





Advancing the diagnosis of poverty traps: A regional application of Emergy Theory and the 5SEnSU model in Brazil

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ABSTRACT

Poverty traps constitute significant impediments to sustainable development, particularly in structurally unequal nations such as Brazil. This study presents an Emergy-based Five-Sector Sustainability (5SEnSU) Model as an innovative framework for diagnosing regional poverty traps, integrating environmental, economic, and social dimensions within a systemic, biophysical perspective. Unlike traditional models, the proposed approach quantifies poverty-related imbalances through a unified metric—solar emergy joules (sej)—facilitating direct comparison across sectors and regions. Application of this model to Brazil's macro-regions revealed substantial spatial heterogeneities: the North Region exhibited the highest Intensity of Poverty Traps (IPT = 23.0), primarily driven by external trade dependency and labor undervaluation, while the Southeast faced severe ecological degradation risks (IPT = 7.1). In contrast, the Northeast and Midwest demonstrated entrenched labor inequalities (IPT = 4.8 and 5.7, respectively), despite more favorable economic indicators. Nationally, key challenges were underscored by an unfavorable Labor Income Ratio (LIR = 2.7) and Export Money Ratio (XMR > 1), indicating widespread undervaluation of labor and inequitable external trade. Nevertheless, strengths such as a relatively favorable Money Import Ratio (MIR < 1) and significant carbon neutrality potential were identified. The emergy-based 5SEnSU Model provides a robust diagnostic tool for policymakers, offering high-resolution insights to design targeted interventions for resource redistribution, ecosystem restoration, and social inclusion. This work advances sustainability assessment by offering a replicable and quantitatively consistent method focused on the biophysical perspective of poverty traps within socioecological systems. The model does not directly address social and political power relations, but it provides complementary insights grounded in resource flows.

1. Introduction

Poverty remains one of the most pressing global challenges. Its eradication, in all its forms, is the first goal of the United Nations Sustainable Development Goals (SDG1) (UN, 2015). Achieving this objective requires breaking persistent poverty traps—self-reinforcing cycles driven by the lack of economic, environmental, and social capital (Haider et al., 2018). Addressing such complex systems demands robust analytical frameworks to support evidence-based policymaking (Elamathy and Sathiyathan, 2024).

A review of global contributions to poverty alleviation highlights the evolution of academic and policy thinking. Amartya Sen's work on

welfare economics and social choice (Nobel Committee, 1998), Angus Deaton's research on consumption and development (Nobel Committee, 2015), and the experimental approaches of Banerjee, Duflo, and Kremer (Nobel Committee, 2019) collectively reshaped the understanding of poverty and influenced the design of more effective interventions (Callaway, 2019). Parallel to this, the transition from the Millennium Development Goals (MDGs) to the SDGs marked a critical shift from a narrow, target-based framework toward a more integrated and systemic view of development challenges (Jong and Vijge, 2021; Parotto and Pablos-Méndez, 2023).

Despite these conceptual and policy advances, many structural barriers persist, particularly in the Global South. In Brazil, a country with

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significant natural and economic resources, poverty remains closely linked to deep-rooted inequalities. Land ownership is highly concentrated—1 % of the population owns nearly 50 % of the land (Zimmerman, 2022)—and while the Gini index decreased from 0.596 in 2004 to 0.540 in 2009, income inequality remains among the highest in the world (Hasell et al., 2023). These disparities are not due to a lack of resources but to unequal access and distribution—an issue reflected globally (Coscieme et al., 2019; Estes, 2019).

In this context, diagnostic tools that address the systemic interconnections among environment, economy, and society are essential. Energy accounting and the Five-Sector Sustainability Model (5SEnSU) offer promising methodologies. Recent applications of these tools at the national level—such as in Mozambique—have demonstrated their ability to reveal ecologically unequal exchanges and identify resource-based poverty traps (Giannetti et al., 2023). However, there is still limited work applying these methods at a regional level within large and diverse countries.

This study extends that research by applying an integrated Emergy-5SEnSU framework to Brazil's macro-regions. This approach allows for the identification of regional poverty traps based on emergy flows, trade patterns, and social inequality, providing a more nuanced picture of how vulnerabilities differ across territories.

The proposed framework builds upon and unifies two important but traditionally separate streams of sustainability assessment. On one side, Wackernagel et al. (2021) highlight the systemic risks of overshooting Earth's biocapacity, framing poverty as a product of ecological overshoot. On the other, Odum (1996) offers a systems-based foundation that quantifies the unequal flow of energy and resources across sectors. Integrating these perspectives within the 5SEnSU structure provides a multidimensional view of poverty traps—grounded in thermodynamics, ecological economics, and social equity.

By doing so, this study contributes a novel ecological modelling framework that can inform policy interventions aimed at redistributing resources, reinforcing regional productive systems, and reducing environmental degradation. Although Brazil is the empirical focus, the methodology is broadly applicable to other socioecological systems, particularly in countries marked by structural inequality and environmental stress.

2. Conceptual review

2.1. Poverty traps

Poverty traps are situations where individuals or communities remain caught in a cycle of poverty due to structural and systemic barriers that impede their ability to escape (Barrett and Carter, 2013; Haider et al., 2018; Radosavljevic et al., 2021). Understanding the interplay between environmental resources, seen as common goods, and strategies to overcome poverty traps can be attributed to the independent contributions of Elinor Ostrom and Hermann Daly. Elinor Ostrom, a 2009 Nobel Prize in Economic Sciences and the first woman to earn this distinction conducted analyses of economic governance, especially regarding the management of common resources. Conversely, Hermann Daly emphasized the necessity for a stationary economy that acknowledges ecological limits and prioritizes the equitable redistribution of regenerative resources (Daly and Cobb Jr., 1989). These scholars clearly underscored the importance of examining environmental resources to alleviate poverty.

In line with these perspectives, the concept of poverty traps, as outlined by Wackernagel et al. (2021), incorporates an application of Odum's Emergy Theory (Odum, 1996). Wackernagel et al. (2021) argues that humanity's growing demand for natural resources surpasses Earth's capacity for biological regeneration. As a result, the ability of ecosystems to renew biomass has become a critical constraint for the global economy. The uneven exposure of national economies to these biocapacity limitations hinders sustainable development and obstructs

efforts to eradicate poverty—a condition referred to as the "ecological poverty trap." Odum's Emergy Theory offers a quantitative framework for identifying sustainable policies and standards for both humanity and nature, thereby reducing reliance on trial and error. The theory underscores the principle of self-organization for maximum prosperity, known as the Law of Maximum Empower. According to Odum, the unequal distribution of emergy flows—both in international trade and within societal exchanges—creates tensions and distortions. An emergy assessment can aid in developing policies that address these imbalances, promoting strategies to dismantle the poverty trap caused by unequal resource exchanges.

Fig. 1 illustrates the principal challenges to overcoming poverty traps, integrating Wackernagel et al. (2021) concept of resource security for poverty eradication and Odum's Theory (Odum, 1996). On the one hand, there may be an environmental surplus of resource regeneration and greenhouse gas absorption; on the other, inequalities in international trade and internal resource distribution persist. Poverty traps reside at the intersection of these dynamics, presenting a critical area where science and policy can collaborate to conceive effective solutions.

2.2. Ecologically unequal exchange and political ecology

The persistence of poverty traps in structurally unequal societies such as Brazil cannot be fully understood without considering the broader dynamics of ecologically unequal exchange (EUE) and political ecology. Originating from world-systems theory and ecological economics, EUE highlights how international trade systematically transfers biophysical resources—materials, energy, land, and labor—from peripheral to core economies under conditions of unequal compensation (Hornborg, 1998; Foster and Holleman, 2014). These asymmetric exchanges reinforce global hierarchies by enabling high-income countries to appropriate resources at low ecological cost while displacing environmental degradation and social impoverishment to low- and middle-income regions.

Within this debate, Hornborg (2014) has stressed the importance of distinguishing between economic and biophysical domains, while Martinez-Alier (2014) situates EUE in the lived struggles of local communities, characterizing the "environmentalism of the poor." This political ecology perspective is particularly relevant for Brazil, where conflicts over mining, agribusiness, and hydropower reflect how resource extraction perpetuates socioecological inequalities. Recent empirical studies further substantiate these arguments, showing that net flows of energy, materials, and labor consistently drain from the Global South to the Global North (Dorninger et al., 2021; Hickel et al., 2022). Expanding this framework, Althouse et al. (2020; 2023) and Svartzman and Althouse (2020) show how global value chains and monetary hierarchies perpetuate ecological asymmetries, thereby constraining the developmental prospects of peripheral economies.

