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Foreword

The Low Carbon Soybean (LCS) Program is an initiative aiming to add value to soybean produced in systems that contribute to the reduction of greenhouse gas emissions, the cause of global warming. The goal of the LCS Program is to certify the sustainability of Brazilian soybean production, making tangible both qualitative and quantitative aspects of the grain produced with technologies and agricultural practices that reduce the intensity of greenhouse gas (GHG) emissions. The concept is based on measuring the benefits and certifying production practices with demonstrably low GHG emissions. Embrapa Soybean coordinates the methodological construction, with the participation of specialists from different Embrapa units and representatives of the productive sector. The LCS Program adopts a sectoral innovation model with the partnership of seven supporting companies: Bayer, Bunge, Cargill, Coamo, Cocamar, GDM, and UPL. The scope of the LCS Program includes a comparison of typical production systems (crops and production practices used) in the areas applying for the LCS label, i.e., those using mitigation practices. The LCS Program estimates that the potential for reducing GHG emissions through the adoption of research-recommended sustainable technologies is approximately 30%. This is because the agricultural practices that reduce GHG emissions are the same practices that increase productivity and reduce costs, thus creating a win-win situation for the production system. The technical guidelines, which are structured throughout the certification process, form the basis of the certification protocol and checklist used in practice by accredited certifiers to assess and award the LCS label. It is a constructive process that is constantly evolving. The technical guidelines will be updated after the field validation and a second approach will be published.

Alexandre Lima Nepomuceno

General Head - Embrapa Soja

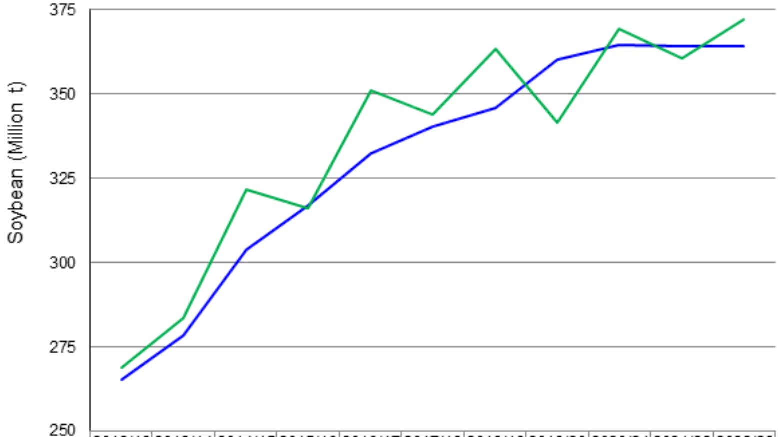
Sumário

Introduction

Soybean (*Glycine max* L. Merr.) is a protein-rich and oilseed grain whose versatile use of its derived products, meal, and oil, allows it to be transformed into more than 200 products (Hasse, 1996; Mandarino et al., 1996). Among its various uses, the following stand out: (a) human consumption, served both directly (soybean-based products in the diet) and indirectly (for example, soybean as a raw material for animal feed production); and (b) production of renewable energy, encompassed by biofuels (biodiesel based on soybean oil) (Gazzoni et al., 2021).

Soybean meal is the most consumed product in the world, surpassing canola, sunflower, and cotton (United States, 2023). Its primary destination is animal feed, as it is a fundamental source of plant protein with high biological value. Thus, it has been essential in sustaining the global meat market, which, in turn, sustains a growing demand for grains for feed production.

Globally, soybean oil is the second most consumed oil, ahead of canola and sunflower oils, and surpassed only by palm oil. Human consumption accounts for 78.6% of this product (United States, 2023), while its use in other markets is highlighted by biodiesel production, in countries like Brazil, where it represented 65.8% of the raw material used in biofuel generation in 2022 (ANP, 2023). In this context, the robust markets for derived products have ensured a heated demand for soybeans, even in the face of events affecting the global agribusiness, such as the covid-19 pandemic (Figure 1).



	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2022/23
Demand	265	278	304	317	332	340	346	360	364	364	364
Production	269	283	322	316	351	344	364	342	369	360	372

Figure 1. Evolution of global demand and production of soybeans.
Source: United States (2023).

In this global scenario, soybean area and productivity in Brazil showed a geometric growth rate (GGR) of 4% and 2% per year, respectively, between the 1976/1977 and 2022/2023 harvest seasons, resulting in an annual GGR for production of 6.1% (Conab, 2023). Studies conducted by Embrapa (Hirakuri et al., 2018, 2019a, 2019b, 2020) showed that the territorial expansion occurred mainly through the introduction of soybean in degraded or underutilized pasture areas and areas occupied by other crops, while the increase in crop productivity was due to the evolution of production technologies adopted by soybean farmers (Seixas et al., 2020; Gazzoni et al., 2021).

With this evolution in area and productivity, Brazil overtook the United States in the late 2010s to become the largest producer of soybean in the world (United States, 2023), accounting for 42% of production in the 2022/2023 harvest. In this context, soybean has established itself as the main crop in Brazilian agribusiness, with a solid production chain that generates significant socioeconomic benefits for different regions of the country, including job creation, capital movement, and robust socioeconomic development (Gazzoni et al., 2021).

In the 2021/2022 and 2022/2023 harvest seasons, Brazil produced 125.5 million and 154.6 million metric tons (t) of soybean, respectively (Conab, 2023). According to a study conducted by the Center for Advanced Studies in Applied Economics at Luiz de Queiroz Agriculture College from São Paulo University (USP, 2023), this large scale of production allowed the soybean and biodiesel chain to achieve a Gross Domestic Product (GDP) of R$ 673.7 billion and to be responsible for 2.05 million jobs in 2022 (USP, 2023). Additionally, the country remained the largest exporter of soybean in grain form and the second largest exporter of its derived products, meal, and oil. In 2022, national exports of soybean, meal, and oil reached US$ 46.6 billion, US$ 10.3 billion, and US$ 3.9 billion, respectively (Brazil, 2023a).

The technological evolution of grain production in Brazil has allowed for intensification of land use, with two or more annual crops, and advances in productivity, leading to large-scale production and generating a land-saving effect, especially for crops such as soybean, corn, rice, beans, and sorghum (Telhado; Capdeville, 2021), in addition to certifying bodies operating in the market, in the socio economic development of different regions. However, for the oilseed production chain to remain a vector of human development, there is a critical challenge that has not yet been met: the reduction of greenhouse gas (GHG) emissions generated in the production systems of which it is a part (Gazzoni; Dall'Agnol, 2018).

In June 1988, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) proposed the creation of the Intergovernmental Panel on Climate Change (IPCC), which was endorsed by the United Nations General Assembly in December 1988 (Leite, 2015). The Panel conducts studies to determine the state of knowledge on climate change, identifies issues on which there is consensus in the scientific community and areas that require further research, and establishes standards for emissions calculation procedures.

In this context, after decades of research, the 6th synthesis report on climate change 2023 (Lee et al., 2023) found that the increase in global temperature is primarily due to the expansion of CO_2 concentration in the atmosphere, resulting from the burning of fossil fuels, changes in land use, and industrial activities. Studies estimated that the global average temperature during the period 2011-2020 was 1.09 °C (0.95 °C - 1.20 °C) higher than that observed during the period 1850-1900. Of this increase, 1.07 °C is attributable to human activities. According to the 6th report on climate change, this warming is the main cause of melting glaciers, rising sea levels in some coastal regions, and droughts and floods in many areas.

In addition to the high pressure on industrial activities, this realization has led to intense discussions on Land Use Change (LUC). Although LUC can be associated with different purposes, agriculture has received particular attention in these discussions, as described in Gazzoni and Dall'Agnol (2018). According to the Climate Watch platform (2023), which covers more than 190 countries, indicates that Brazil emitted 1.47 billion metric t of CO_2e in 2019 (Figure 2A), accounting for 3.05% of total greenhouse gas emissions China was the first and emitted 12 billion metric t of CO_2e (Figure 2A). In terms of per capita emissions, the country emitted 6.95 t of CO_2e per person, making Brazil as the sixty-ninth largest emitter (Figure 2B). Solomon Islands was the first, and emitted 70 metric t of CO_2e per capita (Figure 2B).

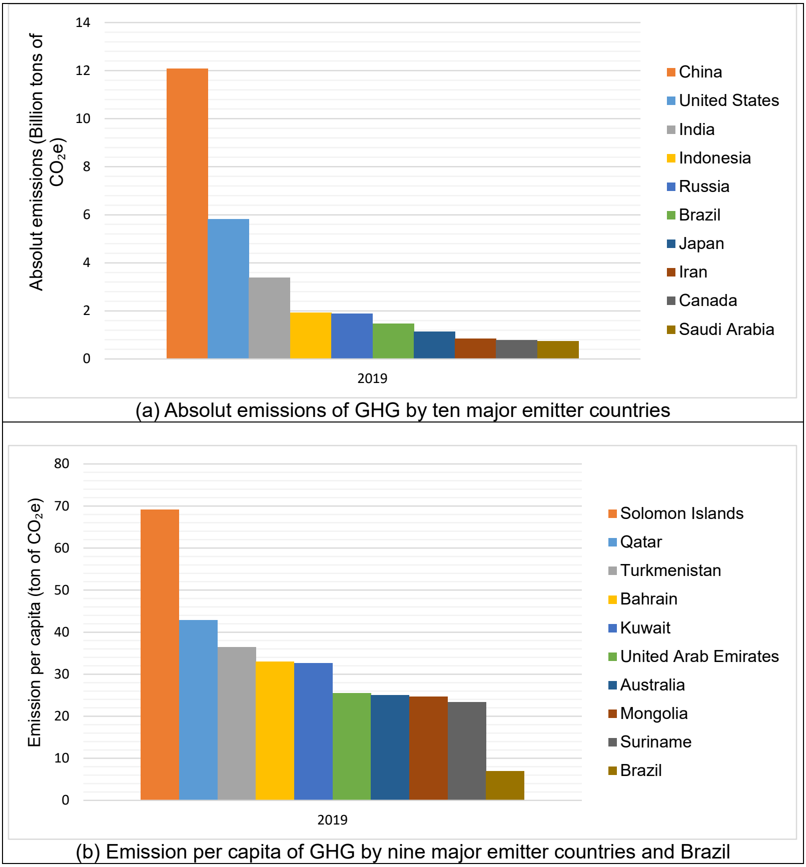


Figure 2. Greenhouse Gas emissions (GHG) by the major emitting countries and Brazil, measured in carbon dioxide equivalent (CO_2e).

