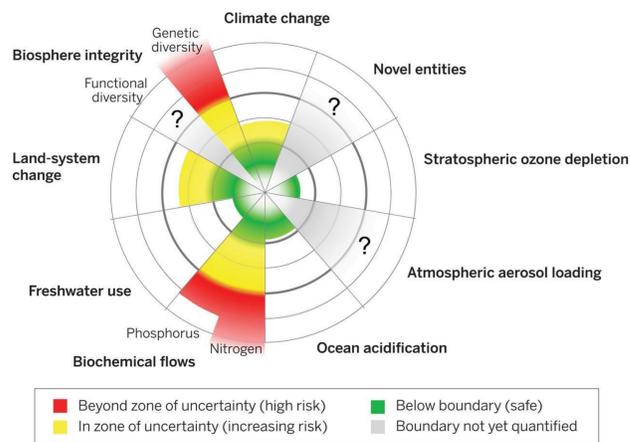


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Introduction & Rationale

Planetary Boundaries Under Pressure



Traditional models of agricultural expansion are increasingly constrained by planetary boundaries, necessitating new approaches to sustainable food production and land use.

Rural Credit as a Policy Lever

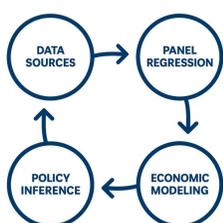
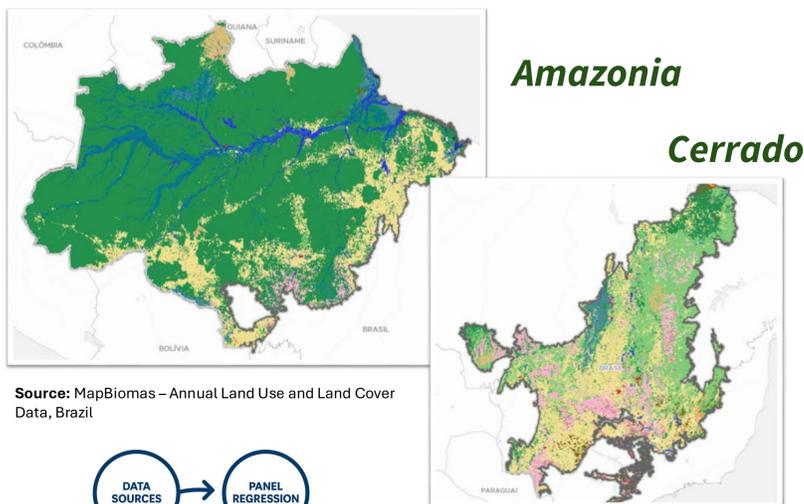
Credit can function as a fiscal-environmental instrument when linked to verifiable conservation outcomes.



Research Objective

"To assess how Brazilian sustainable agricultural credit policies impact forest deforestation rates in the Cerrado and Amazon biomes"

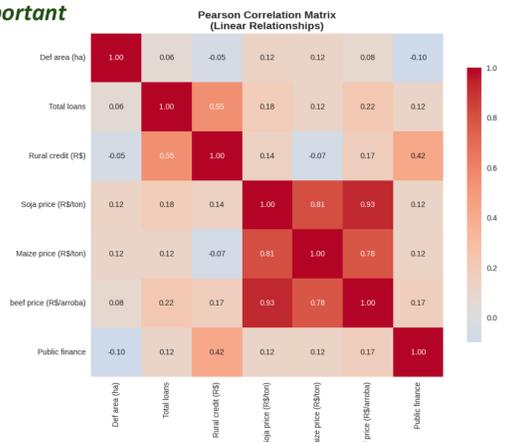
- Evaluate Policy Effectiveness:** Measure the correlation between sustainable credit allocation and changes in deforestation patterns
- Compare Biome Responses:** Analyze differential impacts across the Cerrado savanna and Amazon rainforest ecosystems
- Connect Finance to Conservation:** Establish relationships between financial incentives and biodiversity preservation outcomes



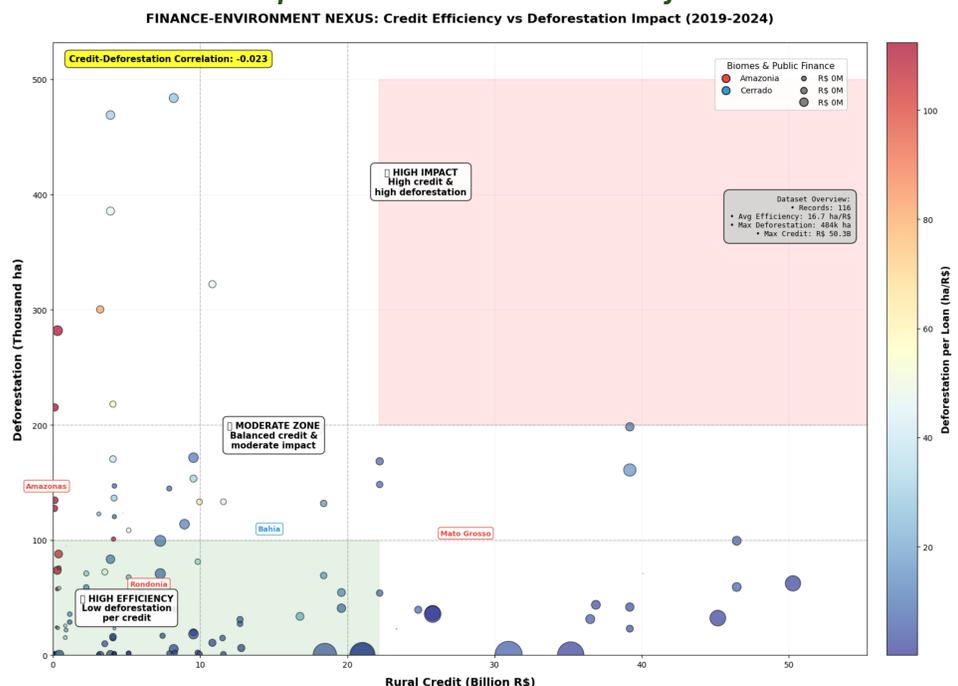
Key Results

The Pearson Correlation Matrix reveals complex economic relationships with several important patterns:

- A weak but statistically significant correlation exists between total loans and deforestation ($r = 0.365$, $p < 0.01$), suggesting some relationship between credit availability and deforestation patterns
- Public finance variables show inconsistent relationships, with some regions demonstrating inverse correlations with deforestation
- No strong linear relationships were detected between commodity prices (soy, maize, beef) and deforestation rates
- Rural credit volume shows only marginal correlation with deforestation outcomes



Our quadrant analysis reveals three distinct efficiency patterns in the relationship between rural credit and deforestation



Critical Finding: Credit allocation efficiency varies dramatically across states, suggesting that regional governance structures, enforcement capacity, and local institutional factors play crucial roles in determining environmental outcomes.

Effective deforestation reduction requires context-sensitive approaches that strengthen local governance alongside financial regulations, rather than relying on uniform national policies alone.

Final remarks

- Credit-deforestation links are real but complex** – weak correlations mask significant regional efficiency variations that demand targeted approaches.
- Policy effectiveness hinges on implementation** – governance and enforcement quality outweigh biome characteristics in determining environmental outcomes.
- New rules (CMN 5081/2023)** that decouple credit and deforestation **addresses critical gaps** but requires robust enforcement and complementary measures to achieve transformative impact.
- Integrated solutions beyond credit alone** are essential – combining economic incentives with land-use planning and institutional strengthening.

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Public Policies for Agricultural Financing

Comparative Analysis of Traditional Production-Focused vs. Sustainable Integrated Approaches

Focus on Productive Capacity and Profitability Traditional Agricultural Model	Integration Between Productivity and Emission Mitigation Sustainable Agricultural Model
<ul style="list-style-type: none"> Priority for Traditional and Intensive Crops Emphasis on high-yield monocultures and conventional agricultural practices Broad Access to Credit with No Environmental Requirements Financing available without specific environmental conditions Interest Rates and Terms Defined by Productive/Financial Risk Financial conditions based exclusively on economic viability General Criteria of Collateral and Economic Feasibility Assessment focused on collateral and expected financial return Little or No Requirement for Environmental Monitoring Low regulation and oversight of environmental impacts Emphasis on Market Stability Focus on predictability and security of traditional markets 	<ul style="list-style-type: none"> Requirement for Social and Environmental Compliance Mandatory adoption of sustainable and socially responsible practices Differentiated Interest Rates and Terms Conditioned on Green Practices Financial benefits linked to adoption of sustainable technologies Additional Criteria for Allocation Based on Environmental Impact Multidimensional assessment considering environmental externalities Monitoring, Reporting and Verification (MRV) Robust systems for tracking and transparency of results Integrated Environmental Safeguards Environmental protection mechanisms incorporated into production processes

Major Findings

ADVANCES

- Rural credit increasingly tied to environmental compliance
- Subnational fiscal tools incentivize conservation (Ecological VAT)
- New frameworks (e.g., **Decree 11.873/2023**) expand restoration targets to **40 million ha (Brazilian Green Way)**

GAPS

- Implementation capacity varies widely by region
- Limited transparency and monitoring systems
- Weak inclusion of smallholders and traditional communities

The Greening of Brazil's Agricultural Policy

Main credit lines:

- Pasture recovery
- Integrated Crop-Livestock-Forestry systems (ILPF)
- Organic agriculture
- Bioinputs and renewable energy

Impact:

"47% of rural credit in 2022-2023 was allocated to sustainable lines"

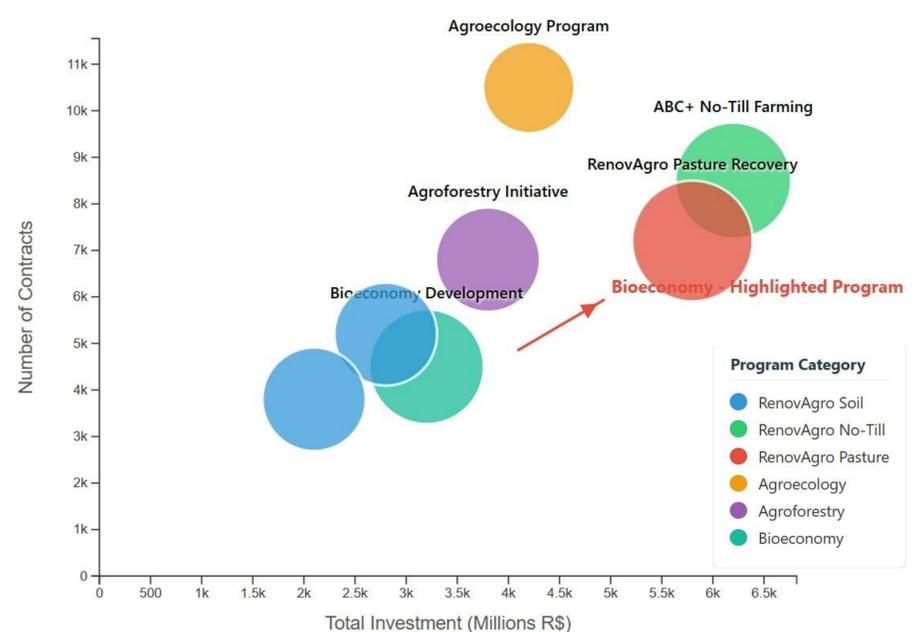
Challenges & Recommendations

Key Challenges:

- Fragmented coordination among federal, state, and municipal institutions undermines policy consistency.
- Lack of unified monitoring and verification systems (MRV) prevents accurate tracking of climate and sustainability impacts.
- Economic incentives still favor conventional agricultural practices in several regions.
- Limited technical assistance and credit access for smallholders and traditional communities.

