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AGRICULTURAL CORN PROFILES FOR BRAZILIAN STATES – REFERENCE I FOR THE RENOVABIO POLICY

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Summary

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Abstract

RenovaBio is the policy that encourages the decarbonization of the transport sector in Brazil, promoting the use of biofuels with better energy-environmental efficiency compared to fossil fuels. To this end, RenovaCalc is used as a carbon accounting tool and its content includes fields to describe various stages of ethanol, biodiesel, biomethane and aviation biokerosene production, in line with the Life Cycle Assessment of products. For ethanol, producers who use corn and sugarcane, as feedstock, can fill in primary data (specific to the current system) or default data (data from a typical system, added with penalties), the last one for scenarios where verifiable information is missing. The current profile of the typical system, used as a base for default data, reflects production on a national scale, which may not well represent the different producing regions of Brazil. Hence, this study aims to characterize typical corn production systems, taking into account the diverse realities of Brazilian producing regions. Following the imposition of penalties, these characterizations, considering regional scale, can be used within a default data option in RenovaCalc. In the study, two policy premises were acknowledged: (i) encouraging the use of primary data in RenovaCalc and (ii) transparency in the methodology and parameters used in the tool. The study adopted the state scale, as the smallest level to characterize regional Brazilian profiles. The methodology involved identifying the Brazilian states that produce corn in the 1st and 2nd crop periods; the search for reliable sources regarding regional scale crop production methods in each harvest is followed by the combination of the production profiles of the 1st and 2nd crop for each state. Subsequently, efficiency indices for the consumption of inputs were proposed to be used in RenovaCalc.

Simulations were also carried out for carbon intensity (CI) in two versions of the toll, the current one (7.0) and other with future updates (9.0). Profiles were characterized based in inventories published on ecoinvent v3.9, GFLI v2022 and SICV Brazil 2022. As an improvement, there were optimized the distinction between the sources of limestone and fertilizers, in addition to the differences in the quantity of inputs consumed, compared to the current typical national profile. In simulations using RenovaCalc version 7.0, the CI of state profiles ranged from 253 to 402 kgCO2eq/Mg of corn, while using RenovaCalc version 9.0 (future version), the CI variation was 256 to 410 kgCO_2eq/Mg of corn. All simulations exceeding the current national profile of 253 kgCO2eq/Mg of corn, except for Mato Grosso and Goiás (more efficient in corn production). Maranhão and Pará were characterized as the states with the highest CI. It concluded that updating the typical corn profile on a regional (state) scale is satisfactory to represent realities of Brazilian producing regions. After adding the necessary penalties for policy security, it is better to use the typical corn profile on a state rather than a national scale, as default data at RenovaCalc. The study also recommends the updating of biomass production profiles, following the time interval consistent with other updating of the policy, maintaining the assertiveness, without violating its basic premises.

Keywords: *Zea mays*, cropping system, GHG emissions, carbon intensity

1. Introduction

1.1. RenovaBio

Brazil has committed to addressing the global impacts of climate change by ratifying the Paris Agreement. To fulfill its obligations, the government has established ambitious targets: a 37% reduction in greenhouse gas (GHG) emissions by 2025, and a 50% reduction by 2050 relative to 2005 levels (Federative Republic of Brazil, 2022). These goals demanded the implementation of strategic measures, including a substantial increase in the proportion of renewable resources in the energy matrix, including biofuels. In this sense, it was signed the National Biofuels Policy, known as RenovaBio (Law No. 13,576, December 26, 2017), focusing the improve of role of sustainable biofuels in the Brazilian fuel energy matrix.

RenovaBio encourages certified biofuels to receive decarbonization credits (CBIO), as a reward for an environmental service, if they prove the reduction of GHG emissions per MJ, over their life cycle, compared with traditional fossil fuels. This mechanism is designed to promote the energy and environmental efficiency of each certified biofuel. These credits can be traded on financial markets, providing additional income for producers (MME, 2017). Currently, RenovaCalc is used as the official carbon accounting tool for RenovaBio, supporting seven biofuel production pathways, for ethanol (both first and second generation), biodiesel, biomethane, and aviation biokerosene (Matsuura, 2018).

The first step in biofuel certification, at RenovaBio, is to evidence compliance with the eligibility criteria for the energy feedstock. It is indirectly related to some of the environmental laws, in force in the country, such as the “Brazilian Forest Code” (“Código Florestal Brasileiro”, Law nº 12.651, of May 25, 2012). These criteria require the production of biomass in rural properties following the “Rural Environmental Registry” (“Cadastro Ambiental Rural”, CAR, in active or pending status) and in areas free from native deforestation, after November 2018 (publication date of Resolution Nº. 758/2018, of the National Agency for Petroleum, Natural Gas and Biofuels - ANP). This risk management mechanism is designed to inhibit the expansion of energy biomass production onto native vegetation, thereby avoiding GHG emissions resulting from this category of land use change (LUC). Thus, the eligibility stage associates the generation of CBIO with sustainable land use.

The second step of certification involves carbon accounting converted into equivalent carbon, using RenovaCalc (Matsuura, 2018). It follows the premises of the life cycle assessment (LCA) of products, which is standardized by ISO 14040:2006, ISO 14044:2006 (ISO, 2006 a, b) and ISO 14067:2018 (ISO, 2018). In this context, emissions from every stage of the biofuel life cycle are carefully assessed. This accountability considers a comprehensive database to express the carbon intensity (CI) of inputs, including fuel and electricity, encompassing emissions from agricultural, industrial, and distribution processes, including specific filling structures, as depicted in Figure 1. Furthermore, emissions from fuel consumption in vehicle engines are accounted for using values derived from scientific literature.

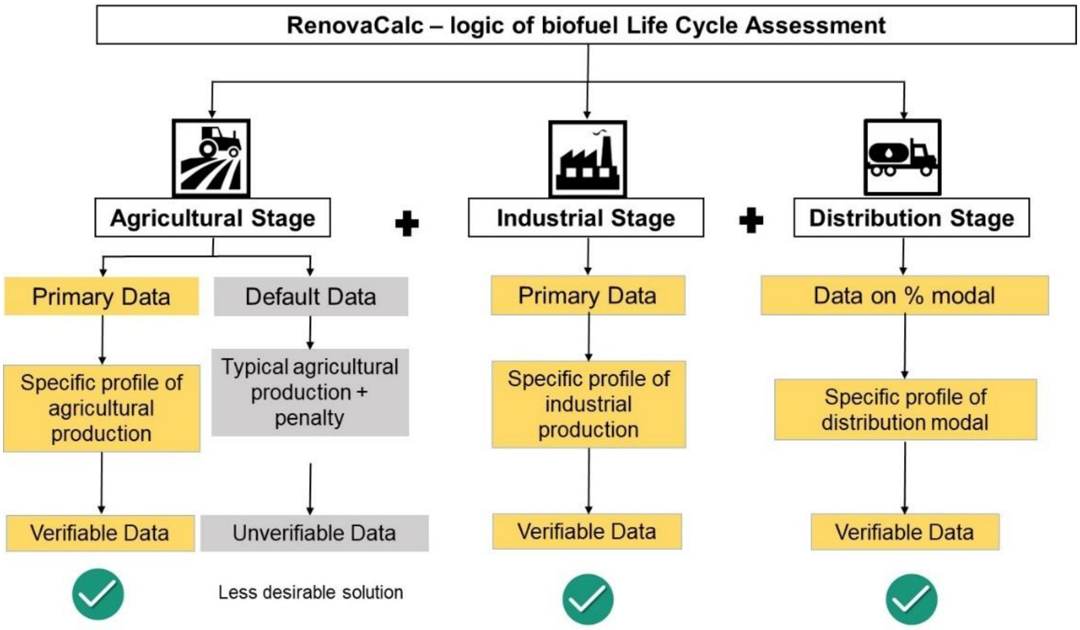


Figure 1. Simplified diagram of the biofuel production steps (corn ethanol) considered in RenovaCalc, indicating the type of data required and the need for verification.

Accounting from agricultural stage at RenovaCalc allows the use of primary or default data for sugarcane, corn, and soybean, with plans of add palm oil, before 2025. The primary data option describes the specific biomass production profile, requiring verification of a broad set of data, carried out by certification bodies. Data of area, production, grain moisture and several inputs (soil amendments, chemical and organic fertilizers, fuels and other energy sources) are request, reflecting the efficiency in the field production system. On the other hand, the default data characterizes the typical biomass production profile, added with a penalty, with the function of ensuring that there is no underestimation of emissions from biomass production. In this case, the set of verifiable data is much more restricted. It is worth noting that the default option should only be used in cases where there is no verifiable information for all the parameters requested in RenovaCalc.

The penalty method used in the agricultural stage serves as a safeguard, particularly in the lack of primary, verifiable, and auditable information. This approach mitigates the risk of overestimating decarbonization bond issuance, which may not accurately correspond to the avoidance of 1 t CO_2eq. (equivalent to 1 CBIO). Consequently, it stands as a crucial mechanism in preventing instances of greenwashing.

Accounting from industrial stage, as well as the distribution stage, allows only primary data. The fields of industrial processing involve the output of products and co-products, consumption of industrial inputs, electrical energy, and other energy sources. In the distribution phase, emissions are calculated based on the declaration of transport mode usage, guided by pre-established profiles (Matsuura, 2018).

1.2. Corn as feedstock at RenovaCalc

Corn is the second most prominent commodity in Brazilian agriculture, produced in an area of 22.3 million hectares, in the 2022-2023 harvest, with a volume of 131 million Mg of grains (CONAB, 2024a). Its production occurs at different periods of the year, depending on the soil and climate conditions of the region of the country. The planting of the first (1st) crop is carried out in the traditional rainy season, which varies from August/September in the South region to October/November in the Southeast and Central West and the beginning of the year in the Northeast. The planting of the second (2nd) crop occurs under dryland conditions, in February/March, after the summer crop, and predominantly in the states of the Southeast and Central West, in addition to Paraná (Pereira-Filho & Garcia, 2021).

Corn serves primarily as a staple food for human consumption and animal feed.

However, in recent times, grains have found a new path within the biofuels industry, contributing to the production of ethanol and biodiesel. Biodiesel is derived from corn oil, extracted in the same industrial facility where ethanol is produced (see Figure 2), with yield ranging from 13-15L per Mg of corn (Moreira & Arantes, 2018). Other products of economic interest generated in this process are DDG (distillers dried grains) and DDGS (distillers dried grains with soluble), used in animal feed, with high added value (Milanez et al., 2018).

