Ecological Economics 182 (2021) 106929

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

Gross domestic product alone provides misleading policy guidance for post-conflict land use trajectories in Colombia

Onil Banerjee[a,*], Martin Cicowiez[b], Renato Vargas[c], Carl Obst[d], Javier Rojas Cala[e], Andrés Camilo Alvarez-Espinosa[f], Sioux Melo[f], Leidy Riveros[f], Germán Romero[f], Diego Sáenz Meneses[g]

[a] *Inter-American Development Bank, Climate Change and Sustainable Development, 1300 NY Avenue N.W., Washington, DC 20577, USA*
[b] *Universidad Nacional de La Plata, Facultad de Ciencias Económicas, Calle 6 entre 47 y 48, 3er piso, oficina 312, 1900 La Plata, Argentina*
[c] *CHW Research, 40 avenida 52-90 zona 16 Edif. Trento Suite 402, Guatemala City 01016, Guatemala*
[d] *IDEEA Group, 219 Rathmines St, Fairfield 3078, Victoria, Australia*
[e] *Ministerio de Ambiente y Desarrollo Sostenible, Calle 37 No. 8–40, Bogotá, Colombia*
[f] *Departamento Nacional de Planeación, Dirección de Ambiente y Desarrollo Sostenible, Calle 26 13–19 Piso 8, Bogotá, Colombia*
[g] *Dirección de Ambiente y Desarrollo Sostenible, Calle 26 No 13–19 Piso 8, Bogotá, Colombia*

ARTICLE INFO

Keywords:
Integrated economic-environmental modeling (IEEM) platform
Gross domestic product (GDP)
Wealth
Economic impact analysis
Natural capital accounting
Ecosystem services

ABSTRACT

Gross Domestic Product (GDP) is the most widely used measure of economic performance world-wide. Where long-run economic sustainability and human well-being are concerned, GDP can provide misleading policy advice. While the limitations of GDP are discussed conceptually in the literature, we provide a quantitative example demonstrating the implications of using only GDP to inform policy design. In the context of Colombia's post-conflict development, we show that continuing the recent trend of increasing deforestation reflects positively on GDP by about US$59 million by 2035. However, when we consider the natural capital assets and environmental quality that underpin economic growth summarized by the Genuine Savings indicator of wealth, reducing deforestation and enhancing agricultural productivity results in a more prosperous and sustainable post-conflict future for Colombia with a US $48 billion increase in wealth. Policy makers relying only on GDP as a guide to policy effectiveness risk undermining their country's development prospects and inter-generational well-being which is at the very core of sustainable development. While natural capital accounting sheds light on past economy-environment interactions, future looking integrated analytical frameworks such as that presented in this paper are required to evaluate policies on the basis of their potential impacts on sustainable economic development and wealth.

1. Introduction

The Government of Colombia signed a peace agreement with the Revolutionary Armed Forces of Colombia in November of 2016, after over 50 years of civil conflict. As is the case with many other post-conflict countries, this period of recovery places mounting social and economic pressure on Colombia's natural capital base. Drawing from the experience of other post-conflict countries, following the resolution of conflict, deforestation and natural resource extraction intensify and the return of displaced people coupled with ineffective land-use planning drive environmental degradation (Suarez et al., 2017). To guide public policy in this post-conflict period, it is critical to have indicators that highlight impacts on the social, economic and environmental dimensions of economic development policy.

Policy makers have traditionally used Gross Domestic Product (GDP) based indicators as the barometer of their economies and an indicator of the effectiveness of their economic development policies. As a measure of annual income flow that does not take into account changes in stocks of a country's capital, GDP is not an appropriate metric of sustainable economic development (Stiglitz et al., 2010; Stiglitz et al., 2009; Lange et al., 2018; Polasky et al., 2015; Arrow et al., 2012; UNEP, 2018). In the context of Colombia, this is particularly problematic since economic development assessed on the basis of GDP alone could unknowingly be underpinned by the liquidation of the country's natural capital base.

---

* Corresponding author.

E-mail addresses: onilb@iadb.org (O. Banerjee), Carl.Obst@ideeagroup.com (C. Obst), jerojasc@minambiente.gov.co (J.R. Cala), acalvarez@dnp.gov.co (A.C. Alvarez-Espinosa), smelo@dnp.gov.co (S. Melo), leriveros@dnp.gov.co (L. Riveros), dsaenz@dnp.gov.co (D.S. Meneses).

https://doi.org/10.1016/j.ecolecon.2020.106929
Received 7 August 2020; Received in revised form 23 October 2020; Accepted 8 December 2020

With recent developments in natural capital accounting, more robust indicators of economic development that account for changes in natural capital stocks and environmental quality are now within reach. We demonstrate how Genuine Savings, an indicator of wealth, provides critical information for guiding public policy toward a pathway of prosperity and inter-generational wealth (Hamilton, 2000; Hanley et al., 2014). While natural capital accounting (Hein et al., 2020) enables the calculation of wealth for a period in the past, we present a future looking Integrated Economic-Environmental Modeling (IEEM) framework for evaluating the impacts of public policy and investment. We apply IEEM to evaluating post-conflict land use trajectories in Colombia and demonstrate the dangers of using GDP alone and the advantages of Genuine Savings to guide sustainable development policy in Colombia and beyond.

2. Background

2.1. Post-conflict Colombia

In Colombia and other post-conflict countries, government

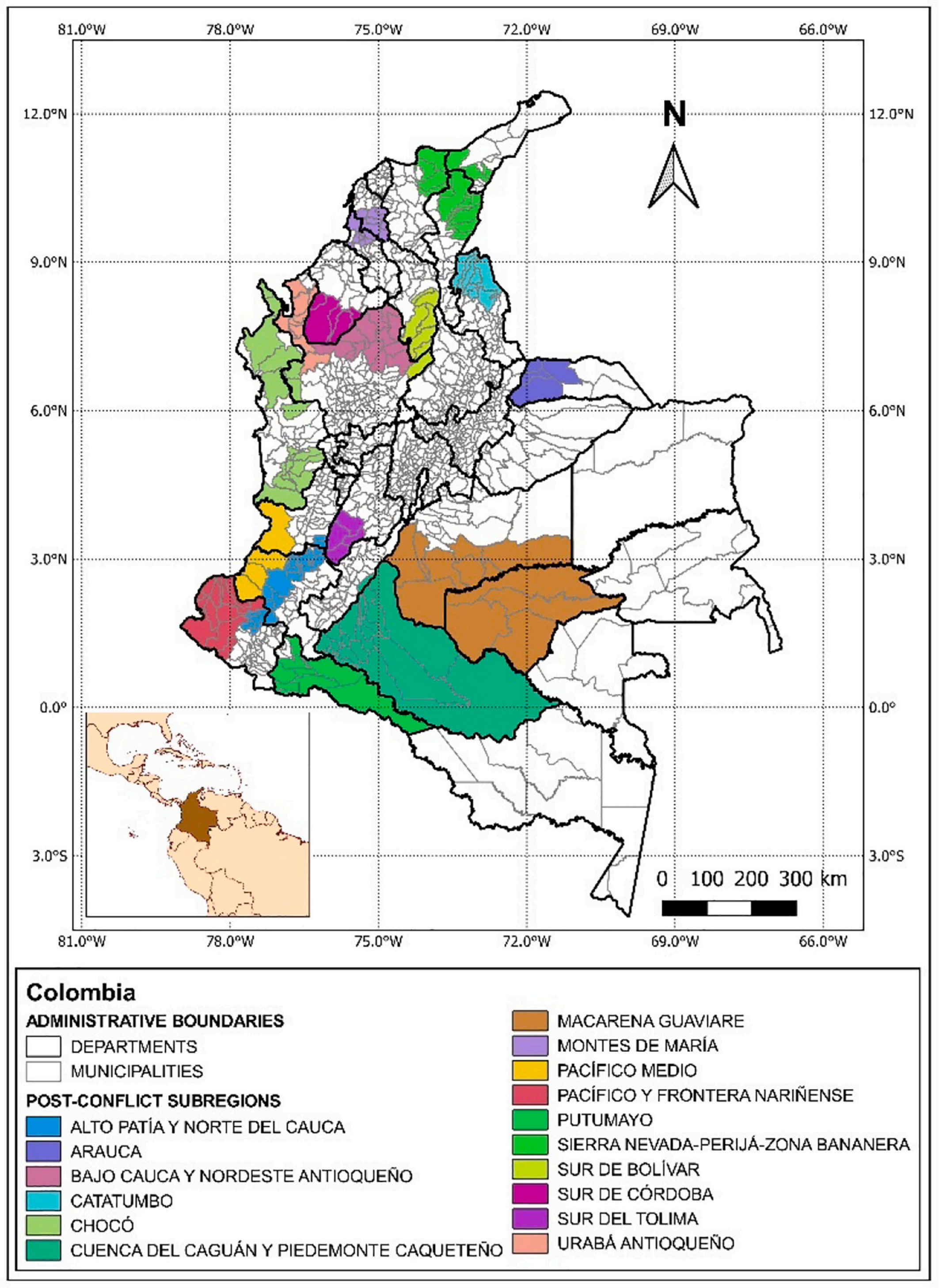


Fig. 1. Colombia's post-conflict subregions.

investment is focused squarely on security and social and economic recovery, which increases pressure on natural capital and deforestation (Bustos and Jaramillo, 2016; Conca and Wallace, 2009; Mcneish, 2017). This is of national and global concern as Colombia is home to 10% of the planet's biodiversity and is one of the most biodiverse countries (CONPES, 2018; Moreno et al., 2019). Over half of the country is forested and it has the greatest abundance of water resources among countries in Latin America and the Caribbean (World Bank, 2015).

Colombia's conflict had its most profound impact on 170 municipalities across 36% of the nation's territory (Fig. 1). These 170 municipalities have been grouped into 16 post-conflict subregions where public investment has been prioritized. In the post-conflict period, these municipalities face the most intense pressure on natural capital as displaced people return home and attempt to rebuild their livelihoods. Many of these municipalities coincide with areas of exceptionally high biodiversity and natural capital values (Calderon et al., 2016).

Colombia's armed conflict has had spatially diverse impacts on the environment and deforestation. In some areas, landmines and the prohibition of access has resulted in de facto conservation (Álvarez, 2003; Dávalos et al., 2011; Fergusson et al., 2014). Abandonment of land in the San Lucas mountain range, other areas in the Amazon, and Orinoquía, for example, has led to forest regrowth and improvements in biodiversity (Baptiste et al., 2017). However, in the past 25 years, the country lost 5.2 million hectares of forest cover, 3 million hectares of which were deforested in municipalities affected by the armed conflict (Departamento Nacional De Planeacion, 2017b). Even Colombia's protected areas have not been spared, with their deforestation spiking post-conflict and accounting for 11% of the national total in 2017. Deforestation, land degradation and soil erosion have been estimated to cost the country on average 0.7% of GDP annually (Sanchez-Triana et al., 2007). Deforestation has impacts on local microclimates and contributes to climate change. By 2014, 55% of Colombia's 23.7 million tons of CO_2 equivalent emissions came from deforestation and land use (IDEAM et al., 2008).

Although each post-conflict zone in Colombia has its own development dynamic, clearing for agriculture and livestock drive deforestation and were responsible for 65% of deforestation over the previous decade (World Bank, 2015). In the Amazon, poor displaced migrants push their way into the forests, extract high-value timber, burn the remnant forest and plant subsistence crops. After 2 or 3 years of cultivation, the soil becomes unproductive and farmers move to adjacent areas to repeat the process. Cleared areas are purchased cheaply and consolidated for extensive cattle ranching which was responsible for 50% of the land cleared between 2005 and 2012 (Etter et al., 2006; Nepstad et al., 2013; PARES, 2018).

Deforestation in the country is also closely related to illegal activities which have proliferated due to weak governance in parts of Colombia's territory. This lawlessness and the presence of armed groups have led to the transformation of forests to illicit crops, the illegal extraction of minerals, illegal logging, and the construction of informal roads. Since the Peace Accord, Colombia's coca production has tripled, accounting for a staggering 70% of the coca cultivated globally (UNODC, 2019). A startling 34% of the coca area is planted on terrain that used to be forest in 2014 (SIMCI-UNODC, 2018).

2.2. *Measuring sustainable economic performance for peace*

GDP is the most widely used indicator of economic performance and is calculated as the total gross value added by all residents in an economy within the System of National Accounts (SNA) (European Commission et al., 2009). The SNA is an internationally agreed statistical standard for compiling measures of economic activity and is implemented by almost all countries globally. The GDP family of indicators, including GDP per capita, have important limitations, however. From the perspective of income, it counts all net income (output less intermediate consumption) generated by a country's resident economic units as contributions to GDP within a year. It does not, however, distinguish whether that income involves the liquidation of the underlying stocks of, either natural, or produced capital.

In a business analogy, the liquidation of any capital prevents that capital from generating returns in the future. In the realm of publicly traded businesses, it is illegal to report the liquidation of produced capital as profit, i.e., profit is measured after deducting depreciation and the liquidation of assets. However, notwithstanding the advice of the SNA to compile net indicators that do account for that depreciation, and which are available within the System, in the case of GDP the cost of using up produced capital is not deducted, but rather added. Another troubling feature of GDP is that positive contributions to GDP can reflect an increase in activities that are not necessarily positive for society in an overall sense. For example, GDP will include the production, including wages and salaries, associated with the increased economic activity generated through the clean-up of an oil spill or the extraordinary provision of private and public medical services during a pandemic.