Source: adapted from data of Climate Watch (2023).

In this context, despite Brazil´s low per capita contribution to global GHG emissions and its efficient agriculture, the authors emphasize that the country is under pressure to develop more sustainable agro-environmental and socioeconomic production systems to ensure GHG mitigation and human development in rural areas.

Land use change and forests, energy acquisition activities, and processes represent the origin of most of Brazil's GHG emissions (Figure 3). Thus, agriculture has been the largest source of GHG emissions in the country, both directly through agricultural production and indirectly through land use change. This scenario indicates the challenge and opportunity to create alternatives for a better GHG balance in Brazilian agriculture, suitable for the profiles of current and potential farmers and adding value to agricultural production.

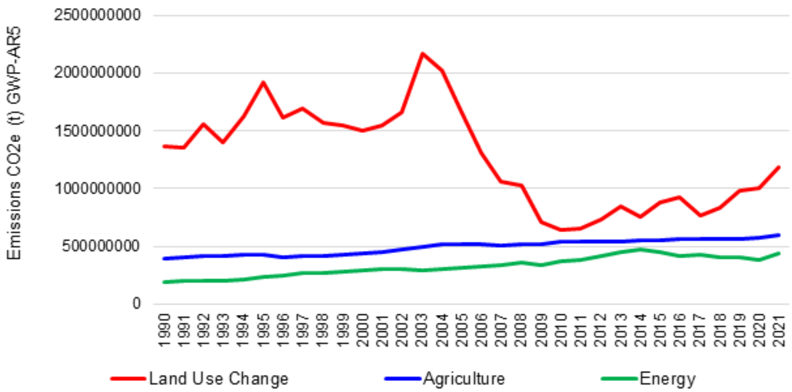


Figure 3. Emissions of GHG from the three main sectors (measured in t of CO_2 equivalent).

Source: SEEG (2023).

Faced with this challenge to support and promote more sustainable agriculture, Embrapa Soybean created the Low Carbon Soybean (LCS) concept brand, with the following scope: soybean from no-till production systems with reduced GHG emission intensity, thus being more efficient and sustainable in environmental, economic and social terms (Nepomuceno et al., 2023). The LCS concept brand will have its implementation by voluntary, private, and independent certification (third-party) through a protocol composed of measurable, reportable and verifiable (MRV) indicators defined based on the best available scientific knowledge. A relevant aspect that emerges from the scope is that the concept brand is attributed to soybean production systems that meet the requirements of the established protocol and that are physically linked to one or more plots of land on a rural property or estate. Thus, it is not a certification process that applies to the entire rural property, but rather to the plots cultivated with certified soybean production systems that are labeled as low carbon according to the criteria and premises of the protocol. This premise indicates that the adoption of the production system certified by the LCS concept brand is not mandatory for the entire area of the rural property. The concept brand was conceived in 2021 and obtained registration at the National Institute of Industrial Property (INPI) on 02/22/2022, under the number 922638306 (Figure 4).

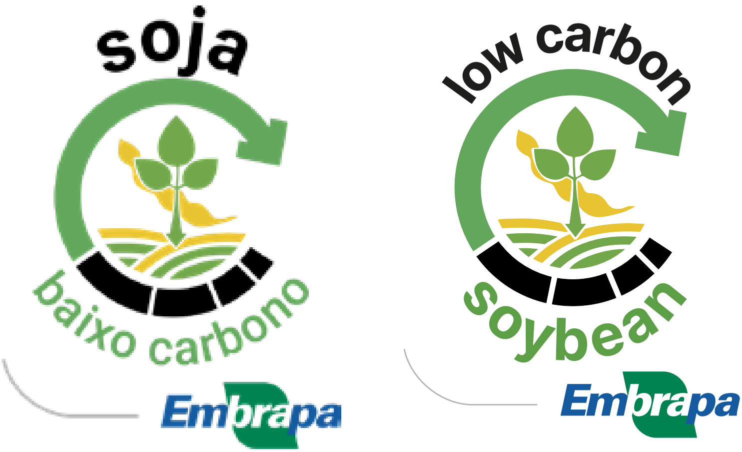


Figure 4. Low Carbon Soybean concept brand in Portuguese and English versions.

Source: Nepomuceno et al. (2023).

All the research, development, and innovation activities aimed at establishing, validating, and operationalizing the LCS certification protocol are grouped and coordinated within the Low Carbon Soybean Program (LCS). In its first phase, the LCS Program has the financial support of seven companies related to soybean agribusiness and the participation of experts from several Embrapa units. As part of the LCS Program, this document includes a Technical Certification Guideline (TCG) for obtaining the concept brand standard, which includes the premises for certifying the reduction of GHG emissions associated with the agricultural production process of candidate areas. In accordance with the ISEAL Alliance´s Code of Good Practices for Setting Social and Environmental Standards - Standard Setting Code (Iseal, 2014), the structuring of the TCG was carried out through expert discussions involving three types of events:

- Technical workshops with Embrapa researchers in soil science, environmental science, agronomy, entomology, and plant pathology. The aim was to discuss ways of structuring certification based on factors influencing the GHG balance in soybean production systems and relevant issues such as GHG emission calculation techniques and legal deforestation (with its impact on LUC);
- Meetings with stakeholders, such as the Ministry of Agriculture and Livestock (Mapa), sectoral confederations, producer associations, agricultural cooperatives, certification bodies, financial institutions, and trading companies, among others. The goal was to gain insight from these stakeholders on business opportunities and factors that may drive or limit the adoption of certification;
- Workshops with representatives of companies supporting the LCS Program to present results and gather relevant feedback for certification development.

Participants in these meetings emphasized that the complexity of the certification process can be the main barriers to farmer adoption and market acceptance. Thus, based on a careful analysis of the information gathered, a structure was created that is straightforward, minimally complex, and focused on GHG mitigation. This structure includes two TCGs: 1) Rural Property Adaptation and 2) Production System Adaptation.

Each TCG has eligibility criteria that candidate areas must meet to receive the LCS label. The Achievement Indicators in Table 1 will evaluate such compliance.

Table1. Structuring of the Low Carbon Soybean (LCS) concept brand certification (LCS certification).

Guideline	Eligibility Criterion	Achievement Indicator
Rural Property Adaptation	**Legalization and Labor Issues**	Legalized rural property
		Rural property without environmental fines or embargoes
		Owner without conviction for child labor or slavery-like conditions
		Active CAR for rural property
	Elimination of Deliberate Burnings	Rural property free of vegetation and straw burnings
	Regulations and Risk	Compliance with Soybean free period
		Respect for sowing calendar
		Water use rights granted and environmental licensing obtained
Production System Adaptation	**Mandatory Agricultural Practices**	No-Till System correctly adopted
		Good inoculation practices adopted
		Fertilization and soil correction according to technical analysis and recommendations (quantity, placement, frequency)
		Pesticides technically prescribed
	Additional Agricultural Practices	Minimum value of the Sustainable Agricultural Practices Adoption Index (SAPAI) achieved
		Improvement of Carbon Balance
		Greenhouse Gas Emissions Intensity (GHGEI) of the candidate production system lower than the baseline (reference)
		Compensation for emissions related to Land Use Change

The achievement indicators associated with the various eligibility criteria are mandatory, meaning that if they are not met, the candidate is automatically removed from the process until they regularize their situation and resume the process. The LCS certification is dynamic and follows the continuous improvement process advocated in the ISEAL Alliance Code of Good Practice (Iseal, 2014). As such, its structure will be periodically reviewed and refined at intervals of no more than three years, under the responsibility of the LCS Program Management Committee or a committee designated by it.

Technical Guide: Rural Property Adaptation

Although the LCS concept brand is applicable to the production system (conducted in one or more areas/tracts, duly identified) and not to the rural property itself, it is important that it meets minimum requirements to enable the granting of the standard, legitimizing it before society and markets. Thus, the first TCG covers three Eligibility Criteria that must be fully met by the rural property: Legalization and Labor Issues; Elimination of Deliberate Burnings; Regulations and Risk.

Eligibility Criterion: Legalization and Labor Issues

The concept of a rural property is not well defined in Brazil. According to Pereira (2023), Brazilian Law 9,393 of 12/19/1996 defines rural property as a continuous area formed by one or more land parcels of land located in the rural zone of the municipality. On the other hand, Brazilian Law 4,504, of 11/30/1964 (Land Statute) and Brazilian Law 8,629, of 02/25/1993, define rural property as the rustic building, of continuous area regardless of its location, intended or that can be intended for agricultural, livestock, plant extraction, forestry, or agro-industrial exploitation, based on public valorization plans or private initiatives (Arruda, 2011). The Brazilian Instruction Normative 82 of the National Institute of Colonization and Agrarian Reform (Incra, in Portuguese) (Incra, 2020) has a similar concept, defining rural property as a continuous extension of land with agricultural, livestock, plant extraction, forestry, or agro-industrial purpose (actual or potential), located in rural areas or urban perimeters (Carmo Júnior, 2019).

The three definitions have a view of rural property based on contiguous areas. However, while the first restricts rural property to the rural zone of the municipality, the other two eliminate this restriction, in addition to emphasizing a common point: the use of the property for some types of exploitation (agricultural, livestock, plant extraction, forestry, or agro-industrial), actual or potential. Regardless of its conceptualization, rural property, like urban property, requires registration and records to be legalized.

