Ecosystem services in an Environmental-Integrated Computable General Equilibrium (EI-CGE) model

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Abstract

Long-term economic development is inextricably linked to the quantity and quality of natural capital, and the ecosystem services it generates. Ecosystem services—such as crop pollination, freshwater supply, and climate regulation—not only sustain agricultural and industrial activities but also underpin human well-being. However, traditional economic analysis often omitted natural capital. This research argues that integrating environmental considerations into economic models is critical for addressing the adverse impacts of unsustainable production and consumption patterns. Using Mexico as a case study, the research employs an Environmental-Integrated Computable General Equilibrium (EI-CGE) model to assess how climate-induced declines in ecosystem services affect agricultural output, economic output and households' consumption. The results highlight the cascading effects of ecosystem degradation on value chains and underscore the necessity for policy innovations aimed at sustainable development in the face of climate change and environmental degradation.

Keyword selection: natural capital, agricultural production, climate change.

Introduction

Traditional indicators of economic performance, such as Gross Domestic Product (GDP), fail to capture the depletion or degradation of natural capital. As a result, an economy may exhibit short-term growth even while eroding its environmental base—a phenomenon that has prompted calls for more inclusive metrics and models integrating environmental values into economic decision-making. In recent years, researchers and international organizations have emphasized the need to incorporate ecosystem services into macroeconomic analyses and public policy design. For instance, initiatives like the United Nations' System of Environmental–Economic Accounting (SEEA) underscore that sustainable development policies must reflect the interdependencies between natural capital and economic output.

Climate change and environmental degradation pose serious risks to ecosystem services that are essential for agriculture, agro-industrial production, and human consumption. Although scientific understanding of these risks has advanced, many economic models and policy evaluations continue to overlook the role of ecosystem services as foundational inputs to economic activity. A significant knowledge gap persists in tracing how climate-induced ecological changes propagate through value chains and affect macroeconomic aggregates such as GDP, employment, and household welfare. For instance, a decline in wild pollinator populations can lead to reduced crop yields, directly affecting food supply and farm incomes. Similarly, shifts in precipitation patterns may restrict water availability for irrigation, thereby limiting agricultural productivity. These ecological disruptions can result in higher food prices, with downstream effects on employment in agri-food systems, household income and consumption, and overall economic stability, particularly in regions heavily reliant on natural capital.

This research bridges this gap by integrating natural capital into a country-level CGE model, thereby evaluating the economy-wide impacts of ecosystem service decrease. Focusing on Mexico—one of the world's megadiverse nations and a pioneer in environmental–economic accounting—this research assesses how climate-induced changes in ecosystem services influence agricultural production and consumption. By establishing explicit linkages between environmental degradation and economic performance, this analysis offers insights into potential policy responses aimed at ensuring long-term sustainable development.

Methodology

The integration of ecosystems services into economic modelling frameworks offers the potential to identify, quantify and evaluate the multiple benefits, impacts, and trade-offs between the economy and the environment. Achieving this integration requires a comprehensive understanding of the interactions between the socioeconomic and environmental systems. This research develops an Environmental-Integrated Framework (EI), which explicitly incorporates the monetary values of market and non-market ecosystem services into the System of National Accounting (SNA) structure. The framework includes the development of an Environmental-Integrated Social Accounting Matrix (EI-SAM). Mexico is selected as a case study due to its long-standing environmental accounting practices, which are aligned with the SEEA standards (United Nations, 2021).

The first step includes the collection of ecosystem service valuation data from official sources. The valuation includes environmental flows not captured in the conventional SNA, which must be estimated using non-market valuation methods (e.g., avoidance cost or replacement cost). This data is used to define the contribution of ecosystem services to agricultural production and include monetary valuation of provisioning services, including functions such as pollination, water supply, soil fertility, among others. The second step integrates these values into the EI-SAM by extending the matrix with additional rows and columns to capture ecosystem service flows. In this formulation, transactions and payments related to ecosystem services are allocated to a newly defined institutional sector, "the environment", which is treated as the owner of natural capital. This design establishes explicit linkages between the flows of ecosystem service provision and its utilisation by economic activities and households. The EI-SAM serves as a tool to identify upstream and downstream environmental dependencies in value chains and to assess the potential macroeconomic benefits of conserving natural capital (Di Cori et al., 2022). Special emphasis is placed on economic sectors heavily reliant on environmental inputs, such as agriculture, forestry and fishing. The development of the EI-SAM requires extending the production accounts (activities and commodities) and delineating transactions between traditional institutional agents (households, enterprises, government) and the new economic agent, “the environment”.