Sustainable Agriculture Programs Performance (2013-2023)

Circle Size = Average Contract Value | Top 5 Labeled



- RenovAgro No-Till Farming** and **Pasture Recovery** lead in both investment and number of contracts, reflecting their centrality in low-carbon agricultural expansion.
- Agroecology** presents the **highest participation rate**, with over 10,000 contracts, signaling growing adoption by smallholders despite lower average investment per project.
- Agroforestry** and **Soil Management** occupy a mid-range position — strategic but still limited in financial scale.
- The **Bioeconomy program**, although smaller in contract numbers, shows **high average value per contract**, highlighting its potential for innovation-driven, knowledge-intensive projects.

YEAR / MILESTONE	INSTRUMENT / REGULATION	MAIN FOCUS
2010	CMN Resolution No. 3,896/2010	Creation of the Low-Carbon Agriculture Program (ABC)
2011-2020	ABC Program implementation	Over R\$ 17 billion in loans; about 15 million ha restored; estimated mitigation of 83 MtCO₂e . 65% of resources are concentrated in the Center-West and Southeast regions.
2021	Launch of ABC+ Plan	Expanded targets: 1.07 GtCO₂e reduction by 2030; 72 million ha under sustainable practices.
2023	RenovAgro introduced in 2023/24 Agricultural Plan	Green credit line focused on bioinputs, ILPF, waste management, renewable energy, and environmental compliance. Up to R\$ 5 million per beneficiary , 8-year grace period , and 7-8.5% interest rate .
2023	CMN Resolution No. 5,081/2023 and BCB No. 140/2021	Integration of agricultural credit with environmental safeguards: restrictions for farms with illegal deforestation , suspended CAR , or overlap with protected areas .
2023-2024	Complementary actions	BNDES + MapBiomas + INPE use satellite data to block loans in deforested areas. Additional incentives: -0.5 p.p. for validated CAR and -0.5 p.p. for recognized ABC+ sustainable practices .

Strategic Recommendations

- Strengthen inter-institutional governance by aligning Federal level and state programs through a shared sustainability framework.
- Integrate data systems (Environmental register, credit, and emissions monitoring) to enable territorial performance tracking.
- Expand fiscal incentives (e.g., Ecological VAT, credit tax rebates) to reward verified conservation outcomes.
- Scale technical assistance and participatory policy design, ensuring inclusiveness and transparency.
- Leverage blended finance instruments to attract private investment in low-carbon agriculture.

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Good Agricultural Practices, Traceability, and Certification: Challenges for Integrated Platforms



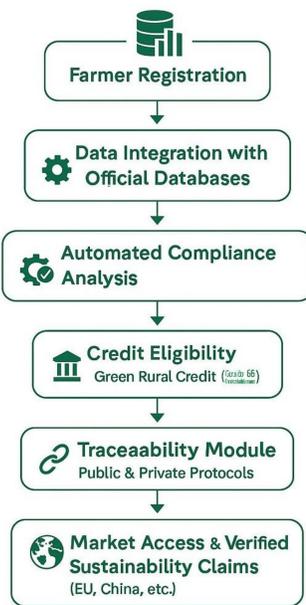
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Context and Motivation

World agri-food exports face tightening sustainability regulations. The EU Deforestation Regulation (EUDR) demands full traceability, yet fragmented data governance and high certification costs prevent large-scale adoption. This study evaluated an integrated digital platform to align Good Agricultural Practices (GAP), certification, and traceability into one transparent system.

Conceptual Model: Integrated Platform

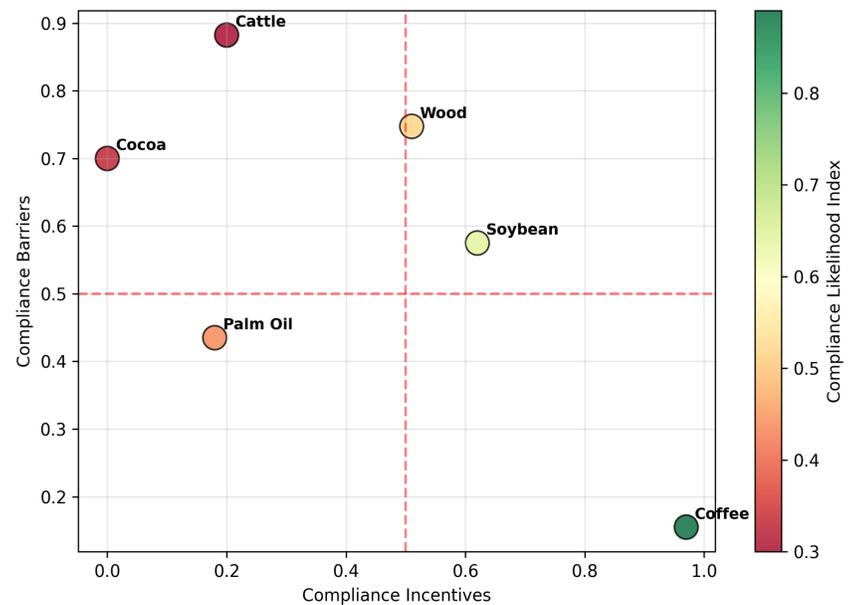


Producers register their farms and management practices, while the system automatically verifies compliance using government datasets. Certification entities (GAP, Integrated Production, Organic, etc.) feed real-time updates, enabling automatic qualification for credit programs such as the Rural Credit. This interoperability ensures transparent traceability, verifiable compliance, and inclusion of smallholders through non-exclusive access and data privacy safeguards.

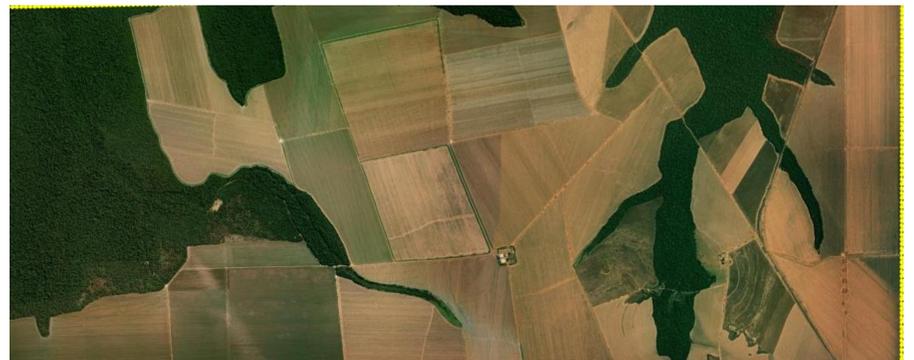
Layer	Main Function	Examples / Sources
Data Integration Layer	Cross-verification of CAR, PRODES, CAF, SNCR	INPE, INCRA, SERPRO
Compliance Layer	Legal, social, and environmental qualification	CAR status, embargoes, labor data
Certification Layer	Official standards and seals	GAP, PI-Brasil, Organic
Financial Layer	Credit and fiscal incentives	Green Rural Credit, Plano Safra
Traceability Layer	Chain-of-custody data & protocols	SISBOV, SIBRAAR, RenovaBio
Market Layer	Transparency and verification	QR code, authenticity code, blockchain

Each layer operates autonomously but is fully interoperable. The system consolidates property, compliance, certification, and traceability data through standardized APIs, enabling continuous monitoring and credit eligibility verification across multiple sustainability protocols.

EUDR Compliance Conditions by Commodity



Four strategic scenarios emerge: Coffee (top-right) demonstrates optimal conditions with strong market incentives and low barriers. Soybean and Wood (bottom-right) benefit from market access but face operational hurdles. Palm Oil and Cocoa (top-left) have moderate capacity but limited market leverage. Cattle (bottom-left) represents the worst-case scenario with both minimal incentives and major structural barriers, demanding urgent comprehensive intervention.



Rural property registered in Brazil's Rural Environmental Registry (CAR) under number MT-5108006-55C212BDAF00438D9FFF5F3AD4B311C2, located in the municipality of Tapurah, Mato Grosso state. The property spans 5,168.31 hectares, with 1,304.70 hectares of native vegetation and 3,613.10 hectares of consolidated agricultural land. Its registration status is "Analyzed, pending environmental regularization;" (**open access**).

A Pathway to Compliance

Brazil's experience shows that environmental compliance can be achieved through data transparency, interoperability, and inclusion, rather than trade restrictions. The **Agro Brasil + Sustentável** platform represents a turning point in aligning sustainability verification with global market access and WTO principles.

"Digital traceability adoption could reduce certification costs by 35–45% and increase transparency coverage by 25% among smallholders" (Oliveira et al., 2024).