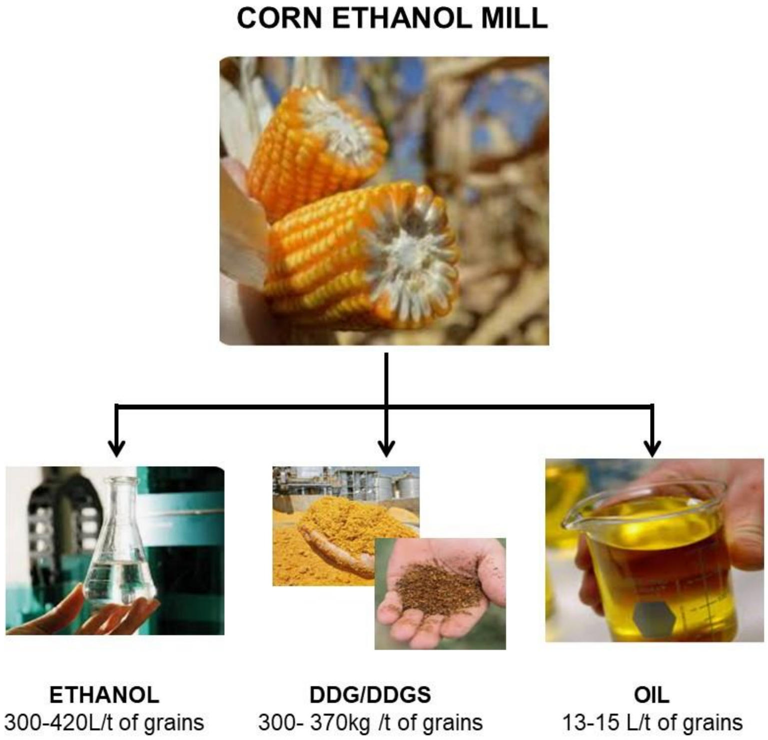


Figure 2. Representation of products generated in a typical industrial corn ethanol mill.

In the last years, corn ethanol has emerged as the fastest-growing biofuel within the Brazilian energy matrix, propelled not only by the encouraging force of the RenovaBio policy, but also, by its economic benefit as a destination for corn cultivated in the Center-West region of Brazil, where transportation expenses are notably high (Milanez et al., 2018). Looking back, we can see the production of 791 million liters of corn ethanol in 2018, compared to production of 6.1 billion liters in the 2023-2024 harvest (Figure 3), which corresponds to a significant increase in volume, in less than five years. In this scenario, the state of Mato Grosso took center stage, accounting for 81% of the total accumulated production, yielding 15 billion liters between 2018 and 2023. Following closely behind was the state of Goiás (CONAB, 2024b).

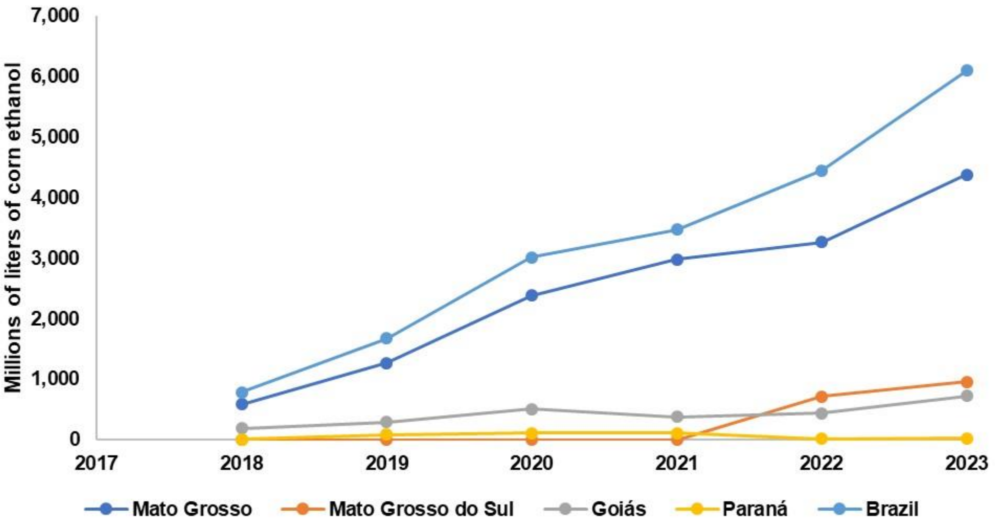


Figure 3. Evolution of corn ethanol production in Brazil. Source: CONAB, 2024b.

Corn ethanol production offers a complementary and valuable alternative to the production of ethanol from sugarcane, which is traditionally the main source of this biofuel in Brazil. Its expansion reflects the search for diversification in the biofuel matrix, contributing to national energy security. Figure 4 shows the evolution of the production of corn ethanol on the national scene, reaching 16.6% of the total production in 2023/24, with an increasing trend in 2024/25. The wide availability of feedstock in the national territory, associated with the extensive range of products generated in its processing (Figure 2), reinforced the establishment of corn as an important biomass in the RenovaBio policy.

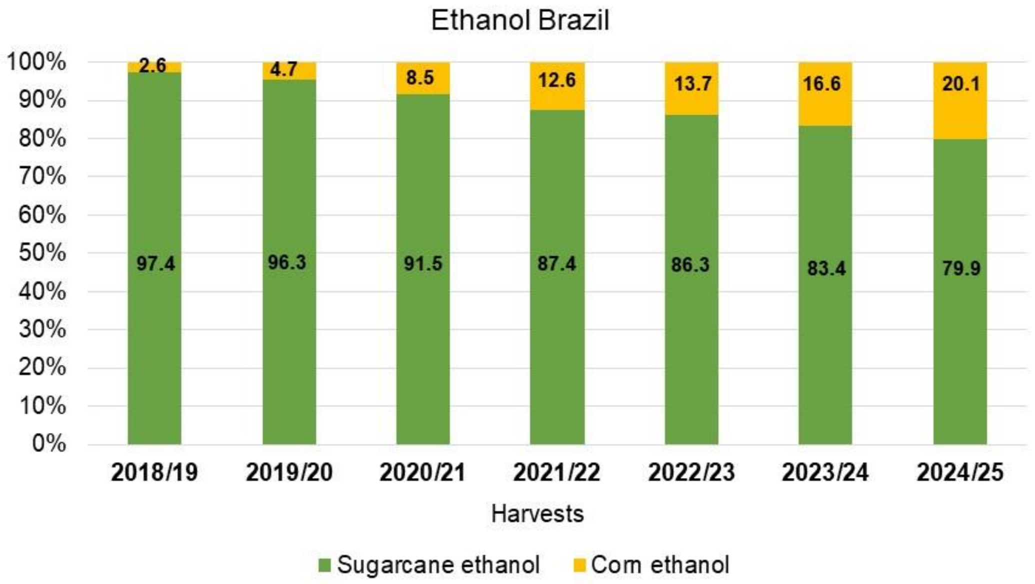


Figure 4. Percentage (%) of corn and sugarcane ethanol participation in national ethanol production, covering the 2018/2019 harvests until 2024/2025 (CONAB, 2024b).

The ease of processing is a favorable point for the use of corn, as it generates specialized facilities, flex units alongside sugarcane, and even in biodiesel plants through its oil extraction. In this way, the corn ethanol producer has specific fields to fill in in RenovaCalc (Matsuura, 2018), with the option of using primary or default agricultural data (Figure 1). Its utilization extends to benefiting the 13 certified corn ethanol mills under the policy (see Figure 5), as well as other biodiesel facilities.

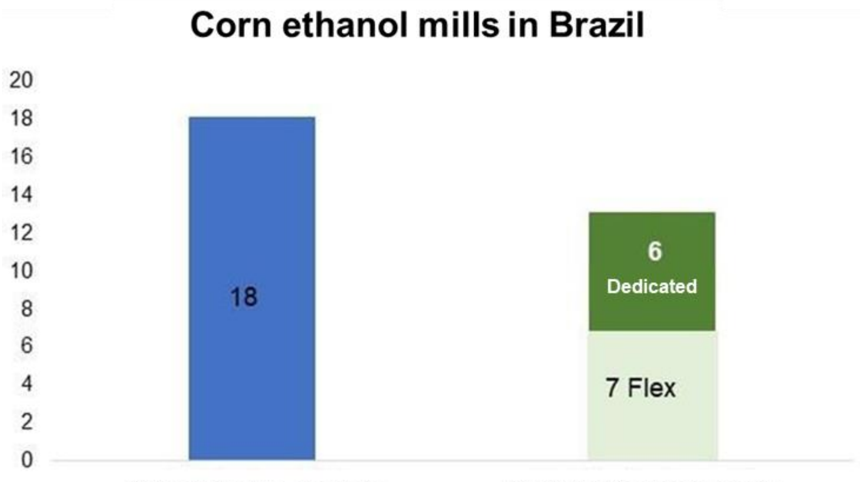
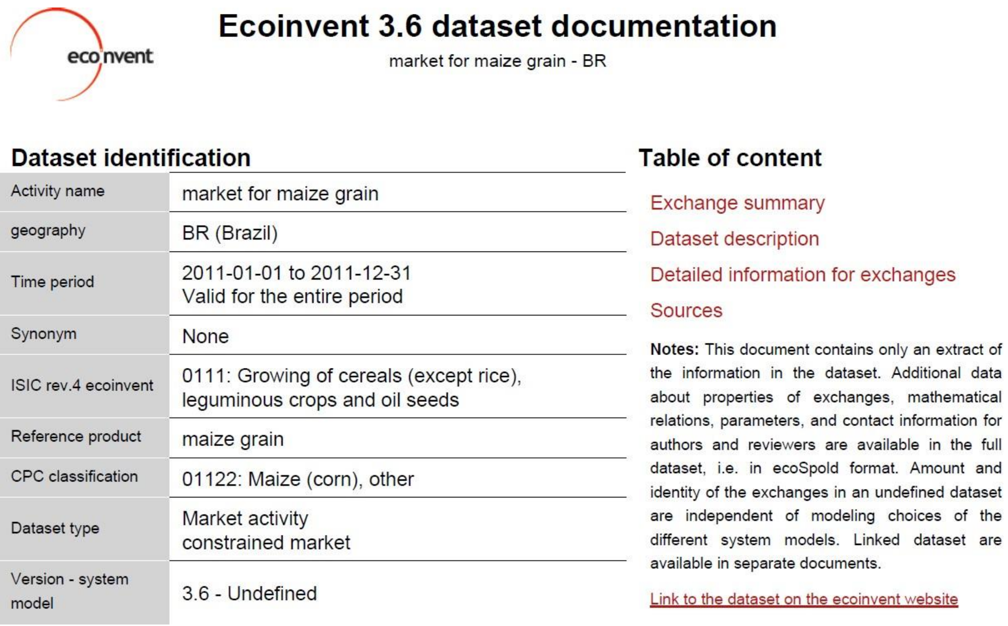


Figure 5. Corn ethanol mills authorized by the ANP to operate and those certified (dedicated and flex mills) at RenovaBio (ANP, 2023).

The availability of corn default data (typical + penalty) in RenovaCalc required the prior identification of the typical agricultural production profile of Brazilian corn. The first typical profile was recognized in 2017, during the construction of RenovaCalc and regulation of RenovaBio. It used a Brazilian corn production inventory (national scale), which was published in ecoinvent 3.6 (most current version available at the time), the main international database of Life Cycle Inventories (LCI). The base inventory utilized was the “market for maize grain BR” (Figure 6).



