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RESEARCH ARTICLE

Nature-Based Solutions: Sustainable Development of Latin America

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Abstract: Latin America is a region with abundant natural resources and diverse cultures, much of which lies between the tropics. Sustainable agriculture, pasture, and forestry practices can have a reduced environmental impact in this region compared to other parts of the world. These integrated systems practices can create a balanced use of chemical inputs, harmonious relations between humans and soil–plants–livestock, and even provide a nature-based solution to climate change by sequestering carbon emissions and are also less likely to lead to soil degradation. These practices are central to a new economic paradigm focused on a sustainable and circular bioeconomy and depend on public policies, incentives, financial mechanisms, and commitments from the business. Carbon-farming sustainable agriculture focused on increasing soil health and reducing emissions can gain scale with market-driven mechanisms to surpass the various challenges. This paper presents condensed information from primary and secondary sources, representing established knowledge in the field of soil carbon sequestration in agricultural lands and its role in carbon neutrality. By implementing these strategies, we can support farmers while contributing to the objectives set by the Paris Agreement and the UN's sustainable development goals.

Keywords: nature-based solutions, carbon sink in agricultural lands, integrated agricultural systems, living soils

Here are some highlights of the paper. Integrated agricultural systems can restore degraded soil and transform agriculture and pasture from carbon emitters to carbon sinks.

Maintaining natural ecosystems safeguards soil organic carbon, a vital resource, and prevents the release of greenhouse gases into the atmosphere, underscoring their critical role in climate change mitigation.

Nations with significant land use emissions and land use change, and nature-based solutions can and should be the focus of public policies and corporate practices to find a new competitive, responsible, and inclusive low-carbon circular bioeconomy.

1. Introduction

Latin America boasts abundant natural resources and a multitude of cultures. Thanks to its tropical location, the region benefits from more sustainable agricultural and pasture practices compared to other areas of the world. Therefore, the region can spearhead the swift to the sustainable circular bioeconomy [1, 2] and, in doing so, contribute to tackling the deadliest market failure of our time: climate change [3].

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Sustainable agriculture and forestry must take a central role in promoting sustainable resource use, while ensuring balanced chemical inputs and harmonious human–soil–plant relations [4]. This integrated approach acts as a catalyst for a powerful synergy, delivering better environmental management, nutritious food and resources, renewable energy and fibers, rich soils, and, crucially, sustainable income generation for communities surrounding natural resources.

Soils represent a significant carbon (C) sink (as we will detail ahead) and the plants over it as well because they use carbon dioxide (CO2) in their photosynthesis process. Besides that, a considerable amount of 22% [5] of the global emissions is because of land use, land use change, and forestry, reported by the Intergovernmental Panel on Climate Change, merged into a two-part volume referred to as Agriculture, Forestry and Other Land Use (AFOLU). This shows that the way we practice agriculture, pasture, and forestry is not sustainable and will not support the growing demand for food, feed, fiber, and energy in the future. Highly irrigated and chemically managed monocultures have led to soil degradation, reduced natural cover and many forms of greenhouse gas emissions. This can be changed.

The American continent has a diverse surface cover, from forests, grasslands, deserts, savannahs to fertile soil to agriculture. In terms of agricultural lands, pastures occupy the largest area

(905 million ha), followed by croplands (340 million ha). In agriculture, the main area cultivated with annual crops is soybean (91 million ha), corn (72 million ha), and wheat (35 million ha). With a much lower area, sugarcane (14 million) and coffee (5 million ha) are the main semi-perennial and perennial crops, respectively, cultivated in the continent [6]. The complex matrix of soil, climate, vegetation, and management found across the continent maintains great variability of soil C stocks. The continental average soil C stocks for 0–30 cm were estimated at 51 Mg ha^{-1}, ranging from 63 Mg ha^{-1} in Central America to 48 Mg ha^{-1} in South America [6].

Many sustainable agriculture management practices could be adopted across the Americas, increasing the ability to emit less and sink more C from the atmosphere. A range of practices such as no-tillage, cover cropping, organic amendments, pasture restoration via integrated systems like silvopastoral and crop–livestock–forest models, and forest restoration exemplify sustainable land management approaches.

Recently, Lal et al. [6] performed an exploratory estimative of the potential soil C storage induced by adopting conservation agriculture in 50% of the continent's area and pasture reclamation in 40% of the continent's area. The results showed that both practices have the potential to accumulate 2.68 Pg C (1.25–4.11 Pg C) over 20 years. The C removals have the potential to offset 7.9% (3.7–12.2%) of the total annual global GHG emissions from agriculture and 4.1% (1.9–6.3%) of global GHG emissions from AFOLU [6].

Metrics (typically developed elsewhere with different climates and geography) fall short of documenting the positive externalities that the production in this area can provide. The underreporting of positive externalities in existing metrics, including gains in biodiversity, GHG emissions reduction, water conservation, and biomass circularity, poses a significant challenge to the formulation of adequate public policies and market-driven mechanisms that incentivize ESG principles, a prerequisite for achieving the sustainable development goals (SDGs) and fulfilling our climate commitments [7][1].

This paper summarizes established knowledge on soil C sequestration in agricultural lands and its potential role in carbon neutrality. It aims to provide accessible information on nature-based solutions (NBS) and contribute to SDG goals 13 (Actions Against Climate Change), SDG 2 (Sustainable Agriculture), SDG 12 (Responsible Production), SDG 15 (Preservation of Life on Land), SDG 16 (Justice and Effective Institutions), and SDG 17 (Partnerships and Means of Implementation).

2. Methodology

This paper is a literature review, bringing together information from primary and secondary sources that the same authors of this paper prepared in many other technical documents and reports over the last 5 years. As such, it consists of a collection of established knowledge in the particular field of soil C sequestration in agricultural lands (soil, pasture, and crops) and its role in carbon neutrality as strategies that can be applied on large scales in Latin America, where the agriculture production is one of the main causes of national emissions of green gases to the atmosphere.

Furthermore, it identifies that the techniques available and technologies are at potentially low cost, being beneficial to farmers and, at the same time, contributing toward the goals set in the Paris Agreement. It intends to contain technical information about NBS in an easy and accessible format to readers from outside the area of soil C sequestration.

[1]Acordo de Paris. https://brasil.un.org/sites/default/files/2020-08/Acordo-de-Paris.pdf

3. Nature-Based Solutions

NBS are production practices to promote nature as a means of providing solutions to climate change (mitigation, adaptation and resilience), increase air quality, recover biodiversity, use less water, and promote food security and health, social, and economic justice [8]. The European Commission defines as cost-effective solutions those that simultaneously provide environmental, social, and economic benefits and help build resilience, bringing: "more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions" [9]. NBS is also known as a way to realize socially inclusive green growth because of its ability to simultaneously deliver multiple benefits to sustainability goals, such as biodiversity, climate change mitigation, adaptation, and social well-being [10].

The International Union for Conservation of Nature (IUCN) defines NBS as "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human wellbeing and biodiversity benefits" (IUCN, 2016) and recommends it is used as an umbrella concept covering a whole range of ecosystem-related approaches as shown in Figure 1 [11] all of which address societal challenges.

