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Integrating the Value of Natural Capital in Evidence-based Policy Making

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Abstract

This paper describes how Natural Capital Accounting (NCA) can be integrated into economy-wide analytical frameworks to enhance evidence-based decision-making. Examples from applications of the Integrated Environmental-Economic Modelling (IEEM) Platform show how explicitly accounting for the contributions of the environment to the economy in economic forecasting can lead to substantially different policy recommendations, overcoming some of the scope limitations of traditional economic performance analysis. Furthermore, the paper describes how NCA can be integrated into more traditional economic performance measurements, such as the System of National Accounts and their indicators such as adjusted Gross Domestic Product and Genuine Savings. Integration of natural capital into economy-wide analytical frameworks leads to better policy uptake of research findings and it empowers policymakers to avoid short-sighted decisions, which, although they can generate short-term economic gain, can have adverse consequences for economic, social, and environmental sustainability in the long run.

JEL codes: C68, E21, E23, E27, Q15, Q18, Q2, Q3, Q5.

JEL subjects: C68 Computable General Equilibrium Models; E21 Consumption, Saving, Wealth; E22 Investment, Capital, Intangible Capital, Capacity; E23 Production; E27 Forecasting and Simulation: Models and Applications; Q15 Land Use, Irrigation, Agriculture and Environment; Q18 Agricultural Policy, Food Policy; Q2 Renewable Resources and Conservation; Q3 Nonrenewable Resources and Conservation; Q5 Environmental Economics.

Executive Summary

This paper describes how Natural Capital Accounting (NCA) can be integrated into economy-wide analytical frameworks to enhance evidence-based decision making. We have based this integration on solid theoretical advancements in the measurement of wealth and the international acceptance of the System of Environmental-Economic Accounting (SEEA) as the first statistical standard for environmental-economic accounting consistent with the System of National Accounts (SNA). We briefly review the historical developments in the measurement of economic performance, from the wartime beginnings of the SNA and its flagship indicator, Gross Domestic Product (GDP), to more recent multi-dimensional measures of economic development like wealth and Genuine Savings. We present three practical case study applications of the Integrated Economic-Environmental Modelling (IEEM) Platform, which are published in the peer review literature, that demonstrate how accounting for the contributions of the environment to the economy in public policy and investment analysis can lead to substantially different policy recommendations, overcoming some of the scope limitations of GDP.

In the first case study, IEEM was applied to post-conflict Colombia to examine potential deforestation trajectories and the establishment of a Payment for Ecosystem Services (PES) Program. This implementation has key takeaways for policymakers that show how deforestation as a policy of omission can appear positive for GDP in the short-term, but have strong negative impacts on the future well-being of the country through reduction in natural capital stocks and greenhouse gas emissions damages. Indeed, halting deforestation could have a short run negative impact on GDP which could guide policy in the wrong direction as becomes evident when we consider the impact of deforestation on wealth. Reducing deforestation would boost wealth in the long-term, equivalent to US$2,664 million while on the other hand, increasing deforestation would reduce wealth by US$569 million. These are non-trivial quantitative findings that provide a strong argument for the use of wealth indicators for informing public policy and investment. While the argument for indicators that go beyond GDP is not new, quantitative demonstration of how a GDP versus wealth approach can result in polar-opposite policy positions is.

In the second case study, we examine synergies and trade-offs in strategies for implementing the Sustainable Development Goals (SDGs) in Guatemala. Specifically, we examine strategies to end hunger, achieve food security, improve nutrition and promote sustainable agriculture (SDG 2), and; strategies to ensure availability of water and sanitation for all (SDG 6). The quantitative consideration of synergies and trade-offs is critical given that positive actions to achieve goals in one policy arena might carry unintended consequences in another. This is particularly relevant when tackling any of the extensive list of 169 targets present in the 17 SDGs. Our application of IEEM to SDGs 2 and 6 in Guatemala focused on investments to improve agricultural output and incomes through increasing irrigated area, and increasing water and sanitation access, respectively.

Our results demonstrate that these investments would lift 2.4 million individuals out of poverty, would boost GDP by US$1.37 billion, diversify the agricultural sector, create new employment and generate additional wealth. While these are all positive indications of promising strategies, enhancing irrigated agricultural development would be insufficient to reach the goal of doubling income, with an income gap of 83% remaining. We show that an unintended consequence of this strategy for increasing agricultural productivity would render agriculture more economically

attractive and as a result, stimulate new deforestation to generate land for agriculture as well as increased greenhouse gas emissions.

This case study highlights the importance of adopting an integrated analytical framework such as IEEM for analysis of complex policy goals and their interactions. We demonstrate specific trade-offs and synergies that these SDG strategies imply. For example, the increase in deforestation moves Guatemala away from SDG 15 while SDG 13 calls for action on climate change, though the expansion of agriculture gives rise to 642,346 tons of additional greenhouse gas emissions. Agricultural expansion has consequences for overall water consumption, increasing consumption by 1,860 megaliters per capita. This is problematic where climate change projections describe a future Guatemala that has less water available for all uses.

In the third case study, we implement our IEEM framework linked with Ecosystem Services Modelling (IEEM+ESM) to evaluate various lines of action derived from Rwanda's Green Growth Strategy and underpinning government policy proposals. The specific portfolio of policies we examine aim to enhance standing forest stocks, improve household fuelwood consumption efficiency and increase agricultural productivity through irrigation and fertilization. Our results show that all scenarios considered to restore forests, improve household fuelwood consumption efficiency, and expanding irrigation and fertilization were positive from the perspective of GDP and in most cases, wealth. Increasing fertilization generated the greatest economic gain given current low rates of application.

The strength of our linked IEEM+ESM approach is demonstrated in a number of ways. For example, while fertilization generated the greatest economic gains, it is in fact the expansion of forest plantations that contribute to reversing a 25-year trend of forest loss in Rwanda and provide the greatest returns in terms of ecosystem services supply. Furthermore, increased fertilization poses serious challenges in terms of water quality. Finally, another powerful aspect of our analytical approach is the ability to interpret spatially differentiated impacts. Provincial-scale analysis reveals that changes in ecosystem services, and their contributions to human well-being, are not equally distributed across Rwanda and thus require spatially targeted policy responses.

Integration of natural capital into economy-wide analytical frameworks leads to better policy uptake of research findings and it empowers policymakers to avoid short-sighted decisions, which, although they can generate short-term economic gain, can have adverse consequences for economic, social, and environmental sustainability in the long run. It also habilitates a portfolio approach to budget allocation where complex policy goals such as the SDGs and Green Growth are concerned, allowing policymakers to consider synergies and trade-offs between different sustainable development strategies.

1. Introduction

On 3 September 1939, at the outset of the Second World War, the young economist and *Industry Illustrated 'Trends'* writer Richard Stone was asked to join the Ministry of Economic Warfare of the United Kingdom and was given the task of tracking the imports of neutral countries. Noticing that all Italian oil-tankers were making for neutral ports around the Atlantic, he calculated that they would reach their destination on June 10, 1940. Because oil is a key input that underpins any army's supply lines and Italy was safeguarding it, Stone also predicted that Italy would declare war on that day, but was ridiculed by the Italophile section of the Foreign Office with one response: 'Unfounded suspicions … Italy is a delightful country … firm friend … a catholic country [which] needed a lot of paraffin for altar candles'. Precisely on the predicted date, Italy would prove Richard Stone correct (Pesaran and Harcourt, 2000) and that would catch the eye of John Maynard Keynes' long-time associate, central wartime policy-maker and economist, Sir Austin Robinson.

In 1941, Robinson convinced the Secretary to the War Cabinet to authorize him to recruit James Meade and Richard Stone to construct detailed national accounts for the United Kingdom as an essential part of planning wartime production, based on the supply and demand ideas set forth by Keynes in his book *How to Pay for the War* (1940). The collaboration of Meade's conceptual work and Stone's practical implementation ended up becoming a famous set of tables which were circulated as a white paper with the 1941 Budget. Those would later become the article *The Construction of Tables of National Income, Expenditure, Savings and Investment* (Meade and Stone, 1941). For the remainder of the War, Stone was responsible for the national accounts at the Central Statistical Office and produced national income and expenditure figures covering 1938-44 to help guide wartime production and decision making.

This solid start would catapult Stone into becoming the first director of the Department of Applied Economics at Cambridge in 1945, as well as a central figure in the development of the standardized System of National Accounts (Stone et al., 1947) that was subsequently adopted by the United Nations (Pesaran and Harcourt, 2000). Stone was central in pushing for the development of econometric methods and various other techniques to analyze National Accounts data at Cambridge. Almost four decades later, an accomplished Sir John Richard Nicholas Stone was awarded the Nobel Memorial Prize in Economic Sciences in 1984 "…for having made fundamental contributions to the development of systems of national accounts and hence greatly improved the basis for empirical economic analysis." (Royal Swedish Academy of Sciences, 1984).

One of the indicators produced within what evolved as the System of National Accounts (SNA), the Gross Domestic Product (GDP), went on to become the international protagonist of economic performance and its growth rate a national goal. However, while the SNA is certainly a milestone in the development of economic theory and practice because of its radical-at-the-time use of double-entry bookkeeping, this narrative illustrates the historical context of war that underpinned its creation and, thus, the central concerns of its developers at the time, which revolved around financing the war efforts and ensuring that factories had enough raw materials and resources to produce much-needed armament, army vehicles, fuel and essential gear and food for the troops. It also explains in part why it is currently being challenged by extensions and newer measures meant to reveal aspects of the world that were hidden from view by the very nature of the things meant

to be captured by the asset boundary of the SNA, and thus by GDP. The problems of economics and society are no longer exclusively those of securing supply lines in wartime.

As the Inclusive Wealth Report (UNU-IHDP and UNEP, 2012, 2014; UNEP, 2018) and the World Bank's Changing Wealth of Nations (Lange et al., 2018, 2006, 2006) series have made explicit over the years, society today places greater attention on matters that go beyond national income and cares about human health and well-being, placing value on the health of the environment, natural capital and the ecosystem services that it provides. The second section of this paper describes the problems with traditional economic performance measurements and presents the System of Environmental-Economic Accounting (SEEA; (European Commission et al., 2013), a complementary system to the SNA that expands beyond its limited asset boundary and overcomes its limitations related to accounting for natural capital in a consistent manner. This system is an internationally agreed upon statistical development that can inform multi-dimensional measures of wealth discussed in section 2.3. Section 2.4 describes how these statistical developments bridge multiple disciplines including ecology, geography and the environment and provide the data to enable new modelling approaches for capturing economy-environment-society interactions and generate more robust evidence-based policy advice (section 2.4).

Section 3 showcases one of these new modelling approaches, the Integrated Environmental-Economic Modelling Platform (IEEM) (Banerjee et al., 2016; Banerjee et al., 2019a, 2019b) which links Computable General Equilibrium (CGE), Land Use Land Cover Change (LULC) and ecosystem services modelling. More than that, it is firmly grounded on data provided by SEEA. We present the IEEM approach and demonstrate how policy recommendations are fundamentally different when taking a systemic and integrated approach to environmental and economic performance analysis than when relying on traditional measures like GDP alone. We have found that short term gains in GDP from natural capital exploitation and degradation often are accompanied by long term losses that outweigh them, but which are only revealed when assessing lost future income streams made evident by the Genuine Savings indicator. This multi-dimensional approach has also allowed us to consistently identify and quantify unintended negative consequences of policies that are effective for the goals for which they are designed, but that work against other explicitly desired development objectives. Finally, the spatial nature of LULC modelling has allowed us to capture the true economic impacts of changes in productivity prompted by initiatives that seem equally beneficial from a natural capital perspective (for example a deforestation ban vs. improved silvopastoral systems) but that have very different and unintuitive economic consequences.

Inclusive wealth indicators and integrated economic and environmental analytical approaches are not meant to replace or reject GDP and SNA. On the contrary, these elements build upon the great tradition of National Accounts, using modern statistical standards, state-of-the-art modelling techniques, and access to newer kinds of data in non-conventional ways to complement GDP, and at the same time wrest some of its supremacy. Were Sir Richard Stone alive, he would probably spearhead these newer developments to track welfare from a broader perspective himself, taking advantage of satellite images, artificial intelligence and ubiquitous data generation. After all, outlined in a research proposal that he submitted to the Nuffield Foundation in the summer of 1945, Stone's foundations for Cambridge's Department of Applied Economics, which would become home to some of the most famous contributors to modern economic science during his tenure, read:

> "…The ultimate aim of applied economics is to increase human welfare by the investigation and analysis of economic problems of the real world. It is the view of the Department that this can best be achieved by the synthesis of three types of study which now tend to be pursued in isolation. The Department will concentrate simultaneously on the work of observations, i.e. the discovery and preparation of data; the theoretical appraisal of problems, i.e. the framing of hypotheses in a form suitable for quantitative testing; and the development of statistical methods appropriate to the special problems of economic information." (Pesaran and Harcourt, 2000, p. F149).

Indeed, the special problems of modern times and the Anthropocene require us to innovate more than ever.

2. Background

2.1. Traditional economic performance measurement and its limitations

Modern standard economic measurement is based on the SNA, which was born in 1947 at the heart of the recently formed United Nations as a set of recommendations that carried over from the League of Nations Committee of Statistical Experts led by Richard Stone (Stone et al., 1947). These recommendations would mature into the 1953 report "*A System of National Accounts and Supporting Tables*" (United Nations, 1953), which consisted of a set of six standard accounts and a set of 12 standard tables that presented detail classifications of the flows in the economy. It featured a then innovative double entry format where each payment made in the economy became a corresponding payment received by another agent in the economy (or institutional sector, as termed within the system) echoing the macroeconomic concept of *circular flow of income*, which could trace its roots as far back as the 1700s with Richard Cantillon and François Quesnay (Miller and Blair, 2009). More than that, the SNA provided countries with an international lingua franca of economics, since its concepts and definitions of the accounts were widely applicable for most countries, including developing ones (European Commission et al., 2009).

In order to adapt to other statistical standards, such as the Balance of Payments (International Monetary Fund, 2009) and to the changing ways of conducting business that arise with new markets, new technologies, and new sectors of the economy, the SNA has been subject to five revisions by the United Nations in 1960, 1964, 1968, 1993, and 2008. In its current incarnation, the SNA declares that it "…is designed for economic analysis, decision-taking and peacemaking, whatever the industrial structure or stage of economic development reached by a country" and thus its classifications and accounting rules are meant to be universally applicable (European Commission et al., 2009). In one of its most simplified forms, the SNA summarizes the economy as an equality where the value of local production of goods and services added to imports should be equal to the purchases of those goods and services; i.e. the household final consumption of goods and services, exports, government purchases, and investment in capital goods (Miller and Blair, 2009).

The SNA provides many mechanisms for dividing the transactions between agents in the economy into sets of accounts. The rationale for this division is that the balancing item of each account is of economic/policy interest (European Commission et al., 2009). One of such balances is the result of deducting the cost of inputs (except labor) from the value of goods and services that are sold by

an industry. What is left is newly generated income that will be distributed between the owners of that industry's capital, payments to employees and compensation for the risk incurred during a given accounting period. This is known as Value Added and it is of economic interest because adding together the value added of all the economy's industries (with adjustments for capital formation and taxes) is equivalent to GDP (European Commission et al., 2009). This one figure, then, summarizes the economic efforts of all the residents in a country in a manner that is easy to convey and interpret and for that reason, it has become the mostly widely used metric of economic performance (Hoekstra, 2019). Intuitively, a larger GDP than last year's which generates additional income to be distributed to growing populations has a positive connotation while the opposite is perceived as negative.