These debates connect directly with the need for systemic and biophysical methods to diagnose the structural conditions that sustain poverty traps. Odum's systems ecology and emergy accounting have been mobilized to reveal the energy basis of economic processes and to expose the material foundations of inequality (Foster and Holleman, 2014). Despite critiques (Hornborg, 2014), emergy provides a conceptual and methodological bridge between ecological economics and political ecology by explicitly linking biophysical flows to social and economic asymmetries. Building on this dialogue, emergy accounting offers a conceptual and methodological bridge to advance the understanding of poverty traps as products of both ecological constraints and structural inequities.

2.3. Linking energy flow and socioeconomic dynamics

Howard T. Odum was a scientist who played a significant role in the development of systems ecology and in understanding how ecosystems self-organize and function (Giannetti et al., 2019). Odum's approach

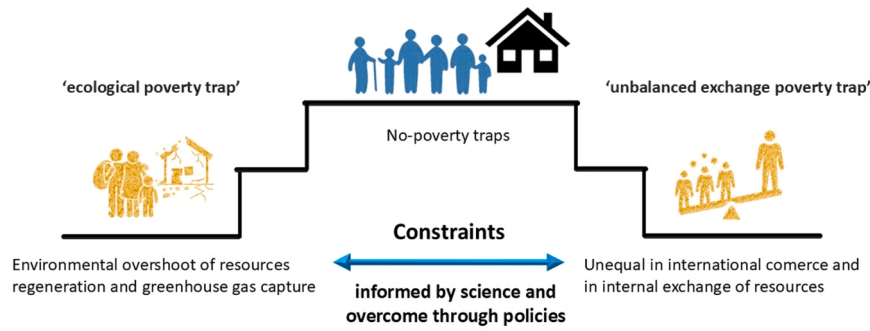


Fig. 1. The constraints to overcome for poverty eradication. Poverty traps definitions based on Wackernagel et al. (2021) and Odum’s Theory (Odum, 1996).

highlights the critical role of energy in ecosystems, focusing on its flow and transformation within the biosphere. Concepts such as the "law of maximum (EM)power" and the "law of net yield" describe how living systems optimize energy use to maintain self-organization and stability (Odum, 1996). In particular, the maximum (EM)power principle provides a thermodynamic explanation for the ubiquitous process of hierarchical self-organization observed in all environmental and socioeconomic systems (Cai et al., 2004). Emergy-based environmental accounting is an application of these principles and is an explicit method for assessing socioeconomic and environmental alternatives.

According to the principles of thermodynamics, a significant amount of available energy (En) is lost (or degraded) at each step along the energy transformation chain. Odum’s theory presents a significant advancement in the application of thermodynamics to living systems. It emphasizes that energy availability diminishes with successive transformations while the quality of the remaining available energy increases. As a result, the concept of energy quality emerges as a system-emergent property, which is quantitatively assessed through two key variables: Emergy (Em) and transformity (Tr).

$$Em = En \times Tr \tag{1}$$

Emergy quantifies the contribution of free inputs from the local environment alongside resources obtained from external locations, including labor and information. To calculate emergy, expressed in solar emergy joules (Em, sej), energy inflows (En, J) are multiplied by their corresponding transformity (Tr, sej/J), which represents the total resources required to produce one unit of a service or commodity. A general term, Unit Emergy Value (UEV, sej/unit), is employed for input flows measured in non-energy units.

Transformity can be split into generative, Tr(gen), and dissipative, Tr(dis) (Giannantoni, 2002, 2006).

$$Tr = Tr(gen) \times Tr(dis) \tag{2}$$

where Tr(dis) reflects efficiency (a value positive <1), while Tr(gen) is responsible for the increased energy quality. The biosphere is defined by its generative processes, and according to the Principle of Maximum EmPower, systems undergo self-organization to optimize the utilization of available environmental resources. This process minimizes energy dissipation while maximizing energy quality generation, achieving the highest energy flow per unit of time, referred to as empower.

Odum’s theoretical framework is pivotal in analyzing transactions through the exchange of emergy, addressing both quantitative and qualitative dimensions. When resources or labor are exchanged, a monetary transaction occurs. The emergy associated with the received monetary compensation is determined by multiplying its monetary value by the Emergy Money Ratio (EMR, sej/\$) that translates monetary transactions into emergy units, reflecting the relationship between economic activity and resource use. The capacity of money to acquire resources is determined by the emergy supporting the economy and the circulating monetary supply. The average emergy/money ratio is

calculated by dividing the total emergy consumption of a state or nation by its gross domestic product, offering insight into the resource intensity of economic output.

When a region exports resources with high emergy content, such as raw materials or agricultural products, while receiving goods or services with lower emergy value in return, it incurs a net loss of embedded energy within its system. This emergy imbalance can be used to evaluate which party benefits most in exchanges between nations or within society. Each transaction represents an energy exchange in terms of quantity and quality, and prolonged inequitable trade can lead to one party gaining at the expense of the other. Over time, such imbalances contribute to socioeconomic inequalities and reinforce "poverty traps," where affected regions face continuous resource depletion. The most common example is the export of natural resources (wood, minerals, petroleum, etc.) by countries with recognized socioeconomic problems to the countries called more developed countries, since a large amount of emergy (in the form of goods) is generally exported and emergy (in the form of money) is received in exchange in smaller quantities. This imbalance undermines their ability to invest in essential infrastructure, education, and innovation—factors crucial for breaking cycles of poverty. Indices that measure foreign and domestic emergy trade shed light on these unequal exchanges, emphasizing the need for policies that enhance emergy retention within local systems to support sustainable and equitable development.

2.4. Mapping sustainability with the 5SEnSu model

The Five-Sector Sustainability Model (5SEnSu Model; Giannetti et al., 2019) is founded upon six core axioms. The first three (i, ii, and iii) are derived from the principles articulated by Goodland (1995) and Goodland and Daly (1996), which emphasize the biophysical limits of natural systems in relation to their capacity to sustain current patterns of resource exploitation. The remaining three (iv, v, and vi) were developed by Giannetti et al. (2019).

Axiom I – Resource Regeneration Rate: "Natural resources must be utilized at rates that do not surpass their capacity for regeneration."

This axiom emphasizes the importance of utilizing renewable natural resources—such as forests, fisheries, and freshwater—within the context of their natural replenishment cycles. For instance, in numerous tropical regions, deforestation occurs at a rate significantly exceeding the natural regeneration of forests. This practice not only leads to biodiversity loss and soil degradation but also disrupts water cycles and carbon sequestration, thereby undermining the long-term ecological and economic sustainability of the region.

Axiom II – Environmental Assimilation Capacity: "Pollutant emissions must remain within the natural environment’s ability to absorb and neutralize them." Ecosystems possess a limited capacity to assimilate pollutants through processes such as decomposition, sedimentation, and chemical transformation. For example, nitrogen runoff from intensive agricultural practices can exceed the natural assimilation capacity of freshwater systems, leading to eutrophication.

Axiom III – Substitution of Non-Renewable Resources: “Non-renewable resources should be used only while renewable alternatives are being developed”.

The extraction and utilization of non-renewable resources should be strategically confined to a transitional phase that facilitates the development of sustainable alternatives. For instance, the global reliance on fossil fuels has persisted despite the growing feasibility of renewable energy sources. Delayed investments in renewable energy have led to energy insecurity, geopolitical tensions, and exacerbating environmental impacts, such as climate change.

Axiom IV – Balance Between Sources and Sinks: “There must be harmony between resource extraction and the environment’s capacity to assimilate waste”.

This axiom reflects the dual role of the environment: as a source of inputs (e.g., raw materials, energy) and as a sink for outputs (e.g., waste, emissions). An imbalance between these functions can destabilize ecosystems and reduce their capacity to support human societies.

Axiom V – Production Within Ecological Limits: “The production of goods and services must respect the boundaries of sustainable resource use and responsible consumption”.