The nature-based concepts are complementary to others, such as the Circular Economy and Bioeconomy. The Circular Economy is a model of production and consumption designed to produce zero waste. This involves sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products for as long as possible. The bioeconomy encompasses all sectors that produce, use, process, distribute or consume bio-based resources, or take advantage of ecosystem services as shown in Figure 2 [12].

By definition, in the European Union's strategy, the bioeconomy (Figure 2) includes all sectors of the economy that are based on the use of renewable biological resources to produce value-added products such as food, feed, energy, and fibers [13]. In the following figure based on the Global Bioeconomy Summit, there is a summary of the many areas that are related to building this new type of economy:

Bioeconomy can use technology to increase the circularity of resources and improve the sustainability of production. This type of economy strives to achieve the SDGs by providing sustainable economic growth, which enhances human well-being and social equity while reducing resource consumption and regenerating ecosystems. Responsible businesses play an essential role in developing science and technology and deploying it ethically, unlocking the potential of escalating production, zeroing waste, and curbing emissions.

The realisation of this new economic paradigm depends on public policies and incentives, but also on financial mechanisms and private commitments by companies to human rights principles [14], carbon neutrality, transparent accountability mechanisms and monitoring, reporting and verification protocols that are accurate and specific to the reality of tropical agriculture. Accordingly, many studies are being developed to create knowledge about the specificities of Latin America to increase the potential of the economic mechanisms and the private commitments to work as nudges helping the economy shift toward the implementation of NBS and a circular and sustainable bioeconomy.

4. Carbon Farming

A key point to this new economic paradigm is to develop effective and viable ways to sequestrate C. Sustainable farming is

Figure 1
Categories of nature-based solutions

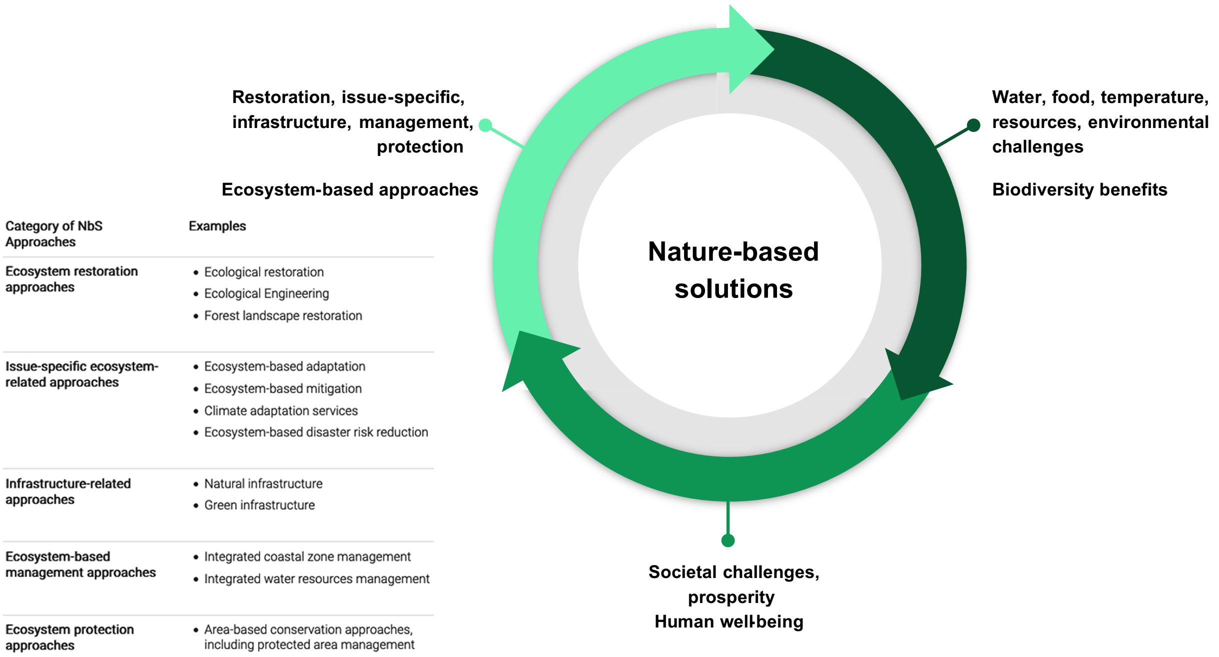
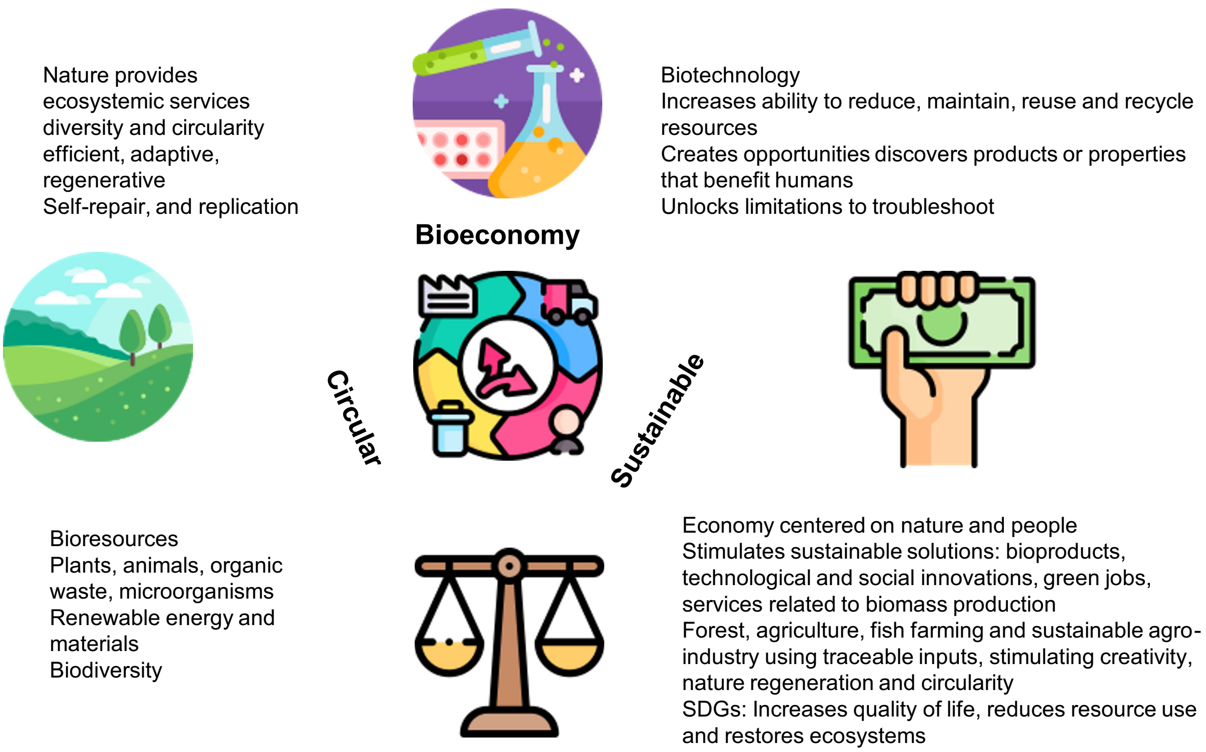


Figure 2
Bioeconomy steps and components



one of the best options available to that. This was the conclusion of the report that the Inter-American Institute for Cooperation on Agriculture created under the initiative Living Soils in the Americas [15], which is an extensive network involving governments, international organizations, universities, the private sector, and civil society organizations to join efforts against land degradation promoting soil health, C sequestration, and other associated benefits to people and the environment.