GDP has limitations as to the insights it affords. This is not a fault of GDP but is a consequence of its very own mathematical definition. First, GDP considers all income as flows that contribute to its increase, but it does not distinguish whether income is being generated from the returns of capital investment or from the liquidation of capital stocks. As we and others have argued elsewhere, in business accounting, selling assets prevents companies from generating future returns from those assets, and reporting their liquidation as profits is illegal for companies in many countries (Banerjee et al., in press). Yet GDP reports many forms of capital liquidation including produced, natural or human capital, as positive contributions to economic growth. The sale of logs from a sustainably managed forest plantation that is later reforested, and the sale of wood from an illegally deforested pristine rainforest subsequently converted to pasture for cattle both count as a positive contribution to GDP. They differ enormously, however, in how they impact future societal welfare with the consequences of liquidating natural capital, its underpinning biodiversity and the ecosystem services that provide benefits to current and future generations (Daily, 1997).

Nonetheless, we must recognize that the SNA is not only GDP and that there are different indicators and accounts within the system that provide advice on how to deal with such issues. Indeed, the current revision of the SNA recognizes that:

> "Certain key aggregate statistics, such as GDP, that are widely used as indicators of economic activity at the level of the total economy, are defined within the SNA, but the calculation of such aggregates has long ceased to be the primary purpose for compiling the accounts" (European Commission et al., 2009).

It could be argued that the concept of a balance sheet for natural capital and other stocks could help circumvent the issues identified. Within the SNA, balance sheets record the status of each stock or asset at the beginning of the accounting period, transactions that add to, subtract from, or reappraise the total stock of that asset, and the status of the stock at the end of the period. Then, the Net Domestic Product is obtained from deducting the consumption of fixed capital from GDP and could be considered a better metric (European Commission et al., 2009; Repetto, 2007). However, depreciation of national stocks (of buildings, machinery, vehicles, infrastructure) has proven difficult to track by statistical offices and the implementation of balance sheets has not been widely implemented and its implementation is the exception rather than the rule. This is true of both manufactured and natural assets within the SNA, such as mines, standing timber, or heads of cattle.

Assume for a moment that national balance sheets were in fact widely implemented and produced with the same regularity and thoroughness as the income flow accounts used to calculate GDP; we would encounter another limitation of GDP. Within the SNA, the concept of the production boundary requires that every sale, purchase, or stock is owned by a resident, including the Government (European Commission et al., 2009). This lack of information on changes in natural and manufactured stocks already places blindfolds on policymakers, but GDP's limitations for informing policy do not stop there. GDP does not account for output that falls outside the production boundary, such as the ability of natural capital to provide ecosystem services that increase productivity in agriculture or contribute to drinking water quality, for example. Non-market, non-material ecosystem services fall entirely outside of national accounting systems (Banerjee et al., in press).

The current revision of the SNA acknowledges this limitation and points out that economic analysis is narrowly defined by the SNA. This is critical in that the SNA makes no claim to accounting for the contribution of natural capital or ecosystem services that is not mediated by people. Specifically:

> "A purely natural process without any human involvement or direction is not production in an economic sense. For example, the unmanaged growth of fish stocks in international waters is not production, whereas the activity of fish farming is production." (European Commission et al., 2009)

As we will see in the following sections through policy examples, advancements in the understanding of the indissoluble links between natural capital, the ecosystem services it provides, and a productive and sustainable economy put into question the validity of the above statement (Banerjee et al., in press). An important avenue of criticism of GDP is linked precisely to the question of whether the delimitation of the production boundary of the SNA captures all that is relevant to economic well-being.

Nobel scholar Joseph Stiglitz and his colleagues (2010, 2009) explain that GDP is popular because the monetary valuation of goods and services makes it easy to add up quantities of dissimilar things, but the problem is that many important services that affect society have no market price, such as the value of clean drinking water or the crop pollination services bees provide. As such, there is often a difference between what the consumer pays and the value of the goods and services that went into their production. They argue that the family of indicators within the SNA deal with the perspective of material living standards (income, consumption and wealth), but that there are various other dimensions of well-being that are poorly addressed by SNA, namely natural capital and ecosystem services, health, education and governance among others (Stiglitz et al., 2010, 2009).

A broader approach is taken by initiatives such as the Inclusive Wealth Report and the Changing Wealth of Nations that consider that wealth is the return to all forms of capital including produced capital and renewable and non-renewable resources regardless of ownership, as well as intangible capital which includes the stock of human skills and know-how, and the quality of institutions (Arrow et al., 2010; Lange et al., 2018, 2011, 2006; Polasky et al., 2015). From this perspective, a country may become wealthier by consuming one form of capital, while investing in other forms of capital.

While GDP is an effective measure of gross income flow, by ignoring the cost of the depletion or degradation of natural capital, it is a poor indicator of sustainable development and wealth (Lange et al., 2018; Polasky et al., 2015). 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). Using GDP as an indicator of development can have serious consequences for countries. For example, a high rate of GDP growth achieved through the over-exploitation of natural capital could be taken as an indication that a country is on a strong sustainable development path. The eventual liquidation of a country's natural capital, however could result in a sudden decline in GDP growth. This situation is exacerbated when a country does not reinvest the income from the exploitation of natural capital in other forms of capital, such as human capital (Banerjee et al., 2016). There are several countries that have experienced this fate through the exploitation of mineral and oil resources, without adequate reinvestment in human and produced capital.

To expand or contend GDP, many other alternatives have been devised from a neoclassical welfare economics or from a capital theory perspective under the term "Beyond-GDP". These include green accounting, which are measures that start with GDP but subtract welfare-reducing impacts, such as natural capital degradation, and add monetary value for welfare-enhancing dimensions such as leisure time (Hoekstra, 2019). There are also subjective well-being measures that provide data on the reported "life satisfaction" or "happiness" of a population, which generally tend to conclude that higher levels of GDP do not necessarily lead to higher well-being (Hoekstra, 2019). We will explore some of the beyond-GDP alternatives further into our discussion, but before we do so, we need to address an important development that will help streamline these initiatives from a statistical standpoint, namely the SEEA (Bartelmus et al., 1991; United Nations, 1993; United Nations et al., 2003; European Commission et al., 2013).

2.2 The System of Environmental-Economic Accounting and its extensions

As a result of the 1991 Special Conference on Environmental Accounting in Baden, Austria and the 1992 United Nations (UN) Conference on Environment and Development, the then launched Agenda 21 emphasized the importance of environmental accounting and called for a program to develop national systems of integrated economic and environmental accounts for all nations (United Nations et al., 2014). Methodological discussions from 1987 had matured into the methodological underpinnings of integrated environmental and economic accounting within the United Nations Statistical Division (Bartelmus et al., 1991), and in 1993, a collection of the principles for Integrated Environmental and Economic Accounting was published as a Handbook of National Accounting that capitalized on the novel SNA Satellite Accounts approach meant to introduce topics that went beyond traditional economic performance measurement "without overburdening the central framework of the SNA" (United Nations, 1993). Even if it was conceived as a satellite system, SEEA was designed to be compatible with SNA from the beginning (Banerjee et al., 2016; Obst and Vardon, 2014).

In 1994, the UN Statistical Commission established the London Group on Environmental Accounting as a forum for sharing experiences in the development of frameworks for environmental accounting. This group was instrumental in the revision of the 1993 SEEA and the production of the 2003 SEEA, as a set of best practices for environmental accounting (United Nations et al., 2003). One important aspect of the 2003 document was that it was endorsed by the

same institutions as SNA; namely the United Nations, the European Commission, the International Monetary Fund, the Organisation for Economic Co-operation and Development, and the World Bank. This set a precedent for its later development into a statistical standard, moving away from its satellite or experimental status (Edens and Haan, 2010; Obst et al., 2016). At the Statistical Commission's 43rd Session in March of 2012, the SEEA Central Framework was adopted as the International Standard for Environmental-Economic Accounting (Banerjee et al., 2016; European Commission et al., 2013).

The SEEA tracks changes to natural capital stocks and its contribution to the economy regardless of ownership (Dube & Schmithusen, 2003). In addition to the SEEA Central Framework Standard topic specific expansions include: (a) SEEA Water, a SEEA subsystem that provides a conceptual framework for organizing hydrological and economic data; (b) SEEA Energy, which defines agreed concepts and classifications for energy and energy-related emissions accounts; (c) SEEA Experimental ecosystem accounting; and (d) SEEA Agriculture, Forestry, and Fisheries. SEEA Applications and Extensions provides a demonstration of how SEEA may be used in research, policy, and decision making. Additional thematic areas for which guidance material exists include Air Emissions, Environmental Activity, Land and Material Flow Accounting (Banerjee et al., 2016).

In addition to SEEA's compatibility with the SNA 2008, it is compatible with the Balance of Payments and International Investment Position framework, the International Standard Industrial Classification of All Economic Activities (ISIC), the Central Product Classification system (CPC), and the Framework for the Development of Environment Statistics. This compatibility offers an unprecedented opportunity to advance the field of integrated economic-environmental modeling, with economy-wide Computable General Equilibrium (CGE) models which rely on the concepts and definitions of the aforementioned standards. Integration of SEEA in economy-wide policy modelling enables a robust representation of the environment in these modeling frameworks which traditionally had very little to say about the environment. Our previous work has shown that strong assumptions are often required to reconcile environmental and economic data for use in economy-wide modelling frameworks. The SEEA obviates the need for many of these strong assumptions and data reconciliation which greatly reduces start-up costs and the timeliness of policy advice (Banerjee et al., 2016).

The SEEA organizes data on economic-environmental interactions in three categories: (a) It describes the physical flows of materials and energy within the economy and between the economy and the environment, (b) it accounts for environmental resource stocks and changes to stocks, and (c) it accounts for transactions between economic units that are considered environmental (e.g., environmental protection and preservation) in monetary terms. The accounts themselves are made up of four types of tables: (a) Supply and Use Tables represent flows of environmental inputs, products, and residuals in physical and monetary units. Three subsystems were developed for Supply and Use Tables since not all physical flows should be recorded similarly or aggregated. The subsystems are material flow accounts, water accounts (cubic meters), and energy accounts (joules); (b) environmental asset accounts represent opening and closing stocks in physical and monetary terms (Banerjee et al., 2016; European Commission et al., 2013).

For the purposes of this paper, one of the most important developments after the publication of the 2012 SEEA (European Commission et al., 2013) was the advancement of SEEA Experimental

Ecosystem Accounting (United Nations, 2019; United Nations et al., 2014). This extension accounts for ecosystems and the services they provide through the integration of biophysical and land cover spatial data and links that information with economic activity (United Nations et al., 2014). The integration of spatially aware Land Cover Land Use data and related statistics into an accounting logic that can be regularly updated by dedicated teams at statistical offices around the world in the same manner as SEEA and SNA is an important step forward for integrated economic-environmental analytical frameworks like IEEM (Banerjee et al., 2016, 2020a, 2020b).

Information about the environment is inherently spatial, yet environmental accounting largely ignored the specific location of environmental assets for decades (European Commission et al., 2013). Ecosystem Accounting overcomes this limitation by the introduction of basic spatial units, land-cover/ecosystem functional units, and ecosystem accounting units. Basic spatial units are small areas, obtained by overlaying a grid on a map of the relevant territory. The size of this grid is often delineated by satellite remote-sensing pixels (or cadaster units), delineated as small as possible given available information. Land-cover/ecosystem functional units are collections of basic spatial units that share similar characteristics of an ecosystem such as forests, shrublands, cropland, and others. Countries often compile these in the form of LULC maps for agricultural planning. Ecosystem accounting units are delineated according to the accounting purpose and are collections of basic spatial units that are aggregated into relevant boundaries, such as administrative limits, environmental management areas, large-scale natural features such as river basins, and other relevant elements of delimitation. These elements join to form socio-ecological systems that integrate ecosystem functions and dynamics with human activities (United Nations et al., 2014). These areas are then designated as ecosystem assets.

Ecosystem Accounting deals with the measurement of the extent of ecosystem assets, its condition and the flow of ecosystem services that contribute to well-being and the economy. It recognizes provisioning services also known as material services (Díaz et al., 2015; IPBES, 2019) which are the regular elements that are tracked by SNA (e.g. output of timber or wheat) but also regulating or non-material ecosystem services (e.g. tons of CO_2 absorbed), and cultural services (e.g. number of visits to a national park) (United Nations, 2019; United Nations et al., 2014). Currently, Ecosystem Accounting is undergoing a revision process which will culminate in its elevation to an international Statistical Standard by 2021, consistent and compatible with the SNA and SEEA (United Nations, 2019).

SEEA, Ecosystem Accounting and its extensions are not themselves extended indicators of welfare, rather they are accounting structures that present environmental-economic information in a standard manner that extends how we measure economic performance in the SNA and enable us to make certain adjustments to SNA indicators including GDP (European Commission et al., 2013; Repetto, 2007). What the SEEA and Ecosystem Accounting does enable, however, is the estimation of various multi-dimensional measures of wealth. Examples include the Inclusive Wealth Index (UNEP, 2018, p. 2018) and Wealth Accounts and Adjusted Net Savings used by the World Bank in the Changing Wealth of Nations (Lange et al., 2018). They also can inform various other indicators for tracking progress related to the UN's Sustainable Development Goals (SDGs), the European New Green Deal, the OECD's Green Growth program, the Convention on Biological Diversity's Strategic Plan for Biodiversity, the Biodiversity Indicators Partnership related to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), the Strategic Framework of the UN's Convention to Combat Desertification, the UN Environment

Programme's Global Environmental Outlook, and the Biodiversity Finance Initiative (BIOFIN), among others.

2.3. Multi-dimensional measures of wealth

The SEEA provides data for the deduction of natural capital depletion from SNA indicators for the estimation of Depletion-adjusted Net Value Added, Depletion-adjusted Net Operating Surplus, Depletion-adjusted balance of primary income, Depletion-adjusted Net Disposable Income, and Depletion-adjusted Net Saving (European Commission et al., 2013). However, the limitations and critique of GDP are not linked to natural capital alone.