Ecoinvent 3.6 dataset documentation

market for maize grain - BR

Dataset identification

Activity name	market for maize grain
geography	BR (Brazil)
Time period	2011-01-01 to 2011-12-31 Valid for the entire period
Synonym	None
ISIC rev.4 ecoinvent	0111: Growing of cereals (except rice), leguminous crops and oil seeds
Reference product	maize grain
CPC classification	01122: Maize (corn), other
Dataset type	Market activity constrained market
Version - system model	3.6 - Undefined

Table of content

Exchange summary

Dataset description

Detailed information for exchanges

Sources

Notes: This document contains only an extract of the information in the dataset. Additional data about properties of exchanges, mathematical relations, parameters, and contact information for authors and reviewers are available in the full dataset, i.e. in ecoSpold format. Amount and identity of the exchanges in an undefined dataset are independent of modeling choices of the different system models. Linked dataset are available in separate documents.

Link to the dataset on the ecoinvent website

Figure 6. Identification of the “market for maize grain – BR” inventory in the ecoinvent database (version 3.6)

The LCI “market for maize grain BR” was done based on agricultural inputs and energy consumption most common in corn production, covering the period between 2012 and 2016, for the five largest producing states in Brazil (Figure 7). It was decided to represent the most significant harvest in each state: 2nd crop for the states of Mato Grosso, Paraná, Mato Grosso do Sul and Goiás and 1st crop only in the state of Rio Grande do Sul. Corn cultivation in the 2nd crop occurs after the production of another crop in the same year, which is normally soybeans. The elaboration of this LCI relied on consultations with Agrianual (cost survey bibliographies) validates by experts to gather essential information (Folegatti-Matsuura & Picoli, 2018).

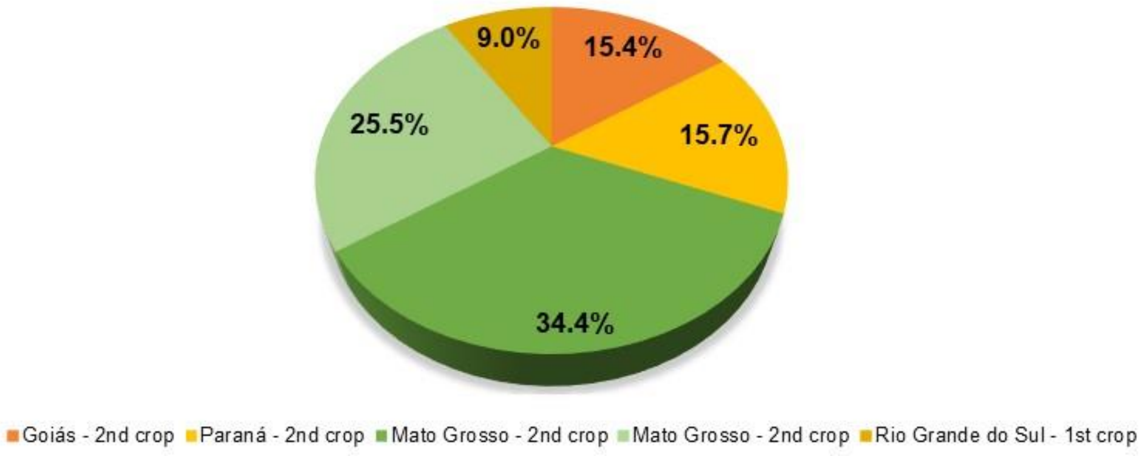


Figure 7. Participation of the main producing states in the typical corn production profile in Brazil, with 1st and 2nd crop production, used in RenovaCalc (up to version 7.0).

Frame 1 illustrates the typical corn production system described in the “Brazilian maize market”, which originated the efficiency indices used in ANP Resolution Nº. 758/2018. It was assumed that grain production occurs in a crop rotation/succession system, which implies the sharing of natural and technological resources between the commercial crops involved in the system. Limestone, for example, is an agricultural input that serves more than one commercial crop in a cropping system, based on the regular practice of producers of applying doses of 3000 kg/ha every 3 years. This allocation partially relieves corn with regard to GHG emissions (Mendes et al., 2021). The reference yield was obtained from the statistical data of the IBGE – Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística) for the calendar year 2015 (IBGE, 2015).

The fertilizer sources ($N\text{-}P_2O_5\text{-}K_2O$) were urea, as a nitrogen source, single superphosphate, as a phosphate source, and potassium chloride, as a potassium source. Pesticides, except glyphosate and 2,4-D, were considered in aggregate, by adding up the quantity of their active ingredients, and linked to the “pesticides, unspecified” inventory. The estimation of fossil fuel (diesel) consumption was derived from declarations of machinery and implement usage across various agricultural operations. Data processing and emission estimations were conducted by the LCA RenovaBio task force group (GT ACV), adhering to the protocols and guidelines established by Nemecek and Schnetzer (2011). It is noteworthy that the inventory deposited in ecoinvent also underwent third-party review, by LCA specialists.

Frame 1. The values of the parameters reflecting the typical condition for corn cultivation in Brazil during the 2012-2016 harvests are based on the Life Cycle Inventory (LCI) “market for maize grain BR” from ecoinvent 3.6.

Parameter	BR EI 3.6	General Description
Production System	100% in cropping system	Cropping system representing corn from the 1st (RS) and 2nd harvests (MT, PR, GO and MS), in rotation with other crops. Corn in monoculture was not considered.
Grain yield (kg/ha)	6,203	Brazilian corn yield for the 2015 harvest (IBGE).
Limestone (kg/ha)	262	Limestone calculated considering the application of approximately 3020 kg/ha every 3 years, respecting the allocation rate with other crops.
Seed (kg/ha)	29	Dose of seeds used in the main state producers, considering weighting by production.
N (kg/ha)	78	Nitrogen, using Urea as the predominant source, with doses obtained for the main producing states, considering weighting by production.
P_2O_5 (kg/ha)	68	P_2O_5, using Single Superphosphate as the predominant source, with doses obtained for the main producing states, considering weighting by production.
K_2O (kg/ha)	69	K_2O, using Potassium Chloride as the predominant source, with doses obtained for the main producing states, considering weighting by production.
Pesticides (kg/ha)	7.3	The sum of all active ingredients used throughout the agricultural cycle was used, with doses and number of applications obtained for the main producing states, considering weighting by production.
Diesel B10 (L/ha)	30	Diesel calculated based on the producers' declaration in terms of hour/machine for each of the operations used in the main producing states, considering the weighting by production.

MT: Mato Grosso; PR: Paraná; GO: Goiás; MS: Mato Grosso do Sul.

Table 1 presents the efficiency indices utilized in ANP Resolution No. 758/2018 (ANP, 2018) to characterize the typical profile of Brazilian corn. These indices were derived from Frame 1 by dividing each parameter by the grain yield. Subsequently, penalties were established to formulate the default profile. This process utilized the upper limit of values observed in the field for each parameter, achieved through consultations with experts and discussions within the LCI/Working Group of RenovaBio, emphasizing a conservative approach.

Table 1. Typical and default profiles for corn production used in RenovaCalc (up to version 7.0).

Parameter	Typical profile	Default profile
Calcitic or dolomitic limestone (kg/Mg of corn)	42.3	105.8
Agricultural gypsum (kg/Mg of corn)	-	-
Seeds (kg/Mg of corn)	4.6	11.6
Synthetic nitrogen fertilizers (kg N/Mg of corn)	12.6	31.4
Synthetic phosphate fertilizers (kg P_2O_5/Mg of corn)	10.9	27.3
Potassium synthetic fertilizers (kg K2O/Mg of corn)	11.2	28.0
B10[1] diesel fuel (L/Mg of corn)	4.8	12.0

[1] Diesel mixed with 10% of biodiesel

Fonte: Matsuura et al. (2018).

Simulations using RenovaCalc (up to version 7.0) led to carbon intensities (CI) of 253.5 e 557.8 kg de CO_2eq/Mg of corn, respectively, for current typical and default corn profiles. There were used information described on Table 1, added with yield of 6,203 kg/ha of grain (Frame 1).

1.3. Agricultural corn profiles represented on a regional scale

Currently, the diversity of management and technological advances used in corn field production can be well represented in RenovaCalc by filling in primary agricultural data. Associated with primary industrial data, it faithfully represents the corn ethanol certified on RenovaBio policy. However, the default (typical + penalty) option for the agricultural stage, as it is a generic alternative for data representation, does not present sufficient sensitivity to characterize technological updates and changes in corn production at the level of Brazilian regions.

The evolution of the RenovaBio policy has demonstrated the feasibility of enhancing the tool's ability to better represent corn producing regions, even for default data. This improvement aims to accurately reflect variations in corn production practices used across different regions of the country, maintaining the fundamental principle of the policy of rewarding producers based on their energy-environmental performance, and also, encourage the use of primary data throughout all stages of biofuel production.

The scarcity of public information with technical parameters of corn production across different regions of the country makes this task quite difficult, especially considering the size of Brazil and the fact that corn is produced in the country's 26 states (CONAB, 2024a). One potential database was RenovaCalc itself, coming from primary data provided by feedstock producers. However, it's noteworthy that, for corn ethanol, thus far, the primary data currently available solely represents the state of Mato Grosso (MT), lacking information for other states across the country. Other available documentation does not cover the entire national territory, such as Agrianual (2020, 2021, and 2022), which compiles data from nine Brazilian states (including the first and second harvests). The use of unofficial sectoral data could compromise the credibility of the policy.

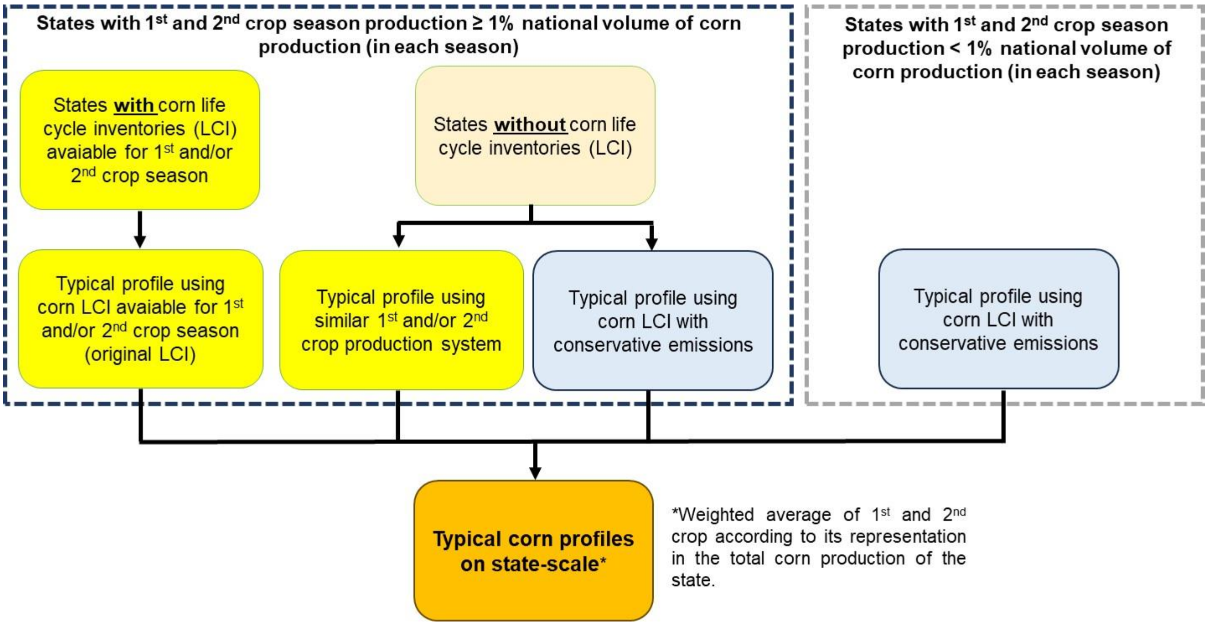
Thus, the present study aimed to characterize typical corn production systems, considering the reality of the different Brazilian producing regions, which, after suffering penalties, could be used in the “regionalized default” data option in RenovaCalc.

