Ecosystem accounting for social-ecological policy: an applied ecological economics research agenda from Guatemala

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Abstract

Economy and ecology are inseparable since economic decisions affect the natural systems that sustain them. Conventional economics still treats this dependence as an externality to be corrected through prices, even as ecosystems lose resilience and the economy presses against planetary boundaries. Ecological economics offers a more adequate framework, one that situates the economy within a finite biosphere and within limits set by biophysical criteria. This article synthesizes the foundations of the field and brings the Anglo-American and Latin American traditions together toward an applied ecological economics rooted in social metabolism, strong sustainability, and the critique of extractivism. It then systematizes the measurement instruments that make ecological dependence visible for policy, from valuation methods and multicriteria analysis to the ecological footprint, doughnut economics, and the System of Environmental-Economic Accounting. The argument is grounded in Guatemala, a megadiverse Mesoamerican country with a heavily extractive export structure and one of the longest national series of environmental-economic accounts (also called natural capital accounts) in Latin America. The Guatemalan accounts reveal a systematic depreciation of natural capital that conventional economic accounts, including their most well-known indicator (gross domestic product), fail to capture. Forest, water, soil, and wealth indicators all register losses that standard statistics fail to record, and they reshape what counts as economic growth once the depletion of the biophysical base is included. Building on this evidence, the article proposes an applied ecological economics research agenda. The agenda is organized into five interrelated work areas that connect ecosystem accounting, earth system science, and economics. Together they trace a concrete route from theory to public policy and territorial governance, toward transitions that are ecologically viable and socially fair, using Guatemala as a case study.

Keywords: ecological economics, ecosystem services, Guatemala, natural capital accounting

Author summary

Many planetary-scale problems, including climate change, biodiversity loss, soil degradation, and water scarcity, stem from how economies are measured, governed, and managed. Conventional economic thinking treats the natural world as a free input, so countries can show economic growth on paper while forests and soils that sustain that growth are being consumed. We argue that ecological economics offers an honest way to develop natural capital accounts and a research agenda around them. The paper brings together the foundations of the field from the Anglo-American and Latin American traditions, reviews the practical tools available today, and uses Guatemala as a case study to show what changes when accounts are taken seriously. We propose a five-area research agenda on applied ecological economics that connects accounting, earth system science, and economics to guide land-use decisions, fiscal policy, and territorial governance toward ecologically viable and socially fair outcomes.

1. Introduction: the ecological crisis and the limits of the conventional economic paradigm

The economic system depends deeply on nature and its ecological functioning, and every economic decision affects the natural systems that sustain it. The regenerative capacity of ecosystems, therefore, sets the limits of any economic activity that can remain viable over the long run. Modern economics, however, rests on the premise that growth has no limits and that natural ecosystems can always be replaced by other forms of capital [1]. Events have overtaken this view, since ecosystems have lost much of their capacity to recover. At least six of the nine planetary boundaries critical to Earth's stability have already been transgressed [2-4]. The COVID-19 pandemic illustrated this interdependence clearly, as disruptions to ecological systems eventually lead to borderless economic and social crises [5-7].

The tension between perpetual economic growth and planetary boundaries sits at the center of the contemporary debate on the relationship between the economy and the biosphere [8,9]. Climate change, biodiversity loss, alterations in the nitrogen and phosphorus cycles, and unsustainable soil use demonstrate that the economy faces concrete and unavoidable biophysical limits [3]. Conventional economics tends to treat these ecological risks as externalities that can be corrected through prices or regulation, without structurally addressing the causes of the tension between the economic system and the biosphere's finite nature. Ecological economics offers an important alternative here, as an interdisciplinary epistemology that integrates economics, ethics, the natural sciences, and politics to frame economic and social metabolic processes within biophysical limits. Its central contribution is to provide tools for understanding how socio-environmental risks compromise economic stability, food security, and public health [8].

This article pursues three connected aims, beginning by synthesizing the foundations of ecological economics and bringing the Anglo-American and Latin American traditions together toward an applied ecological economics. It then systematizes measurement instruments and analytical frameworks for public policy oriented to natural capital accounting. It also sets out the practical implications for Guatemala, a Latin American country that has implemented environmental accounting within its national accounts and whose productive structure is heavily extractive. In this article, ecosystem accounting and natural capital accounting are used as equivalent terms, and the research agenda proposed for Guatemala focuses in particular on the ecosystem accounting component of the SEEA framework (SEEA-EA). To meet these aims, the article draws on recent academic publications and international reports, with emphasis on the Latin American context. It is organized into six sections covering the introduction, the conceptual foundations, the methodology, the results on instruments, the Guatemalan case, the discussion, and the conclusions.

2. Foundations and main concepts of ecological economics

Neoclassical economics assumes that growth is unlimited, driven by technological and efficiency gains. The evidence, however, shows that gains in productive efficiency can trigger a rebound effect that prevents the decoupling of economic growth from environmental impact [2,10,11]. The neoclassical view holds that natural and manufactured capital can be exchanged, but it fails to recognize that certain ecological functions are irreplaceable and that once crossed, some thresholds are irreversible [1]. This idea of infinite resource substitution also ignores ecological irreversibility and the law of entropy. For Nicholas Georgescu-Roegen, entropy means that every economic activity transforms concentrated and useful natural resources into dispersed and degraded energy and materials, rendering the economic process irreversible and limiting indefinite growth [2,12].