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Interoperability, Additionality and Science: Aligning Finance, Law, and Production for a Real Green Transition

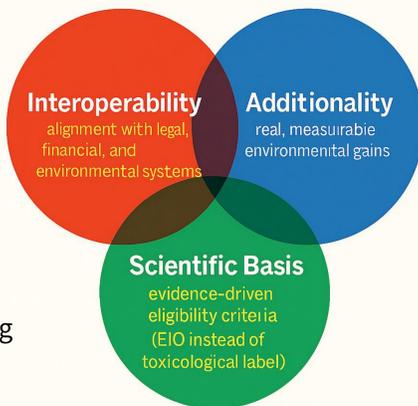
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Building a Science-Based Sustainable Taxonomy for Brazilian Agriculture

Context: Sustainable taxonomies aim to direct capital flows to environmentally sound activities.

Yet, agriculture faces a unique challenge: how to classify sustainability in productive systems that already operate under one of the world's strictest environmental laws — the **Brazilian Forest Code**.

Interoperability: It means aligning international financial systems. It connects credit policies and production monitoring with global parameters. Without interoperability, sustainability does not attract financial flow.



Additionality: Represents *real and measurable gains*: lower emissions, restored soils, conserved biodiversity. **Sustainable finance must** reward projects that go **beyond compliance**, not just those already within the law.

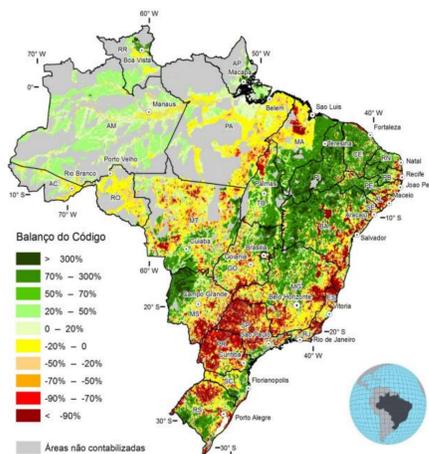
"Interoperability makes sustainability operational; additionality makes it meaningful."

"Science transforms compliance into credibility."

Impact Analysis: Legal Vegetation & Pesticides

Zero Net Deforestation: the Rational Path

"Legal is not enough — sustainable means offsetting more than we change."



Source: UFMG, 2015

Therefore: True sustainability begins beyond compliance

The Forest Code already sets strict limits — legal suppression requires environmental compensation and prior authorization.

Focus on **Net-Zero Deforestation**: Any land-use change from forest to agriculture must be compensated by conserving or restoring a **larger equivalent area** elsewhere, increasing **carbon removal**.

This ensures **additionality** and recognizes **productive inclusion**.

Implement the **Environmental Reserve Quota (CRA)**, which is a negotiable title that represents an area of preserved native vegetation is a must.

From Labels to Science: Using EIQ for Sustainable Finance

Regulatory classifications by ANVISA (GHS) or IBAMA (PPA) reflect labeling, not risk. They are unsuitable for financial eligibility criteria.

Why: regulation without science is not fair.

EIQ mean values across three pesticide groups:

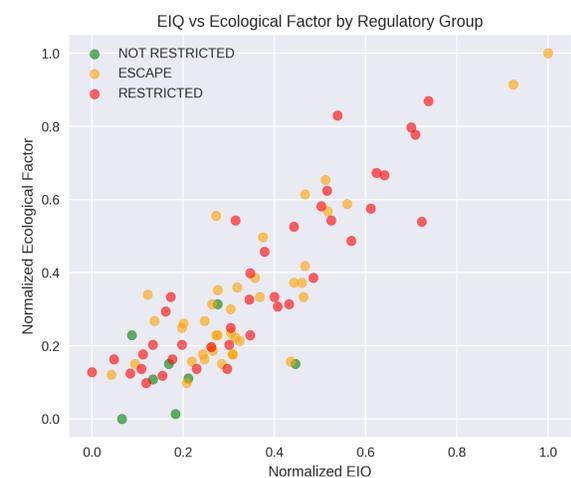
- **Restricted (TSB-prohibited) ≈ 55.5**
- **Escape formulations ≈ 53.5**
- **Non-restricted ≈ 39.9**

Instead, use **quantitative thresholds**:

- EIQ > 70 → priority mitigation
- EIQ > 85 → restricted
- EIQ > 90 → phase-out

Almost all pesticides that should be restricted by taxonomy have formulations with a lower classification, allowing their use. Labeling classification is not useful for public policies

"Labels inform consumers; science guides policy."



No statistical difference between restricted × escape groups (Kruskal-Wallis $p < 0.05$)

(Source: EIQ-Calc and author analysis)

From Intent to Impact: Technical Evaluation of the Brazilian Sustainable Taxonomy

Original Premises of the Taxonomy (Intent)	Ex-Ante Technical Assessment	Observed or Potential Consequences
1. Exclude financing for any activity involving native vegetation suppression.	Overlaps with restrictions already established under the <i>Forest Code</i> . Sustainable use and legal suppression with compensation are misclassified as "unsustainable."	Legal and environmentally compliant producers become ineligible for credit; discourage voluntary conservation and restoration; risk of anticipatory clearing.
2. Restrict the use of pesticides classified as "toxic" by ANVISA (GHS) or IBAMA hazard categories.	Label-based classifications reflect hazard, not real environmental or occupational risk. Statistical tests (EIQ analysis) show no significant difference between restricted and "escape" formulations.	Regulatory inconsistency and no effective risk reduction. Science-based EIQ thresholds should replace label bans.
3. Limit eligibility to activities with low environmental impact and high social co-benefits.	Excludes most conventional agricultural production systems despite verified compliance with national law.	Potential exclusion of 90% of creditable activities; distortions in rural finance allocation; penalizes producers already transitioning.
4. Define "green" eligibility primarily by exclusion (binary logic).	Sustainable transition requires <i>gradual performance scaling</i> , not binary classification.	Hinders innovation, prevents partial eligibility for improving farms, and weakens incentive-based progress.
5. Assume homogeneity with international taxonomies (EU, ASEAN).	Imported frameworks neglect tropical conditions, large-scale production, and mixed-use landscapes.	Incompatibility with local agroecological zones; need for adaptive equivalence rather than copy-paste regulation.

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Validation Models and Connection with Farmers

To ensure transparency and inclusion, we developed a **web calculator** that estimates a sustainability index aligned with the **Taxonomy**.

The tool guides farmers through simple questions on:

- Land use and legal reserve compliance
- Pesticide management (EIQ thresholds)
- Soil and biodiversity indicators

The system calculates a score (0–100) and shows the level of eligibility under the taxonomy.



"Measuring what sustainable agriculture looks like."
(Scan the QR code and calculate your index.)



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Aligning Rural Credit with Sustainable Practices: Environmental Indicators for Agricultural Policy



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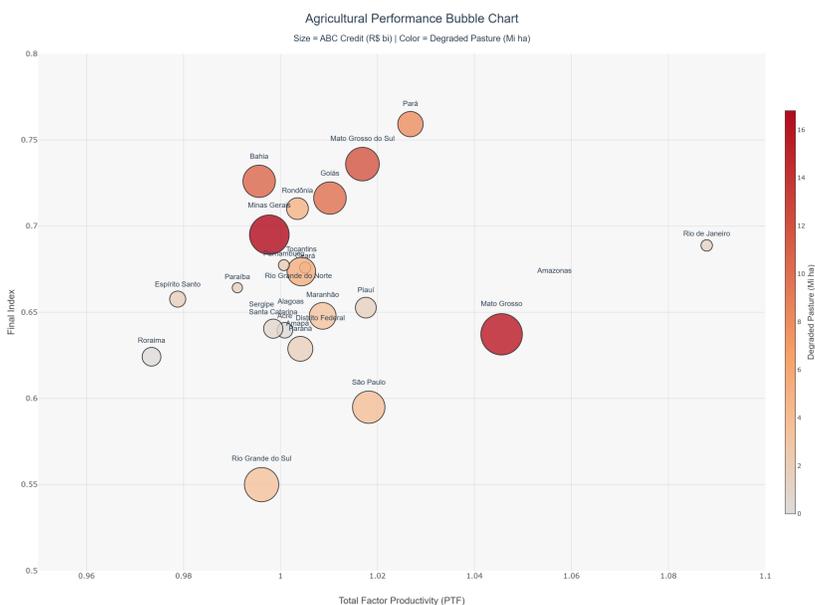
Policy Background and Rationale

Rural credit plays a decisive role in steering agricultural transitions toward sustainability. In Brazil, credit lines under program PPA 2024–2027 include environmental components but still lack robust integration between financial incentives and measurable environmental outcomes.

- Agriculture represents 27% of Brazil's GDP and 30% of GHG emissions.
- The sector mitigation plan ABC+ (2020–2030) targets 72 million ha of sustainable practices.
- Total Factor Productivity (TFP) / GHG emissions ratio adopted as a PPA indicator.



Agricultural Performance



Gaps and Indicators

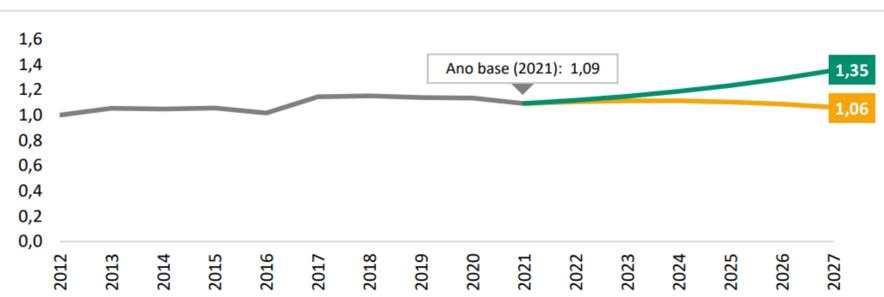
Policy Gaps

Despite progress, the *green* credit remains concentrated:

- 65% of credit in MidWest and Southeast;
- 98% in four technologies (pasture recovery, ILPF, no-till and planted forests).
- Administrative complexity and low CAR validation (<10%) hinder access.

Environmental Indicators

The PPA's main sustainability metric—TFP/GHG ratio—grew 7.4% annually (2010–2018), signaling improved efficiency, but transparency in methodology and MRV is lacking.