The ecological thresholds of the planet must constrain economic production. Ignoring these limits leads to unsustainable growth, resource depletion, and increased systemic risk. Massive resource inputs (e.g., water, energy, raw fibers) combined with short product lifecycles contribute to landfills, pollution, and excessive carbon emissions, far beyond what ecosystems can sustain.

Axiom VI – Socioeconomic Equity: “The relationship between human labor and the economic system must be fair, ensuring equitable access to goods and services”.

Sustainability is not only ecological but also social. A balanced relationship between production and consumption implies just compensation for labor and universal access to the benefits of economic activity. In many developing countries, economic growth has not translated into equitable development. Informal labor markets, wage stagnation, and limited access to essential services perpetuate poverty cycles, despite increases in national GDP. This highlights the need for inclusive economic policies aligned with sustainability principles.

Although at first sight Axioms IV and V may resemble Axioms I and II, their formulation as independent principles has a specific purpose. Axiom IV explicitly integrates the dual role of the environment as both source and sink, highlighting the systemic balance required between resource use and waste assimilation. Axiom V advances this reasoning by directly linking ecological thresholds to production and consumption processes, thereby making explicit the connection between biophysical limits and socioeconomic dynamics. In this way, both axioms complement rather than duplicate the first two, reinforcing the internal consistency of the 5SEnSU Model and its capacity to represent sustainability as an integrated system.

Grounded on these six axioms, the Five-Sector Sustainability Model (5SEnSU) was developed as an operational framework to translate these principles into practice. Fig. 2 illustrates how the model conceptualizes the environment as both a provider of resources (Sector 1) and a recipient of waste (Sector 2), while society acts as both a contributor of labor and knowledge (Sector 4) and a consumer of goods and services. The production system (Sector 3) operates at the center of these exchanges, transforming inputs into outputs. A key insight of the model is that, while monetary flows occur exclusively within human systems (on the right-hand side), both energy and material flows underpin environmental and human exchanges alike. In our framework, however, particular emphasis is placed on environmental exchanges (on the left-hand side), since these are often treated as free inputs and waste disposal as a free service, thereby obscuring the ecological effort required for resource regeneration and pollutant assimilation—processes typically neglected in conventional economic accounting. The 5SEnSU model is holistic and integrative. It covers multiple dimensions of sustainability, enables analysis from environmental, social, and

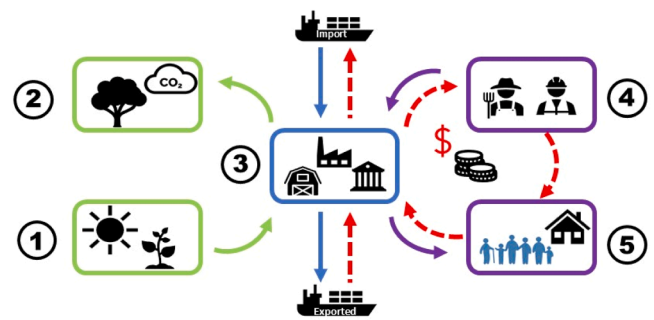


Fig. 2. The 5SEnSU Model: Sector 3 is the productive sector or the country/region of interest, which is like a ‘node’ of exchange flows with foreign trade, the environmental sectors (1 and 2), and the social sectors (4 and 5). Dashed lines represent cash flows, and continuous lines represent material and energy flows.

production perspectives, and supports a range of indicators—from energy and material balances to financial and labor metrics. Its flexible, multi-criteria design allows for customized assessments based on specific priorities and contexts.

The 5SEnSu Model has been widely applied to assess the sustainability of systems at smaller scales, such as production processes. Its effectiveness has been demonstrated in various contexts, including organic and conventional chicken production systems in Brazil (Nascimento et al., 2022), evaluating cleaner production practices and promoting sustainable development in the water and wastewater treatment sector (Giannetti et al., 2022), and rice production in Brazil and Cuba (García et al., 2021). Additionally, the 5SEnSu model’s structures and tools have been integrated into broader frameworks designed to assess sustainability in production contexts, such as the SUAPRO procedure (Sustainability Assessment Procedure for Operations and Production Processes) developed by Agostinho et al. (2019) and the Value Stream Mapping for Sustainability proposed by Silva et al. (2024) as a management tool for enhancing sustainability in companies.

At larger scales, the 5SEnSu Model has proven its versatility by being applied to urban analyses and regional assessments across various contexts. These include investigating the correlation between sustainability indicators and “intelligence” in Brazilian cities (Pierucci et al., 2024), evaluating the potential and limitations of the “Mandala SDG” as an innovative tool for measuring urban sustainability (Pierucci et al., 2023), and analyzing specific impacts across regions and sectors. Examples include assessing sustainability trends in the Brazilian MATOPIBA region (Agostinho et al., 2023), exploring the relationship between circularity and sustainability across economic blocs (Santos et al., 2022), and examining the links between circular economy practices and sustainability in G20 countries (Terra dos Santos et al., 2023).

Recent applications of energy accounting integrated with the Five-Sector Sustainability Model (5SEnSU) have demonstrated the utility of this framework in diagnosing structural inequalities and poverty traps, as exemplified by its use in the national-level assessment of Mozambique (Giannetti et al., 2023). While such studies have emphasized the relevance of unequal exchanges between environmental, social, and economic sectors at the country level, the present research advances this approach by applying it to a regionally disaggregated context within Brazil. By exploring how energy flows, resource dependencies, and economic-environmental imbalances manifest across distinct macro-regions. This study advances a more granular understanding of the biophysical flow dynamics of poverty traps. Furthermore, it contributes to the literature by identifying region-specific mechanisms of vulnerability—such as trade deficits, renewable resource depletion, and labor income inequality—and by proposing energy-based policy recommendations tailored to these local realities. This regional lens reveals the heterogeneity of sustainable development challenges within a single nation and underscores the diagnostic power of the integrated

Emergy–5SENSU framework for informing equitable and sustainability-driven public policies.

3. Methods

3.1. Methodological framework for identifying and analyzing poverty traps

The method section refers to the Integration of Emergy Theory with the 5SEnSu Model, explaining how emergy-based indicators were utilized to analyze poverty traps in Brazil within the framework of the 5SEnSu Model. This approach highlights the study's emphasis on resource use, recognizing that biophysical resources are fundamental to an ecocentric perspective (as outlined by Wackernagel et al., 2021, and Odum, 1996), which are essential for sustaining societal development. This perspective aligns with the concept of strong sustainability (Giannetti et al., 2020; Washington et al., 2017; Montani, 2007), which emphasizes that true wealth lies in the availability and responsible stewardship of natural resources.

Fig. 3 illustrates the methodological flowchart used in this study, outlining the main steps taken to identify and analyze poverty traps in Brazilian regions. This flowchart provides a clear and structured representation of the logical sequence followed in the study, enhancing understanding of the methodological procedures and highlighting the integration of the analytical tools used. The process begins with defining the research objective, followed by gathering environmental, economic, and social data from recognized institutional sources. Environmental Accounting based on Emergy is then applied to quantify the emergy flows involved, facilitating the derivation of resource emergy values that are used to calculate indicators for assessing national and regional poverty traps. The 5SEnSu Model is utilized to guide the selection of indicators that reflect the five interdependent sectors impacting regional sustainability. Based on these analyses, the Performance Potential Index is computed, enabling the assessment of a region's capacity to either escape or remain in a poverty trap. Finally, the results are interpreted according to the obtained indicators, informing the development of public policies aimed at reducing socio-economic and environmental inequalities.

3.2. Data collection

The data used in this study are based on Brazilian government monitoring sources and studies in the scientific literature. The

methodology is similar to that of Giannetti et al. (2023), with modifications. The novelty demonstrated in the methodological approach lies in the regional disaggregation of emergy flows by macroregions of Brazil, allowing the construction of new localized indicators for each of the five sectors of the 5SEnSu model. Unlike previous applications at the national level, this study introduces spatially explicit emergy-based metrics, allowing the identification of intra-country asymmetries and region-specific poverty traps. In addition, the study adapts the Emergy Exchange Ratios and Environmental Load Factors to reflect regional differences in ecosystem productivity, trade patterns, and income distribution—providing a more accurate and context-sensitive sustainability diagnosis. This refinement enhances the resolution and applicability of the 5SEnSu framework for subnational policy planning and resource management.