Limiting global warming to acceptable levels is not necessary to reduce GHG emissions but also to increase C removal from the atmosphere. While GHG emission reduction can be achieved by multiple sectors (energy, industry, agriculture, etc.), C removals are predominantly done by NBS, including agriculture and forests [16]. In this context, Amelung et al. [17] estimated that soil C represents about one-fourth of NBS potential for C sequestration.

No matter if more simplified or detailed, the "gold" principles to assess if a sustainable management practice is efficient in achieving soil sequestration are: (1) does it provides abundant and continuous C inputs into the soil that leads to an increase in C stocks, and at the same time (2) does it reduce GHG emissions that were coming from the soil, therefore reducing the C losses? These questions are important because not all the CO2 removed from the atmosphere by plants remains stored in the plant's biomass or in the soil for much time. Most of it, around 60–90% of the C that was incorporated as organic components, returns to the atmosphere when plants die or are harvested, and the rest of the biomass emits through the decomposition process [6].

Notwithstanding, characteristics like too much rain and high temperature can accelerate this decomposition rate. This leads to some regional climate-specific differences, for example, North America showed the highest soil C stocks, 28.07 Pg, compared to different regions in the world. By contrast, areas such as Central America have meager amounts of stored soil C, 1.22 Pg, besides the high C stock per hectare [6]. On the other hand, South America has relatively large cropland and tropical weather, which possibly explains why this region shows only a moderate amount of soil C stocks, that is, around 9.42 Pg C [6]. Therefore, there is a significant potential for soil C accumulation in the Americas by increasing sustainable soil management (SSM) practices.

Four scenarios are particularly relevant to implementing these SSM: (1) in places where soil C stocks have reached equilibrium, there is the possibility to increase C levels through SSM; (2) where the soil C stocks are increasing slowly and could increase much more if SSM were adopted; (3) where soil C stocks shows signs of declining, and it is possible to stop or mitigate C losses with SSM; and (4) where soil C stocks are declining, but reversing this fall is possible through SSM [18].

For each of these four scenarios, one mix of technologies and practices is needed to achieve agricultural systems that are more sustainable and can play an essential role in tackling climate change. Some of the possibilities are summarized here.

5. Agriculture

The main element linked to soil processes that underlie the provision of ecosystem services is the soil organic carbon (SOC). "Soils are the most complex and diverse ecosystem in the world" [19], and the main driver behind SOC loss in the conversion from natural ecosystems to agroecosystems is the radical decrease in the plant (and fauna, as a consequence) biodiversity and organic matter input, both in total mass and in material diversity [19]. The loss of biodiversity and the reduction of the information above ground is reflected below ground, with a disruption of the soil food web and a significant contraction of the biomass of soil fauna. As soil organisms are responsible for maintaining the multifunctionality of soils underpinning the provision of soil-related ecosystem services, their loss compromises the whole system. The attempt to simplify a strategy to maximize the condition of one ecosystem service (i.e., food, fiber, and fuel production) thus leads to a cascade of losses in providing other services. This culminates in a greater dependence on external inputs, creates unintended consequences (e.g., soil compaction, erosion, higher soil pest populations), and may, in the long run, reduce even the one service the system was designed to maximize (i.e., crop yields) [6].

Fortunately, there are these SSM that are management strategies to deter, mitigate, and reverse SOC stock depletion and the loss of soil multifunctionality in agroecosystems, such as organic fertilization, biological control, integrated systems, no-tillage, and plant diversification. No-tillage and plant diversification will be detailed next.

- Among management practices for enhancing SOC in agriculture, no-tillage stands out as a leading option, extensively studied and documented. Beyond its well-established benefits like erosion control, soil water conservation, and maintaining soil fertility through reduced fertilizer dependence, no-tillage's SOC-accumulation potential has emerged as a valuable ecosystem service. This characteristic has garnered global recognition as a GHG mitigation strategy, prompting its inclusion in several countries' NDCs.

Recent studies by Maia et al. [18] collecting data from different biomes confirm this positive effect, although some critics such as that SOC accumulation is limited to the most superficial layers of the soil (0–30 cm) and that the benefits disappear when deeper layers are considered [20], as well as the doubt about the ability of this SSM management system to effectively contribute to mitigating global changes [21]. The empirical data show that in Latin America, specifically Brazil, introducing no-tillage where conventional agriculture and pasture are in place increased SOC varying between 9% and 25% [18].

Important to mention that land use change from native vegetation to no-tillage decreased SOC stocks by between 4% and 8% in the 0–30 cm layer after 20 years of land use in various regions of Brazil. But the rate is lower than it would be if the conversion were to conventional tillage. Therefore, no-tillage is an option only for areas with pastures and traditional agriculture.

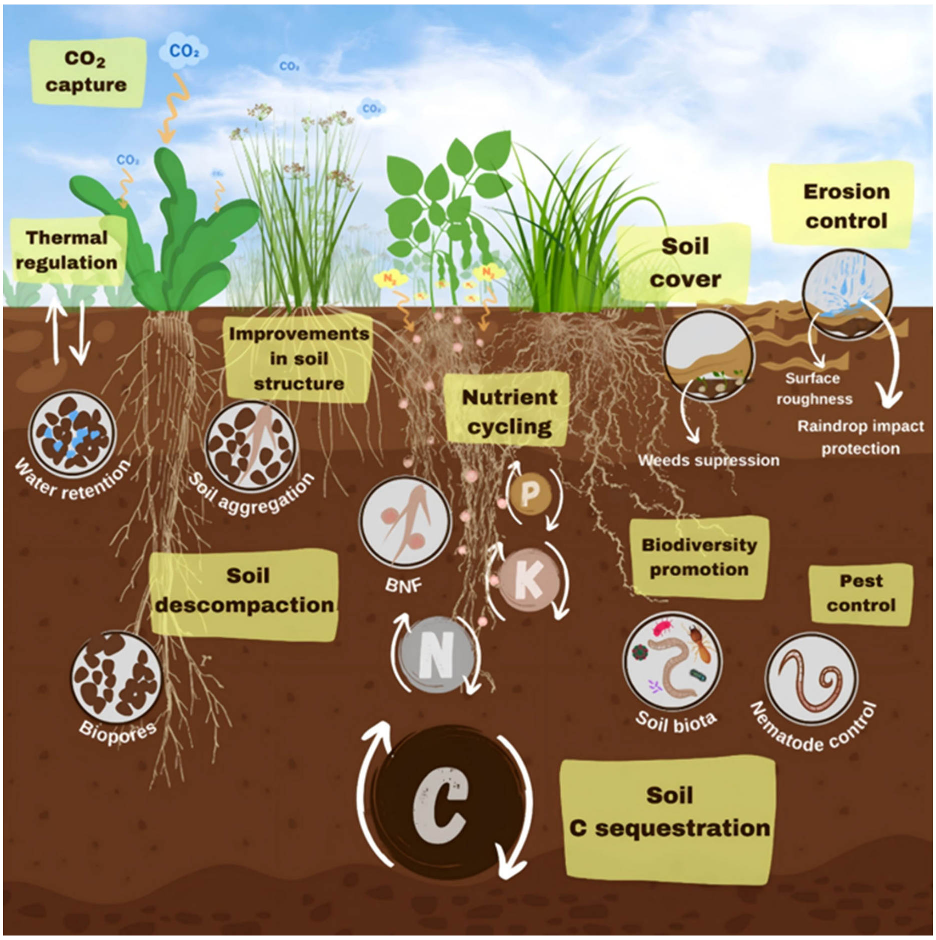
The data show that maintaining natural ecosystems should be a priority to avoid possible SOC losses with consequent GHG emissions to the atmosphere. On the other hand, adopting no-tillage in areas previously managed by conventional tillage systems and pastures can be an alternative for promoting C sequestration in agricultural soils (superficial and deeper layers) in the various regions that were studied [18].

