WRITTEN OBSERVATIONS TO THE INTER-AMERICAN COURT OF HUMAN RIGHTS ON THE CLIMATE EMERGENCY AND HUMAN RIGHTS

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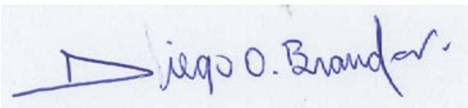

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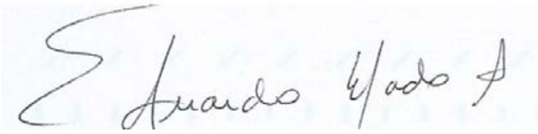

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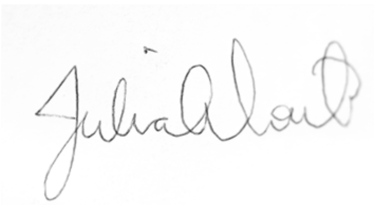

TOWARD AN AMAZON GREEN DEAL: THE URGENT NEED FOR AN INNOVATIVE SOCIOBIOECONOMY AND REGENERATIVE LIVESTOCK FARMING TO PREVENT THE AMAZON TIPPING POINT

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CONTENTS

1. Summary

Deforestation and forest degradation are historically associated with the expansion of pasture areas and the growing number of cattle in the Legal Amazon. Over the last five decades, agriculture and livestock farming, along with real estate speculation and timber smuggling that also cause deforestation, are responsible for more than 70% of Brazil's greenhouse gas emissions. Reducing greenhouse gas emissions from deforestation, degradation, fires and livestock production in the Legal Amazon is essential to maintain temperatures below critical points, as well as ecosystem services that depend on the standing forest, such as recycling rain, environmental cooling and food supply. The Legal Amazon is home to 43% of Brazil's cattle herd, highlighting its national relevance in livestock production. Of the 808 municipalities in the Legal Amazon, 537 face serious problems of pasture degradation, resulting in high CO2 and methane emissions, as well as low stocking rate. Around 55% of total methane emissions in the Brazilian agricultural sector originate in the Legal Amazon due to enteric fermentation and waste management. Solving these challenges largely depends on political and business actions, including national and international commitments to eliminate deforestation, restrict meat exports associated with deforestation, and promote public policies that encourage sustainable production models. Actions that encourage the adoption of regenerative agriculture, low-emission and high-carbon removal agricultural practices, especially in the Amazon, have the potential to drastically reduce net emissions from livestock farming, even neutralize them, through the growth of livestock farming. Studies indicate that the recovery of degraded pastures and the intensification of livestock farming can reduce the time it takes to slaughter animals to 24 months, reducing methane emissions in the Legal Amazon by around 33%. The implementation of integrated systems, such as the Integrated Crop-Livestock-Forest, appears as an essential mechanism to increase agricultural and livestock production in the region, allowing cereal production to be doubled and livestock production to be increased by 30%,

without resorting to deforestation. Agroforestry Systems are highly recommended in the Amazon region, promoting the production of native fruits and wood, as well as the intercropping of grains with livestock, making agricultural systems more resilient to climate change. It is imperative that Brazil establish a Green Deal for the Amazon, with an urgent commitment to adopt an innovative socioeconomic approach, focused on preserving forests and promoting regenerative and carbon-neutral livestock farming. This can be achieved through initiatives that encourage regional development, through education for technological innovation and adding value to forestry products, strengthening local entrepreneurship for the benefit of indigenous peoples and local communities.

2. INTRODUCTION

1 The Amazon rainforest covers 40% of South America and is the largest and most biodiverse rainforest biome on the planet (ca. 13% of global biodiversity) (Zapata-Ríos et al., 2021; R. Mittermeier and A. B. Rylands, personal communication). Its high biodiversity plays a critical role in maintaining the resilience of Amazonian ecosystems, providing resistance to natural or human-induced disturbances, while maintaining their basic functions (Borma et al., 2022). Amazon forests store between 150 and 200 billion tons of carbon above and below ground and sequester 1.2 billion tons of carbon dioxide per year (Malhi et al., 2021). In addition, they recycle rainfall by throwing in the order of 1,220 mm.year^{-1} ± 15% of water vapor into the atmosphere through evapotranspiration from the forest. This ecosystem service is important because it cools the Earth's surface (*cooling effect*) and contributes to the transport of moisture to other regions outside the Amazon Basin, such as the Andes and La Plata Basin (Costa et al., 2021a). As the largest tropical terrestrial carbon sink on the planet, the more than 5 million km^2 of Amazon rainforest is a crucial part of global efforts to keep global warming below 2.0 ºC (IPCC, 2021).

2 Most of the Amazon biome is found on Brazilian lands, covering an area of 4.1 M km^2 (**Figure 1**). This corresponds to just over 60% of the entire biome, attributing to Brazil a great responsibility in the management of this territory. With a focus on territorial management, the Brazilian State delimited a political and socio-geographical division called the Brazilian Legal Amazon. This region corresponds to 59% of the Brazilian territory, consisting of nine states: Acre, Amazonas, Amapá, Maranhão (just West of the 44° Meridian), Mato Grosso, Pará, Rondônia, Roraima, and Tocantins. This region has a human population of around 29 million people, 80% of which is urban and encompasses the Indigenous Peoples of the Amazon (ca. 300,000 Indigenous people) (Albert et al., 2021). The 5 M km^2 of Legal Amazon is covered not only by the Amazon biome, but also by the Cerrado, a tropical savanna biome that differs substantially in vegetation structure, biodiversity, soil attributes, and climatic conditions (Durigan and Ratter, 2016; Borma et al., 2022).

Figure 1. Boundaries of the Amazon biome in Brazil (green) and the geopolitical boundary of the Legal Amazon formed by nine Brazilian states. Data source: INPE, 2023a.

3 The occupation of the Amazon through the expansion of farmlands and an infrastructure to support commodity economies (e.g., roads, urbanization) has been the focus of Brazilian policies since the 1960s (Hecht et al., 2021; Berenguer et al., 2021). These policies caused pressures for land use that resulted in the loss of more than one hundred million hectares over the last 50 years (15.5%) (INPE, 2023a; Mapbiomas Amazônia, 2022).

4 It is estimated that more than 60% of all deforested land in the region has been converted to pasture (INPE/EMBRAPA, 2018) and that 60% of pasture lands in the biome are in a greater or lesser state of soil degradation (Dick et al., 2021). The expansion of cattle ranching over the natural forests of the Amazon is associated with multiple forms of clandestine and illegal economies, such as timber, land grabbing, and gold mining (Hecht et al., 2021). 32% of undesignated public lands in the Brazilian Amazon (18.6 million hectares) were deforested by the end of 2020 and self-declared as private properties in the national registry, indicating the process of land grabbing as a major driver of deforestation in the Brazilian Amazon

(Alencar et al., 2020). In 2020, of the 58,878 deforestation alerts by satellite monitoring and 838,189 ha of deforested area in the legal Amazon, 99.88% and 99.43%, respectively, showed signs of irregularity or illegality (Mapbiomas, 2021). Such an economic model based on neo-extractivism, with minimal diversification of production and aimed at the commodity market, benefits a few and burdens millions, through environmental degradation, loss of biodiversity and forest services of climate regulation, which drive social inequality, poverty, threats to the right to land and good living of Indigenous Peoples and local communities (Hecht et al., 2021; Soares-Filho et al., 2006).

5 Brazil is the seventh largest emitter of greenhouse gases (GHG) in the world, attributed to emissions resulting from changes in land use (in particular deforestation) and livestock (SEEG, 2023, Brazil 2020). Livestock farming has been widely considered a major emitter of methane (CH_4) globally and a major driver of climate change (Liu et al., 2021; IPCC, 2022). On the other hand, the loss of the approximately 119 billion tons of carbon stored in the trees of the Amazon would be equivalent to 15 years of the current global anthropogenic emissions of GHG into the atmosphere (Soares-Filho et al., 2006). The increase in GHG emissions and its consequent changes in climate could reduce the yield of agricultural crops produced in the Amazon, such as soybeans, by up to 44% by 2050 (Lapola et al., 2011).

6 The concomitant pressures on the Amazon rainforest caused by climate change, deforestation, frequent fires, result in more forest loss by positive feedback mechanisms. Mathematical models estimate that up to 50% of its original area could be lost by 2050, especially in the Southern and Eastern regions of the forest, surpassing a tipping point for the Amazon (Nobre et al., 2016). This tipping point represents a significant change in the functioning of the humid tropical forest ecosystems that dominate the region, leading to other vegetation states, similar to degraded vegetation and with affinities with tropical savanna climate (Nobre et al., 1991, 2016; Hirota et al., 2021). The intensification of climate cycles, evidenced by the increase in the frequency, duration (4-5 weeks longer) and severity of droughts in the Amazon in the last two decades (e.g., 2005, 2010 and 2015-16, 2020), and the average warming of 1°C verified in the last 40 years in the Amazon (Marengo et al., 2021; Gatti et al., 2021) may represent an abrupt disturbance in carbon cycles (Malhi et al., 2021), being the first indications of how close we are from the Amazon tipping point (Lovejoy and Nobre, 2018).

7 Reducing GHG emissions from deforestation and degradation is critical to keep forest carbon stocks and maintain temperature below tipping points. This will contribute to avoid irreversible changes in regional and global climate systems (Lenton et al., 2008; Nobre et al., 2016), the impacts of which will rapidly spread across socioeconomic and ecological systems

(McKay et al., 2022; Banerjee et al., 2022). On the other hand, mitigation of livestock emissions should be implemented with innovative technologies and management practices (Liu et al., 2021; Assad et al., 2021). There are major challenges to be faced by Brazil to achieve net-zero emissions in accordance with its self-determined commitments to the Paris Agreement on Climate Change. The time is ripe for these challenges with the current Brazilian government and the recent Amazon Summit[4] of the eight Amazon countries with contribution of civil society, but this will require an Amazon Green Deal from all of society.

8 These observations present historical data on the change in land use and agriculture in the Legal Amazon over 32 years and its consequent GHG emissions at the national and regional levels. An analysis of the impacts of cattle ranching in the Amazon on methane emissions is presented from the perspective of the increase in the number of cattle in the region from 1990 to 2021. This scenario of changes in the Amazon is used to propose some climate mitigation and adaptation measures, considering the need to keep the forest standing and reduce the vulnerability of local and Indigenous populations in the region.

3. Deforestation and Land Use Change in the Legal Amazon

3.1 Deforestation and Degradation in the Legal Amazon

9 In the Legal Amazon, 75.7% of the region is covered by ombrophilous and seasonal forests that occur in both the Amazon and Cerrado biomes. Non-forest formations occupy 4.2% of the territory and consist of open vegetation with a predominance of shrubs and herbaceous plants, typical of the savannas (Mapbiomas Brasil, 2023). Agriculture occupies 17.6% of the region, 78% of which is pasture (68 million hectares (Mha)) and 18% agriculture. Agriculture in the region has a predominance of temporary crops (99%), mostly soybean (82%; 13 Mha).

10 The Amazon Forest lost 56 million hectares of its forests between 1985 to 2021, which roughly represent 13% of the world's loss (Mapbiomas Amazônia, 2022). Previously to 1985, Amazon had lost a large area of forests starting in 1970s. Presently, estimates indicates that more than one hundred million hectares have been deforested over the last 50 years (15.5%). Forest cover has reduced by about 12% in these 32 years. 11% of the forests were converted to pasture areas and 1% to soybean plantations (MapBiomas Brasil, 2023, **Figure 2**).