The legalization of rural property is an essential prerequisite for providing legal security to farmers and making them eligible for public funding. In addition, adequate compliance with environmental and labor issues is essential to ensure environmentally and socially responsible agricultural production (Brazil, 1943).

The legalization of rural property in Brazil requires (a) regularization with Incrafor land management purposes; (b) regularization with the Brazilian Federal Revenue Service (RFB, in Portuguese) for tax purposes (Brazil, 2023a); (c) execution of a public deed; and (d) registration/updating of the land registry.

The Brazilian Forest Code establishes the country's environmental laws and regulates compliance with environmental issues. State regulations and/or legal standards may supplement the Forest Code. National and state laws focus on the use, preservation, and restoration of environmentally valuable areas, such as Permanent Preservation Areas (PPA), Legal Reserves (LR), Conservation Units (CU), and Restricted Use Areas (RUA) (Vieira, 2019).

On the other hand, a set of laws outlined in the Consolidation of Labor Laws regulates labor relations in the country. This legal instrument covers topics such as minimum wage, working hours, vacation, 13th salary, and the Severance Indemnity Fund for Employees (FGTS, in Portuguese), among others (Brazil, 2023b).

In this context, in order to combat illegality and motivate actions for the legalization of rural property, as well as to promote the social responsibility of farmers, the criterion of legalization and labor issues adopts four indicators of achievement: legalized rural property; rural property without environmental fines and embargoes; owner without convictions for child labor or analogous to slavery; rural property with an active Brazilian Rural Environmental Registry (CAR, in Portuguese) (Brazil, 2023c).

Achievement Indicator: Legalized Rural Property

The rural property must be registered in the National Rural Cadaster System (SNCR, in Portuguese), which is administered by Incra (Instituto Nacional de Colonização e Reforma Agrária - National Institute of Colonization and Agrarian Reform). This registry is certified by the Certificate of Registration of Rural Property (CCIR, in Portuguese). This certificate allows transfer, lease, mortgage, subdivision, division (divorce or inheritance), and transactions with financial institutions. Unlike the Rural Property Cadaster (Cafir, in Portuguese), the SNCR does not restrict rural property to rural areas. Thus, rural property may be located in urban areas if it is used for agricultural, livestock, extractive, forestry, or agro-industrial purposes, as described above. For information on who must register as a landowner and the procedures for electronic registration, please contact Incra (Incra, 2020).

The National Cadaster of Rural Real Estate (CNIR, in Portuguese) is a structural database that integrates information on rural properties shared by various federal agencies, and is managed by Incra and the Special Secretariat of the Federal Revenue of Brazil, in accordance with Laws 5,868 of 12.12.1972, and 4,504 of 30.11.1964. The CNIR integrates the data of the two mandatory rural property registries: the Cafir and the SNCR (Brazil, 2022a).

The Cafir consists of the Register of Rural Property, managed by the RFB for the collection of the Rural Property Tax (ITR, in Portuguese), in accordance with Law 9,393 of 19.12.1996. In this registry, rural property is considered as a continuous area formed by one or more parcels of land located in the rural zone of the municipality. If the property area is partially located in urban and rural zones, only the portion located in the rural zone is registered. Each rural property registered in the Cafir has an identification that is currently represented by the Brazilian Real Estate Registry (CIB) (Brazil, 2022a).

According to the Law 6,015 of 31.12.1973, after the regularization in the Cafir and SNCR, the Public Deed of the property must be requested, referring to: a) the registration in the name of the declarant, in the case of the owner; b) the documentary proof of possession, in the case of a possessor; c) the plan and the descriptive memorial of the property, if it has been subject to the Agrarian Reform. Once the Public Deed has been issued, it must be registered and/or updated in the Real Estate Registry Office (Fritzen, 2020). Thus, in order to comply with the Indicator of Achievement, the rural property that includes the candidate area must have a Public Deed issued and the registration updated or registered in the Real Estate Registry Office, with proof of its regularization with the RFB and Incra (Brazil, 2022a).

Achievement Indicator: Rural Property without Environmental Penalties and/or Embargoes

Law 9,605 of 02/12/1998 classifies environmental crimes in Brazil into five main types: (1) crimes against fauna; (2) crimes against flora; (3) pollution and other environmental crimes; (4) crimes against urban planning and cultural heritage and (5) crimes against environmental administration (Brazil, 1998). In this regard, those who commit any of these types of crimes may face:

- Penalties with the imposition of fines.
- Environmental embargo, either preventive or applied as a sanction.

The environmental embargo is a temporary or permanent restriction on the use of a specific area within the rural property, aimed at preventing the continuation of environmental damage, promoting environmental regeneration and allowing the recovery of the degraded area. There are two types of environmental embargoes: 1) precautionary embargo, which is imposed immediately to prevent further environmental damage; 2) sanctionary embargo, which is imposed only after the completion of legal proceedings.

The administrative procedure for environmental embargoes consists of the following stages: (a) preparation of the notice of environmental violation; (b) notification of the accused party; (c) conciliation hearing (if requested by the notified party); (d) preliminary defense; (e) instruction; (f) first instance judgment; (g) appeal to the higher authority and (h) judgment.

The administrative process begins when environmental inspectors detect irregularities on rural properties and issue a notice of violation, accompanied by an area embargo (Testa, 2022). Once the notice is issued, the violator is notified to attend an environmental mediation hearing, the purpose of which is to clarify the factual and legal reasons that led to the issuance of the notice of violation and to present possible legal solutions to conclude the process, such as payment discounts, installment plans, and the conversion of fines into services for the preservation, improvement, and restoration of environmental quality (Cruz, 2022).

If the infringer does not attend the conciliation hearing or if it is inconclusive, the 20-day period for filling an initial defense begins, according to Decree No. 6,514/2008 (Cruz, 2022; Farenzena, 2023). After the presentation of the initial defense by the infringer, or if the 20-day period expires without the presentation of a defense or final arguments, the administrative case is forwarded to the supervising environmental authority for judgment, which issues a decision on the environmental infraction. The decision may cancel the notice of environmental violation, reduce, maintain, or increase the value of the fine, or specify and determine the measures to be taken, respecting the limits established by the current environmental legislation in force, and notify the infringer of the decision (Cruz, 2022).

According to Decree No. 6,514/2008 and Law 9,605/1998, the dissatisfied party has 20 days to file an administrative appeal against the decision of the first instance authority. The appeal is submitted to the judicial authority, which has five days to reconsider its decision or to refer it to a higher authority, which may confirm, modify, annul, or revoke the contested decision in whole or in part.

Once a fine has been imposed, the possibility of appeal is exhausted, and the violator has five days to pay it, starting from the date of receipt of the notification (Cruz, 2022; Faranzena, 2022). If the environmental damage must be repaired by the violator, this obligation must be supervised by the administration, which may file a civil public action for its repair, regardless of the statute of limitations, considering that the repair of environmental damage is an indefeasible obligation (Cruz, 2022).

Considering the context, in order to comply with this achievement indicator, the rural property must not have recorded violations, unpaid debts, or embargoed areas, either through a duly completed administrative process or as a precautionary measure. It should be noted that the Brazilian Institute of the Environment and Renewable Natural Resources has a platform for consulting environmental violations and embargoes (Ibama, 2023a) and another for consulting negative debt certificates (Ibama, 2023b), which can be used in certification audits. When applicable, government certificates can also be used in this audit, as well as documents from State Environmental Secretariats (Sema) and related institutions.

Achievement Indicator: Property Owner without Conviction for Child Labor or Conditions Analogous to Slavery

There is a misalignment between rural business and labor legislation, as the legal framework is not suitable for the characteristics of agricultural production due to a) seasonality and production cycles, b) local and operational specificities, and c) family labor performance and remuneration, among others. Therefore, it is crucial to adopt indicators that encourage social responsibility in agricultural production, are aligned with the profile of Brazilian agriculture, and are auditable (Brazil, 2020).

Another point addressed in the discussions and formulation of the TCGs was the need to consider the broad defense of the candidate in the case of processes. Thus, it includes issues marked by a legal process where it is possible to audit the existence of a conviction for a social crime. In this context, the eradication of child labor exploitation and the exposure of workers to conditions analogous to slavery were the two social issues included in this Achievement Indicator.

According to the Brazilian Constitution of 1988, child labor refers to economic activities and/or survival activities, with or without profit, paid or unpaid, performed by children or adolescents under the age of 16, except for the condition of an apprentice from the age of 14, regardless of their occupational condition. On the other hand, work performed in conditions analogous to slavery results from the following actions, adopted individually or together (Brazil, 2020): a) submission of the worker to forced labor; b) submission of the worker to exhaustive working hours; c) subjection of the worker to degrading working conditions; d) restriction of the worker's movement, whether due to debt incurred, by restricting the use of any means of transport by the worker, or by any other means to retain them at the workplace; e) overt surveillance at the workplace by the employer or their agent, to retain them at the workplace; f) possession of documents or personal belongings of the worker by the employer or their agent, to retain them at the workplace.

Given the described scenario, to meet this Achievement Indicator, the candidate must not have been convicted of exploiting child labor and/or exposing workers to conditions analogous to slavery. In this sense, they must comply with articles 403 and 636 of the Brazilian labor law. The Ministry of Labor and Employment maintains a register of employers who have subjected workers to conditions analogous to slavery (Brazil, 2020) and a portal for consultation of labor debts, according to the cited articles of the Brazilian labor law (Brazil, 2023b), usable to assist in the certification audit.

Some other social issues identified in workshops, meetings, and discussions, were relevant. However, their complexity and/or the impossibility of auditing make their adoption unfeasible or detrimental to their acceptability by the market, such as in the case of moral harassment of employees and members of the local communities. Should new platforms or systems make their auditing feasible, these social issues may be included in future versions of the LCS Certification, as advocated by the principle of continuous improvement adopted in the LCS Program.