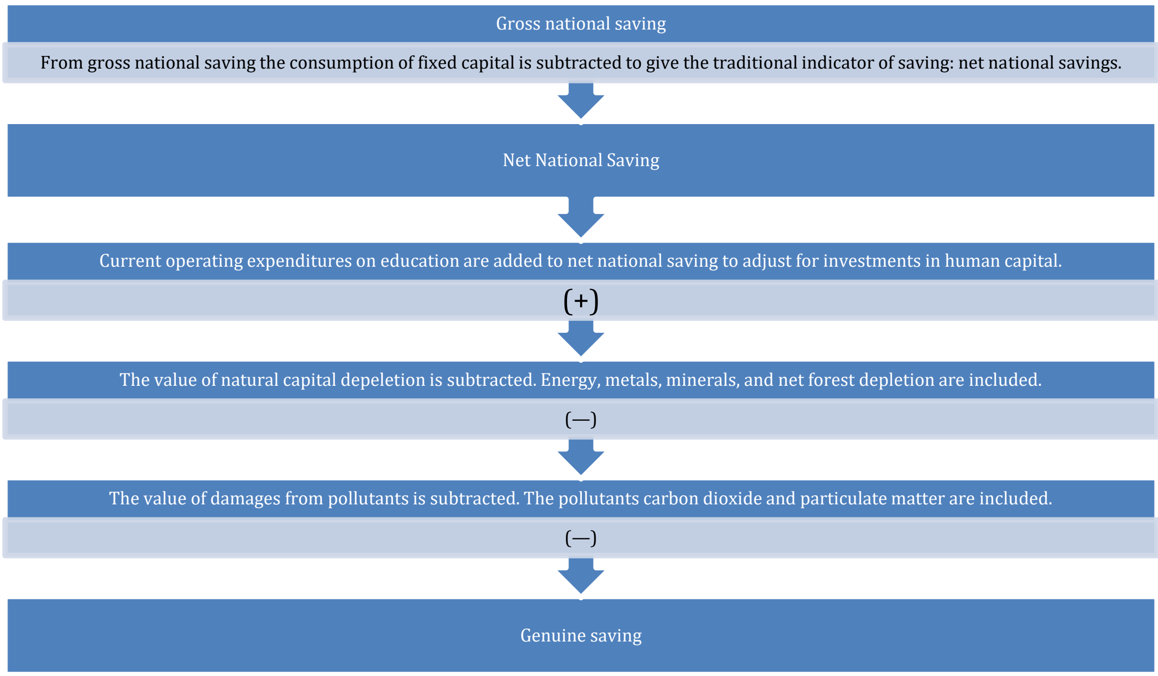
Theoretical and empirical developments to address the limitations of GDP (Stiglitz et al., 2010, 2009) can be categorized as a movement "Beyond-GDP" (Hoekstra, 2019). The Inclusive Wealth Index, for example, considers that comprehensive wealth is defined as the aggregate value of all capital assets that contribute to increasing current and future well-being. However, in order to be truly inclusive, its measures must include all forms of capital, namely financial capital, human capital, manufactured capital, natural capital, and social capital (2010, Arrow et al. 2004; Polasky et al., 2015). Another important aspect of the concept of Inclusive Wealth is that it has a clear footing in neoclassical economic theory (Arrow et al. 2010), unlike sustainable development indicators that take a more eclectic approach.

The inclusive wealth approach (2010, Arrow et al. 2004; Polasky et al., 2015) has underpinned estimations for several countries with initiatives like the UN's Inclusive Wealth Report (UNEP, 2018, p. 2018; UNU-IHDP and UNEP, 2014, 2012) and the World Bank Changing Wealth of Nations series (Lange et al., 2018, 2011, 2006). The Inclusive Wealth Index and Adjusted Net National Savings track wealth through time, though make some theoretical compromises due to the availability of data (Polasky et al., 2015). Increasing availability of data under the SEEA and Experimental Accounting will contribute to the robustness of these indicators in the future. The inclusive wealth literature combines macroeconomic metrics with biophysical and ecological data and modeling to capture natural capital and ecosystem service contributions to well-being.

It is important to point out that these inclusive wealth indices may not be entirely consistent with the SNA, SEEA and Experimental Ecosystem Accounting Approaches. As an example, the UN's Inclusive Wealth Index ascribes welfare values to different ecosystem services (e.g. the welfare value of standing forest). There is nothing inherently wrong with this approach, however, there are advantages to maintaining consistency with the international agreed upon statistical standards that begin with the SNA. The examples that we present at the end of this paper largely aim to maintain consistency with these international statistical standards, which we have found to be powerful when discussing results from analytical work to decision makers including Ministries of Finance, Central Banks and other Government institutions (Banerjee et al., in press).

In the application of the IEEM Platform for public policy and investment analysis, we have used an adjusted form of the Genuine Savings indicator which concentrates on the economic and environmental dimensions of wealth. Genuine Savings is Gross National Savings that accounts for the consumption of capital of all forms, including natural capital, investment in human capital and the damage from pollutants. Figure 1 shows the workflow for calculating Genuine Savings.

Figure 1. Flow chart of Genuine Saving Calculation.



Source: Adapted from Lange et al. (2006).

Hoekstra (2019) has categorized four permutations of Beyond GDP metrics that take into account the conceptual underpinning and whether the initiative is one indicator or a set of indicators. Among the conceptual index initiatives, Subjective Wellbeing relates to "Good mental states, including all of the various evaluations, positive and negative, that people make of their lives, and the affective reactions of people to their experiences". Wellbeing is evaluated through a satisfaction questionnaire (OECD, 2013). Green Accounting, a predecessor to SEEA and wealth accounting, addresses some of the limitations of GDP proposed by Kuznets (Eisner, 1988) and led to the development of the Measure of Economic Welfare (Nordhaus and Tobin, 1972), the Index for Sustainable Economic Welfare (Daly and Cobb, 1989), the Genuine Progress Indicator (Cobb et al., 1995) and the Ecological Footprint approach (Wackernagel, 1994).

Among the non-conceptual index category is the Human Development Index which aggregates indicators related to the economy, health and education into an index based on a simplified version of Sen (1988). Indexes allow for the ranking of countries, which is why they are popular (Hoekstra, 2019). Other examples include the Competitiveness Index of the World Economic Forum and the Global Innovation Index. A good example of the non-conceptual indicator category are the Sustainable Development Goals (United Nations, 2015).

2.4. Integrating Natural Capital and Ecosystem Services in Economic Modeling

In the final section of this paper we present examples of policy analysis using the IEEM Platform, which integrates the three dimensions of sustainable development and wealth, namely economy, society and environment. At the core of the IEEM Platform is a dynamic computable general equilibrium (CGE) model which are considered the workhorse for policy analysis (Jones, 1965)

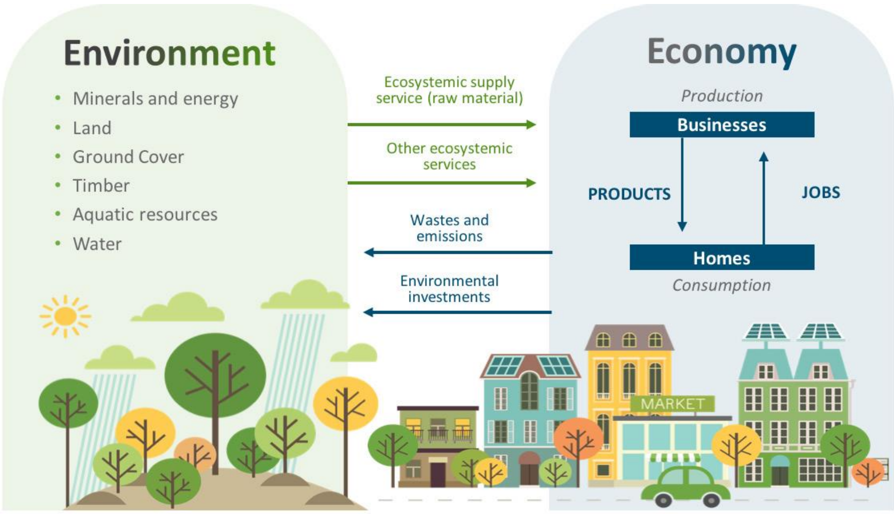
for the last few decades. IEEM was developed to address a major limitation in conventional CGE modeling which is the absence of a representation of the environment or the impacts of policies on the environment. Positive results of CGE analysis could mask changes to natural capital stocks, their condition, as well as environmental policy. The IEEM Platform addresses this limitation through the integration of data on natural capital and ecosystem services organized under the SEEA. Prior to IEEM, the integration of natural capital in a CGE framework typically addressed one natural capital asset at a time and required strong assumptions and significant data reconciliation efforts (Banerjee et al., 2016).

With a dynamic CGE model at the core of IEEM, a basic understanding of CGE models is useful. There is a rich literature that discusses the strengths and limitations of CGE modeling and applies it to questions of public policy and investment at national, regional and global scales (Burfisher, 2011; Dervis et al., 1982; Dixon et al., 1992; Dixon & Jorgenson, 2012; Horridge, 2000; Kehoe, 2005; Lofgren et al., 2002; Robinson et al., 1999; Shoven & Whalley, 1992). A CGE model is a mathematical representation of an entire economy, formalized by a system of equations that describe demand for commodities, intermediate and factor inputs, equations that relate prices and costs, and market-clearing equations for factors and commodities (Dixon et al., 1992). CGE models are the only real option for analyzing policies that are expected to have wide-spread and multi-sectoral impacts (Arrow, 2005).

The basic data that underpins any CGE model as well as IEEM is a Social Accounting Matrix (SAM), which is a table of transaction values and transfers (flows) that describes the structure of production and final demands, and the circular flow of income between all agents in an economy including industries, institutions, and factors of production for a reference year (King, 1985). This SAM is normally populated with data from SNA and its Integrated Economic Accounts (European Commission et al., 2009) and is consistent with traditional measures of economic performance such as GDP. For this reason, its results and recommendations are explained in a language that is more easily understood by policymakers. The data and SAM underpinning IEEM have special features that arise from the integration of data organized under the SEEA (Banerjee et al., 2019c).

Figure 2 shows how IEEM captures the interactions between the economy and the environment. On the left side, the environment is quantified according to the SEEA accounts structure. On the right, the economy is composed of firms that use labor, capital and other factors of production, as well as intermediate inputs to produce goods and services that are consumed by households, the government and export markets. The environment supplies the economy with provisioning ecosystem services. Through economic activity and household consumption of goods and services, emissions and waste are generated and returned to the environment. The model has a modular structure that can use one or more natural capital accounts as they become available. IEEM contains specific modules for forests, land, water, mineral and subsoil resources, fisheries, waste and residuals modules, and environmental investments, as they are represented in the SEEA, in order to capture their specific dynamics (Banerjee et al. 2016).

Figure 2. Environment-economy interactions within IEEM.



Source: author's own elaboration based on Banerjee (2019).

The IEEM Platform makes an important contribution to the modeling of real world problems due to: (i) its integration of rich environmental data based on the SEEA; (ii) IEEM's environmental modeling modules that capture the specific dynamics of each environmental asset (e.g. growth, harvesting and improvements, as well as legal or illegal deforestation and degradation); and (iii) IEEM indicators, such as genuine savings, changes to natural capital stocks and ecosystem service supply, that go beyond GDP to reflect impacts on manufactured capital, human capital and natural capital—the three pillars of wealth and sustainable development.

The integration of natural capital in a CGE that is achieved through IEEM is a first step toward capturing natural capital and ecosystem services' contribution to well-being. The next step and latest methodological advancement in integrated economic-environmental modeling is the linkage of IEEM with ecosystem services modeling (IEEM+ESM) (Banerjee et al., 2020a and 2020b; Banerjee et al., 2019b). This integration of IEEM with spatial modeling enables the contributions of natural capital and ecosystem services, both market and non-market, material and immaterial, to be increasingly accounted for in country or region-wide public policy and investment decision-making as more environmental data become available.

3.0 Public Policy Analysis with the IEEM Platform

In this section we present three cases applying the IEEM Platform to public policy analysis in Colombia, Guatemala and Rwanda. We follow the same format for the presentation of all three cases, in which we: (i) describe the country context, policy issue and planned government policy response; (ii) introduce the scenarios to asses policy alternatives; and (iii) present the relevant results framed around the policy conclusions. Throughout, we emphasize how IEEM's integrated approach provides additional insights that would be missed with traditional economic performance metrics alone. One common thread among these examples is that the countries featured here have made significant advances towards the implementation of SEEA. The additional insights afforded by SEEA's integration in IEEM provide a strong argument for widespread implementation of the SEEA for both future-looking policy analysis and the to track country economic performance and wealth.

3.1. Colombia

3.1.1. Policy context and planned government response

In 2016, the Government of Colombia signed a peace agreement with the Revolutionary Armed Forces of Colombia (FARC-EP: Fuerzas Armadas Revolucionarias de Colombia—Ejército del Pueblo) to end over 50 years of conflict. Based on lessons learned from other post-conflict countries, Suarez et al. (2018) found that peace time could intensify pressure on natural capital due to the return of displaced populations and the need to rebuild their livelihoods largely dependent on the primary sector.

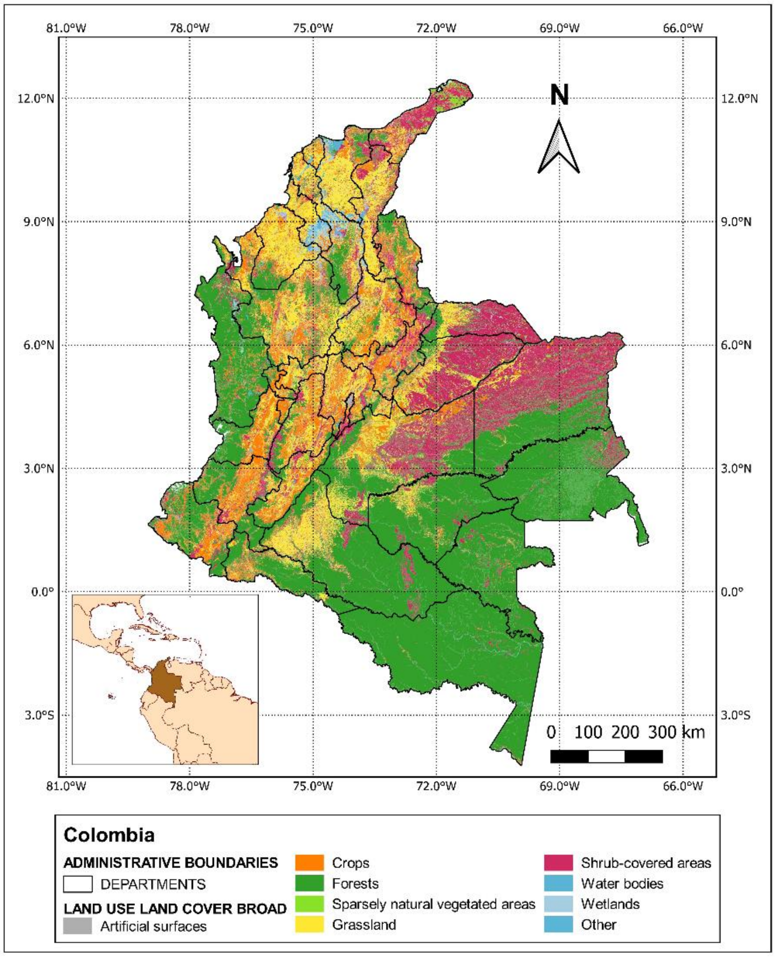
This is particularly troubling, because Colombia houses 10% of the planet's biodiversity and is one of the most biodiverse countries, second among all by some measures (CONPES, 2018; DNP, 2019). Figure 4 shows Colombia's land cover and use. Over half of the country is forested and it has the greatest abundance of water resources among countries in Latin America (World Bank, 2015). Non-renewable natural resource extraction accounted for 8.9% of GDP by November 2016 (DNP, 2017), when the Government of Colombia signed the peace agreement.