[4] https://www.gov.br/mre/pt-br/canais_atendimento/imprensa/notas-a-imprensa/declaracao-presidencial-por-ocasiao-da-cupula-da-amazonia-2013-iv-reuniao-de-presidentes-dos-estados-partes-no-tratado-de-cooperacao-amazonica

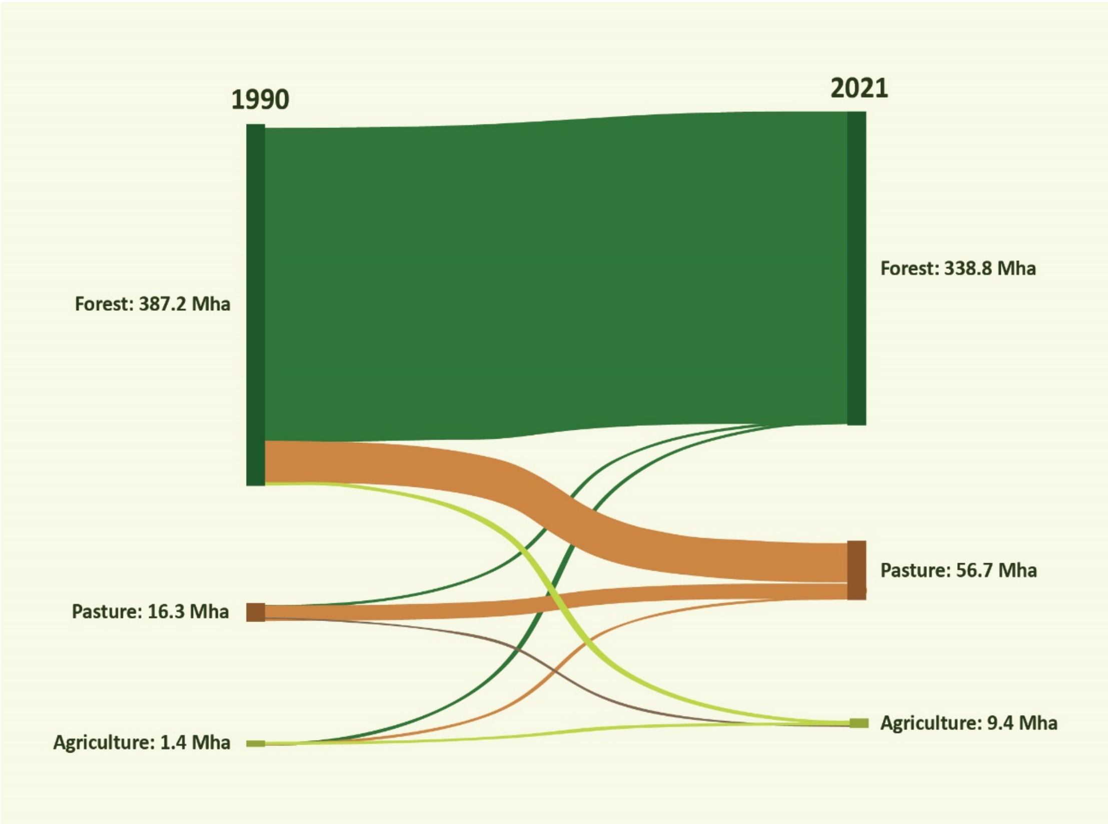

Figure 2. Senchi diagram showing transitions between land covers between 1990 and 2021. Data source: Mapbiomas Brasil, 2023.

11 In 2021, the deforestation rate was 1.3 Mha, an increase of 22% since 2019 (**Figure 3A**). From 2021 to 2022, deforestation decreased by 12%. The 84% reduction in deforestation in the Amazon from 2004 to 2012 is attributed to forest conservation policies in Brazil through the increase in protected areas and actions plans for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm) initiated in the second half of the 2000s (Assunção et al., 2015; INPE, 2013; Sanquetta et al., 2020).

12 The states in the Legal Amazon with the largest deforested areas from 1990 to 2021 were Pará (15 Mha), Mato Grosso (13.9 Mha), and Rondônia (6.1 Mha). Mato Grosso and Pará, states that accumulated the largest number of cattle in 2021 (56 million; 58% of a total of 96.7 million heads), accounted for 87% of deforestation (**Figure 3B**, details of the evolution of cattle ranching in **section 2.2**). Tocantins, although it is the second state with the lowest absolute deforestation (638,000 hectares), is the fourth largest in number of cattle. It is worth remembering that 91% of the state is in the Cerrado biome, therefore with a reduced forest area. An important fact is that much of the deforestation in the Brazilian Amazon occurs within undesignated public lands, such as a process of irregular occupation of public lands known as land grabbing. From 1997 to 2018, a total of about 2.6 million hectares of forested area were lost on these lands (Azevedo-Ramos et al., 2020). Before the 1990s, from 1975 to

1986, the total deforestation in the Legal Amazon was 21 Mha (4.36%), with Amazonas state having lost 731,000 hectares of its natural cover (<0.22%), Pará 7 Mha (1.44%) and Mato Grosso 6.4 Mha (1,30%) (INPE, 1989).

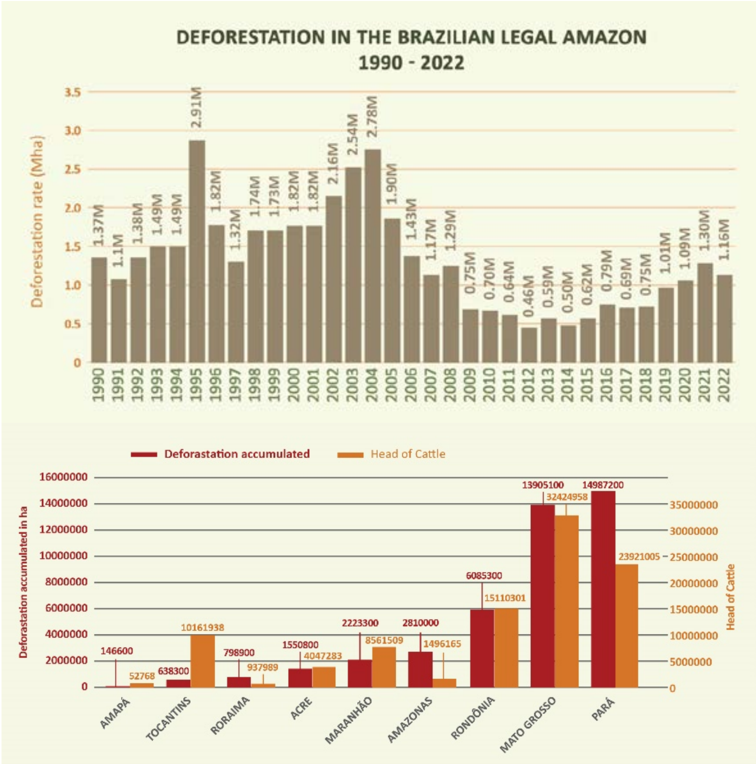

Figure 3. **A.** Deforestation accumulated in the Legal Amazon from 1990 to 2022, and **B.** in the nine states that compose the Legal Amazon region (red bar). Differences in the number of cattle heads per state per state is also shown (orange bar). Data source: INPE, 2023a; IBGE 2021a[5].

13 The degradation of the Amazon rainforest is as critical as deforestation. Fire, edge effects and timber extraction caused 36 Mha of the Amazon biome to show some stage of degradation (5.5%) between 2001 and 2018 (Lapola et al., 2023). This area corresponds to 112% of total area deforested in this same period. The combination between logging and forest fires led the Brazilian Amazon to emit 2.7 billion tons of CO_2 between 2007 and 2015, almost half of the emissions from deforestation in the same period (5.1 billion tons) (Assis et al., 2020).

14 Pasture field clearing, deforestation and other types of forest degradation and fragmentation in general initiate forest fires in the Amazon (Malhi et al., 2009; Cano-Crespo et al., 2021).

[5] https://sidra.ibge.gov.br/pesquisa/ppm/quadros/brasil/2021

According to INPE's data on the number of fire (INPE, 2023b), there were 75,021 fires[6] in the Legal Amazon in 2021 (**Figure 4**). This year, the state of Pará accounted for 30.5% of the fires, followed by the state of Amazonas (19.8%). It is worth mentioning that deforestation rates are not always directly associated with the highest number of fires, such as Amazonas, which was the fourth state with the highest deforestation rate in 2021 (7%), but the second with the highest number of fires in the year.

The exploitation of timber in the Amazon causes degradation of the forest by altering its structure and microclimate, increasing the deposit of organic matter on the soil and decomposition. The mapping of logging in the Brazilian Amazon carried out by SIMEX (Logging Monitoring System) identified 377,624 hectares of logging from August 2020 to July 2021, with 38% of this area (i.e., 142,428 hectares) having been exploited in an unauthorized manner by the environmental authorities. Of these, about 72% are within rural properties with an Environmental Rural Registry (CAR, in Portuguese) (SIMEX 2022 Network[7]). Mato Grosso was the state with the largest area for logging between August 2020 and July 2021 (73.4%), followed by Pará (15.1%) and Rondônia (4.3%). In this context, it is important to note that undesignated public lands were the most exploited in the region, whether through legal and authorized means (corresponding to 82.6%, i.e., 311,996 hectares), or illegally (covering 72%, i.e., 102,003 hectares). It is noteworthy that Indigenous territories constitute the second land category with the highest incidence of logging, with most of it occurring in an unauthorized manner and, therefore, illegally (representing 11% of the total, i.e., 16,211 hectares).

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6 INPE. Database of fires. Available at: http://www.inpe.br/queimadas/bdqueimadas. Accessed: Sept. 10. 2023.

7 Logging Monitoring System (Simex): Mapping logging in the Amazon - August 2020 to July 2021 (p.1). Belém: Imazon, Idesam, Imaflora and ICV. Available at: https://imazon.org.br/imprensa/quase-40-da-extracao-de-madeira-n a-amazonia-no-e-autorizada-mostra-pesquisa-indita/

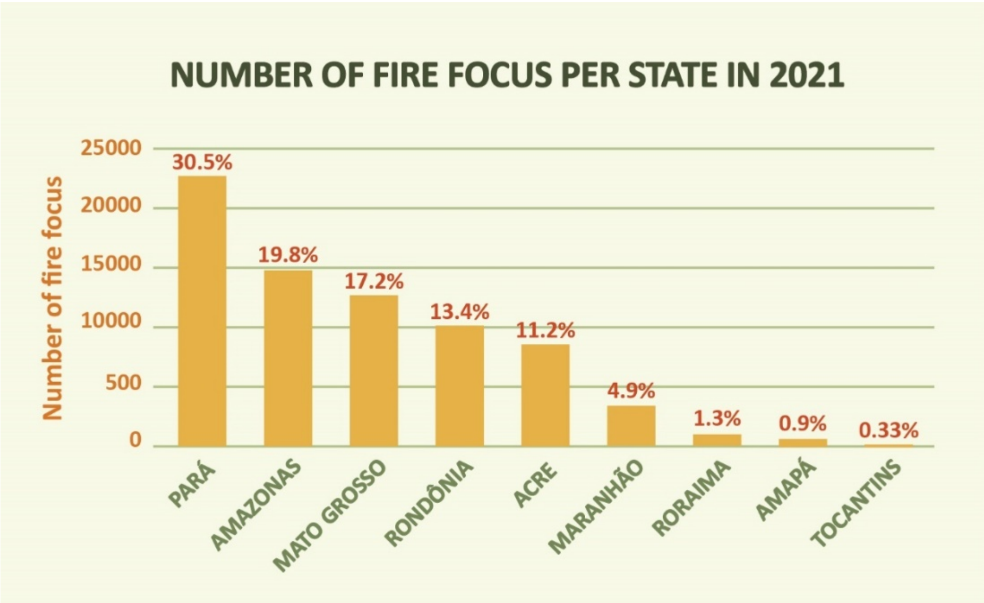


Figure 4. Number of fire focus counted by the states of the Legal Amazon in 2021. Data source: INPE, 2023(b)

3.2 Evolution of Agriculture in the Legal Amazon from 1990 to 2021

16 Over the last few decades, Brazilian soybean and cattle ranching have experienced significant growth in the states of the Legal Amazon. Through the absolute numbers of soybean planted area and cattle herd registered in Municipal Agricultural and Livestock Production in 1990, 2009, 2014 and 2021 (IBGE, 2021a), it is possible to observe the evolution in each federative unit and in the Legal Amazon (**Tables 1 and 2**).

17 Soybean production in the Legal Amazon is concentrated in the state of Mato Grosso (MT), where the soybean planted area increased from 1,552,910 hectares in 1990 to 10,461,712 hectares in 2021. Mato Grosso maintained the largest planted area in 1990, 2009, 2014 and 2021, although its proportion in relation to the total area in the Legal Amazon decreased to 96.9%, 86.5%, 82.2% and 75.4%, respectively. Tocantins and Maranhão stand out, with more than 1 million hectares of soybean planted, followed by Maranhão and Pará, with 753,000 and 400,000 hectares, respectively. Roraima, Amapá, Acre and Amazonas recorded soybean planted areas of less than 100 thousand hectares by 2021 (**Table 1**). In total, the soybean planted area in the Legal Amazon grew from 1.6 million hectares in 1990 to 13.9 million hectares in 2021, an increase of 769%.