Faced with this limitation, theoretical and practical alternatives such as the steady-state economy, degrowth, and the circular economy suggest redefining human well-being and separating it from unlimited material growth [13-16]. These currents insist that technological innovation alone is not enough to achieve sustainability and that systemic changes in how we produce and consume are needed. The degrowth and post-growth proposals question the compatibility of economic growth with ecological sustainability from several disciplinary angles [17]. Ecological economics gathers and articulates these critiques within a common interdisciplinary framework that treats the economy as a subsystem dependent on the biosphere.

Ecological economics emerged in the 1980s and consolidated through several contributions that questioned the foundations of conventional economic thought. The monetary value of ecosystem services was shown to exceed global gross domestic product (GDP), revealing the magnitude of what standard accounting omits [18,19]. Ecological economics reframes the economy as part of the biosphere and subject to its biophysical laws, thereby resting on the notion of strong sustainability, which requires conserving critical natural capital and operating within ecological limits [1,3,20]. Environmental economics, anchored in Pigou and Coase, instead assumes that environmental problems are market failures that can be corrected through taxes or property rights, and it rests on weak sustainability, in which natural capital can be substituted for manufactured capital [21-23]. Ecological economics holds that the economy is a subsystem of the biosphere subject to absolute thermodynamic limits, which demands strong sustainability because critical natural capital cannot be substituted [1,2,24]. The two traditions differ across several dimensions (Table 1).

Table 1

Comparison of environmental economics and ecological economics by their view of sustainability

Dimension	Environmental economics	Ecological economics
Theoretical foundation	Neoclassical economics (Pigou, Coase)	Thermodynamics and systems ecology [1,24]
View of the economy	Autonomous system with correctable market failures	Subsystem of the biosphere subject to thermodynamic limits
Type of sustainability	Weak. Natural capital can be substituted by manufactured capital [22,23]	Strong. Critical natural capital cannot be substituted.
Preferred instruments	Pigouvian taxes, property rights, cost-benefit analysis	Multicriteria analysis, biophysical accounting, SEEA, deliberative processes
Internal tensions	Stock management versus recognition of critical non-substitutable capital [22]	Political ecology and distributive justice [25] versus degrowth [17]

Note. Own elaboration based on [24,1,23,22,25,17].

Within each of these two fields, there are internal tensions that generate diverse perspectives and ongoing debate. In environmental economics, the natural resource economics literature emphasizes the optimal management of stocks, while authors such as Pearce recognize the existence of critical capital that cannot be substituted [22]. In ecological economics, political ecology adds power and distributive justice, and degrowth proposes a break with the growth paradigm [17,25]. Despite their differences, both traditions agree that certain ecosystems deserve priority protection and that public regulation is indispensable, which includes elements of distributive justice and equity. This convergence opens space for an applied ecological economics that combines instruments from both traditions according to the policy problem at hand.

Ecological economics addresses intergenerational sustainability and recognizes the intrinsic value of ecosystems and the cultural connection of communities with nature [26]. It also integrates the well-being of human communities, future generations, and non-human life in dialogue with Latin American indigenous views that conceive of nature as a subject of rights

[20]. Marginalized groups are often the main defenders of the commons, and even moderate extractivism sustains dependencies and social costs that fall on them [25,27]. Overcoming the ecological crisis requires recovering the epistemologies of the peoples of the global South [28]. Together, these Latin American contributions push ecological economics beyond efficiency and valuation, anchoring it in justice, cultural plurality, and the defense of territory, which the applied framework of this article directly takes up.

A key concept in ecological economics is social-ecological metabolism, which studies the flows of matter and energy within society to provide an integrated view of the economic process [2,29]. Flow analysis helps understand how the economy and ecosystems connect and reveals inequalities in the distribution of costs and benefits. A further distinctive feature is the emphasis on sufficiency, which, unlike efficiency, focuses on doing only what is necessary [20]. Accumulating goods beyond a certain point does not improve quality of life, so there are ecological and well-being reasons to limit consumption. This view aligns with studies showing that, once basic needs are met, economic growth contributes less to happiness [6].

Latin America is a paradigmatic case of the tensions between economic growth and ecological limits [25,27]. The region combines exceptional biological megadiversity with productive structures that depend heavily on the extraction of natural resources. This responds to a pattern of global insertion that generates short-term rents but erodes natural capital and perpetuates structural dependence over the long run. This pattern has taken on new and more sophisticated forms under what is now called neo-extractivism. In countries such as Ecuador, the oil sector remains the main source of public financing, which shows the difficulty of reconciling economic and conservation objectives [30]. In practice, natural asset liquidation can result in a negative net balance of natural capital, even when social indicators show temporary improvements [31]. Neo-extractivism thus tends to obscure the true magnitude of ecological loss in pursuit of short-term economic gains.

The implications of this pattern for economic accounting and regional well-being have been widely documented [30]. Conventional indicators such as GDP capture the market value of extracted resources but do not account for the depreciation of natural capital or the associated social and environmental costs. When these omissions are corrected through expanded accounting instruments, several Latin American countries show trajectories of net impoverishment rather than development. They consume their natural patrimony at a rate that exceeds the generation of human and manufactured capital [32,33]. A fundamental political dimension adds to this evidence, since the socio-environmental conflicts that emerge from these dynamics become legitimate expressions of the resistance of communities defending their livelihoods and ecological patrimony [25].