The extension considers a comprehensive understanding of economic-environmental transactions. It incorporates the flows of ecosystem services into the value chains[1] as inputs, and also it takes into account the by-products generated by economic activities, referred to as residuals (Banerjee et al., 2019, p. 283). This inclusion enhances a better understanding of the environmental impact on economic activities. The matrix also formalises theoretical or notional environmental property rights, reallocating resource rents and the associated property income payments[2] to the environment as an institutional sector. This inclusion enhances transparency in tracking the contribution of natural capital to economic output.

The final step involves integrating the EI-SAM into an Environmental-Integrated Computable General Equilibrium (EI-CGE) developed as an extension of the IFPRI–CGE model implemented in MPSGE by Rutherford (2006). The EI-CGE framework employs Constant Elasticity of Substitution (CES) production functions that allow for substitution between traditional inputs (labour and manufactured capital) and natural capital with the elasticity of substitution set to zero. This specification reflects the non-substitutability of natural capital, recognising its irreplaceable role in production and the inability of manufactured capital to fully substitute for degraded ecosystem services. This allows the model to simulate how changes in ecosystem service availability and quality, particularly those driven by climate change, affect production, prices, trade, household consumption, and income distribution.

[1] The use of these inputs is analogous to the use of physical capital stocks and intermediate goods. Some environmental inputs (market goods) are already counted in the economic output. However, non-market good and services and by-products (*residuals and waste) that are created* economic activities (production and consumption) are not considered by the SNA, so they have to be estimated.

[2] These payments to the environment are theoretical or not real in the sense that they do not imply the removal of property rights from the asset owners. Instead, the intention of these payments is to allocate the benefit the environment provides to the economic system.

The EI-CGE model incorporates explicit economic-environmental linkages, including the behaviour of the environmental agent and endogenous demand for regulation and maintenance ecosystem services. This endogeneity allows the model to capture how environmental degradation influences factor demand and production costs. By simulating the potential effects of future trajectories in natural capital, particularly those influenced by climate-related changes (Allan et al., 2019), the model provides a robust analytical platform for evaluating environmental policy, assessing economic vulnerability to ecosystem decline.

Data: Environmental integrated social accounting matrix (EI-SAM)

The EI-SAM was constructed based on 2018 input–output tables and institutional accounts published by the Mexican National Institute of Statistics and Geography (INEGI). It includes 33 activities and commodities classified according to the North American Industrial Classification System (NAICS). Six production factors are disaggregated: labour, manufactured capital, and natural capital—which itself is subdivided into soil fertility, water, pollination, and regulation and maintenance ecosystem services.

Additional data for the EI-SAM are drawn from sources such as INEGI's KLEMS project, fiscal records from the Secretaría de Hacienda y Crédito Público (SHCP), remittance data from BANXICO (Bank of Mexico). Additionally, the EI-SAM matrix incorporated data on 10 different household types derived from the household income and expenditure is the National Household Income and Expenditure Survey (ENIGH by its acronym in Spanish), conducted by INEGI.

In relation of natural capital information, the EI-SAM is built using on the framework recommended by the SEEA Ecosystem Accounting (EA) (United Nations, 2021), and uses data from the Mexican System of National Accounts (SCNM), as compiled by INEGI and organized in accordance with SEEA principles. Also, data from the Natural Capital Accounting and Valuation of Ecosystem Services (NCAVES)[3] project, which served as a pilot initiative to test the System of Environmental-Economic Accounting for Ecosystem Accounting and provided monetary valuations for final provisioning and regulatory services in agriculture, including crop provision and pollination, as well as for water supply and nature-based tourism. A distinctive aspect of EI-framework is the disaggregation of ecosystem service values using agroecological zones **(**AEZ). Ecosystem service values are disaggregated using AEZs consistent with the Global Trade Analysis Project (GTAP) framework. This allows the model to capture heterogeneities in ecosystem service availability and climate impacts across Mexico's diverse regions.