STATE (UF)	Soybean Planted Area (hectares)			
	1990	2009	2014	2021
Mato Grosso (MT)	1,552,910	5,831,468	8,628,608	10,461,712
Tocantins (TO)	30,120	315,560	719,356	1,171,308
Maranhão (MA)	15,305	409,402	677,540	1,023,541
Pará (PA)	0	71,410	243,171	753,781
Rondônia (RO)	4,640	111,426	195,180	400,459
Roraima (RR)	0	1,400	16,000	57,277
Amapá (AP)	0	0	17,220	6,715
Acre (AC)	0	50	400	6,185
Amazonas (AM)	0	204	0	3,000
Legal Amazon	**1,602,975**	**6,740,920**	**10,497.475**	**13,883.978**

Table 1. Evolution of soybean planted area in hectares in the states of the Legal Amazon between 1990 and 2021**.** Data source: IBGE, 2021a.

18 In the context of the evolution of the cattle herd in the nine states of the Legal Amazon in the time intervals analyzed (**Table 2, Figure 6**), the total number of cattle was 27 million in 1990. By 2009, that number had grown to 75 million, representing an absolute increase of 48 million head or 181%. In the subsequent period, from 2009 to 2014, the herd continued to increase, reaching a total of 82 million. In 2021, the total herd reached 97 million, registering an additional 15 million head increase compared to 2014 or 18%. The absolute change of 70 million between 1990 and 2021 represented an increase of 263%.

19 It is clear that the area occupied by cattle in the Legal Amazon has grown significantly over these three decades, especially in the states of Mato Grosso and Pará. Mato Grosso also stands out as the state with the largest cattle herd among the time intervals analyzed. From 1990 to 2021, there was a notable increase of more than 23 million head (**Table 2**). Consequently, the herd expanded from 9,041,258 head of cattle in 1990 to 32,424,958 in 2021, representing an increase of 258%. Throughout this period, the size of the cattle herd fluctuated between 33.5% and 36.6% of the total herd present in the Legal Amazon. The following Table 2 represents the absolute evolution of cattle herd size in the nine states of the Legal Amazon.

	cattle herd size			
STATES (UF)	**1990**	**2009**	**2014**	**2021**
Mato Grosso (MT)	9,041,258	27,357,089	28,592,183	32,424,958
Pará (PA)	6,182,090	16,856,561	19,911,217	23,921,005
Rondônia (RO)	1,718,697	11,532,891	12,744,326	15,110,301
Tocantins (TO)	4,309,160	7,605,249	8,062,227	10,161,938
Maranhão (MA)	3,900,158	6,885,265	7,758,352	8,561,509
Acre (AC)	400,085	2,511,285	2,799,673	4,047,283
Amazonas (AM)	637,299	1,350,816	1,405,208	1,496,165
Roraima (RR)	345,650	475,380	735,962	937,989
Amapá (AP)	69,619	104,977	167,529	52,768
Legal Amazon	**26,604,016**	**74,679,513**	**82,176,677**	**96,713,916**

Table 2. Absolute evolution of cattle herd size in the states of the Legal Amazon between 1990 and 2021. Data source: IBGE 2021b.

20 The states of Pará, Rondônia, Tocantins and Maranhão rank below Mato Grosso in terms of the number of cattle in the legal Amazon. Pará went from 6 million head of cattle in 1990 to 24 million in 2021, which represents an increase of almost 18 million head, equivalent to a growth of 287%. Rondônia grew from 1.7 million to 15 million head of cattle in the same period, representing a growth of 779%. Tocantins grew from 4.3 million to 10 million head, an increase of 119% between 1990 and 2021. The sum of the cattle herds from these four states together increased from 16 million in 1990 to 58 million in 2021, representing an increase of 275%.

21 The herds in the states of Acre, Amazonas, Roraima and Amapá sum 7% of total heard of the Legal Amazon. Acre increased from 400 thousand head of cattle in 1990 to 4 million in 2021, representing a 912% increase over the period. Amazonas also recorded a significant increase, going from 637 thousand head of cattle in 1990 to 1.5 million in 2021, representing an increase of 135%. Roraima had 345 thousand head of cattle in 1990 and this number rose to 937 thousand in 2021, a growth of 171%. Amapá presented a peculiar dynamic (**Figure 5**), increasing from 69 thousand head of cattle in 1990 to 167 thousand in 2014 and then reducing to 53 thousand in 2021, being 24% lower compared to 1990. Due to its low herd size, Amapá has been traditionally a large importer of animals from other Amazonian states such as Pará (Arima et al., 2005). In all, the number of combined head of cattle in these four states grew from 1.7 million to 6.5 million, or 282%, between 1990 and 2021.

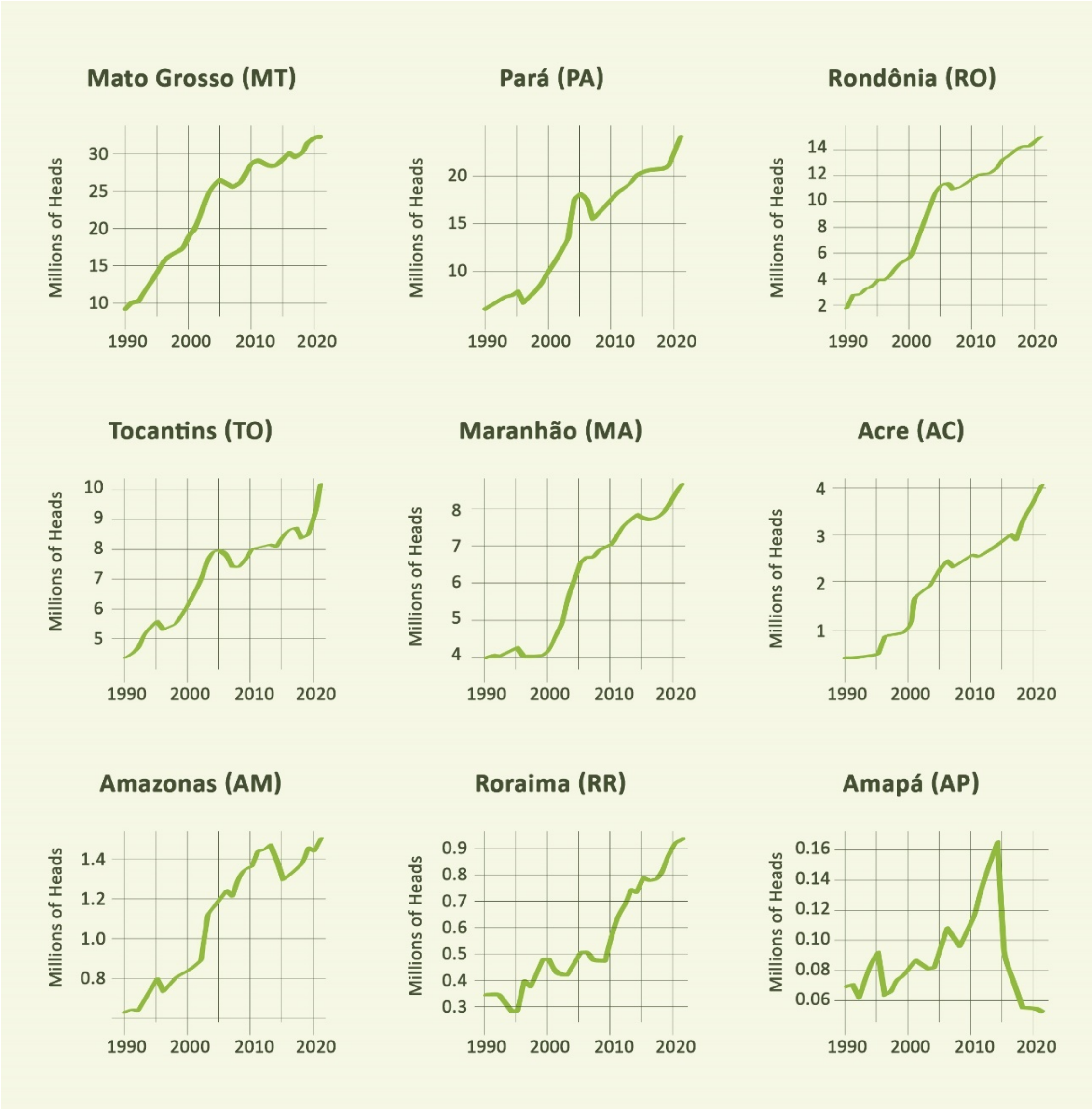


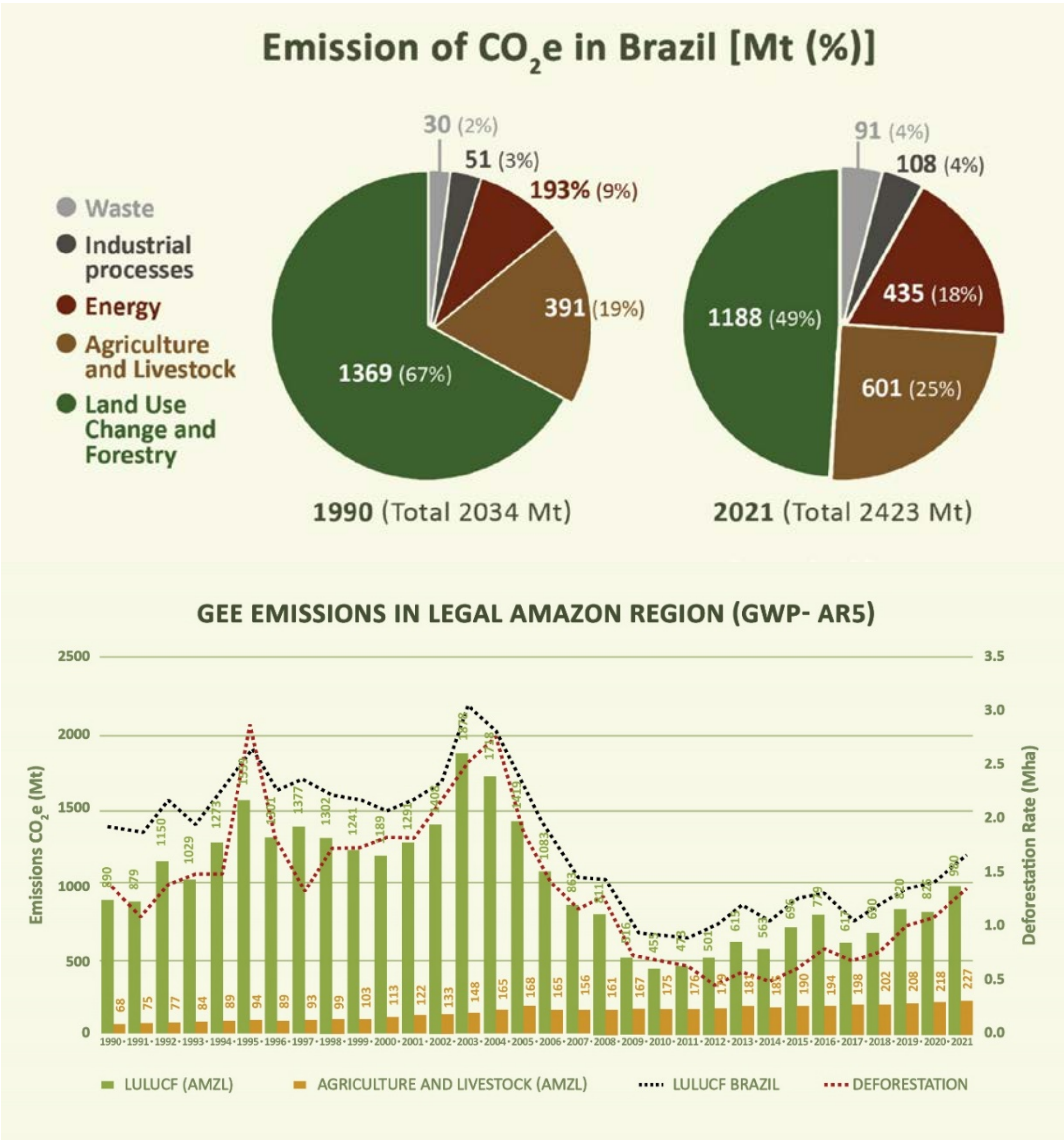
Figure 5. Size of the cattle herd in the Legal Amazon between 1990 and 2021. Data source: https://sidra.ibge.gov.br/pesquisa/ppm/quadros/brasil/2021

4. Greenhouse Gas Emissions from Land Use, Land-Use Change, and Forestry and Cattle Ranching in the Legal Amazon

4.1 Greenhouse Gas Emissions from Land Use, Land-Use Change, and Forestry (LULUCF)

22 The land use change and forestry sector are responsible for reporting total emissions and GHG emissions related to changes in above- and below-ground biomass and organic matter stocks. This also includes emissions from soil liming in recently deforested lands and

emissions from forest residue burning (SEEG 20208). The land use change and forestry sector are responsible for most of Brazil's emissions (1.188 million tons (Mt)), followed by the agricultural (agriculture & livestock) sector (601 Mt) (Figure 6A). GHG emissions in Brazil increased by 16% from 1990 to 2021. While LULUCF emissions have decreased in these 32 years, emissions from agriculture have almost doubled. Of the total 2.4 billion gross tons of CO2 equivalent emitted in 2021 by the Brazil, more than 51% was emitted by the land use sector (approximately 1.2 billion gross tons of CO2). Adding emissions from deforestation and other changes in land use with those from the agricultural sector, it is concluded that these activities in a broad sense account for 74% of all Brazilian climate pollution.



