 2025

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

Panel A of Fig. 3 shows the policy impacts on stocks of forest resources. In the baseline, by 2025, Guatemala loses half of its standing forests due to logging and deforestation. The efficiency and efficiency + health scenarios reduce the loss by 100,000 hectares, while 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 and 0.163 ha/capita in both the efficiency and efficiency + health scenarios. In the efficiency + zero deforestation scenario, forest stock per capita increases to 0.175 ha/capita.

Impacts on sectoral output are shown in Table 2. In the efficiency scenario, the greatest positive impacts are experienced by the forestry, textiles and electricity sectors while those impacted most negatively are the fuelwood, trade and transport, and export-oriented agricultural sectors such as coffee and banana. The efficiency + zero deforestation scenario has overall greater positive impacts on sectoral output, except for the fuelwood sector. The negative impact on the agricultural sector is considerably greater than in the efficiency scenario, however. In the efficiency + health scenario, the magnitude of the positive impacts is amplified across sectors.

Table 2 Impacts on sectoral output, percent deviation from baseline in 2025 *Source*: Authors' own elaboration

Commodity	Base value added (millions of Quetzales)	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

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 outcome in terms of emissions. Figure 4, Panel B demonstrates that those households consuming a greater share of fuelwood, particularly the poorer rural households, experience the greatest shift in their emissions profile and therefore benefit the most from the fuelwood strategy in terms of income savings and health benefits.

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.

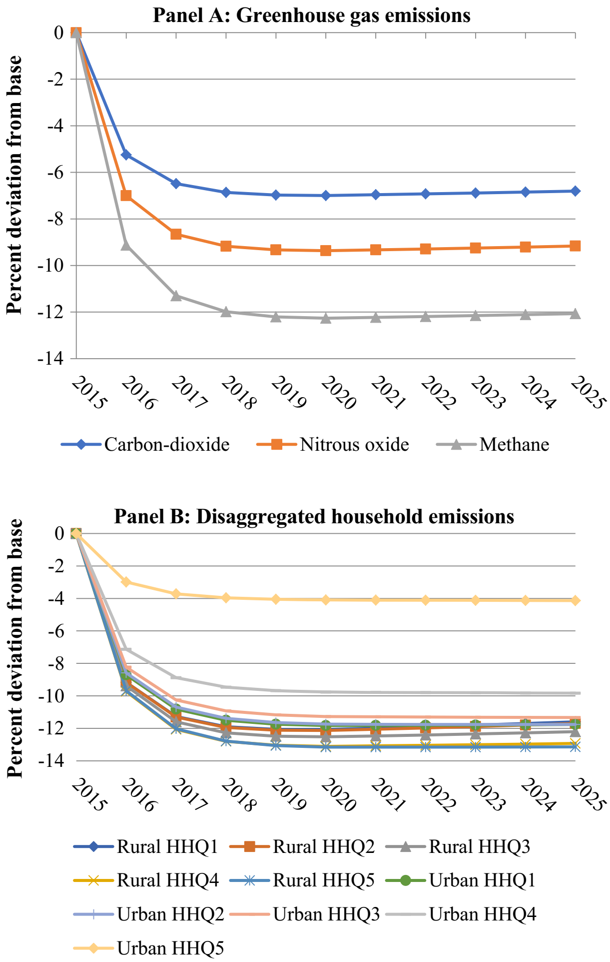

Fig. 4 Panel A: Greenhouse gas emissions. Panel B: Disaggregated household emissions *Source*: Authors' own elaboration

Figure 6 shows some of the multidimensional impacts of the efficiency scenario. The figure shows a decline in agricultural land use with an increase in forest land use as the pace of deforestation slows with the implementation of the fuelwood strategy. Forest product output declines as fuelwood prices fall. Water use remains similar to baseline consumption levels despite the small reduction in agricultural output. Total greenhouse gas emissions falls as a result of the improvements in fuelwood use efficiency.

Genuine savings reflects policy impacts on national wealth and the national balance sheet. Specifically, it is a measure of the true level of savings of a country and takes into account the depreciation of produced capital, investment in human capital, the reduction in stocks of minerals, energy and forests, and damages from air pollution (World Bank 2005; United Nations et al. 2005; Arrow et al. 2004, 2012). IEEM generates an estimation of adjusted genuine savings which emphasizes IEEM's environmental dimension, without the consideration of investment in human capital.