The literature on social metabolism shows that the consumption patterns of industrialized countries are sustained by externalizing impacts onto peripheral regions, such as Latin America [2]. This dynamic produces what some authors call unequal ecological exchange, a transfer of environmental burdens from the global South to the North. The North imports resource-intensive goods with high environmental impacts at prices that do not reflect their real ecological cost, while the South bears the resulting environmental liabilities. Overcoming this pattern requires national environmental policies, together with reforms to international trade rules that allow ecological costs to be internalized into export prices [34].

3. Methodology

This article is a narrative review that combines three complementary methodological strategies to address the relationship between economy and ecology from an applied perspective. These strategies include a literature review on ecological economics and natural capital accounting, consultations with experts, academic discussions at the Universidad del Valle de Guatemala (UVG) on recent strategies and actions, and a case study applied to Guatemala. Integrating the three strategies enables triangulation among conceptual foundations, contemporary institutional debates, and empirical evidence from a national process of implementing the System of Environmental-Economic Accounting (SEEA) [35]. This design follows a qualitative approach oriented to synthesizing evidence and articulating an analytical framework for an applied ecological economics agenda in Latin America.

The first strategy was a literature review of academic sources and international organizations published since the 1970s, with emphasis on the Latin American context. Source selection prioritized peer-reviewed publications in indexed journals and, as a complement, institutional literature from organizations such as the World Bank, the Economic Commission for Latin America and the Caribbean (ECLAC), the United Nations Development Program, the Food and Agriculture Organization, and IPBES. The thematic axes covered the foundations of ecological economics, instruments for measuring natural capital, environmental governance frameworks, the economics of extractivism, and applied environmental accounting. The material was organized in a thematic scheme that grouped sources into three analytical dimensions, the conceptual, the methodological, and the applied. This procedure enabled articulation of the Anglo-American and Latin American traditions of ecological economics within a common analytical framework [17,25].

The second strategy was a systematic consultation with experts and academic discussions at the UVG, aimed at contrasting the literature with recent institutional strategies and actions in Guatemala. The discussions took place within a joint program between the *Centro de Estudios Ambientales y de Biodiversidad* (CEAB) and the *Observatorio Económico y Social* (OES), which brings together perspectives from economics, the environmental sciences, and the earth system sciences. The topics covered the economic dependencies on natural capital, the operationalization of spatial accounting units, and the articulation between territorial planning and environmental accounts. The participants' contributions helped identify research priorities, areas for public policy application, and analytical gaps in integrating environmental accounting with national decision-making processes. This consultation validated the review's findings and oriented the proposed agenda toward concrete institutional challenges [36].

The third strategy was a case study of Guatemala as an applied illustration of the tensions between economy and ecology in Latin America. Guatemala was selected for three converging reasons, since it is a megadiverse country with high economic dependence on natural capital, it was a regional pioneer in implementing the SEEA, and it has officially produced environmental accounts. These accounts come from the *Instituto Nacional de Estadística* (INE, National Institute of Statistics), the *Banco de Guatemala* (Banguat, Bank of Guatemala), and the *Instituto de Agricultura, Recursos Naturales y Ambiente* of the *Universidad Rafael Landívar* (IARNA-URL, Institute of Agriculture, Natural Resources and Environment). The case analysis used secondary data from the SEEA statistical compendium [37], the natural capital accounting synthesis report [38], and recent studies on hydrological ecosystem services in Guatemala [39]. The case was systematized around four analytical dimensions, the biophysical, the monetary, the institutional, and the distributive. This approach links the conceptual framework with concrete public policy instruments and draws lessons transferable to other countries in the region.

4. Results

4.1 Instruments for decision-making

Classical economics measures ecosystems only through the prices that markets assign to them. This reduces the complexity of natural systems to a single dimension and ignores essential ecological functions, deeply rooted cultural values, and irreversible biophysical processes. In response to these limitations, ecological economics proposes a plurality of measurement instruments that combine monetary methods, biophysical indicators, and deliberative mechanisms of collective valuation [18,25,40]. This plurality recognizes that different values require different metrics and different decision processes.

Ecosystems hold several types of value that go beyond what markets can register. Direct use value derives from goods and services consumed directly, and indirect use value is associated with regulating functions such as water purification or climate stabilization. Option value reflects the future potential of resources that have not yet been used, and existence value recognizes that ecosystems and biodiversity have intrinsic value independent of human judgment [41]. These approaches show that setting a market price does not capture the full dependence of human and non-human life on nature. Ecological economics, therefore, proposes that complementary and deliberative valuation methods are necessary for decisions that pursue sustainability [20,29].

Among the economic valuation methods, contingent valuation, hedonic pricing, travel cost, and replacement cost stand out. There is an important distinction between economic valuation, which uses welfare logic to assign monetary values, and multicriteria evaluation, which compares policy options without reducing them to a single metric [20]. The choice among methods is not neutral, since it depends on assumptions about the substitutability of natural capital, the irreversibility of damages, and the role of the market in distributing benefits. When damages are irreversible or ecological thresholds are uncertain, precaution justifies adopting minimum conservation standards defined by biophysical criteria [3,20].