[8] https://seeg-br.s3.amazonaws.com/Nota_Metodologica_SEEG_7_MUT_-_Revisada_Fev_2020.pdf

Figure 6. A. GHG emissions in Brazil, in 1990 and 2021, by economic sector**. B.** Evolution of GHG emissions between 1990 and 2021, for the land use, land use change and forestry (LULUCF) and agricultural sectors in the Legal Amazon and Brazil. Rates of deforestation over time seems to follow emissions by LULUCF in the Legal Amazon. Data source**:** SEEG, 2023 Platform[9].

23 About 40% (980 Mt CO_2e) and 9% (227 Mt CO_2e) of Brazilian emissions in 2021 were attributed to changes in land use and agriculture in the Legal Amazon, respectively. On the other hand, while emissions from LULUCF increased by 9% (90 Mt CO_2e) from 1990 to 2021, reflecting a huge variability between different periods, emissions from agriculture rose by 70% more or less uniformly (159 Mt CO_2e) (**Figure 6B**). The relationship between deforestation and GHG emissions is so close in Brazil that the variation in LULUCF emissions in the country follows the rate of deforestation in the Amazon region (SEEG, 2020). In 2018, deforestation in the Amazon accounted for approximately 59% of GHG emissions from land-use change, and 25.7% of the country's annual emissions (SEEG, 2023). The 84% reduction in deforestation in the Legal Amazon from 2004 to 2012 resulted in a decrease of more than 240% in the sector's gross CO_2 equivalent emissions. The agricultural sector, on the other hand, continued to increase its emissions by 8%, mainly driven by the increase in the cattle herd. The contribution of LULUCF emissions from the Legal Amazon to LULUCF emissions in Brazil rose from 65% to 82% from 1990 to 2021.

24 The state of Pará emitted the most by the LULUCF sector in 2021, releasing about 381 million tons of GHG into the atmosphere (**Figure 7**). Mato Grosso was the state that emitted the most in the same year by the agricultural sector, with 87 million tons. Amazonas, although the third largest emitter of the Legal Amazon by LULUCF (124 Mt CO_2e), had lower deforestation than Rondônia, the fourth largest emitter state due to land use changes. Mato Grosso, Pará and Amazonas accounted for almost 67% of emissions.

9 https://plataforma.seeg.eco.br/total_emission

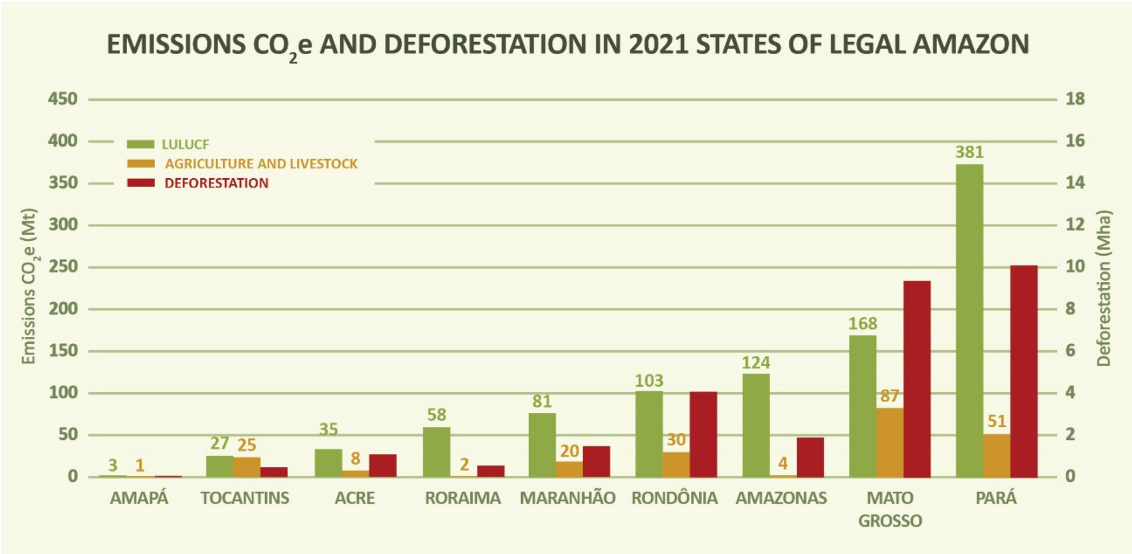


Figure 7. Differences in GHG emissions from LULUCF and agricultural sectors among all states in the Legal Amazon in 2021. Deforestation data is used for visual comparisons (Data source**:** SEEG Platform, 2023).

25 Although emissions from degradation are not yet computed in national inventories, studies show that net emissions due to forest degradation contributed to 16.2% of 5.4 Gt CO_2 emitted from 2007 to 2016 (Assis et al., 2020). Total emissions from forest fires in the Brazilian Amazon during drought years such as 2015 (989 ± 504 Mt CO_2 per year) are more than half of the emissions resulting from forest clearing (Aragão et al., 2018). This shows the importance of including degradation, especially by fires, in national inventories.

26 The Amazon Rainforest plays an essential role in sequestering carbon from the atmosphere through photosynthesis, removing part of the carbon emitted by different human activities (agriculture, energy, changes in land use, etc.). In 2021, forests absorbed about 666 Mt CO_2e, with 81% of this sequestration occurring within the Legal Amazon. Most of the removal (58%) occurs from areas of native vegetation in protected areas (conservation units and Indigenous territories), with the rest of the removals coming from the growth of secondary vegetation as occurs in abandoned pastures, which are equivalent to 42% (-277 Mt CO_2e) (SEEG, 2023[10]). Amapá and Amazonas were the only states where carbon emissions from LULUCF and agricultural sectors were completely offset through carbon sequestration by the forest (**Figure 8**). Pará and Mato Grosso were the states with the highest GHG removal in 2021, but due to their high LULUCF emissions, the state continues to be a source of GHG into the atmosphere. Even if emissions from land-use change are zero, the removal of carbon equivalent by the forests of Mato Grosso, Tocantins and Rondônia is not enough to balance

10 chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://energiaeambiente.org.br/wp-content/uploads/2023/04/SEEG-10-anos-v5.pdf emissions due to agricultural activity. This underscores the need to reduce Brazilian GHG emissions through both actions to combat deforestation and degradation in the Legal Amazon, and investments in low-GHG cattle ranching and restoration of unproductive pastures.

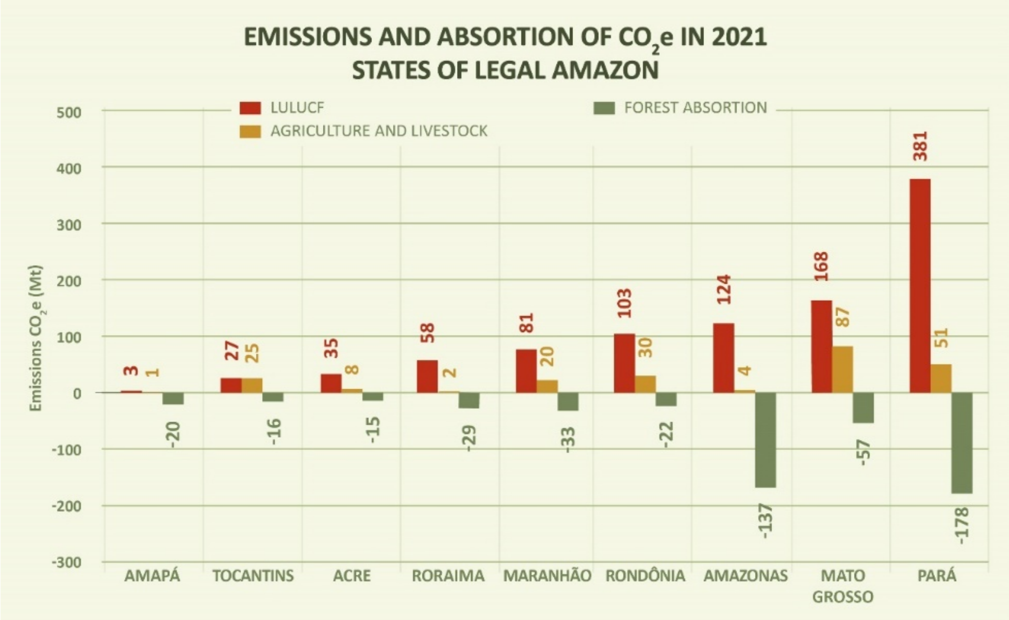


Figure 8. GHG (CO_2e) emissions from land use changes, and agricultural sectors in the nine states of the Legal Amazon. Carbon dioxide removal by land-use change refers to the amount of carbon gases fixed by vegetation growth and is presented with negative values. (Data source: SEEG, 2023 platform).

4.2 Methane Emissions from Cattle Ranching in the Legal Amazon

27 Animal production systems in the Amazon, especially ruminant production, contribute significantly to GHG emissions (**Figure 9**). Among the sources of emissions from these systems, the enteric fermentation process stands out, which occurs in the digestive tract of ruminants and results in the production and release of **methane** gas. Animal waste management and storage systems also affect **methane (CH_4)** and **nitrous oxide (N_2O)** emissions, which are generated during waste decomposition. In addition, losses of ammonia (NH_3) and nitrogen oxides (NOx) by volatilization, as well as losses of nitrogen by leaching and runoff in manure management systems and soils, cause indirect GHG emissions.

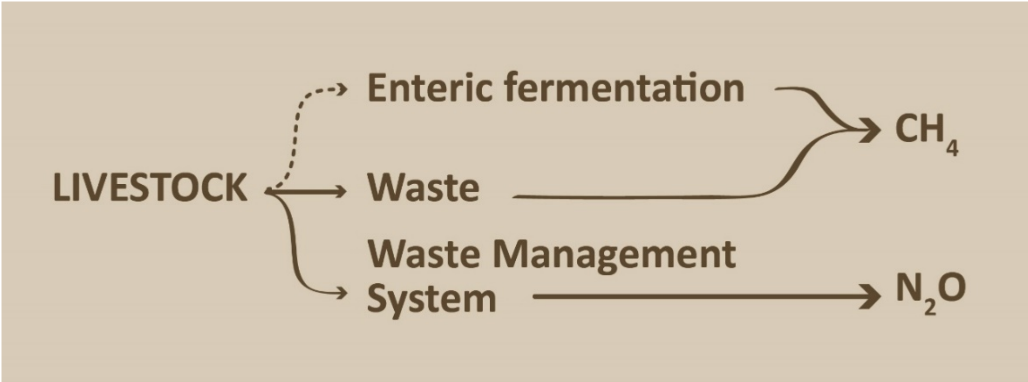


Figure 9. General scheme of GHG emissions by type of gas in livestock. Data source: Adapted from Estevam et al., 2023.

28 Methane is in second place as the gas that contributes most to the warming of the planet through the absorption of radiation in the atmosphere, second only to carbon dioxide (Zotti & Paulino, 2009). While the lifetime of methane in the atmosphere is 10 times shorter than carbon dioxide, it has about 25 times the potential to cause global warming (Boucher et al., 2009). In 2021, the methane emitted by the agricultural sector was equivalent to 70.6% of the total methane emission in the country. Thus, actions aimed at mitigating emissions are necessary to reduce the impacts of Brazilian agriculture on the production of greenhouse gases.