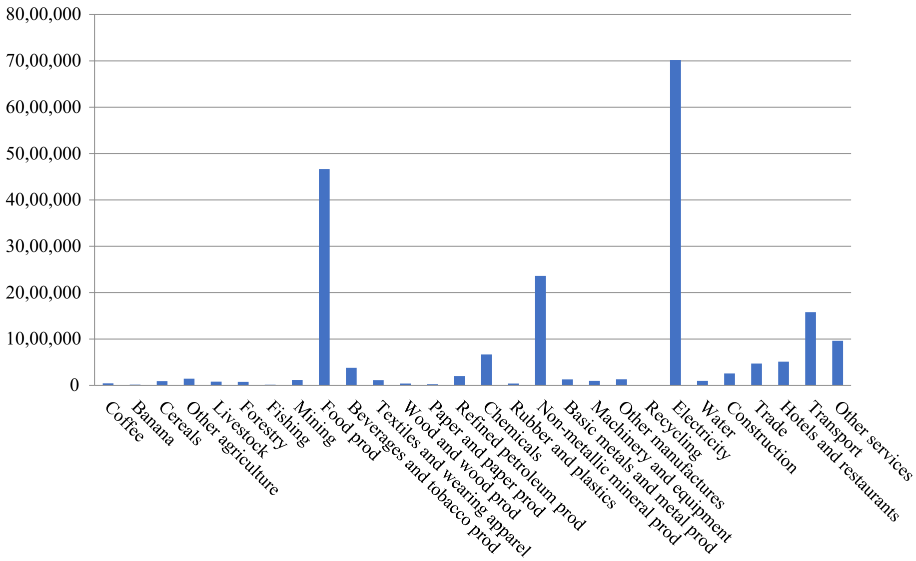

Fig. 5 Baseline emissions *Source*: Authors' own elaboration

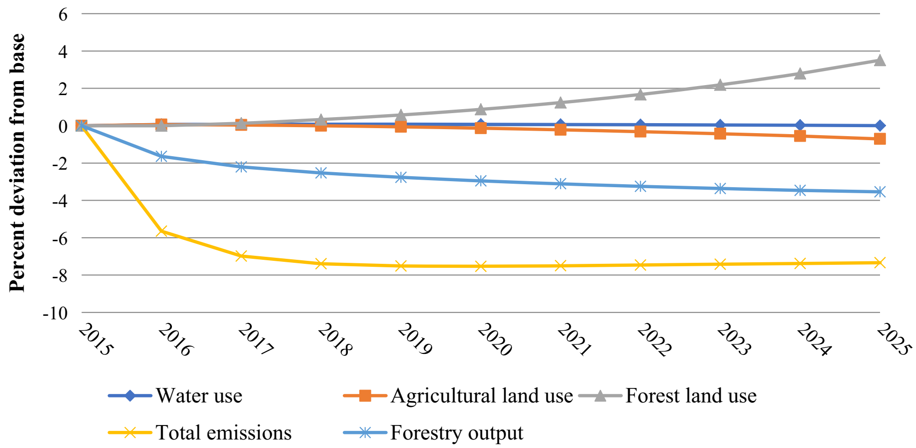

Fig. 6 Multiple impacts of household fuelwood efficiency shock *Source*: Authors' own elaboration

Adjusted genuine savings in IEEM is calculated as follows. Depreciation is the reduction in the value of an asset through time due to wear and tear; depreciation of the forest stock is calculated using IEEM results as the product of the annual volume of deforestation and the output price of timber 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 greenhouse gas emissions.

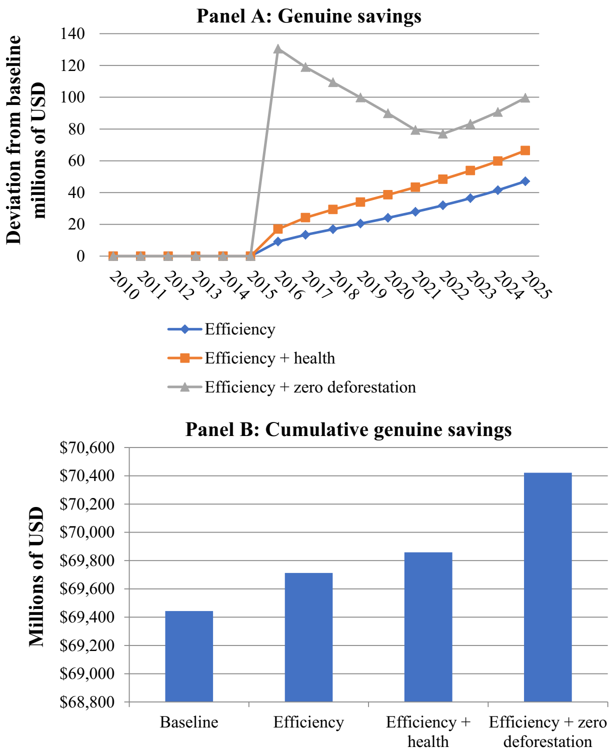

Fig. 7 Panel A: Scenario impacts on genuine savings until 2025. Panel B: Cumulative impact on genuine savings in 2025, real 2010 USD *Source*: Authors' own elaboration

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 efficiency strategy; the positive health impacts contribute to greater savings than in 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. This is due to the implementation of the zero deforestation policy. While always above baseline levels, genuine savings slowly begins to fall to US$76 million in 2022 from its peak of US$130 million following implementation of the strategies. After 2022, savings begins to rise again. This trend is explained by the sudden increase in standing forest stock following implementation of PROBOSQUE. 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.

Panel B of Fig. 7 shows cumulative genuine savings in 2025 with the efficiency + zero deforestation scenario generating an additional US$978 million in savings above baseline levels.