The choice of 2007 as the base year was due to data availability, but the same procedure can be applied when more updated data becomes available. Information related to foreign trade exchanges (exports and imports of goods) in 2007 were considered. The services sector, such as health, education, and others, is not included in this study. The used data covered information regarding: remaining biome area (ha) by state (PROBIO, 2006a, 2006b, 2007a, 2007b, 2007c, 2007d); soil and forest loss (ha) (Demétrio, 2011); carbon sequestration by biome according to IPCC (2006). Renewable resources (sej/year); non-renewable resources (sej/year); imported resources (sej/year); exported resources (sej/year); emergy per capita (sej/person.year); emergy to money ratio (EMR) by state (Demétrio, 2011; Giannetti et al., 2013). Money received from imports and exports (USD/year). Economically active persons (un); annual income by state (USD/person.year); hours worked (hours/person); CO₂eq emissions from industrial production (SEEG, 2025); and their ratios.

3.3. Accounting of national and regional emergy flows

By considering a region as an open system, emergy accounting helps identify and understand the ecosystem's contributions to the local and global economy, based on human-nature relations, and estimates these contributions through flows of energy and matter. In this sense, the emergy accountability captures aspects related to the extraction of resources, their transformation into products and their commercialization (Hossaini and Hewage, 2013). According to Pulselli et al. (2007), emergy accounting can be applied to a region to study the relationship between humans and the environment, as human activities are shaped not only by economic rules but also by ecosystem constraints.

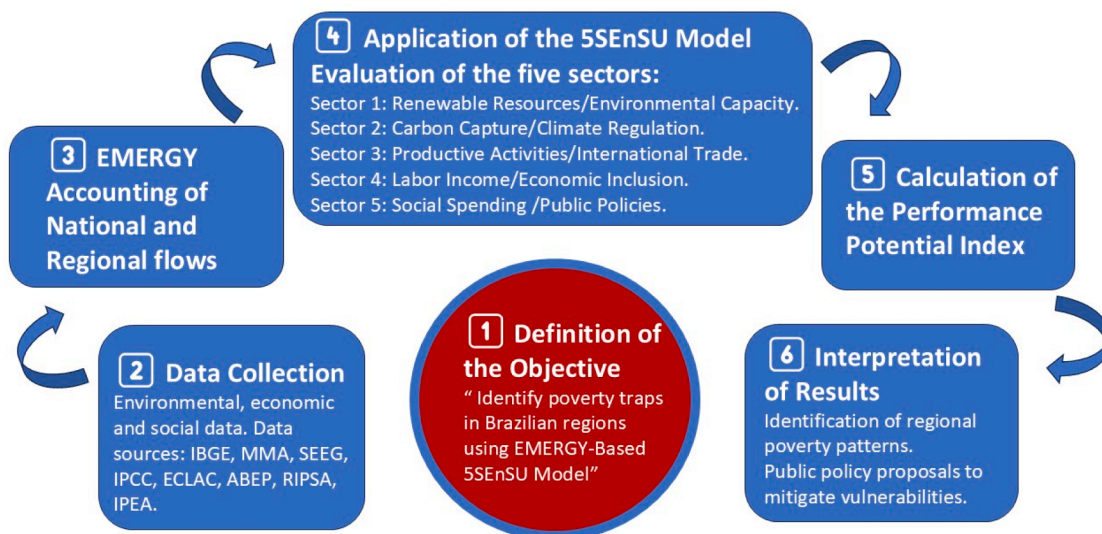


Fig. 3. Flowchart of the methodological steps.

After data collection, the energy flows of the entries in the accounts were distributed according to Odum's (1996) proposition and following the suggestions of Giannetti et al. (2013). Sources of emergy that cross the system boundary from outside include: renewables (R), fuels and minerals (F), goods (G), and the services embodied in these imports (P2I). Sources of emergy obtained from storage within the country include resources that are used faster than they are renewed (such as soils, N0), and non-renewable resources (such as fossil fuels and minerals, N1). Exports from the country include services and labor (P1E) embodied in finished products, and non-renewable resources (N2) that are exported without use in the internal economy. The gross domestic product (GDP) represents the circulation of money within the economy, serving as a monetary measure of the economy's output.

By using these flows, emergy accounting allows for the development of indicators that capture aspects related to poverty traps. Details of the calculation models are available in the Supplementary Material.

3.4. 5SEnSU model and indicator selection criteria

This study employs the emergy-based 5SEnSU Model to evaluate structural poverty traps from a systemic and biophysical perspective. The 5SEnSU framework (Fig. 2) highlights the interdependence among five core sectors (Giannetti et al., 2019, 2023). The environmental sectors—Sector 1 (natural resources) and Sector 2 (ecosystem services)—form the foundational support for the system. Sector 1 provides renewable resources (e.g., biomass, soil fertility), while Sector 2 delivers essential services such as carbon sequestration and climate regulation. Together, these sectors sustain the functioning of the economic system (Sector 3), which, in turn, interacts dynamically with the social domains (Sectors 4 and 5). These latter sectors contribute labor and consumption while also serving as key recipients of real wealth—an essential dimension in understanding poverty and inequality.

Overcoming what has been termed the “ecological poverty trap” requires addressing two fundamental challenges: (i) ensuring the regeneration of renewable natural capital and (ii) achieving net-zero greenhouse gas emissions. Within the 5SEnSU framework, these functions are attributed to Sectors 1 and 2, respectively: Sector 1 as a supplier of renewable emergy, and Sector 2 as a receptor of anthropogenic emissions. The undervaluation or degradation of these environmental sectors compromises long-term sustainability and reinforces poverty conditions.

In contrast, Sectors 4 and 5 represent the mechanisms through which real wealth is redistributed—or not—within society. Under-compensation of labor or suppressed consumption capacity results in entrenched poverty, manifesting as an “unbalanced exchange poverty trap.” This internal dynamic mirrors patterns of ecologically unequal exchange at the global level, where resource-rich but economically marginalized regions often export high-emergy goods while receiving disproportionately low returns.

Fig. 4 synthesizes the connections between each sectoral indicator, sustainability challenges, and corresponding policy interventions. The selection of indicators (as shown in Fig. 4) reflects emergy accounting principles and their diagnostic capacity to identify structural vulnerabilities underlying poverty traps. The criteria used in selecting indicators were: (i) theoretical consistency with emergy-based systemic assessments, (ii) relevance to inequality and resource dependency dynamics, and (iii) availability of disaggregated regional data, especially in the Brazilian context.

3.5. Environmental sustainability indicators (Sectors 1 and 2)

Sectors 1 and 2 provide the environmental basis for sustainable development. Their associated indicators reflect the region's biophysical capacity to maintain ecosystem integrity and support long-term development pathways.

Sector 1 (Environmental Resources) is represented by the Lost Renewable Ratio (LRR), which measures the degradation of renewable natural capital (e.g., deforestation, soil erosion) in relation to the renewable emergy available (sej/year). Unlike conventional land-use metrics, the LRR integrates both biophysical productivity and emergy values, offering a deeper insight into environmental decline. Values of $LRR \geq 1$ indicate that degradation is occurring faster than regeneration, signaling the existence of an ecological poverty trap. This can compromise food security, economic viability, and social resilience.

Sector 2 (Ecosystem Services) is assessed via the Emission Capture Ratio (ECR), which compares local CO₂ emissions with the ecosystem's capacity for carbon sequestration (in gCO₂e q per hectare). $ECR \geq 1$ indicates that emissions surpass the region's natural absorption capacity, resulting in ecological stress and heightened vulnerability. Unlike conventional carbon footprint indicators, ECR is regionally grounded and tailored to inform local environmental policy.