Achievement Indicator: Rural Property with Active CAR

The Brazilian Forest Code (BFC) focuses on the following areas of environmental value: Permanent Preservation Areas (PPA), Legal Reserve (LR), Conservation Units (CU), and Restricted Use Areas (ARU).

The PPA is a protected area, whether covered by native vegetation or not, with the function of preserving water resources, the landscape, geological stability, and biodiversity, facilitating the genetic flow of fauna and flora, protecting the soil, and ensuring the well-being of human populations (Vieira, 2019). The BFC includes the following types of PPAs in urban or rural areas:

a) marginal strips of any perennial and intermittent natural watercourse, excluding ephemeral ones, from the edge of the regular bed channel, with minimum widths defined according to the length of the watercourse;

b) areas around natural lakes and lagoons, with a marginal strip of 100 meters in rural areas and 30 meters in urban areas;

c) areas around artificial water reservoirs resulting from the damming or impoundment of natural watercourses in the strip defined in the environmental license of the enterprise;

d) areas around perennial springs and water holes, regardless of their topographic situation, with a minimum radius of 50 meters;

e) slopes or parts thereof with a steepness greater than 45º, equivalent to 100% on the line of the steepest slope;

f) *restingas* (coastal sandbanks), as dune fixers or mangrove stabilizers;

g) mangroves, in their entirety;

h) edges of plateaus or mesas, up to the line of relief break, with a strip never less than 100 meters in horizontal projections;

i) on the tops of hills, mountains, and mountain ranges, with a minimum height of 100 meters and an average slope greater than 25º, the areas delimited from the contour line corresponding to 2/3 of the minimum height of the elevation, always related to the base, which is defined by the horizontal plane determined by an adjacent plain or water body, or, in undulating terrain, by the nearest saddle point of the elevation;

j) areas with altitudes above 1,800 meters, regardless of the vegetation;

k) in veredas and wetlands, a marginal strip in horizontal projection, with a minimum width of 50 meters, from the permanently swampy and waterlogged space.

The LR consists of an area within a rural property to ensure the sustainable economic use of natural resources, aiding in the conservation and rehabilitation of ecological processes, promoting biodiversity conservation, and sheltering and protecting native wildlife and flora (Vieira, 2019). Every rural property must maintain an area with native vegetation coverage as LR, without prejudice to the application of PPA rules, observing the following minimum percentages related to the property area:

I. Located in the Legal Amazon (Figure 5):

a) 80% of the property is in forested areas. This condition does not apply to properties that carried out deforestation in the Amazon between 1989 and 1996, provided they adhered to a minimum of 50% LR required then. These properties are not obligated to restore their areas to the 80% reserve. In the case of the Legal Amazon, in forested areas, the state government, upon consultation with the State Environmental Council, may reduce the LR to up to 50% for regularization purposes when the state has an approved Ecological-Economic Zoning and more than 65% of its territory occupied by public domain conservation units, duly regularized, and by homologated indigenous lands; or when the municipality has more than 50% of its area occupied by public domain conservation units and homologated indigenous lands.

b) 35% of the property in Cerrado areas;

c) 20% of the property in general field areas.

II. Located in other regions of the country:

Under certain conditions, the BFC may allow the PPA to constitute part of the LR. Additionally, commercial exploitation of the LR can be carried out subject to compliance with determined requirements and under a sustainable management plan for the approval of the area by the competent authorities. Another important aspect regarding the LR is that all deforestation activities carried out before 2008 (July 22nd) are not considered illegal. However, rural property is required to restore the LR if it exceeds four fiscal modules (FM), whose value varies according to the state and municipality. When the rural property is smaller than four FM, the LR is the area with native vegetation as of July 22nd, 2008.

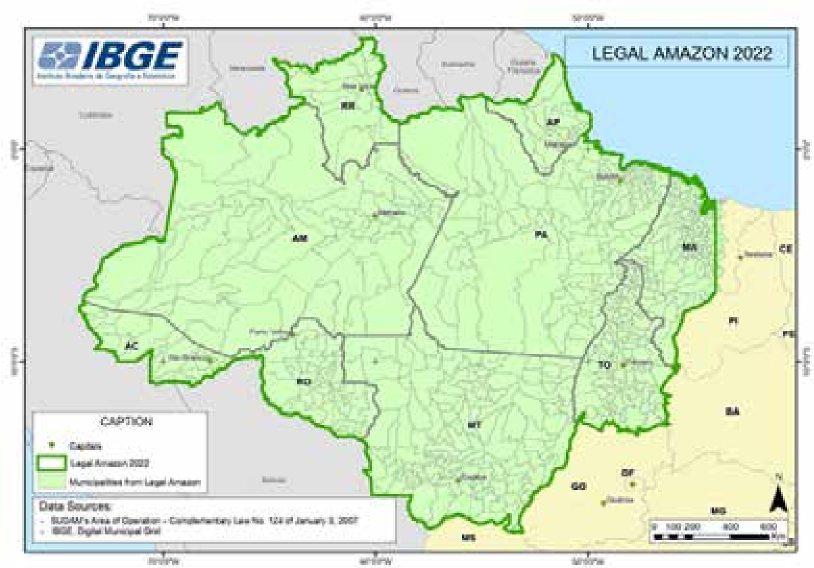


Figure 5. Location and geographical scope of the Legal Amazon, updated in 2022.

Source: IBGE (2023).

A Conservation Unit (CU) encompasses the territorial space and its environmental resources (including jurisdictional waters), with relevant natural characteristics, legally established by the government, with conservation objectives and defined boundaries to which protection guarantees apply under a special management regime (Vieira, 2019). A CU is governed by the National System of Conservation Units (NSCU), categorized as:

1. Integral Protection Units: Ecological Station, Biological Reserve, National Park, Natural Monument, and Wildlife Refuge;

2. Sustainable Use Units: Environmental Protection Area, Area of Relevant Ecological Interest, National Forest, Extractive Reserve, Fauna Reserve, Sustainable Development Reserve, and Private Natural Heritage Reserve.

RUA includes wetlands, *Pantanal* plains, and areas with slopes between 25º and 45º. In the marshlands and *Pantanal* plains, ecologically sustainable exploration is allowed, considering the technical recommendations of official research bodies. New suppression of native vegetation for alternative land use is subject to authorization from the state environmental agency based on the recommendations mentioned in the BFC. In areas with slopes between 25º and 45º, sustainable forest management and agrosilvopastoral activities are allowed, as well as the maintenance of physical infrastructure associated with these activities, adhering to proper agronomic practices. The conversion of new areas is prohibited, except in cases of public utility and social interest (Vieira, 2019).

The instrument adopted for the preservation and restoration of these environmentally valuable areas in Brazil is the Rural Environmental Registry (CAR, in Portuguese), which constitutes the electronic public record integrating environmental information of rural properties and holdings, serving as the principal database for monitoring, controlling, and combating deforestation in the country (Brazil, 2023c). Thus, it can assist producers and public policymakers in environmental and economic planning. According to the current legislation, environmental regularization in Brazil consists of four stages:

1. Registration in the CAR: mandatory for all rural properties in the country, providing access to benefits outlined in the BFC (Law No. 12,651/2012);

2. Monitoring: after the registration in the CAR, the property owner or holder will monitor the status of the property, making necessary adjustments for CAR activation and completing the environmental liabilities analysis;

3. Regularization: after CAR activation and completion of the environmental analysis, the property without liabilities will be in regular status, while a property with liabilities must join an Environmental Regularization Program (ERP) and formalize a Commitment Term, offering the following alternatives: reconstitution of vegetation remnants in PPA, RUA, and/or LR, and compensation for LR. Following the ERP completion, the property will be regularized and without environmental liabilities;

4. Negotiation: rural properties with excess native vegetation classified as LR, Environmental Servitude, or Environmental Reserve Quotas are considered regularized and can negotiate their assets with properties pending regularization.

To progress from the second to the third stage of environmental regularization, the rural property registration in the CAR must be active, with the environmental liability analysis (areas of PPA, restricted use, LR, and native vegetation remnants) completed. Below are listed the possible conditions in which the property registration may be found (Brazil, 2023c):

- Active: when the registration is completed, and data analysis is in progress, with obligations to update the registered information being fulfilled, or when the data analysis is completed confirming the regularity of the information regarding the areas of PPA, restricted use, LR, and native vegetation remnants;
- Pending: when incorrect declarations or overlaps with Indigenous Lands, Conservation Units, Federal Lands, restrictive areas, embargoed areas, or other rural properties are identified. The registration will also be considered pending when irregularities are noted regarding PPA, RUA, LR, consolidated areas and native vegetation remnants until the notified procedures are fulfilled within the specified deadlines or until the obligations to update the information are met following notification;
- Suspended: when there is a justified judicial or administrative decision from the competent authority;
- Canceled: when the declared information is wholly or partially false, misleading or omitted, and after failure to meet the deadlines established in notifications or by a justified judicial or administrative decision from the competent authority.

Considering the context described, this Achievement Indicator specifies that the property where the area under the production system applying for the LCS label is located must have an active CAR, as described in the flowchart in Figure 6. In summary, the rural property containing the candidate area must have registration in the CAR, and the registration cannot be pending, suspended, or canceled. Essentially, a property will be eligible for the LCS label under the following conditions: a) active CAR, with no environmental liabilities; b) active CAR, with the property adhering to a restauration plans to eliminate its environmental liabilities; c) active CAR, with environmental liability analysis ongoing.