Finally, GDP (and indeed measures of profit for publicly traded businesses) does not account for the degradation of natural capital, which can be conceptualized as being analogous to the depreciation of produced capital (Edens and Hein, 2013). Natural capital degradation, a degraded forest, for example, has lower potential economic returns associated with it than a well-managed forest, though this distinction is not reflected in measures of GDP even if adjusted for population growth through the GDP per capita measure.

To assess changes in an economy's capital base, the SNA turns to the concept of assets, which are stores of value representing a benefit or a series of benefits that accrue to the owner over time (European Commission et al., 2009). Balance sheets record the opening value of the stock of assets at the beginning of the accounting period, transactions that add to, subtract from, or reappraise the stock, and the closing value at the end of the period. Unfortunately, many countries do not measure their depreciation due to the difficulties inherent in measuring all types of assets, their age, and level of wear on an annual basis. This is true of both produced capital (factories and machinery) and natural capital such as standing timber, mineral and energy resources, heads of cattle and coffee plantations.

Further, even where valuations of assets and depreciation/degradation are recorded, it is limited to values arising within what is called the production boundary of the SNA. The production boundary limits measurement to those cases where labor and capital are combined with intermediate inputs to produce outputs of goods and services. Outputs that are created as a result of purely natural processes without the addition of labor and/or capital are excluded from the SNA's production boundary (Eigenraam and Obst, 2018).

This lack of information on changes in natural and produced capital already places blindfolds on policymakers, but there are additional limitations in the use of GDP limitations for informing sustainable development policy. Since GDP does not account for output that falls outside the production boundary, such as the ability of natural capital to provide ecosystem services, the benefits that people receive from nature (Daily, 1997), are also not fully recognized, for example increased productivity in agriculture or contributions to drinking water quality. Non-market, non-material ecosystem services (Millenium Ecosystems Assessment, 2005; IPBES, 2019) fall entirely outside of national accounting systems.

Cautionary comments from its architects regarding the equation of GDP and its family of indicators to social well-being go back as far as the time of its inception (Costanza et al., 2014a) and are even included in the latest SNA manual itself (European Commission et al., 2009). In the past couple of decades, however, outright criticisms and calls for the abandonment of GDP as the de facto standard in economic and social performance have intensified (Stiglitz et al., 2009; Costanza et al., 2009; Hoekstra, 2009; Costanza et al., 2014b).

For example, Professors Joseph Stiglitz, Amartya Sen and Jean-Paul Fitoussi have argued that the family of indicators within SNA, including

GDP and others, cover only what they term “material living standards”, but ignore health, education, personal activities, environmental sustainability, political voice and governance, social connections and relationships, and economic and physical insecurity as well-being dimensions that are as important as the former (Stiglitz et al., 2009; Stiglitz et al., 2010).

Costanza and his colleagues argued that GDP-style accounting promotes maximizing growth at the expense of profitability, efficiency, sustainability or flexibility and recognize that with alternative indexes and indicators researchers have become much better at measuring “what actually makes life worthwhile” (Costanza et al., 2014b). They have called for the dethronement of GDP within the context of defining sustainability for the aptly-named UN Sustainable Development Goals; an idea that has also been promoted by Jeffrey Sachs (Sachs, 2015). Herman Daly has fervently criticized the idea that more GDP growth makes us richer, pointing out that it is only growth in net wealth that does so, because it is incapable of assessing whether beneficial activities grow faster than costly ones, as both are lumped together within it simply as “activity” (Daly, 2017; Daly, 2008).

A number of alternatives have developed to go “beyond GDP”, both as an extension of neoclassical economics that start with GDP but subtract welfare reducing impacts and add monetary value for welfare-enhancing dimensions (Hoekstra, 2009; Arrow et al., 2004; Arrow et al., 2012; Polasky et al., 2015; UNEP, 2018; UNU-IHDP and UNEP, 2014; UNU-IHDP and UNEP, 2012; Lange et al., 2018; World Bank, 2005; World Bank, 2011; Kalimeris et al., 2020). There are also more subjective reinterpretations in the form of indexes and indicators that measure life satisfaction or happiness, as well as the dependency of welfare on natural resources (Hoekstra, 2009; Kalimeris et al., 2020; OECD, 2013; Nordhaus and Tobin, 1972; Daly and Cobb, 1994; Cobb, 1995; Rees and Wackernagel, 1996).

In the context of post-conflict Colombia, illegal deforestation that generates a supply of timber and opens new cleared land for agriculture will be reflected in positive contributions to GDP. Thus, what is not accounted for is the loss of capital and the associated future returns (e.g., from sustainable logging of timber in forested areas) as well as the array of market and non-market ecosystem services that the forest would have provided. By not accounting for these changes in natural capital and ecosystem services values, we effectively ascribe them a price of zero (Pearce et al., 2006). Similar analogies apply to poorly managed fisheries, mineral and energy resources and watersheds. Without question, a business that did not manage its underlying capital base would live out a short life on the publicly traded stock market, and yet entire economies around the globe are managed on the basis of the incomplete information provided by GDP-based indicators.

Efforts have been underway for decades to further develop statistical systems that account for natural capital and the services it provides by extending the accounting framework of the SNA (UN., 1993). Work in this direction took a significant leap forward in 2012 with the international statistical community’s adoption of the System of Environmental-Economic Accounting Central Framework (SEEA) (United Nations et al., 2014a) as the first natural capital accounting statistical standard that complements the SNA by describing accounting for environmental assets (mineral and energy resources, land, soil, timber, aquatic resources, water resources and other biological resources), environmental flows and environmental activities. In the SEEA, environmental assets are quantified in physical terms and monetary terms when a market price is observable, or by a market equivalent valuation approach. The SEEA extends the asset boundary to include all components of the biosphere including those without a market price.

Beyond the Central Framework, the SEEA’s Experimental Ecosystem Accounting framework extends the production boundary of the SNA to include all material, non-material and non-market ecosystem services (United Nations et al., 2014b; UNEP et al., 2017). It also accounts for changes in ecosystem extent (size) and condition which affect future ecosystem service output. These new accounting systems enable decision-makers to understand policy impacts on standard economic indicators, as well as impacts on natural capital and ecosystem services. With information collected under the SEEA coupled with the SNA, it becomes possible to calculate indicators that speak to changes in wealth whose three pillars- manufactured capital, human capital, and natural capital- align with the three dimensions of sustainable development (Banerjee et al., 2019a; Banerjee et al., n.d.; Guerry et al., 2015). Specifically, the information compiled under the SEEA allows countries to evaluate metrics of current and future wealth coherent with GDP, as the aggregate value of manufactured and natural capital such as Genuine Savings and the inclusive wealth index (Stiglitz et al., 2009; Stiglitz et al., 2010; Lange et al., 2018; UNU-IHDP and UNEP, 2014; UNEP, 2018).

While GDP, and GDP-related indicators such as GDP per capita, will continue to be an important measure of current economic performance and income, there are great risks to using only GDP as an indicator of economic sustainability in post-conflict Colombia. With other post-conflict countries indicating a tendency toward increased natural capital depletion including deforestation and land conversion, GDP will effectively ignore this destruction of Colombia’s natural capital base, and thus not serve to alert policy makers to the undermining of the country’s future growth prospects.

In this context, the compilation of metrics of wealth, specifically Genuine Savings, using extended accounting frameworks such as the SEEA, can support recognition of the principle that increasing standards of living are possible through building national wealth with investment in manufactured, human and natural capital, as well as in strong governance to make productive use of those assets. Genuine Savings is defined as gross national saving plus investment in education, minus depreciation of manufactured capital, depletion of subsoil assets and timber resources, and the damage cost of air pollution (Lange et al., 2018).

While different, Genuine Savings has a relationship with GDP. Specifically, an increase in GDP is typically accompanied by an increase in the incomes of households, firms and the government. This increase results in increased savings for the economy overall, which is an important component of Genuine Savings. Most public policy and investment scenarios we evaluate in IEEM do not consider adjustments in the level of investment in education, a proxy for the stock of human capital, we calculate an adjusted form of Genuine Savings that focuses on the natural capital dimension of wealth which is calculated as follows:

$$GenuineSAV_t = GNSAV_t - DeprCapStock_t - DeplForStock_t - DeplMinStock_t - EmiVal_t$$

where:

$GNSAV_t$ = Gross National Savings ($GNDI_t - PrvCon_t - GovCon_t$).

$GNDI_t$ = Gross National Disposable Income.

$DeprCapStock_t$ = depreciation of reproducible capital stock.

$DeplForStock_t$= depletion of forest stock.

$DeplMinStock_t$ = depletion of mineral stock.

$EmiVal_t$ = Cost of damage from greenhouse gas emissions; US$30 per ton of CO2 equivalent based on (Lange et al., 2018).

For natural capital, the value of depletion is defined as:

$$\sum_{i=t}^{t+T-1} \frac{qdepl_t \cdot unitrent_t}{(1+intrat)^{i-t}}$$

where:

$qdepl_t$ = quantity of the resource extracted.

$unitrent_t$ = unit rent in year t, which is endogenous in IEEM.

$intrat_t$ = interest rate (4% as in Lange et al. (2018) which is based on the long-term average rate of return on financial assets globally. This is an estimate of the opportunity cost of holding.

wealth as natural capital compared with investing in financial assets.)

For example, with $t = 2014, \dots, 2035$ and $T = 22$:

$$\frac{qdepl_{2014} \cdot untrent_{2014}}{(1+intrat)^0} + \frac{qdepl_{2015} \cdot untrent_{2015}}{(1+intrat)^1} + \dots + \frac{qdepl_{2035} \cdot untrent_{2035}}{(1+intrat)^{21}}$$

Recent work by the authors applied Genuine Savings to evaluate government strategies to make progress toward the Sustainable Development Goals in Guatemala (Banerjee et al., 2019a) and Green Growth Strategies in Rwanda (Banerjee et al., n.d.). In this paper, we focus on forest natural capital stocks and environmental quality proxied for by changes is greenhouse gas emissions. As Sir Partha Dasgupta points out, without metrics of wealth, it is not possible for governments to assess whether or not their economic development policies are sustainable (UNEP, 2018).

3. Methods for evaluating post-conflict land-use trajectories in Colombia

This section presents the Integrated Economic-Environmental Modeling (IEEM) Platform approach to public policy analysis for sustainable economic development. IEEM was developed for medium and long-run public policy analysis across all sectors of the economy and has been developed for over 20 countries and applied to hundreds of policy questions (Banerjee et al., 2019a; Banerjee et al., 2019c; Banerjee et al., n.d.; Banerjee et al., 2016). We apply the IEEM framework to Colombia to evaluate post-conflict land-use trajectories and their impacts on wealth and other economic indicators.

IEEM advances the state-of-the-art in decision making frameworks, enabling policy makers to understand the full range of economic and environmental implications of public policy and investment. The IEEM Platform for Colombia is calibrated with the country's recently published SNA and SEEA natural capital accounts (DANE, 2017). While a country's natural capital accounts present a snapshot of past environmental-economic interactions, IEEM is the first future-looking economy-wide framework that integrates natural capital accounts, has environmental modeling modules to capture the dynamics of each environmental asset and ecosystem services, and enables one to ask, 'what if' questions to evaluate how a given policy will impact the three pillars of sustainable development and inter-generational wealth.

At the core of IEEM is a dynamic computable general equilibrium model. The theory, structure and strengths and limitations of this type of modeling for public policy and investment analysis are discussed in a large body of literature developed over the last 4 decades (Burfisher, 2011; Dervis et al., 1982; Dixon et al., 1982; Dixon et al., 1992; Dixon and Rimmer, 1998; Dixon and Rimmer, 2002; Dixon and Jorgenson, 2012; Kehoe, 2005; Arrow, 2005). IEEM is publicly available[1] and its mathematical structure, database and a user guide are available to the interested practitioner (Banerjee and Cicowiez, 2020; Banerjee et al., 2019b; Banerjee and Cicowiez, 2019). Fig. 2 summarizes the main income flows captured by IEEM for a given period. CGE-based models including IEEM consider only the real side of the economy and exclude monetary aspects. Consequently, they do not consider phenomena such as inflation. Instead, they focus on capturing changes in the way that real economic resources are allocated across the economy through time.

The productive economic sectors are represented by activities that maximize benefits in competitive markets. The production technology used in each economic sector, in its simplest form, is summarized in Fig. 3. This figure shows that first, value-added and intermediate inputs are combined in fixed proportions. The value-added, in turn, is generated by combining primary factors of production, namely labor capital and for some economic sectors, natural capital. Intermediate inputs can come from domestic supply or from the rest of the world as imports. Economic sectors can produce one or more products in fixed proportions. In turn, each product can be produced by more than one economic sector.

The total production of each good or service can be destined to the domestic market or exported to the rest of the world. IEEM's production function allows economic sectors to endogenously determine the energy sources they use in production. More advanced nested specifications are possible with IEEM depending on the specific policy question, for example, the substitution of energy sources, inclusion of water as a factor of production, the use of fertilizers and feed as substitutes for land in agricultural production, among others.

Institutions in IEEM are comprised of households, firms, government, and the rest of the world. Households obtain their income from ownership of productive assets and from the transfers they receive from other institutions. Households spend their income buying the goods and services they consume, by saving, paying taxes, and by making transfers to other institutions. The government receives income through tax collection, provides goods and services, makes transfers to households, and saves or takes on debt, both domestic and foreign. The rest of the world demands exports and supplies imports. The IEEM model for Colombia enables the consideration of eight types of taxes, namely taxes on household income, economic activities, consumption, value added, exports, imports, factor income, and the use of factors of production by economic activities. Trade and transport margins are explicitly modeled, assuming that the corresponding services are required in fixed proportions to move a good from the producer to the consumer.