Both LRR and ECR provide essential insights for environmental

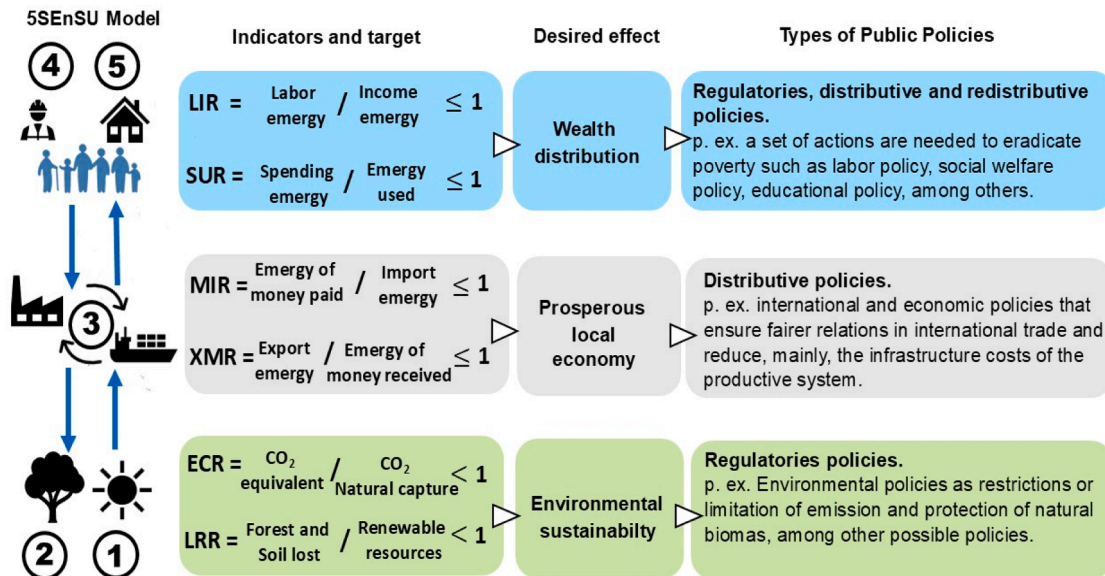


Fig. 4. 5SEnSU Model, indicators, desired results, and suggestions of public policies to overcome the pitfalls of poverty and transform a sustainable and developed society.

regulatory strategies, including land-use planning, emission control, biome conservation and restoration, and climate adaptation measures.

3.6. Prosperous local economy indicators (Sector 3)

The economic sector's performance is shaped by its role in global and national trade networks, particularly its emergy-based trade balance. To assess this, monetary flows are converted to emergy using regional Emergy-to-Money Ratios (EMRs), capturing the real energetic cost of monetary transactions (Odum, 1996; Campbell et al., 2009; Demétrio, 2011). The two indicators that assess the economic performance of foreign trade are:

The Export Money Ratio (XMR) assesses the emergy value of exported products relative to the emergy equivalent received in monetary compensation. Values > 1 indicate unfavorable trade terms, reflecting a loss of real wealth—an economic “decapitalization.”

The Money Import Ratio (MIR) evaluates the emergy value of money spent on imports against the emergy content of the imported goods. $MIR > 1$ reveals structural dependency and inequitable trade relations.

These indicators (XMR and MIR) unveil hidden metabolic asymmetries that perpetuate poverty and are instrumental in designing distributive economic policies. Relevant strategies include fostering value-added production, infrastructure development, economic diversification, and negotiating fairer trade agreements.

3.7. Wealth distribution indicators (Sectors 4 and 5)

The social sectors of the 5SEnSU Model examine how wealth generated within the system is distributed among the population—an essential condition for social resilience and inclusive development.

Sector 4 (Labor Compensation) uses the Labor Income Ratio (LIR), comparing the emergy invested in labor with the emergy equivalent of income earned. $LIR \leq 1$ suggests fair compensation, while values > 1 point to undervaluation of human effort—a key mechanism in poverty reproduction.

Sector 5 (Household Consumption) employs the Spending Used Ratio (SUR), which evaluates the portion of emergy received as income that is reinvested locally. Lower values indicate limited internal wealth circulation and weak social cohesion.

These indicators (LIR and SUR) guide distributive and redistributive policy interventions, such as labor regulation, wage policy, local procurement, and investment in health and education. They expose systemic inequalities and inform policy to dismantle internal poverty traps.

Altogether, these six indicators (LIR, SUR, MIR, XMR, ECR, and LRR; Fig. 4) form a coherent and operational framework for diagnosing the systemic conditions that sustain poverty. Their emergy-based foundation enables a biophysical understanding of development, offering policy-relevant insights that integrate environmental limits, economic justice, and social equity.

3.8. Summary indicators

Summary indicators serve to capture general trends and aggregated impacts, allowing decision-makers to identify critical vulnerabilities and prioritize strategic interventions. To this end, two indicators are proposed: Performance Potential Index (PPI) and Intensity of Poverty Traps (IPT).

The Performance Potential Index (PPI) measures the overall functionality of the system by calculating the proportion of indicators that do not signal the presence of poverty traps. It is defined as:

$$PPI = \text{No. of indicators without poverty traps} / 6 \text{ Equation 2}$$

The PPI ranges from 0 (all indicators signal poverty traps) to 1 (no indicator signals a poverty trap). This index facilitates comparative analysis across regions or time periods, highlighting areas of socio-ecological vulnerability that may require targeted policy action. In addition to the PPI, a radar chart is included in the supplementary

material to illustrate the distribution of individual indicators. This approach helps to avoid obscuring divergent trends that can often result from aggregation, a common challenge in multicriteria analysis.

The Intensity of Poverty Traps (IPT) complements the PPI by quantifying the severity of poverty conditions within a given system. It is calculated as the sum of all indicator values that exceed the threshold of 1, as follows:

$$IPT = \sum (\text{indicators} > 1) \quad (3)$$

Higher IPT values indicate greater systemic imbalances and stronger feedback that reinforces poverty traps. When analyzed alongside the PPI, this index offers a nuanced understanding of both the presence and intensity of constraints affecting sustainability.

This set of eight indicators supports an integrated diagnostic assessment of poverty traps by incorporating environmental, economic, and social dimensions through the synergy of the Five-Sector Sustainability Model (5SEnSU) and Emergy Theory. This approach enables a systemic and biophysical evaluation that is essential for developing informed, equitable, and ecologically grounded policy strategies.

4. Results

4.1. Brazil's poverty traps

Brazil's sustainability diagnosis reveals a combination of strengths and challenges that influence its long-term development prospects. Fig. 5 presents key indicators that provide valuable insights into these dynamics, highlighting the urgent need for targeted strategies to address poverty traps and advance sustainable development.

Brazil exhibits several strengths that contribute to poverty reduction and sustainable development. The relatively favorable Spending Used Ratio ($SUR < 1$) indicates favorable consumption of resources, where the population of Brazil uses emergy that comes from productive systems, social development (originating from government policies), and free resources from nature, with consumers paying 0.4 for these goods and services (from the economy and nature) than the amount paid in emergy. Regarding international trade, the Money Import Ratio ($MIR < 1$) indicates that imports, evaluated in emergy, positively benefit the national economy. Additionally, Brazil's capacity to maintain a degree of carbon neutrality, supported by renewable energy and ecosystem services, offers a crucial advantage in avoiding environmental poverty traps. However, the Lost Renewable Ratio ($LRR = 0.7$) indicates that 70 % of Brazil's renewable resources are already being utilized, suggesting that resource depletion could emerge as a future risk to sustainability if not managed carefully.

Brazil faces significant challenges that hinder its ability to combat poverty effectively. The Labor Income Ratio ($LIR = 2.7$) suggests that economic activities do not reward work adequately, there is a need for better and fairer pay for work, the generation of jobs with higher salaries, and improving income distribution. With the economy receiving 2.7 times more energy from people's work than the value generated internally, this imbalance threatens long-term welfare development, economic growth, and the sustainability of poverty alleviation programs. Additionally, Brazil's reliance on exports, reflected by the unfavorable Export Money Ratio ($XMR > 1$), reveals an inequitable exchange where the emergy value of exports exceeds the compensation received. This dynamic, typical of countries dependent on agricultural commodities and mineral exports, exposes the economy to global market fluctuations, undermining stable growth and limiting domestic investment.