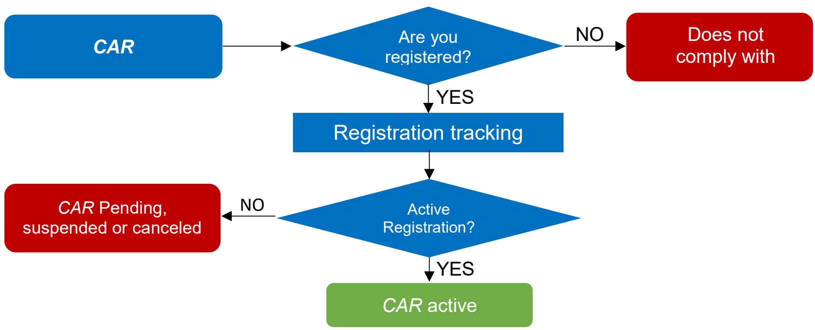


Figure 6. Flowchart of environmental regularization for rural properties with areas where the adopted production systems are candidates for the LCS standard.

Eligibility Criterion: Elimination of Deliberate Fires

Fires are a relevant source of GHG. Additionally, fires generate negative impacts on the land, such as soil nutrients, organic matter, biodiversity, water and energy efficiency, crop productivity, and air quality (Kumar et al., 2015). The authors also highlighted those fires could worsen respiratory and cardiovascular diseases, as well as the health of children and pregnant women, in addition to increasing individuals' medical expenses and affecting their productivity at work.

According to a study conducted by an international team of scientists within the framework of the Sustainable Amazon Network (RAS, in Portuguese), a research consortium coordinated by Embrapa and other national and international institutions (Lima, 2021), the extreme drought caused by El Niño in 2015 and 2016, coupled with forest fires in the Amazon, led to the death of about 2.5 billion trees and emitted 495 million metric tons of carbon dioxide into the atmosphere, in an area representing only 1% of the entire Brazilian Amazon forest. That means that the forest, whose primary function is to fix carbon in plant biomass, can be one of the largest sources of GHG emissions on earth, if disturbed by fire.The above-cited research (Kumar et al., 2015; Lima, 2021) highlights the adverse effects of fires on the environment and living beings. In this context, the Elimination of Deliberate Fires Criterion aims to mitigate GHG emissions and ensure a better quality of life for living beings through the following Achievement Indicator: (1.2.1) Rural property free of vegetation and straw burning of any nature.

Achievement Indicator: Rural property free of vegetation and straw burning of any nature

The area burned between 1985 and 2022 in Brazil was 185.7 million hectares (21.8% of the national territory), corresponding to 16 million hectares per year (Mapbiomas, 2023). The Cerrado and Amazon biomes accounted for about 86% of the area burned during this period. In the Cerrado biome, 7.9 million hectares were consumed by fire annually, whereas, in the Amazon biome, the average was 6.8 million hectares per year. However, when analyzing the area of the biomes, the Pantanal stands out, with 51% of its territory consumed by fire during the period. These data indicate that widespread fires are frequent in Brazil. And that must stop. So, to be eligible for the LCS Standard, rural properties must be free from deliberate fires, both in vegetation and straw, of any nature. Platforms such as the Burned Areas Program (Inpe, 2023) and geo-technological tools will be applicable for certification and auditing this criterion.

Eligibility Criterion: Regulations and Risk

Biotic and abiotic stresses caused a loss of 14.8 million metric tons of soybeans in Brazil between the 2015/2016 and 2019/2020 harvests, representing a financial loss of R$ 19.3 billion (Hirakuri, 2021), which posed a severe risk to Brazilian soybean production. In this sense, the Regulations and Risk Criterion aims to enhance the resilience of the certified area through the following Achievement Indicators:

1.3.1. Soybean free period complied with;
1.3.2. Sowing calendar respected;
1.3.3. Water use rights and environmental licensing obtained.

Achievement Indicator: Soybean free period

Complied with Asian soybean rust, caused by the fungus *Phakopsora pachyrhizi*, is one of the most severe diseases of the crop, with damage achievement from 10% to 90% in different geographical regions where it has been reported (Godoy et al., 2022). Due to this potential for damage, in May 2021, Mapa published Ordinance No. 306, establishing the National Soybean Rust Control Program – Phakopsora pachyrhizi (PNCFS, in Portuguese) (Brazil, 2023d). Among the measures to control the disease-causing fungus is the Soybean free period, a regulation updated annually by ordinances, which consists of a continuous period during which no soybean-living plants are allowed in a specific area.

This period must be at least 90 days without the crop and volunteer plants in the field. The goal is to reduce the fungal population in the environment during the off-season and thus delay the occurrence of the disease during the season. In 2023, the Soybean free period covered 20 states and the Federal District (Brazil, 2023d). In this context, for eligibility to receive the LCS Standard, the rural property must comply with the Soybean free period established for its federative unit. Whenever the rural property location is in a federative unit that does not adopt an annual regulation for the Soybean free period, This Achievement Indicator will not be applicable, and the area will be eligible to receive the LCS certification for this criterion (Embrapa Soja, 2023a).

Achievement Indicator: Sowing Calendar Respected

As identified, late sowings of soybeans can receive inoculum (spores of the fungus causing the Asian soybean rust) even in the vegetative stages, requiring the early application of fungicides and demanding more applications (Brazil, 2022b). The more applications made, the greater the exposure to fungicides and the higher the chance of accelerating the process of selecting fungal populations resistant to these fungicides. This scenario contributed to the observation of populations less sensitive to fungicides that inhibit demethylation (IDM or triazoles), inhibitors of external quinone (IQe or “strobilurins”), and succinate dehydrogenase inhibitors (SDI or “carboxamides”) in the field.

In this context, the scheduling of soybean sowing has been a measure of the PNCFS, aiming to reduce the number of fungicide applications during the harvest and thus reduce the pressure for fungal resistance to fungicides (Brazil, 2022b). However, for eligibility to receive the LCS Label, the rural property must follow the soybean-sowing calendar for its federative unit, defined by a specific annual ordinance. Whenever the rural property is located in a federative unit that does not adopt a mandatory regulation governing the sowing calendar, this Achievement Indicator will not be applicable, and the area won´t be eligible to receive the LCS Standard for this criterion.

Achievement Indicator: Water Use Rights and Environmental Licensing

Granted to farmers in regions affected by continuous water scarcity, such as the Semi-arid region in Brazil, where most crops are only viable with artificial water application. On the other hand, in zones affected by water scarcity during specific times of the year, such as central Brazil, several crops produced during the off-season of the main crop suffer from dry periods, and these areas are viable with supplementary water application during the dry months (ANA, 2021). In other regions of agricultural importance, such as parts of Rio Grande do Sul (Hirakuri et al., 2019b) and Sealba (Sergipe, Alagoas and Bahia in Northwest region) (Hirakuri et al., 2016; Hirakuri et al., 2018), irrigation is also crucial to mitigate abiotic stress risks in the adopted production systems.

In this context, irrigation becomes a relevant strategy to increase the productive stability of commercial crops and optimize soil coverage throughout the agricultural year (Dalmagro et al., 2022). Additionally, irrigation enables the intensification of production systems, making it possible to carry out three harvests in a year, which reduces emissions associated with land use change and leads to the land-sparing effect (Gazzoni et al., 2021). Thus, it can generate positive impacts both financially and in terms of carbon dynamics in the soil.

However, adopting irrigation must be done responsibly to avoid negative environmental impacts. In this sense, only rural properties with regularized water use rights and environmental licensing will be eligible for the LCS label. The water permission and control over the use of water resources determine a period for its use, and the license authorizes the location, installation, and operation of irrigation structures in a project (e.g., rural property). This Achievement Indicator is not applicable for properties that only produce under rainfed conditions and do not have an irrigation system. Such areas will be eligible to receive the LCS label.

Technical Guideline: Adaptation of the Production System

The global demand for agricultural products such as meats, grains, and oilseeds surged significantly in the 2000s, with a particular emphasis on China and other developing Asian countries (United States, 2023). The continued growth of this demand poses a challenge for supplying countries, as they must meet this increasing demand while adhering to their GHG mitigation commitments (Agência Brazil, 2021; Brazil, 2021). Brazil, one of the world's leading suppliers of agricultural products, is one such country (United States, 2023).

For Brazil to expand its production while fulfilling its GHG mitigation commitments, it is essential for major crops, like soybeans, to adopt sustainable practices that improve the balance between GHG emissions and removals from the atmosphere. In this context, this Technical Guideline (TG) covers the Eligibility Criteria that must be met by soybean production systems seeking the LCS Standard, aiming to recognize those that mitigate GHG emissions through the following Eligibility Criteria:

2.1. Mandatory Agricultural Practices

2.2. Recommended Agricultural Practices

2.3. Improvement of Carbon Balance

Eligibility Criterion: Mandatory Agricultural Practices

In Brazil, agriculture is the second-largest source of GHG emissions (Figure 3). To turn this challenge into an opportunity, the Mandatory Agricultural Practices Criterion focuses on sustainable technologies that significantly reduce net GHG emissions in soybean production systems. This observation is based on long-term research conducted by Embrapa and other organizations focused on Brazilian agriculture.

In this context, the following sustainable practices are mandatory for eligibility, as defined in the Achievement Indicators:

2.1.1. Correctly adopted No-Till System (NTS)

2.1.2. Adoption of good co-inoculation practices

2.1.3. Fertilization and soil correction based on technical analyses and recommendations (quantity, placement, frequency)

2.1.4. Pesticides technically prescribed.

Achievement Indicator: Correctly Adopted No-Till System (NTS)

One of the fundamental agricultural practices related to GHG dynamics in soybean production systems is the No-Till System (NTS). To improve the GHG balance in soybean production systems, the LCS certification recommends adopting NTS according to its three main principles (Debiasi et al., 2020):

- **Soil mobilization restricted to the seeding line:** This allows only preparations aimed at correcting the chemical and physical properties of the soil, constructing, adapting, or maintaining soil conservation systems and roads, supported by technical proof and adherence to the guidelines outlined in the annexed certification protocol document.
- **Use of production models with greater biological diversity:** This includes the addition of straw and roots compared to typical regional systems, with diversification of plant species through crop rotation, succession, or intercropping. Minimum diversification requirements are detailed in the annexed certification protocol, varying by region's edaphoclimatic conditions.
- **Maintenance of permanent soil cover, alive or dead.**

In addition to these three principles, for eligibility to receive the LCS Standard, the candidate area must utilize soil conservation strategies when necessary, including mechanical practices for controlling surface runoff, such as terracing and contour farming. A document annexed to the certification protocol will contain agronomic criteria and minimum requirements regarding the need for mechanical practices and controlling surface runoff.

