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Do Large Slaughterhouses Promote Sustainable Intensification of Cattle Ranching in Amazonia and the Cerrado?

Ana Beatriz Santos * and Marcos Heil Costa

Department of Agricultural Engineering, Federal University of Viçosa, Viçosa-MG 36570-900, Brazil; mhcosta@ufv.br

* Correspondence: ana.bsantos15@gmail.com; Tel.: +55-31-3899-1902

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Abstract: This study investigated the influence of large slaughterhouses on five variables, two related to environment impact (land use change rate and greenhouse gases emissions (GE)), and three related to cattle-ranching intensification (protein from crops, calories from crops and stocking rate). In Amazonia, the results show a reduction of the land use change rate and GE in zones both with and without the influence of large slaughterhouses. The hypothesis that slaughterhouses are leverage points to reduce deforestation in the biome was not confirmed. The slaughterhouses also seem to have no effect on cattle ranching intensification, as protein and calories production increased significantly in both zones, while the stocking rates did not change in the influence zones. In the Cerrado, cattle-ranching intensification is a reality, and is occurring independently of the presence of large slaughterhouses. In conclusion, the results show no evidence that large slaughterhouses have promoted either cattle-ranching intensification or improvements in the sustainability of the cattle-ranching activity in Amazonia and the Cerrado.

Keywords: beef supply chain; beef cattle; sustainability assessment; land use change; greenhouse gases emissions

1. Introduction

In recent decades, the expansion of cattle ranching in Amazonia and the Cerrado has raised concerns regarding the increase of CO_2 emissions associated with beef production. Historically, Brazil's largest share of greenhouse gases (GHG) emissions comes from land use change, particularly the conversion of natural vegetation to pasturelands [1]. Despite the decrease in Brazilian CO_2 emissions between 2005 and 2010 (from 1.7 to 0.3 Mt-CO_2/year), the LULUCF (Land Use, Land Use Change and Forestry—see Appendix A for a full list of abbreviations) sector emissions still represented 45% of the total emissions in 2015 [2].

Sustainable intensification of cattle ranching has been proposed as a promising solution to reconcile the need for increased beef production and the need for reduction of GHG emissions [3,4]. This concept suggests that producing more beef on less land (referred to as intensification) may slow deforestation and suppression of native Cerrado vegetation and reduce GHG emissions. According to Strassburg et al. [4], increasing Brazilian pasture productivity to 49–52% of its potential would be sufficient to meet demands for beef until 2040. In addition, about 14.3 Gt-CO_{2e} could be mitigated; of this, 87% (12.5 Gt-CO_{2e}) would be due to the projected reduction in deforestation [4].

In addition to emissions from land use change, cattle ranching is the largest source of methane (CH_4) in the country. Together, the LULUCF sector and CH_4 emissions from enteric fermentation represented 58% of Brazilian GHG emissions in 2015 [2]. Several studies have demonstrated that investments in pasture management and animal feed are able to increase animal production and reduce the time cattle spend in pasture [5–8]. However, grass-feeding is the predominant management system in the country, and animal-feed supplementation with protein and calories is still uncommon [6]. The low rate of weight gain due to unsupplemented feeding makes the average slaughter age in Brazil about four years old, twice what it is in the United States [9].

Brazil's National Policy on Climate Change (PNMC—Política Nacional sobre Mudanças no Clima) has mandated a reduction of GHG emissions in several economic activities; in agriculture, it supports the adoption of techniques that make cattle ranching more productive on existing pasturelands [10]—i.e., intensification. According to Dias et al. [11], the average stocking rate grew from 0.70 to 1.48 head/ha in the Cerrado and 0.69 to 1.53 head/ha in the Amazon between 1990 and 2010. The adoption of technologies was responsible for a great part of this increase [12], but in various localities the pasture productivity remains low [11] and there is no evidence that cattle ranching is increasing in a sustainable way.

In the beef supply chain, slaughterhouses are potential leverage points for promoting sustainable intensification due to their interactions with ranchers, their location at the agricultural frontier, and their ability to restrict ranchers' access to the market [13]. In the last decade, international campaigns promoted by non-governmental organizations (NGOs) have linked illegal deforestation to the emergence of large slaughterhouses in Amazonia [14,15]. In July 2009, individual meatpacking companies in Pará signed the legally binding Terms of Adjustment of Conduct (TAC), which imposes penalties on companies purchasing from properties with recent illegal deforestation. These agreements have since been replicated in the states of Acre, Rondônia, Amazonas and Mato Grosso [13]. The four biggest meatpackers of the country (JBS, Bertín, Marfrig, and Minerva) also signed in 2009 an agreement with NGO Greenpeace. This agreement imposed that meatpackers would buy only from Brazilian Amazonia ranches with zero-deforestation and meet standards issued by international multi-stakeholder commodity roundtables [13,16].

The public concern about the contribution of beef production to forest loss and climate change demonstrates probable environmental benefits from slaughterhouse market domination as they have a direct influence on ranchers. Gibbs et al. [13] quantified the responses of four large JBS slaughterhouse units in southeastern Pará to zero-deforestation agreements signed in 2009. These units respected the agreement, avoiding trade with ranchers with illegal deforestation on their lands. Besides, there was a greater adherence to the Rural Environmental Registry (CAR—Cadastro Ambiental Rural) and a decrease of deforestation on the properties of JBS partners.