To tackle its challenges, Brazil could implement targeted strategies that align with specific sustainability indicators identified in Fig. 5. For example, strengthening local value chains and reducing reliance on exports would address the Export Money Ratio (XMR), aiming to decrease the emergy lost through undervalued exports. Encouraging domestic production and reinvestment, alongside efforts to enhance fair

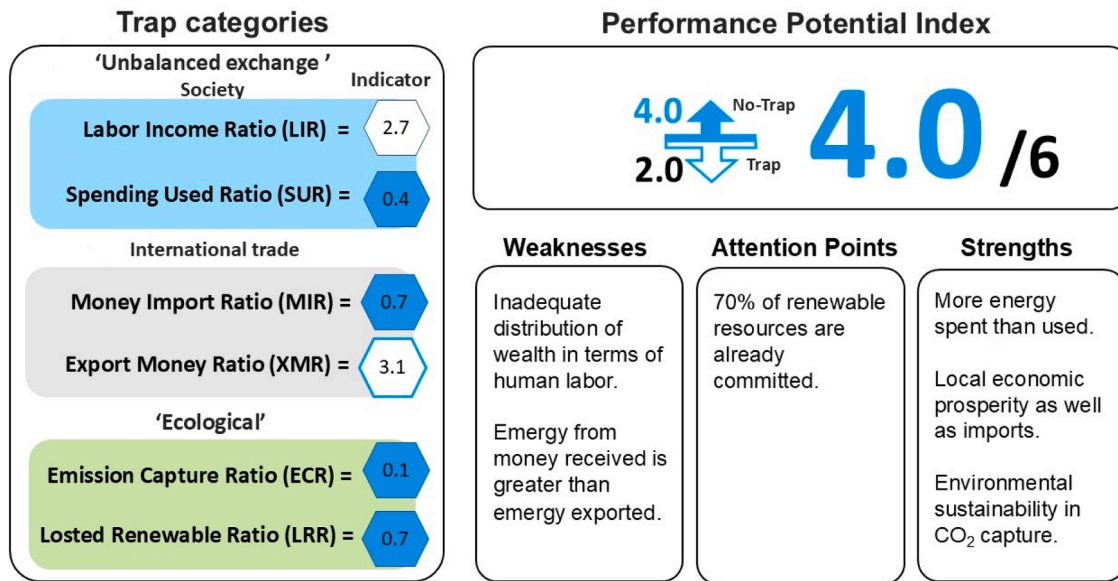


Fig. 5. Trap category indexes and their impact on the Performance Potential Index (PPI). The categories are divided into three groups: 'Unbalanced exchange' (LIR and SUR indicators), 'International trade' (MIR and XMR indicators) and 'Ecological' (ECR and LRR indicators). The resulting PPI is 4.0, indicating that four out of six possible pitfalls are out. Diagnosis of 'weakness', 'attention', and 'strength' is also presented." A radar chart is provided in the supplementary material to show the distribution of individual indicators.

compensation in global trade, also improves the Money Import Ratio (MIR) by reducing dependence on high-energy imports. On the environmental front, promoting resource efficiency, circular economy initiatives, and investments in renewable energy is crucial to lowering the Lost Renewable Ratio (LRR), helping to reverse environmental degradation. Similarly, enhancing carbon sequestration through ecosystem restoration and low-carbon transitions can positively impact the Emission Capture Ratio (ECR), reinforcing climate resilience. To address social poverty traps, policies aimed at improving wage equity and labor valuation—such as minimum wage adjustments, labor rights enforcement, and education—would directly improve the Labor Income Ratio (LIR). Likewise, stimulating local consumption through indirect wage gains (e.g., conditional cash transfers, social programs) would enhance the Spending Used Ratio (SUR) by ensuring that earned emergy is retained and circulates within the local economy.

Continuing current trends without these corrective strategies could jeopardize the nation's ability to sustain growth and social welfare. Therefore, integrated actions targeting all six indicators (LIR, SUR, MIR, XMR, ECR, and LRR; to see in Fig. 5) are essential to break poverty traps and secure long-term prosperity by balancing environmental sustainability, economic vitality, and social equity.

4.2. Regional disparities

Fig. 6 presents a regional assessment that reveals significant disparities in economic and environmental vulnerabilities across Brazil's regions. The Performance Potential Index (PPI) values indicate that the Northeast, Midwest, and South regions each score a PPI of 4, matching the national average (PPI = 4, as shown in Fig. 5). In contrast, the North and Southeast regions show lower performance, with a PPI of 3, highlighting their greater challenges in these areas. The North and Southeast regions are particularly affected by poverty traps, each facing three distinct types for different reasons. Their heightened vulnerability is further evidenced by the Intensity of Poverty Traps (IPT), with the North and Southeast regions recording the highest IPT values at 23.0 and 7.1, respectively. In comparison, the other regions exhibit IPT values below the national average (IPT = 5.8), indicating less severe poverty traps.

A comparison of Figs. 5 and 6 reveals that national poverty traps arising from exchange rate imbalances in international trade (Export

Money Ratio, XMR) and domestic economic inequities (Labor Income Ratio, LIR) are prevalent across all five Brazilian regions. This underscores the pervasive nature of these challenges throughout the country.

The next sections are presented separately to discuss about unique characteristic of each Brazilian region.

4.3. North region (IPT = 23.0)

The North Region faces pronounced economic dependency, characterized by an unfavorable trade balance and a strong reliance on primary sector activities. This structural condition constrains opportunities for local reinvestment, exacerbates income inequality, and limits social mobility. Indicators such as the Money Import Ratio (MIR) and Export Money Ratio (XMR), both of which exceed unity, underscore the region's dependence on external markets and emphasize the urgent need for public policies aimed at strengthening local value chains, diversifying the economic base, and promoting social inclusion. Moreover, the Labor Income Ratio (LIR) reveals a critical poverty trap rooted in regional exchange imbalances: local populations receive significantly less compensation for their labor relative to its true value when assessed through emergy accounting. The LIR is markedly higher in the North compared to other regions, further amplifying socioeconomic vulnerabilities. Addressing these challenges demands policy interventions that promote indirect income redistribution through targeted social programs, aiming to reduce inequality and advance sustainable development. These efforts are further complicated by the North's unparalleled environmental importance as the host of the world's largest tropical rainforest, the Amazon. Thus, a pressing question remains: how can public policies effectively combat poverty while preserving the ecological integrity of this globally vital region?

4.4. Southeast region (IPT = 7.1)

The Southeast Region exhibits three distinct poverty traps, with environmental degradation emerging as a critical concern. This degradation stems from the overexploitation of renewable resources and the declining capacity of essential ecosystem services, as evidenced by the Lost Renewable Ratio (LRR), which indicates that resource use has