Achievement Indicator: Good Co-Inoculation Practices Adopted

Co-inoculation involves the combined use of Bradyrhizobium and Azospirillum bacteria in soybeans. Plants inoculated with both microorganisms show more abundant and earlier nodulation, resulting in increased soybean productivity, among other benefits (Hungria et al., 2015). Furthermore, in cases where the nitrogen balance is positive, the formation and maintenance of organic matter are stimulated, leading to carbon sequestration in the soil and reducing its return to the atmosphere.

Thus, co-inoculation is critical for GHG mitigation, offering the following benefits:

- Productivity increased;
- Atmospheric carbon removal;
- Nitrogen fertilizer use elimination, reducing nitrous oxide emissions and other nitrogen losses.
- The attached document to the certification protocol presents detailed good practices for soybean co-inoculation.

Achievement Indicator: Fertilization and Soil Correction Based on Technical Analyses and Recommendations (Quantity, Placement, Frequency)

Fertilization management is crucial for reducing net GHG emissions due to its impact on the total soil organic carbon (SOC) content (Ortas; Bykova, 2020; Dold et al., 2021), the high energy cost associated with the mining, processing, and transportation of fertilizers and correctives (upstream emissions), and direct GHG emissions related to nitrogen fertilizers (N_2O) and acidity correctives – lime (CO_2) (Matsuura et al., 2018). Therefore, adopting appropriate fertilization practices is essential to improve the GHG balance in soybean production systems.

For eligibility to the LCS Standard, the production system must be carried out in an area correctly characterized by soil chemical analysis in the 0-20 cm and 20-40 cm layers, with georeferenced sampling, to map the area, and performed at least once every three years. In addition, a few soil parameters need investigation: SOC (total soil organic carbon), pH, H+Al, CTC (Cation Exchange Capacity), Al, P, K, Ca, and Mg levels.

The annexed document defines requirements for sampling, number of samples, determination methods, and collection methods. Companies accredited to the program must independently conduct sampling and analysis. Additionally, recommendations are to:

- **a) Evaluate soil physical fertility** using direct methods to qualify soil structure, such as rapid soil structure diagnosis (Ralisch et al., 2017);
- **b) Evaluate biological soil fertility** using soil bioanalysis methodologies (BioAS) (Mendes et al., 2021);
- **c) Quantify nutrient balance** in the production system using tools like Afere (Embrapa Soja, 2023b).

This part of the guidelines emphasizes that adopting sustainable agricultural practices, especially those that reduce GHG emissions, is essential for obtaining the LCS Standard. These practices involve managing soil, fertilizers, and biological inoculation to ensure better productivity and environmental outcomes.

Technically Prescribed Pesticides

Adopting rational cultural management based on technical knowledge and efficient chemical and biological agricultural inputs is essential for commercial crops to achieve high productivity, which is crucial for improving the GHG balance in soybean production systems. Furthermore, appropriate technical guidance and quality products can lead to the rational use of these inputs, which can also contribute to mitigating GHG emissions, especially upstream emissions. In this sense, for eligibility for the LCS Standard, the soybean production system must adopt only products prescribed by a legally qualified professional.

Eligibility Criterion: Complementary Agricultural Practices

While the use of efficient products and the adoption of the NTS, co-inoculation, and rational fertilization have a significant impact on the GHG balance of soybean production systems, other agricultural practices and technologies also contribute to mitigating net GHG emissions:

a) Agricultural Risk Zone Mapping (ARZM);

b) Integrated Pest Management (IPM), Integrated Disease Management (IDM), and Integrated Weed Management (IWM);

c) Other soil conservation practices and system managements complementary to NTS;

d) Use of high-quality seeds;

e) Integration of crop-livestock-forestry systems;

f) Adoption of digital and georeferenced tools for site-specific management, among others.

These are techniques that producers can use based on the capabilities of their local conditions. While not mandatory, the more widespread and effective the use of these practices, the better the results in terms of avoided emissions and carbon sequestration per metric ton of grain produced will be.

To encourage the adoption of these recommended practices and to promote a soybean production system that reduces GHG emissions, the Complementary Agricultural Practices Criterion uses the Sustainable Agricultural Practices Adoption Index (SAPAI) as an achievement Indicator (section 2.2.1.). The candidate production system must meet increasing minimums (targets) over time to encourage its continuous improvement.

Established Value for the Sustainable Agricultural Practices Adoption Index (SAPAI)

SAPAI is an indicator based on practices contributing to GHG mitigation to complement the Mandatory Agricultural Practices described in section 2.1. The Sapai can range from 0 to 10 and reflects the adoption status of recommended practices.

To be eligible for the LCS Standard, the soybean production system must meet minimum and increasing Sapai values over time, aiming to set goals to ensure continuous improvement. The annexed certification protocol document for granting the LCS Standard contains detailed complementary agricultural practices that form part of the Sapai, and the minimum values to be met by candidate production systems. A specific document attached to the Technical Guidelines describes the calculation methodology for Sapai.

Eligibility Criterion: Improvement of the Carbon Balance

Several tools provide estimates of GHG emissions in Brazil, such as the Seeg platform, which gives results segmented by sectors (Figure 3). As noted in the estimations from the tool (Seeg, 2023), agriculture has been the main contributor to GHG emissions in Brazil due to:

- **Land Use Change (LUC)**, especially the clearing of natural vegetation for agricultural activities; and
- **Emissions linked to agricultural production itself**

Addressing these two emission sources and promoting the use of technologies that remove atmospheric CO_2 is fundamental for the success of any instrument aiming at improving the GHG balance in Brazilian agriculture. In this context, the Carbon Balance Improvement Criterion aims to contribute to GHG mitigation through two Achievement Indicators:

2.3.1. GHG Emissions Intensity (GHGEI)

2.3.2. Emissions related to Land Use Change.

Achievement Indicator: GHG Emissions Intensity (GHGEI) below Baseline (Reference)

To implement and validate GHG mitigation actions in soybean production systems, one needs to have a tool for calculating GHG emissions associated with the crop, which allows identification of the chief emission and removal factors.

In this context, the LCS Program has adopted and adapted the GHGEI, an Achievement Indicator created to relate net GHG emissions (Global Warming Potential - GWP) (Mosier et al., 2006) with soybean crop productivity (Bayer et al., 2014, 2016). The embedded goal in its design is for the soybean production system to improve the GHG balance by adopting sustainable agricultural practices.

The GHGEI calculation considers the emissions of the three main GHGs in the agricultural context: carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). These gases have different GWP values considering a 100-year time horizon (GWP100). These values, updated by the IPCC with the most recent version, are provided in the

6th Assessment Report (Armour et al., 2021). CO_2 is the gas with the lowest GWP100, considered as a standard equal to 1. Methane from fossil and non-fossil sources has a GWP100 of 30 and 27, respectively, meaning that 1 kg of methane emitted has a global warming effect up to 30 times greater than CO_2. Nitrous oxide, in turn, has a GWP100 of 273, implying that this gas has a warming potential 273 times greater than CO_2. The combined mass of these gases per unit area (kg ha^{-1}), expressed in CO_2 equivalent (CO_2e), is done according to Equation 1.

This section emphasizes that adopting complementary agricultural practices and technologies is essential for improving the carbon balance and reducing GHG emissions in soybean production systems. It introduces an indicator (Sapai) to track the adoption of these practices over time and aims to ensure continuous improvement in GHG mitigation efforts. It also stresses the need to assess and manage emissions through specific tools like the GHGEI, which quantifies the carbon footprint of soybean production.

$$CO_2e = (CO_2\ x\ 1) + \left(CH_4\ x\ GWP100_{CH_4}\right) + \left(N_2O\ x\ GWP100_{N_2O}\right) \qquad (1)$$

Where:

- CO_2e= GHG emissions expressed in kg ha^{-1} of carbon dioxide equivalent;
- CO_2 = Carbon dioxide emissions, in kg ha^{-1};
- CH_4 = Methane emissions (fossil or non-fossil), in kg ha^{-1};
- GWP100(CH_4) = Global Warming Potential (GWP) over a 100-year horizon for methane (according to the latest IPCC update);
- N_2O = Nitrous oxide emissions, in kg ha^{-1};
- GWP100 (N_2O) = Global Warming Potential (GWP) over a 100-year horizon for nitrous oxide (according to the latest IPCC update).
- In turn, by using Equation 1, it is possible to calculate GHGEI.

$$GHGEI = \frac{GWP\ soy}{Prod} \tag{2}$$

Where:

- GHGEI = Greenhouse gas emission intensity of the soybean production system, in kg of CO_2e per metric ton of soybean produced in the evaluated harvest;
- GWPsoy = Global Warming Potential (GWP) associated with the soybean production system, in kg ha^{-1} of CO_2e in the evaluated harvest;
- Prod = Soybean grain productivity, in t ha^{-1}, in the evaluated harvest.

The annex to the certification protocol outlines the minimum methodological requirements for estimating soybean productivity. In turn, the calculation of GWP_{soy} considers the CO_2e emissions during the crop production process (inputs and crop residues) (source), as well as CO_2 removals due to carbon fixation (sink) in soil organic matter (SOM) or in vegetal biomass, according to Equation 3.

In the case of vegetal biomass, only removals from woody tree species intended for timber production for sawmill products, aiming to create durable products such as furniture, wooden buildings, fences, etc., are considered as removals.