Evolution of the relationship between TFP/GHG and targets for the 2024/2027 PPA



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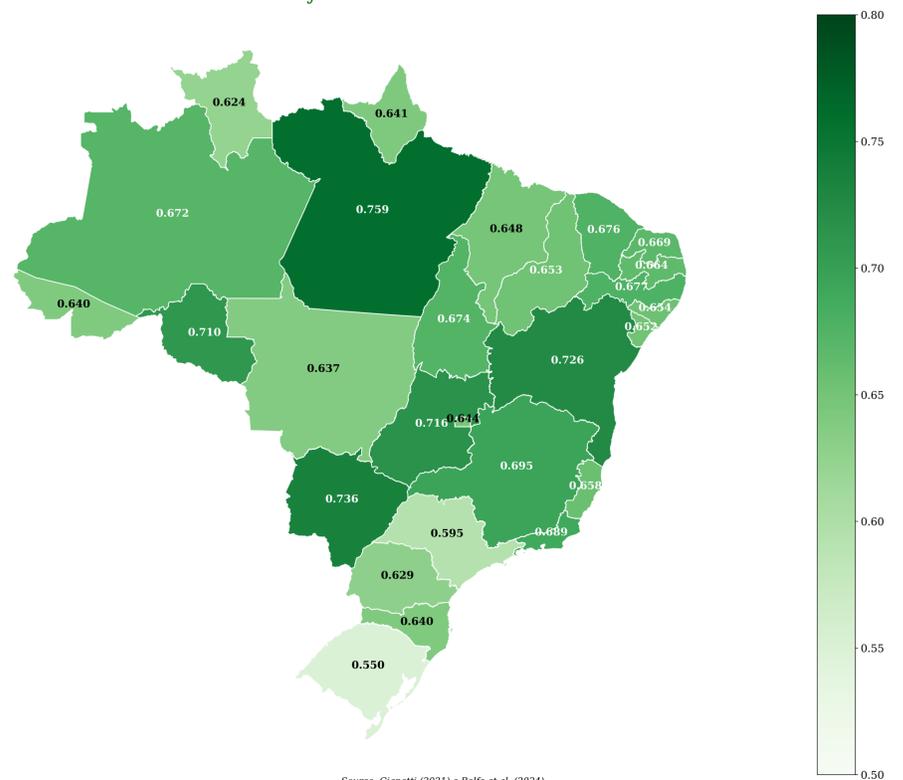
Territorial Prioritization: Construction of the Territorial Priority Index

The construction of a territorial priority index must take into account a balance of resources for stagnant states that do not have a tradition of seeking sustainable financing.

A mixed-methods approach combined policy document review with geospatial data analysis. The study built a Territorial Priority Index based on (i) historical credit allocation (ABC resources), (ii) degraded pasture areas (<0.7 AU/ha) and (iii) Total Factor Productivity (TFP).

$$TP_i = \alpha \cdot \left(\frac{1 - C_1}{C_{max}} \right) + \beta \cdot \left(\frac{D_1}{D_{max}} \right) + \gamma \cdot (TFP)$$

Territorial Priority Index for Sustainable Credit



Source: Gianetti (2021) e Bolfe et al. (2024)

Territorial prioritization for ABC credit allocation based on environmental impact potential. Darker shades indicate territories where credit allocation would yield highest environmental returns.

Governance and Policy Recommendations

Aligning rural credit with sustainability requires:

- Strengthen MRV systems integrating financial and environmental data.
- Geospatial credit prioritization for degraded pasture recovery.
- Smart territorial targeting, and clear recognition of certified sustainable practices.
- Simplify access for small producers and low-adoption technologies (bioinputs).
- Enhance transparency in TFP/GHG indicator calculations.

“Climate-aligned credit is not just finance — it’s governance for sustainable agriculture.”

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CONTEXT / INTRODUCTION

Problem:

- Farmers remain largely excluded from carbon markets due to the absence of measurable, reportable, and verifiable (MRV) indicators linked to on-farm carbon sequestration.

Opportunity:

- Soil Organic Matter (SOM), routinely analyzed in fertility diagnostics, contains about 58% organic carbon and can serve as a low-cost, verifiable metric for climate benefits.



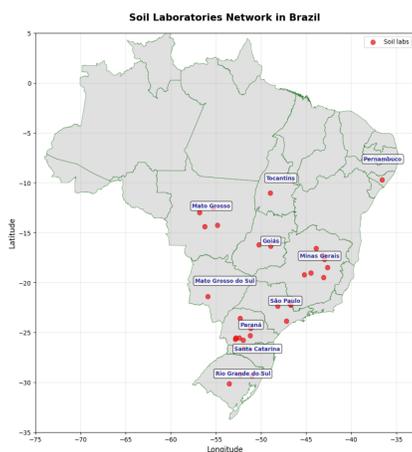
Agronomic Drivers of SOM

Parameter	Effect on SOM	SoilBio Indicator
No-till & ILPF	↑ SOM vs. conventional tillage	↑ β-glucosidase, ↑ arylsulfatase
Permanent cover	↑ Carbon input, ↓ erosion	↑ β-glucosidase
Biomass input (>8 t ha ⁻¹ yr ⁻¹)	↑ SOM accumulation	↑ Enzymatic activity
Reduced disturbance	↑ SOM stabilization	↓ Enzymatic variability
>5 yrs under conservation	Consistent SOM gains	↑ Long-term enzyme trend
Crop diversification	↑ Microbial activity	↑ β-glucosidase, arylsulfatase

SCIENTIFIC BACKGROUND

Strategic soil labs network

“Standardized SOM and bioindicator data can transform farmers into certified carbon suppliers.”



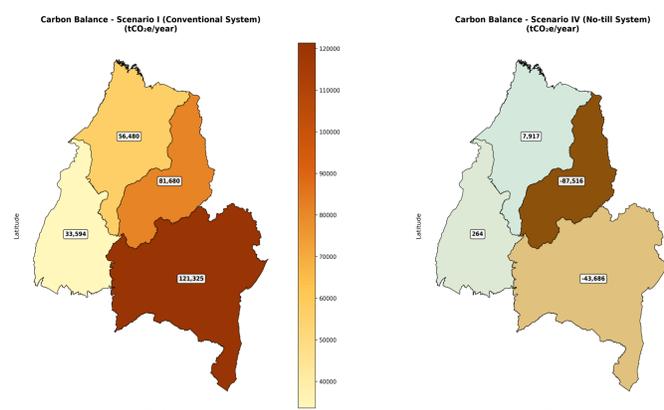
Source: Embrapa, 2024

- Annual SOM measurements (0–10 cm) from accredited labs.
- Data linked to **geographic coordinates** and **Rural Environmental Registry (CAR)**.
- Voluntary national network of soil laboratories adhering to MAPA and Embrapa protocols.
- Recognition through official registry of “Carbon-Eligible Laboratories.”

Embrapa’s SoilBio platform already aggregates thousands of standardized laboratory analyses, including biological indicators (β-glucosidase, arylsulfatase).

Regional SOM Database Model

Expands MRV coverage, reduces transaction costs, and democratizes access for smallholders. The MATOPIBA cerrado is an example of the potential for carbon sequestration through sustainable practices



Source: Solidariedad, 2022

- SOM is a core indicator of **soil fertility, productivity, and carbon sequestration potential**.
- Healthy soils mean lower emissions and greater resilience — where carbon balance begins with organic matter restoration.

SIMULATION AND IMPACT ANALYSIS

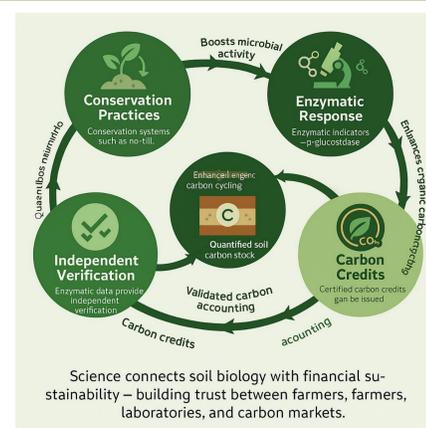
Objective: Assess carbon credit generation potential for a 100-ha farm in the Brazilian Cerrado adopting no-till and permanent cover cropping.

Scenario	ΔSOM (5 yrs)	tCO ₂ e ha ⁻¹	Total (100 ha)
Conservative	+0.25 %	6.25	625
Moderate	+0.50 %	12.5	1,250
Optimistic	+1.00 %	25.0	2,500

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CONCLUSIONS AND POLICY INSIGHTS



- SOM is a **technical, economic, and ecological indicator** bridging soil health with climate finance.
- Temporal dynamics demand **multi-year monitoring** and robust baselines.
- Regional SOM databases, governed by MAPA and Embrapa, can underpin certified MRV systems.

- Integration with Brazil’s Emissions Trading System (SBCE) enables scalable inclusion of smallholders.
- Aligned with the “4 per 1000” global initiative, reinforcing soil carbon as a climate lever.



Healthy soils are climate assets — measurable, verifiable, and bankable.

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INTRODUCTION

Agricultural credit has evolved from a productivity-oriented subsidy into a strategic instrument for **climate mitigation, adaptation, and inclusive rural development**.

This analysis synthesizes **three decades of global and regional experiences** — from IFAD and World Bank frameworks to emerging initiatives in Brazil, Nigeria, and South Asia — proposing a **conceptual model** for “**Green Safra Plans**,” a scalable template for the World Bank and G20 to foster sustainable agricultural finance globally.

CONCEPTUAL ARCHITECTURE

System Dynamics

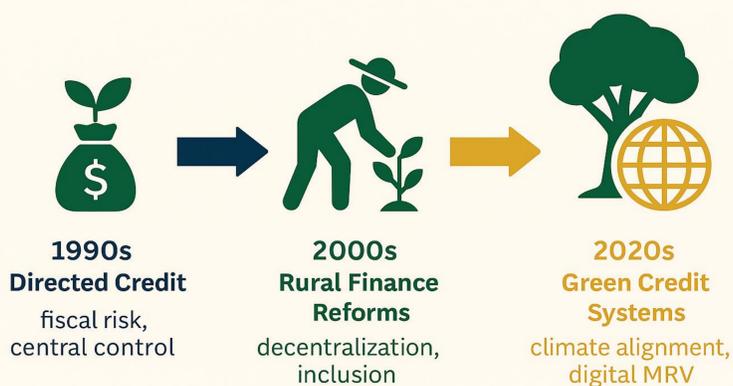
Capital flows **from the global to the local** levels through banks and blended-finance instruments, while information and MRV data **flow upward**, validating performance and enabling transparency. This dual movement closes the feedback loop — making credit both a **driver of productivity** and a **mechanism for climate accountability**.