Climate change impacts of ecosystem services

Ecosystem services directly influence agriculture and indirectly others economic sectors. A decline in the provision of ecosystem services lead to a decrease in agricultural productivity, disrupting the food system and thus threatening food security. However, the relation between agriculture and ecosystem services is not simple, there are trade-offs and synergies between them (Power, 2010). Zhang et al. (2007) states that agricultural ecosystems consume and supply ecosystem services and dis-services[4]. Ecosystem services provide benefits to agriculture; without them it could not exist. Yet, ecosystem dis-services harm agriculture and increase production costs (Diagram 1). Simultaneously, agricultural production generates and preserves valuable ecosystems services for human well-being but produces negative effects on ecosystem services flows. This research will focus on ecosystem services relevant to food production.

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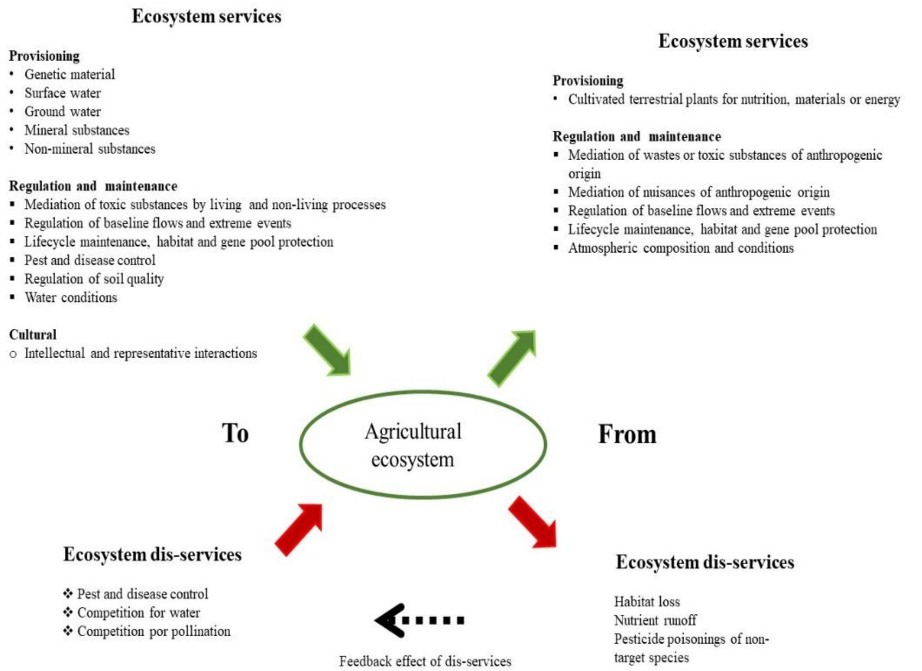
[3] The NCAVES project included five megadiverse countries: Mexico, Brazil, China, India, and South Africa. It was funded by the European Union (EU) and implemented by the United Nations Statistics Division (UNSD), the UN Environment Programme (UNEP), and the Secretariat at the Convention on Biological Diversity (CBD).

[4] It refers to adverse contributions that ecosystems make to human well-being. They generate costs or negative outcomes.

Diagram 1

Relation between agriculture and ecosystem services and dis-services



Source: Authors' own elaboration base on Zhang et al. (2007).

Evidence suggests that decreases in crop productivity are linked to the negative impacts of climate change on critical ecosystem services (Potts et al., 2016). However, the role of ecosystem services in mediating these effect remains poorly understood, complicating efforts to attribute changes conclusively. Much of the existing research has focused primarily on the direct impacts of climate change on crop production (Hasegawa et al., 2022) rather than on how ecosystem services mediate these effects (Millard et al., 2023). As Millard et al. (2023) explained, this focus may be due to the fact that direct effects of climate change on crop yields are more easily measurable. Understanding the intricate relationship between ecosystem services and crop production is therefore vital for the future of global agriculture. Addressing these knowledge gaps is essential for developing effective strategies to sustain agricultural productivity within climate change.