In terms of foreign trade, goods and services are assumed to differ according to their country of origin following the Armington assumption. Thus, two-way trade can be modeled, that is, the same good or service is imported and exported simultaneously. The combination of domestic and imported products is made at the border of the modeled country. Imperfect substitution between imports and domestic purchases is implemented with a Constant Elasticity of Substitution (CES) function. On the production side, a symmetrical assumption is made where exports are an imperfect substitute for sales to the domestic market. This imperfect transformation is implemented using a Constant Elasticity of Transformation (CET) function. In addition, Costa Rica is modeled as a small country, so it takes as given the world prices of the products it trades with the rest of the world.

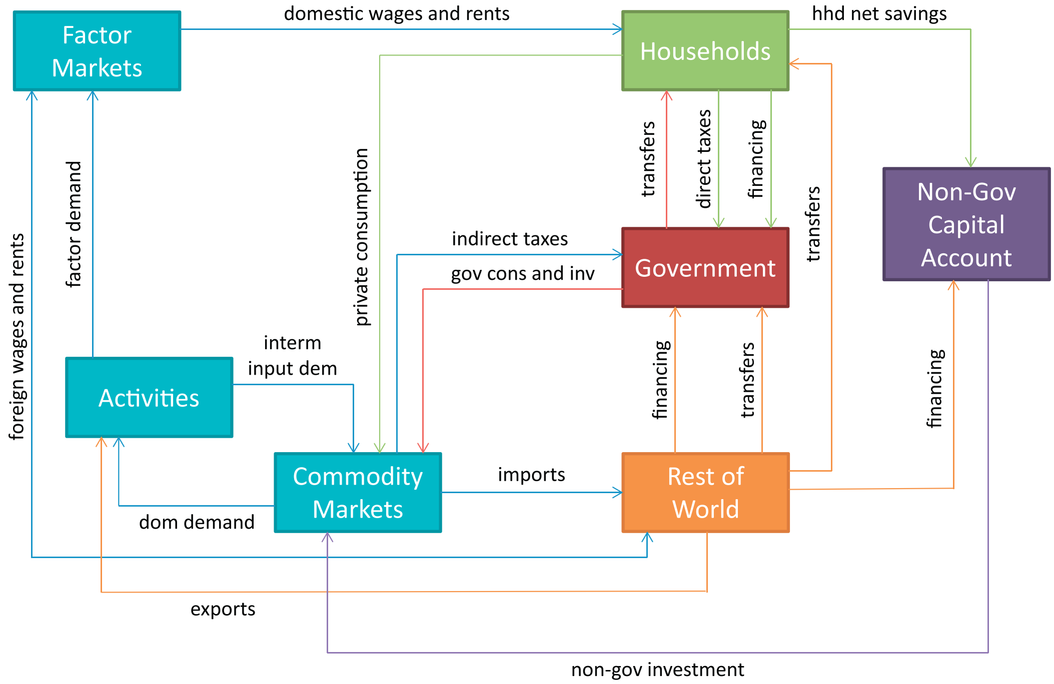
In the labor market, it is assumed that there is unemployment that is represented by a wage curve. The wage curve establishes a negative relationship between the level of wages and the unemployment rate. In the scenarios considered herein, labor is perfectly mobile between economic sectors while capital once installed, is immobile between sectors.

IEEM is a recursive dynamic model where economic agents are myopic and their expectations are stationary. In other words, economic agents expect future prices to be identical to current period prices. There are four sources of dynamics in IEEM: capital accumulation and growth in the labor force, factor productivity and natural capital supply. At the beginning of each period, the sectoral capital stocks are adjusted based on levels of previous period investment. The endowments of the other productive factors grow exogenously. The investment and capital stocks of each period are differentiated between public and private investment.

To evaluate post-conflict land use trajectories in Colombia, we

---

[1] All IEEM models, databases and documentation will be available here: https://www.iadb.org/en/topics/environment/biodiversity-platform/the-idbs-biodiversity-platform%2C6825.html



Source: authors' own elaboration.

Fig. 2. The circular flow of income in IEEM.
Source: authors' own elaboration.

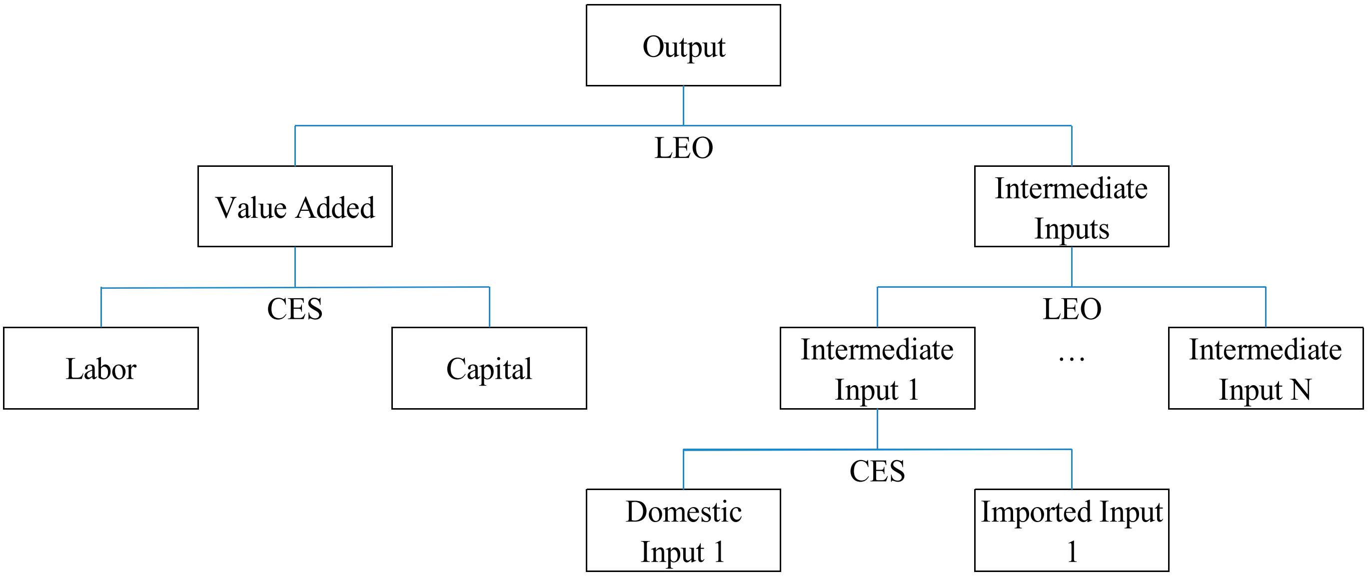


Fig. 3. Production technology.
Note: CES = constant elasticity of substitution and LEO = Leontief. Source: authors' own elaboration.

develop a baseline and three scenarios. Additional information on the development of the baseline and scenario design is available in Appendices A and B of this paper, respectively. The baseline, BASE scenario is the reference scenario to which the 3 land use trajectory scenarios are compared. The BASE projects the Colombian economy to the year 2035 without the introduction of any new policy or investment. Projections are based on the most recent available national and international data on economic trends, land use and economic output (IMF, 2019; DANE, 2016). Rates of deforestation and their projection are obtained and validated from government sources (IDEAM, 2020; IDEAM, 2019). Fig. 4 shows the BASE distribution of land use and land cover across the country.

The first non-baseline scenario, Deforestation Increase (DEFINC), implements a 16% increase in deforestation between 2020 and 2035. This increase in deforestation is based on recent analysis which showed that deforestation in recently demilitarized zones of Colombia tended to increase by this amount (Fergusson et al., 2014). This rate of deforestation is less than the observed rate of 20% per year between 2016 and 2018 (DNP, 2019). The second scenario, Deforestation Decrease (DEFDEC), represents a 75% reduction in deforestation between 2020 and

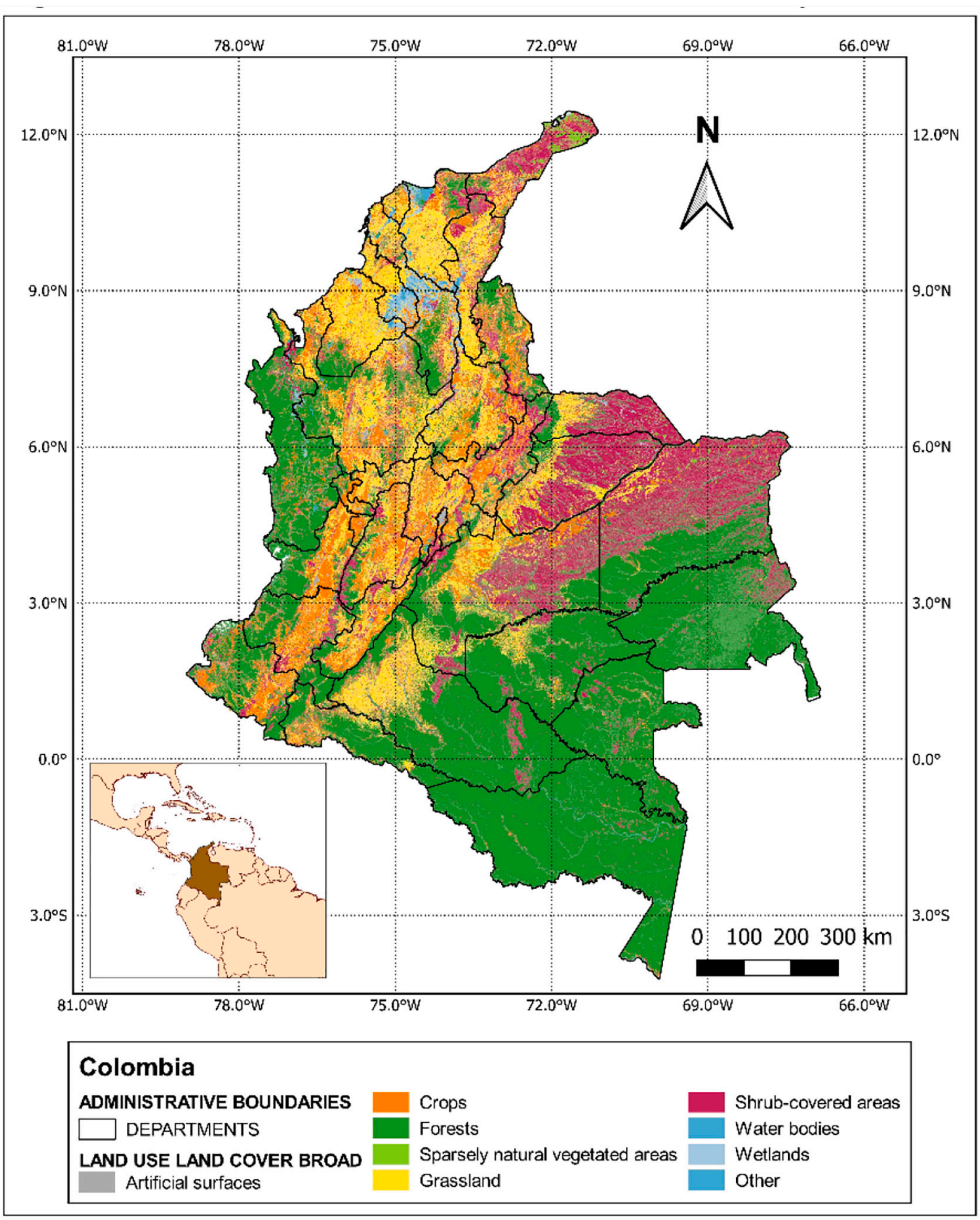


Fig. 4. Land use land cover classes 2012 base year.
Source: Based on CORINE (IDEAM, 2010).

2035, which could be achieved through more effective land-use planning, enforcement of forest law and improved monitoring of the agricultural frontier.

The final scenario, Deforestation Decrease and Productivity (DEFDECTFP) embodies a government strategy to reduce deforestation by 75% while enhancing rural livelihoods through development and implementation of more productive agricultural systems (Rodríguez, 2017). We simulate an increase in agricultural total factor productivity to illustrate how productivity growth could compensate for the negative effects of decreased deforestation on agricultural output. In Colombia, there is considerable evidence that shows that current agricultural total factor productivity is low, including in comparison to its neighbors, and there is significant scope to increase it (Acosta and De los Santos-Montero, 2019; Rodríguez, 2017). Agricultural total factor productivity growth in Colombia was estimated at between 0.8% and 1.3% between 1975 and 2013. Disaggregating crops from livestock, livestock productivity was higher, and between 1.6% and 2.2%. Some historical periods were shown to have higher rates of growth than others due to differing political and economic circumstances, for example, the period from 1984 to 1989 showed growth of about 2.4% (Jiménez et al., 2018). In our scenario, we implement a total factor productivity increase of 2.5% per year over a 5-year period, after which factor productivity remains constant. The government achieves reduced deforestation through more effective monitoring and enforcement of forest legislation while the extension of agricultural technologies is made possible through more efficient deployment of existing resources across government.

Fig. 5. Changes in land use relative to baseline in hectares.

Table 1
National-scale forest cover in BASE and scenarios in hectares.

	2020	2035	Difference
BASE	57,898,517	53,464,928	-4,433,589
DEFINC	57,898,517	52,791,984	−5,106,533
DEFDEC	57,898,517	56,619,354	−1,279,163
DEFDECTFP	57,898,517	56,619,354	−1,279,163

4. Results

Fig. 5 presents changes in demand for land between 2020, the base year of our simulations, and 2035. Where deforestation continues unabated, forest stocks and their accompanying biodiversity decline by 722,940 ha. Policies implemented to reduce deforestation result in over 3 million hectares of forest protected. With a reduction in deforestation, we also see a reduction in livestock and crop areas relative to business-as-usual. As we will see below, enhanced agricultural systems and productivity and efficiency gains more than compensate for these reduced areas.