Indicators and analytical frameworks aim to establish global standards for tracking socioeconomic and ecological dimensions. The ecological footprint shows that humanity consumes resources equivalent to 1.7 planets [42]. Reducing this footprint requires ecological taxes and other incentives within sound institutional frameworks [43,44]. Doughnut economics offers a visual framework that integrates an ecological ceiling, defined by planetary boundaries, with a social floor, defined by minimum standards of human well-being [45]. The space between the two is the safe and just zone in which the economy should operate, which displaces GDP as the central objective of economic policy [46]. Material flow analysis and life cycle analysis measure social metabolism and resource dependence, and they show that economic growth has gone hand in hand with rising material and energy use [2].

Public policy has traditionally relied on cost-benefit analysis (CBA) as a central decision criterion. This method faces fundamental limitations, as it reduces the complexity of ecosystems to monetary values and omits long-term risks, irreversibility thresholds, and ethical dimensions that markets cannot capture [17]. The critique of CBA extends to the use of high discount rates, which reduce the present value of long-term environmental benefits and favor short-term investments at the expense of future generations. In contexts of climate change and biodiversity loss, discount rates should be adjusted to intergenerational horizons [32]. This debate also raises ethical considerations toward future generations, because a positive discount rate implies that their well-being counts less than that of the present. That is ethically problematic when irreversible ecological damages are at stake [20].

The choice of fiscal instruments is also not neutral and always produces distributive effects, creating winners and losers. Environmental taxes tend to be regressive when they fall on basic consumption goods and disproportionately affect lower-income households. Emission quota systems, in turn, can consolidate advantages for those who already hold greater economic capacity and bargaining power. In Latin America, where structural inequalities are deep and access to natural resources has historically been concentrated, incorporating equity and distributive justice criteria into the design and evaluation of environmental policy instruments is indispensable [25].

Environmental impact assessment is another key instrument for screening projects before they proceed. Its effectiveness increases when it incorporates early community participation, sound sustainability criteria, and transparent monitoring of results [47]. Strategic environmental assessment applied to policies, plans, and programs has greater potential to detect cumulative and synergistic effects than project-by-project assessment [29]. This approach is particularly relevant in contexts of mining or agro-industrial expansion, where individual impacts are smaller than cumulative ones.

Multicriteria analysis has gained relevance as a tool for complex decisions with non-commensurable objectives. Unlike CBA, multicriteria analysis compares alternatives by considering environmental, social, cultural, and economic criteria simultaneously [20]. This approach is especially valuable when conflicts of interest are explicit, since making the trade-offs among different objectives visible supports democratic deliberation on social priorities rather than hiding them under seemingly neutral technical calculations. Resilience theory complements this approach, since resilience does not mean simply resisting disturbances but maintaining essential functions and the capacity to reorganize after crises, which implies managing ecological and institutional diversity [41].

Environmental-economic accounting is arguably the strongest bridge between ecological measurement and public policy decisions [35]. The SEEA was adopted by the United Nations as a global statistical standard in 2012. This system links national accounts with data on water, energy, emissions, forests, and ecosystems, which yields coherent tables that reveal sectoral dependencies and environmental costs. Unlike isolated indicators, the SEEA integrates data that support public decision-making by systematically articulating economic and environmental information, addressing key dimensions such as relevance, accessibility, coherence, timeliness, and interpretability [35].

The quality and credibility of the data generated by the SEEA are a strategic political asset, not merely a technical resource. Sound data can displace discussions based on perceptions or sectoral interests and give greater weight to evidence so that environmental priorities are reflected in the allocation of public resources. Environmental governance, however, requires recognizing the inherently political dimension of these analytical frameworks. Multicriteria frameworks, natural capital accounting, and impact assessment can be neutralized if they are used symbolically or if participation processes are superficial [48]. The effectiveness of these tools depends as much on technical capacities as on the political will to apply their results. In Latin America, environmental management instruments are often adopted as institutional signals without effective implementation backed by sufficient resources [34].

4.2 Guatemala: ecological structure, extractivism, and environmental-economic accounting

Guatemala clearly illustrates the tensions between the economy and ecosystems that characterize Latin America. The country hosts extraordinary biodiversity and ecosystems of global value, such as the Maya Forest, the highland volcanoes, and the coastal mangroves. It also faces sustained deforestation, although official monitoring by the Instituto Nacional de Bosques (INAB, National Forest Institute) and the Consejo Nacional de Áreas Protegidas (CONAP, National Council of Protected Areas) shows that the annual net loss rate has decelerated over successive periods. The rate fell from 1.43% in the 1991–2001 interval to 0.36% in the 2016–2020 period [49]. The expansion of the agricultural frontier, fuelwood extraction, mining, and monocultures of oil palm and sugarcane remain the main drivers of forest loss [50]. This loss reduces the availability of drinking water in watersheds and on slopes, increases vulnerability to landslides, and raises local food insecurity [51].

The country hosts 14 ecoregions and extraordinary biodiversity, but it has experienced one of the highest deforestation rates in Latin America and the Caribbean [52]. In 1950, forests covered close to 7 million hectares, equivalent to 64.5% of the national territory, a share that fell to 34.2% in 2010 and to 33.3% in 2020, when official monitoring recorded 3.6 million hectares of forest cover [49,53]. In the 2016 to 2020 period, gross losses of 244,395 hectares were partly offset by the recovery of 191,658 hectares, which yields a net loss of 52,736 hectares, or 13,184 hectares per year [49].