2. Methodology

The study was carried out by Embrapa Environment in partnership with Embrapa Corn and Sorghum with support from the National Agency for Petroleum, Natural Gas and Biofuels (ANP) and the private corn production sector. The initiative was part of the project: “Improving carbon accounting in RenovaBio” (FINEP- Embrapa).

2.1. Composition of corn production profiles

The regional scale was chosen as the smallest acceptable unit for regionalization, so as not to violate the premise of “Encouraging the use of primary data in RenovaCalc”, adopted in RenovaBio (ANP, 2018). Figure 8 shows the simplified scheme of the strategy for constructing the typical corn production profile for each of the Brazilian states.



*Weighted average of 1st and 2nd crop according to its representation in the total corn production of the state.

Figure 8. Diagram of strategy adopted to represent the typical corn production profile in Brazilian states, considering the availability of corn agricultural information.

The studying stages were:

a) Analysis of the percentage representation of the 1st and 2nd corn crop production of each Brazilian state, in the national production of each harvest. For this, the statistical database of the Brazilian Institute of Geography and Statistics (IBGE), 2019, 2020 and 2021 harvests (IBGE, 2023), was used.

b) Retrieval of primary corn production data directly from RenovaCalc or searches for information on corn agricultural production in more recent public databases, recognized nationally and internationally. Two international product life cycle inventory databases (ecoinvent database and Global Feed LCA Institute (GFLI) database) were consulted, in addition to information from Embrapa's own database and the statistical database of IBGE and of the National Supply Company - CONAB.

c) Decision to characterize the typical corn production system for the 1st and 2nd corn crop in all Brazilian states with production ≥ 1% of the national production volume; the remaining states (with production < 1% of the national production volume) being characterized by a generic and conservative profile in terms of

GHG emissions.

d) Use of the LCI for the 1st corn crop in seven Brazilian states and the 2nd corn crop of eight Brazilian states published by Embrapa on ecoinvent v.3.9 (2022) and GFLI (2022), to characterize the typical corn production profile of these states, when their representation is ≥ 1% of the national production volume.
e) Identification of the similarity in the way of producing 1st and/or 2nd corn crop (production systems) across the Brazilian states. For this, consultations were made with experts in corn production from Embrapa Maize and Sorghum and members of the GT ACV RenovaBio.
f) Use of the 1st and/or 2nd corn crop LCI available in ecoinvent (2022) and GFLI (2022) to represent the corn production profile of another state with a similar production system, pre-identified in item "e".
g) Use of the LCI for corn from the 1st and/or 2nd crop of the state with a more conservative production profile, in terms of GHG emissions, to represent the profile of the other states with representation < 1% of national production (within each harvest separately).
h) Proposal of a single typical production profile for each Brazilian state. The production profiles for corn from the 1st and 2nd crop were combined, using weighted average of each harvest, according to its representation in the total corn production of the state.

2.2. Corn profiles validation

Typical profiles were validated by: a) experts in corn production and members of the GT ACV RenovaBio; b) corn production sector in online workshop; and c) data availability in a technical report for analysis and feedback with duly justified suggestions, with a technical-scientific basis and following the premises of the study.

2.3. Efficiency indices and carbon intensity (CI) at RenovaCalc

The proposition of efficiency indices for inputs used in corn production, data requested in RenovaCalc (ANP, 2023), was carried out for each input and all Brazilian states. The calculation entails dividing the consumption of each input of the typical production profiles (including specific soil amendments; nitrogen, phosphorus, and potassium from various sources; diesel, and other fuels) by their corresponding yield, defined as:

$$IEFic = \frac{Input\ Cycle}{Corn\ Yield} \qquad \text{Eq (1)}$$

Where:

IEFic: efficiency indices in the use of agricultural input (kg/Mg of corn)
Input cycle: consumption of input in the corn production cycle (kg/ha)
Corn Yield: Mg of corn/ha

The accounting of carbon intensity (CI - kg of CO_2eq/Mg of corn) for the typical production profile for each Brazilian state was carried out directly in RenovaCalc (up to version 7.0 - RC 7.0), in force in 2023, and in up to 9.0 (RC -9.0), which will be implemented. Thus, a simulation was performed considering a corn production area of 100 ha, agricultural yields and industrial efficiency indices of each state.

RenovaCalc up version 9.0 received a series of updates compared to version 7.0, as described below:

- Use of version 3.9.1 of the ecoinvent database to calculate the carbon footprints of corn production inputs.
- Use of “market” type “datasets” whenever available, considering the geographic scope preferably BR (Brazil), RoW (rest-of-world) or GLO (Global).
- Use of the Carbon Footprint calculated in the SimaPro software (version 9.5.0.0), with GWP 100 (IPCC, 2021), without accounting for infrastructure and emissions from land use change (LUC).
- Update of characterization factors, in accordance with AR6 (IPCC, 2019).
- Update of emission factors for mineral and organic fertilizers and crop residues to the values presented in the IPCC (2019).
- Update of agricultural residues rate based on the IPCC (2019).

2.4. Comparative analysis of carbon intensity

A simulation was carried out using the Monte Carlo method, in order to generate 10,000 carbon intensity (CI) samples for each state. The differences in these samples were evaluated between states, two by two (contrast A and B), and the percentage of times in which a state (A) has a higher or lower CI than a state (B) was calculated (number of times that A> B or that A<B). For these percentage values, a threshold of 70% was established to indicate a clear tendency for the carbon intensity (CI) of one state to differ significantly from that of another (Goedkoop et al., 2016).

No comparative analyses were carried out involving states with total corn production (1st + 2nd crops) less than 1% of the national corn volume, considering that these were characterized by profiles coming from the combination of systems from states with more conservative emissions.

3. Results and discussion

3.1. Brazilian corn producing states and selection of the database to compose their typical profiles

Brazil had 14 states corn producing accounted for at least 1% of the national output during the 2019, 2020, and 2021 harvests (IBGE, 2023). These states contributed 98% of the country total corn producing (Figure 9). Notably, the leading producers were Mato Grosso, Paraná, and Goiás (60% of Brazilian corn), but is important to explain that all Brazilian states produce corn in some quantity, expected Amapá. The wide use of corn grain as animal feed, industrial processing even the use, inside the rural property corroborate the extensive production in the country (Perreira Filho & Gracia, 2021).

Historically, corn is the second grain in the ranking of Brazilian production (IBGE, 2023) and places the country as the third largest producer in the world (FAO, 2023). This global representation is largely due to the growth in a cropping system (rotation/succession) with soybean, as 2nd crop production, which delivered 72% of the national corn in the last years (IBGE, 2023). This scenario reinforced the need for a robust and recognized database to characterize regional corn production. Therefore, the first option was the database coming from RenovaCalc itself, considering that the crop has already been included in the RenovaBio policy, since its origin in 2018 (Matsuura et al, 2018). However, it was found that few corn ethanol producers certified using primary agricultural data, considering the period 2018-2023, which would make proposing profiles for the entire national territory unfeasible. This led to source another database.

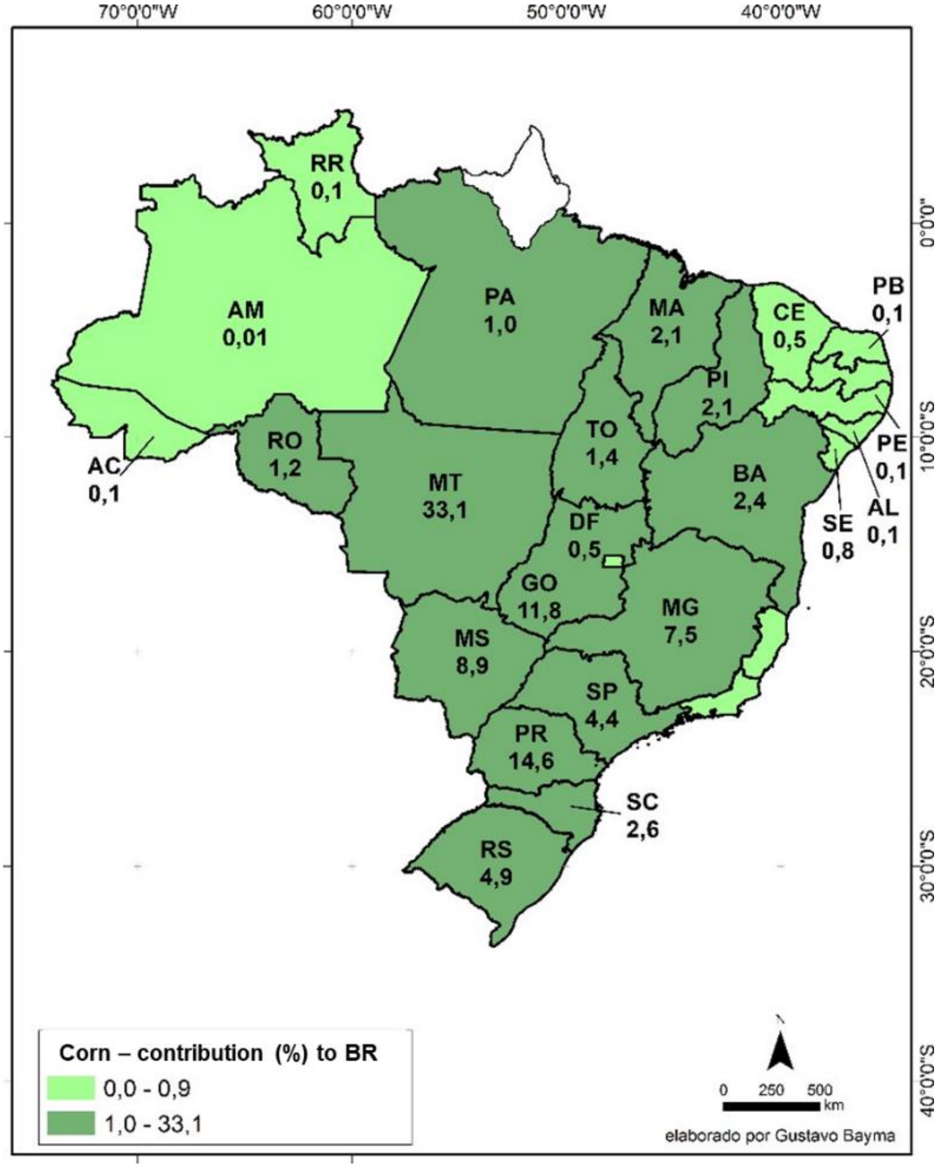


Figure 9. Corn producing states and their percentage contributions to the production of the crop in Brazil (sum of 1st and 2nd corn crop), in the years 2019, 2020 and 2021, from IBGE.