With no-tillage, another important technique is using cover crops as catalyzers of soil C sequestration and crop yields. Plant diversification focuses on reversing the loss of soil multifunctionality in agroecosystems by adding functional biodiversity through selected plants to restore the complex biotic interactions responsible for delivering all soil-related ecosystem services. One strategy to implement this is through the incorporation of cover crops [22].

Cover crops have been used in agroecosystems for millennia due to their cultivation's multiple benefits to soil health (Figure 3), crop yields, and the environment. Cover crops are multifunctional and directly or indirectly support the supply of several soil-related ecosystem services such as nutrient cycling and provision, water filtering and flow regulation, climate regulation, erosion control, and soil biodiversity [23–25]. Many such benefits are related to the capacity cover crops have for increasing SOC stocks in agroecosystems [22].

In tropical climates, cover cropping can increase SOC by 7.2% on average, as shown in a recent global meta-analysis published by Jian et al. [26]. Nevertheless, many challenges regarding cover cropping are still posed to Latin American researchers, consultants, and farmers. The scarcity of organized data on SOC and nutrient inputs by climate and plant species and ecological

Figure 3
The multiple benefits delivered by cover crops in agricultural systems



functionality limits the ability of researchers to design more accurate use recommendations. One of few studies that synthesized the effects of cover crops was performed in the Argentine Pampa and revealed that soil C content of the 0–20 cm layer rose ca. 4% in fine-textured soils and 9% in coarser ones [23].

The need for more information regarding cover crops adoption by farmers in Latin America is another challenge that researchers and consultants face when modeling distinct predictive scenarios, from climate mitigation by on-mass adoption of cover cropping to market opportunities generated by their use. Furthermore, using cover crop mixes adds yet another layer of complexity to the questions that remain open for investigation.

The integration of cover crops into Latin American production systems is an opportunity worth investing in to increase soil C inputs and stocks, reverse the losses of soil multifunctionality, and promote the sustainability of the systems. We can increase the probability of successfully integrating cover cropping as a standard management practice in Latin American farms by finding answers to the open research questions.

About pasture, Latin American economies are highly dependent on animal production. However, there are different natural conditions, forage resources, cattle species, and management types in place from Mexico to Argentina. The region's carrying capacity could be significantly increased by recovering degraded soil, intensifying production, and integrating pasture with crops and forest.

However, the region has a vast area of low productivity and poorly managed pasture. Estimates show that, in Brazil, for example, the productivity of the fields increased from the current 32–34%, only a little to 49–52% of its potential; the effect would be very significative. This small change would free pastureland enough to meet all the food and biofuel demands until 2040 without the need for any native vegetation areas to be converted into agriculture [27]. And the most effective and promising strategies to promote pasture intensification in Brazil are: (1) implementing integrated agricultural systems, for example, mixing crop with livestock, or livestock with forest, or even the three together crop, livestock, and forest; another very recommended technique is the direct recovery and replanting of the grasses [22].

This agroforestry or silvopastoral system (SPS) is a deliberate combination of trees, pastures, and livestock that allows a mixture of different quantities of these three components depending on the features of the ecosystem to be managed. And these multipurpose systems can represent more effective cost–benefit opportunities and can also meet multiple goals [28], like increasing biodiversity, preserving water resources, cooling temperatures in the pasture, and improving the rural landscape. Agroforestry provides many ecological services to prevent climate change and thrills under tropical weather; therefore, it should be mainstreamed in Latin America.

In Caquetá, Colombia, a recent study showed that the low-productivity pastures (all in the Amazon region) increased SOC stocks, by 0.26 Mg ha^{-1} yr^{-1}, mainly in the 20–30 cm layer, after the implementation of SPS. These findings are important because they show that SPS could be a promising alternative to restore pastures and turn the soil into a significant C sink in tropical regions, mainly in deeper layers [29]. In Brazil, a recent meta-analysis confirmed these findings as well. According to the study, the recovery of degraded pastures, or even a slight improvement in the management of low-productivity areas, can increase the level of livestock productivity considerably [30], by reducing the C emissions and promoting SOC sequestration [30].

Pastures receive the following denomination: (1) degraded; (2) nominal, the non-degraded grassland that shows no significant management improvements; or (3) improved. This taxonomy was proposed by the IPCC [31]. Using these terms, empirical studies in Brazil compare native vegetation, degraded, nominal pasture, and improved pasture and conclude that for a 30 years period, at a depth of 0–30 cm, SOC stocks increased up to 15%, while degraded pastures reduced the stocks by 10%. Nevertheless, if degraded pastures are recovered, they enhance the SOC by up to 23%, which in some cases can be sufficient to compensate for the losses caused by degradation and result in a net gain in SOC stocks [30]. Therefore, this is a reinforcing reason to justify that recovering degraded soils should be the priority in public policies in Figure 5 [32].

Long-term use of poorly managed pastures induces a cascade of soil degradation: acidification reduces nutrient availability, carbon stocks decline, compaction compromises porosity, aeration, and water conductivity, increasing mechanical resistance to root growth, and diminishing soil macrofauna diversity, microbial biomass, and enzymatic activity.

Some cultures are being used successfully to recover degraded pasture soils, for example, the sugarcane in central southern Brazil (Figure 4) [32].

Recovering degraded pastures with sugarcane, for example, is then feasible in most wet tropical countries of Latin America, and it can be used not only to produce sugar, as it has been since colonial times, but also to produce renewable energy like ethanol and bioelectricity, and its molecules can be used in bioindustries like the ones producing biodegradable plastics [32]. The increase in SOC and renewable fuel production is then a double positive to combat climate change, reduce fossil fuel imports, increase air quality (ethanol is less harmful than gasoline), achieve other environmental benefits, stimulate local agroindustry jobs, and generate income.