A growing body of analytical and modelling approaches has been developed to estimate the impacts of climate change on ecosystem services, particularly in terms of estimating biophysical changes. The estimation of these impacts is used to develop functional relationships—often referred to as damage functions—that link variations in climate variables (e.g. temperature, precipitation) to the quantity and quality of ecosystem services. These damage functions serve a critical role in CGE models, as they provide the mechanism through which physical impacts of climate change are translated into economic variables (Roson & Sartori, 2016, p. 79). In this research, damage functions were created based on a literature review of empirical studies that estimate the effects of climate change on ecosystem services relevant to agricultural production (pollination, water provision, and soil fertility).

Scenarios

The study of sustainability leads to the development of the concept of weak and strong sustainability. These two paradigms address the problem of providing a non-declining utility over time or maintaining human well-being for future generations. Furthermore, these concepts focus on the different positions related to the substitution between natural capital and manufactured capital. Week sustainability is related with the environmental economic approach. It assumes that natural capital can be substituted by manufactured and human capital. On the contrary, strong sustainability is related with the ecological economic approach. It recognizes that natural capital is an essential input and cannot be substituted by any other form of capital. It is important to mention that the model assumes an elasticity of substitution between natural and manufactured capital close to zero, meaning that ecosystem services are treated as non-substitutable inputs. As a result, the simulation does not capture the potential mitigating effects of technological change and may overestimate the short-term impacts of ecosystem service loss.

To evaluate the impacts of ecosystem service disruptions, two scenarios are developed and compared against a calibrated 2018 baseline, following the Shared Socioeconomic Pathway 2 – 4.5. The baseline reflects Mexico's macroeconomic structure in 2018—comprising 3.1% agriculture, 37.8% manufacturing, 47.2% services, and 11.9% construction, energy, and minerals—and is calibrated using the EI-SAM. The first scenario, termed "weak sustainability," simulates the decline in ecosystem service supply. This scenario reflects a neoclassical perspective, where natural capital is considered substitutable, and minimal adjustments in investment lead to larger economic disruptions. The second scenario, "strong sustainability," assumes the same reduction in ecosystem services but adjusts investment in natural capital according to its use, thereby reflecting a long-run sustainable path in which the economy takes responsibility for natural capital depletion.

Results and discussion

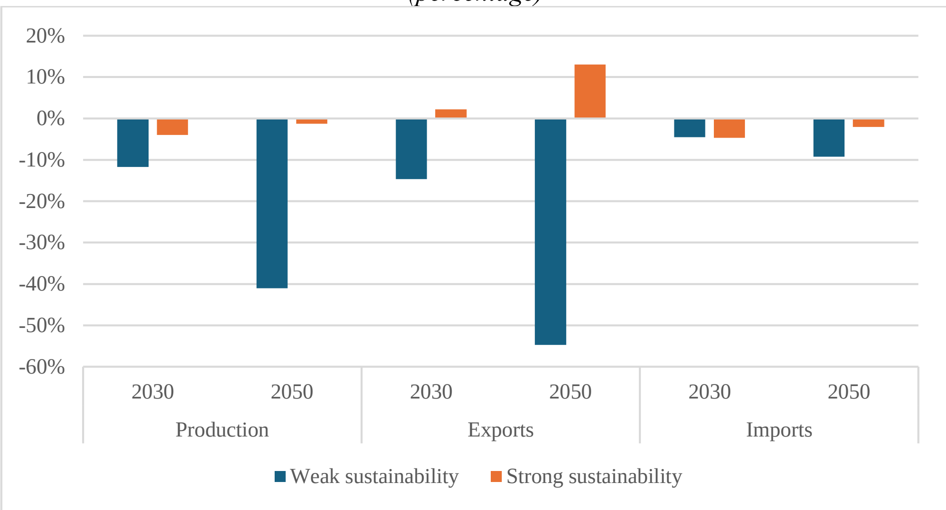
Simulation results indicate that a reduction in ecosystem services availability has significant adverse effects on the agricultural sector. This outcome is consistent with the model's assumption of a zero elasticity of substitution between manufactured and natural capital, which reflects the limited substitutability between these inputs and underscores the critical role of ecosystem services in sustaining economic activity. As ecosystem services become scarcer, their implicit price increases, thereby raising production costs and ultimately lowering agricultural output. The contraction in agriculture also has ripple effects on downstream sectors, particularly the food processing industry, which relies heavily on agricultural inputs.