Evolution of Agricultural Credit and Sustainability (1994–2025)

Year	Milestone
1994 – Directed Credit (Calomiris & Himmelberg)	Highlighted risks of politically guided agricultural loans and concentration effects.
2000 – IFAD Rural Finance Policy	Defined inclusive, decentralized, and sustainable rural finance principles.
2018 – Yuan & Gallagher	Demonstrated that institutional capacity and governance drive green finance outcomes.
2021 – Green Growth & Agriculture in Brazil	Showed that greening credit requires <i>new rules, not new banks</i> .
2022 – World Bank Agricultural Credit	Reframed credit as a tool for structural transformation toward low-carbon growth.
2024 – IPEA / Credit Risk Review	Merged climate finance and agricultural credit: climate risk = credit risk.
2024 – Inclusive Green Finance / Nigeria ACGS	Proved inclusion and risk mitigation as key enablers of viable green credit.
2025 – Systematic Review Protocol	Established standardized MRV and <i>Green Credit Scoring</i> for global comparability.

From Directed Credit to Green Finance



From Theory to Practice

Principles and Implementation Mechanisms

Global Principle	Practical Mechanism and Contribution
Alignment with Climate Commitments	Link national agricultural credit programs to climate strategies and emission targets. Funding flows should be guided by green taxonomies and verified environmental outcomes. This ensures that every loan contributes to both productivity and decarbonization goals.
Mitigation of Climate and Credit Risks	Establish <i>Green Guarantee Funds</i> that share climate-related losses between the public and private sectors. Combine these guarantees with climate-indexed insurance to reduce default risk and attract private capital into sustainable agriculture.
Inclusion and Decentralization	Deliver credit through cooperatives, rural credit unions, and digital platforms. These channels expand access for smallholders and women farmers while using local data and MRV systems to validate sustainable practices in real time.
Conditionality and Environmental Performance	Tie interest rates, grace periods, and subsidies to measurable sustainability indicators—such as soil health, reforestation, or emission reductions. This transforms environmental performance into a financial advantage and builds long-term behavior change.
Integrated Governance	Create joint governance structures linking Ministries of Agriculture, Finance, and Environment with Central Banks and development banks. This ensures that agricultural policy, fiscal incentives, and prudential regulation all reinforce the same sustainability targets.

GLOBAL SUCCESS CASES

Global Lessons for an Effective Road Map



Brazil

- Strength: large-scale financial infrastructure.
- Lesson: Modernize governance, not institutions.

Sub-Saharan Africa

- Strength: Public risk-sharing attracts private capital and expands rural inclusion.
- Lesson: *Green Guarantee Funds* lower credit risk, build resilience, and enable blended finance.

South Asia

- Strength: Strong interministerial governance and MRV digitalization.
- Lesson: Transparency, inclusivity, and mandatory green lending targets work.

Blueprint for Global Green Safra Plans

Core Design Principles (Bullet Points):

- Hybrid Capitalization:** combine public, private, and climate funds (GCF, GEF, green bonds).
- Conditional Credit:** link interest rates and subsidies to measurable environmental performance.
- Inclusive Delivery:** decentralize via cooperatives, fintechs, and microfinance institutions.
- Risk Mitigation:** deploy *Green Credit Guarantee Funds* and climate insurance.
- Integrated Governance:** align agricultural, fiscal, and environmental policies.
- Transparent MRV:** use digital monitoring, *green credit scoring*, and standardized reporting.
- Scalability:** use the Brazilian *Plano Safra* as a pilot for the World Bank's global platform.

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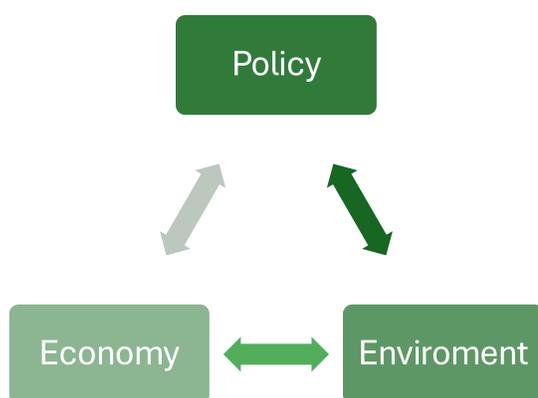
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WHY STATIC MODELS ARE NO LONGER ENOUGH

- Traditional policy evaluation methods are static and linear.
- Agricultural and land-use systems, however, are dynamic and nonlinear.
- **Differential equation models reveal how policy actions propagate through time and feedback on themselves.**



OBJECTIVE

To institutionalize dynamic system models as official metrics for public policy and land-use governance.

MODEL ARCHITECTURE

$$\begin{cases} \frac{dF}{dt} = aF - bFD \\ \frac{dD}{dt} = cFD - dD \end{cases}$$

Model Components and Flows

- **F(t) accumulated financing**
- **D(t) deforestation area**

In this system, **a** is the credit growth rate, **b** the negative effect of deforestation on credit, **c** the conversion of credit into deforestation, and **d** the natural stabilization rate of cleared areas.

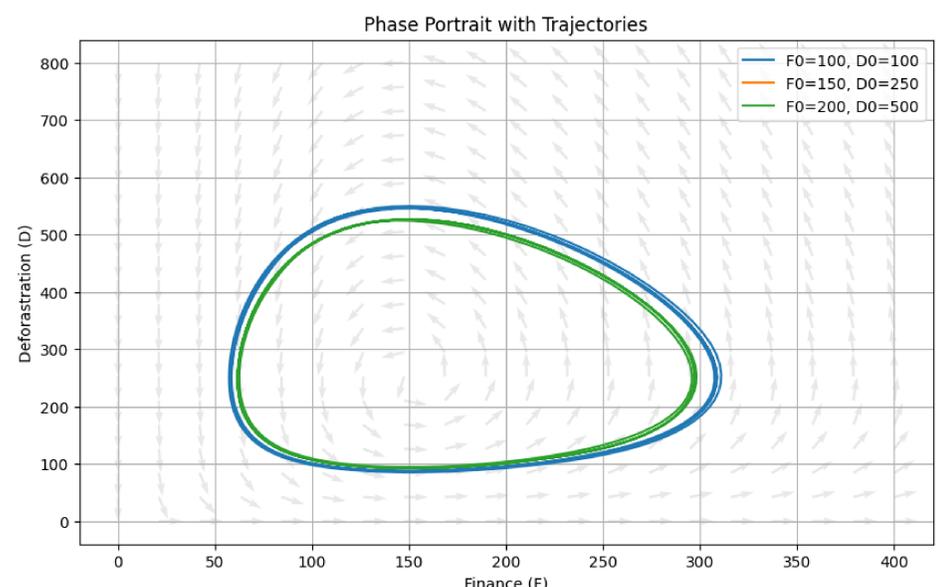
KEY INSIGHTS

- **Dynamic feedbacks** reveal policy oscillations and instability thresholds.
- **Coupled variables** (credit–deforestation) exhibit limit cycles under excessive financial pressure.
- Stable equilibria occur only under **adaptive credit policies**.

Implications for Governance

- Integrate differential models into monitoring dashboards (MAPA, IBGE, MMA).
- Shift from *ex-post* evaluation to *ex-ante* simulation.
- Identify “tipping points” before policy failure.

“Dynamic equations can guide sustainable decision-making — before crises emerge.”



The system exhibits self-regulating oscillations between rural credit and deforestation, revealing the feedback loops that shape agricultural frontier dynamics.

CONCLUSIONS

- Dynamic systems modeling bridges ecology and economics.
- It captures the feedback loops that shape deforestation cycles and supports evidence-based governance in the Amazon.
- Dynamic systems modeling bridges ecology and economics.

Explore our interactive simulator to see these principles in action



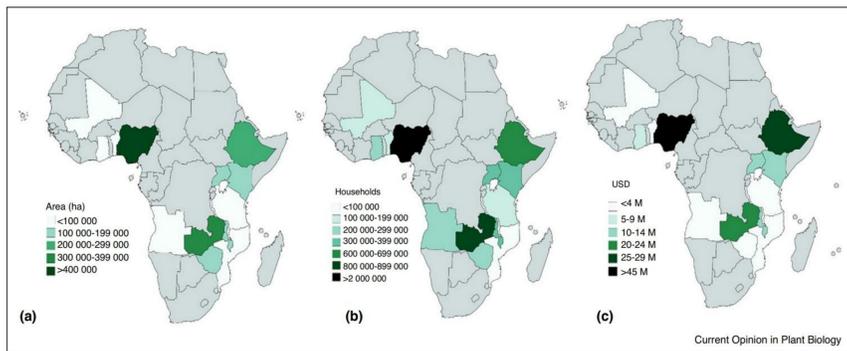
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Climate Crisis and Innovation Dilemma

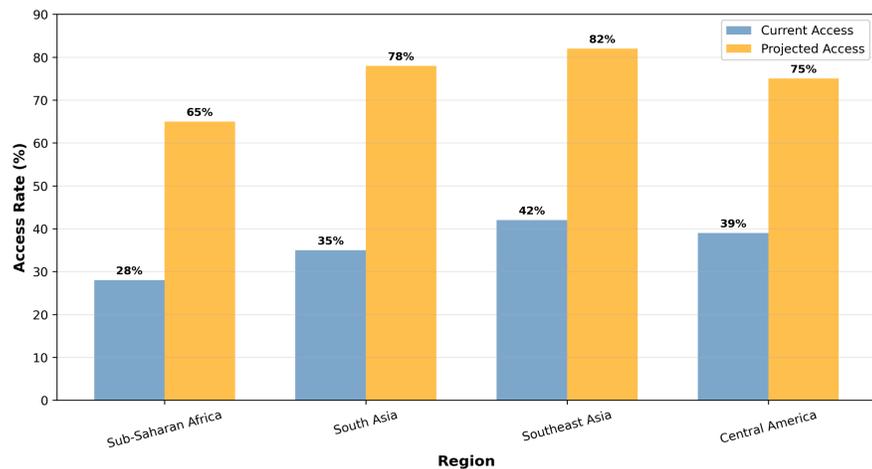
“Unequal Access to Climate-Resilient Varieties”

- Agricultural systems face unprecedented stress from temperature rise, erratic rainfall, and extreme events.
- Existing breeding programs are insufficient to meet adaptation needs.
- Farmers in the Global South face the highest exposure but the lowest access to climate-resilient varieties.
- IP frameworks designed for trade and innovation now intersect with adaptation and justice.