Table 1 shows the starting stock of forest cover in 2020 compared with 2035 for the BASE and scenarios. Deforestation between 2035 and 2020 in the BASE is 4.43 million hectares. While there is still deforestation in DEFDEC, it is reduced in an important way in this scenario, with the difference between 2035 and 2020 amounting to 1.279 million hectares. Undeniably, this is still a huge area of forest to lose but is a sharp contrast between both the baseline projection and the level of deforestation exhibited in some post-conflict municipalities.

GDP trends are shown in Fig. 6. Since GDP is a measure of income flow, we find that reducing deforestation causes GDP to drop below the business-as-usual level by US$342 million in 2035. Maintaining post-conflict levels of deforestation would contribute US$59 million to GDP. Increasing investments in agricultural technology and enforcing forest laws boosts GDP by almost US$4 billion. (See Fig. 7.)

IEEM is able to assess changes in poverty, which is a particularly important indicator given the context of the policies explored here and for development policy more broadly. The impacts of reducing deforestation and enhancing agricultural productivity are also pro-poor, reducing poverty by 0.15%.

A powerful advantage of the IEEM Platform is the ability to assess public policy and investment impacts on the three dimensions of sustainable development and wealth through Genuine Savings. We estimate an adjusted form of Genuine Savings which emphasizes the environmental dimension of wealth (Banerjee et al., 2019a; Banerjee et al., n.d.).

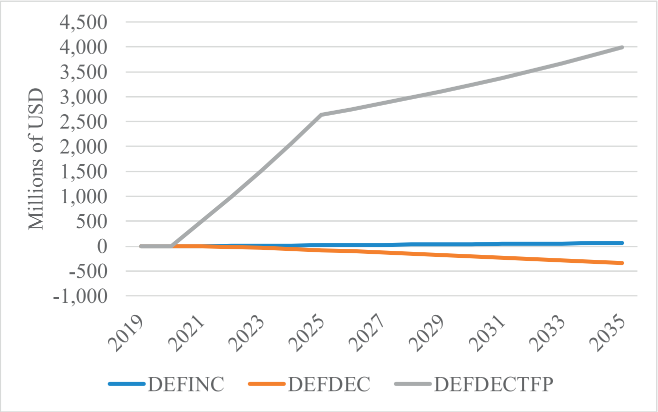


Fig. 6. Changes in GDP relative to base in millions of USD.

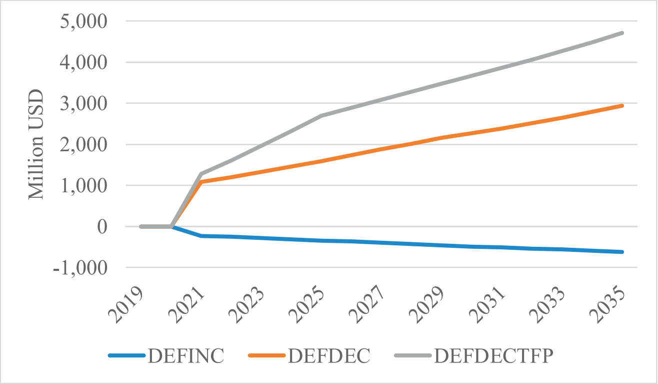


Fig. 7. Changes in Genuine Savings relative to base in millions of USD.

Considering long-run wealth and sustainability, we find that reducing deforestation and enhancing agricultural productivity increases wealth by US$4716 by 2035 relative to the base. Deforestation erodes Colombia's natural capital base, biodiversity and source of prosperity, resulting in a decline in wealth of US$627 million. Cumulative wealth impacts by 2035 are cause for serious concern as deforestation liquidates the country's natural capital base and compromises its development prospects, reducing wealth by US$6.4 billion. Reducing deforestation alone generates greater prosperity in the order of almost US$30 billion for post-conflict Colombia while coupled with improving agricultural production systems, wealth grows by almost US$48 billion.

5. Discussion and conclusions

If Colombia continues on its post-conflict track of natural capital depletion and degradation, forest stocks will be 722,940 ha lower in just 15 years. Since GDP does not deduct the cost of ecosystem degradation, policy makers relying only on GDP as the barometer of the economy would not be alerted to the fact that the economic growth associated with the deforestation was undermining the country's natural capital base and thus its economic development prospects and intergenerational wealth. Policy makers may even reconcile that this trade-off between economic growth on the one hand and natural capital, biodiversity and environmental quality on the other, reflects a necessary evil given the need to provide livelihood opportunities for returning displaced families in rural environments in fragile post-conflict times. Indeed, increased deforestation's once-off contribution of US$59 million to GDP may seem like a good return compared to a business-as-usual approach, particularly since households would also be recorded as consuming more and may perceive themselves to be better-off in the short-run.

What this focus on GDP alone obscures, however, is that Colombia's long-run economic development prospects would, all the while, be eroding through the destruction of one of its (and the world's) most precious asset bases. Gains from increasing deforestation would be short-lived and once gone, households would be left worse-off. Declining well-being would eventually force rural households to seek alternative income opportunities that could accelerate natural capital depletion, increase competition for resources, provoke conflict for land, and jeopardize the peace. Most critically, once policy makers recognize that GDP growth has come at the expense of its natural capital base, Colombia would have less capacity to respond to rising poverty with the country's future development prospects reduced by US$6.4 billion.

Ministries of Finance, Central Banks and Statistical Offices of government are increasingly incorporating natural capital accounting into their country's statistical and reporting systems (United Nations Committee of Experts on Environmental-Economic Accounting, 2017) and hence are becoming well-positioned to advise their policy makers of unsustainable economic development pathways as they become observable in the data. Routine reporting of wealth indicators, such as Genuine Savings, is a natural next step for countries that have implemented natural capital accounting under the SEEA, though some socialization of these new indicators is required for them to become interpreted with ease by policy and decision makers. While natural capital accounting provides a snapshot of natural capital use for some historical point in time, the ability to conduct forward-looking analysis such as that presented here is critical to inform the development of policies such that the erosion of the natural capital base is avoided entirely rather than mitigated ex-post. The IEEM Platform applied in this analysis is one such tool that enables one to ask 'what if' questions and examine potential economic, wealth and natural capital impacts through time.

We have shown that reducing the rate of deforestation relative to a business-as-usual case would boost forest stocks by 3.1 million hectares. Colombia would protect a greater share of its natural capital base and by focusing on increasing agricultural productivity, it would enhance its wealth by almost US$48 billion. This ensures the benefits are not once-off and short-lived gains like those that continued deforestation could provide. The strong prospects for wealth that improved agricultural systems and efficiency indicate are particularly relevant in Colombia where productivity in post-conflict zones is lower than the national average. Inefficiency in agricultural production is between 41% and 61% depending on the crop, while overall factor productivity in Colombia has historically been low. The results presented here present a strong business case for investments in factors known to be responsible for this low agricultural productivity and efficiency including land tenure conflict, lack of incentives for research and development in agriculture, weak agricultural extension, and poor rural infrastructure and connection to markets (Departamento Nacional De Planeacion, 2017b; Departamento Nacional De Planeacion, 2017a).

With the peace agreement, this new post-conflict era is the greatest source of opportunity and, at the same time, risk to Colombia's wealth of natural capital and biodiversity (World Bank, 2015). The first three years of Colombia's post-conflict period have elapsed with modest investment in rural development. Deforestation has skyrocketed in areas previously shielded from illegal logging by a de facto control function exercised by guerrilla groups. Without adequate planning, management and law enforcement, unsustainable agriculture, mining and other activities will continue to push the agricultural frontier into pristine ecosystems, leading to higher rates of deforestation and environmental degradation. The time for difficult choices is now, where the short-run gains of a business-as-usual approach reflect positively on GDP growth, but are in stark contrast to the policy guidance provided by Genuine Savings where large gains in inter-generational wealth and well-being are possible by reducing deforestation and focusing on developing rural agricultural livelihoods. Peace and prosperity in Colombia depend critically on these urgent decisions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was funded by the Inter-American Development Bank.

Appendix A. IEEM colombia dataset

A.1. Social accounting matrix

The basic accounting structure and much of the underlying data required to implement IEEM, like other CGE models, is derived from a Social Accounting Matrix (SAM).[2] Most features of a SAM for IEEM are familiar from SAMs used for other models. However, a SAM for IEEM has some unconventional features related to the explicit treatment of natural capital and financial flows.

In this paper, IEEM is calibrated to a 2014 SAM and other data for Colombia.[3] The year 2014 is the latest year for which all the required data was available at the time of this writing. While data for 2016 was available, with questions related to its reliability, it was suggested that the 2014 calibration year be maintained. Table A.1 shows the accounts in the SAM, which determine the disaggregation of the model. Our SAM includes 105 activities and 29 commodities; 98 factors (labor, capital, 92 land categories, 4 other natural resources); one representative households; and other institutions (non-profit institutions serving households, enterprises, government, and rest of the world). To save space, all figures, and tables in the main text aggregate SAM data to 13 activities and commodities and 6 factors (i.e., labor, capital, and land [3], and other natural resources).

---

[2] A SAM is a square matrix representation of the transactions between productive sectors represented by activities and commodities (or products), households, factors of production (e.g., labor, capital, and natural resources), government, savings, investment, and the rest of the world for a specific year. For each of these accounts, a cell represents a payment column-wise and a receipt row-wise (i.e., a payment from the column of the cell to its row). In turn, due to the accounting consistency of a SAM, the total expenditure of every account must equal its total income. In other words, the total of every row must be equal to the corresponding total of the column.

[3] To build our SAM for Colombia, we follow a top-down approach as described in Round (2003) and Reinert and Roland-Holst (1997).

Table A.1
Disaggregation of database for IEEM Colombia.

Category	Item
Sectors (activities and commodities)	*Agriculture, Forestry and Fishing (93):*
	Crops (32 by department); livestock (32 by department); forestry (28 by department); fishing
	Mining industry (3):
	Coal; oil; other mining
	Manufacturing industry (11):
	Food industry; beverages and tobacco; textiles and leather; refined petroleum products; chemicals; rubber and plastic; non-metallic mineral products; basic metals; machinery and equipment; vehicles; other manufacturing
	Other industry (4):
	Electricity, gas, water, construction
	Services (5):
	Trade, hotels and restaurants, transport, public administration, other services
Factors	Labor
	Private capital
	Government capital
	Natural resources: land (92 for agriculture and forestry), fisheries resources and extractive industries (3)
Institutions*	Households
	Non-profit Institutions serving households (NPISH)
	Enterprises
	Government
	Rest of the World
Distribution margins	Domestic products
	Imports
	Exports
Taxes and subsidies	Direct taxes
	Commodity taxes
	Value-added tax
	Import tariffs
	Activity taxes
Investment	Investment, private
	Investment, government
	Investment, change in inventories

[*] The institutional capital accounts are for domestic non-government (aggregate of households, NPISHs, and enterprises), government, and rest of the world. Source: Authors' own elaboration.

In the remainder of this section, we show how selected pieces of information contained in the SAM may be extracted and presented in a set of figures that together describe the structure of Colombia's economy in 2014.[4] The information presented in Figs. A.1–A.4. cover sectoral structure, structure of sectoral factor use, and demand structure.