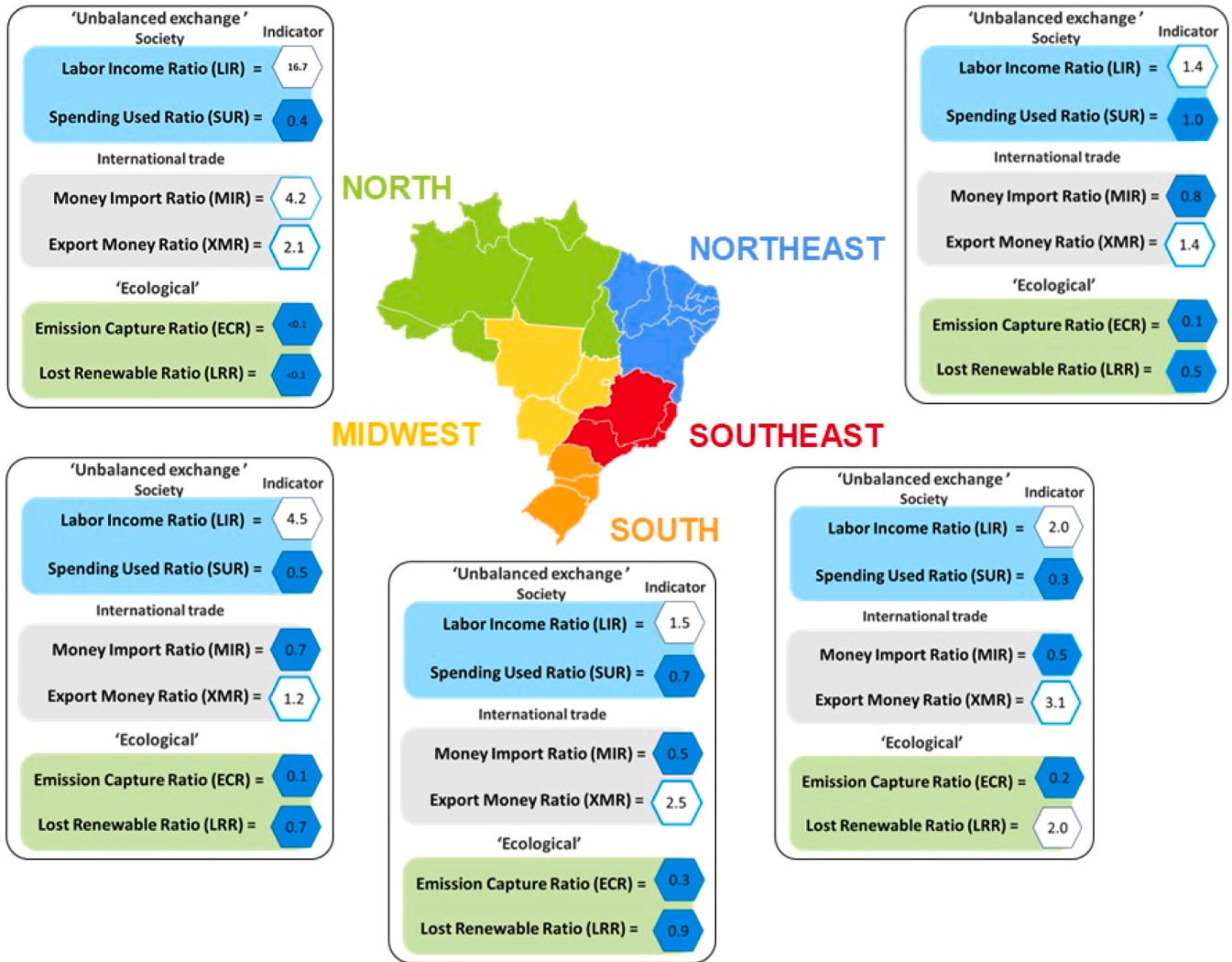


Fig. 6. Indices of trap categories by region of Brazil and their respective socioeconomic and ecological indicators. A radar chart is provided in the supplementary material to show the distribution of individual indicators.

surpassed sustainable thresholds. Such environmental pressures pose substantial risks to long-term economic stability, industrial productivity, and resilience to environmental crises. Addressing these challenges requires strategies focused on improving resource efficiency, investing in renewable energy, and restoring degraded ecosystems. As Brazil’s most economically advanced region, the Southeast faces environmental dynamics comparable to those encountered in developed countries. This parallel raises a crucial question: could environmental compensation mechanisms between regions offer a viable pathway forward? Given the substantial natural capital concentrated in other regions, particularly the Amazon in the North, instruments such as payments for ecosystem services could be leveraged to promote sustainable development. A cooperative framework between the Southeast and North could foster synergies, simultaneously addressing the distinct poverty traps of each region while advancing economic and ecological balance at a national scale.

4.5. Northeast (IPT = 4.8) and Midwest Regions (IPT = 5.7)

The Northeast and Midwest Regions exhibit more favorable socioeconomic indicators than the North; however, both continue to grapple with entrenched inequalities. The Labor Income Ratio (LIR) reveals a persistent disconnect between labor remuneration and the wealth

generated, with the Midwest facing a particularly acute poverty trap. Despite the region’s strong performance in agricultural exports, particularly grains and meat, the resulting economic gains remain highly concentrated among large landowners, limiting broader social benefits. As urbanization in the Midwest intensifies, targeted investments in education and human capital development will be critical to fostering social mobility and economic resilience. Similarly, the Northeast continues to struggle with structural inequities that impede its development. Both regions require strategic policy interventions aimed at strengthening labor rights, promoting wage equity, and expanding access to education and vocational training. These measures are crucial for empowering local populations, reducing disparities, and supporting pathways toward sustainable and inclusive development.

4.6. South Region (IPT = 4.0)

The South Region mirrors the national pattern of poverty traps, where positive economic performance coexists with persistent social disparities. Despite its robust agricultural and industrial sectors contributing to economic growth, inequality remains a critical challenge, particularly among rural communities and small-scale farmers. Ensuring regional stability requires implementing inclusive policies that prioritize support for small-scale farmers through access to credit,

technology, and markets. Expanding social programs to address education, healthcare, and housing gaps while promoting equitable wealth distribution is essential for fostering long-term development. Additionally, investments in local infrastructure and sustainable farming practices can enhance productivity while reducing vulnerability to economic or environmental shocks. By addressing both social and structural inequities, the South Region has the potential to overcome poverty traps and serve as a model for balanced regional development.

5. Discussions and concluding remarks

The study offers socio-economic insights that complement its primary foundation in biophysical assessment. While the Emergy-Based 5SEnSU Model does not directly address social, political, and power relations, these dimensions are essential for a comprehensive understanding of poverty traps. To situate the analysis in dialogue with these broader perspectives, references to ecologically unequal exchange and political ecology were incorporated (Hornborg, 1998; Foster and Holleman, 2014; Martínez-Alier, 2014). This enables the results to be interpreted not only as a mapping of biophysical constraints, but also as inputs to discussions on how trade asymmetries and resource extraction perpetuate socioecological inequalities (Dorninger et al., 2021; Hickel et al., 2022).

5.1. Contributions and applicability of emergy-based 5SEnSU model

The proposed Emergy-Based 5SEnSU Model has implications for development in practice and academic research. For development practice, offering decision-makers a framework to identify barriers that sustain poverty traps. The method serves exclusively as a guiding tool, refraining from prescribing specific actions and recognizing that solutions must emerge through the national, regional, and international social contract. From a research perspective, the study’s strength lies in its exploration of diverse conceptual approaches, which helps deepen the understanding of the relationships between various forms of capital, environmental resource-related poverty traps, and imbalanced

exchanges in both foreign trade and domestic society.

Fig. 7 encapsulates the six key factors that influence whether poverty traps are sustained or overcome, organized within the 5SEnSU framework. The positive elements (highlighted in blue)—such as the real enrichment of the national productive sector, the transfer of real wealth to society, and the maintenance of natural resource regeneration and carbon neutrality—generate systemic benefits and contribute to breaking cycles of socioeconomic vulnerability. These drivers foster a more inclusive and sustainable economic dynamic by enhancing environmental resilience, ensuring fair international trade, and distributing economic gains equitably across the population. In contrast, the negative factors (shown in white), related to the ‘ecological trap’ and ‘unbalanced exchange trap’, reflect persistent structural weaknesses such as resource overconsumption, inequitable trade relationships, and low labor compensation. When these impacts dominate, they reinforce poverty traps, perpetuating environmental degradation, external economic dependence, and social inequality. The diagram (Fig. 7) highlights the need to amplify the positive impacts while mitigating the negative ones. This integrative perspective highlights the importance of coordinated public policies that target all three sustainability dimensions—economic equity, environmental sustainability, and a fair global trade system—as essential to achieve meaningful and lasting poverty alleviation.

The Emergy-Based Five-Sector Sustainability (5SEnSU) Model in the assessment of poverty traps elucidates four key characteristics:

- (1). *Systemic and Multidimensional Approach* - The Emergy-Based 5SEnSU Model integrates five interdependent sectors: renewable resources, emissions capture, productive activities and trade, labor income, and social spending. This comprehensive perspective enables the identification of the complex causes and effects of poverty traps, taking into account both environmental and socio-economic factors.
- (2). *Incorporation of Emergy Theory* - The application of emergy theory, developed by H.T. Odum, offers a quantitative framework for assessing the flows of energy and resources that sustain economic