Deforestation is a major environmental impact of the conflict (Leopoldo Fergusson et al., 2014), with an estimated one million hectares of forest loss in some of the country's most fragile ecosystems. In twenty-five years, the country had lost 5.2 million hectares of forest cover, 3 million hectares of which were deforested in municipalities affected by the armed conflict (DNP, 2017). Deforestation, land degradation and soil erosion have been estimated to have cost the country on average 0.7% of GDP annually (Sanchez-Triana et al., 2007). During the last year of the armed conflict, the Colombian Amazon region accounted for 35% of the country's total deforestation; that same figure climbed to 70% a mere two years later (Pares, 2018).

Depending on the conflict area, there were different deforestation drivers, which include crops and livestock expansion in the Amazon through slash and burn practices from poor displaced populations followed by land speculation by cattle ranching operations, illegal mining in the North Pacific, and coca plantations and the extraction of high value wood in the Southern Pacific region. The expansion of agriculture and livestock was responsible for driving 65% of deforestation in the country over the previous decade (World Bank, 2015). Cattle ranching alone is credited with being

responsible for 50% of the total of new lands colonized between 2005 and 2012, with the Amazon region accounting for 44% of new clearings (Etter et al., 2006; González et al., 2018; Pares, 2018).

Figure 3. Land use and land cover map of Colombia, 2012.



Source: Authors' own elaboration, based on IDEAM (2012)

The Colombian Government envisioned a future where peace contributed to reducing deforestation and environmental degradation. This future would save Colombia US$812,955 per year in environmental degradation. Specifically, reducing deforestation from 6.5 to 2.6 hectares per 1,000 hectares would save US$361,313 in restoration of deforested areas (at US$9,635/ha of restored forest). Additional savings included US$28,905 in avoided losses based on commercial cost of wood lost, and US$78,886 from avoided CO_2 emissions (US$5/ton CO_2 equivalent; DNP, 2017). Based on targets to reduce deforestation by 150,000 hectares in 2025, the savings in terms of restoration would be on the order of US$1.4 billion in 2025.

As a specific policy measure, the Colombian Government has proposed Payment for Environmental Services (PES) as a sustainable way of promoting economic alternatives to populations affected by the armed conflict. The proposal for a PES program aims at reducing deforestation and it places particular emphasis in areas that are part of the Forests for Peace

program, which is designed to create territories that integrate biodiversity conservation with productive projects that will benefit populations in former conflict areas (CONPES, 2017a). The PES program has been designed to be implemented in three stages, with an impact on 150,000 hectares between 2017 and 2019; 350,000 hectares between 2020 and 2025; and 500,000 hectares between 2026 and 2030 for a total of 1,000,000 hectares. It is expected to be implemented in 366 municipalities of Colombia, of which, 96 were heavily affected by the armed conflict (CONPES, 2017a).

3.1.2. IEEM Scenarios

IEEM was used in this context to examine two sets of scenarios[1]. The first set evaluated possible post-conflict land use trajectories as they relate to deforestation trends. The second set examined the Government proposal for establishing a PES Program to preserve high conservation value ecosystems, restore degraded ecosystems, and implement sustainable production systems. Table 1 describes all scenarios, which are compared in reference to the "Business as Usual Scenario" that projects the Colombian economy to 2035 without the implementation any new public policy or investment. It is important to point out that this baseline scenario represents a situation in which the relationships between the multi-dimensional factors that conform the model and their trends remain linearly stable throughout the entire modelling period. This serves the purpose of having a common "apples to apples" comparison point between scenarios. However, the economy is subject to uncertainties and extreme events, which will make this stability unlikely in the long run.

Table 1. Description of scenarios analyzed with IEEM.

Name	Description
BUSINESS AS USUAL	
Business as Usual Scenario (BASE)	• Projects the Colombian economy to 2035 without the implementation any new public policy or investment. • GDP grows on average at 3.7% per year over the period 2019 to 2035. • The supply of agricultural land grows by the rate of deforestation which is 0.3% per year across all departments, and extractive natural resource endowments grow at the same rate as GDP. • Baseline areas in the base year are 8,476,711 ha for agriculture, 34,426,622 ha of livestock, 63,214,574 ha of natural forest, and 584,802 ha of forest plantations.
POST-CONFLICT LAND USE TRAJECTORY SCENARIOS	
Deforestation Increase (DEFINC)	• Implements a 16% increase in deforestation between 2018 and 2035 based on post-conflict evidence by (L. Fergusson et al., 2014). This is close to the observed rate of 20% per year between 2016 and 2018 (DNP, 2019), post-peace agreement.
Deforestation Decrease (DEFDEC)	• Simulates a 75% reduction in deforestation between 2018 and 2035 which would be expected from more effective land-use planning, enforcement of forest law, and improved monitoring of the agricultural frontier.

[1] For all scenarios, at the macro level, IEEM-COL 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.

	• Allocation of deforested land between alternative uses is endogenous and responds to relative prices.
Deforestation Decrease and Agricultural Total Factor Productivity Increase (DEFDECTFP)	• 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. • Implies a 12.5% increase above BASE TFP from 2022 onward.
PES SCENARIOS	
Payment for Ecosystem Services (PES)	• Based on PES program proposed by the Colombian Government (CONPES, 2018, 2017b). • Implements 500,000 hectares of PES for strict preservation, beginning in 2019 and concluding in 2032. • Assumes that one hectare of strict conservation of PES avoids the deforestation of one hectare of forest. • Payments and compliance are maintained, so 500,000 ha of PES will avoid deforestation of 500,000 ha of forest into perpetuity. • Annual PES costs are financed by the Government range from about US$15 million in 2020 to about US$137 million in 2035. • Financed by water use taxes; transfers from the energy sector; a 1% transfer of current income from municipal and departmental governments; a carbon tax, and; international grant financing.
Silvopastoral Systems (SPS):	• Derived from shortcomings from the previous scenario, it explores investments that can reduce demand for agricultural land, as well as generate revenue to finance the PES program. • Implements sustainable silvopastoral systems (SPS) to restore degraded pasture lands and enhance livestock productivity for meat and milk production thereby slowing new agricultural land demand. • Colombian productivity improvement figures based on (Rodríguez, 2017). • Implements 17,500 ha of high yielding SPS which are expected to yield a milk production productivity gain of 2.9 times and meat productivity gain of 3.1 times. • Implements 87,500 ha of average yielding SPS which result in both a milk and meat productivity gain of 2.2 times. • Livestock producers are responsible for establishment, maintenance and operational costs, while the Government is responsible for other program costs.
Payment for Ecosystem Services and Endogenous Estimation of Livestock Total Factor Productivity (PES+SPSe):	• Establishment of PES as in the PES scenario. • Explores the levels of productivity gains in SPS that would be required to maintain real GDP at its baseline level. • Implies an endogenous increase in livestock TFP that allows for GDP in the scenario to track the baseline GDP projection.

The first set of scenarios examined relevant post-conflict land use trajectories given the potential pressures imposed by returning displaced populations to forested and rural environments who would seek new livelihood opportunities, often based on natural resource extraction and agriculture, among other drivers of environmental change. The Deforestation Increase (DEFINC) scenario implemented a 16% increase in deforestation between 2018 and 2035 as a result of analysis by Fergusson et al. (2012) that showed that deforestation in recently demilitarized zones increased by 16%. It is worth noting that two years into the peace period the observed rate was already 20% per year (DNP, 2019).

The Deforestation Decrease (DEFDEC) scenario, in turn, simulated 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. In addition to the DEFDEC conditions, the Deforestation Decrease and Agricultural Total Factor Productivity Increase (DEFDECTFP) scenario added a 5-percentage point increase in agricultural Total Factor Productivity (TFP) between 2018 and 2022 to capture efforts to increase agricultural productivity in the rural environment.

The second set of scenarios examined a Government for the establishment of a PES Program (CONPES, 2017a). Our analysis focused on the component of the program that would establish one million hectares of PES over the next 14 years, allocating 50% of this area to strict conservation and the other 50% for restoration and the implementation of sustainable production systems. PES establishment costs, which range from about US$15 million in 2020 to about US$137 million in 2035, were treated in our model as direct transfers from the government to property owners.

The Payment for Ecosystem Services (PES) scenario implemented 500,000 hectares of PES for strict preservation, beginning in 2019 and concluding in 2032. We took an optimistic approach and assumed that one hectare of strict conservation of PES avoided the deforestation of one hectare of forest. This meant that a one-time 500,000 ha of PES would avoid deforestation of 500,000 ha of forest into perpetuity and no additional avoided deforestation would be assumed past the year 2032 once all PES agreements were established.

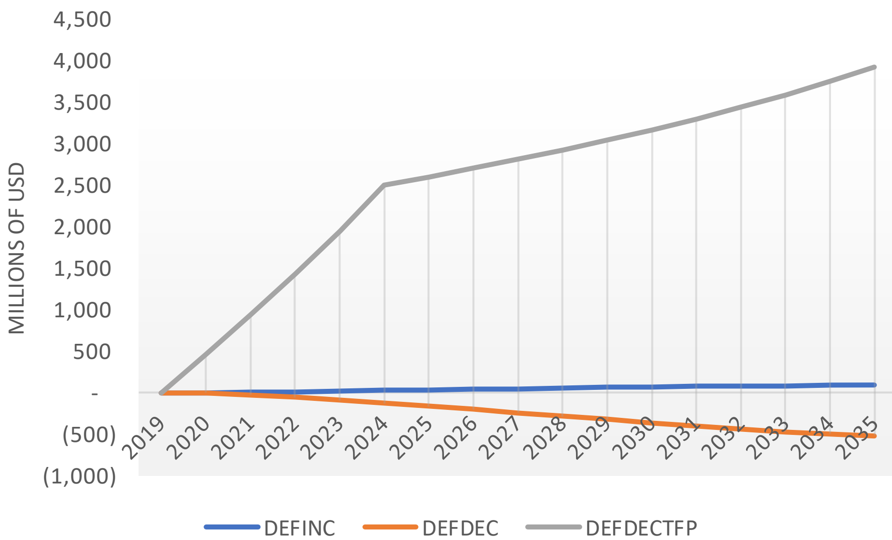
To complement the one-time nature of the PES scenario, the Silvopastoral Systems (SPS) scenario implemented sustainable silvopastoral systems (SPS) to restore degraded pasture lands and enhance livestock productivity for meat and milk production, based on local productivity levels estimated by Rodríguez (2017). Two levels of productivity gains were considered to account for variability in productivity due to soils, climate and other biophysical conditions. Finally, the Payment for Ecosystem Services and Endogenous Estimation of Livestock Total Factor Productivity (PES+SPSe) scenario implemented the establishment of PES and explored the levels of productivity gains in SPS that would be required to maintain real GDP at its baseline level. This information can be used to inform the development of targeted agricultural research investment programs.

3.1.3. Results and policy takeaways

Our goal with this section is to show through practical examples how policy advice can be fundamentally different when contrasting traditional economic performance measures like GDP with more comprehensive multi-dimensional measures of wealth. The results for the case of Colombia are particularly illustrative for this purpose.

In traditional economic analysis, we would assess the impacts that these policies would have on GDP alone. Figure 4 shows the changes that the land use trajectory scenarios would have on GDP. Decreasing deforestation would have a negative impact on GDP of US$520 million, but this can be offset with enhancements in total agricultural productivity, which would result in an increase in GDP of US$3,925 million by 2035.

Figure 4. Changes in GDP relative to base in millions of USD.



Source: IEEM-COL results (Banerjee et al., in press).

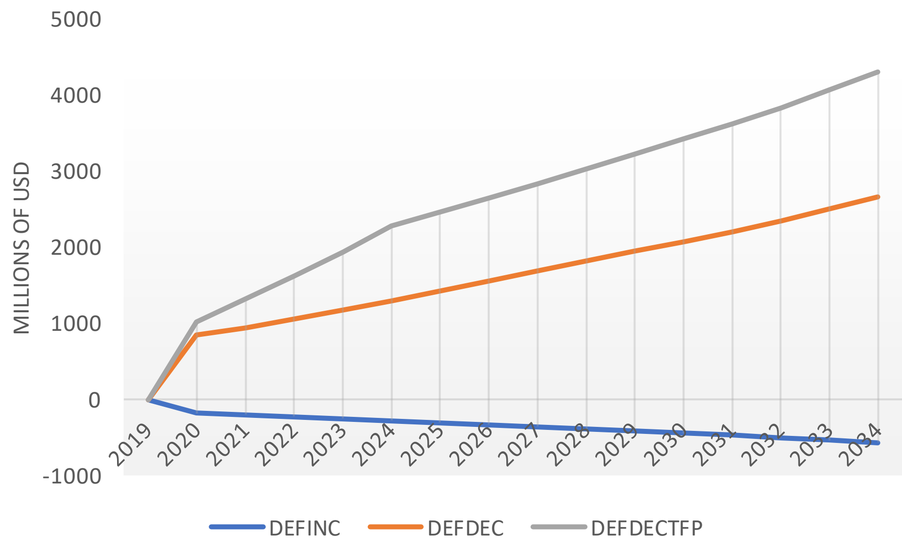
Agricultural productivity in the post-conflict zones is much lower than the national average so this finding is particularly relevant for informing investment in agricultural research and extension. The technical inefficiency in agricultural production in post-conflict zones is between 41% and 61% depending on the commodity (DNP, 2017). From the perspective of the traditional measure of GDP, reducing deforestation appears to imply an economic loss while an increasing trend of deforestation may seem to policymakers like a reasonable trade-off for enhancing economic opportunities for returning rural migrants.

However, as our previous discussion has emphasized, GDP's limitations make it inappropriate for the evaluation of sustainable development and well-being. Figure 5 shows the scenario impacts on the more comprehensive Genuine Savings indicator (Lange et al., 2018, 2011, 2006; Polasky et al., 2015). Contrary to the finding that reducing deforestation would negatively impact GDP, here we find that reducing deforestation would boost wealth and welfare long-term, equivalent to US$2,664.32 million by 2035. On the other hand, increasing deforestation would reduce national wealth and welfare by US$569.21 million. Reducing deforestation and enhancing agricultural productivity would have a synergistic impact on wealth and well-being, on the order of US$4,310.20 million by 2035.

These are non-trivial findings that can be expected to become more common as integrated spatially aware models, such as IEEM are adopted. In essence, the Genuine Savings indicator has allowed us to see the forest not only as standing timber, of which we can profit immediately by felling, but as a source of wealth that can provide a continuous income flow into the future in the form of increased productivity of various sectors directly and indirectly related to forests, in addition to sustainable wood production. The orders of magnitude between smaller short-term gains and larger long-term losses of degradation are also revolutionary from a financial analysis perspective, which

can mean the difference between approval or rejection of large-scale financing schemes. Moreover, the spatial nature of these analyses localizes those benefits to broad geographical areas, which addresses the perceived detachment that national accounts data can have with respect to the winners and losers of policies, thus informing policy discourse.

Figure 5. Changes in genuine savings relative to base in millions of USD.