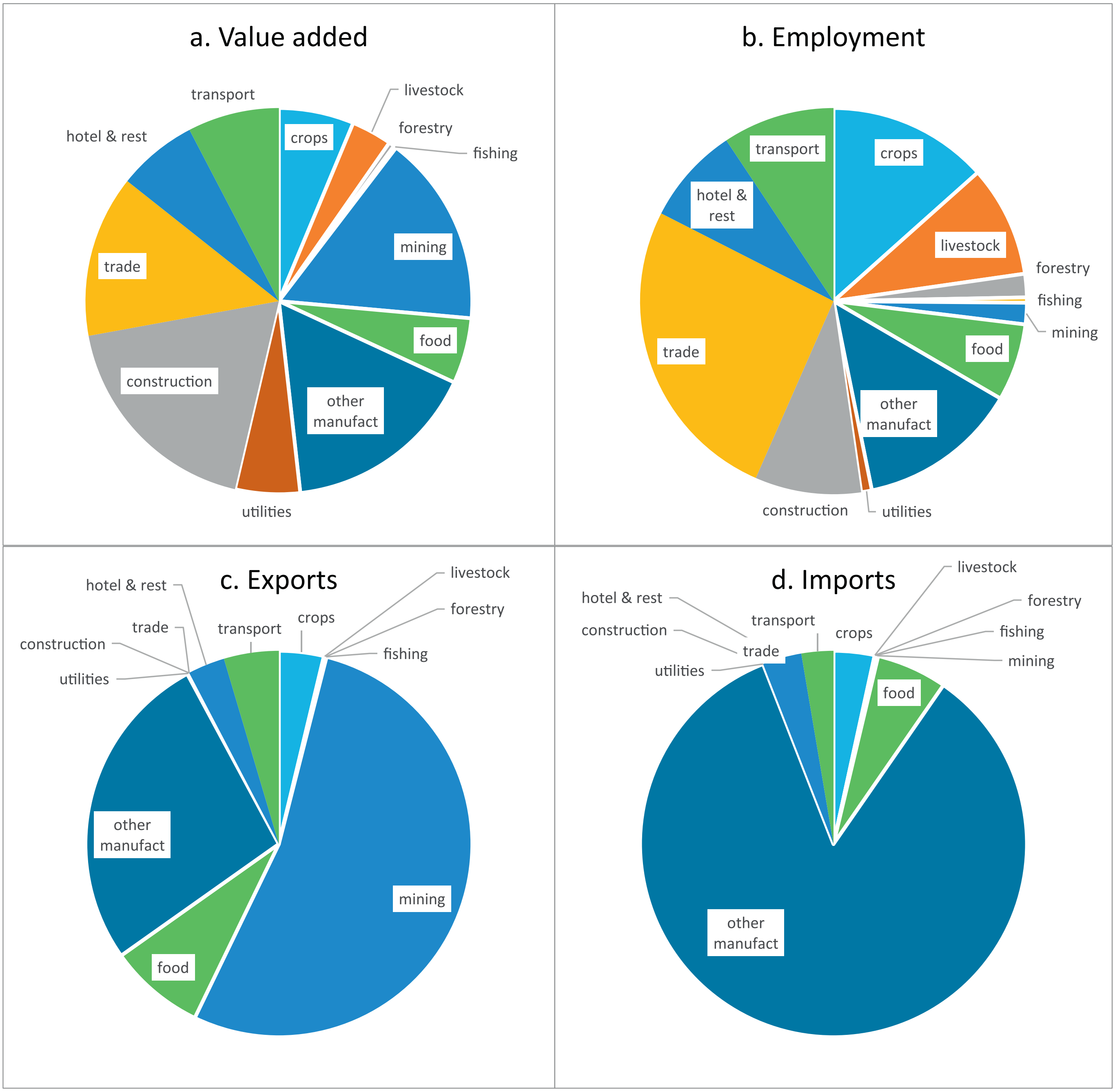
Fig. A.1 summarizes the sectoral structure of the Colombia economy in 2014: it shows sectoral shares in value-added, production, employment, exports, and imports. To complement, Fig. A.2 shows the split of domestic sectoral supplies between exports and domestic sales, and domestic sectoral demands between imports and domestic output. For instance, while mining represents a significant share of exports (around 52%), its shares of value-added and production are much smaller (in the range of 6.6–9.1%). Also, note that taken together, the agriculture and food processing sectors represent 11.5% of total exports.

Fig. A.3 shows factor intensities in the value-added of each sector. Among other things, it shows that crops, livestock, and forestry are relatively intensive in their use of labor. On the other hand, sectors such as mining and transport are relatively intensive in their use of capital. In CGE applications, factor intensities of the production sectors have a major impact on the results obtained from policy simulations. Hence, this information is useful when we analyze the results from the simulations.

Fig. A.4 shows the demand structure for each commodity in the SAM. For instance, 43.7% of the crops output is used as an intermediate input by the manufacturing sector, while 42.7% is consumed by the households. Fig. A.4 also shows that the capital goods (i.e., gross fixed capital formation) are mostly composed of other manufacturing- mainly, machinery and equipment- and equipment and construction.

---

[4] The appendix contains tables with similar information but with additional sectoral disaggregation.



Source: Authors' calculations based on 2014 Colombia SAM.

Fig. A.1. Colombia: sectoral structure in 2014 in percent.
Source: Authors' calculations based on 2014 Colombia SAM.

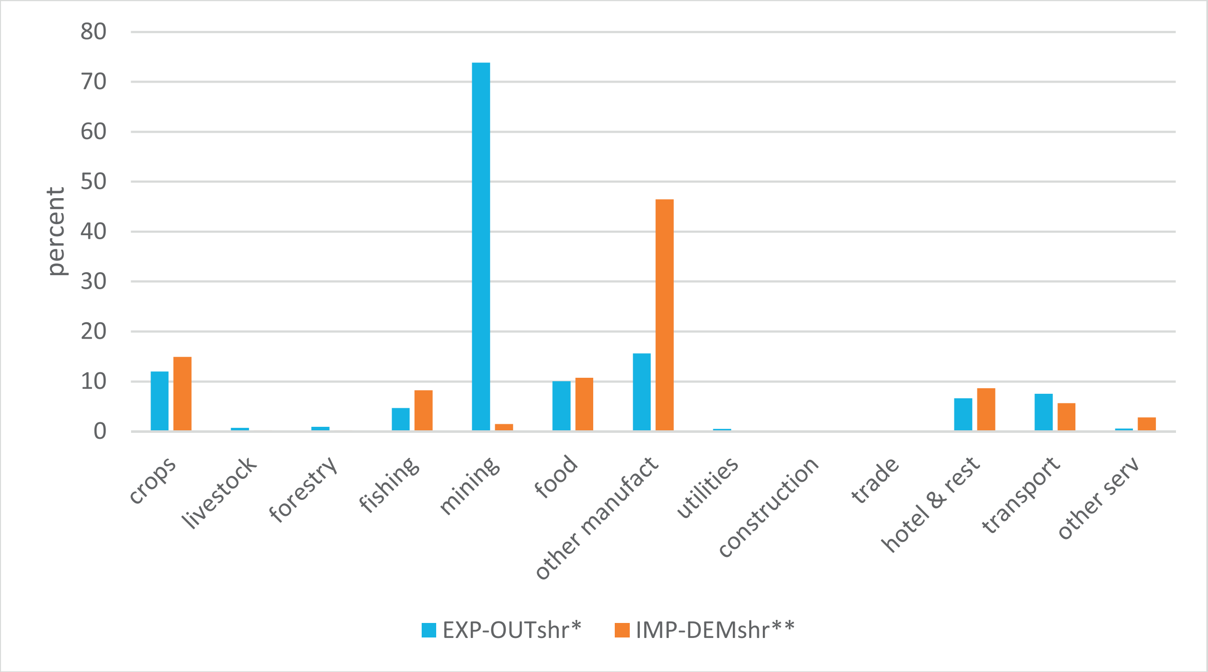


Fig. A.2. Colombia: export and import intensities in 2014, in percent.
Notes: *Ratio between exports and production; **Ratio between imports and consumption.
Source: Authors' calculations based on 2014 Colombia SAM.

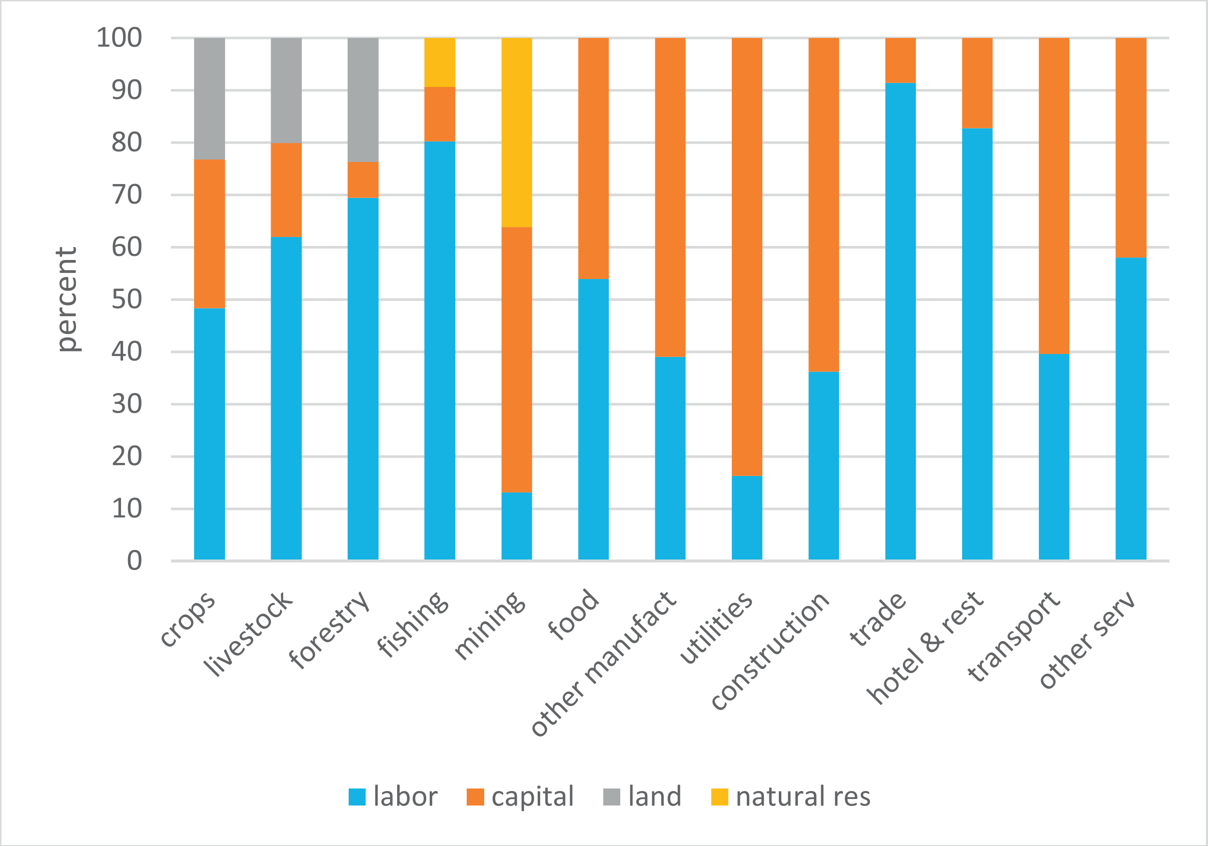


Fig. A.3. Colombia: sectoral factor intensity in 2014, in percent.
Source: Authors' calculations based on 2014 Colombia SAM.

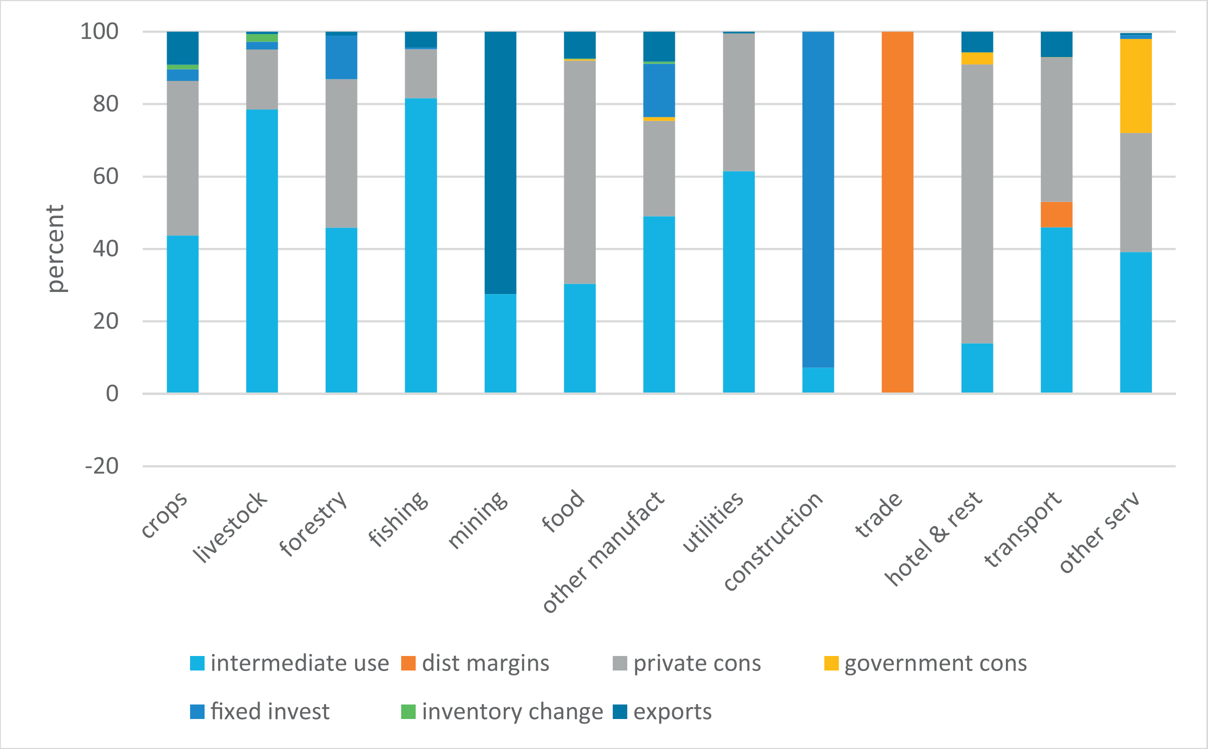


Fig. A.4. Colombia: sectoral demand composition in 2014, in percent.
Notes: *Includes trade and transport margins. Source: Authors' calculations based on 2014 Colombia SAM.

A.2. Non-SAM data

Beyond the SAM, data related to factor stocks and various elasticities are also used to calibrate the model. For capital depreciation rates, we follow Agénor et al. (2004) and assume 5.0% and 2.5% for private and public capital, respectively. For unemployment and underemployment, we use the estimates from the Gran Encuesta Integrada de Hogares (GEIH), the main household survey in Colombia: 9.1 and 29.1%, respectively. For projections of the population, split into multiple age groups, we use the 2019 UN World Population Prospects dataset.

The required (exogenous) elasticities apply to production, trade, consumption, and SDG functions. The values, which are based on Sadoulet and de Janvry (1995), Dimaranan (1997), and Muhammad et al. (2011), are shown in Table A.2. In sum, the value-added elasticities of substitution are in the range of 0.20–0.95, the Armington and CET elasticities are both in the range of 0.9–2.0, and the expenditure elasticities for household consumption demand are in the range 0.7–1.4.

Table A.2
Value-added, trade, and consumption elasticities.