The Guatemalan productive structure combines agricultural exports with high ecological impact and growing mining activity, both metallic and non-metallic. Agricultural activities and their direct linkages account for 24% of national GDP and close to 40% of total export value, with products such as cardamom, banana, coffee, palm oil, and cane sugar as the main items

[50]. In 2020, cardamom accounted for 9.8% of total exports, banana for 7.2%, and coffee for 5.6%, indicating the persistent dependence on agricultural commodities with high water and soil demands [54]. These export sectors operate under exclusive deals negotiated with political elites that have captured the state and blocked policies of economic and social transformation, configuring what has been called a trapped economy [55].

The export sectors generate significant foreign exchange but also sizable environmental liabilities that do not appear in conventional national accounts [56]. In 2014, municipalities with metallic mining licenses showed, on average, 44% more deforestation than the national mean, indicating a persistent association between extraction and environmental fragility [57]. The cases of nickel mining at Lake Izabal and the palm concessions in the northern watersheds have been the subject of documented socio-environmental conflicts that reveal the disconnection between the economic cycles of extraction and the ecological cycles of regeneration [51]. This structural gap between private profitability and ecosystem degradation is a central argument for incorporating natural capital accounting into development planning.

In this context, the implementation of the SEEA in Guatemala represents an advance of regional relevance. The SEEA in Guatemala emerged from a public-academic partnership among the INE, the Bank of Guatemala, and the *Universidad Rafael Landívar*. Guatemala was a pioneer in this process, as it was one of the first countries in the world to compile ecosystem accounts for the entire national territory [38]. The SEEA improves the quality of environmental information systems by structuring economic and ecological data in a coherent and integrated format [35]. The Guatemalan experience has laid the basis for integrating natural capital into public planning. The World Bank has complemented this effort with expanded wealth indicators that incorporate natural capital into the measurement of national wealth, in line with the proposal to treat nature as depreciable capital rather than as income [32,58].

The Bank of Guatemala's foreign trade statistics reveal the persistence of a primary specialization profile characterized by high demand for natural capital. The five main agricultural export products, coffee, banana, sugar, cardamom, and oil palm, rose from 20.8% of total export value in 2002 to 29.1% in 2012, consolidated around 28% between 2012 and 2019, and moderated to 25.7% in 2022 as non-traditional exports grew [59]. In absolute terms, the combined value of these five products grew from USD 883 million in 2002 to USD 4,298 million in 2022. This near fivefold increase reflects a real intensification of extractive pressure on soils, water, and ecosystems [59]. This structure, in which the main generators of foreign exchange are also the main demanders of natural resources, configures a structural dependence on natural capital that is not accounted for in export prices or in conventional national accounts [50].

The main quantitative findings from Guatemala's SEEA Central Framework accounts document a depreciation of natural capital that conventional accounting misses (Table 2). The accounts were compiled by the INE, the Bank of Guatemala, and IARNA-URL between 2001 and 2013 and updated with support from the World Bank Wealth Accounting and the Valuation of Ecosystem Services (WAVES) Partnership through 2019. These results, invisible to conventional GDP accounting, provide solid evidence that the current development pattern entails a systematic depreciation of natural capital and compromises long-term sustainability [37,38].

In the forest domain, the accounts reveal that Guatemala lost 40% of its forest cover between 1970 and 2005, at an annual deforestation rate of 1.7%, three times the average for

Latin America and the Caribbean. They also show that more than 95% of timber extraction occurred outside institutional control [38]. The real contribution of forests to the economy was 3.15% of GDP in 2001, more than three times the figure recorded by conventional national accounts. This gap exposes the systematic undervaluation of natural capital in official statistics [37,60]. The accumulated economic cost of forest degradation, measured as lost erosion-control capacity and carbon storage, reached GTQ 2,919 million between 1991 and 2003, equivalent to USD 374 million [38].

In water and agriculture, the accounts show that maize and sugarcane are the country's main water users and that their production depends entirely on climatic variability, which represents a structural vulnerability not captured by GDP [37]. These Central Framework results confirm that Guatemala faces a structural gap between its economic growth model and the regenerative capacity of its productive ecosystems, a gap that becomes visible only when environmental accounts are incorporated into development analysis.

Table 2

Main quantitative findings from Guatemala's SEEA Central Framework accounts

Indicator	Quantitative result	Period
Forest account (CIB)		
Forest cover loss	40% absolute loss; per capita stock fell to 28% of 1970 level	1970–2005
Annual deforestation rate	1.7% per year, three times the LAC average	2001–2006
Timber extraction outside institutional control	More than 95% of total volume	2001–2010
Real contribution of forests to GDP	2.58% under SEEA vs. 0.93% in conventional national accounts	2006
Annual GDP loss from forest depreciation	0.94% of GDP per year	2001–2006
Accumulated economic cost of forest degradation	GTQ 2,919 million (USD 374 million)	1991–2003
Water account (CIRH)		
Largest user of water (total use)	Rain-fed agriculture, close to 40% of national water use	2001–2006
Largest single consumptive water extractor	Coffee processing, 54% of national water extraction	2003
Sugarcane share of irrigation water	43% of all irrigation water in the country	2003
Energy and emissions account (CIEE)		
Household share of final energy use	46% of national consumption, mostly from fuelwood	2006
Household share of national GHG emissions	60% of national total, mostly from biomass combustion	2006
Total GHG emissions	45.6 million tonnes of CO_2 equivalent (productive activities and households)	2006
Largest single sectoral GHG emitter	Electricity generation, 5.6 million tCO_2e	2006
Subsoil resources account (CIRS)		
Metals and non-metals mining share of GDP	Rose from 0.08% to 0.39%, more than fourfold	2001–2006
Oil and gas share of GDP	Rose from 0.31% to 0.65%, more than twofold	2001–2006
Environmental expenditure account (CGTA)		
Central government environmental spending	Never exceeded 0.3% of GDP, equivalent to 2% of national budget	2001–2006
INAB and CONAP combined budget vs. forest depreciation	Less than 10% of annual forest depreciation value	2001–2006