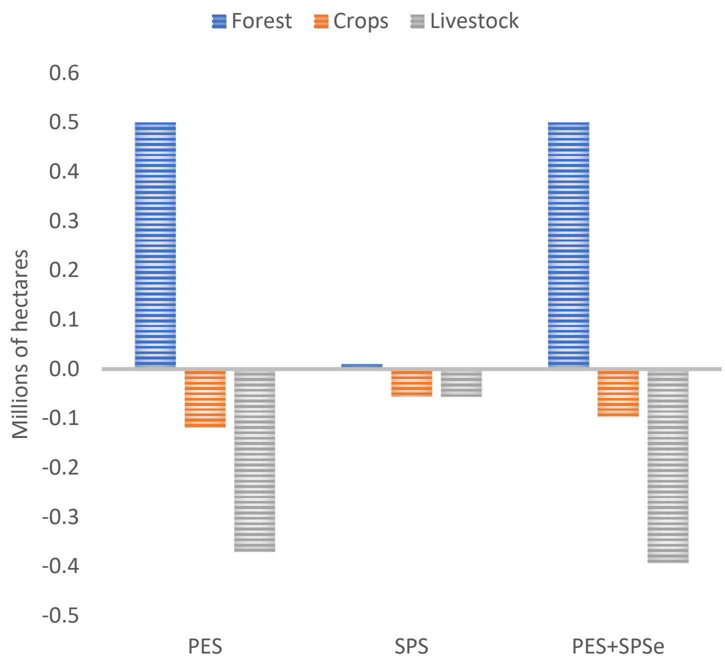


Source: Authors' calculations based on IEEM-COL results (Banerjee et al., in press).

This is the critical takeaway message for policy makers to consider. Integrated analysis with IEEM shows that the deforestation of 860,000 hectares expected in the post-conflict period would be accompanied by an increase in GDP of about US$90.75 million. However, since this increase would compromise future income by deteriorating the natural capital base, Genuine Savings shows us that the losses from increased deforestation would be 6.27 times greater than the gains in the long run in the order of US$569.21 million. Decreasing deforestation alone would result in increased wealth and welfare long-term, equivalent to US$2,664.32 million by 2035, while additionally increasing agricultural total factor productivity would have a significant positive impact on wealth and well-being of about US$4,310.2 million by 2035, as measured by the Genuine Savings indicator (Banerjee et al., in press).

With regards to the PES scenarios, the land use constraints that the program implies limits land availability for the agricultural and livestock sectors, reducing land availability by 488,525 hectares (Figure 6). Given that the agricultural sector is a major source of rural employment, this would trigger a drop of US$61.19 million in private consumption, placing pressure on employment and poverty rates. In the PES scenario, conserving 500,000 hectares would push GDP downward by US$89.85 million with respect to the baseline scenario in 2035 (Banerjee et al., in press).

Figure 6. Changes in land use relative to base in millions of hectares

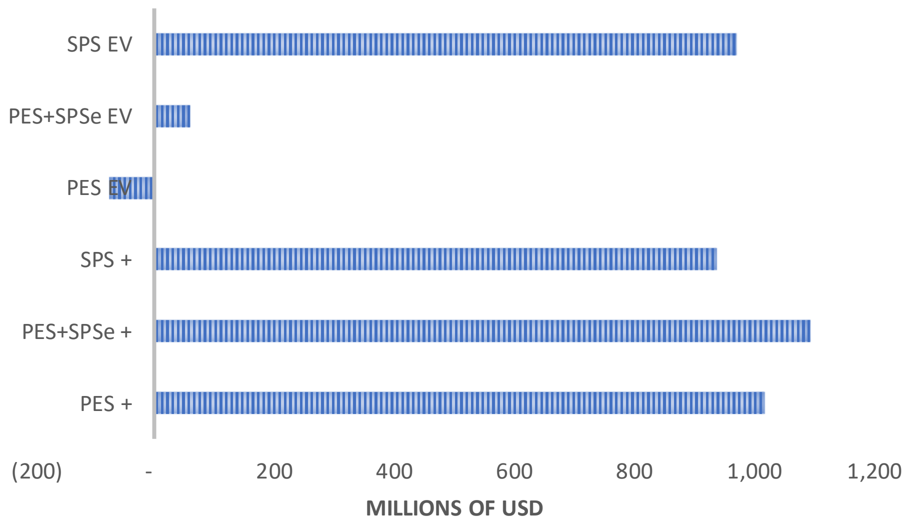


Source: Authors' calculations based on IEEM-COL results.

However, combining PES with investments sustainable silvopastoral systems would improve economic outcomes. Private consumption in this case would increase by US$232.97 million. Once again, forest conservation measures rely on improving agricultural productivity to alleviate the pressure to expand the agricultural frontier by making already available land more productive and by making licit agriculture more profitable.

We estimated the returns on the investment for each policy alternative. Figure 7 shows the net present value (NPV) of the investments, calculated with a 12% discount rate, the standard discount rate used by some multi-lateral investment banks. Scenario names in the figure that end with EV are calculated using only equivalent variation while those that end with a plus (+) sign are calculated based on equivalent variation, adjusted for changes in natural capital stocks and environmental damage proxied for by greenhouse gas emissions. Considering just equivalent variation, both SPS and PES+SPSe generate positive returns in terms of NPV, on the order of US$971 million and US$61 million, respectively while the PES scenario results in negative returns (US$75 million). When changes in natural capital stocks and environmental damage are considered, PES+ becomes an attractive investment proposition with an NPV of US$ 1,018 million. PES+SPSe+ generates the highest returns on investment an NPV of US$1,095 million while that of SPS+ comes in third place with an NPV of US$939 million.

Figure 7. Net present value based on equivalent variation (terminating with EV) and equivalent variation adjusted for changes to forest stocks and greenhouse gas emissions damage, in millions of USD.



Source: Authors' calculations based on IEEM-COL results.

Both land use trajectory and PES scenarios send a clear message to Colombian policy makers: long-term prosperity and inter-generational wealth can be secured through the application of strict conservation through the implementation of PES programs while investing in agricultural productivity in post-conflict zones of the country. Higher agricultural productivity can help rebuild rural livelihoods while PES can conserve the natural capital base upon which those livelihoods depend. The durability of the peace in post-conflict Colombia depends on it.

3.2. Evaluating Synergies and Trade-offs in Achieving the SDGs in Guatemala

3.2.1. Policy context and planned government response

From 2016 onwards, Guatemala offered a unique opportunity to evaluate multiple dimensions of the commitments agreed upon for the post-2015 SDGs (United Nations, 2015). On the one hand, the country had made efforts to implement environmental-economic accounting for forests, water, land and ecosystems, waste, subsoil resources, fisheries, and energy (Ine et al., 2013). On the other, it had harmonized its National Development Plan K'atun and sectoral policies with the 2030 Agenda for Sustainable Development and the SDGs. The Agenda, with its universal call to action to end poverty, protect the environment, and ensure prosperity for all, required countries to make significant advances on 17 SDGs and 169 targets within them. Limited budgets in middle-to-lower income countries like Guatemala forced governments to prioritize those SDGs that are aligned with national development priorities, and thus it is critical that policy makers have information on the potential impacts, synergies, and trade-offs of strategies for achieving the SDGs (Ruijs et al., 2018). With a population of 16.9 million at the time, Guatemala exhibited some of the worst

malnutrition and maternal child mortality rates in Latin America, as well as a poverty rate of 59.3%, thus targeting public resources effectively was an important concern.

In consultation with the Guatemalan Government, we designed scenarios that could inform: (i) strategies to end hunger, achieve food security, improve nutrition and promote sustainable agriculture (SDG 2), and; (ii) strategies to ensure availability of water and sanitation for all (SDG 6). To address SDG 2 from an agricultural perspective, the authorities had identified the potential to increase crop yields by 150% and income by an even greater degree (Amezquita, 2012). This would be achieved by expanding irrigation, given that the then irrigated area in the country totaled only about 29% of the 850,120 ha area with high suitability for irrigation. Guatemala's Great National Agriculture and Livestock Plan lays out some of the details of the proposed policy response (MAGA, 2016a) which is aligned with the country's Irrigation Development Policy and National Irrigation Diagnostic (MAGA, 2013, 2012).

To address SDG 6, the relevant policy is Guatemala's National Water and Sanitation Policy (SEGEPLAN, 2013) which acknowledged that 3 million people lacked access to basic water and sanitation services. The national coverage was estimated at 75.3% for water and 55.6% for sanitation, making infectious and parasitic diseases the main cause of death for children under 5 years of age in the country. To address these challenges, the National Water and Sanitation Policy set coverage targets to 95% in the case of water, and 90% in the case of sanitation (SEGEPLAN, 2013).

3.2.2. IEEM scenarios

To understand the multi-dimensional impacts of the policies proposed by the Guatemalan Government we created four scenarios to explore efforts to achieve SDGs 2 and 6 (Banerjee et al., 2019a) through application of the IEEM Platform. Specifically, we examined: target 2.3, which aims to double agricultural productivity and income of small-scale producers; target 6.1, which aims to achieve universal and equitable access to safe and affordable drinking water; and target 6.2, which aims to ensure access to adequate and equitable sanitation and hygiene for all (United Nations, 2015). Table 2 details these four scenarios. As in the case of Colombia, a baseline scenario projects the economy without policy intervention and is the business as usual reference scenario to which all other scenarios are compared.

Table 2. Description of scenarios analyzed with IEEM.

Name	**Description**
BASE	• Based on business as usual economic trends.
IRRIG 1	• Simulates rehabilitating and modernizing existing irrigation supply systems and infrastructure. • Increases irrigated area by 6,399 hectares. • Cost of investment US$6,045,780 distributed over 5 years. • Investments financed through an international development grant (50%) and an increase in Guatemala's external debt.
IRRIG 2	• Increases IRRIG1. • Additional 100,000 hectares of land under irrigation. • Additional cost of US$1.95 million over 5 years (US$19.5/ha). • Cost added to IRRIG1 to reach US$7,995,780. • Area added to IRRIG1 to reach 106,399 hectares.

WTSN	• Increases access to water coverage to 81.5% from 75.3% and sanitation to 66% from 55.6%. • The cost of the policy is US$1.6 billion or US$123,630,769 per year from 2018 to 2030. • An increase in total labor productivity of rural households of 0.44% is implemented based on (Kiendrebeogo, 2012). • Investments are financed through an international development grant (50%) and an increase in Guatemala's external debt.
COMBI	• Simulates the joint impact of IRRIG2 and WTSN.

Source: author's own elaboration.

Our first irrigation (IRRIG1) scenario simulated the rehabilitation and modernization of existing supply, increasing irrigated area by 6,399 hectares, with a cost of US$6,045,780 distributed over 5 years financed with aid and external debt. The government of Guatemala had not increased or redistributed its budget to enact this policy, which caused us to consider aid and debt financing for the investment. For all investments implemented in IEEM, a source of financing must be specified as the accounting logic of IEEM requires that all expenditure be met with equivalent income. This was a reasonable assumption as it was consistent with the investments of international development agencies that, in 2016 alone, had spent US$17.3 million in enhancing food security in drought prone areas of the country.

The second irrigation (IRRIG2) scenario built on the first, adding 100,000 hectares of new irrigated land in the Guatemalan Dry Corridor, which was a stated goal in the country's Great National Agriculture and Livestock Plan (MAGA, 2016b). This strategy has an additional cost of US$1.95 million over 5 years for a total investment of US$7,995,780 and a total area of 106,399 hectares, financed in the same way as IRRIG1.

Our third scenario (WTSN) models the impacts of Guatemala's Water and Sanitation National Policy (SEGEPLAN, 2013) which aims to increase water access coverage to 81.5% from 75.3% and sanitation to 66% from 55.6%, with a cost of US$1.6 billion from 2018 to 2030. Review of the Government's budget revealed that only US$1.3 million were assigned to water quality interventions, far less than what the implementation of this policy required. Consequently, we assumed foreign and debt financing for WTSN in equal proportions. In this scenario we also implemented an increase in total labor productivity of rural households of 0.44%, owing to estimates that showed that increases of one percentage points in access to drinking water in rural areas would lead to increased productivity of the agricultural workforce of between 0.025% and 0.116% due to better health and less downtime resulting from sickness (Kiendrebeogo, 2012). Finally, we estimated the joint impacts of the IRRIG2 and WTSN scenarios in a combined scenario (COMBI), which merged all three lines of actions to achieve SDGs 2 and 6.

3.2.3. Results and policy takeaways

The example of Guatemala provided us with a better understanding of the challenges and trade-offs that the multi-dimensionality of well-being poses for policymakers in a way that is not possible with traditional analysis (Banerjee et al., 2019a). Positive actions to reach goals in one policy arena might carry unintended consequences in another. This is particularly important when analyzing proposed actions to tackle any of the extensive list of 169 targets present in the 17 SDGs (United Nations, 2015). Our scenarios were designed to evaluate policies intended to meet SDG targets 2.3

(agricultural productivity of smallholders), 6.1 (safe and affordable drinking water), and 6.2 (equitable sanitation and hygiene). However, IEEM's multi-dimensional modeling modules would foreshadow that the policies proposed by the Guatemalan Government would extend well into SDG 1 (poverty), SDG 7 (affordable and clean energy), SDG 8 (decent work and economic growth), SDG 10 (inequality), SDG 12 (responsible consumption and production), SDG 13 (climate action), and SDG 15 (life on land), in a complementary manner in some cases and in competitive ways in others (Banerjee et al., 2019a).

With other modelling approaches, such as econometric analysis, researchers must anticipate and search explicitly for these unintended consequences by adding variables and providing theoretical support for them, which can become a fruitless exercise in guesswork and often falls outside the scope of analysis. The systems approach of IEEM allows one to readily account for all contributing factors and stakeholders of environmental-economic analysis in different spheres (social, economic and environmental), providing an opportunity to detect problems, which can arise from otherwise successful policies that are shown to reach or surpass the goals for which they are intended, without having to specifically plan for that detection.

The first question to pose is if the strategies embodied by our scenarios make progress toward the targets set out in SDG 2 and SDG 6. We first looked at traditional macroeconomic indicators and how they would behave under each scenario. Results in Table 3 show that reaching these goals would require substantially larger investments, specifically, to double agricultural output and incomes.

Table 3. Macroeconomic indicators; difference from baseline by 2030 in millions of US$.

	IRRIG1	IRRIG2	WTSN	COMBI
Absorption	$ 69.2	$ 1,078.0	$ 108.1	$ 1,184.7
GDP	$ 79.9	$ 1,243.3	$ 129.8	$ 1,371.4
Private Consumption	$ 51.1	$ 797.9	$ 74.5	$ 871.4
Fixed Investment	$ 18.1	$ 280.1	$ 33.6	$ 313.3
Exports	$ 34.2	$ 533.6	$ 60.2	$ 593.2
Imports	$ 23.5	$ 368.3	$ 38.5	$ 406.5
Genuine Savings	$ 36.5	$ 563.1	$ 33.7	$ 595.4

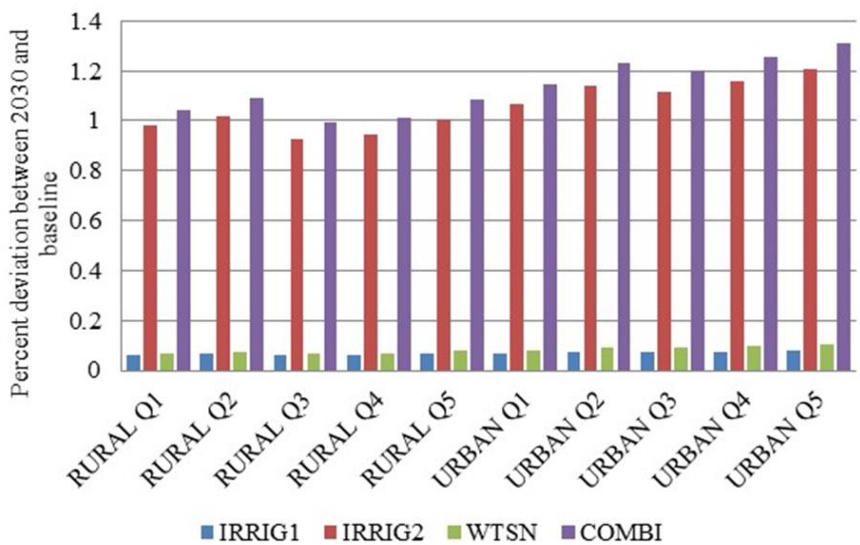
Source: IEEM platform results (Banerjee et al., 2019a).