Source: Cairns, 2018

Current and Projected Access to Improved Varieties by Region



TRIPS & UPOV Under Stress

Framework	Core Function	Flexibility	Limitation for Climate Adaptation
TRIPS (WTO)	Sets global IP standards	Allows national sui generis systems	No incentive for adaptation traits
UPOV 1991	Protects new plant varieties	Exemptions for research/farm-saved seeds	Restricts equitable diffusion
National Laws	Implement TRIPS/UPOV domestically	Variable enforcement	Often silent on climate-related breeding

Both frameworks can evolve — not by rewriting them, but by embedding adaptive incentives that balance innovation and justice.

Adaptive Incentive Framework

Validated Climate-Resilient Traits

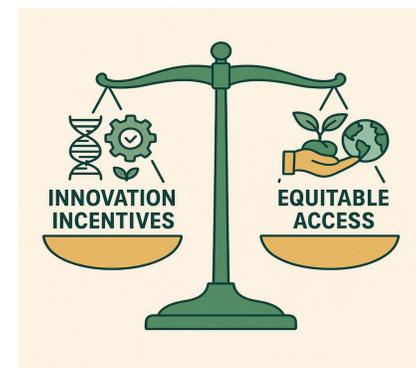
Climate-Adaptive Trait	Example Indicators	Verification Source
Drought tolerance	Yield > 85% under water stress	Field trials
Flood resilience	Recovery > 70% post-inundation	Controlled experiments
Heat resistance	Stable productivity > 35 °C	Greenhouse tests
Pest/disease resistance	30% lower loss vs. baseline	Pathogen screening

Science-based verification ensures that adaptive traits deliver measurable resilience under stress conditions



Adaptive IP transforms protection into partnership — driving innovation for breeders while delivering resilience for farmers.

Balancing Benefits and Obligations



- Enhanced IP benefits for adaptive breeding
- Recognition badges/certification for “Climate Smart Breeder” programs
- Access to international funds (GCF, GEF) for adaptive R&D
- Tiered pricing models based on regional income levels
- Compulsory licensing clauses for public emergencies
- Partnership channels with CGIAR & FAO seed banks

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Recalibrating Livestock Emissions Inventories: Accounting for Genetic Composition in Tropical Pasture Systems

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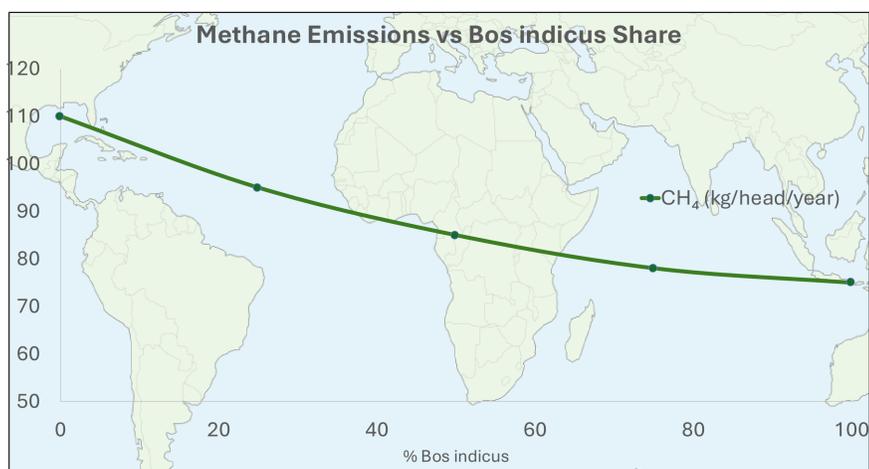
INTRODUCTION

- Accurate GHG accounting is vital for climate-smart livestock systems.
- Global inventories use emission factors based on *Bos taurus* breeds under temperate conditions.
- This generates **systematic overestimations** for tropical *Bos indicus*-based herds, typical of Brazil.

Key Problem: Current IPCC Tier 1 factors do not capture breed composition or tropical pasture realities.

OBJECTIVES

To propose the inclusion of **Bos indicus ancestry (%)** as a variable in national and international livestock GHG inventories.



INTERPRETATION

- Tropical-adapted zebu cattle emit less CH₄ per unit of feed intake.
- Overestimation in Brazilian inventories ≈ **15–25 Mt CO₂e/year**.

METHODOLOGICAL FRAMEWORK

- Comparative literature review of methane yields (Y_m) across genetic types.
- Calculation of adjusted Tier 2 coefficients for Emission Factors (EF):

$$EF_{adj} = EF_{default} \times (1 - \alpha \cdot BI\%)$$

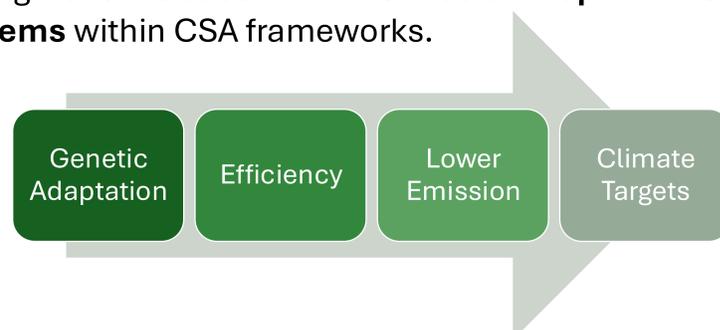
where *BI%* is proportion of *Bos indicus* genetics and α the correction coefficient.

KEY FINDINGS

Breed Type	Feeding System	CH ₄ Emission (kg/head/yr)	Δ vs IPCC Default
<i>Bos taurus</i>	Feedlot (temperate)	110	—
<i>Bos indicus</i>	Pasture (tropical)	75	-32%
Crossbred	Mixed diet	90	-18%

POLICY IMPLICATIONS

- More accurate emissions improve transparency in **NDC** reporting.
- Recognition of *Bos indicus* genetics supports fair climate finance allocations.
- Strengthens the case for **low-emission tropical livestock systems** within CSA frameworks.



CONCLUSIONS



- Integrating genetic composition improves precision, fairness, and credibility of livestock GHG inventories.
- Tropical breeds are part of the solution—not the problem—for sustainable food systems.

Scan the QR code and calculate your index

Cap and Taxes: Embedding Carbon Incentives into Value-Added Tax Systems to Drive Agricultural Sustainability

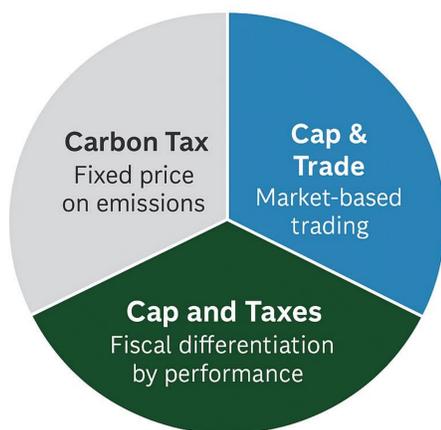


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Context and Rationale

- Traditional VAT systems rarely integrate environmental performance.
- Carbon pricing mechanisms often exclude agriculture from direct fiscal signals.
- Cap and Taxes combines a target emissions cap with differentiated VAT rates linked to sustainability performance.
- The model is inspired by Brazil's **ICMS Ecológico** and **Mais Leite Saudável Program**, extending fiscal neutrality to climate incentives.

Comparative Framework of Carbon Pricing Instruments



Turning tax systems into drivers of sustainability.

Dynamic Fiscal-Environmental Model

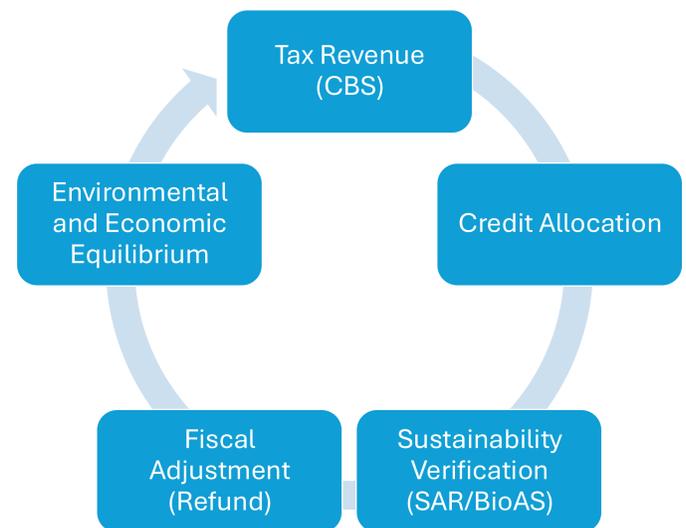
$$\frac{dC}{dt} = \alpha C + \rho CS + \beta T$$

$$\frac{dS}{dt} = \theta CS - \lambda S$$

where:

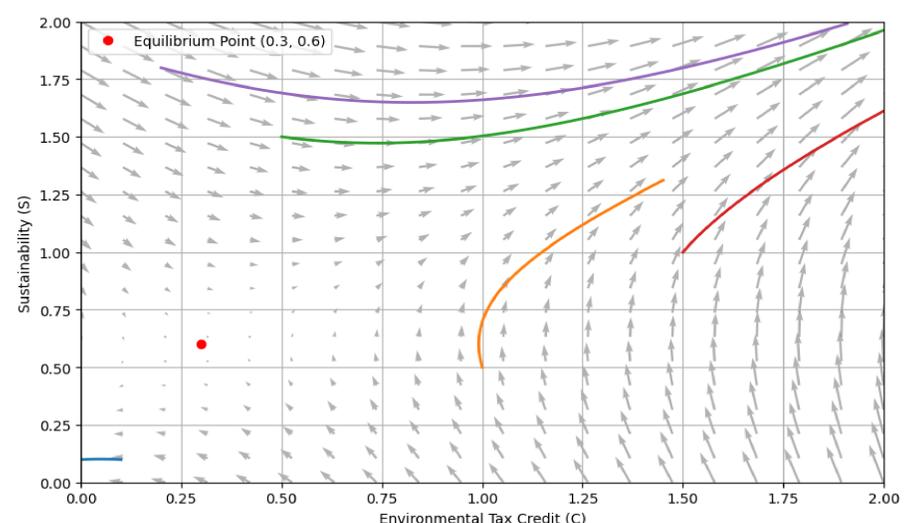
- **C(t)**: Fiscal Credit (R\$ billions)
- **S(t)**: Sustainability Index (Legal Reserve Surplus)
- **T**: Effective Tax Load
- $\alpha, \beta, \theta, \rho, \lambda$: System parameters

"Cap and Taxes ensures climate effectiveness and fiscal balance through performance-based VAT adjustments".