About forestry, stopping deforestation and stimulating forest restoration are central strategies in the Latin American effort to mitigate climate change. International initiatives to restore forests have been promoted around the world; a relevant example is the Boon Challenge that is involving 61 countries (29 located in the Americas) and aims to bring 350 Mha of degraded and deforested landscapes into restoration by 2030 [33]. Another more recent example is the United Nations Decade on Ecosystem Restoration (2021–2030) which has established the target for member states to

Figure 4
Changes in soil health index and soil-related ecosystem services in Brazil's land transition native vegetation–pasture–sugarcane

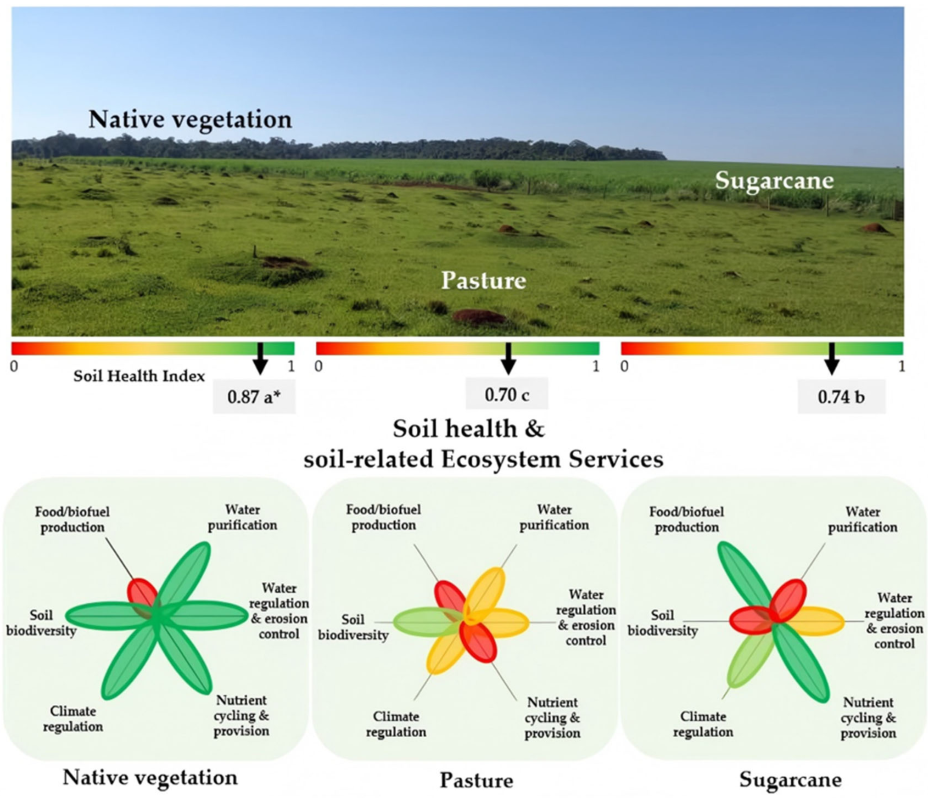
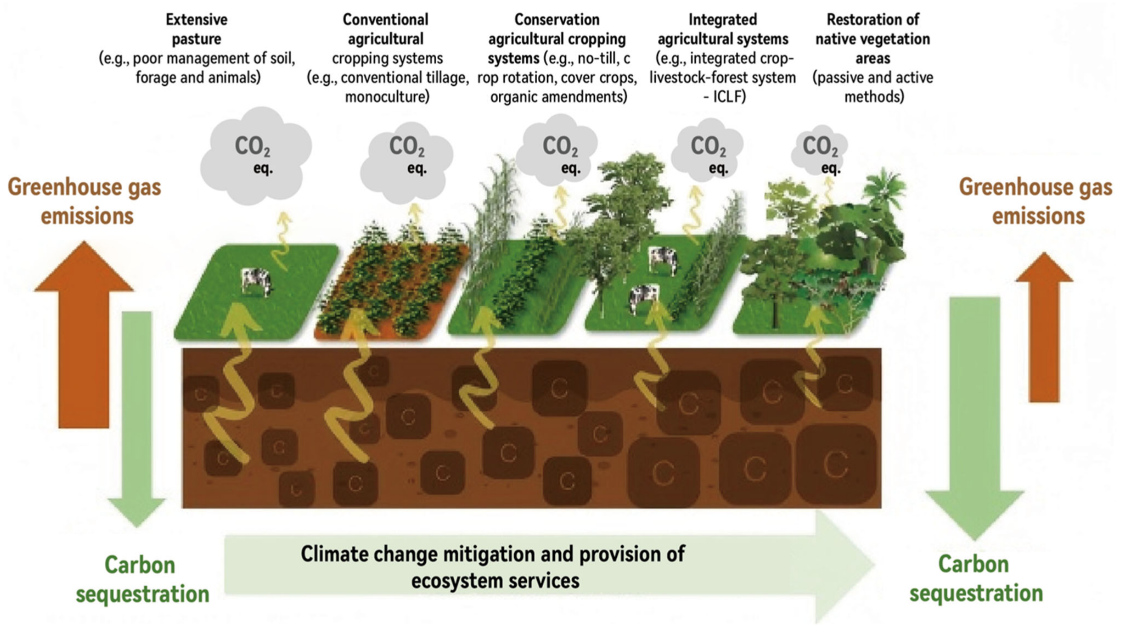


Figure 5
Pathways for a climate-smart intensification and diversification of production systems in Latin America



build collectively a broad-based movement global to ramp up forest restoration around the world [34].

However, it is an important finding that forests cannot be restored predominantly with plantations of commercial trees. Those types of plants are much less effective at storing C than natural forests [35]. This means that native tree plantations, maintaining biodiversity, not monoculture, is also an effective way to accumulate soil C. However, there is a price problem with this alternative, compared with the option of simply waiting for the natural regrowth of the native forest. Native tree plantation costs around US$2,788 ha/year, while natural forest regrowth costs only US$1,250; this difference in implementation costs can make them less competitive for C farming [36].

Second-growth forests (which have re-grown after a timber harvest or clearing for agriculture) also can contribute; they have high rates of C accumulation in aboveground biomass and take 66–80 years to reach the biomass stocks comparable to old-growth forests. However, restoring large areas of tropical forests requires not only political will to fight the causes behind it but also agronomical knowledge specific enough to indicate which restoration approach provides the best returns on investment, having in mind the accumulation of C and other expected benefits, for example, the reduction of the risk of extinction, the better quality of the water supplies, and an increase in the food security [36].

Efforts must be made to stop illegal deforestation and promote cooperation and coordination among local governments, financial partners of the private sector, and the organizations and institutions providing expertise and research that support the implementation of restoration and conservation across the region. One example is the Initiative 20 × 20, a country-led effort in Latin America, where the most ecologically valuable forests in the world are, but that already has 20% of its forest lands (nearly 350 million ha) completely deforested and a further 20% (300 million ha) badly degraded. The scope of Initiative 20 × 20 thus is to protect and restore 50 million hectares (roughly the size of Paraguay and Nicaragua combined) of forests, farms, pasture, and other landscapes by 2030 [37].