Where investment in agriculture and water and sanitation were considered together along with baseline economic growth, over 2.4 million individuals would be lifted out of poverty. Considering baseline economic growth and the investment in IRRIG2, agricultural output would increase by 59%. To double agricultural output by 2030, additional and potentially different investments would be required to increase agricultural output by the remaining 41%. The investments in irrigated agricultural development were also insufficient to reach the goal of doubling income, with an income gap of 83% remaining.

Our scenarios expanded irrigated cropping of higher value crops, not necessarily traditional export crops. Stimulating this sector resulted in lower prices and in fact lower employment and wages for

unskilled labor, resulting in relatively small impact on incomes attributable to irrigated agricultural expansion. With poor households deriving much of their income from providing unskilled labor, increases in income for these poor households was below average compared to other households. This is evident in Figure 8 which shows the percent deviation in per capita income between 2030 and 2017, distinguishing between urban and rural households and income quintile. The first quintile represents lower income households and the fifth quintile represents higher-income households.

Figure 8. Percent deviation in per capita income between 2030 and baseline; rural/urban household income quintile.



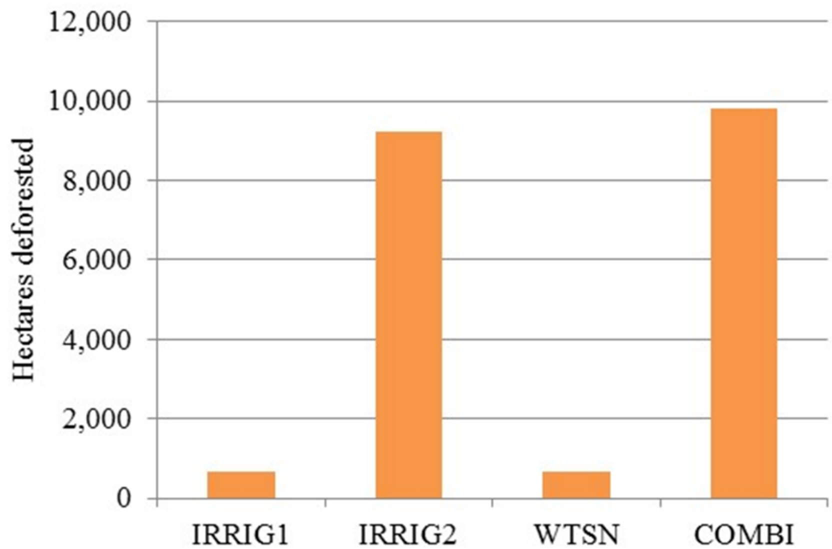
Source: IEEM platform results (Banerjee et al., 2019a).

Indeed, while rural households would be better off as a result of the policy, income inequality between rural and urban households would increase slightly with urban households earning greater returns through providing capital and land to the agricultural sector. Furthermore, the aggregate sector that includes higher value crops, would export 18% less than it did in the baseline. If more export-oriented agricultural sectors were targeted for irrigated agricultural expansion, there would be little, to no decline in prices and rural poor households would have been better off. Thus, in light of SDG Target 2.3 and its emphasis on doubling rural incomes, a complementary strategy of promoting exports of higher value irrigated and rainfed agricultural crops would boost rural incomes of the poor to a much greater extent.

In the Guatemala country context, improving the returns to agriculture can provide an incentive for land use change and in this case all of our scenarios resulted in increased deforestation as shown in Figure 9. In 2017, the total forested area in Guatemala was 3.0286 million hectares. The IRRIG1 scenario would result in the deforestation of 37,177 hectares which would be a 649 hectare increase above the baseline. The IRRIG2 scenario would result in an increase of 45,737 hectares of deforestation, 9,209 hectares of which is attributable to the investment in irrigation. The COMBI impact would be 9,820 hectares of additional deforestation above the baseline level for a total of

46,348 hectares. Increased economic output driven by the scenarios would also trigger increases in CO_2 emissions, with the COMBI scenario increasing emissions by 642,346 tons of CO_2 equivalent over baseline levels in 2030.

Figure 9. Scenario impacts on cumulative deforestation in hectares between 2030 and 2017.



Source: IEEM platform results (Banerjee et al., 2019a).

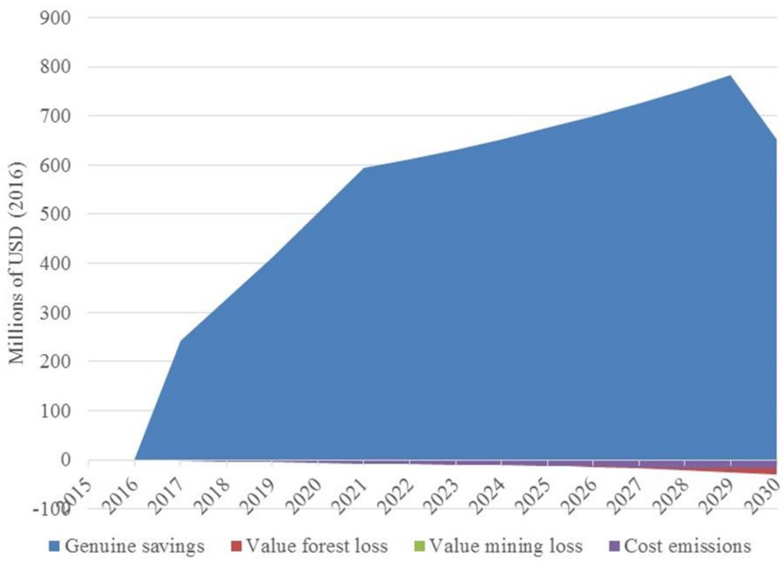
The analysis presented so far, with the exception of emissions, has focused on traditional economic indicators. The scenario results indicate that we could expect a positive economic outcome from the strategies proposed by the Guatemalan government to make progress toward the SDGs, though the increased deforestation is negative from at least an environmental perspective. Moving beyond traditional economic analysis, IEEM enables us to consider additional metrics of sustainability including natural capital stocks and wealth indicators, specifically Genuine Savings (Banerjee et al., 2019a; Lange et al., 2018, 2011, 2006; Polasky et al., 2015).

All scenarios and investments considered in this application (COMBI scenario) would be wealth enhancing as shown in Figure 10, increasing genuine savings by US$595 million. The IRRIG1 scenario would result in a US$36.5 million increase in wealth above the baseline in 2030. IRRIG2 would increase wealth by US$563.1 million and the WTSN scenario would enhance wealth by US$33.7 million. How is it that in this analysis, wealth is expected to increase despite the depletion of natural capital stocks and the damage caused by increased greenhouse gas emissions? These results would seem to be in stark contrast with those of the previous case study application to Colombia.

These counter-intuitive results with regards to wealth are driven by the large positive impacts of irrigation infrastructure on household savings (recall the calculation of Genuine Savings shown in Figure 1). This increase in household savings outweighs the negative impacts of forest loss and increased greenhouse gas emissions. The US$1.607 billion investment in water and sanitation would generate a US$69.5 million welfare gain, though the net present value of the investment

would be negative. From an economic perspective, this analysis shows that such investment is unlikely to occur without strong political will. It also shows that a portfolio approach to policies and the SDGs in this particular case can be effective way of financing some critical policies that may not generate the highest returns from a narrow economic perspective.

Figure 10. Decomposition of Genuine Savings, COMBI scenario; millions of USD (2016).



Source: IEEM platform results (Banerjee et al., 2019a).

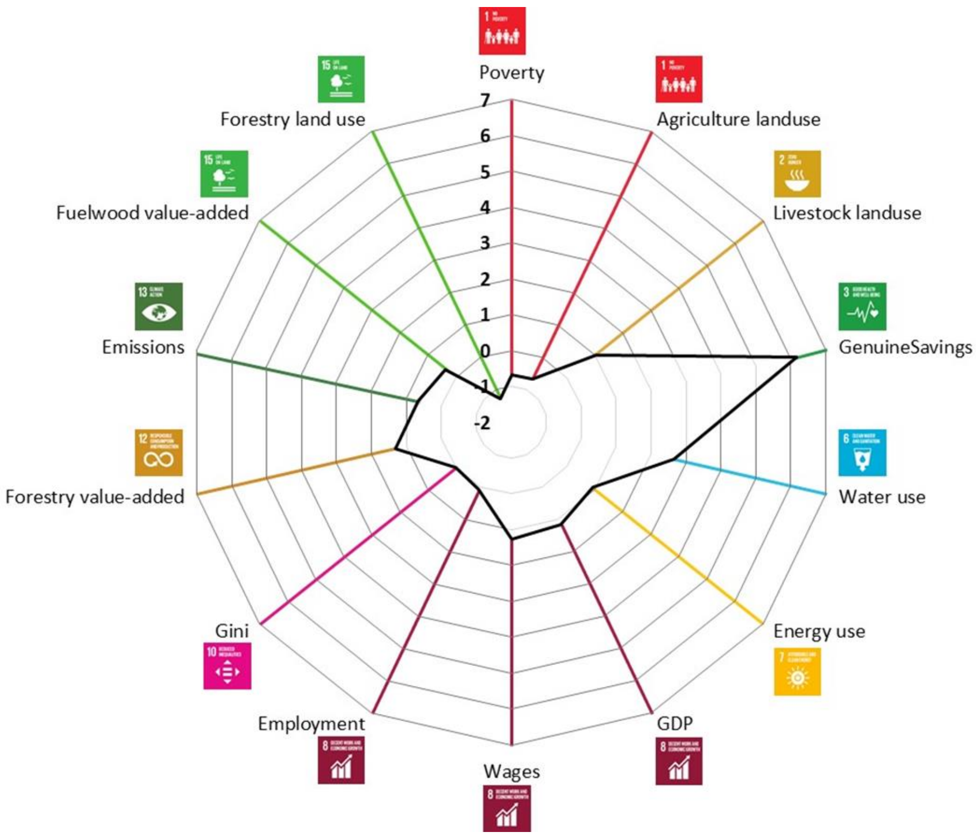
A multi-dimensional analytical platform such as IEEM enables us to consider how the proposed Government strategies would affect the target SDGs, but also if could be mutually supportive to achieving the overall Agenda for Sustainable Development. A further question is, are there additional trade-offs involved between different SDGs? So far we found that improvements in water and sanitation (SDG 6) that increase agricultural labor productivity would in turn increase agricultural output and contribute to SDG 2 Target 2.3. How would other SDGs be impacted?

In the case of Guatemala, all investment scenarios would contribute to achieving the first SDG of ending poverty in all its forms as well as the eighth SDG of promoting inclusive and sustainable economic growth, and employment. The SDG investment strategies evaluated would boost GDP by US$1.37 billion, diversify the agricultural sector and create jobs. However, investments in agricultural expansion and in water and sanitation would also lead to trade-offs.

Specifically, the increase in deforestation moves Guatemala away from SDG 15, specifically Target 15.2 which aims to halt deforestation. SDG 13 calls for action on climate change, though the expansion of agriculture gives rise to 642,346 tons of additional greenhouse gas emissions which should be summed with those emissions generated by deforestation and the burning of forests. How increased emissions affect Guatemala's commitments to the Paris Agreement and SDG 13 will require careful consideration of potential trade-offs and in the design of mitigation strategies. Finally, irrigated agricultural expansion also has consequences for overall water consumption, increasing consumption by a non-trivial 1,860 megaliters per capita. This is problematic where climate change projections describe a future Guatemala that has less water

available for all uses. Figure 11 summarizes the insights IEEM affords on how the proposed Government strategies to make progress toward SDGs 2 and 6 impact multiple other SDGs such as SDG 1 (poverty), SDG 7 (affordable and clean energy), SDG 8 (decent work and economic growth), SDG 10 (inequality), SDG 12 (responsible consumption and production), SDG 13 (climate action), and SDG 15 (life on land).

Figure 11. IEEM Platform results; COMBI scenario, percent deviation from baseline.



Source: IEEM platform results (Banerjee et al., 2019a).

Integrated environmental and economic modelling habilitates a portfolio approach to budget allocation towards achieving SDGs. Platforms such as IEEM provide impacts expressed in terms of GDP, income and employment, which continue to rank high on the agenda of policy makers and Ministries of Finance. In the Guatemalan example, the US$1.37 billion from investing in irrigated agricultural development and enhancing water and sanitation coverage already makes a good case for allocating money for these investments, and also provides Ministers of Finance and other decision makers with an estimate of the gaps that would be needed to fulfill targets through other complementary economic measures. The results of the analyses of wealth, stocks of natural capital and environmental quality provide policy makers with tools to address public concerns regarding environmental impacts of policies, understanding the requirements in terms of mitigating policies that would be needed to ensure sustainable economic development and a well-balanced approach to meeting the SDGs.

3.3. Rwanda

3.3.1. Rwanda policy context and planned government response

In this case study, we evaluate various lines of action derived from Rwanda's Green Growth Strategy and underpinning policy proposals. We apply our linked IEEM and Ecosystem Services Modeling (IEEM+ESM) framework to assess these lines of action from an economic, natural capital and ecosystem services supply perspective. The specific portfolio of policies we examine aim to enhance standing forest stocks, improve household fuelwood consumption efficiency and increase agricultural productivity through irrigation and fertilization.

In 2011, Rwanda's Government set the ambitious goal to restore 2 million hectares of the country's forest cover under the Bonn Challenge, a global goal to bring 150 million hectares of degraded and deforested landscapes into restoration by 2020, launched by the Government of Germany and the IUCN (BMU et al., 2016). This goal permeated into the country's legislation, development policies and Green Growth Strategy. The country had an interest in aggressively enhancing forest natural capital for the critical ecosystem services it delivers to all Rwandans.

Forests and the fuelwood and charcoal derived from them are the most important source of energy for Rwandans, where only 5% of the population is connected to the electrical grid and 86% of the country's energy comes from biomass (Ndegwa et al., 2011). Moreover, the fuelwood and charcoal trade is an important source of income for households. In 2009 the value of the charcoal market was 37.9 billion Rwandan Francs (RWF). The fuelwood trade had been estimated at 58.9 billion RWF with the total wood energy sector contributing to about 3.4% of GDP (Drigo et al., 2013; Ndegwa et al., 2011). Charcoal and fuelwood are main drivers of deforestation in Rwanda (Nahayo et al., 2016) and current charcoal supply falls short of demand by about 870,000 tons. This deficit, combined with the expected growth of the Rwandan population generates additional pressures for deforestation (NISR, 2009).