The ecoinvent (v 3.9) and the GFLI (2022) LCI databases were consulted and chosen, as they are internationally recognized. Information from Embrapa's own database and the statistical databases of IBGE and CNAB were also considered. The inventories of these databases met the required quality because they were essentially based on corn production profiles in cropping systems with soybeans and other crops, identified by the project “Prospecting demands and strategic planning for technology transfer and communication for soybean production in Brazil” – ProspecSoy (Hirakuri et al. 2018, 2019a, 2019b and 2020), generated in panels conducted by the Embrapa Soja team, based on data from the 2017, 2018 and 2019 harvests.

The ProspecSoy used data collection based on structured and unstructured questionnaires, answered by key informants (rural producers; agronomists; rural extension agents; technical consultants; members of rural associations, cooperatives and unions; financial agents; representatives of agricultural input resellers; and representatives of phytosanitary defense agencies) from different soybean/corn-producing Brazilian microregions (25). This survey allowed the characterization of corn system with data related to the types and doses of agricultural inputs consumed (soil amendments, fertilizers and pesticides), mechanized operations practiced, as well as its performance. The yield values of the panels were compared with data from IBGE and proved to be consistent for the period studied.

Figure 10 presents the geographic location of panels used in ProspecSoy project and the corn ethanol plants, providing that the data collection represents Brazilian corn regions. The inventories were published on a state scale, considering the set of microregions sampled in these states. Data allowed proposing corn inventories at 1st crop, produced in 7 Brazilian states (Rio Grande do Sul, RS; Minas Gerais, MG; Paraná, PR; Piauí, PI; Bahia, BA; Goiás, GO; and Maranhão, MA), and 2nd crop, produced in 8 states (Mato Grosso, MT; PR; Mato Grosso do Sul, MS; GO; MG; São Paulo, SP; Tocantins, TO; and MA). These states were chosen as they had production ≥ 1% of the national production volume at the period of the collection. The states of Santa Catarina (SC), Rondônia (RO) and Pará (PA) were not part of the collection, even though they had ≥ 1% of the national production volume.

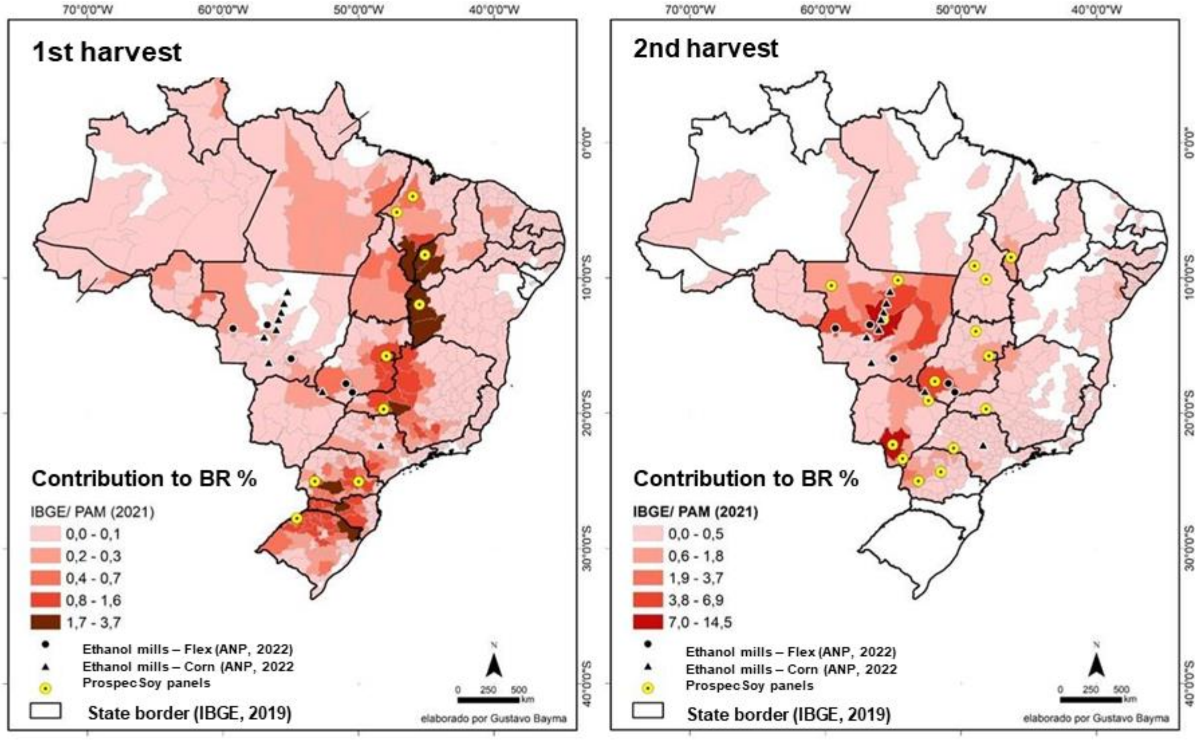


Figure 10. Geographic location of panels of data collection for corn production on 1st crop (left) and 2nd crop (right) systems, which respective contribution to Brazilian corn production volumes; and location of corn ethanol plants.

One highlight is that all Brazilian corn ethanol plants, both exclusive and flex-fuel with sugarcane, are located in the states inventoried for crop production (Figure 10). It allows to infer that the use of these inventories is consistent to represent the production of this biomass for ethanol. The concentration of units was observed in the Central-West region of Brazil, indicating greater adherence to the profile of 2nd crop. However, it is worth noting that, in the case of corn grains that can be stored in silos for long periods, it is not possible to ensure whether the origin of this raw material would actually be from the 1st or 2ndcorn production.

The representativeness of the corn production system inventoried from the panels varied depending on the microregion or state scale (Table 2). The states whose panels were most representative were BA and PI in the 1st crop harvest and GO, MA and MS in the 2nd crop harvest. The only states that have a significant corn production, but that were not inventoried in the panels were SC, PA, TO and MT, for the 1st corn, and RO and Bahia (BA), for the 2nd corn.

Table 2. Microregions sampled in panels characterizing typical corn production systems and their percentage contribution to national and state production of 1st and 2nd crop, considering production from the 2019-2020-2021 harvests.

Microregion represented by panel	Contribution of the microregion to BR (%)	State	Contribution of the microregion to the state (%)	Som to the state (%)
		1st crop		
Ponta Grossa	0.91	PR	7.12	13.17
Cascavel	0.77	PR	6.05	
Alto Parnaíba Piauiense	3.46	PI	50.87	50.87
Barreiras	3.68	BA	60.01	60.01
Entorno de Brasília	1.43	GO	25.67	25.67
Imperatriz	0.28	MA	5.86	16.21
Pindaré	0.49	MA	10.34	
Santa Rosa	0.91	RS	4.94	4.94
Uberaba	0.79	MG	4.41	4.41
		2nd crop		
Alto Teles Pires	14.46	MT	30.97	35.77
Aripuanã	1.20	MT	2.57	
Colíder	1.04	MT	2.23	
Cascavel	1.30	PR	8.17	10.10
Ivaiporã	0.31	PR	1.93	
Cassilândia	0.82	MS	6.61	71.27
Dourados	6.94	MS	55.80	
Iguatemi	1.10	MS	8.87	
Entorno de Brasília	1.18	GO	11.49	74.17
Sudoeste de Goiás	0.08	GO	0.76	
Porangatu	6.34	GO	61.92	
Iguatemi	0.87	MS	10.15	66.99
Dourados	4.12	MS	47.93	
Cassilândia	0.77	MS	8.92	
Uberaba	0.38	MG	10.00	10.00
Assis	0.74	SP	23.36	23.36
Porto Nacional	0.25	TO	30.84	50.38
Miracema do Tocantins	0.40	TO	19.54	
Gerais de Balsas	0.90	MA	72.09	72.09

* Data processed from originals available at IBGE (2023). BR: Brazil; PR: Paraná; PI: Piauí; BA: Bahia; GO: Goiás; MA: Maranhão; RS: Rio Grande do Sul; MG: Minas Gerais; MT: Mato Grosso; MS: Mato Grosso do Sul; SP: São Paulo; TO: Tocantins.

The high representation of inventoried states (Figure 9 and Table 2) on corn production and the availability of information accessible, both nationally and internationally through ecoinvent and GFLI databases, qualified them to be used as a reference in RenovaBio. This underscores that its use in RenovaCalc will begin after the penalty is incorporated.

Furthermore, a limitation of this study concerns the temporality of the data, which reflect the 2017-2018-2019 harvests. Nevertheless, these sources remain the most current and comprehensive available, justifying their use. The policy aims to update its information based on the best available science and to maintain a traceable database free from economic interests.

3.2. Composition of the corn production profiles

The typical profiles of corn production for Brazilian states combined the LCI from 1st and 2nd crop production. This integration respects the proportions that these crops contribute to the total production in each state (Table 3). Before this integration, the experts who validated the profiles of each crop, highlighted the need for four adjustments, which were accepted and incorporated into the study. The first one occurred in the yield of corn in the 2nd crop in SP, adjusting the value from 4,500 to 5,500 kg/ha of grains, which was deemed more realistic for the state.

The second adjustment involved the limestone dosage for all crops, which was reported to be lower than it is usually observed in practice. Thus, an average value of 500 kg/ha was adopted, taking into account the benefits of using this input for two crops within a production system. The reason was based on the practice of applying 3,000 kg/ha of limestone every three years, equating to an annual amount of 1,000 kg/ha. This amount is shared among several crops, including soybeans, cotton, and beans, with corn being part of the cropping system in the first or second crop cycle. This is above the value used as a reference in ANP Resolution No. 758/2018 (ANP, 2018), which was 262 kg/ha (Table 1).

The third adjustment was in the consumption of fertilizers: quantity of nitrogen fertilizer, which has urea as its source, applied in the MS-2nd crop (from 29.3 to 100.0 kg N/ha); potassium fertilizer applied in BA-1st crop (from 0 to 80 kg K_2O/ha) and GO-1st crop (from 36 to 80 kg K_2O/ha). Small corrections were also made to the amount of P_2O_5 in the form of MAP and DAP, in order to align the formulation of these fertilizers between the amount of N and P_2O_5, such as changing the dose from 61.3 to 63.5 kg P_2O_5/ha to obtain 124.5 kg of MAP, with 13.7% N and so on. These changes did not exceed amounts greater than 3 kg/ha.

The fourth correction was in the quantity of non-specific pesticides in BA-1st crop (from 2.3 to 6.7 kg/ha), GO-1st crop (from 2.3 to 6.6 kg/ha), MG-1st crop (from 11.8 to 7.0 kg/ha) and PI-1st crop (from 2.8 to 6.9 kg/ha), according to the experts. The glyphosate dose was also modified in MG-1st crop (from 2.2 to 1.5 kg/ha).