Besides that, utilizing a novel multicriteria optimization model encompassing global terrestrial biomes, climate change, and biome-specific costs, recent research pinpoints Latin America as a near-unanimous priority area for maximizing restoration outcomes, including biodiversity conservation and climate mitigation.

Among the causes of deforestation is the conversion of native forests for producing commodities, forestry, and shifting agriculture, as reported by Statista [38]. Therefore, commodities like soy, beef, palm oil, and cereals, as well as commercial tree planting, have had a direct impact on land use change and the environmental and social policies resulting in large-scale deforestation, among other environmental consequences, in favor of the expansion of monocultures [39]. Notwithstanding, the growth in the deforested area is related to international demand for commodities. Most importers are countries with decreasing deforestation rates or increasing forest cover [39], characterizing an environmental damage export.

Another critical point to be discussed is that, despite the general association of commodities production with deforestation, in most places in Latin America, and mainly in Brazil, the expansion of agricultural frontiers occurs far from the native forests such as the Amazon [40]. The portion of the production that is responsible for deforestation corresponds to a small group of rural properties and municipalities [38]. But the issue affects grain and meat producers generally [40]. It has inspired public regulation like the European [41] and the creation of multistakeholder initiatives to track production, such as Imaflora's Timberflow[2], using a uniform framework for verification and auditing deforestation/conversion-free beef supply chain.

Above all, monitoring more properties would be essential to a zero-deforestation cattle supply chain. While this does not eliminate illegalities and misleading initiatives, it could signal an effort to decouple livestock production from deforestation. Once it is highly concentrated in a few municipalities, this facilitates the application of targeted enforcement policies [39].

[2]IMAFLORA: Timberflow. https://timberflow.org.br/

6. NBS and Market-Driven Mechanisms

Summarizing the topic before, the more diverse and integrated agriculture with forestry and pasture, the greater the possibilities to increase the provision of ecosystem services, among which is the ability of the living soil and plants to sink C from the atmosphere back into the ground. Another point is that the high amount of depleted soil needs to be recovered and the native vegetation restored to reduce emissions and to increase other ecosystem services that are fundamental to Latin America's mitigation, adaptation, and resilience to climate change.

This strategy of ecosystem-based adaptation harnesses the increase in biodiversity and the indirect benefits of more ecosystem services that conservation, sustainable management, and restoration bring and are one of the most cost-effective to adapt and build the resilience of human communities and societies to the impacts of climate change [42]. Integrated agricultural systems and restored areas of native vegetation under SSM can secure productivity, increase soil C sequestration, increase food and energy production (Figure 7), as well as protect water resources and fisheries; promote human health and well-being; strengthen people's livelihoods, build more equitable societies; rebuild and strengthen nature, and on top of all that reduce climate risks. Therefore, adopting NBS is essential to cool our planet and sustain vital resources and living conditions [43].

Natural restoration, pasture restoration, and the adoption of conservation agriculture practices bring many opportunities to Latin America far beyond the environmental gains. Green jobs, quality of life, technology, efficiency, and access to markets demand quality products.

NBS investments can often benefit multiple sectors and communities simultaneously. For example, a project that restores not only reduces the risks of climate change's negative consequences, such as desertification, but also can improve the quality of the resources, increase food security, and provide habitat for many species, on top of sequestering C. In addition, restoring and sustainably managing natural resources can create jobs and improve livelihoods for local communities.

Another topic is that NBS is independently implementable and can be integrated into traditional "built" infrastructure systems, often called green–grey infrastructure. Green–grey infrastructure is a kind of NBS that is built to preserve, enhance, or restore elements of a natural system, and doing so delivers infrastructure services that will be more precise, resilient, regenerative, and sometimes even cost less [44].

Therefore, unlocking investment in NBS is critical to accelerating progress. It widens the options and enhances the appeal and feasibility of NBS for governments and infrastructure service providers. Widespread infrastructure investment creates ample opportunity for scaling NBS. Between 2008 and 2017, LAC poured about US$125 billion per year into infrastructure, or roughly 2.8% of regional gross domestic product (GDP) per year. This amount corresponds to what the entire world spends annually on biodiversity conservation, so routing even a tiny share of LAC infrastructure spending to NBS would represent a significant new funding source for sustainable development [45].

Nature-based enterprises can attract ESG finance and generate new jobs, innovations, skills, and broader economic impacts. They can contribute to the region's sustainable development and achievement of the SDGs. So, supporting start-ups of this type and scaling up the existing ones must be a strategy to increase environmental and societal impact and investment.

Market-driven mechanisms to promote support for the SDGs. The climate emergency is in code red [5], then it demands that the economy moves toward a paradigm that puts nature and people at its heart, not only profit [46], policies need to align with climate goals and other international commitments regarding nature, including through incentive structures, and fiscal and budgetary policies; and more holistic objectives are used to measure progress, beyond economic growth/GDP [47]. A nature-positive economy is required to coordinate businesses, governments, and others to take action at scale "to reduce and remove the drivers and pressures fueling the degradation of nature, and work to actively improve the state of nature and the ecosystem services it provides"[3].

- Non-binding legal norms from discerning consumer markets and regional frameworks like the EU [48, 49] are influencing corporate behavior beyond compliance. For companies seeking global market access, these foreign rules become de facto standards, shaping responsible business practices in a transnational legal landscape.

Another drive of change is the possibility of gaining from sustainability, attracting investors that have assumed ESG commitments, or creating tradable value through green bonds or the various C markets (regulated and voluntary) emerging around the world [50]. A C offset is a reduction in emissions of CO2 or other GHG made to compensate for emissions caused elsewhere. It can be a way to attract investment to sustainable alternatives, increasing its competitiveness and also increasing the broader adoption of better alternatives to the environment.

Creating a C project nowadays is not a trivial process. It is still very expensive to create the inventory and implement the governance practices. But in the future can become a commercial initiative that receives private or public funding because it will result in fewer emissions than it would emit in the business-as-usual context. It is essential to these projects the definition of baseline from which they will mitigate. The number of C credits the project receives is calculated by subtracting the project emissions from the baseline emissions.

And to these projects to be recognized, create credits, become tradable, and receive money, they have to follow a methodology developed by a standard setter. The two more accepted methodologies are from the standard setters, the Gold Standard and VERRA. This last is the one that has more alternatives (7 types of protocols) to agriculture projects. The protocols following the consistent methodologies are to prove the project is improving or adopting sustainable agriculture, quantifying SOC, and N2O emissions, improving, and adopting sustainable pastures, for example. In 2021, the independent mechanisms that covered agriculture credits were Verified Carbon Standard (VERRA), Gold Standard, American Carbon Registry, Climate Action Reserve, and Plan Vivo, as shown in Table 1 [50].

Some domestic mechanisms also accept agriculture projects: Alberta Emission Offset System, Australia Emission Reduction Fund, California Compliance Offset Program, Kazakhstan Crediting Mechanism, and the Thailand Voluntary Emission Reduction Program. The Brazilian regulated C market that is being created[4] will also accept this type of project. Besides the regulated and voluntary market, other public policies can set prices to C.