4.2.1 Enteric Fermentation

29 Enteric fermentation occurs in one of the stages of digestion of ruminant herbivorous animals, such as cattle, buffaloes, sheep and goats (**Figure 10**). The digestive process of these animals results in the generation of hydrogen gas (H_2), which is used by methanogenic bacteria to reduce carbon dioxide, resulting in the formation of **methane** gas, which is then expelled via eructation into the atmosphere. Monogastric (non-ruminant) herbivorous animals, such as horses and pigs, also emit methane, however, in smaller amounts, as they do not ferment the food ingested during digestion (Assad et al., 2019).

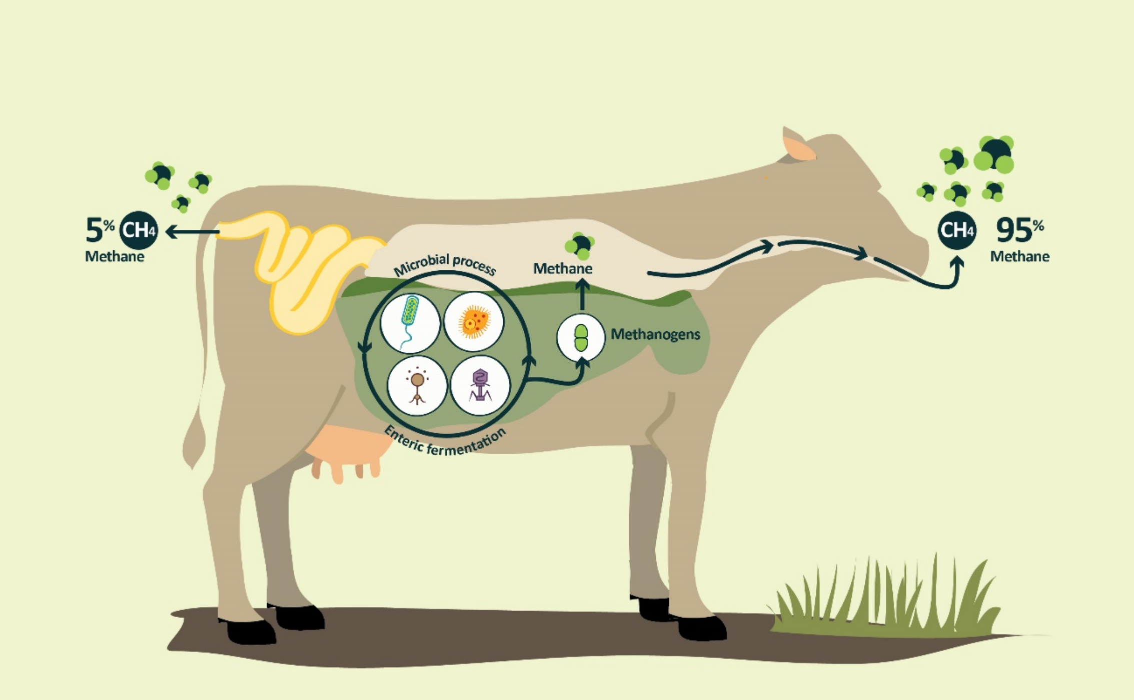


Figure 10. Methane gas release process via enteric fermentation in cattle. Source: Adapted from New Zealand Agricultural Greenhouse Gas Research Centre[11].

30 In the context of the tropicalization of the methodology for calculating GHG emissions, it is important to consider the particularities of animal production systems, taking into account local conditions such as animal categories, age, management condition, purpose of production and digestibility rates. GHG emissions are influenced by factors such as animal diet composition, forage quality, rumen microorganisms, genetics, herd management, production environment.

31 The IPCC guidelines provide standard emission factors (*default*), that is, average emissions from an animal, considering the type of herd and its location, at the continental level, and also by generalized category of production system (beef or milk). The documents also provide technical guidelines for the specific calculation of cattle emission factors, considering the specificities of the animal diet and management conditions. However, this level of accuracy applies to controlled operations, with a high level of information and data organization, conditions found in some technical production units. For emission calculations and inventories at the regional and national level, the application of the specific emission factor calculation methodology becomes impractical.

11 https://www.nzagrc.org.nz/domestic/methane-research-programme/the-science-of-methane/

32 Brazil has specific emission factors for the calculation of emissions from enteric fermentation of national cattle, at the Tier 2 information level. The values that were used in the accounting of the emissions disclosed in the National GHG Inventory were obtained through scientific research carried out in the country, and, therefore, adequate for the Brazilian reality. The data, segregated by animal category, breeding system (beef or milk), sex, age and state of the federation, can be accessed in the sectoral reference reports of the national communication.

33 **Figure 11** shows the flow of the methodological rationale used by the Sectoral Reference Report (RRS) of the Fourth National Communication[12] to quantify and establish enteric fermentation emission factors for the different classes of animals. In the case of pigs, sheep and other categories (buffaloes, goats, horses, mules and donkeys), the same default enteric methane emission factors were considered, pre-established for each animal class grouping, indicated by the IPCC (2006).

[12] Brazil's Fourth National Communication to the United Nations Framework Convention on Climate Change.

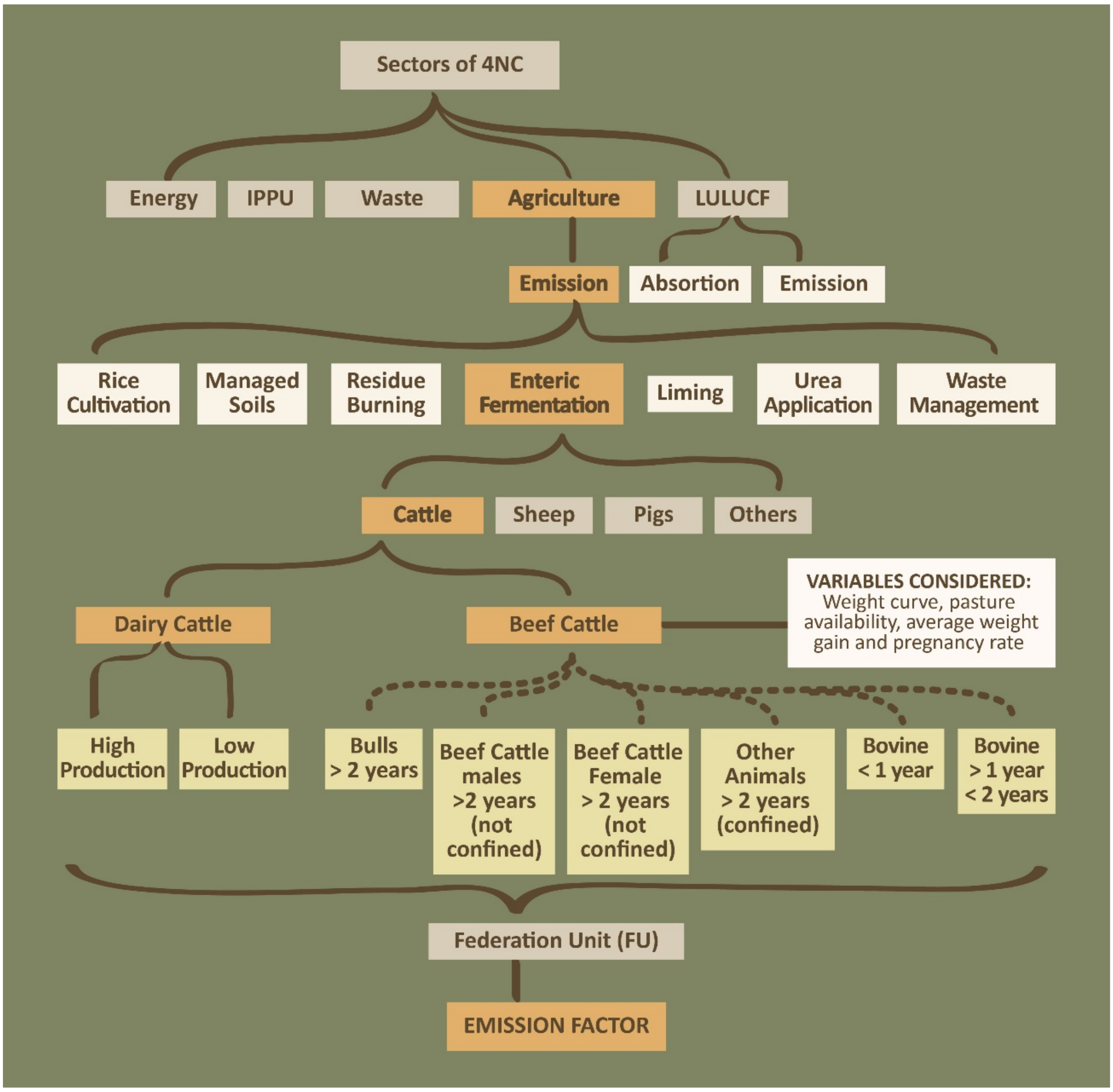


Figure 11. Flow of categories considered for emission factors in Enteric Fermentation according to the Fourth National Communication of Brazil (4NC) to the United Nations Framework Convention on Climate Change. Data source: Adapted from Estevam et al. (2023).

34 When comparing the default values of IPCC emission factors (Tier 1) with those obtained at the national level, it is possible to observe a significant difference between the Tiers and categories of animals. For example, for beef cattle (bulls), the emission factor is 71 kg CH_4.animal^{-1}.year^{-1}, while for beef cattle - males older than 2 years - not confined, the values vary from 63 to 72, depending on the federation unit (state). The Tier 1 values of the IPCC Guidelines (2006) consider only an average value (default) for the age classes of beef cattle, as can be seen in **Table 3** below.

EMISSION FACTOR (YEAR 2016)	Kg CH_4 animal^{-1} year^{-1}	
Class	IPCC (Tier 1)	4 NC (Tier 2)*
Beef cattle – Bulls		71
Beef cattle Males over 2 years of age, not confined		63 - 72*
Females older than 2 years of age, not confined	56	73 - 79
Beef cattle – Under 1 year of age		34
Beef cattle between 1 and 2 years of age		52
Low-producing dairy cattle	78	81 - 93*
High-producing dairy cattle	103	60 - 96
Feedlot cattle > 2 years of age	58	60 - 67

*Values defined by Brazilian State

Table 3. Comparison of emission factors from enteric fermentation for cattle, according to IPCC and Fourth National Communication of Brazil to the United Nations Framework Convention on Climate Change.

35 One point of attention is related to the methane emission values of dairy cattle, segmented by the IPCC into the high and low productivity classes. However, the definitions of high and low productivity diverge from the Brazilian classification. According to the IPCC, a high-yielding dairy cow produces, on average, 3,400 kg of milk head^{-1} year^{-1}. On the other hand, low-yielding cows produce 1,250 kg of milk per head^{-1}year^{-1}, and intermediate production cows produce 2,050 kg of milk per head^{-1} year^{-1}, emitting an average of 87 kg CH_4 animal^{-1} year^{-1}. In the case of Brazil, the milk productivity limit value of 2,000 kg of milk per head^{-1} year^{-1} is accepted as a dividing mark between the population of high and low production cows. In other words, while the IPCC considers a production of 2050 kg as intermediate, in the Brazilian system it is considered as high.

36 In this sense, the IPCC also defines average values of emission factors for beef cattle, according to high and low productivity classification, which vary between 55 and 58 kg CH_4 animal^{-1} year^{-1}, with high productivity compared to semi-confinement or intensive confinement conditions. In this case, it is considered for comparative purposes with the Brazilian rearing system, the national intensive confinement system.

37 It is important to note that enteric fermentation is the class that presents the highest representativeness in relation to livestock emissions, especially with regard to methane emissions. Therefore, it is crucial that the choice of emission factor to be used is the most representative of the actual conditions.

38 Methane emissions should be analyzed from an energy perspective, in which the higher the animal's energy expenditure, the greater the demand for food, i.e., the greater the methane emission. According to the literature, it is considered that about 2% to 12% of the gross

energy consumed by ruminant animals is lost in the form of methane, representing a significant loss of energy in the agricultural production system (Machado et al., 2011).

39 This loss is related to factors involving the genetic characteristics of the animals, as well as variables related to the quantity and quality of food available for consumption, types of carbohydrates, digestibility of food, and other resources used in their nutrition (Sene et al., 2019). Therefore, emission factors are related to specific characteristics of herd type, sex, age, management and location. Mitigation strategies through the improvement and manipulation of animal diets take into account the reduction of methane emissions, while seeking to increase productivity, especially through improvements in **pasture conditions** and in the nutritional composition offered to animals (Machado et al., 2011).