Total forest cover in Rwanda in 2014 was 686,636 ha, which represented about 28.8% of the country's terrestrial area. This extent was comprised of 37.6% natural forest (258,067 ha, mostly contained in the country's four protected areas; (Banerjee et al., 2018)) and 62.4% of poorly diversified forest plantations (428,569 ha), 55% of which are comprised of eucalyptus species (MINIRENA, 2014) and at least half of them experienced low productivity levels and faced the end of their productive cycle (A. Isaac et al., 2016).

The Government's response to energy demand, deforestation and low productivity forest plantations was outlined in a series of legislative and policy developments that included Rwanda's first National Forestry Policy in 2004 along with its 2010 revision; Rwanda's Economic Development and Poverty Reduction Strategy (EDPRS I for the period of 2008 to 2012); the Forest Landscape Restoration Opportunity Assessment for Rwanda (MINIRENA, 2014); the Rwanda Supply Master Plan for fuelwood and charcoal (Drigo et al., 2013); the Forest Law promulgated in 2013 (Republic of Rwanda, 2013); the Strategic Plan for the Forest Sector 2009-2012 (National Forestry Authority, 2010); the National Forest Policy (Ministry of Forestry and Mines, 2010); and the pledge to the Bonn Declaration. This legislative framework for forestry and fuelwood was closely aligned with the programs and actions outlined in the EDPRS II, Rwanda's Vision 2020, and Rwanda's Green Growth Climate Resilient Strategy.

The EDPRS II set the target of increasing forest cover from 28.8% to 30% of the country by 2018. For fuelwood, the target was designed to reduce consumption from 86% to 50% by 2020. In addition, Rwanda's Green Growth Strategy outlined lines of action for increasing sustainable forestry and agroforestry for the provision of ecosystem services including timber and energy provisioning services to meet current and future demand. Agroforestry systems would comprise an important component of this commitment (MINIRENA, 2014).

Rwanda recently began implementation of SEEA accounts, specifically, land and water accounts. Through a collaboration funded by the Science for Nature and People Partnership, the development of an IEEM model for Rwanda was proposed integrating the country's new SEEA accounts for analyzing Rwandan's Green Growth Strategy (Republic of Rwanda, 2011). Given the importance of land use dynamics in understanding the impacts of green growth in Rwanda, the innovative IEEM+ESM approach was applied.

3.3.2. An overview of the IEEM+ESM approach

The IEEM Platform integrates non-material, regulating and cultural and aesthetic ecosystem services by linking IEEM with spatial ES modeling (IEEM+ESM) (Banerjee et al., 2020a and 2020b; O. Banerjee et al., 2019a and 2019b). The bridge between the two modeling frameworks is made possible through a Land Use Land Cover change (LULC) modeling module. There are various LULC change models that may be used including the CLUE modeling framework (Verburg et al., 2008, 1999; Verburg and Overmars, 2009).

The LULC change model is used to spatially allocate IEEM demand for land across a high-resolution spatial grid to produce LULC projections for a baseline and policy scenarios. These spatial datasets are used as the basis for ecosystem services model runs with tools such as the Natural Capital Project's InVEST suite of models (Sharp et al., 2018) or the Artificial Intelligence for Ecosystem Services (ARIES) tools (Villa et al., 2014).

The main variable of change in the ecosystem services modeling are the new LULC maps for each scenario, though for some ecosystem services, some climate variables or changes in land management practices may be included. Common ecosystem services to consider are erosion retention, nutrient retention, water supply, carbon storage and crop pollination. Our IEEM results largely cover provisioning and material ecosystem services. Changes in ecosystem service supply for each scenario are calculated as differences from the baseline projections of supply.

3.3.3. IEEM Scenarios

The policies proposed by the Government of Rwanda to enhance standing forest stocks, improve household fuelwood consumption efficiency and increase agricultural productivity were used to design scenarios to evaluate with IEEM+ESM. The BASE scenario simulates a balanced growth path with the economy and land use following past trends from 2014 to 2035. It is the reference scenario to which all other scenarios were compared.

Table 4 provides an overview of each of the scenarios.

Table 4. Description of scenarios analyzed with IEEM.

Name	Description
BASE	• Based on business as usual trends.
FOR1	• Forest plantation area is increased by 110,400 hectares to 2035. • Total investment cost is US$285,581,699 (US$20,398,693 annually). • Land endowment is fixed, therefore forest plantation expansion causes a reduction in land for agriculture.
FOR2	• Forest plantations increased by 110,400 hectares between 2018 and 2035. • Cost of the policy is US$285,581,699. • Land endowment is not fixed, so forest plantations can expand without reducing availability of agricultural land.
FUEL	• Efficient cookstoves and kilns reduce woody biomass used by 25%. • Rural household labor productivity is increased by 0.125% due to less work hours lost to acute respiratory diseases, eye disease and burns.
IRRIG	• 85,473 ha of farmland currently cultivated without irrigation or with irrigation infrastructure in disrepair are brought into irrigated agricultural production. Irrigation will increase yields and crop values given quality improvements and seasonality of irrigated crops.
FERT	• Increase in area and quantity of fertilizer applied to all cropland to 45 kg/ha/yr.
COMBI1	• Joint implementation of FOR1, FUEL, IRRIG, and FERT.
COMBI2	• Same as COMBI1 but does not account for urban expansion.

Source: author's own elaboration based on (Banerjee et al., 2020a).

In FOR1, forest plantation area is increased to meet the target of 30% of the forest land. This required an additional 110,400 hectares to be established between 2018 and 2035, planting 7,393.14 hectares per year at the 2015 planting rate (MINIRENA, 2014). The increase in agroforestry was introduced as an investment of US$285,581,699, for an annual investment of US$20,398,693. In this scenario, land endowment was fixed, which meant that any increases of forest land would come at the cost of agricultural land. FOR2 is the same as FOR1, but relaxed the fixed land endowment option, which meant that forest plantations could also expand on land other than agricultural land.

The FUEL scenario introduces more efficient cook stoves and charcoal kilns, providing efficiency gains on the order of 25% (A. O. Isaac et al., 2016) for a total investment cost of US$4,529,051 implemented over 5 years from 2018 onwards. Based on Garcia-Frapolli et al. (2010), we estimated a 0.125% increase in rural household labor productivity attributable due to less work hours lost to acute respiratory diseases, eye disease and burns. The IRRIG scenario brings an additional 85,473 hectares of farmland into irrigated production while the FERT scenario increases fertilizer applied to cropland to 45 kg/ha/yr to be more in-line with international averages, although still relatively low. COMBI1 is the joint application of FOR1, FUEL, IRRIG, and FERT, while COMBI2 is the same as COMBI1, but does not account for urban expansion.

3.3.4. Results and policy takeaways

As in the previous examples, the first step in our analysis involves analyzing scenario impacts on traditional macroeconomic indicators. FOR1 impacts would be modest and negative in terms of absorption, private consumption and fixed investment Table 5. The GDP impact is small but positive while exports and imports grow faster. The key driving these perhaps surprising results is

the increased competition for land arising from new forest plantations. In FOR1, for each new hectare of forest plantation there is a 0.25 ha reduction in land available for both agriculture and livestock. As a result, the agriculture and livestock sectors grow more slowly, also resulting in slower growth in income, savings, private consumption and investment (Banerjee et al., 2020a).

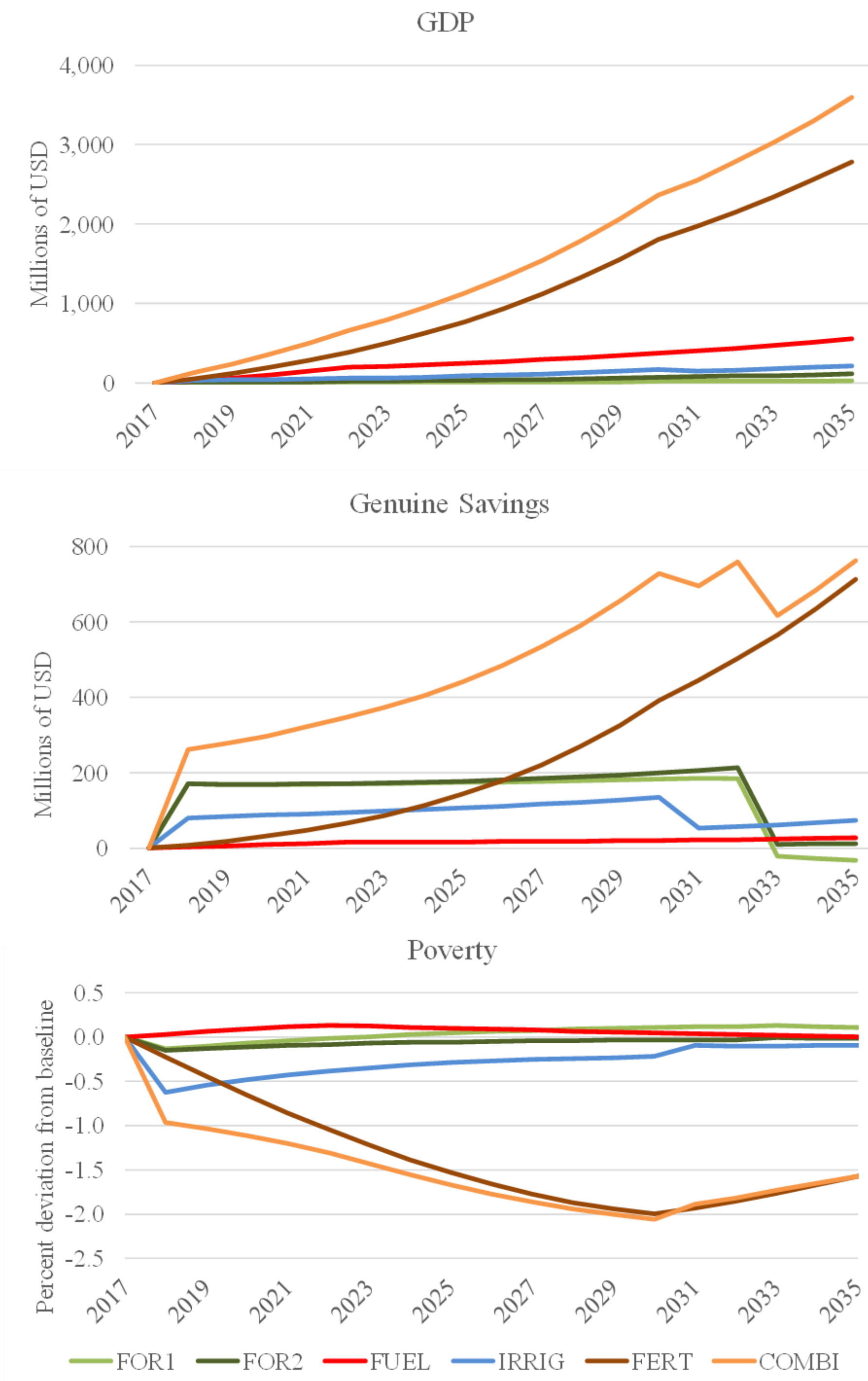
Table 5. Difference in macroeconomic indicators for baseline versus scenarios in 2035; millions of 2014 US$

	FOR1	FOR2	FUEL	IRRIG	FERT	COMBI
Absorption	(25)	92	490	185	2,653	3,312
Private consumption	(5)	79	479	141	2,121	2,744
Fixed investment	(20)	12	11	44	532	567
Exports	72	47	165	43	596	886
Imports	19	22	94	13	467	607
GDP	28	116	561	215	2,781	3,591
Genuine savings	(34)	11	27	73	713	763

Source: IEEM+ESM results (Banerjee et al., 2020a)

In contrast, FOR2 lifts the constraint of competition between forest plantations, agriculture and livestock land uses and the impacts of forest plantation expansion are positive across all macroeconomic indicators. The FUEL scenario results are positive across indicators, including private consumption, exports, imports and GDP. These impacts are greater than those in the FOR scenarios, and compared to IRRIG, with the exception of fixed investment where IRRIG has a more pronounced effect (Banerjee et al., 2020a). Figure 12 shows the trajectory of GDP, Genuine Savings and poverty.

Figure 12. Deviation from baseline for key macroeconomic indicators.

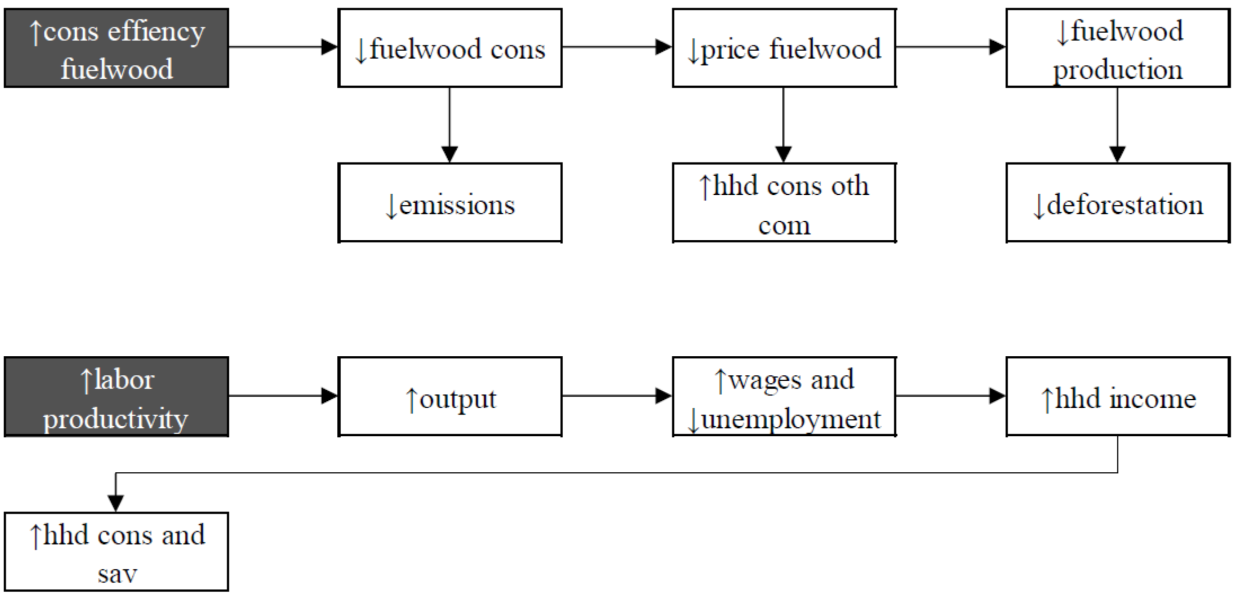


Source: IEEM+ESM results (Banerjee et al., 2020a).

There are two main transmission pathways that explain FUEL scenario results shown in Figure 13. First, with the increase in household fuelwood use efficiency, the same amount of cooking energy is obtained with 25% less fuelwood. This results in a decline in fuelwood prices, which benefits

households by leaving them with greater disposable income for consumption of other goods and services including education and health services. The second transmission pathway is related to the positive health benefits arising from reduced exposure to fuelwood emissions and particulates in the household. These positive health benefits enhance rural agricultural labor productivity, reduce unemployment and increase agricultural sector output, wages, income and household consumption and savings possibilities. Ecosystem services in FUEL are essentially unchanged from BASE due to little change in land use and land cover.