The experts also determined that the corn production profile for the 1st harvest in the state of Rio Grande do Sul (LCI-RS1st) could be extrapolated to Santa Catarina due to their similarities. In the same way, the profile for Paraná (LCI-PR1st) was deemed suitable to represent São Paulo, and the profile for Goiás (LCI-GO1st) was used to represent Tocantins and Mato Grosso. Regarding the 2nd harvest corn, experts pointed out the production profile of the state of GO (LCI-GO2nd) as similar to MG and MT (LCI-MT2nd), as suitable to represent RO. All other states that lacked an LCI in ecoinvent 3.9 and GFLI version 2022, and did not have a profile identified as similar to another state, were represented by the corn production profile of Bahia for the first crop (LCI-BA1st t) and Maranhão for the second crop (LCI-MA2nd), as these states have higher emissions, respecting a conservative approach.

Table 3 displays the contributions of each Brazilian state to national corn production, alongside the combinations of LCI utilized for each state. These combinations include the original LCI for states with data in the LCI databases, the LCI of a similar state for those with comparable cropping systems, and the conservative profiles LCI-BA1st and LCI-MA2nd for all other states. The combination followed the proportion of grain production from the 1st and 2nd crop relative to the total corn production within each state (weighted average). The conservative profile was applied in a few states with production exceeding 1% of the national output (MS and RO for the first harvest, and PA for both the first and second harvests). This demonstrates that states with significant production are characterized by highly specific production profiles.

Table 3. Final composition of data for 1st and 2nd crop corn with original inventories deposited in ecoinvent version 3.9 (2022) and GFLI version 2022 or similar inventory from other state.

State	State contribution to Brazil (%)	1st harvest		2nd harvest	
MT	33.11	LCI-GO1st	1%	LCI original	99%
PR	14.60	LCI original	23%	LCI original	77%
GO	11.77	LCI original	13%	LCI original	87%
MS	8.88	LCI-BA1st	2%	LCI original	98%
MG	7.48	LCI original	64%	LCI-GO2nd	36%
RS	4.88	LCI original	100%	------	0%
SP	4.43	LCI-PR1st	50%	LCI original	50%
SC	2.55	LCI-RS1st	100%	------	0%
BA	2.38	LCI original	98%	LCI-MA2nd	2%
MA	2.13	LCI original	59%	LCI original	41%
PI	2.11	LCI original	86%	LCI-MA2nd	14%
TO	1.37	LCI-GO1st	33%	LCI original	67%
RO	1.16	LCI-BA1st	16%	LCI-MT2nd	84%
PA	1.00	LCI-BA1st	56%	LCI-MA2nd	44%
SE	0.79	LCI-BA1st	100%	------	0%
CE	0.50	LCI-BA1st	100%	------	0%
DF	0.45	LCI-BA1st	45%	LCI-MA2nd	55%
AC	0.09	LCI-BA1st	85%	LCI-MA2nd	15%
RR	0.08	LCI-BA1st	100%	------	0%
AL	0.07	LCI-BA1st	100%	------	0%
PE	0.06	LCI-BA1st	99%	LCI-MA2nd	1%
PB	0.06	LCI-BA1st	100%	------	0%
ES	0.04	LCI-BA1st	85%	LCI-MA2nd	15%
RN	0.03	LCI-BA1st	100%	------	0%
RJ	0.01	LCI-BA1st	46%	LCI-MA2nd	54%
AM	0.01	LCI-BA1st	92%	LCI-MA2nd	8%

LCI: Life Cycle Inventory. MT: Mato Grosso; PR: Paraná; GO: Goiás: MS: Mato Grosso do Sul; MG: Minas Gerais; RS: Rio Grande do Sul; SP: São Paulo; SC: Santa Catarina; BA: Bahia; MA: Maranhão; PI: Piauí; TO: Tocantins; RO: Rondônia; PA: Pará; SE: Sergipe: CE: Ceará; DF: Distrito Federal; AC: Acre; RR: Roraima; AL: Alagoas; PE: Pernambuco; PB: Paraíba; ES: Espírito Santo; RN: Rio Grande do Norte; RJ: Rio de Janeiro; AM: Amazonas.

The result of the general characterization of the typical corn production profile in Brazilian corn producing states, compared with the national profile (in force in ANP Resolution 758/2018) are shown in Table 4 (for states ≥ 1% of national production) and

Table 5 (for states < 1% of national production). The system is described in terms of the use of soil amendments, fertilizers, pesticides and fuel.

A significant difference observed for typical regional profiles in relation to the current one (ANP Resolution No. 758/2018) concerns the greater specificity of fertilizer sources. The regional data had fertilizers composed of urea, MAP, DAP, TSP and potassium chloride, whereas previously they were described only as urea, SSP and potassium chloride. This modification changes the carbon intensity due to the difference in the carbon footprint of these agricultural inputs and, in the case of limestone, also in the emission factors in the field, according to the IPCC (2006).

The typical regional profiles included the most common crops, inputs and doses that participate in corn rotation or succession systems. Grain yield varied between 4,908 and 8,050 kg/ha (82 to 134 bags/ha), among states with production greater than 1% at the national level (Table 4), in line with values observed in official statistics (4,989 to 7,297 kg /ha – 81 to 121 bags/ha - CONAB, 2024a). On the other hand, corn yield attributed to states with less than 1% of national production varied between 5,280 and 6,600 kg/ha – 88 to 110 bags/ha (Table 5), which were considered above those declared in statistical databases, which were 537 to 6,000 kg/ha – 9 to 100 bags/ha (CONAB, 2024a).

It was found that the agricultural practices were similar in the three years studied (Hirakuri et al. 2018, 2019a, 2019b e 2020), with more significant variations in the doses of inputs and number of applications. This homogeneity in practices, as well as adjustments in doses, was confirmed in a workshop carried out with the production sector and proved to be in line with the most current crop harvests.

Concerning the applying of soil correctives, the doses of limestone were corrected and allocated, as mentioned earlier, while gypsum was only used in the states of MT, GO, MS, MG and TO, indicating these producers' interest in correcting soil chemical conditions in depth, favoring root development. The low use among most producers is justified by the literature not pointing out yield benefits in soybean-corn systems with the use of this agricultural input (Neis et al., 2010), even though it favors the yield of other crops in the system, such as wheat (Rampin et al., 2011).

The use of seeds was constant for the states studied, as producers declared using doses based on the number of seeds per area and not weight, with values between 40,000 and 80,000 seeds/ha (Cruz et al, 2011), which corresponds to around 18 to 23 kg/ha, depending on the classification of the sieve. Regarding fertilizer doses, it varied greatly in both N (78 to 156 kg/ha) and P_2O_5 (35 to 124 kg/ha), in different sources, and K_2O (36 to 125 kg/ha), in the form of KCl, according to Table 4. Cruz et al. (2011) pointed out that these values resulted in higher yield when compared to those observed for the average extraction levels of $N:P_2O_5:K_2O$ of 16:9:6 kg/Mg of grains. However, this conversion is highly dependent on precipitation during cultivation. There was an increase in fertilizer consumption, generally associated with the expectation of an increase in grain yield. In fact, the consumption of nitrogen fertilizer must be carried out respecting grain yield expectations, depending on weather conditions, especially in the 2nd harvest. It is worth noting that, according to IPCC (2019), around 1% of the total N applied is emitted in the form of nitrous oxide (N_2O), which has a global warming potential 273 times higher than CO_2. Thus, its use, without yield return, results in significant emissions to the environment.

Regarding to diesel consumption, variations were observed among states, underscoring disparities in machinery usage. Consumption rates spanned from 26.5 (PI) to 42.4 L/ha (MS), averaging at 35 L/ha (Table 4). Notably, the previous iteration of the BR corn profile, outlined in ANP Resolution No. 758/2018, reported a consumption rate of 30 L/ha (Frame 1). Just like N, emissions from diesel combustion are significant, particularly in heavy vehicles, according to Nemecek and Kägi, 2007) and its usage efficiency must be prioritized in fuel systems for more sustainable production practices. As occurred for limestone, in the present study diesel also underwent an allocation treatment, because part of its consumption, when destined for tillage and application of correctives, which benefit several crops in the system, was distributed between corn and the other crops (Mendes et al., 2021).

Pesticides do not have major impacts on climate change, but they can affect issues related to human and animal health. In the present study, pesticide consumption varied between 3.0 kg of a.i./ha (MT) and 8.6 kg of a.i./ha (BA), with an average of 5.7 kg a.i./ha, a value close to that stated in Frame 1. The variation between states was expected, as specific soil and climate conditions interfere with the incidence of pests, diseases and weeds in agricultural cultivation, which affects pesticide consumption.

The comparison between regional and national (ANP Resolution No. 758/2018) typical profiles demonstrated a general increase in agricultural input consumption for most of the regional data. However, these changes were more subtle for MT and GO. This may be a consequence of the significant contribution of these two states to the Brazilian profile of ANP Resolution nº 758/2018 (Figure 11).

Regarding the typical profile of MT (Table 4), the largest Brazilian corn grain and ethanol producing (Figures 3 and 9), it was observed its similarity to the primary data of three companies located in this state certified by RenovaBio (Table 6). Such consumption of nitrogen fertilizer and diesel confirms the upward trend in the consumption of inputs related to ANP Resolution No. 758/2018 (Table 1), which was also observed in the corn production profile update of the other Brazilian states (Table 4 and 5). The absence of limestone and P_2O_5 in the profile of the three companies, as well as K_2O in one of the companies, is possibly a lack of information, because high-yield corn crop requires amended soils and significant doses of P_2O_5 and K_2O to respond to the applied N (which, in this case, has increased in quantity).

Table 4. Typical inputs and doses used in corn production in Brazilian states, with production ≥ 1% of the national production.