Note. *GHG = greenhouse gases. GTQ = Guatemalan quetzal. TJ = terajoules. ANS = adjusted net saving. LAC = Latin America and the Caribbean. GDP = gross domestic product. GNI = gross national income. The accounts were developed by the INE, Banguat, and IARNA-URL with support from the World Bank WAVES Partnership (2014–2019). Own elaboration based on [38,37].*

The ecosystem accounting component of Guatemala's SEEA program extends the analysis beyond individual asset accounts (Table 3). It captures the spatial integrity and functional condition of natural systems, revealing thresholds that asset-by-asset accounting cannot. Nine of the country's 14 ecoregions exhibit critical fragmentation that compromises their capacity to provide natural goods and services [38]. Soil degradation compounds this picture, with 10% of the territory severely degraded and 63% at risk of reaching that state. The annual cost of this soil degradation is equivalent to 0.55% of GDP [38]. Recent watershed-scale work, building on WAVES-era data, operationalizes river basins as ecosystem accounting areas. It links hydrological ecosystem service flows directly to the structure of economic activity at the sub-national scale [39].

Table 3

Main findings from Guatemala's SEEA Ecosystem Accounting

Indicator	Quantitative result	Period
Ecoregions with critical fragmentation	9 of 14 ecoregions with compromised integrity	2003
Soil degradation status	10% of territory severely degraded, 63% at risk of reaching that state	2010
Annual cost of soil degradation	0.55% of GDP per year	2010
Annual cost of waterborne diseases from contaminated water	0.97% of GDP per year	2010
Operational spatial units for ecosystem accounting	River basins formally defined as ecosystem accounting areas for Guatemala	2025
Hydrological ecosystem services linked to economic activity	Sub-national analysis integrating water-related service flows with economic activity by basin	2025

Note. GDP = gross domestic product. WAVES = Wealth Accounting and the Valuation of Ecosystem Services. Own elaboration based on [38,39].

The aggregate indicators that close the SEEA framework synthesize these sectoral findings into macroeconomic measures of sustainability (Table 4). The environmentally-adjusted GDP, computed using depreciation of forest capital alone, is consistently negative from 2001 to 2006 and amounts to less than 1% of GDP. Even this partial correction of the national accounts reveals economic growth based on the consumption of natural patrimony [37]. Wealth accounting reinforces this reading by tracking the contribution of natural capital to national prosperity over decades. Guatemala's share of natural capital in total wealth fell from 23% in 1995 to 21% in 2014. That share remains more than double the global average of 9% [58,61]. Average adjusted net saving over 1995 to 2016 reached only 1.6% of gross national income, with several years recording negative values.

Table 4

Aggregate SEEA indicators of sustainability for Guatemala

Indicator	Quantitative result	Period
Environmentally-adjusted GDP (forest depreciation only)	Negative adjustment, less than 1% of GDP, evidence of growth based on degradation	2001–2006
Apparent decoupling of GDP from environmental pressure	Attributable to international price effects rather than national efficiency gains	2001–2006
Natural capital share of total wealth	21% of total wealth, more than double the global average of 9%	2014
Trend of natural capital share	Decline from 23% to 21% of total wealth	1995–2014
Average adjusted net saving	1.6% of GNI, with several years showing negative values	1995–2016

Note. GDP = gross domestic product. GNI = gross national income. ANS = adjusted net saving. Own elaboration based on [37,38,61,58].

Guatemala's SEEA accounts have begun to inform public policy instruments, illustrating the potential of environmental accounting to transform planning and budgeting decisions (Table 5). Despite this progress, the environmental accounts produced have not yet been systematically incorporated into development planning, public budgeting, or investment appraisal. The *K'atun* 2032 National Development Plan establishes sustainable management of natural resources, articulated with the guarantee of human rights, as one of its priority axes, although the challenge of integrating it effectively with existing environmental measurement instruments persists [38].