Figure 13. FUEL transmission pathways.



Source: IEEM+ESM results platform results (Banerjee et al., 2017). Notes: cons is consumption; hhd is households; oth com is consumption of other commodities; sav is savings.

The IRRIG scenario results in positive macroeconomic indicators with impacts larger than in the FOR scenarios. The productivity gain from irrigating crops boosts crop production, reduces crop prices, and frees up factors of production for use in other sectors of the economy. The overall effect is positive for wages, employment and household welfare. However, in the short run and due to the inflow of foreign exchange required to finance the investment in irrigation, there is an appreciation of the real exchange rate, which has a negative impact on exports. In the longer run, once the investment is complete, the real exchange rate returns to BASE levels and exports once again grow faster (Banerjee et al., 2020a).

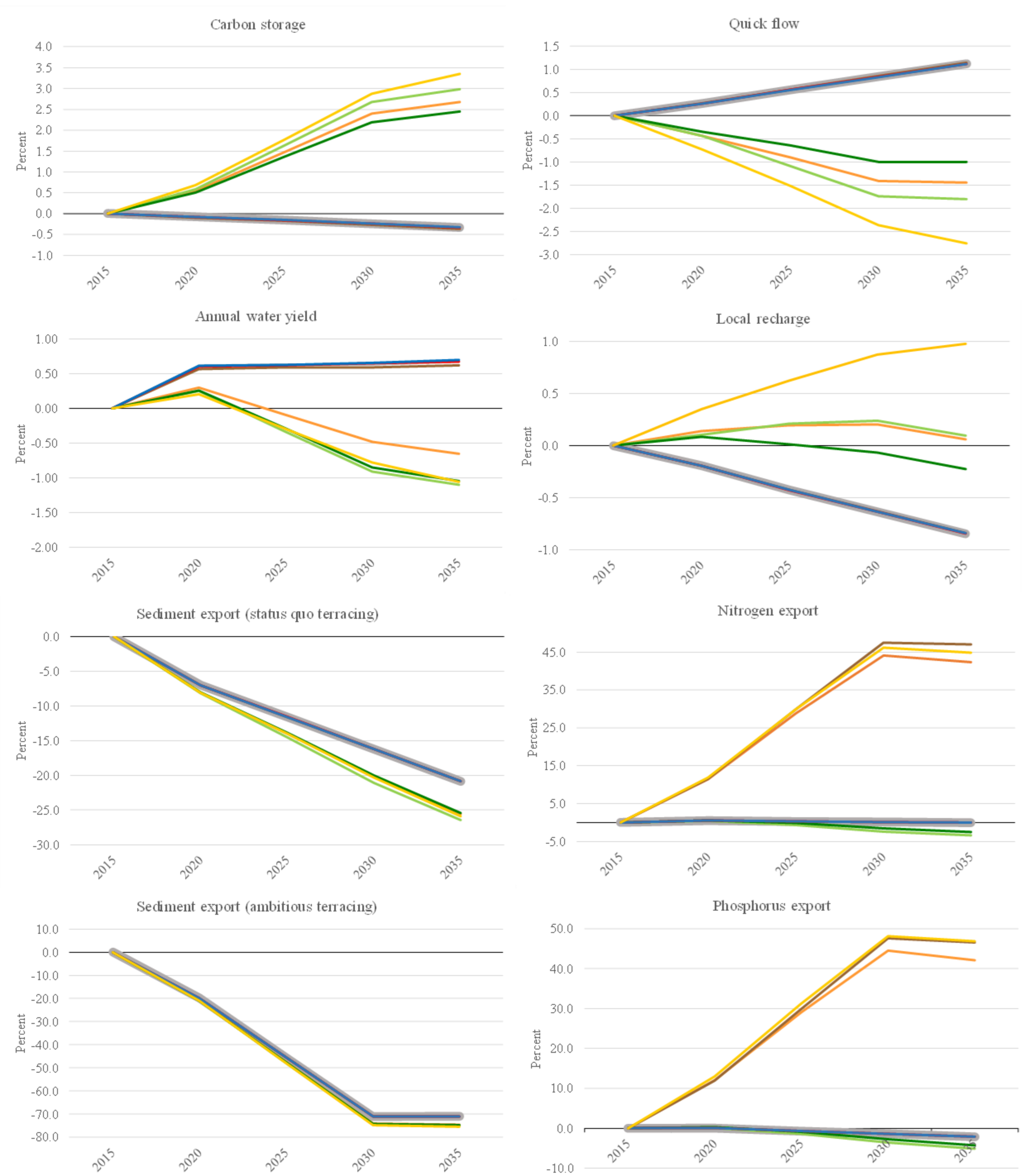
The FERT scenario shows there are very large gains to be had with increasing fertilization in Rwanda, on the order of a US$2,781 million increase in GDP. The joint impact of all scenarios represented by COMBI1 generates the largest gains with a US$3,591 million boost to GDP. While agricultural product prices may fall as a result of the increase in total factor agricultural productivity and the large increase in output, the volume of this output compensates by generating additional household income, which is used for consumption, savings and investment. A portion of this increase in output is exported, while we also see an increase in imports due to increased demand for all goods and services (Banerjee et al., 2020a).

The transmission pathways for the IRRIG, FERT and COMBI scenarios are similar. Both IRRIG and FERT scenarios result in an increase in agricultural total factor productivity, which in turn increases agricultural output while reducing agricultural factor use. This reduction in agricultural factor use frees up capital, labor and land for use in other sectors of the economy, enabling them to increase their output. The overall net effect is an increase in wages, a reduction in unemployment and an increase in household income, consumption and savings (Banerjee et al., 2017).

Turning to our indicator of wealth, Genuine Savings, we find that all scenarios are wealth-enhancing with the exception of FOR1 due to competition for land and how this impacts household savings. Nonetheless, in decomposing Genuine Savings, the FOR scenarios have a positive impact on its natural capital stock component. In the case of the IRRIG and FERT scenarios, there is a reduction in forest natural capital stocks which has a negative impact on Genuine Savings. On the other hand, the foreign investment financing in these scenarios contributes positively to Genuine Savings by enhancing output and incomes. Overall, land-use impacts in IRRIG are small while in FERT, the large increase in agricultural productivity frees up land to be reallocated to livestock. FERT has the largest impact on Genuine Savings, increasing it by US$713 million while COMBI1 boosts Genuine Savings by US$763 million (Banerjee et al., 2020a).

Our linkage of IEEM with ecosystem services modeling allows for detailed analysis of ecosystem service supply impacts at national and provincial levels (Figure 14). For carbon storage and water yield models that are mainly driven by LULC change, FOR and COMBI lead to increased carbon storage and reduced water yield. The BASE, FERT, FUEL, and IRRIG scenarios showed the opposite trend. In the FOR and COMBI scenarios, quick flow was reduced which benefits water quality. Local water recharge, which is critical for maintaining dry-season flows, tended to be stable or increasing (Banerjee et al., 2020a).

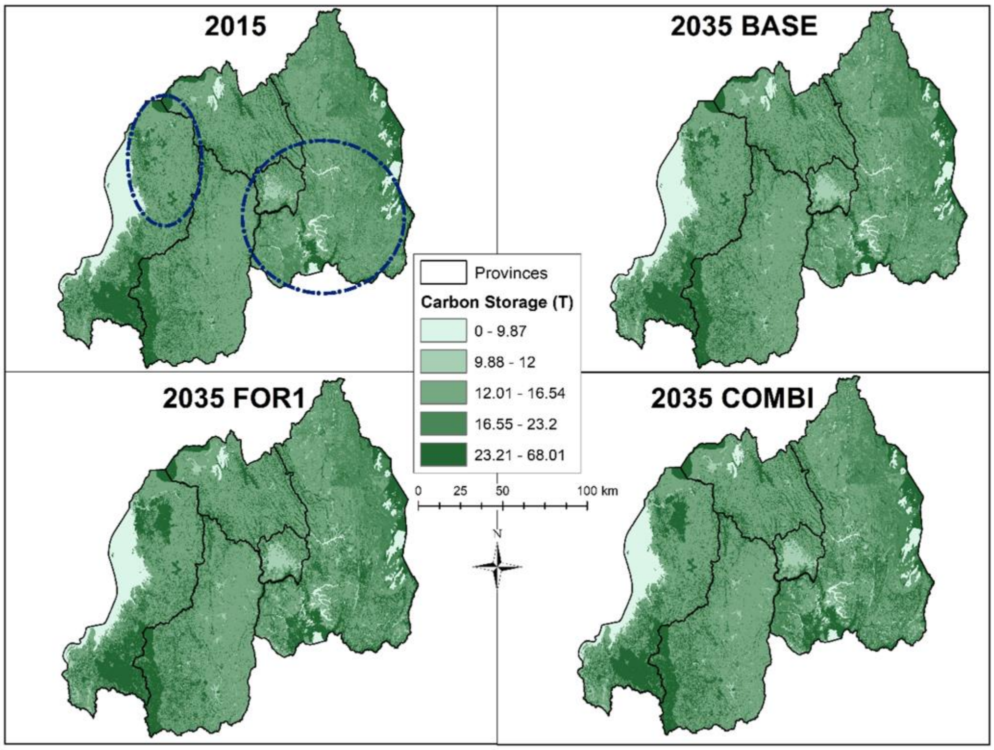
Figure 14. Percentage change in ecosystem services at the national scale for Rwanda for baseline and scenarios from 2015 to 2035.



Source: IEEM+ESM results (Banerjee et al., 2020a). For carbon storage, annual water yield, local recharge, an increasing trend is considered favorable. For quick flow, sediment, nitrogen, sediment, and phosphorus export, a decrease is considered favorable.

The FOR and COMBI scenarios reduced sediment export. Nitrogen and phosphorus export by 2035 increased by about 47% in the FERT scenario, by between 45 and 47% in COMBI2, and 42% in COMBI1. Slight decreases for nitrogen and phosphorus export were found in BASE, FUEL, and IRRIG. FOR scenarios reduced nitrogen export by 3% and phosphorus export by around 5% (Banerjee et al., 2020a). Figure 15 shows carbon storage across Rwanda.

Figure 15. Carbon storage for BASE in 2015 and 2035, and for FOR 1 and COMBI in 2035, in tons. Dashed circles indicate areas that experienced the greatest change in the scenarios.



Source: IEEM+ESM (Banerjee et al., 2020a).

In terms of evaluating Green Growth, the FERT and COMBI scenarios are the greatest "winners" for Rwanda from the perspective of economic growth. However, from an ecosystem services perspective, the FOR and COMBI scenarios, which help reverse a 25-year trend of forest loss in Rwanda, provide the greatest gains in ecosystem services. Of these, the FOR scenarios yield reductions in nutrient export while when combined with fertilization in the COMBI scenarios, the net effect is an increase in nutrient export, though to a lesser degree than the FERT scenario.

Increases in nutrient inputs to surface waters matter because localized problems already exist with water quality and availability in Rwanda, particularly in the dry season (Nahayo et al., 2018, 2016; REMA, 2015). Increases in nutrient inputs of over 40% would likely make these problems more pervasive. Increasing water demand (i.e., in the FERT and COMBI scenarios) may further exacerbate water-quality problems by reducing streamflow that dilute nutrients and other water

pollutants. Water demand and water quality are thus the two most notable ecosystem service trade-offs that emerge.

Better water-quality outcomes may also be possible if reforestation can be carefully targeted to intercept sediment and nutrients before they reach major waterways (Chaplin-Kramer et al., 2016). A COMBI-type outcome that produces both positive economic and ecosystem service outcomes may thus be possible with very careful spatial targeting of reforestation, including along water courses, to protect water quality. Achieving these multiple benefits may require a payments for ecosystem services-like incentive system informed by ecosystem service models. However, green growth scenarios that reduce nutrient inputs into Rwanda's agricultural system, i.e., the FOR scenarios, could best ensure greater water-quality protection, economic considerations aside. Economic arguments generated with the IEEM+ESM Platform such as those presented here can provide the basis for the development of such incentive systems (Banerjee et al., 2020a).

All scenarios but COMBI2 account for urban expansion. COMBI2 preserves more farmland, but also more forests, grasslands, and shrublands that are lost to urban development in COMBI1. COMBI2 thus has both greater detrimental nutrient export and beneficial carbon storage and local recharge. Given Rwanda's limited land base and high population density, urbanization is being implemented as a needed strategy to reduce population pressure on natural resources in rural areas and diversify the urban economy (REMA, 2015; World Bank and Government of Rwanda, 2018), but it comes with its own impacts to local ecosystems and ecosystem service supply (Banerjee et al., 2020a).

One of the more powerful aspects of our IEEM+ESM approach is the ability to interpret impacts spatially. Provincial-scale analysis reveals that changes in ecosystem service, and their contributions to human well-being, are not equally distributed across Rwanda. Changes in the Northern, Western, and Southern provinces generally mirrored national-scale trends, while those in Kigali City are influenced by urbanization and those in the Eastern Province by reallocations of land use, which differed between scenarios. The Eastern Province is the flattest and driest region of Rwanda and is where the most substantial changes took place. Eastern Province ecosystem service trends differ more by scenario than the nation as a whole; notably the COMBI scenarios provide greater nutrient uptake from forest plantation expansion than in the FERT scenario, somewhat mitigating the effects of water-quality changes. Multi-jurisdictional effects may also be felt related to water quality and quantity, such as in neighboring Tanzania and Uganda, who share the Akagera watershed with Rwanda (Banerjee et al., 2017, 2020a).

Despite the key tradeoffs identified related to fertilizer and water use, water quality and quantity are far more difficult to value monetarily than our economic analysis. To address this limitation, concurrent efforts are focused on introducing feedbacks between IEEM and ESM, where changes in ecosystem service supply have a direct and quantified effect on the economy, which in turn generates new expectations for LULC change and therefore ecosystem service supply. Thus, while IEEM can make these "hidden costs" more visible, feedbacks between ecosystem service supply and the economy must be considered if the full cost of alternative policies and investments to achieve green growth are to be taken into account (Banerjee et al., 2020a).

4. Conclusions

We have shown how some of the limitations of traditional economic performance measures through SNA and GDP with their limited definition of the economy have been addressed through the development of the SEEA and ecosystem accounting. While environmental and ecosystem accounting is only a framework to organize environmental information in a format that is compatible with SNA, its extended view of the production boundary provides inputs for estimating more inclusive measures of wealth and wellbeing. Furthermore, advances in elevating the SEEA and SEEA Experimental Ecosystem Accounts to the category of International Standards, position these standards for wide-spread adoption around the world enabling cross-country and temporal analysis.

The three case studies we present demonstrate how integrating information on natural capital and ecosystem services in economy-wide analytical approaches is effective in capturing policy impacts on the three dimensions of sustainable development and wealth. These examples unambiguously show that policy advice based on traditional metrics can be misleading and that consideration of wealth impacts can lead to fundamentally different strategies for securing long-run prosperity and inter-generational wealth. With the global economy and society currently in a reset mode with the COVID-19 outbreak, the time is opportune not only to rethink but to fundamentally change how we view economic growth and its contribution to human well-being, from an income-centric perspective, to a new global wealth paradigm.

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