4.2.2 Determination of Methane Emissions in the Legal Amazon by Category of Cattle

40 Despite the unavailability of the number of cattle divided into categories for the Amazon, in 2021, it was possible to estimate the cattle population in six categories (**Table 4**), based on the 2006 Agricultural Census, which had these data. Based on the total number of animals, the calculation of the proportion of animals per category (PC%) was made using the equation:

$$PC = \frac{Number\ of\ Cattle\ Herd\ per\ Category}{Total\ Number\ of\ Cattle\ Herd}\ x\ 100$$

Categories	Adopted Nomenclature	PC %
Bovine < 1 year	< 1 year	21.8
Bovine > 1 year < 2 years	1-2 year	26.8
Bulls	bulls	2.8
Beef Cattle Female > 2 years (not confined)	female 2 years+ nc	32.3
Beef cattle males >2 years (not confined)	males 2 years+ nc	15.7
Other Bovine > 2 years (confined)	2years + conf	0.6

Table 4. Proportion of animals per category (PC%) in the Brazilian region. nc = no confined; conf = confined.

41 By adjusting the herd by animal category, the determination of CH_4 emissions only, not considering N_20, allows us to establish some indicators:

(a) The emission of methane in the Legal Amazon, through enteric fermentation and waste management, represents around 55% of total methane emissions in the Brazilian agricultural sector. The cattle herd in the legal Amazon represents 43% of the Brazilian cattle herd.

(b) Of the 808 municipalities in the Legal Amazon, 537 are in the condition of severely degraded pastures, that is, high CO_2 emissions, low stocking capacity, and, therefore, high methane emissions.

Data on methane emissions can be found in **Table 5** below.

YEAR	HEAD OF CATTLE BEEF AND MILK – LEGAL AMAZON										
2021	MT	PA	RO	TO	MA	AC	AM	RR	AP	TOTAL number of cattle head	%
	32,424,958.00	23,921,005.00	15,110,301.00	10,161,938.00	8,561,509.00	4,047,283.00	1,496,165.00	937,989.00	52,768.00	96,713,916.00	43% of the herd
	ENTERIC FERMENTATION CH_4 - EMISSION FACTOR 0.063*										
	MT	PA	RO	TO	MA	AC	AM	RR	AP	TOTAL TON CH_4	%
	2,042,772.35	1,507,023.32	951,948.96	640,202.09	539,375.07	254,978.83	94,258.40	59,093.31	3,324.38	6,092,976.71	41% of CH_4 emissions from agriculture
	METHANE: WASTE MANAGEMENT - EMISSION FACTOR 0,0016*										
	MT	PA	RO	TO	MA	AC	AM	RR	AP	TOTAL TON CH_4	
	51,879.93	38,273.61	24,176.48	16,259.10	13,698.41	6,475.65	2,393.86	1,500.78	84.43	154,742.27	
Total CH_4	2,094,652.29	1,545,296.92	976,125.44	656,461.19	553,073.48	261,454.48	96,652.26	60,594.09	3,408.81	**6247718.97	
Total CO_2										174,936,131.26	

Source: IV Inventory of brazilian emissions/absortions INCT 2020*
Source: PPM/IBGE (2021)**

Table 5. Methane emissions from cattle ranching in the Legal Amazon. Data source: adapted from the IV National Inventory of GHG Emissions/Removals, Brasil-MCTI (2021).

5. Innovative Sociobioeconomy to Prevent the Amazon Tipping Point

42 The economic development model in the Amazon has resulted in the conversion of 15% of the natural areas since 1975, much of it converted into unproductive pastures, focused on extensive breeding and with low use of technologies. This model has resulted in environmental and social degradation, placing Brazil as one of the largest GHG emitters in the world, and the northern region of Brazil, with one of the worst social development indices (PNAD[13],IBGE[14]) accessed September 2023). This model has also posed a threat to the Amazon's climate system, pushing it dangerously to the brink of irreversible change, which will result in the loss and degradation of its forests and biodiversity, and of ecosystem services vital to the well-being of people living inside and outside the Amazon.

43 To move away from such an undesirable future, it is necessary to adopt a new sociobioeconomic model for the region, which “combine activities that maintain productive

13 https://www.ibge.gov.br/estatisticas/sociais/populacao/9127-pesquisa-nacional-por-amostra-de-domicilios.html

14 https://sidra.ibge.gov.br/pesquisa/ppm/quadros/brasil/2021

and conserved multifunctional landscapes and cultural diversity, while promoting economic and social added value to the Amazon's biodiversity” (Garrett et al., 2023).

44 To achieve this goal, it is essential to implement public policies, management systems and practices that encourage cattle ranching in the Amazon that is net-zero emissions of methane and carbon. This approach must be based on eliminating deforestation and forest degradation, while promoting the restoration of forests. These forests will be able to increase biodiversity, contribute to carbon capture, soil protection and cooling the environment, while ensuring a sustainable source of income and improving the quality of life for local communities, thus helping both, to mitigate climate change and adapt to ongoing changes.

5.1 Induce Net Zero Livestock Farming through a Regenerative Agriculture

5.1.1 Strategy to Reduce Methane Emissions

45 Livestock stands out as a significant source of GHG emissions. However, it is important to analyze livestock activities considering different management systems and practices.

46 It is of paramount importance to consider the emissions from livestock activity not only attributing them to individual animals, but rather understanding the system as a whole. When analyzing Brazilian cattle ranching, and especially in the Legal Amazon, we must keep in mind that the animals are raised, mostly, on pastures. Data from ANUALPEC (2022) indicate that 93% of the national herd is managed on pastures, and 30% of the herd raised on pasture is finished (fattened) in a confined environment. Thus, unlike the feedlot production systems of the northern hemisphere, Brazil has a system focused on extensive breeding.

47 In addition, the climatic characteristics of tropical regions bring specificities in relation to emissions associated with waste management processes, use of natural resources, and agricultural practices. When the production system is properly managed, it is possible to neutralize emissions and even remove atmospheric carbon at rates higher than the emissions generated by animals, that is, transform production systems into carbon sinks. Efficient and sustainable management can play a key role in reducing emissions from livestock, making it a more environmentally balanced activity and contributing to climate change mitigation.

48 The development of cattle ranching in the Legal Amazon should be based on stopping deforestation and on the recovery of the approximately 23.5 million hectares of degraded

pastures in the region. Of this total, 5 million are severely degraded pastures with heavy CO_2 emissions[15]

49 The rapid expansion of beef cattle ranching in the Amazon region was based on basically extensive cattle ranching (with low use of technology), subsidized by a generous governmental policy of tax incentives, developed on abundant, cheap land devoid of adequate infrastructure. This more extensive model of initial cattle ranching development, typical of agricultural frontier regions at the time, was also a consequence of the lack of pasture management technologies and the few options for suitable forage for planting in the Amazon. As a result, serious errors in pasture formation and management were often made, resulting in the short productive life span of these areas (Dias-Filho, 2015).

50 Due to the inability to maintain productive pastures over time, production targets were, with few exceptions, achieved at the expense of abandoning unproductive (degraded) pastures and the formation of new pastures in primary forest areas. With technological advances based on incentives from Low Carbon Agriculture[16] financing, this immense area of degraded pastures can adopt techniques to decarbonize agriculture and gradually reverse the situation from degraded pastures to recovered pastures, thus allowing to increase pasture productivity and meat supply, without deforestation. Based on meat production in the Legal Amazon in 2010, which was 2.7 million tons, it was projected that the implementation of high-tech regenerative practices by 2022 would lead to an optimization in meat production, resulting in an annual increase of 5.6 million tons (equivalent to about R$ 30 billion, based on the price of cattle in 2010) in degraded pastures with greater agronomic potential. The investment in these practices would be around 2.1 billion dollars over 10 years and should be focused on the states of Mato Grosso, Pará and Rondônia (Barreto & Silva, 2012). On the other hand, in the study by Carlos et al. (2022), the cost of recovering degraded pastures in the Amazon would be 4.5 billion dollars, considering pastures in a severe stage of degradation.

51 In addition to the traditional forms of pasture recovery (fertilization and liming), in the Amazon biome the following are also being observed: i) insertion of forage legumes (such as forage peanuts) in intercropping with forage, which promote greater nitrogen input to the soil due to biological nitrogen fixation (BNF) and, consequently, reduce the use of nitrogen fertilizers by up to 60%, in addition to being highly palatable to livestock; and ii) insertion of the crop component, promoting the adoption of crop-livestock integration only in the first two years of the system, to increase soil fertility.

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15 https://atlasdaspastagens.ufg.br/

16 https://www.embrapa.br/en/tema-agricultura-de-baixo-carbono/sobre-o-tema

52 With these characteristics, the average emission by enteric fermentation and emission of manure from cattle during their lifespan of 36 months is 6,700 Kg CO_2e animal^{-1}. By adopting the pasture improvement technologies available today, this same animal can reach a slaughter age of 24 months, reducing CH_4 emissions and consequently CO_2 equivalent by 12 months. At the end of 24 months, the animal will have emitted 4,480 Kg CO_2e animal^{-1}, providing a CH_4 emission reduction of 33%. In other words, it is possible to intensify the productivity of livestock, reducing the time it takes to slaughter the animal, and optimizing the use of the soil. The end result would be: there is no need to deforest to increase livestock production in the Legal Amazon. The growth curve of cattle in Brazil, with an average lifespan of 36 months, is represented in **Figure 12**. These changes in livestock farming at the national level would result in total net carbon removal of 1,223.6 Mt CO_2e, averaging 94.1 Mt CO_2e year^{-1} by 2030.

Figure 12. Cattle growth curve in Brazil. Data Source: Project BRA/16/G31 Fourth inventory of anthropogenic GHG emissions and removals in Brazil. Agricultural reference report, subsector – enteric fermentation. Data source: Brasil-MCTI, 2021.

5.1.2 Intensification of Livestock, Early Slaughter and Heat Tolerance through Genetic Improvement and Management with Native Trees

53 In the Brazil´s specific case, the growth of production may have an even higher increase since the growth of exports has placed the country as one of the main agricultural producers in the world. Concomitant with the increase in demands, the environmental, economic and social impacts of global climate change are one of the greatest challenges facing humanity today. Thus, current production systems will increasingly have to continue to evolve to ensure production growth and adapt to climate change, while preserving ecosystem services more effectively.

54 Recent studies have emphasized that while changes in average climate conditions may affect agricultural productivity and require adaptation policies, a large part of agricultural crop losses and food security risks are expected to be associated with interannual variations in climatic conditions and the occurrence of extreme weather events (persistent droughts, heavy precipitation events, persistent rainfall, occurrence of floods, frosts, high temperatures, heat waves, etc.). Alves de Oliveira et al. (2021), for example, demonstrated that in scenarios of high carbon emission and forest loss resulting from the Amazon tipping point, wet-bulb temperatures could reach extremely high levels, exceeding 40 °C on 25 days per year, by the end of this century in the Amazon Basin region. These temperatures exceed the average (28.14 °C) and maximum temperature (31.90 °C) considered ideal (i.e., ~27 °C) for the well-being of cattle. This highlights the need to provide shade, whether natural or artificial, for grazing, as discussed by Storti et al. (2019).

55 Some breeds existing in Brazil have part of these characteristics, but most have difficulties in adapting and tolerating heat, and at the same time maintaining productive efficiency, especially in the Amazon. Some scenarios can be studied and compared according to a proposal, which would be to seek heat-tolerant breeds, which allow early slaughter with greater carcass efficiency, reaching 330 kg in up to 20 months. Breeds that are on the path of genetic improvement seeking not only weight gain, but also early slaughter and adaptation to heat stresses (Flori et al., 2012), according to genetic test fields, indicate that the gain can be from 1 $Kg.day^{-1}$ to 1.5 $kg.day^{-1}$. In the worst situation, the animal can be slaughtered at 24 months and in the best situation at 18 months. This means a reduction of at least 12 months in the current average slaughter time, and up to 2.9 times of productivity gain, i.e., more animals per hectare, with carcass weight for slaughter of 300 kg, and tolerant to high temperatures with pasture production.

56 Implementing an intensified system with *Brachiaria,* at a cost of about $800 per hectare per year, has the potential to generate net negative emissions of approximately 4 to 5 tons of CO_2 per hectare annually. The effort to recover 40 hectares of degraded pastures in terms of carbon is nullified by avoiding 1 hectare of deforestation, requiring an investment of $32,000 per year (Nobre et al., 2023).