5 Concluding Remarks and the Way Forward

This paper develops and operationalizes the IEEM Platform. By integrating data organized under the SNA and SEEA, the IEEM Platform considers quantitatively and comprehensively how economic activities critically depend on the environment, both as a source of environmental resource inputs, and as a sink for outputs in the form of emissions and effluents. Once developed for a country, the IEEM Platform can generate more timely evidence-based policy advice at lower cost across economic and environmental policy issues than if data collection were required on a case by case basis. The consistency and compatibility of the SEEA with economy-wide frameworks reduces the need for strong assumptions in reconciling environmental and economic data in IEEM calibration. The language of IEEM and the indicators it generates are grounded in economics, which resonates with decision makers in Central Banks, Ministries of Finance and other government institutions responsible for budget allocations.

To illustrate the analytical capabilities of the IEEM Platform, an IEEM for Guatemala was developed and applied to examine the country's fuelwood efficiency and forest incentive strategies. Implementation of these strategies would result in a reduction in fuelwood consumption and emissions, though a small overall increase in household consumption of the energy bundle. With a reduction in fuelwood production and consumption, there is a significant decrease in deforestation. Households benefit from the strategies with higher disposable income, though their increased levels of consumption include greater consumption of most environmental resources and an increase in the levels of emissions and effluents returned to the environment. For the first time in a forward looking framework, IEEM enables estimation of policy impacts on national wealth in the form of genuine savings and other metrics of wealth, where both the fuelwood and forest incentives strategies were found to contribute positively to the country's underlying wealth and thus prospects for future economic growth.

In advancing the IEEM agenda, IEEM Platforms are being developed for several countries including Colombia, Costa Rica and Rwanda. The scope of issues for which IEEM can provide evidence-based policy advice is considerable. Applications are currently underway examining, for example: Rwanda's Green Growth Strategy; Guatemala's strategies for achieving the Sustainable Development Goals as well as Nationally Determined Commitments; post-conflict land-use trajectories in Colombia, and; climate change impacts and the costs and benefits of natural disaster preparedness.

While the IEEM Platform enables consideration of policy impacts on provisioning ecosystem services, we have expanded its scope to include regulating and cultural ecosystem services. The approach we have developed is to link the IEEM Platform with ecosystem service modelling (IEEM + ESM) where future policy scenarios are undertaken with IEEM to estimate economic and land use and land cover (LULC) impacts Banerjee et al. (2017a). By development and implementation of a LULC model, the changes in land use reported by IEEM are allocated across the landscape according to user-specified decision rules (see for example Verburg et al. 2008). ESM modules are calibrated with a baseline LULC map and other spatial datasets and parameters[6]. In conducting scenario analysis, most parameters in the ESM are relatively static through time with the exception of LULC. Thus, as IEEM and the LULC model are used to generate future scenario-based LULC maps, these new maps are used in ESM to estimate future ecosystem service supply. The final step in our IEEM + ESM

[6] One type of publically available ecosystem service modelling modules is the InVEST modelling suite developed through the Natural Capital Project (Sharp et al. 2016). Ecosystem service modules for specific ecosystem services can be calibrated for a country and used for generating ecosystem accounts and scenario analysis.

approach is to create feedbacks between IEEM and ESM where changes in future ecosystem service supply have impacts on the economy. These feedbacks are implemented as shocks in IEEM which may then have impacts on LULC and again on future ecosystem service supply; this process is repeated iteratively until the final year of the analysis. The IEEM + ESM approach is currently being implemented to explore climate change in Guatemala and agricultural development in Rwanda Banerjee et al. (2017b).

The IEEM approach to evaluating policy impacts on wealth and well-being integrates economic and ecological models, incorporating dynamic interactions between both economic and ecological systems in a forward looking, temporally dynamic framework. The adjusted genuine savings indicator generated by IEEM is a semi-inclusive measure of wealth. With a comprehensive metric of inclusive wealth elusive, as Stiglitz et al. (2010) suggest, monetary metrics of semi-inclusive wealth can be supplemented with biophysical metrics where some ecosystem services are difficult or not possible to ascribe a monetary value to Polasky et al. (2015) and Stiglitz et al. (2010).

This is precisely the approach taken with the IEEM Platform and in the IEEM + ESM approach, where economic indicators such as gross domestic product, employment and adjusted genuine savings are complemented with indicators related to natural capital stocks and ecosystem service supply in physical units. After decades of efforts to develop an international standard for environmental accounting culminating in the SEEA Central Framework (Vardon et al. 2016), advances continue to be made in the development of a first standard for ecosystem accounting (UNEP et al. 2017). As these accounting methods develop, so will our ability to integrate ecosystem services in the IEEM Platform and the inclusivity of the indicators IEEM generates to account for inter and intra-generational trade-offs and scalability that are keystone for ensuring the advice we provide is evidence-based and responds to the challenges of sustainable economic development.

Acknowledgements This work was funded by the BIO Program of the Inter-American Development Bank.

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