The model simulations indicate that the negative impacts of climate change on ecosystem services are most pronounced in rainfed crops, such as maize and avocados, which are highly dependent on ecosystem functions, and are less capital-intensive compared to irrigated or industrialized agricultural systems. In 2018, these two crops comprised approximately 25% of total agricultural output, highlighting their economic significance and vulnerability to ecosystem degradation. Moreover, because avocado production is predominantly export-oriented, reduced output in this sector not only affects domestic supply but also diminishes foreign exchange earnings, thereby influencing the country's overall economic performance.

The adverse impacts extend beyond domestic production to significantly affect international trade balances and households' income. A decline in agricultural output translates into lower export revenues, with particularly severe consequences under the weak sustainability scenario. The case of avocado production is particularly illustrative. As a predominantly export-oriented crop, a decline in avocado yields affects not only domestic food supply but also foreign exchange earnings, with broader implications for macroeconomic performance. Avocados represent around 15% of total agricultural exports, with nearly 90% of production destined for international markets. Under the weak sustainability scenario, the deterioration of ecosystem services leads to a significant contraction in avocado output, thereby reducing export volumes, depressing trade revenues, and amplifying the economy's exposure to external shocks. However, under the strong sustainable scenario agricultural exports increases.

The contraction in agricultural output also has an impact on international trade balances. As domestic production declines, export capacity weakens, especially in high-value and export-dependent crops. The weak sustainability scenario results in particularly sharp reductions in export revenues due to unmitigated natural capital depletion. Simultaneously, the economy experiences a surge in agricultural imports. The rate of import growth is significantly higher under the weak sustainability scenario compared to the strong sustainability scenario, where reinvestment in ecosystem services helps stabilize output. This shift underscores the rising dependency on imported food products to meet domestic demand, exposing the economy to import price volatility, currency depreciation risks, and balance-of-payments vulnerabilities. The net result is a deterioration in the agricultural trade balance, further constraining macroeconomic stability in the absence of ecosystem restoration strategies.

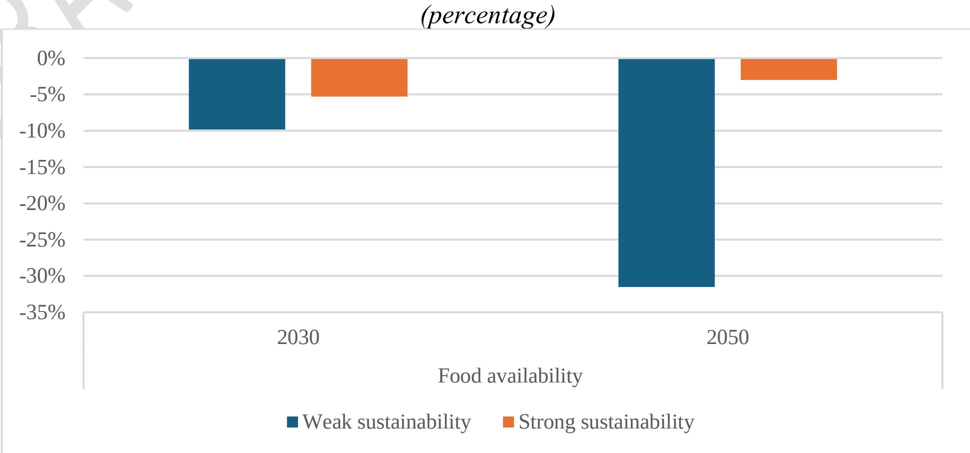
Figure 1
Mexico agricultural production, exports and imports, 2030 and 2050
Comparison between baseline and climate change scenarios
(percentage)



Source: Author's Computation.