The Brazilian Renewable Energy policy, for example, creates the possibility of this type of offset. It first creates a mandate to

[3]Cambridge Institute for Sustainability Leadership: The case for nature positive action. https://www.cisl.cam.ac.uk/resources/nature-positive

[4]D11075/22 – Decreto que lança as bases para a criação do mercado regulado no Brasil. http://www.planalto.gov.br/ccivil_03/_ato2019-2022/2022/decreto/D11075.htm

Table 1
Independent mechanisms that cover agriculture

Name of the mechanism	Total of credits issued in 2021 (MtCO2e)	Registered activities	Average price (USD)
Verified Carbon Standard	295.1	110	4.2
Gold Standard	43.8	51	3.9
American Carbon Registry	8.8	18	11.4
Climate Action Reserve	4.8	44	2.1
Plan Vivo	0.01	1	11,6

fossil fuel distributors to buy the correspondent amount of Decarbonization Credits (CBIO), issued by biofuels producers and importers and duly certified by the National Petroleum Agency (ANP). The amount of decarbonization that renewable energy offers to compensate for the correspondent emissions of the fossil fuel distributed is calculated based on a broad inventory of the renewables purchase and sale invoices, their transportation, and the calculation from the cradle to the grave of the production methods. This is all automatically made by a calculator developed by Embrapa called Renovacalc [51].

Each CBIO is equivalent to 1 ton of CO2 emission avoided; it does not expire and can only be withdrawn from circulation once when its abatement is used to offset someone else's emissions and therefore, its retirement is requested. Each year, by law, fuel distributors should request the retirement of CBIOs held by them in an amount equivalent to the decarbonization targets set for them by the Energy Agency (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis).

CBIOs can be bought voluntarily as well, creating a type of C market that can be used by companies committed to offsetting their emissions. But the voluntary use of the CBIO is very small so far compared to the mandatory. For example, in 09/09/2022, there were 4.590.661 renewables producers or importers that created CBIOs, 21.750.579 were bought by fuel distributors that are due by law to buy and retire CBIOs, and only 72.155 were held by not obligated investors, individuals, and non-resident.

Furthermore, some projects can become a sort of C farming, becoming net negative in their emissions, therefore promoting C sequestration instead of only reducing their emissions. Agriculture and forestry, especially in integrated production systems, can do that. The atmospheric CO2 is taken up by the crops, trees, pastures, and other organisms through photosynthesis and then is stored as C in biomass (trunks, branches, foliage, and roots) and soils. This type of C sink helps to offset sources of CO2 in the atmosphere, such as fossil fuel emissions, but is rarely taken into account due to the challenges of calculating their impact [52].

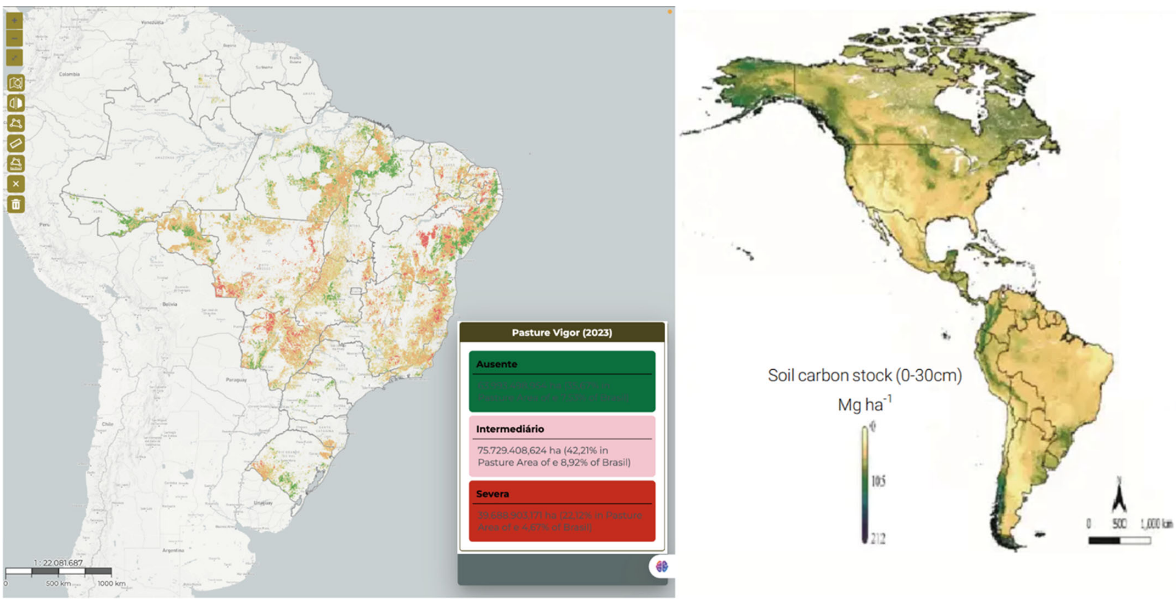
Exceptions made to degraded areas and where there had been forest fires. These, when regenerated with grass, crops and planted forestry, are easier to establish the baseline and therefore calculate the potential C sequestration. And there is a considerable amount of territory in this situation. The red dots on the following map show Figure 6 [53] the degraded areas in Brazil.

If only these severely degraded areas would be recovered with sustainable practices and integrated agricultural systems, the potential of increasing the C stock in soil and vegetation would be already very significant. This transition toward ever-green agriculture that is regenerative will not happen without economic incentives. Therefore, repurposing the multi-billion agricultural support to transform agricultural systems needs to start reflecting this new objective that goes beyond food security.

The current agriculture incentives (USD 540 billion a year) are "biased towards measures that are harmful and unsustainable for nature, climate, nutrition and health while disadvantaging women and smallholder farmers in the sector" [54]. Repurposing them to promote NBS has the potential to address multiple challenges.

Agriculture is the ultimate source of our fibers, food, and feed. Has a critical role to play in ending poverty (SDG1), ensuring food security and improving nutrition (SDG2). It can become the major

Figure 6
Pasture quality and soil carbon stock



source of fuel as well, providing the renewables necessary to phase out the fossil fuel dependence (SDG7). There are millions of farmers, many of whom are women (SDG5), smallholders, and agriculture is their primary source of livelihood (SDG1). It drives economic activity broadly throughout vast agroindustrial systems that include production, differentiation, aggregation, processing, industrialization, distribution, retail, and consumption (SDG12).

Agriculture, partnerships with other players in the supply chain and coherent policymaking (SDG 17), can result in significant means of implementation, many benefits for the sector (including economic), and also for the environment and human health. By mandating evidence on the potential positive impacts on the environment and society, creating market mechanisms, and eliminating harmful agricultural support, this worldwide multi-billion tool can mark a profound watershed for sustainable development, justice, and effective institutions (SDG16).

On top of all these positive effects on other SDGs, the sustainable techniques of regenerative agriculture can increase the C sequestration to such a point that C farming becomes feasible. And if applied in a massive scale can become a practical and inexpensive way to sink the C that is already emitted (SDG 13), beefing up actions against climate change.