Vegetal biomass from herbaceous species, or even from woody species used for biofuel purposes, treated as plant residues left on the soil, or intended for other products with a short lifespan, are not accounted for as removals. In these cases, emissions from the decomposition or burning of biomass from biofuel crops are balanced by the removals from the growth of new crops planted in the same area, making the biomass stock balance approximately stable in the long term.

$$GWP_{soy} = \left(E_{inp} + E_{res}\right) + RR \tag{3}$$

Where:

- Einp = GHG emissions (CO_2, N_2O, and CH_4) associated with the inputs used in the soybean production process in the evaluated harvest, in kg of CO_2e ha^{-1};
- Eres = N_2O emissions associated with the decomposition of soybean crop residues in the evaluated harvest, in kg of CO_2e ha^{-1};
- RR = CO_2 removal rate, through its fixation in soil organic matter (SOM) or vegetal biomass, expressed in kg of CO_2e ha^{-1} year^{-1}. Removals, when they occur, are preceded by a negative sign (negative emissions), indicating that this term is, in practice, subtracted from the sum of the two previous terms.

The GHG emissions associated with the inputs are estimated through Life Cycle Analysis (LCA) (Matsuura et al., 2018) by using a cradle-to-gate approach. That is, it considers emissions from processes, operations, and inputs used during the soybean production stages in the field and subsequent cleaning and drying of the grains to 13% moisture, excluding those associated with the storage and processing of the grains. The emissions associated with inputs are calculated according to Equation 4.

$$E_{inp} = E_{upstream} + E_{process} + E_{ee} \tag{4}$$

Where:

- Eupstream = Upstream emissions or background emissions, referring to the processes of mining/extraction, processing, transporting, and storing, among others, involved in the production of inputs used in the soybean production system, in kg CO_2e ha^{-1}.
- Eprocess = Direct emissions from the inputs used in the soybean production system, in kg CO_2e ha^{-1}.
- Eee = Indirect emissions from the generation of electricity purchased from third parties.

Upstream process and indirect emissions correspond to scopes 3, 1, and 2 within the emission accounting and reporting standards for products (GHG Protocol, 2011).

In general, the emissions calculated according to Equation 4 require the inventory of all inputs and their respective quantities used per unit area in the soybean production process. These quantities are multiplied by scientifically accepted and published emission factors, such as those found in internationally recognized databases (e.g., Ecoinvent) or accessible in international emission inventory protocols such as those developed by the IPCC. Priority shall be given to the use of emission factors determined for Brazilian conditions, taking into account regional variations, and published in internationally recognized media (e.g., IPCC Tiers 2 and 3). The annex to the certification protocol provides details on the calculation procedures and the input inventory process.

For inputs that are shared with other crops in the same production system (e.g., electricity purchased from third parties and soil acidity correctives), the methodology described here recommends the use of allocation methods, which are detailed in the material annexed to the certification protocol. A similar approach should be used for emissions associated with the cultivation of cover crops or “service” crops, which should also be shared among the revenue-producing crops in the soybean production system.

N_2O emissions from the decomposition of soybean crop residues are obtained indirectly by considering three main pieces of information: 1) the number of aboveground and root residues in kg ha^{-1}; 2) the nitrogen content in the aboveground and root residues in g kg^{-1}; and 3) the emission factor for N_2O (% of nitrogen released from soybean residues that is converted to N_2O). The modeling of these three pieces of information is based on the best and most recent scientific data available, with priority given to IPCC Tiers 2 and 3. The appendix to the certification protocol provides the methodological details of the estimation the E_{res} parameter.

To calculate the annual CO_2 removal rate through fixation in SOM or vegetal biomass, use Equation 5.

$$RR = \frac{CS_{t2} - CS_{t1}}{t} \tag{5}$$

Where:

- CS_{t2} = Carbon stock fixed in soil organic matter (SOM) or in vegetal biomass from a tree crop intended for timber production, at time t_2, in kg of $CO_2e\ ha^{-1}$;
- CS_{t1}= Carbon stock fixed in SOM or in vegetal biomass from a tree crop intended for timber production, at time t1, in kg of $CO_2e\ ha^{-1}$;
- t = Time (years) between the two assessments ($t_2 - t_1$).

If the production system includes more than one form of removal, the final CO_2 removal rate (RR) will be the sum of the values obtained for each form (e.g., SOM + biomass). Additionally, before CO_2 removals can be credited to soybeans, they must be shared with other commercial agricultural activities in the LCS areas using scientifically valid and internationally accepted allocation methods. The material attached to the certification protocol describes the details of the RR sampling procedures, calculation and allocation methods. RR assessments must shall be repeated at intervals of no more than three years.

Equations 2 to 5 are applied to production systems eligible for the LCS label as well as to a reference production system, which, in the case of this certification, refers to the typical soybean production system of the region. Within the scope of TCG 2 (Table 1), the typical production system represents the standard agricultural practices and technologies used in the soybean production process in each region, exhibiting a representative average grain productivity for that region, obtained from official crop survey agencies or through prediction models. The minimum spatial subdivision considers the soybean macro-regions (MRS, in Portuguese) according to the most recent approximation at the time of certification. Currently, soybean production in Brazil is regionalized into 5 MRS, according to the 3rd approximation (Kaster; Farias, 2012). Typical production systems will be updated at least once every three years. The characterization of typical systems for each region, to be used as the basis for applying equations 2 to 5, is included in the annex to the certification protocol.

Once the GHGEI values for the candidate and typical production systems are estimated, the variable ΔGHGEI (kg CO_2e t^{-1}) is calculated according to Equation 6). Negative values of ΔGHGEI indicate that the net emissions in the candidate production system are lower than in the typical system, demonstrating additionality of GHG mitigation compared to the regional production standard (business-as-usual). Figure 7 illustrates this logic, showing that the integration of good agricultural practices gradually reduces the GHGEI in the candidate system compared to the typical system, generating increasing values of the ΔGHGEI module, thus expressing the additionality of each practice for reducing GHG emissions.

$$\Delta GHGEI = GHGEI_C - GHGEI_T \quad (6)$$

In which:

- $GHGEI_C$ = Greenhouse gas emission intensity estimated for the production system candidate for the LCS label, in kg CO_2e t^{-1} $year^{-1}$;
- GHGEIT = Greenhouse gas emission intensity estimated for the typical regional production system, in kg CO_2e t^{-1} $year^{-1}$.

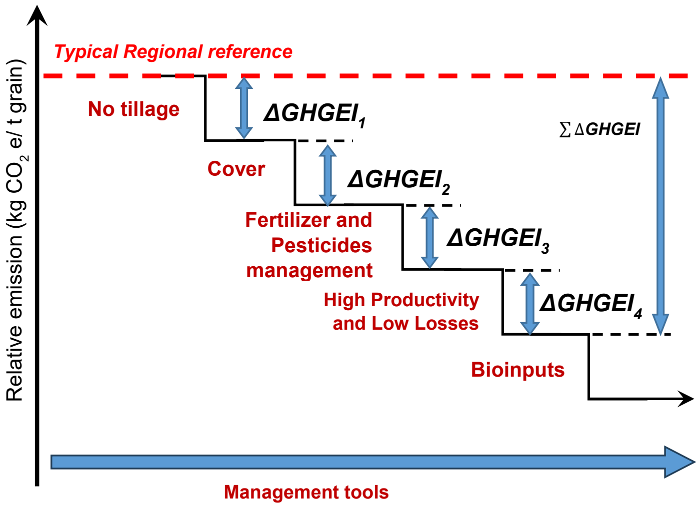


Figure 7. Diagram representing the reduction of greenhouse gas emission intensity (GHGEI) in the candidate production system compared to typical regional systems (ΔGHGEI) due to the integration of distinct good agricultural practices.

Source: adapted from Nepomuceno et al. (2023).

The values of $GHGEI_c$ and $\Delta GHGEI_t$ can be biased by extreme climatic events that significantly affect grain productivity, such as droughts, hail, floods, frosts, etc. This situation is partially addressed using modeled or regional average productivity to estimate GHGEI in the typical system. However, in the case of local climatic events common to all MRS, the GHGEI and ΔGHGEI may not reflect the actual situation. Therefore, although the GHGEI and ΔGHGEI values are calculated annually, the final value for assigning the label (Figure 8) should be the average of three harvests. In this sense, to be eligible for the label, the average ΔGHGEI must be negative, or even positive, if due to a proven influence of meteorological factors. Additionally, the material annexed to the certification protocol provides the criteria for excluding specific harvests from the calculation of this average.

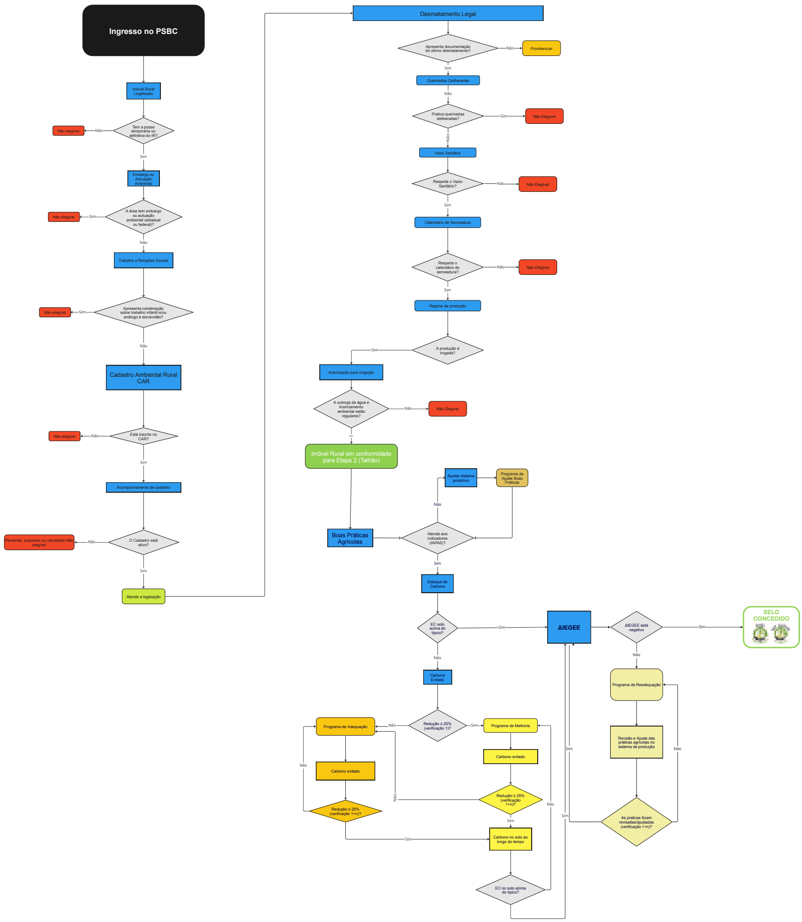


Figure 8. GHGEI regularization flowchart.