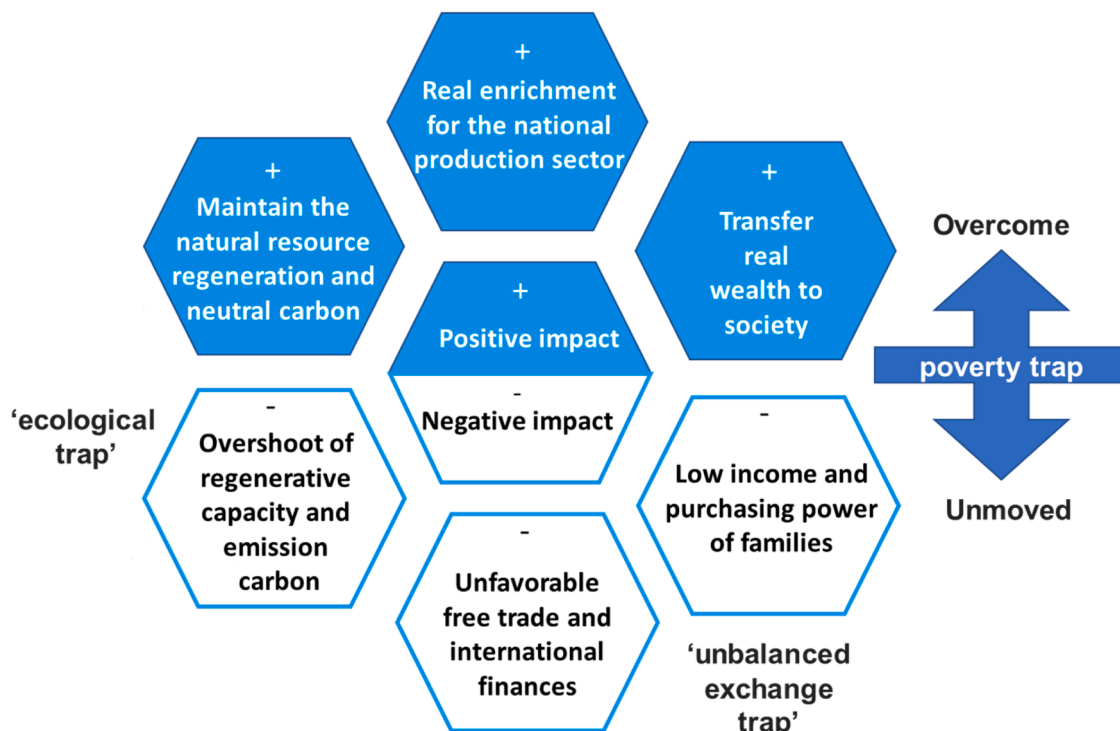


Fig. 7. Actions to overcome poverty trap.

and social activities. This approach reveals imbalances in resource exchanges and their effects on the continuity of poverty. Emergy allows for quantifying everything in the same unit (i.e., the flows of factors that influence poverty traps). With the same unit, it is possible to make comparisons, calculate proportions, and indicators for diagnosing poverty traps, not to mention the characteristic of emergy that avoids the subjectivity of the quantification approach (as classical economics does), since it considers a biophysical approach from the donor side.

- (3). *Diagnostic Capacity* - The Emergy-Based 5SEnSU Model supports the calculation of specific indicators such as the Lost Renewable Ratio (LRR), which assesses the degradation of renewable resources; the Emission Capture Ratio (ECR), which measures the ability to absorb CO₂ emissions; the Export Money Ratio (XMR) and Money Import Ratio (MIR), which analyze external economic flows; the Labor Income Ratio (LIR) and Spending Usage Ratio (SUR), which evaluate social inequalities and public spending; the Performance Potential Index (PPI) and Intensity of Poverty Traps (IPT) aid in comparative analysis, instrumental for comparing different regions and highlighting those in greater need of attention concerning socio-economic vulnerability. This combination of indicators facilitates mapping regional vulnerabilities and proposing specific policies.
- (4). *Connection with Public Policies and Regionalized Approach* - The model identifies specific bottlenecks that hinder sustainable development, thereby assisting in the creation of more effective public policies. For example, it informs mitigation strategies by highlighting that excessive dependence on foreign trade or inadequate income distribution serves as a barrier to development. The Emergy-Based 5SEnSU Model approach facilitates the assessment of regional differences and the adaptation of recommendations to local specifics, making it particularly effective for countries with significant disparities, such as Brazil.

Nevertheless, socio-economic insights remain partial, as they are rooted in biophysical accounting. As emphasized by [Hornborg \(2014\)](#) and [Martinez-Alier \(2014\)](#), poverty traps also reflect power relations, institutional asymmetries, and distributive conflicts. The 5SEnSU Model contributes to this dialogue by clarifying structural biophysical constraints, while complementary perspectives from political ecology and EUE help explain the socio-political dynamics of inequality. In this sense, the Emergy-Based 5SEnSU Model advances the diagnosis of structural biophysical barriers to sustainable development, but its conclusions should be interpreted as complementary rather than comprehensive. By situating emergy accounting in dialogue with political ecology and ecologically unequal exchange ([Foster and Holleman, 2014](#); [Dorninger et al., 2021](#); [Hickel et al., 2022](#)), the study underscores the value of integrative approaches that combine biophysical rigor with socio-political analysis. Such articulation is essential for designing strategies to overcome poverty traps in ways that are ecologically grounded, socially just, and economically viable.

5.2. Limitations and prospects for future research

The Emergy-Based 5SEnSU Model offers an innovative and systemic framework for evaluating poverty traps, yet it has limitations. One major challenge lies in data availability and updating, as the accuracy of the indicators depends heavily on the quality and timeliness of the databases used. Outdated or inconsistent data can compromise the reliability of regional evaluations. This dependency highlights the need for improved and timely data collection systems, as well as the development of data processing and analysis tools that can ensure reliability and consistency in future applications. Additionally, the model requires specialized training in environmental accounting and systemic modeling, creating a barrier for public managers and decision-makers who may lack the necessary technical expertise. To overcome this limitation, simplified

tools and targeted training programs could help bridge the gap between scientific modeling and public policy decision-making.

Furthermore, while the model has been successfully applied in Brazil, its application in other regions with distinct socioeconomic and cultural contexts may demand adaptations. Adjustments to local socioeconomic, cultural, and institutional conditions are necessary, and further case studies are needed to test and refine the model for international application. Factors such as cultural norms, social values, and political dynamics—which significantly influence poverty traps—are not explicitly integrated into the framework. This represents a limitation, as the model emphasizes biophysical flows; future work should incorporate these cultural, social, and political dimensions more directly. Addressing these limitations is essential for broader applicability and effectiveness in diverse global contexts.

Future research should focus on refining the model to enhance its applicability across diverse socioeconomic and cultural contexts, ensuring it considers variations in social values, governance structures, and economic conditions. Investigating practical policy mechanisms to promote sustainable wealth distribution, equitable trade, and efficient resource management is crucial for translating theoretical insights into actionable strategies. Furthermore, expanding empirical validation through larger, more diverse datasets would strengthen the model's reliability, scalability, and adaptability, enabling it to tackle regional and global challenges. Continuous refinement of the framework will also be necessary to address evolving socio-environmental dynamics. Collaborative, interdisciplinary studies integrating ecological, social, and economic perspectives could offer innovative solutions to combat poverty traps while fostering inclusive and sustainable development.

Author's contributions

B.F.G. conceived the idea, developed the theory, and supervised the project of G.A.N.'s thesis. G.A.N. and F.J.C.D. collected the primary data and performed the calculations. L.G.N. and R.A.N. verify calculus, methods, and care for the graphic art. C.M.V.B.A. and F.A. were fundamental to the improvement in the quality of the text. All authors discussed the results of this work and the literature in greater depth.

Supplementary data

The complete set of calculations and supporting information is available in the Supplementary Material. The supplementary material, provided as an Excel spreadsheet, comprises the following sheets: TS1 – References of the data sources consulted; TS2 – Environmental accounting in emergy for the states, Brazil, and their respective regions; TS3 – Calculation report of the indicators used for diagnosing poverty traps in the state of São Paulo; TS4 – Consolidated spreadsheet containing the detailed calculations of the poverty trap indicators for the states, the national territory, and the regions.

CRediT authorship contribution statement

Biagio F. Giannetti: Writing – review & editing, Writing – original draft, Validation, Formal analysis, Data curation, Conceptualization. **Glauco A.do Nascimento:** Investigation, Data curation. **Luiz Ghelmandi Netto:** Methodology, Data curation. **Rafael Araujo Nascimento:** Methodology, Data curation. **Fernando J.C. Demétrio:** Investigation, Data curation. **Cecília M.V.B. Almeida:** Writing – review & editing, Writing – original draft. **Feni Agostinho:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

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

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Data availability

the supplementary material ad been submitted

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