Agricultural inputs	MT	PR	GO	MS	MG	RS	SP	SC	BA	MA	PI	TO	RO	PA
Predominant crops in a cropping system[1]	1st C Soybean or Cotton	1st C Soybean Other 2nd C Cover crop Pasture	1st C Soybean or Pasture	1st C Soybean or Pasture	1st C Soybean Other 2nd C Cover crop Pasture	1st C Soybean Other 2nd C Cover crop Pasture	1st C Soybean Other 2nd C Cover crop Pasture e	1st C Soybean Other 2nd C Cover crop Pasture	1st C Soybean or Cotton	1st C Soybean Other 2nd C Cover crop Pasture	1st C Soybean Other 2nd C Cover crop Pasture	1st C Soybean or Cotton	1st C Soybean or Cotton	1st C Soybean Other 2nd C Cover crop Pasture
Grain yield (kg/ha)	6,317	7,256	6,469	5,266	7,985	7,260	8,050	7,260	6,552	5,262	6,952	4,908	6,345	5,544
Dolomitic limestone (kg/ha)	500	500	500	500	500	500	386	500	500	500	500	500	500	500
Calcitic limestone (kg/ha)	0.0	0.0	0.0	0.0	0.0	0.0	114	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gypsum (kg/ha)	0.2	0.0	13.2	90.6	4.2	0.0	0.0	0.0	0.0	0.0	0.0	7.7	0.0	0.0
Seeds (kg/ha)	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	16.0	20.0	20.0
Urea (kg N/ha)	68	105	69	101	108	68	113	68	134	86	123	64	78	111
MAP (kg N/ha)	9.9	0.0	7.1	0.5	2.9	0.0	0.0	0.0	22.1	0.0	17.5	0	12.0	12.6
DAP (kg N/ha)	0.2	21.7	3.1	0.0	19.2	43.9	14.2	43.4	0.4	30.8	2.5	16.3	0.0	7.7
MAP as P_2O_5 (kg/ha)	52.6	0.0	37.8	2.4	15.6	0.0	0.0	0.0	117.6	0.0	93.1	0.0	63.8	67.2
DAP as P_2O_5 (kg/ha)	0.6	57.3	8.3	0.0	50.8	116.2	37.5	116.2	0.9	81.6	6.5	43.2	0.0	20.5
TSP as P_2O_5 (kg/ha)	0.3	0.3	6.2	32.8	28.8	7.6	18.8	7.6	0.9	28.1	6.0	29.5	0.0	18.8
KCl (kg/ha)	50.1	73.5	70.1	36.1	124.5	80.0	82.5	80.0	79.7	125.0	137.8	56.4	54.7	72.5
Diesel B10[2] (L/ha)	31.8	39.8	37.9	42.4	40.4	41.4	38.8	41.4	30.8	33.5	26.5	27.8	31.5	28.6
Unspecified pesticides (kg/ha)	1.6	3.5	3.8	3.7	5.7	5.0	5.5	5.0	6.6	1.8	6.1	2.8	2.4	4.4
Glyphosate (kg/ha)	1.4	1.0	1.5	1.3	1.5	1.2	1.4	1.2	1.7	1.9	2.2	0.9	1.5	1.9
2,4-D (kg/ha)	0.00	0.12	0.05	0.01	0.00	0.00	0.26	0.00	0.32	0.05	0.12	0.13	0.05	0.23

[1] Cropping system (crop rotation/succession, with no tillage or minimal cultivation and allocation of some inputs and operations among the commercial crops in the system;

[2] Diesel consumption of B10, that was the mixture used when the inventories were published (2022).

MT: Mato Grosso; PR: Paraná; GO: Goiás; MS: Mato Grosso do Sul; MG: Minas Gerais; RS: Rio Grande do Sul; SP: São Paulo; SC: Santa Catarina; BA: Bahia; MA: Maranhão; PI: Piauí; TO: Tocantins; RO: Rondônia; PA: Pará.

Table 5. Typical inputs and doses used in corn production in Brazilian states, with production <1% of the national production.

Agricultural inputs	SE	CE	DF	AC	RR	AL	PE	PB	ES	RN	RJ	AM
Predominant crops in a cropping system[1]	1st C Soybean Other 2nd C Cover crop Pasture	1st C Soybean Other 2nd C Cover crop Pasture	1st C Soybean Other 2nd C Cover crop Pasture	1st C Soybean Other 2nd C Cover crop Pasture	1st C Soybean Other 2nd C Cover crop Pasture	1st C Soybean Other 2nd C Cover crop Pasture	1st C Soybean Other 2nd C Cover crop Pasture	1st C Soybean Other 2nd C Cover crop Pasture	1st C Soybean Other 2nd C Cover crop Pasture	1st C Soybean Other 2nd C Cover crop Pasture	1st C Soybean Other 2nd C Cover crop Pasture	1st C Soybean Other 2nd C Cover crop Pasture
Grain yield (kg/ha)	6,600	6,600	5,280	6,240	6,600	6,600	6,576	6,600	6,240	6,600	5,304	6,408
Dolomitic limestone (kg/ha)	500	500	500	500	500	500	500	500	500	500	500	500
Gypsum (kg/ha)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Seeds (kg/ha)	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Urea (kg N/ha)	135.0	135.0	105.3	126.9	135.0	135.0	134.5	135.0	126.9	135.0	105.8	130.7
MAP (kg N/ha)	22.5	22.5	10.1	19.1	22.5	22.5	22.3	22.5	19.1	22.5	10.4	20.7
DAP (kg N/ha)	0.0	0.0	9.7	2.6	0.0	0.0	0.2	0.0	2.6	0.0	9.5	1.4
MAP, as P_2O_5 (kg/ha)	120.0	120.0	54.0	102.0	120.0	120.0	118.8	120.0	102.0	120.0	55.2	110.4
DAP, as P_2O_5 (kg/ha)	0.0	0.0	25.6	7.0	0.0	0.0	0.5	0.0	7.0	0.0	25.2	3.7
TSP, as P_2O_5 (kg/ha)	0.0	0.0	23.5	6.4	0.0	0.0	0.4	0.0	6.4	0.0	23.1	3.4
KCl (kg/ha)	80.0	80.0	70.7	77.5	80.0	80.0	79.8	80.0	77.5	80.0	70.8	78.6
Diesel B10[2] (L/ha)	30.9	30.9	28.0	30.1	30.9	30.9	30.8	30.9	30.1	30.9	28.1	30.5
Unspecified pesticides (kg/ha)	6.7	6.7	3.8	5.9	6.7	6.7	6.6	6.7	5.9	6.7	3.9	6.3
Glyphosate (kg/ha)	1.7	1.7	1.9	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.9	1.7
2,4-D (kg/ha)	0.32	0.32	0.21	0.29	0.32	0.32	0.32	0.32	0.29	0.32	0.21	0.31

[1] Cropping system (crop rotation/succession, with no tillage or minimal cultivation and allocation of some inputs and operations among the commercial crops in the system;

[2] Diesel consumption of B10, that was the mixture used when the inventories were published (2022).

SE: Sergipe; CE: Ceará; DF: Distrito Federal; AC: Acre; RR: Roraima; AL: Alagoas; PE: Pernambuco; PB: Paraíba; ES: Espírito Santo; RN: Rio Grande do Norte; RJ: Rio de Janeiro; AM: Amazonas.

Table 6. Characteristic profile of the corn production based on primary data declared in RenovaCalc 7.0.

Agricultural inputs	M1	M2	M3
Grain yield (kg/ha)	8,290	6,910	7,890
Limestone (kg/ha)	0	0	0
Gypsum (kg/ha)	0	0	0
Seeds (kg/ha)	24	24	25
N (kg/ha) as MAP	0	0	0
N (kg/ha) as Urea	56	53	51
N (kg/ha) as ammonium sulfate	4	10	25
N (kg/ha) as DAP	0	0	0
Total N (kg/ha)	60	63	76
Total P2O5 (kg/ha)	0	0	0
Total K2O (kg/ha)	0	61	62
Diesel B10 (L/ha)	54	36	33

M1: Mill 1, M2: Mill 2, M3: Mill 3

3.3. Efficiency indices and carbon intensity (CI) at RenovaCalc

Table 7 shows the efficiency indices for different agricultural inputs that characterize typical corn production of Brazilian states. The consumptions of all specific sources of limestone, N, P_2O_5 and K_2O were summed to facilitate comparison with the reference values, contained in ANP Resolution 758/2018 (ANP, 2018). The most of regional (states) indices were modified in relation to the typical national, reflecting the changes in the consumption pattern and technology adopted for the crop. The states of MT and GO had lower values than other Brazilian states, due to the reduction in the consumption of agricultural inputs.

The limestone efficiency indices increased by 87% after typical regional profile proposals, with an average value of 79.0 kg of limestone/Mg of corn, while the previous value was 42.3 kg of limestone/Mg of corn (ANP Resolution 758/2018). However, this update does not seem to be linked to technological change, but rather to the correct information about its use in the production system. The same was observed for the consumption of gypsum, in some states, which had not been reported until then and now appears in the profiles of the states of MT, GO, MS, MG and TO. The seasonal application of correctives tends to hinder their correct declaration as part of the production system, requiring greater attention in data collection.

The efficiency of fertilizer consumption, using typical regional profiles, decreased in relation to the typical profile of ANP Resolution No. 758/2018. The increase in nitrogen fertilizer (N) was 63%, with a predominance of urea, but this use did not result in significant grain yield improvement. The same behavior occurred for the use of phosphate fertilizers, with a 44% increase in consumption, mainly in the form of MAP (68%) and DAP (10%), and with use efficiency between 6.7 and 20.8 kg /Mg of corn (the reference value of ANP Resolution No. 758/2018 is 10.9 kg/Mg of corn). The relative consumption of potassium fertilizer also increased, with an average being 12.3 kg/Mg of corn for regional profiles (the reference value is 11.2 kg/Mg of corn, a difference of 7%).

The diesel efficiency indices showed less variation in relation to the reference indices (4.8 L of diesel/Mg of corn), with an increase of 7% and values varying between 3.8 and 8.0 L of diesel/Mg of corn. Seed consumption showed a reduction of 32% in relation to the production profile used in the ANP Resolution, varying from 2.5 to 3.8 kg of seed/Mg of corn in regional (state) scale profiles.

Regarding pesticides, there was a 63% reduction in the general consumption of this input, reflecting a value of 2.8 kg of pesticide/ha of corn (ANP Resolution No. 758/2018) to 1.1 kg/ha of corn (average between states). Among the different types of pesticides, there was also a reduction in the amount of glyphosate and 2,4-D consumed and a significant increase in pesticides classified as “unspecified”, whose consumption may be associated with the incidence of pests and diseases, which varies with the weather.

Figure 11 shows the carbon intensities (CI) from the production profiles of the 14 largest corn producing states in Brazil, simulated in RenovaCalc version 7.0 (RC7.0, currently in use) and version 9.0 (RC 9.0 to be implemented). The values varied between 253 and 402 kg CO_2eq/Mg corn, in RC 7.0, while in RC9.0 the values were from 256 to 410 kg CO_2eq/Mg corn.

Table 7. Efficiency indices for inputs used in typical corn profile, considering each Brazilian state.