The calculation methodology described above shows that the LCS label takes into account two primary modalities of GHG emission reduction. The first refers to the avoided carbon associated with the reduction of emissions (kg CO_2e t^{-1} of grain), resulting from the rational use of inputs through good agricultural practices. The second refers to the carbon sequestered through fixation in soil organic matter or woody biomass destined for sawmill wood production.

In the specific case of CO_2 removed through SOM fixation, the carbon stocks content (CSC) in the soil of the area under the candidate production system should be greater than those observed for the typical regional system, considering variations in factors such as climate, altitude, and soil texture. This requirement aims to value production systems that, due to being long-term systems, have already led to significant increases in CSC compared to typical systems. Since these systems have already accumulated high CSC, it becomes more difficult to achieve increases that reflect significant RR values, as the accumulation of CSC in the soil follows an exponential function with decreasing increments, as demonstrated in the unicompartimental model proposed by Hénin and Dupuis (1945) and applied in Brazil by various research works (e.g., Bayer et al., 2006). The material annexed to the certification protocol presents the C stocks in SOM of typical systems and the updated methodology for calculation.

Achievement Indicator: Compensation for Land Use Change Emissions

The Forest Certification Protocol (FCP) allows for legal deforestation as long as mandatory environmentally valued areas (PPA, LR, CU, and RUA) are preserved (see section 1.1.4). On the other hand, as indicated in Figure 3 (introduction section), Land use changes and deforestation have been leading sources of greenhouse gas emissions in Brazil, representing a significant obstacle to its mitigation.

To integrate such dichotomous aspects, the LCS certification follows the BFC without imposing a compulsory reference benchmark for legal deforestation. However, if a land use change from a determined type (natural vegetation, planted pasture, permanent crops, sugarcane, and silviculture) to temporary crops has occurred at any point in the candidate area in the last 20 years from the certification audit dates, the emissions (or removals) resulting from this change (E_{LUC}) will be estimated and considered in the LCS certification process. The E_{LUC} calculation uses the method of the difference in stocks measured at two points over time (Ongle et al., 2006, 2019). In the case of LCS, these points represent the previous land use and the current use after conversion. Carbon stocks in the biomass of the aerial parts and roots, in SOM, and dead plant material on the soil surface are considered. These stocks are quantified for the previous and current land uses, and the difference is diluted over 20 years. In LCS certification, E_{LUC} accounts for CO_2 emissions or removals and N_2O emissions due to N mineralization, which occurs alongside the mineralization of CSC (FSOM- Fossil Soil Organic Matter) (Klein et al., 2006; Hergoualc'h et al., 2019). For N_2O emissions, tier 1 emission factors from the latest IPCC versions are used, or, when available, values obtained for Brazilian conditions (tiers 2 or 3).

$$E_{LUC} = \frac{(EC_{prev} - EC_{curr}) + [(E_{N_2O}) x \ (GWP100_{N_2O})]}{T} \qquad (7)$$

Where:

- E_{LUC} = emissions or removals resulting from land use change (kg CO_2e ha^{-1});
- EC_{prev}= carbon stock (biomass of shoot and roots, soil, dead plant material on the soil surface) related to the previous land use, converted to CO_2e and expressed in kg ha^{-1};
- EC_{curr} = carbon stock (biomass of shoot and roots, soil, dead plant material on the soil surface) related to the current land use, converted to CO_2e and expressed in kg ha^{-1};
- E_{N2O} = N_2O emissions related to N mineralization (FSOM). If EC_{prev} – EC_{curr} results in negative values, indicating CO_2e removal, the value of E_{N2O} is considered null;
- $GWP100_{N2O}$ = global warming potential over a 100-year horizon for nitrous oxide, according to the latest IPCC update;
- T = time (20 years).

The values of EC_{prev} are obtained from databases available for different municipalities in Brazil through the BRLUC platform (brluc.

cnpma.embrapa.br) (Garofalo et al., 2022), corresponding to tier 2 of the IPCC. The values of EC_{curr} are measured in the areas where the production systems of candidates for the LCS label are conducted. In the case of the soil CSC, the values correspond to the 1st evaluation made in the area. Any increases in CSC in subsequent assessments will be considered in the calculation of ∆GHGEI, according to Equations 2 to 6.

For the LCS label eligibility, the production system conducted in an area deforested for less than 20 years at the date of the certification audits must compensate for the E_{LUC}. This compensation must be proven in all audits until the period since deforestation exceeds 20 years. One option for compensation is to meet the criterion of Equation 8 so that the ratio between E_{LUC} and the average soybean grain yield (in kg CO_2e t^{-1} of grains) is lower than the mitigation provided by good agricultural practices in the candidate production system, expressed by the ∆GHGEI module. That equation is valid only if the value of ∆GHGEI is less than zero, as foreseen by the Achievement Indicator 2.3.1.

$$\frac{E_{LUC}}{Prod} < |\Delta GHGEI| \quad (8)$$

In which:

- Prod = average soybean yield in the area subject to the candidate production system in the three subsequent harvests after the certification process begins.

It is important to emphasize that, similarly to what is foreseen for the calculation of ∆GHGEI (section 2.3.1), the final value of both terms in Equation 8, for assigning or not assigning the label, must reflect the average of three harvests, aiming to minimize the impact of extreme climatic events on productivity.

Another possibility of compensation foreseen in the LCS certification is the change of land use through reforestation, permanent pasture, or a combination of both, on part of the area associated with the candidate production system. The annual accumulation of carbon in the soil and/or plant biomass on this part of the land, subtracted from the emissions from the inputs used to establish, manage and grow the crops there (calculated according to Equation 4), is directly added to the RR value of the whole production system (Equation 5). In this way, compensation from land use change in part of the area automatically added to the ΔGHGEI value obtained in the soybean production system, increasing the chances of compensation.

After 20 years from the date of deforestation, this Achievement indicator is removed from the auditing process, as from that point onwards $E_{LUC} = 0$.

The material annexed to the certification protocol provides detailed information regarding the E_{LUC} calculating process, the compensation options, and its application as an Achievement Indicator.

The calculation of E_{LUC} will be carried out using the same calculation tool built by Embrapa to estimate GHGEI. Although LCS certification does not restrict legal deforestation, the dossier with audited information on the candidate area will inform the dates of land-use conversions. That will allow producers who meet specific markets with zero-deforestation reference benchmarks to access them.

Integration of eligibility criteria and Achievement indicators in TCG 2

The flowchart in Figure 7 summarizes and integrates the eligibility criteria and achievement indicators related to TCG 2 - Production system adaptation (Table 1). In addition to meeting the qualitative eligibility criteria (mandatory and complementary agricultural practices), to be eligible for the LCS label, the candidate area must have a CSC higher than the typical production system and negative values of ΔGHGEI, demonstrating that the soybean production system has mitigated GHG emissions compared to the regional typical system. In addition, if the last land use change occurred within the last 20 years, E_{LUC} must be offset for the candidate production system to be eligible. If the conversion occurred more than 20 years ago, then $E_{LUC} = 0$, and the candidate production system is eligible for the LCS label.

If the system does not have a higher soil CSC than the regionally typical system, the candidate production system will be redirected to the Adequacy or Improvement programs, depending on whether the avoided CO_2e emissions (avoided carbon) are below or above 15%. The adequacy program focuses on planning and commitment to implement practices, aiming to reduce emissions, primarily through the rational use of inputs. When the avoided carbon exceeds 25%, either directly or after passing through the adequacy program, the production system advances to the improvement program, focused primarily on planning and adopting practices, that increase the RR of CO_2 through fixation in the SOM, until the CSC in the soil exceeds those observed in the typical profile. Once this phase is completed, the production system returns to the ΔGHGEI evaluation point. If ΔGHGEI is not negative in one of the audits, indicating that the GHGEI is equal to or higher than the typical system, the certified production system will be integrated into a program of adjustment of agricultural practices to induce emission reductions and increase removals until ΔGHGEI becomes negative again.

The calculation procedures, as well as the details of the re-adjustment and improvement programs foreseen, are covered in the document annexed to the certification protocol for assigning the LCS label. The calculation tool is described in a specific document (annexed to the Technical Documents).

Final Considerations

The Low Carbon Soybean label is an initiative of Embrapa, in partnership with the private sector, which aims to parameterize the

GHG emissions of soybean production systems based on the MRV (measurable, reportable, and verifiable) methodology, which is scientifically based. Its adoption by producers is entirely voluntary, and their participation in this green initiative can be demonstrated both qualitatively and quantitatively. This initiative provides recognition of the environmentally sustainable origin of their product and, as result, opens up opportunities for financial compensation, including adding value to the marketed soybean product and even obtaining lower interest rates and better premiums on agricultural insurance. These initiatives are already working in the marketplace. In addition, the Low Carbon Soybean concept has a solid and reliable scientific basis, which is recognized by the main stakeholders on the soybean chain, considering the numerous barriers that the market and civil society have created against Brazilian soybean producers. It is important to reiterate that the certification, besides being voluntary, will be private and based on third parties. Thus, once validated by Embrapa and its partners, the methodology will be licensed to trained and certified entities to implement the operation of the LCS protocol in the market.

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