5.1.3 Integrated Production Systems (off-season)

57 Right at the beginning of the occupation of the Brazilian savannas within the Legal Brazilian Amazon, with the introduction of soybean planting, the cultivars had a long cycle and had a productivity of around 1.7 tons ha^{-1} (Arantes and Souza, 1993). In 2016 by IBGE (PAM

2016[17]), the average yield in the savanna reached from 2.9 t ha^{-1} to 3.26 t ha^{-1}. Such official results indicate an average productivity gain of more than 170%, i.e., more than 4% per year. Planting was "single", that is, a single crop per year, which meant using, with the practices of soil preparation, fertilization, planting and harvesting, 42% of the useful time of the agricultural property. After harvesting, the soil was exposed and in the other 58% of the useful time, there were greenhouse gas emissions, erosion, low water infiltration, etc. This practice has rapidly expanded to the Amazon biome, providing soy production at very low latitudes, which in the early 1970s was unimaginable. The problem today is no longer to produce soybeans in the Amazon, but rather what production model is used. **Figure 13** below illustrates an example of how soil management was done.

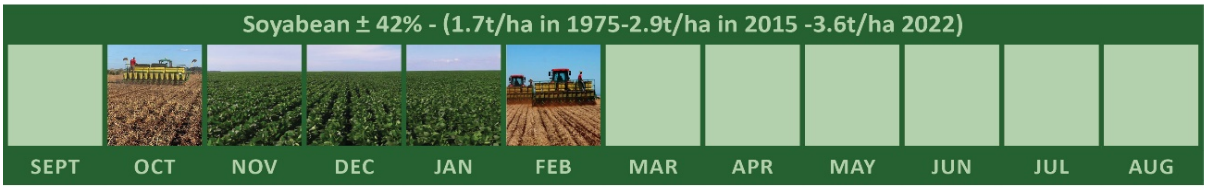

Figure 13. Useful time used in the agricultural property in the planting of single soybeans. Data source: Vilela, L. Embrapa Cerrados (personal communication).

58 In the case of corn, the cultivars have a longer cycle and the time of use was 50%, with yields starting from 1.8 t ha^{-1} in 1975 (average values of the IBGE) in southern Brazil and reaching an average of 5.77 t ha^{-1} in 2016 (PAM, 2016), a gain of more than 320% in productivity, that is, close to 8% per year, as illustrated in **Figure 14**.

Figure 14. Useful time of use of a property in the Cerrado only with corn planting. Data source: Vilela, L. Embrapa Cerrados (personal communication).

59 As with soybeans, the other 50% of the property's useful time was exposed, emitting greenhouse gases, accentuating erosion and reducing water infiltration into the soil (**Figure 15**).

17 https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecuaria/9117-producao-agricola-municipal-culturas-temporarias-e-permanentes.html

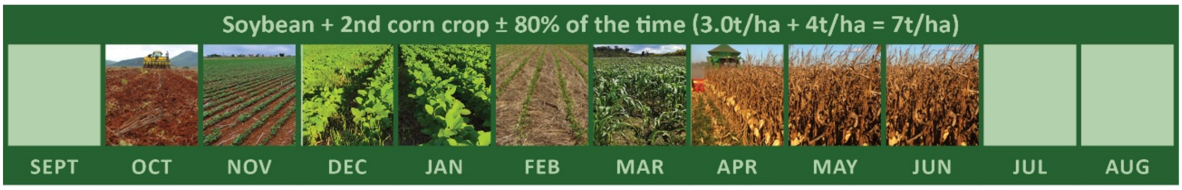

Figure 15. Useful time of use of a property in the Cerrado with the off-season crop. Data source: Vilela, L. Embrapa Cerrados (personal communication).

60 With the integration of production systems with the introduction of off-season crops, **Figure 15**, the time of use of the property rises to 80%, which in addition to diversifying production, keeps the soils covered for longer, avoiding soil losses and increasing the water infiltration capacity. The combination of soybean and corn allows a national average productivity of around 7 tons of grains ha^{-1}, and growing at rates higher than 3 to 4% per year. However, experts warn that the continued soybean-corn production system is not sustainable in the long term. To reverse this cycle of problems, one of the solutions lies in diversification. Diversified production systems promote the improvement of the physiological and biological conditions of the soil, assist in the management of pests and diseases, and ensure better economic results. It is in this productive design that the integration of crops, livestock and crops, livestock, and forests comes into play in the medium and long term. These are the main systems recommended in ABC Agriculture (i.e., Low Carbon Agriculture).

61 Advancing in the integration of systems, there is the option of soybeans + off-season corn and livestock. It is an excellent system, which in addition to allowing a complete soil cover, can in several situations (Resck, 1986), reduce erosion by 99.7% and water losses by 94%, in addition to allowing a gain of 105 kg of meat per carcass equivalent. The effects of mitigation are known and this is a system adapted to tropical situations with agricultural production almost all year round, in addition to allowing the gain of 105 kg per carcass equivalent ha^{-1}, as illustrated in **Figure 16**.

Figure 16. Integrated system: Crops (harvest + off-season) and livestock. Data source: Vilela, L. Embrapa Cerrados (personal communication).

5.1.4 The Benefits of Integrated Crop-Livestock-Forestry (ICLF)

62 Agroecosystems of the 21st century must be able to maximize the quantity of high-quality agricultural products and conserve the system's resources. Sustainable agricultural development depends on actions that address the following aspects: (a) the conservation of biodiversity and environmental services; (b) reduction of pollution/contamination of the environment and man; (c) soil and water conservation and improvement; (d) integrated management of insect pests, diseases and weeds; (e) reduction of anthropogenic pressure in the occupation of fragile ecosystems and environments; (f) adaptation to new market demands. (Balbino et al., 2011).

63 By definition, ICLF is a strategy that aims at sustainable rural production, which integrates agricultural, livestock and forestry activities carried out in the same area, in intercropping, in succession or rotational, and seeks synergistic effects between the components of agroecosystems, contemplating environmental adequacy, economic viability and valuing people (Balbino et al., 2011). Many of the benefits of agricultural integration and the consequent intensification of production and rationalization of the use of resources have been demonstrated year after year and described in the literature (Barros et al., 2016). However, the positive characteristics, generally associated with ICLF, are not sufficient to reach conclusions regarding the environmental performance of establishments or the contributions of production systems to the sustainability of rural territories, according to the different contexts of adoption.

64 Different technological levels were adopted in the experiments observed by Rodrigues et al. (2017), from complete agrosilvopastoral integration to simple succession of degraded pastures - crops intercropped with grass - reformed pasture (ICL). In any case, the implementation of these integration practices invariably implied significant increases in grain productivity and weight gain for a greater number of animals, favoring the indicators of changes in direct land uses. The crop-livestock-forest integration system is the most complete and efficient integrated system advocated by ABC Agriculture.

65 In general, the ICLF systems used in Brazil are composed of: corn, soybean, rice and beans for grain production and *Brachiaria* for forage production, adding the tree components eucalyptus, pine, teak and more recently paricá and mahogany.

66 In the Amazon region, it is strongly recommended the adoption of SAF Agroforestry systems, which in addition to allowing the production of fruits and wood of native species, are also adapted at the beginning of the implementation to the production of grains intercropped with livestock. The presence of trees in agricultural systems increases their resilience in the face

of climate change. Systems such as crop-livestock-forest integration and livestock-forest integration are examples. Trees create favorable microclimates, making these systems better able to cope with droughts, extreme heat, and fires (Assad et al., 2022). In addition, some native trees, such as *Inga edulis*, *Hymenaea courbaril*, and *Dipteryx odorata*, not only fix nitrogen in the soil, but also provide shade and protein-rich food for animals (Carrero, 2016).

67 The main technological benefits of SAF systems are:

(a) Improvement of the physicochemical and biological attributes of the soil due to the increase of organic matter;

(b) Minimization of the occurrence of diseases and weeds;

(c) Increased animal welfare, as a result of thermal comfort;

(d) Greater efficiency in the use of inputs and expansion of the positive energy balance;

(e) Possibility of application of various systems and production units (large, medium and small properties);

(f) Reduction in the opening of new areas;

(g) Improvement in water recharge and quality;

(h) Promotion of biodiversity and favoring new niches and habitats for pollinators and natural enemies of insect pests and diseases;

(i) Intensification in nutrient cycling.

68 The biggest difficulty is to transfer the technology from integrated systems, which involve the planting of trees. Rural producers have more ability to work with pastures and crops, but it is necessary to make an effort to transfer technology.

5.2 Promoting a Sociobioeconomy of Forests and Agroforestry

5.2.1 Restoration to Reduce Pressure on the Natural Forest and Foster the Sociobioeconomy

69 There is an area of more than 50 million hectares with the potential to be restored in the Amazon (Barlow et al., 2022). This includes 24 million hectares of low-yielding pastures. Undoubtedly, it is possible to eliminate deforestation and forest degradation in the Amazon, while promoting the growth of a sociobioeconomy of healthy standing forests and

agroforestry. In fact, estimates from the National Institute for Space Research (INPE) suggest that about 20% of the deforested area has been left abandoned, totaling about 160,000 km^2 in the Brazilian Amazon region. In this context, the adoption of regenerative agricultural practices and the restoration of previously deforested and degraded lands emerge as viable measures to reduce pressure on the forest while producing agricultural and forestry resources.

70 The economic exploitation of standing forest resources reveals substantial potential that surpasses conventional approaches to deforestation (**Figure 17**). In some parts of the Amazon, studies have shown that Agroforestry systems are more profitable than cattle ranching (Figure 17A) or soybean cultivation (Figure 17B). In terms of profitability, one hectare of pasture yields US$ 50 to 100 per year (Barbosa et al., 2015), while soybean cultivation yields US$ 100 to 300, being negative in some years in several regions of the Amazon (Oliveira et al., 2013; Rocha, 2020). In fact, Agroforestry systems with the management of açaí (*Euterpe precatoria*), cocoa (*Theobroma cacao*), cupuaçu (*Theobroma grandiflorum*), cassava (*Manihot esculenta*) and other species can generate from $300 to $700 per year (WWF-Brazil, 2020) (**Figure 17C-D**).

Figure 17. **A.** Degraded pastures, **B.** Soybean cultivation, **C.** Agroforestry system, and **D.** Standing forest.

71 A large-scale forest restoration strategy should be linked to measures to acquire primary production from Agroforestry systems. Such a strategy would require efforts to strengthen associations and cooperatives to acquire all timber and non-timber products from production systems. Such measures are already common in Brazil for agricultural species such as orange, corn, soybean, and cattle. However, they are less frequent in regard to native Amazon species, such as açaí, Brazil nut and cocoa, and are carried out by social organizations such as the Association of Small Agroforesters of the Reca Project (RECA) and the Mixed Agricultural Cooperative of Tomé-Açu (CAMTA).

72 In terms of timber management, the production of native wood obtained from the recovery of degraded lands has been shown to be economically feasibility (Brienza-Junior et al., 2008). Brazil nut (*Bertholletia excelsa*), andiroba (*Carapa guianensis*), and paricá (Schizolobium *parahyba amazonicum*) showed a cost/benefit ratio of 2.26 and an Internal

Rate of Return of 21.7% per hectare after a 30-year cycle. However, the economic efficiency of wood production can be optimized by increasing productivity through genetic selection and investments in innovation in the timber sector, which is still dominated by low-skilled activities (Brienza-Junior et al., 2008).

73 Similarly, the collection of non-timber forest products (NTFP) through sustainable extractivism and agroforestry system management has generated around $2 billion per year throughout the Amazon (IBGE, 2021). Fruits, seeds and roots of açaí (*Euterpe* spp), cocoa (*T. cacao)*, Brazil nut (*B. excelsa*), cupuaçu *(T. grandiflorum*) and cassava (*M. esculenta)* are among the main products traded in the region. In the municipalities of Pará alone, it is estimated that around $1 billion per year is estimated (Costa et al., 2021b). However, most NTFPs are traded without any technological processing, contributing to the low value added in the region (ICMBIO, 2019; Costa et al., 2021b).

74 In addition to the timber products and NTFP already mentioned, there are other species with high economic potential in the Amazon. Some of these include buriti (*Mauritia flexuosa* L.), copaiba (*Copaifera* spp), cubiu (*Solanum sessiliflorum*), cupuaçu (*T. grandiflorum*), guaraná (*Paullinia cupana*), jaborandi (*Pilocarpus microphyllus*), murici (*Byrsonima* spp), taperebá (*Spondias mombin*), tucumã (*Astrocaryum aculeatum*) and tururi (*Manicaria saccifera*). In addition to plant products, species of microalgae and freshwater porifera native to the Amazon are recognized by scientists as having high economic potential. Microalgae act in the production of biodegradable polymers, and porifera (*Metania reticulata*) draw attention due to their bioactivity against diseases such as malaria, in addition to acting as filter feeders with the ability to retain metals from mining activities (Lopes-Assad, 2023).