Agricultural inputs	MT	PR	GO	MS	MG	RS	SP	SC	BA	MA	PI	TO	RO	PA	ANP 758
Limestone (kg/Mg corn	79.15	68.91	77.29	94.95	62.62	68.87	62.11	68.87	76.31	95.02	71.92	101.9	78.80	90.19	42.3
Gypsum (kg/Mg corn)	0.04	0.00	2.04	17.20	0.53	0.00	0.00	0.00	0.00	0.00	0.00	1.57	0.00	0.00	0.00
Seeds (kg/Mg corn)	3.17	2.76	3.09	3.80	2.50	2.75	2.48	2.75	3.05	3.80	2.88	3.28	3.15	3.61	4.6
Synthetic N (kg/Mg corn)	12.38	17.52	12.17	19.21	16.33	15.36	15.80	15.36	23.86	22.26	20.59	16.33	14.22	23.73	12.6
Synthetic P_2O_5 (kg/Mg corn)	8.47	7.95	8.07	6.69	11.93	17.05	6.98	17.05	18.22	20.83	15.20	14.81	10.06	19.22	10.9
Synthetic K_2O (kg/Mg corn)	7.94	10.12	10.83	6.85	15.60	11.02	10.25	11.02	12.16	23.75	19.82	11.49	8.62	13.08	11.2
Diesel B12[1] (L/Mg corn)	5.03	5.48	5.85	8.04	5.06	5.70	4.82	5.70	4.69	6.36	3.81	5.66	4.97	5.16	4.8

Agricultural inputs	SE	CE	DF	AC	RR	AL	PE	PB	ES	RN	RJ	AM	ANP 758
Limestone (kg/Mg corn	75.76	75.76	94.70	80.13	75.76	75.76	76.03	75.76	80.13	75.76	94.27	78.03	42.3
Gypsum (kg/Mg corn)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Seeds (kg/Mg corn)	3.03	3.03	3.79	3.21	3.03	3.03	3.04	3.03	3.21	3.03	3.77	3.12	4.6
Synthetic N (kg/Mg corn)	23.86	23.86	23.69	23.82	23.86	23.86	23.86	23.86	23.82	23.86	23.70	23.84	12.6
Synthetic P_2O_5 (kg/Mg corn)	18.18	18.18	19.54	18.49	18.18	18.18	18.20	18.18	18.49	18.18	19.51	18.34	10.9
Synthetic K_2O (kg/Mg corn)	12.12	12.12	13.38	12.41	12.12	12.12	12.14	12.12	12.41	12.12	13.35	12.27	12.6
Diesel B12[1] (L/Mg corn)	4.68	4.68	5.31	4.82	4.68	4.68	4.69	4.68	4.82	4.68	5.30	4.75	4.8

[1] Diesel mixed considering 12% of biodiesel (value adopted for Brazilian government in 2024)

MT: Mato Grosso; PR: Paraná; GO: Goiás; MS: Mato Grosso do Sul; MG: Minas Gerais; RS: Rio Grande do Sul; SP: São Paulo; SC: Santa Catarina; BA: Bahia; MA: Maranhão; PI: Piauí; TO: Tocantins; RO: Rondônia; PA: Pará; SE: Sergipe; CE: Ceará; DF: Distrito Federal; AC: Acre; RR: Roraima; AL: Alagoas; PE: Pernambuco; PB: Paraíba; ES: Espírito Santo; RN: Rio Grande do Norte; RJ: Rio de Janeiro; AM: Amazonas.

Carbon intensity of typical corn profile of MT was the lowest of all Brazilian states. It was the only value (256 kg CO_2eq/Mg corn) below the reference CI of ANP Resolution No. 758/2018 (260 kg CO_2eq/Mg corn), in the simulation carried out in RC9.0. All other states had higher CIs than the reference, with the highest values observed for MA and PA (410 kg CO2eq/Mg corn). This CI is justified by the previously reported higher consumption of agricultural inputs, with N fertilizer being responsible for 54-70% of the corn CI, followed by N from residues, with 10-17% of the CI, by limestone, with 10-16% of the CI, and diesel, with 3 to 7% of CI. Nitrogen is the main responsible for GHG emissions from corn production, both through fertilization and its presence in crop residues, therefore, its maximum use, with a return in grain yield, is essential for changing this negative impact scenario.

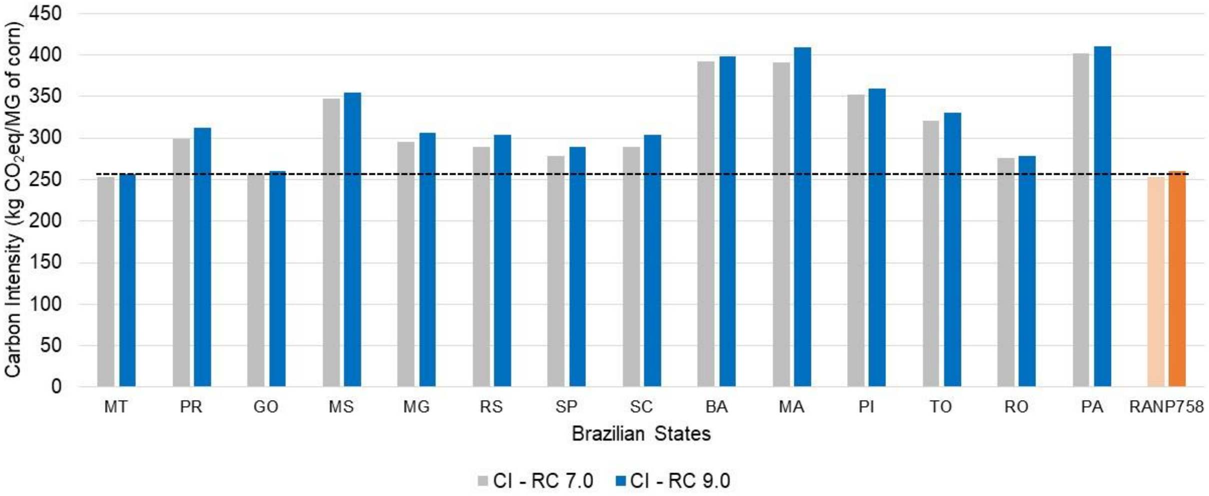


Figure 11. Carbon intensities of agricultural corn profiles for the 14 largest producing states in Brazil, compared with the reference profile contained in ANP Resolution No. 758/2018, in simulations using versions 7.0 and 9.0 of RenovaCalc.

The corn production CIs in the other states, with corn production less than 1% of the national total (SE, CE, DF, AC, RR, AL, PE, PB, ES, RN, RJ and AM), were on average of 395 kg CO_2eq/Mg corn (RC7.0 and RC9.0) Notably. the use of LCI with conservative production profiles, combined with the predominance of cultivation in the 1st crop, was responsible for the CI observed in the majority of these states.

The increase in CI occurred due to the production profiles regionalization, but also due to the update of several RenovaCalc parameters in version 9.0. The impact of the update was a 2.7% increase in emissions. However, this is a necessary and essential action for compliance with international protocols.

Figure 12 shows the percentage of times that a state presents a higher or lower CI than another, when compared two by two. Of a total of 88 combinations, disregarding states with less than 1% of production, there were 84 combinations that showed a tendency towards differences in CI about 70% of the times where the comparison was made.

MA and PA were the states with a tendency to have the highest CI in relation to the other states (11 combinations each one), followed by BA (10 combinations) and TO (6 combinations). On the other hand, MT was the state with the most consistent tendency to present a lower CI in relation to some states (10 combinations), followed by GO (7 combinations). It is also worth highlighting that the combinations between MG-RS-SC did not show a trend for any of the states studied, implying that there are no apparent differences in the corn production profile in these contrasts.

The other states had different behaviors when compared to each other. These differences can justify the regionalization proposed for RenovaCalc, as well as the benefits that this strategy can bring to better represent Brazilian corn in the RenovaBio policy.

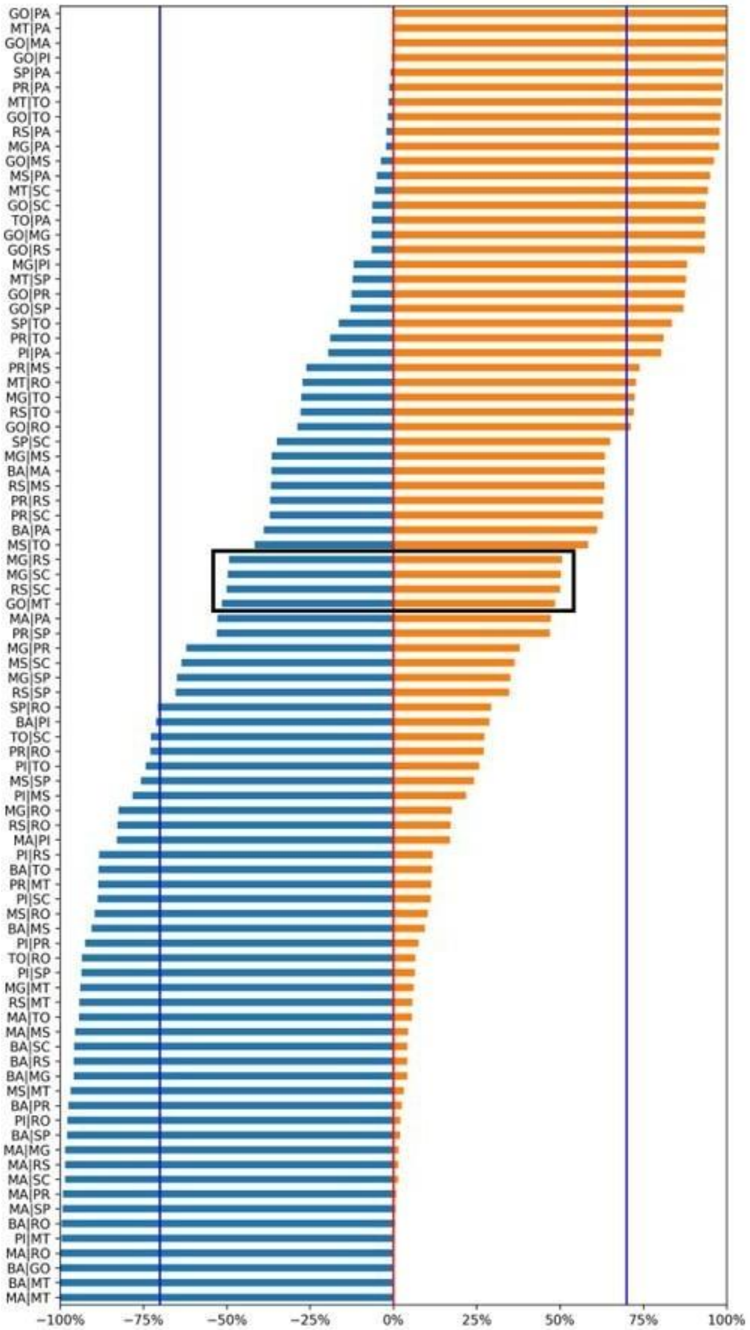


Figure 12. Percentage of times that one state has higher or lower emissions than another state, when compared side by side. Carbon intensity calculated in version 9.0 of RenovaCalc.

4. Final remarks

Default corn production profile, used in the RenovaCalc tool, is based on the typical profile plus a penalty, which prevents underestimating GHG emissions in biomass production. The default profile exists to accommodate situations where the biofuel intends to participate in the National Biofuels Policy, but does not contain enough verifiable information about its biomass production for the certification.

The proposal of typical corn profile on a state scale to represent the regional agricultural corn production is aligned with RenovaBio's premises, which promote the continuous use of primary data in all stages of biofuel production. A reduction to scales smaller than the state level is not advised, as it could result in the representation of specific particularities that would not be applicable to the policy in question.

The use of information from widely recognized public databases, such as ecoinvent and GFLI, to build typical corn profiles, adds to the transparency of the RenovaBio policy, minimizing concerns from the scientific community about the reliability of the data used in RenovaCalc. The correction of specific input values, based on expert analysis, further improves the representation of corn production in Brazil. The only caveat concerns the temporal representativeness of the data, which could be more up to date if there were information with the same level of detail, scope and reliability available.

Variations in the carbon intensity of corn profiles confirm the relevance of using state scale in RenovaCalc. Thus, the provision of typical profiles for all Brazilian corn producing states, either through specific data from each state or by extrapolating data from one state to another, provides the opportunity to better represent regional corn production, which underpins the default data in RenovaCalc, replacing the national profiles considered in ANP Resolution 758/2018.

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