The combined effects of reduced production, falling exports, and rising imports are reflected in declining food availability, measured as domestic production plus imports minus exports, Figure 2. Under the weak sustainability scenario, the contraction in supply leads to increased food prices, which affect both household consumption and agro-industrial processing sectors. As domestic prices rise, consumers and firms substitute toward cheaper imported alternatives, deepening the trade imbalance and weakening domestic supply chains. In contrast, the strong sustainability scenario—which assumes that investment in natural capital increases proportionally to its use—helps buffer these effects. By moderating the rate of ecosystem service decline, this scenario maintains relatively higher levels of domestic production, stabilizes food availability, and reduces the need for large-scale import substitution. These outcomes highlight the importance of integrating natural capital maintenance into macroeconomic planning as a mechanism for improving food security, trade resilience, and long-run economic sustainability.

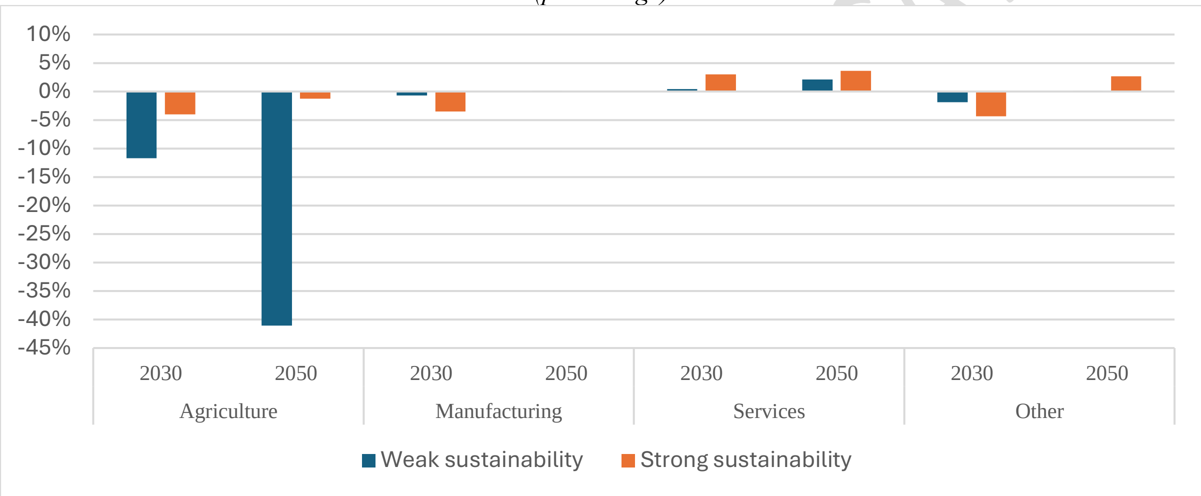
Figure 2
Mexico food availability, 2030 and 2050
Comparison between baseline and climate change scenarios
(percentage)



Source: Author's Computation.

Figure 3 illustrates the macroeconomic impacts of climate-induced ecosystem service loss under both the weak and strong sustainability scenarios. Although agriculture accounts for only 3.1% of baseline GDP, the simulation reveals meaningful differences in total output trajectories between the two scenarios. Under the weak sustainability scenario, the continued depletion of natural capital without reinvestment leads to a gradual decline in output, driven by rising production costs and reduced ecosystem functionality. In contrast, the strong sustainability scenario, in which natural capital is actively maintained through reinvestment, generates a more resilient economic pathway. The results show a positive effect on the service sector, while manufacturing—particularly industries linked to agricultural inputs and food processing—experiences negative impacts. These findings capture the interdependence between ecosystem services and the food value chain and underscore the importance of sustained natural capital investment for economic stability.

Figure 3
Mexico economic output, 2030 and 2050
Comparison between baseline and climate change scenarios
(percentage)



Source: Author's Computation.

Conclusion

This research provides evidence that the natural capital degradation—exacerbated by climate change—poses serious risks to food security and broader economic stability. By integrating ecosystem services into an EI-CGE model, it is demonstrated that declines in natural capital not only reduce agricultural production, lower exports revenues and diminish food availability. The model assumes a zero elasticity of substitution between natural and manufactured capital, meaning that ecosystem services are treated as non-substitutable inputs. This modelling choice intended to underscore the critical dependence of economic activities on ecological functions. The results reinforce the need for a strong sustainability approach, which internalizes environmental costs and prioritizes investment in natural capital maintenance and restoration. By doing so, policymakers can enhance the resilience of economic systems, support long-term food security, and better prepare for the mounting pressures of climate change.

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