Despite the importance of the theme, previous studies have not directly evaluated the consequences of large slaughterhouses influence on the sustainable intensification of the cattle ranching activity. Until now, studies have evaluated cattle intensification from an economic point of view [17,18], as a source of GHG and potential mitigation strategy [3,4,6] and as an outcome of a sample of policies, certifications or agreements [13,19–21]. To evaluate the sustainable intensification promoted, the discussion of the role of large slaughterhouses should not be limited to the analysis of deforestation rates. In this context, it is also necessary to investigate changes in production—mainly the average of cattle herd per hectare and potential agricultural region—and in relevant environmental variables.

In this study, we evaluated whether large slaughterhouses have been able to promote changes in their supply areas to meet sustainable intensification. We analyzed five variables: two related to environmental impact (land use change rate and GHG emissions) and three related to intensification (protein and calories produced by crops, and stocking rate). For the environmental impact variables, we investigated whether the slaughterhouses presence promote a decrease of the land use change and GHG emissions. For the intensification variables, we investigated whether slaughterhouse presence help to promote improvements in ranching practices as indicated by the increase in calories and protein produced by crops—nutrients that might ultimately be used for animal supplementation or for other purposes—and in rangeland stocking rates.

2. Materials and Methods

This work was divided into four parts. First, we selected large slaughterhouses that started operation approximately midway between 2000 and 2013, and we delimited their influence zones. Second, we delimited control zones in regions that are far from slaughterhouse influence and outside both conservation units and indigenous lands. Third, in the influence zones, we tested for changes after the slaughterhouse started operation, looking specifically at rates of land use change, GHG emissions, protein from crops, calories from crops, and cattle stocking rates. Finally, we tested for changes in these variables in the control zones.

2.1. Study Area

The Amazon is the largest biome in Brazil, covering about 49% of the national territory (420 Mha). In recent decades, cattle ranching has dominated the process of occupation and exploration of this biome, following government-sponsored colonization projects and incentives [22]. Currently, about 38 million hectares of pasture is located in the Amazon (25% of the national total). Between 1980 and 2013, cattle herds destined for slaughter grew 800% (from 6.24 to 56.59 million head; Figure 1), which is 58% of the national increase for this period. In addition to the expansion of cattle ranching, a dramatic increase in the number of slaughterhouses registered at the Federal Inspection Service was also observed, from 1 in 1980 to 62 in 2016 (Figure 1).

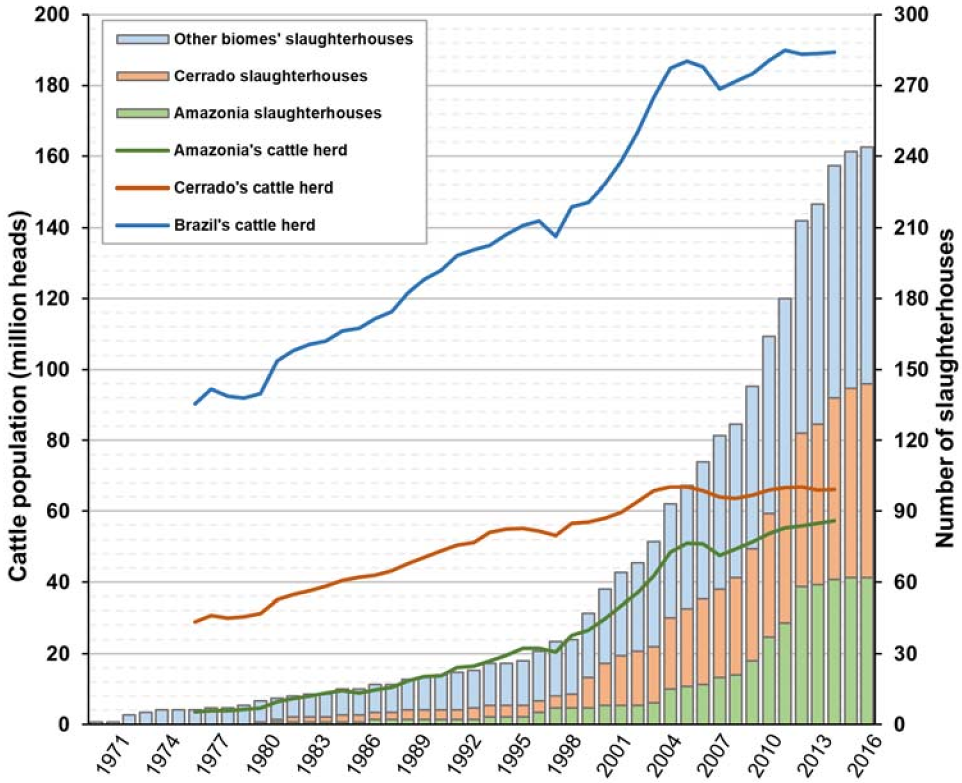

Figure 1. Number of slaughterhouses registered at the Federal Inspection Service and cattle population in Brazil, Amazonia and the Cerrado over time.