	VA	Armington	CET	LES
Crops	0.25	2.00	2.00	0.72
Livestock	0.25	2.00	2.00	0.72
Forestry	0.20	2.00	2.00	1.38
Other forestry	0.20	2.00	2.00	1.38
Fishing	0.20	2.00	2.00	0.72
Coal	0.20	2.00	2.00	1.38
Oil	0.20	2.00	2.00	1.38
Other mining	0.20	2.00	2.00	1.38
Food industry	0.95	1.50	1.50	0.72
Beverages and tobacco	0.95	1.50	1.50	0.72
Textiles and leather	0.95	1.50	1.50	0.97
Refined petroleum products	0.95	1.50	1.50	1.38
Chemicals	0.95	1.50	1.50	1.38
Rubber and plastic	0.95	1.50	1.50	1.38
Non-metallic mineral products	0.95	1.50	1.50	1.38
Basic metals	0.95	1.50	1.50	1.38
Machinery and equipment	0.95	1.50	1.50	1.38
Vehicles	0.95	1.50	1.50	1.38
Other manufacturing	0.95	1.50	1.50	1.38
Electricity	0.95	0.90	0.90	1.38
Gas	0.95	0.90	0.90	1.38
Water	0.95	0.90	0.90	1.38
Construction	0.95	0.90	0.90	1.38

(continued on next page)

Table A.2 (*continued*)

	VA	Armington	CET	LES
Trade	0.95	0.90	0.90	1.38
Hotels and restaurants	0.95	0.90	0.90	1.38
Transport	0.95	0.90	0.90	1.17
Public administration	0.95	0.90	0.90	1.38
Other services	0.95	0.90	0.90	1.38

Notes: VA = CES value-added function; Armington = CES aggregation function for domestic demand (elasticities of substitution between imports and domestic output); CET = Constant Elasticity of Transformation function for domestic output (elasticities of transformation between exports and domestic supply); LES = Linear Expenditure system (elasticities of household consumption with respect to total consumption spending) for households.

A.3. Base scenario

The base scenario represents a business-as-usual projection without policy changes and serves as a benchmark for comparisons. It runs from 2014 (our base year) to 2040. Under this scenario, the annual growth rates for real GDP at factor cost are exogenous. Specifically, we impose the observed growth rate in real GDP at factor cost for the years 2015–2019, and an average growth of 3.4% during 2020–2040 (Fig. 5.1).

For the first five years, we use estimates from DANE. For the second period, we base our growth estimates on the pre-COVID-19 IMF World Economic Outlook (IMF, 2019); i.e., the base scenario excludes the expected negative impacts of COVID-19. The exogenous part of TFP growth is adjusted to generate these growth rates. In non-base scenarios, GDP growth is invariably endogenous. For total population and population in the labor force age 15 to 64, we impose projections from the 2019 World Population Prospects of the UN Population Division.

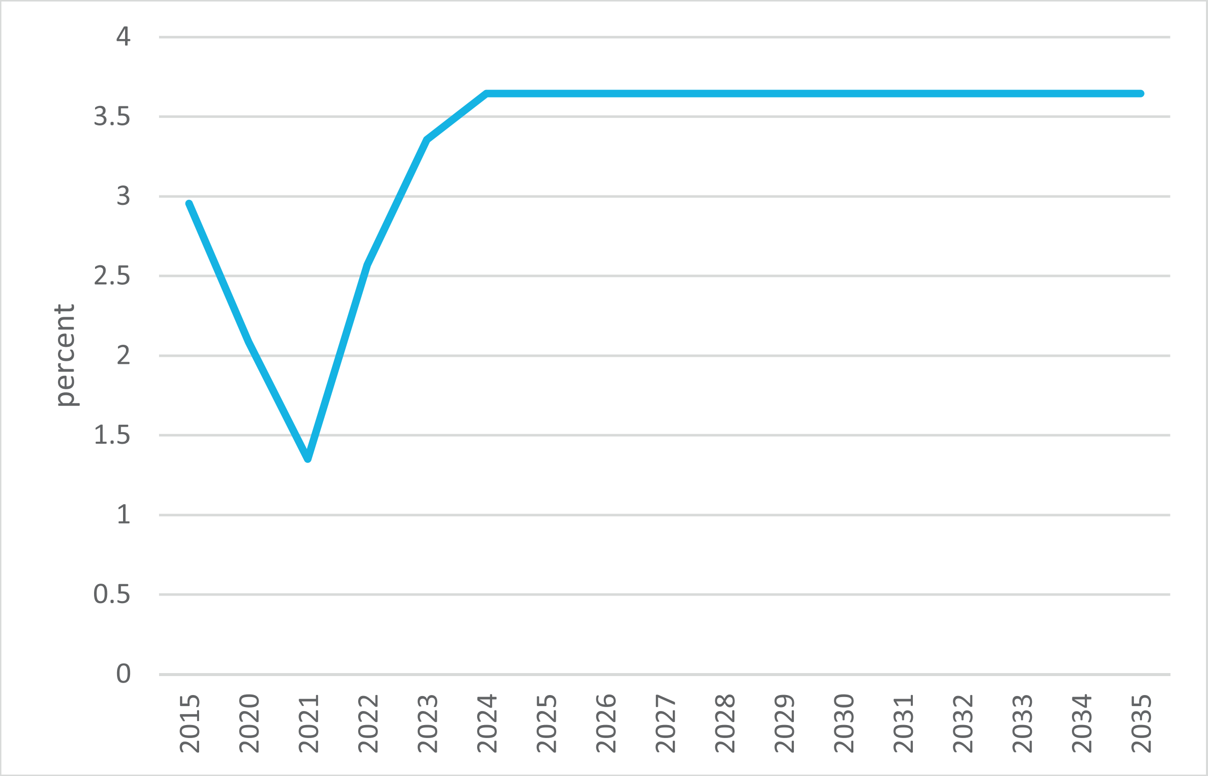


Fig. A.5. Base GDP growth rate, in percent.
Source: Authors' calculations based on simulation results.

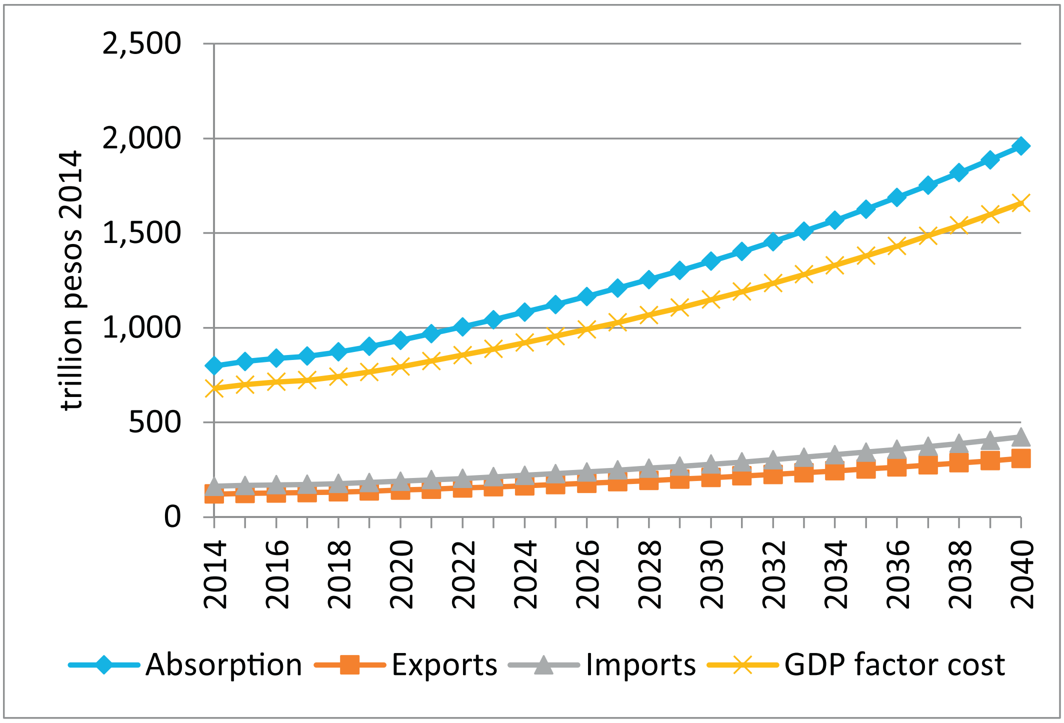
At the macro level, IEEM, like any other CGE model, requires the specification of equilibrating mechanisms (or "closures") for three macroeconomic balances: government, savings-investment, and the balance of payments. For the base scenario, the following closures are used: (a) government: its accounts are balanced via adjustments in net foreign financing; (b) savings-investment: household savings adjust to accommodate exogenous GDP shares for domestic private investment while foreign (private) investment is financed via the balance of payments and government investment is covered within the government budget; and (c) balance of payments: the real exchange rate equilibrates this balance by influencing export and import quantities and values; the non-trade-related payments of the balance of payments (transfers and non-government net foreign financing) are non-clearing, kept fixed as shares of GDP.

In addition, assumptions must be made for exogenous variables for the base scenario. Among the government-related payments, tax rates are fixed at base-year values. Fixed GDP shares at base-year values are imposed for the other payments: (a) government demand for (alternatively, government provision of) government services; (b) transfers from government to households; and (c) domestic financing of the government. For non-government payments, base-year GDP shares are similarly imposed over time for transfers from rest of the world to households, foreign direct investment, non-government net foreign financing, and factor income to/from abroad.

Figs. A.6–A.9 show key macroeconomic and sectoral results for the base. As already stated, given that it is intended to be a business-as-usual scenario, the base is set up to maintain the initial macroeconomic structure. Figs. A.6 and A.7 show the evolution of the levels of GDP, foreign trade, and domestic final demand aggregates. In Fig. A.5, this information is translated into average annual growth rates, which are near identical across the different indicators (at 4.9–5.0% per year during the period 2019–2030). At the sector and island level, the GDP growth rates are generally close to aggregate GDP growth (Fig. A.6 and Table A.5).

For agriculture (i.e., crops and livestock), growth is lower due to slow growth of land supplies and low-income elasticities of demand. GDP growth is strong enough to reduce the (broadly defined) unemployment rate, from 9.1% in 2014 to 5.4% in 2040. The real wage grows at a rate of 2% per year on average. In per-capita terms, household consumption grows at a rate of 2.9% per year.

In what follows, all shocks (i.e., deviations from the base scenario) are introduced during the period 2020–2030; i.e., base and non-base scenarios are the same up to and including 2019.



Source: Authors' calculations based on simulation results.

Fig. A.6. Base, selected macroeconomic indicators, in billion 2014 pesos.
Source: Authors' calculations based on simulation results.

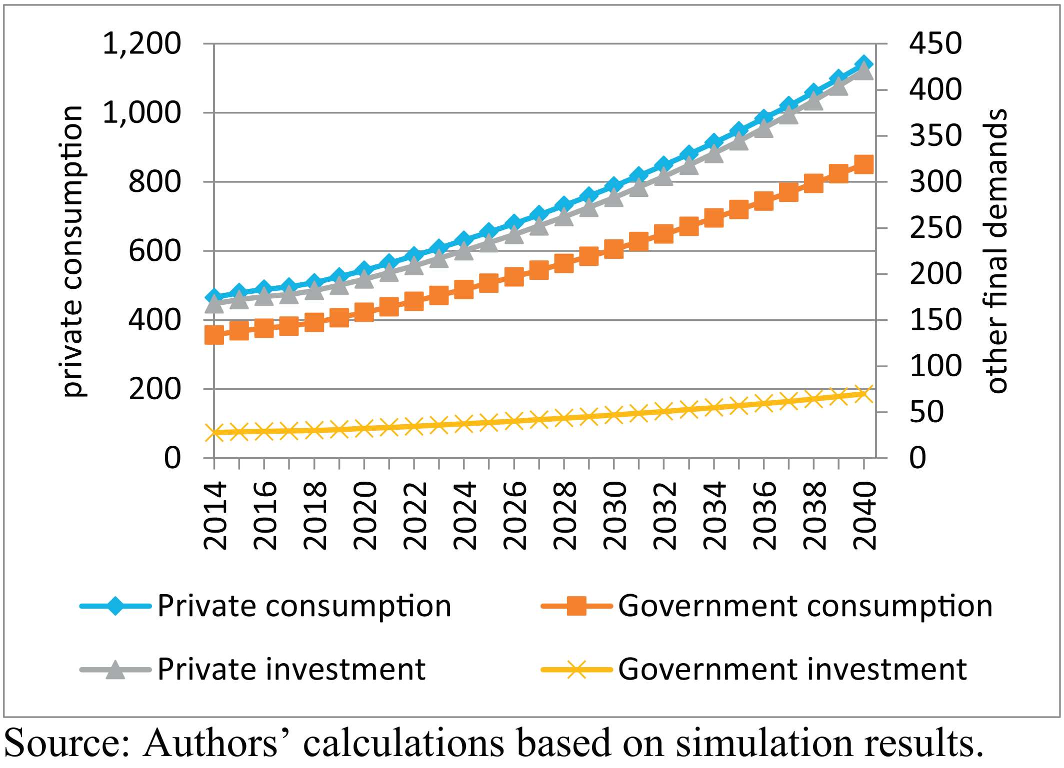


Fig. A.7. Base, domestic final demands, in billions of 2014 pesos.
Source: Authors' calculations based on simulation results.