Fiscal-Environmental Effects

- **Stable Equilibrium Regime**: Balanced incentives generate steady improvements in sustainability (Soil Health \uparrow , credit cost \downarrow).
- **Overshoot Risk**: Excessive credit incentives cause fiscal imbalance without proportional environmental gains.
- **Withdrawal Effect**: Abrupt policy removal leads to sustainability collapse.
- **Fiscal Neutrality**: CBS refund ($\leq 60\%$) maintains public revenue balance.



Key Results

Indicator	Value	Meaning
Fiscal Refund (CBS)	up to 60 %	Revenue neutrality maintained
Emission Reduction (CH ₄ + N ₂ O)	-43 % by 2035	Aligned with PNMC targets
Tax Differentiation Range	± 4 %	Incentive / penalty spread
Sustainability Index (SAR)	+ 0.75 → + 1.00	Verified improvement zone
Fiscal Stability	Stable Equilibrium	No deficit under optimal regime



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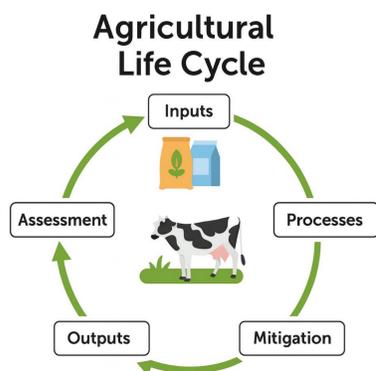
Context and Objectives

"Why Target Non-CO₂ Agricultural Emissions?"



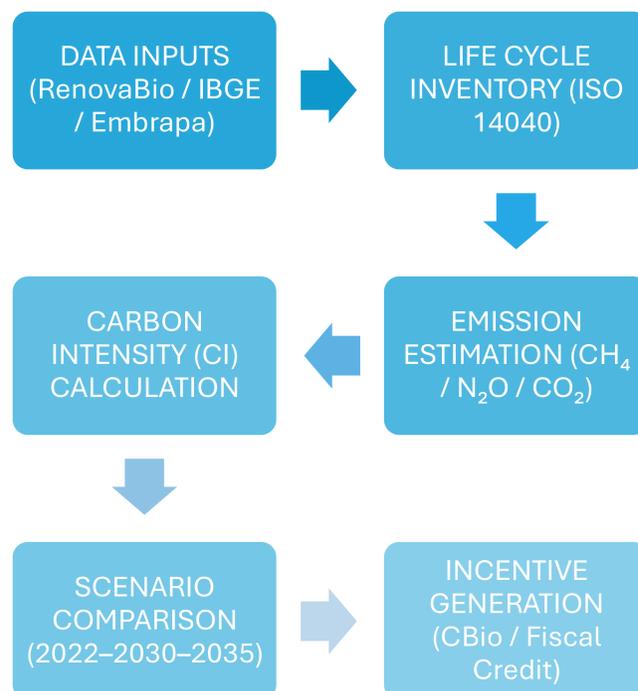
- N₂O and CH₄ emissions from agriculture and livestock remain underestimated in global mitigation frameworks.

- These gases have higher global warming potential (GWP) and require sector-specific incentive mechanisms.
- Brazil's experience with RenovaBio provides a scalable foundation for a non-CO₂ mitigation framework.



Operational Flow :

From Life Cycle Data to Incentive Allocation



Methodological Framework

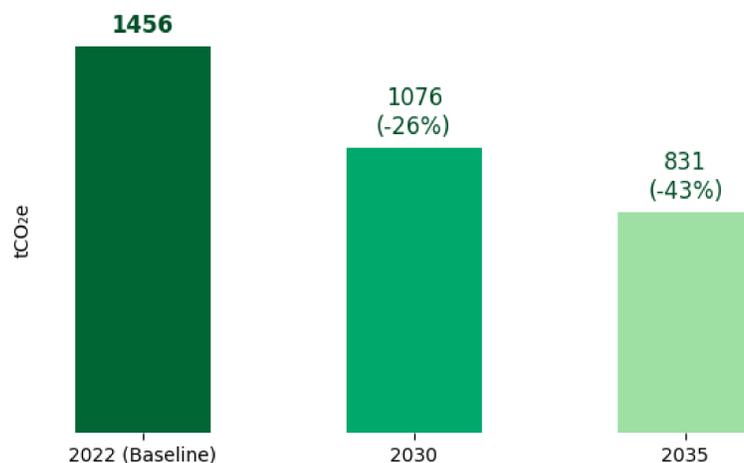
Step	Description	Key References / Tools
1. Scope Definition	Define system boundaries based on ISO 14040/14044 and IPCC 2019 guidelines. Include inputs (fertilizers, feed, energy) and outputs (products, CH ₄ , N ₂ O, CO ₂).	ISO 14040/14044; IPCC (2019)
2. Life Cycle Inventory (LCI)	Collect primary data from national databases (RenovaBio, SINABC, IBGE, Embrapa, FAO). Normalize to 1 ton of product or 1 MJ of energy.	National Inventories; FAOStat
3. Emission and Removal Estimates	Apply Tier 1/2 emission factors for CH ₄ , N ₂ O, CO ₂ . Quantify emissions from enteric fermentation, rice cultivation, managed soils, and fuel use.	IPCC Guidelines; Embrapa Models
4. Stochastic Modeling	Use probability distributions (Normal, Gamma, Logistic) for key parameters. Run Monte Carlo simulations (n=10,000) to estimate uncertainty (P10-P90).	GREET Model; Python SciPy
5. Allocation and Co-product Credit	Apply <i>displacement</i> (energy substitution) or <i>energy allocation</i> for shared emissions between crops and energy co-products.	GREET; RenovaCalc
6. Carbon Intensity (CI) Calculation	Compute CI as the ratio of total emissions minus removals per functional unit: $CI = (\sum EI - \sum RJ) / UF$	ISO 14067; IPCC
7. Scenario Analysis (2022-2035)	Compare Baseline (2022) vs. Mitigation Scenarios (2030, 2035). Evaluate sectoral emission reductions (-26% to -43%).	PNMC; ABC+ Plan
8. Credit and Mitigation Indicators	Convert emission reductions to CBio-equivalent or fiscal incentives. Integrate with TFP/GHG (Total Factor Productivity / Emissions) index.	RenovaBio; MAPA Indicators

The methodological framework integrates life-cycle data, emission modeling, and scenario analysis to quantify mitigation potential across agricultural and livestock systems. These steps form the basis for a performance-based incentive mechanism aligned with Brazil's climate targets.

Results and Policy Insights

- Agricultural mitigation potential reaches **-26% (2030)** and **-43% (2035)** relative to 2022.
- Life-cycle metrics enable integration with credit and fiscal systems.**
- Incentivizes producers to adopt **low-emission practices** with measurable results.

Non-CO₂ Emissions Reduction - Agriculture Sector



Projected emission reductions align with Brazil's 2030 and 2035 sectoral targets.

Turning emission reductions into measurable value for sustainable agriculture.

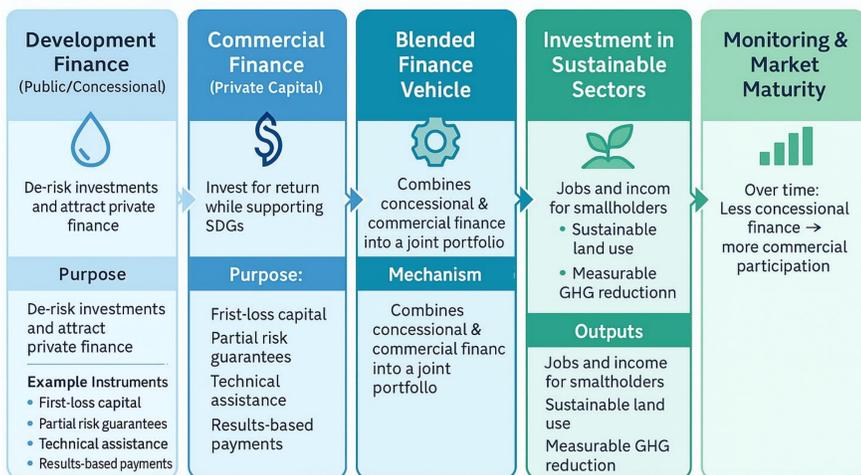
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What Is Blended Finance?

"Blended finance strategically combines concessional public funds with private capital to de-risk and scale sustainable agriculture."

How Blended Finance Works

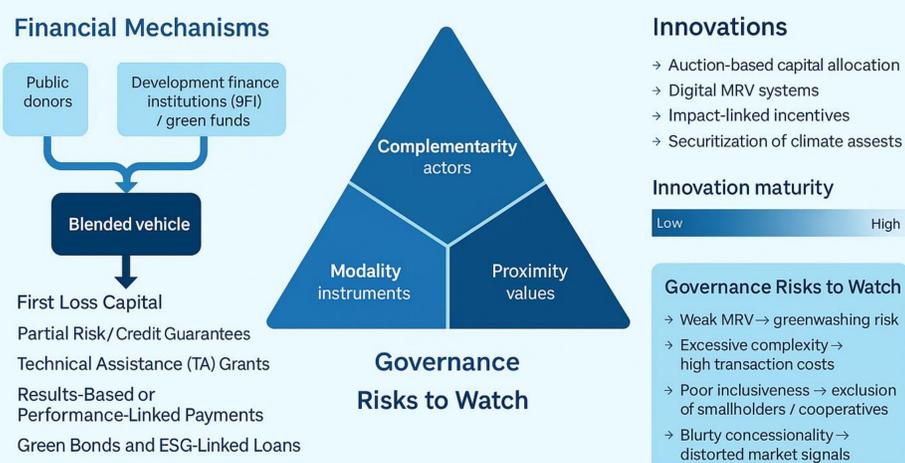


Where and How It Works

"Over 500 agriculture-related blended finance transactions have mobilized USD 20 billion since 2015, yet remain concentrated in few regions."