Table 5

Use of SEEA accounts in public policy instruments in Guatemala

Policy instrument	SEEA account used	Use and application
K'atun 2032 National Development Plan	Forest, ecosystem, and water accounts	Establishes the sustainable management of natural resources as a priority axis. SEEA indicators on deforestation, degradation, and water services oriented the targets to 2032.
National Climate Change Action Plan	Water, forest, ecosystem, energy, and emissions accounts	Informed at least four of the six adaptation lines, namely agriculture and food security, forest resources and protected areas, integrated water management, and marine-coastal zones.
Forest incentive programs (PINFOR and PINPEP)	Forest accounts (flows and assets)	Forest cover data, deforestation rates, and forest dynamics in biological corridors supported the targeting and evaluation of payment-for-forest-services programs.
Competitiveness and rural development strategy	Agriculture and water accounts	Data on water productivity by crop and on the structure of agricultural exports oriented decisions on irrigation efficiency and productive diversification.
IEEM-GUA platform (Integrated Economic-Environmental Model)	Energy, forest, and emissions accounts	Calibrated the environmental computable general equilibrium model applied to the fuelwood-forest sector, quantifying the impact of a 25% increase in household fuelwood-use efficiency.
World Bank WAVES Partnership in Guatemala (2014–2019)	Forest, water, ecosystem, energy, fisheries, and agriculture accounts	Formalized the production of environmental accounts as official INE statistics, linked the SEEA to the national planning cycle, and built institutional capacity in SEGEPLAN, INAB, MARN, and INE.
National State of the Environment Report	All SEEA accounts (physical and monetary)	Integrated economy-environment indicators for periodic environmental reporting, tracking energy footprint, deforestation, and adjusted net saving.
Natural resource investment appraisal	Ecosystem accounts and adjusted net saving	Ecosystem service valuation methods and adjusted net saving were presented as an analytical basis for the ex ante appraisal of public investment projects in the environment.

Note. SEEA = System of Environmental-Economic Accounting. PINFOR/PINPEP = forest incentive programs. IEEM-GUA = Integrated Economic-Environmental Modeling Platform for Guatemala. SEGEPLAN = Secretariat of Planning and Programming of the Presidency. INAB = National Forest Institute. MARN = Ministry of Environment and Natural Resources. Own elaboration based on [38,37].

Overcoming these challenges requires a strategy that combines investment in public statistics, institutional strengthening, and accountability mechanisms that link environmental accounts to budget decisions. The experience of Costa Rica, where payment for ecosystem services is partly based on natural capital accounts, offers a relevant reference for Guatemala. In the Central American context, regional cooperation in environmental accounting could generate economies of scale and comparative frameworks that strengthen the region's negotiating position in international forums on climate finance.

5. Discussion: toward a proposal for an applied ecological economics agenda

In response to the concept and problem of extractivism, Latin America has generated alternative proposals of notable intellectual and political originality. The concepts of *buen vivir* or *sumak kawsay* (good living), incorporated into the constitutions of Ecuador in 2008 and Bolivia in 2009, recognize nature as a subject of rights and propose a model of organization centered on harmony between the community and ecosystems [62,63]. *Buen vivir* is not an alternative form of development but an alternative to development itself, because it questions the premise that nature lacks intrinsic value if it has no human use [62]. These proposals are interpreted as civilizational transitions that recover relational ways of understanding the world, in which human beings are part of nature rather than dominating it [28]. These approaches speak directly to the notions of intrinsic value and the biophysical limits of ecological economics [27].

The experience of Ecuador and Bolivia, however, reveals the tensions of *buen vivir* as a state project. The progressive governments that formally adopted that framework maintained and expanded their extractivist economies, which subordinated the constitutional recognition of the rights of nature to the expansion of the mining and oil frontier [64]. This contradiction between discourse and practice shows that the post-extractive transition cannot be achieved through legal reform alone. It requires structural transformations in the patterns of accumulation, in the relations among the state, capital, and indigenous territories, and in the real mechanisms of political participation [63,65].

In Guatemala, several Maya indigenous communities have historically maintained territorial management practices that incorporate principles of reciprocity, cyclicity, and respect for ecological limits. The milpa system, practiced by the *K'iche', Kaqchikel, Mam, and Ch'orti'* peoples, combines food productivity with the conservation of biodiversity, water regulation, and climate resilience within a single unit of territorial management [51,66]. These practices have weakened over decades of armed conflict, land loss, and the expansion of monocultures, yet they remain present as references and practices in many communities. The Maya agroforestry systems of the highlands combine economic productivity with the conservation of ecosystem services, which illustrates what ecological economics calls sustainable social-ecological metabolism [2]. Community forest management in the Maya Biosphere Reserve also shows that it is possible to conserve biodiversity and generate local livelihoods through territorial governance models that recognize communities' agency over their ecosystems [38].

The proposal of post-extractive economies does not imply halting development but redefining it in terms compatible with planetary boundaries and distributive justice. It is possible to distinguish between the exit from predatory extractivism, which generates more environmental liabilities than economic assets, and the transition toward diversified economies with greater added value and less pressure on ecosystems [27]. In Guatemala, dependence on primary exports with high ecological demand remains high, and natural capital does not accumulate at the pace of economic growth. In this setting, productive diversification is at once a condition for environmental sustainability, the reduction of macroeconomic vulnerability, and the strengthening of communities' territorial rights [61]. Without this structural reorientation, advances in environmental accounting risk remain technical exercises with no real influence on investment and planning decisions [32,34].

The applied ecological economics agenda proposed for Guatemala takes shape in a joint research program between the *Centro de Estudios Ambientales y de Biodiversidad* (CEAB, Center for Environmental and Biodiversity Studies) and the *Observatorio Económico Sostenible* (OES, Sustainable Economy Observatory) of the *Universidad del Valle de Guatemala* (UVG). The program integrates natural capital accounting, earth system science, and economics to assess the dependencies and impacts among society, the economic sectors, and the country's natural capital. Within the SEEA framework, the agenda focuses on ecosystem accounting (SEEA-EA), which directly addresses integrating ecosystem assets and services into economic activity. The conceptual approach recognizes two currents that are opposed in theory but complementary in practice, focused sectoral post-growth and high-efficiency green growth, whose relevance depends on the sector and the territory. Applying both currents translates into a differentiated spatial configuration of land use and economic activity according to ecological footprint. The program is organized into five interrelated work areas that connect measurement, territorial analysis, and governance to guide transitions toward multifunctional landscapes [39].