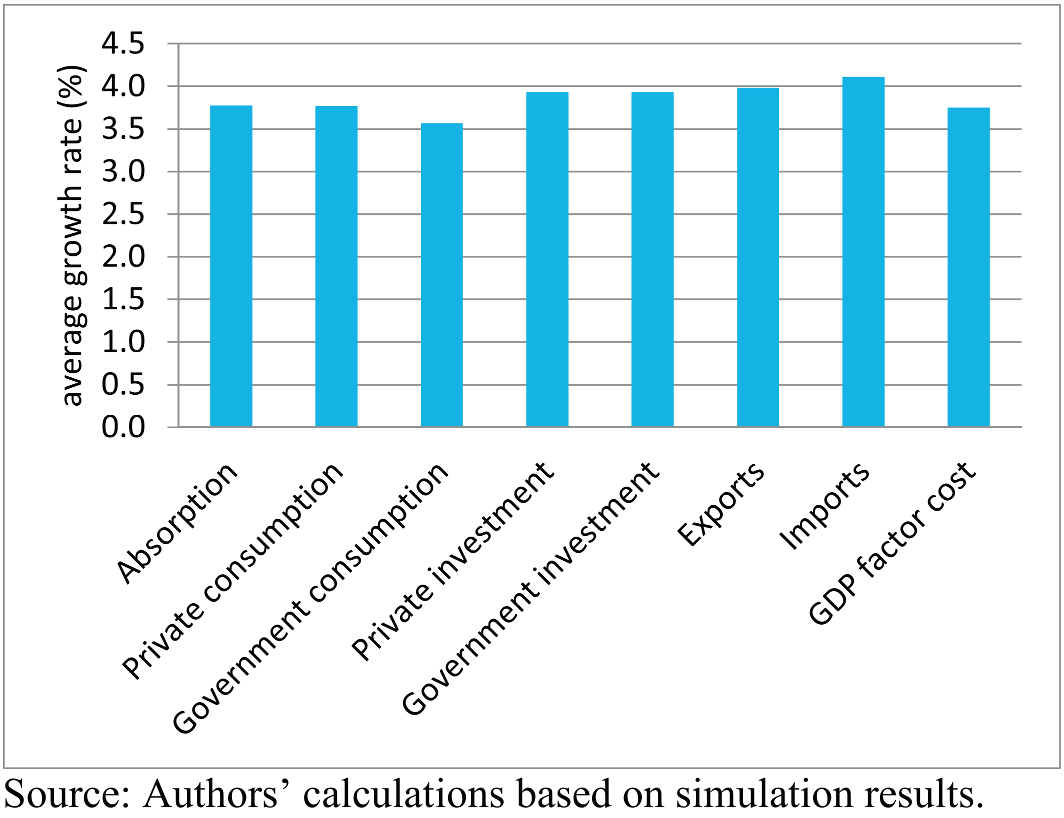
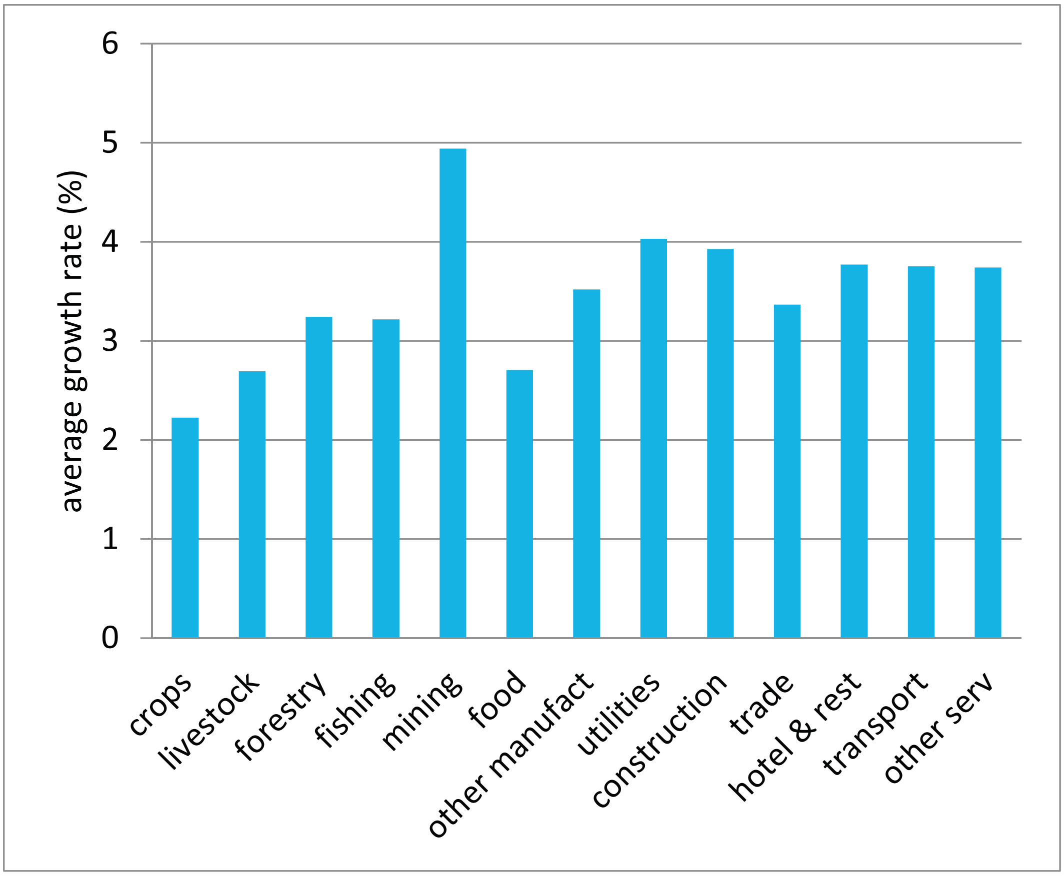


Fig. A.8. Base, real annual macroeconomic growth 2019–2025, in percent.
Source: Authors' calculations based on simulation results.



Source: Authors' calculations based on simulation results.

Fig. A.9. Base, real annual sector growth 2019–2025, in percent.
Source: Authors' calculations based on simulation results.

Appendix B. Details of scenario design

This section provides additional information on scenario design.

B.1. Business-as-usual scenario (BASE)

The BASE scenario is the business-as-usual scenario which projects the Colombian economy to 2035 without the implementation of any new public policy or investment. It is the reference scenario to which all subsequent scenarios are compared. To calibrate our expectations on the growth trajectory of the economy, we draw from International Monetary Fund projections and assume that GDP grows on average at 3.7% per year over the period 2019 to 2035 (IMF, 2019). Population projections were obtained from Colombia's National Administrative Department of Statistics (DANE). The supply of agricultural land grows by the rate of deforestation which is 0.3% per year across all of Colombia's 32 departments and extractive natural capital assets grow at the same rate as GDP.

B.2. Deforestation increase (DEFINC)

The first non-baseline scenario implements a 16% increase in annual deforestation between 2018 and 2035. This increase in deforestation is based on recent analysis by Fergusson et al. (2014) which showed that deforestation in recently demilitarized zones increased by 16%. This rate of deforestation is close to the observed rate of 20% per year between 2016 and 2018 (DNP, 2019). In this scenario, the allocation of deforested land between alternative uses is endogenous and responds to relative prices.

B.3. Deforestation decrease (DEFDEC)

This scenario simulates a 75% reduction in deforestation between 2018 and 2035, which would be expected to arise through more effective land-use planning, enforcement of forest law and improved monitoring of the agricultural frontier. As with the previous scenario, the allocation of deforested land between alternative uses is endogenous and responds to relative prices.

B.4. Deforestation Decrease and Agricultural Total Factor Productivity Increase (DEFDECTFP)

This scenario implements the 75% reduction in deforestation as the previous scenario as well as a 5-percentage point increase in agricultural Total

Factor Productivity (TFP) between 2018 and 2022. This implies a 12.5% increase above BASE TFP from 2022 onward.

For all scenarios, at the macro level, IEEM requires the specification of the balance mechanism for three macroeconomic equilibria.

For the non-base scenarios, these mechanisms are: (i) clearing of government fiscal imbalances through changes in household income tax rates. This assumption ensures that the simulations are budget neutral, that is, there is no additional domestic and/or foreign financing beyond baseline values; (ii) private investment is endogenous and marginal propensity to save clears the savings and investment balance, and; (iii) the real exchange rate adjusts to equilibrate inflows and outflows of foreign exchange, by influencing export and import quantities. This feature ensures that the scenarios are neutral in terms of changes in region net foreign assets. The non-trade-related payments of the balance of payments follow exogenously imposed paths.

References

Acosta, A., De los Santos-Montero, L.A., 2019. What is driving livestock total factor productivity change? A persistent and transient efficiency analysis. Global Food Security 21, 1–12. https://doi.org/10.1016/j.gfs.2019.06.001.

Agénor, P.-R., Chen, D.H.C., Grimm, M., 2004. Linking Representative Household Models with Household Surveys for Poverty Analysis: A Comparison of Alternative Methodologies, World Bank Policy Research Working Paper No.3343. World Bank, Washington D.C.

Álvarez, M.D., 2003. Forests in the time of violence. J. Sustain. For. 16, 47–68.

Arrow, K., Dasgupta, P., Goulder, L., Daily, G., Ehrlich, P., Heal, G., Levin, S., Mäler, K.-G., Schneider, S., Starrett, D., Walker, B., 2004. Are we consuming too much? J. Econ. Perspect. 18, 147–172.

Arrow, K.J., 2005. Personal reflections on applied general equilibrium models. In: Kehoe, T.J., Srinivasan, T.N., Whalley, J. (Eds.), Frontiers in Applied General Equilibrium Modeling: In Honor of Herbert Scarf. Cambridge University Press, Cambridge.

Arrow, K.J., Dasgupta, P., Goulder, L.H., Mumford, K.J., Oleson, K., 2012. Sustainability and the measurement of wealth. Environ. Dev. Econ. 17, 317–353.

Banerjee, O., Cicowiez, M., 2019. The Integrated Economic-Environmental Modeling Platform (IEEM), IEEM Platform Technical Guides: User Guide. IDB Technical Note No. 01843. Inter-American Development Bank, Washington DC.

Banerjee, O., Cicowiez, M., 2020. The Integrated Economic-Environmental Modeling (IEEM) Platform, IEEM Platform Technical Guides: IEEM Mathematical Statement IDB Technical Note No. 01842. Inter-American Development Bank, Washington DC.

Banerjee, O., Cicowiez, M., Horridge, M., Vargas, R., 2016. A conceptual framework for integrated economic–environmental modeling. J. Environ. Dev. 25, 276–305.

Banerjee, O., Cicowiez, M., Horridge, M., Vargas, R., 2019a. Evaluating synergies and trade-offs in achieving the SDGs of zero hunger and clean water and sanitation: an application of the IEEM platform to Guatemala. Ecol. Econ. 161, 280–291.

Banerjee, O., Cicowiez, M., Vargas, R., Horridge, M., 2019b. Construction of an Extended Environmental and Economic Social Accounting Matrix from a Practitioner's Perspective. IDB Technical Note No. IDB-TN-01793. Inter-American Development Bank, Washington DC.

Banerjee, O., Cicowiez, M., Vargas, R., Horridge, M., 2019c. The SEEA-based integrated economic-environmental Modelling framework: an illustration with Guatemala's Forest and Fuelwood sector. Environmental and Resource Economics 1–20.

Banerjee, O., Bagstad, K. J., Cicowiez, M., Dudek, S., Horridge, M., Alavalapati, J. R. R., Masozera, M., Rukundoh, E. & Rutebukah, E.Economic, and land use, and ecosystem services impacts of Rwanda's green growth strategy: an application of the integrated economic-environmental modelling platform. Sci. Total Environ.

Baptiste, B., Pinedo-Vasquez, M., Gutierrez-Velez, V.H., Andrade, G.I., Vieira, P., Estupiñán-Suárez, L.M., Londoño, M.C., Laurance, W., Lee, T.M., 2017. Greening peace in Colombia. Nature Ecology and Evolution 1, 0102.

Burfisher, M.E., 2011. Introduction to Computable General Equilibrium Models. Cambridge University Press, Cambridge.

Bustos, C., Jaramillo, M., 2016. What does the peace in Colombia have to do with the environment? The Guardian October 24, 2016.

Calderon, S.L., Prada, C.Z., Lopez, J.B., Romero, G.D., Cala, J.E.R., Vengoechea, R.C.O., Ibata, L.M., 2016. Dividendos Ambientales de la Paz: Retos y Oportunidades para Construir una Paz Sostenible. In: DNP (Ed.), Archivos de Economia Documento 451. Departamento Nacional de Planeacion, Direccion de Estudios Economicos, Bogota.

Cobb, C.W., 1995. The Genuine Progress Indicator: Summary of Data and Methodology. Redefining Progress, San Francisco.

Conca, K., Wallace, J., 2009. Environment and Peacebuilding in war-torn societies: lessons from the UN environment Programme's experience with Postconflict assessment. Global Governance: A Review of Multilateralism and International Organizations 15, 485–504.

CONPES, 2018. Politica de Crecimiento Verde. Consejo Nacional de Politica Economica y Social, Bogota, DC.

Costanza, R., Hart, M., Posner, S., Talberth, J., 2009. Beyond GDP: the need for new measures of Progress. In: Pardee Paper No. 4. Pardee Center for the Study of the Longer-Range Future, Boston.

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S.J., Kubiszewski, I., Farber, S., Turner, R.K., 2014a. Changes in the global value of ecosystem services. Glob. Environ. Chang. 26, 152–158.

Costanza, R., Kubiszewski, I., Giovannini, E., Lovins, H., Mcglade, J., Pickett, K.E., Ragnarsdóttir, K., Roberts, D., de Vogli, R., Wilkinson, R., 2014b. Development: time to leave GDP behind. Nature 505, 283–285.