7. Challenges

There is no one-size-fits-all SDG solution, the transition to the circular and sustainable economy paradigm as well as an optimal repurposing strategy will depend on many factors, partnerships, and country context. Designing more market-driven mechanisms to speed up the transition to the new economic paradigm would be excellent, but there are many challenges.

One is the lack of regional consistency for C credit integrity. In a recent review of 12 MRV protocols [52], the authors studied only publicly available initiatives that are about soil C, which are accepted by three major registries, comparing them with the other two accrediting organizations. This study points out that essential differences exist among the possibilities of measurement and the techniques to estimate soil C and the net GHG reductions.

Another highlight was that there are also many key accounting issues to report additionality and permanence [52]. Although the protocols reviewed focused only on one area: quantifying and verifying fundamental, net changes in GHGs associated with soils are still tricky because credits generated from the atmospheric drawdown of C with CO2 sequestration in the soil face challenges. For example, how to measure the effect of management changes in arable systems (reduced emissions from avoided land conversion or nitrogen management were not considered) and measuring changes in soil C in these cases remains a challenge.

Setting criteria to define a high-quality soil C credit regionally could help scale up the possibilities of reducing the costs and benefiting small and medium farmers (that nowadays are blocked out of the market due to high prices and complexities that the C inventory represents). As a result, there would be more registries, project developers, and credit buyers, and it would increase the quality, ensuring that lower standards are not rewarded within the market place.

SSM changes can take longer to show results in SOC. They may not be detectable with sufficient confidence with the currently available technologies for over an annual to a decade time period, given the slow rate of accrual and the considerable spatial variation of SOC. Besides, there are other GHGs like nitrous oxide and methane that normally accompany changes in cropland management that need to be taken into consideration. Notwithstanding, there is the test for (1) additionality, which shows the emission reductions exceed those that would have happened without the SSM in the project that will justify the credit, (2) non-leakage, the emission-reducing SSM under the program does not cause increased unaccounted emissions elsewhere, (3) non-reversals, the protection against subsequent losses due to changing patterns or unforeseen climate impacts such as flood or drought, and (4) permanence, the long maintenance of the C that was sunk in the soil over a specified time frame, often defined as 100 years [52].

Complicating further, each protocol has varying thresholds regarding these criteria. For example, some of these require that management-induced changes in SOC are new and have not been already in place in at least 50% of the property in the case of the Soil Enrichment Protocol by the Climate Action Reserve, in less than 20% for Verra's protocol, and under 5% for GoldStandard's SOC Framework [52]. Other less stringent protocols allow for "look-back" periods, which means that farmers adopting them can earn credits for practices adopted up to, for example, 10 years before the implementation of the project. It is a significant difference in the methodology that would better be harmonized to reduce information asymmetries and transaction costs.

These asymmetries in accounting measures can affect many environmental policies, not just the carbon market, and risk undermining the ability to put a price on externalities or to put an economic value on the climate benefits of actions. Published protocols try to address these issues but fall short of showing more consistency and to adopting an approach that would transfer data needs, such as baseline, additionality, C leakage calculations, and measures to prevent double-counting from registries and project developers to the regional agents. Advances in these accounting techniques could potentially save transaction costs and potentially allow a greater amount of revenue could be transferred to producers that are the ones investing the most to implement sustainable practices. A pre-designed and data-driven regional framework could address structural inconsistencies among current protocols and facilitate the design of new projects.

For example, the general characteristics of the soil in the region could as well be harmonized. So, less effort would be spent in inventorying each project's areas. And most protocols allow for the aggregation of field or farm-based projects, a region approach would only add to this. Under a regionally consistent framework, "the regional unit could be a biophysically defined agroecological zone that has similar soils, climate, and agricultural potential or constraints" ([52], p. 5), increasing consistency.

Above all, underinvestment is a problem for any sustainable technology and practice, particularly for NBS. The State of Finance for Nature report [55] estimates that "current investment in NBS globally is approximately $133 billion annually." However, three times that amount are needed by 2030 and four by 2050 to meet climate change, biodiversity, and land degradation targets. This is mismatching the urgency as shown by the World Economic Forum [56], which quantifies that "over half of the global GDP, $44 trillion, is potentially threatened by nature loss while the transition to a nature-positive economy could create 395 million jobs by 2030".

To complement this grim scenario, fake controversies have influenced the implementation of NBS for decades, resulting in significant setbacks worldwide [57]. These are just some of the challenges that show that it is not easy to have a sustainable circular bioeconomy in Latin American countries. Still, it is possible, and scientists, police-marker, market stakeholders, and civil society should put this agenda on the top of priorities for the next decade.

8. Conclusion

If applied in the Americas, sustainable management practices will promote the SDGs and, at the same time, reduce climate change risks.

Therefore, new protocols for promoting soil health and soil C sequestration through curbing land degradation in the Americas can increase productivity, reduce environmental depletion, and create sustainable income for local businesses. Many are opportunities for Latin America to gain from NBS, but to achieve that, policies and markets need to be redesigned to place nature and people at the center of the economy. Organizations also need to transform themselves and commit to ESG so that business plays a transformative role in the economic transition. Banks and asset management recognize environmental and social risks to the company they finance, demand disclosure of ESG data, and finance only nature-positive projects to accelerate the transformation.

Latin American countries can be protagonists in the climate agenda. Still, indeed, more empirical research is needed to increase the knowledge of the particularities of the region and, at the same time, create MRV protocols that can improve the regional consistency of data that are necessary for C credit integrity, and in doing so unlock new forms of NBS financing. Implementing improved agricultural practices through a regional lens holds potential for widespread adoption and enhanced market participation, benefiting a diverse range of farm operations.

9. Scope for Future Works

The authors are working on a 5-year project to study case the empirical data from Brazil's six different biomes with distinct characteristics: Amazonia, Caatinga, Cerrado, Atlantic Forest, Pampa, and Pantanal.

Much more information is needed to inform policies to foster the NBS in the region. In this paper, there is no information about which country has a worse situation and which is better in Latin America. Some of the reports cited as references bring agronomic studies focused on these differences that have to be continuously studied.

Despite many unknown characteristics, it seems clear that at least to Brazil, with its continental proportions, and whose national emissions from land use and land use change, NBS should be the focus of public policies and corporate practices to find a new competitive, responsible, and inclusive low-carbon circular bioeconomy.

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Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

The data that support the finds of this study are openly available in Food and Agriculture Organisation of the United Nations at https://www.fao.org/faostat/en/#home, and in Statista at https://www.statista.com/statistics/1227308/tree-cover-loss-global-drivers/.

Author Contribution Statement

Danielle Mendes Thame Denny: Conceptualization, Investigation, Writing – original draft. **Carlos Eduardo Pellegrino Cerri:** Resources, Writing – review & editing, Supervision, Funding acquisition. **Maurício Roberto Cherubin:** Validation, Data curation, Visualization, Project administration. **Heloisa Lee Burnquist:** Methodology, Formal analysis.

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