The first two work areas address the biophysical-economic interface and its territorial expression. Work area 1 (WA1), centered on natural capital accounting, seeks to develop and apply an analytical framework to assess the social-ecological risk of environmental degradation under climate change and land-use scenarios, with emphasis on hydrological ecosystem services. This area also aims to improve the current SEEA indicators to reflect climatic variability and extreme events, dimensions that are still underestimated in the existing accounts. Work area 2 (WA2), anchored in landscape ecology, builds on the basin typologies already defined as ecosystem accounting areas for Guatemala, and extends them to identify territorial configurations that enhance management among land uses and minimize trade-offs among ecosystem services [39]. The articulation between WA1 and WA2 turns the principles of ecological economics into spatially explicit tools for territorial planning and governance [35,39].

The third and fourth areas address sectoral transformation and the urban-water dependencies that condition the ecological viability of the national economic model. Work area 3 (WA3), within the broader economic studies, empirically assesses green growth and post-growth scenarios to identify which sectors must transition most urgently toward new models of production and consumption, and to determine how the costs and benefits of each pathway are distributed. This area also explores ways to reconcile both strategies in a coherent sequence for Guatemala. Work area 4 (WA4), oriented to urban development, examines how gray infrastructure distorts the hydrological cycle in urban areas and what vulnerabilities emerge when water quality and hydrological connectivity between watersheds and cities are considered. Combining WA3 and WA4 links the macro-sectoral transformation with the territorial scale where most of the Guatemalan population lives and produces, a domain in which doughnut economics offers a useful normative framework for defining social floors and ecological ceilings [45].

The fifth area integrates the institutional and policy dimension, without which none of the others is effective. Work area 5 (WA5) analyzes how governance arrangements at different scales condition the possibility of multifunctional landscapes and which financing models sustain them over time. Implementation of the agenda rests on a core team that combines geospatial, economic, and climate change capacities, in partnership with the UVG's faculty of economics and its minor in environmental economics. This agenda offers a concrete route to connect ecological economics theory with public policy, university training, and regional academic cooperation, making it a first operational step toward an applied ecological economics in Guatemala and, arguably, in Mesoamerica [36,38].

6. Conclusions

Economy and ecology are deeply connected, and this is not a secondary or dispensable relationship. Every economic decision affects natural systems, and every ecological degradation modifies the limits within which economies can operate. Ignoring this interdependence does not eliminate it; it merely displaces the costs onto the most vulnerable and future generations. These findings are particularly relevant for countries such as Guatemala, where the gap between the growth model and the regenerative capacity of ecosystems is structural.

Several central findings ground the relevance of applied ecological economics as a theoretical and normative framework for public policy in the region. Ecological economics offers a framework that differs from the conventional one by incorporating biophysical limits, sufficiency, and intergenerational justice as guiding principles. Unlike the neoclassical approach, which treats environmental problems as externalities that can be corrected through prices, the ecological approach recognizes that the economy operates within a finite biosphere and that certain thresholds cannot be offset by manufactured capital. This implies redesigning policy instruments so that they operate within limits defined by biophysical criteria rather than by economic efficiency alone [1,20].

The available measurement instruments, such as material flow analysis, the ecological footprint, life cycle analysis, and the SEEA, operationalize the principles of applied ecological economics into concrete data that can guide public policy and private decisions. These instruments make the interdependencies between the economic system and ecosystems visible and offer a technical basis for designing regulations, fiscal incentives, and governance mechanisms consistent with biophysical limits. Their effectiveness is not automatic, since it depends on deliberative processes that make conflicts of values and the distribution of costs and benefits among social groups explicit [20,41].

Latin America and Guatemala clearly exemplify the tensions between economic growth and ecological sustainability, and they show both the costs of extractivism and the possibilities offered by natural capital accounting and the territorial management practices of indigenous peoples. The region is at once the stage for the problems that call for ecological-economic diagnoses and a laboratory for concrete alternatives that could allow adjustments to the socioeconomic model. This calls for rethinking the concept of progress from a perspective that integrates social equity, biophysical limits, and cultural diversity as inseparable dimensions of sustainable development.

The transition toward an ecologically viable economy is technical, political, and cultural. It requires transformations in the power relations that determine what is measured, valued, and prioritized in collective decisions [25,48]. Without those transformations, the most sophisticated measurement instruments can coexist with policies that continue to degrade natural capital. In Guatemala, this means linking environmental accounts to development planning and the public budget, strengthening community participation in territorial management, and building institutional capacities so that ecological information influences investment decisions.

Building on these findings, the article proposes an applied ecological economics research agenda, developed in the discussion section. This agenda is conceived as a joint research program between the CEAB and the OES of the *Universidad del Valle de Guatemala*, organized into five interrelated areas. It integrates natural capital accounting, earth system science, and economics to assess the dependencies between Guatemala's economic sectors and its natural capital. The conceptual framework and the analytical instruments needed already exist, but their implementation requires political will and sustained institutional capacity [32,36]. This article is a first step toward putting that agenda into practice in Guatemala and the wider Mesoamerican region.

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