Daily, G.C. (Ed.), 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington, DC.

Daly, H., 2017. A further critique of growth economics. In: Shmelev, S. (Ed.), Green Economy Reader: Lectures in Ecological Economics and Sustainability. Springer International Publishing, Cham.

Daly, H.E., 2008. Growth and development: critique of a credo. Popul. Dev. Rev. 34, 511–518.

Daly, H.E., Cobb, J.B., 1994. For the Common Good: Redirecting the Economy toward Community, the Environment, and a Sustainable Future. Beacon Press, Boston.

DANE, 2016. Tercer Censo Nacional Agropecuario. Departamento Administrativo Nacional de Estadistica, Bogota.

DANE, 2017. Las cuentas ambientales y economicos en Colombia. In: NACIONALES, D. D. S. Y. C (Ed.), Grupo De Indicadores y Cuentas Ambientales. Dirección Nacional de Estadística, Bogota.

Dávalos, L.M., Bejarano, A.C., Hall, M.A., Correa, H.L., Corthals, A., Espejo, O.J., 2011. Forests and drugs: coca-driven deforestation in tropical biodiversity hotspots. Environmental Science & Technology 45, 1219–1227.

Departamento Nacional De Planeacion, 2017a. Diagnostico de Crecimiento Verde: Analisis Macroeconomico y Evaluacion del Potencial de Crecimiento Verde en Colombia. DNP, Bogota.

Departamento Nacional De Planeacion, 2017b. Evaluacion de Potencial de Crecimiento Verde Para Colombia: Dialogo para la Identificacion del Potencial de Crecimiento Verde. DNP, Bogota.

Dervis, K., De Melo, J., Robinson, S., 1982. General Equilibrium Models for Development Policy. Cambridge University Press, Cambridge.

Dimaranan, B.V., 2006. Global Trade, Assistance, and Production: The GTAP 6 Data Base. Center for Global Trade Analysis, Purdue University, West Lafayette.

Dixon, P., Jorgenson, D.W. (Eds.), 2012. Handbook of Computable General Equilibrium Modeling. Elsevier, Oxford.

Dixon, P.B., Rimmer, M.T., 1998. Forecasting and policy analysis with a dynamic CGE model of Australia. In: C. O. P (Ed.), Studies. Centre of Policy Studies, Melbourne.

Dixon, P.B., Rimmer, M.T., 2002. Dynamic General Equilibrium Modelling for Forecasting and Policy: A Practical Guide and Documentation of MONASH, Amsterdam, North-Holland.

Dixon, P.B., Parmenter, B.R., Sutton, J., Vincent, D., 1982. ORANI: A Multisectoral Model of the Australian Economy, Amsterdam, North Holland.

Dixon, P.B., Parmenter, B.R., Powell, A., Wilcoxen, P.J., 1992. Notes and Problems in Applied General Equilibrium Economics, Amsterdam, North-Holland.

DNP, 2019. Bases Técnicas para la Formulación del Documento CONPES para el Control de la Deforestación y Gestión Integral de los Bosques. In: Documento Contrato 102–2019. Dirección de Ambiente y Desarrollo Sostenible. Sin publicar. Departamento Nacional de Planeacion, Bogota sin publicar.

Edens, B., Hein, L., 2013. Towards a consistent approach for ecosystem accounting. Ecol. Econ. 90, 41–52.

Eigenraam, M., Obst, C., 2018. Extending the production boundary of the system of National Accounts (SNA) to classify and account for ecosystem services. Ecosystem Health and Sustainability 4, 247–260.

Etter, A., Mcalpine, C., Pullar, D., Possingham, H., 2006. Modelling the conversion of Colombian lowland ecosystems since 1940: drivers, patterns and rates. J. Environ. Manag. 79, 74–87.

European Commission, International Monetary Fund, Organisation for Economic Cooperation and Development, United Nations & Bank, W, 2009. System of National Accounts 2008. EC, IMF, OECD, UN, WB.

Fergusson, L., Romero, D., Vargas, J.F., 2014. The environmental impact of civil conflict: the deforestation effect of paramilitary expansion in Colombia. In: Universidad del Rosario, Working Paper No. 165, Setpember 2014. Universidad del Rosario Facultad de Economia, Bogota.

Guerry, A.D., Polasky, S., Lubchenco, J., Chaplin-Kramer, R., Daily, G.C., Griffin, R., Ruckelshaus, M., Bateman, I.J., Duraiappah, A., Elmqvist, T., Feldman, M.W., Folke, C., Hoekstra, J., Kareiva, P.M., Keeler, B.L., Li, S., Mckenzie, E., Ouyang, Z., Reyers, B., Ricketts, T. H., Rockström, J., Tallis, H. & Vira, B., 2015. Natural capital and ecosystem services informing decisions: from promise to practice. Proceedings of the National Academy of Sciences 112, 7348–7355.

Hamilton, K., 2000. Genuine saving as a sustainability Indicator. In: Environmental Economics Series Paper No. 77. World Bank, Washington DC.

Hanley, N., Dupuy, L., Mclaughlin, E., 2014. Genuine savings and sustainability. In: Discussion Papers in Environmental Economics Paper 2014–09. University of St. Andrews, St. Andrews.

Hein, L., Bagstad, K.J., Obst, C., Edens, B., Schenau, S., Castillo, G., Soulard, F., Brown, C., Driver, A., Bordt, M., Steurer, A., Harris, R., Caparrós, A., 2020. Progress in natural capital accounting for ecosystems. Science 367, 514–515.

Hoekstra, R., 2009. Replacing GDP by 2030: Towards a Common Language for the Well-Being and Sustainability Community. Cambridge Core.

IDEAM, 2010. Leyenda Nacional de Coberturas de la Tierra. Metodología CORINE Land Cover adaptada para Colombia Escala 1:100.000. Instituto de Hidrología, Meteorología y Estudios Ambientales, Bogotá.

IDEAM, 2019. Proyecciones de Deforestación. In: Unpublished PowerPoint Presentation. Instituto de Hidrología, Meteorología y Estudios Ambientales, Bogotá.

IDEAM, 2020. Programa de Monitoreo y Seguimiento de los bosques y Áreas de Aptitud Forestal [Online]. Instituto de Hidrología, Meteorología y Estudios Ambientales, Bogotá. Available: http://www.ideam.gov.co/web/bosques/deforestacion-colombia [Accessed].

IDEAM, PNUD, MADS, DNP, CANCILLERÍA, 2008. Segundo Reporte Bienal de Actualización de Colombia a la Convención Marco de las Naciones Unidas para el Cambio Climático (CMNUCC). DEAM, PNUD, MADS, DNP, CANCILLERÍA, FMAM, Bogotá.

IMF, 2019. Global Manufacturing Downturn, Rising Trade Barriers. International Monetary Funds, Washington, DC.

IPBES, 2019. Summary for Policymakers in the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn.

Jiménez, M.I., Abbott, P., Foster, K., 2018. Measurement and analysis of agricultural productivity in Colombia. Ecos de Economía 22, 4–37. https://doi.org/10.17230/ecos.2018.47.

Kalimeris, P., Bithas, K., Richardson, C., Nijkamp, P., 2020. Hidden linkages between resources and economy: a "beyond-GDP" approach using alternative welfare indicators. Ecol. Econ. 169, 106508.

Kehoe, T.J., 2005. An evaluation of the performance of applied general equilibrium models of the impact of NAFTA. In: Kehoe, T.J., T. N. S. A. J. W (Eds.), Frontiers in Applied General Equilibrium Modeling: Essays in Honor of Herbert Scarf. Cambridge University Press, Cambridge.

Lange, G.-M., Wodon, Q., Carey, K. (Eds.), 2018. The Changing Wealth of Nations 2018: Building a Sustainable Future. World Bank, Washington DC.

Mcneish, J.-A., 2017. Extracting justice? Colombia's commitment to mining and energy as a foundation for peace. The International Journal of Human Rights 21, 500–516.

Millenium Ecosystems Assessment, 2005. Ecosystems and Human Well-Being: Synthesis. Island Press, Washington, DC.

Moreno, L.A., Andrade, G.I., Goméz, M.F., 2019. Biodiversidad 2018. In: Estado y tendencias de la biodiversidad continental de Colombia. Instituto de Investigación de Recursos Biológicos Alexander von Humboldt, Bogotá, DC.

Muhammad, A., Seale, J.L., Meade, B., Regmi, A., 2011. International Evidence on Food Consumption Patterns: An Update Using 2005 International Comparison Program Data, United States Department of Agriculture Economic Research Service Technical Bulletin Number 1929. United States Department of Agriculture, Washington DC.

Nepstad, D.C., Bezerra, T., Tepper, D., Mccann, K., Stickler, C., Mcgrath, D.G., Barrera, M.X., Lowery, S., Armijo, E., Higgins, M., Monschke, J., Gomez, R., Velez, S., Tejada, M., Tejada, M., Killeen, T., Schwalbe, K., Ruedas, A., 2013. Como Abordar los Motores Agricolas de la Deforestacion en Colombia. Earth Innovation Institute, San Francisco.

Nordhaus, W., Tobin, J., 1972. Is growth obsolete?. In: Economic Research: Retrospect and Prospect Economic Growth, 5. National Bureau of Economic Research, Inc.

OECD, 2013. Guidelines on Measuring Subjective Well-Being. Organisation for Economic Co-operation and Development, Paris, Paris.

PARES, 2018. Cómo Va La Paz: La Reestructuración Unilateral Del Acuerdo De Paz. Fundación Paz & Reconciliación; & La Iniciativa: Unión por la Paz, Bogotá.

Pearce, D.W., Atkinson, G., Mourato, S., 2006. Cost-Benefit Analysis and the Environment: Recent Developments. OECD, Paris.

Polasky, S., Bryant, B., Hawthorne, P., Johnson, J., Keeler, B., Pennington, D., 2015. Inclusive wealth as a metric of sustainable development. Annual Review of Environment & Resources 40, 445–466.

Rees, W., Wackernagel, M., 1996. Urban ecological footprints: why cities cannot be sustainable—and why they are a key to sustainability. Environ. Impact Assess. Rev. 16, 223–248.

Rodríguez, R.C., 2017. Reducción de Emisiones Rancho Ganadero: Una Alternativa Ambientalmente Responsable y Sostenible para el Desarrollo Rural en Colombia. In: Documento del Banco Inter-Americano de Desarrollo. Inter-American Development Bank, Bogota.

Sachs, J.D., 2015. The Age of Sustainable Development. Columbia University Press, New York.

Sadoulet, E., de Janvry, A., 1995. Quantitative Development Policy Analysis. The Johns Hopkins University Press, Baltimore.

Sanchez-Triana, E., Ahmed, K., Awe, Y. (Eds.), 2007. Environmental Priorities and Poverty Reduction: A Country Environmental Analysis for Colombia. World Bank, Washington, DC.

SIMCI-UNODC, 2018. Informe de Monitoreo de Territorios Afectados por Cultivos Ilícitos 2017. Sistema Integrado de Monitoreo de Cultivos Ilícitos y Oficina de las Naciones Unidas contra la Droga y el Delito, Bogota.

Stiglitz, J.E., Sen, A., Fitoussi, J., 2009. Report by the Commission on the Measurement of Economic Performance and Social Progress.

Stiglitz, J.E., Sen, A.K., Fitoussi, J.P., 2010. Mis-Measuring our Lives: Why GDP Doesn't Add up. New Press, New York.

Suarez, A., Árias-Arévalo, P.A., Martínez-Mera, E., 2017. Environmental Sustainability in Post-Conflict Countries: Insights for Rural Colombia. Environment, Development and Sustainability.

UN, 1993. Handbook of National Accounting: Integrated Environment and Economic Accounting. United Nations, New York.

UNEP, 2018. Inclusive Wealth Report 2018. United Nations Environment Programme, Geneva.

UNEP, UNSD, CBD, 2017. SEEA experimental ecosystem accounting: technical recommendations. In: Consultation Draft. UNEP, UNSD, CBD, Geneva.

United Nations Committee of Experts on Environmental-Economic Accounting, 2017. Global assessment of environmental-economic accounting and supporting statistics 2017. In: Statistical Commission Forty-Ninth Session. United Nations Statistical Division, New York.

United Nations, European Commission, Food and Agriculture Organization, International Monetary Fund, Organisation For Economic Cooperation and Development & The World Bank, 2014a. System of Environmental Economic Accounting 2012- Central Framework. UN, New York.

United Nations, European Union, Food and Agriculture, O. O. T. U. N, Organisation for Economic Cooperation and Development & World Bank Group, 2014b. System of Environmental-Economic Accounting 2012: Experimental Ecosystem Accounting. UN, EU, FAO, OECD, WBG, New York.

UNODC, 2019. World Drug Report 2019. In: Booklet 4: Stimulants. United Nations Office on Drugs and Crime, Vienna.

UNU-IHDP & UNEP, 2012. The Inclusive Wealth Report 2012: Measuring Progress toward Sustainability. Cambridge University Press, Cambridge.

UNU-IHDP & UNEP, 2014. Inclusive Wealth Report 2014: Measuring Progress toward Sustainability. Cambridge University Press, Cambridge.

World Bank, 2005. Where Is the Wealth of Nations? Measuring Capital for the 21st Century. World Bank, Washington DC.

World Bank, 2011. The changing wealth of nations: measuring sustainable development in the new millennium. In: Environment and Development. World Bank, Washington DC.

World Bank, 2015. Colombia: Systematic Country Diagnostic. World Bank, Washington DC.