Mechanisms, Innovations & Governance – Scaling Finance and Trust



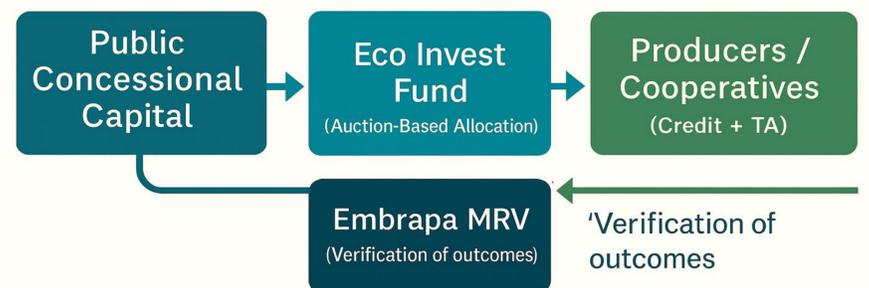
Opportunities and Structural Risks

Theme / Indicator	Verified Estimate
Agriculture shares in blended finance transactions	≈ 28 % of all blended finance deals focused on agriculture (as of 2021).
Share of blended finance committed to Least Developed Countries (LDCs, 2018–2020)	15% of total blended finance commitments went to LDCs.
Private finance mobilized annually in LICs & MICs through blended finance	~ US \$3.3 billion per year (minimum estimate).
Agri-food systems share of total climate finance	< 4 % of global climate finance flows reach agri-food systems.
Smallholder finance gap	≈ US \$15–20 billion annually unmet demand for smallholder finance.
Typical leverage ratio (public: private) in agriculture blended deals	Between 1: 0.8 and 1: 1.5, depending on market maturity.

Brazilian Green Way Blended Finance for Land Restoration

The Brazilian Green Way (Caminho Verde Brasil) is the country's national blended-finance platform to recover up to 40 million hectares of degraded pasturelands over ten years. It integrates public concessional funds with private capital through auction-based mechanisms that reward verified environmental performance.

How the Brazilian Green Way Works



The initiative aligns with the ABC+ Plan and Eco Invest Brazil, positioning the Ministry of Agriculture (MAPA) and MRV systems as anchors for climate-smart investment.



The Brazilian Green Way bridges finance, technology, and climate integrity — turning degraded lands into climate assets."

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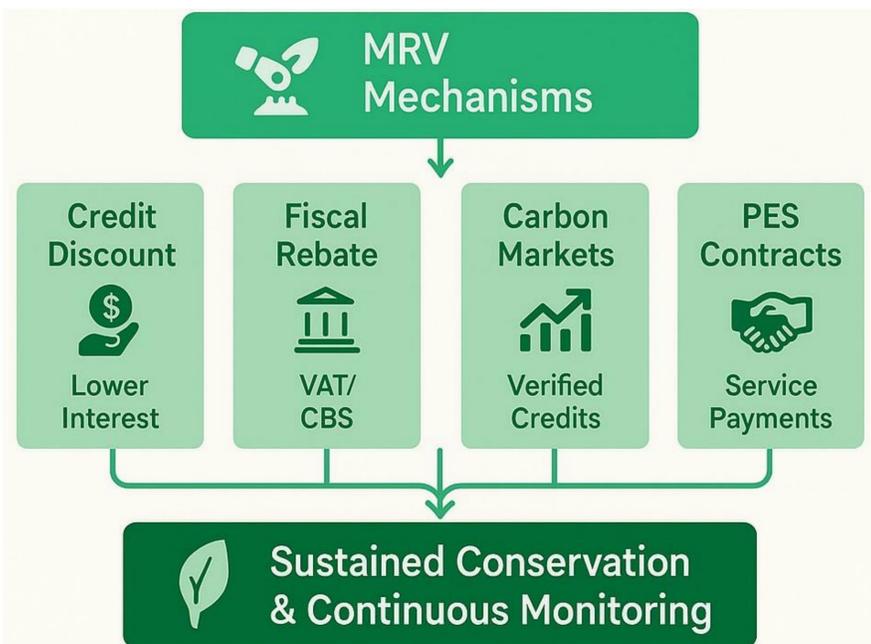
Context and Rationale

Why Compensate Legal Reserve Surplus?

- Native vegetation conservation in rural properties is essential for carbon storage, biodiversity, and water regulation.
- Brazil's **Forest Code (Law 12.651/2012)** mandates minimum conservation but offers no direct reward for exceeding it.
- The *Legal Reserve Surplus* represents a public environmental asset without fiscal recognition.
- Integrating **credit incentives** and **fiscal instruments** can convert conservation into measurable economic value

Integrated financial instruments

Each mechanism addresses a different dimension of sustainability, but none alone fully compensates the opportunity cost of conservation. Integrated financial instruments must operate in synergy, allowing “layered” incentives over the same preserved or restored area.



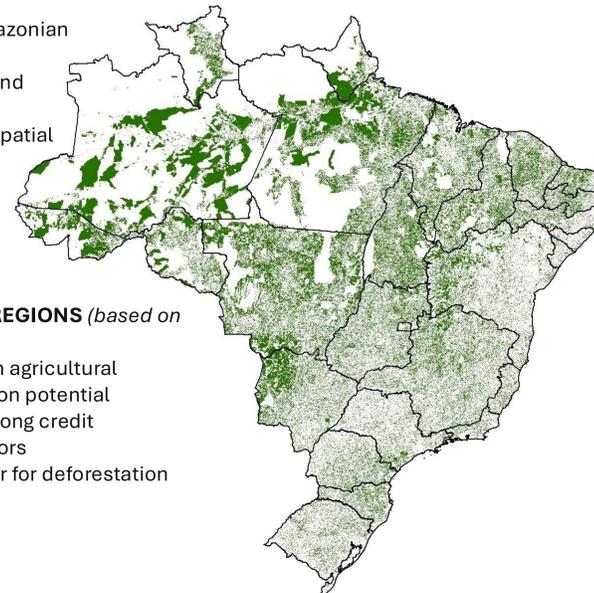
Sustainable Conversion Costs

Mechanism / Modality	Total Cost (US\$/ha)	Annual Cost (US\$/ha/year)	Notes
Conservation via Rural Credit	85 – 100	6 – 8	Fiscal equalization of ~20% for 14 years of conservation credit support. (Authors' estimate)
Global Conservation Payments (TFFF)	—	~4	Annual payments for standing forests (Tier 1 incentive).
Passive Natural Regeneration	~ 49	—	Minimal-cost restoration through spontaneous vegetation recovery.
Assisted Natural Regeneration	~ 344 ± 156	—	Requires fencing, invasive control, and initial maintenance.
Direct Seeding Restoration	~ 1,754 ± 991	—	Intermediate method with moderate establishment cost.
High-Intensity Seedling Planting	~ 2,328 ± 465	—	Active restoration used in most PLANAVEG projects.
PLANAVEG (national average scenario)	~ 1,112	~80	Weighted average for ~12 million ha under restoration targets.
REDD+ (Results-Based Payments)	—	5 – 10	Global range of verified emission reduction payments (USD/tCO ₂ e equivalent).

Declared Protected Areas in Brazilian Rural

LEGAL AMAZON CARTOGRAPHIC VACUUM

- Significant data gaps in Amazonian states in public databases
- CAR coverage incomplete and fragmented
- Critical need for improved spatial data infrastructure



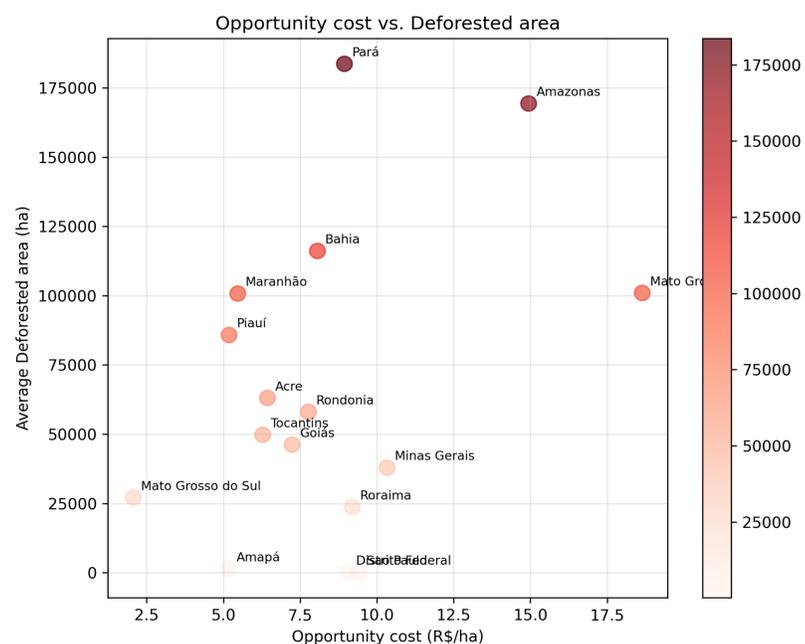
HIGH-OPPORTUNITY REGIONS (based on our statistical analysis)

- **MATO GROSSO:** High agricultural revenue + conservation potential
- **BAHIA (Cerrado):** Strong credit sustainability indicators
- **PARÁ:** Critical frontier for deforestation prevention

Source: Embrapa Territorial, 2021

Note: Data reflects declared - not necessarily validated - vegetation cover in the Rural Environmental Registry (CAR)

Correlation Model for Investments



Sources: VBP Agro (MAPA), Deforestation & Agricultural Area (MapBiomias)
Opportunity Cost = Agricultural Revenue Potential (R\$/ha).

The dispersion reveals biome-specific patterns: Amazon states face different conservation challenges than Cerrado agricultural frontiers, demanding tailored policy instruments.

Brazilian Green Way

Brazilian Green Way is another strategy: mobilized R\$ 30.2 billion (≈ US\$ 6 billion) to restore up to 3 million ha of degraded lands through concessional rural credit, equivalent to US\$ 2,000–4,500 per ha of total restoration cost.

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