5.2.2 Bio-industrialization at the Service of the Peoples of the Amazon

75 Products from Agroforestry systems using native trees can drive a new economic cycle in the Amazon. To achieve this, investments in processing technological will be required to transform primary products into industrialized items with higher added value.

76 The Amazon 4.0 Initiative[18], aimed at boosting innovation in the region for the good of its local populations, proposes as one of the essential pillars for a new sociobioeconomy of healthy standing forests, investments in biofactories of biodiversity products and the implementation of the Amazon Institute of Technology (AmIT), inspired by the renowned Massachusetts Institute of Technology (MIT). AmIT aims to promote innovation and decentralized education, with research and teaching centers throughout the Pan-Amazon. Its

[18] https://amazonia4.org/lca/

approach encompasses topics such as water, forests, socio-biodiversity, altered landscapes, green infrastructure, and sustainable urbanism that will support regional entrepreneurship. A highlight is the integration of knowledge and practices from Indigenous Peoples and local communities, ensuring a holistic perspective (Amazonia 4.0, 2023).

77 Investing in technology is essential to add value to the products of Amazonian ecosystems, including those from the restoration of forests and rivers (Nobre and Nobre, 2018). The selling price of primary products can increase by 2-5 times. For example, fresh *unpeeled* seeds of Brazil nut (*B. excelsa)* ranged from \$2 to \$4 per kilogram, while dehydrated seeds (after pre-processing) are sold for \$15. Andiroba seeds (*Carapa* spp.) were priced between \$0.4 and \$2.3 per kilogram, and the oil extracted from the seeds reached values between \$7 and \$12. Açaí fruits (*Euterpe* spp.) were sold for \$0.4 to \$0.5 per kilogram, with pulp sold for \$2 to \$3 and oil for \$76. These examples illustrate the potential for adding value by investing in basic industrial infrastructure, such as dewatering, pulping, pressing, refrigeration, and pasteurization equipment (Brandão, 2023).

78 RECA [19] and CAMTA [20]are examples of how social organization and technology aligned with forest conservation can increase the income of local communities and small farmers. RECA was founded in 1987 and currently has the involvement of more than 300 farming families, who supply more than two thousand tons of non-timber forest products per year. CAMTA began the industrialization of products originated in Agroforestry systems in 1987, and currently has 170 direct employees and 1800 farming families that supply primary products for industrialization. These social organizations mainly produce fruit pulp, dehydrated seeds, and vegetable oils, and due to bio-industrialization, most farmers in Agroforestry systems have reached the middle class.

79 However, there is a significant lack of enterprises with technologies to add value to the products from Agroforestry systems in the Amazon. Studies that mapped the agro-industries of five non-timber forest products widely used in the Amazonian economy identified only 55 municipalities (county) that have technological infrastructure capable of transforming primary products into products with some level of added value. This was observed when 532 municipalities were assessed, which indicates that 90% of the Brazilian Amazon totally lack basic technological infrastructure to add value to regional products (Brandão et al., 2021).

80 There is still little knowledge about the costs of setting up factories for processing Amazonian products. An example of a more modest factory was implemented at a cost of USD 100

19 https://www.projetoreca.com.br/quem-somos/

20 https://www.camta.com.br/index.php thousand (IDESAM, 2020). This factory is capable of absorbing all the agroforestry production of more than 300 families living in local communities. The factory had equipment and machines for pulping, drying, grinding, distilling and filtering oils and fats of native species. It is estimated that the infrastructure is capable of processing three tons of fixed oils and 90 liters of essential oil per month, generating an estimated annual revenue of around USD 200 thousand, using its entire production capacity (IDESAM, 2020).

81 When more investments are made in industrialization, the results become more promising. Due to the investments made in technologies, CAMTA has become an important exporter of tropical fruits to countries such as Japan, Israel, the United States, and French Guiana (OCB PARA, 2022). This experience has motivated new investments, such as those made in 2022, which totaled R$ 20 million in refrigeration infrastructure, cold room for fruits, fruit packaging room, expansion of the freezing tunnel, certification, improvement of production equipment, creation of new production lines, acquisition of forklifts, effluent treatment machines, ice breaker, new line for açaí washing, pasteurizer and power generators. The example of CAMTA has been disseminated within Brazil, as in other countries such as Bolivia and Ghana (OCB PARA, 2022).

82 An intermediate-cost factory, situated between the modest factory (IDESAM, 2020) and CAMTA's infrastructure (OCB PA, 2022; CAMTA, 2023), is estimated at USD 1.2 million (Amazônia 4.0, 2023). The factory, structured by the Amazônia 4.0 (www.amazon4.org) project, aims to produce fine chocolate from cocoa and cupuaçu, but also allows adaptation to other production chains (Amazônia 4.0, 2023). The central idea of the Amazônia 4.0 project is to demonstrate the feasibility of a new sociobioeconomy through bio-industrialization in rural and urban communities in the Amazon. The investment is related to the technologies used in production, which include a genomics laboratory, a futuristic design inspired by Indigenous huts, broadband internet connectivity, modular materials for expansion, 3D printers for food and packaging, water treatment systems, and energy self-sufficiency. However, there is still a lack of cases of enterprises in the Amazon with technological characteristics typical of Industry 4.0, combining nature-based science and innovations with the traditional knowledge of Indigenous Peoples and local communities.

83 The knowledge acquired through the Amazônia 4.0 project reveals that the potential for added value by industrialization can be even more expressive. For example, cocoa production is usually sold for approximately USD 2 per kilogram of seeds, while fine chocolate can reach values between USD 20 and 40 per kilogram. Traditionally, the proportion of cocoa present in chocolate ranges from at least 25% of total solids (Ministry of Health, 2005) to 70% for the darkest chocolate. This implies that the added value of the seed in the production

of fine cocoa chocolate can be more than 10 times higher compared to simply selling the seeds.

5.2.3 Incentives for Science, Technology and Innovation (ST&I)

84 Some other requirements for strengthening the bioeconomy of standing forests include innovation, science and technology measures, financial compensation for reducing deforestation and forest degradation, fishing and fish farming, ecotourism, payment for environmental services, and the installation of sustainable infrastructure. These options can help reduce pressure on the forest and ensure its long-term conservation. In this context, for a more detailed understanding of each of these economic demands of standing forests, the following paragraphs will synthetically address each of them, including some challenges to their implementation at scale.

85 Mechanisms that offer financial compensation for the reduction of deforestation and forest degradation are necessary in the standing forest bioeconomy. For example, the international mechanism known as REDD+ (Reducing Emissions from Deforestation and Forest Degradation) has been implemented in the Amazon, which is consistent with the decisions of the United Nations Framework Convention on Climate Change (UNFCCC), including the Paris Agreement and the Cancun Safeguards. However, the challenges of financial resource distribution, the pressure exerted by selective logging, illegal mining, and land grabbing[21], and the lack of effective public policies are some of the main challenges faced in the region for the success of REDD+ projects (Abramovay et al., 2021).

86 Fishing and fish farming are vital activities for food security, providing protein and fat for local and regional populations. The main fishing resources include a variety of species, such as curimatã, jaraqui, tambaqui, dourada, filhote, mapará, pacu, surubim, tucunaré and arapaima. However, overfishing and bycatch pose one of the main threats to the region's aquatic biodiversity. Another threat is contamination by heavy metals, such as mercury, from illegal mining. This contamination mainly affects Indigenous and riverine communities, who depend on fishing as a source of protein (Abramovay et al., 2021).

87 The immense socio-biodiversity of the Amazon places it in a privileged position in the context of ecotourism (Gazoni and Brasileiro, 2018). In fact, nature is considered a decisive factor for travelers' choice of destination, both for domestic and foreign tourism. However, the Amazon is not on the list of most visited destinations globally, indicating that the potential

[21] https://www.liberalamazon.com/artigos-de-opiniao/news/a-ameaca-da-grilagem-do-carbono-florestal-na-amazonia

of the Amazon is undertapped. Studies indicate that the main challenges for tourism in the Amazon are to reconcile the reality of commercial capitalism and local communities with their traditional forms of subsistence and social relations, as well as to control the disorderly growth of tourism to avoid problems for nature and local communities (Abramovay et al., 2021).

88 In turn, Payment for Environmental Services (PES) is a voluntary transaction in which a payer provides financial resources or another form of remuneration to an environmental service provider. Environmental services promote the maintenance, recovery, or improvement of ecosystem services, which are the benefits that ecosystems offer to society. The Amazon provides an extensive array of essential ecosystem services, but economically quantifying their attribution also presents significant challenges. This includes accounting for variations in land use and ecological systems among different regions (Strand et al. 2018), and others, such as equitably distributing benefits and ensuring effective and long-lasting positive effects. It is necessary to address these challenges in an integrated and collaborative manner to ensure that PES can effectively contribute to the economy of the standing forest (Abramovay et al., 2021).

89 A new sociobioeconomy of healthy standing forests and flowing rivers in the Amazon requires infrastructure similar to that found in sustainable cities, including renewable energy sources. The economic feasibility of photovoltaic systems in Brazil is proven (IPEA, 2018), and technological advances are rapidly decreasing the costs of solar panels. The cost per watt of energy produced fell from $79.67 in 1977 to $0.36 in 2014 (Diamandis, 2014). Similarly, energy storage equipment, such as lithium batteries, has reduced costs by 400% between 2010 and L2020 (Diamandis, 2014). With the economic feasibility of solar panels and batteries, a future powered by renewable and low-carbon energy becomes possible in the Brazilian Amazon, where approximately 155,000 rural households still do not have access to the electricity grid (Sánchez et al., 2015).

90 Therefore, ST&I, financial compensation for the reduction of deforestation and forest degradation, fishing and fish farming, ecotourism, payment for environmental services, sustainable infrastructure are all important strategies to strengthen a standing forest economy in the region. These measures are essential to move the Amazon away from the tipping point, and are implemented in the long term.

6. CONCLUSIONS

91 Over the last few decades, the expansion of pastures and the increase in the number of cattle in the Legal Amazon have been intrinsically linked to deforestation and forest degradation, making agricultural activity the main source of climate pollution in Brazil. Reducing greenhouse gas (GHG) emissions from deforestation, degradation, and livestock production in the Legal Amazon is a critical need to prevent the regional climate from reaching unbearable extremes due to the loss of essential ecosystem services provided by the forest, such as rainfall recycling, surface cooling, and food security.

92 The Legal Amazon is home to 43% of Brazil's cattle herd, highlighting its importance in national livestock production. However, 537 of the 808 municipalities in the Legal Amazon face serious problems of pasture degradation, resulting in high CO_2 and methane emissions, as well as low stocking capacity. About 55% of total methane emissions in the Brazilian agricultural sector originate in the Legal Amazon, due to enteric fermentation and inadequate waste management. Solving these challenges depends on political and business actions, including national and international commitments to eliminate deforestation, restrict meat exports associated with deforestation, and promote public policies that encourage sustainable production models.

93 Encouraging the adoption of regenerative and low-carbon agricultural practices, especially in the Amazon, has the potential to drastically reduce net emissions from livestock, even neutralize them, through the growth of regenerative livestock farming and the increase of Agroforestry Systems (AFS). The recovery of degraded pastures and the intensification of cattle ranching can reduce the time it takes to slaughter animals to 24 months, reducing methane emissions by about 33% in the Legal Amazon. In addition, the implementation of integrated systems, such as Crop-Livestock-Forest, emerges as an essential mechanism to increase agricultural and livestock production in the region, allowing doubling grain production and increasing livestock production by 30%, without resorting to deforestation. Agroforestry Systems (AFS) are highly recommended in the Amazon region and can serve as a model for pasture areas within private properties, promoting the sustainable production of fruits and native wood, as well as the intercropping of grains with livestock, making agricultural systems more resilient to climate change.

94 In light of this, it is imperative that Brazil establish a Green Deal for the Amazon, as an urgent commitment to reduce deforestation and degradation, and foster regional development through a new sociobioeconomy of healthy standing forest and flowing rivers. This great challenge needs to be encouraged with investments in the education of its population, at basic and technical levels, for technological innovation and integration of scientific and traditional

knowledge, which results in creative and participatory solutions to reduce the impacts of conventional livestock farming and the creation of markets for value-added products from the standing forest, and for the guarantee of benefits to its Indigenous and local population.

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