The Cerrado is the second largest biome in Brazil (200 Mha) and the most important region for cattle ranching, with 56 Mha of pasturelands. The biome contains the largest national herd (66 million head in 2014), representing 35% of the national total (Figure 1). As part of the new Brazilian agricultural frontier, the biome is credited as the driver of the country's ascendance in global agricultural commodity markets [6]. The number of slaughterhouses registered at the Federal Inspection Service in the Cerrado biome grew even more dramatically over the last few decades than the number in the Amazon: from 1 in 1980 to 82 in 2016 (Figure 1).

2.2. Period of Study and Datasets

We evaluated the following variables: land use change rate (ΔLU), GHG emissions (GE), protein from crops (PC), calories from crops (CC), and cattle stocking rate (SR). We obtained ΔLU from the forest cover dataset produced by Hansen et al. [23], while other agricultural variables were calculated from the dataset produced by Dias et al. [11]. Due to limitations of forest cover data availability, the period was 2000–2013.

The SR was obtained by dividing the number of beef cattle by the total pasture area. To construct the cattle maps, we used data provided by the Municipal Livestock Survey (PPM—Pesquisa Pecuária Municipal). We estimated the number of cattle destined for beef production by subtracting the number of dairy cows from the total number of cattle. To convert the tabular PPM data to a gridded cattle dataset, we calculated the ratio between the number of beef cattle and total pasture area in tabular form for each municipality in the Amazonian and Cerrado biomes. The total pasture for each municipality was extracted using Brazilian municipal boundaries polygons (spatial data) provided by IBGE. Due to the lack of data for certain years of the analysis, we replicated the available data in the missing years. Then, we constructed yearly maps for number of cattle by multiplying the municipality ratio (tabular data described above) and the amount of pasture for each grid cell of the municipality (map data). In the end, each municipality grid cell (i, j) was assigned a number of cattle proportional to that grid cell's total pasture area in that year (t).

GE is the sum of GHG emissions due to enteric fermentation and land use change. To estimate the CO_2 emissions due to land use change (E), we prepared a map of live below- and aboveground biomass (BGB and AGB) for the historic extent of the major vegetation physiognomies of the Amazon and the Cerrado. Starting from the BGB and AGB values from the LULUCF Reference Report from the Third National Communication of Brazil to the UNFCCC (United Nations Framework Convention on Climate Change) [24], we calculated total biomass values and then assigned these values to each grid cell in the vegetation map prepared by IBGE [25]. For non-forest vegetation physiognomies or anthropized areas (i.e., land areas transformed by human activity), we assigned biomass values corresponding to the average of subdivisions of the Brazilian classification system according to the dominant phytophysiognomy indicated on the vegetation map layer. The final biomass map of the historic vegetation expressed in Mg dry matter/ha is presented in Appendix B (Figure A1). Using these data, we obtained the total biomass (in Mg) for each grid cell (i, j) for each year t by multiplying the biomass values per area ($B_{(i,j)}$, in Mg dry matter/ha) by the amount of forest area ($F_{(i,j,t)}$, in ha) in the grid cell for that year. Then, we calculated the CO_2 emissions per pixel ($E_{(i,j,t)}$, in Tg-CO_2/year) by subtracting the total carbon in biomass of each grid cell (i, j) for each year (t + Δt) from the previous year's value (year t), according to Equation (1),

$$E_{(i,j,t)} = \frac{44}{12} \times 0.485 \times 10^{-6} \left(B_{(i,j)} \left(F_{(i,j,\ t)} - F_{(i,j,t+\Delta t)}\right)\right) \quad (1)$$

where 44/12 is used to convert g-C to g-CO_2, 0.485 to convert the dry matter biomass to carbon, and 10^{-6} to convert Mg to Tg.

We estimated CH_4 emissions by enteric fermentation (M) based on the Methane Emissions from Enteric Fermentation and Animal Manure Management Reference Report of the Third National Communication of Brazil to the UNFCCC [26]. Initially, we separated each grid cell's annual value for head of cattle ($C_{(i,j,t)}$) into three animal categories: adult males, adult females and young cattle. Using the Tier 2 approach described in IPCC [27], we identified the proportion of cattle in each of these three categories for each state by year ($R_{c,(i,j,t)}$, in percent, where c denotes animal category) and the corresponding emission factors by category ($f_{c(i,j,t)}$, in kg-CH_4 head 1/year^{-1}). As the emission factors and proportions are available only through 2010, we applied the 2010 values for the years 2011, 2012 and 2013. The total CH_4 emissions of each biome are presented in Appendix B and compared with other data. CH_4 emissions were converted to CO_2 equivalents (CO_{2e}) considering the GWP_{100} (Global Warming Potential over a 100-year time interval). The annual emissions per pixel due to enteric fermentation by cattle ($M_{(i,j,t)}$, in Tg-CO_{2e}) were then calculated according to Equation (2),

$$M_{(i,j,t)} = 28 \times 10^{-9} \sum_c C_{(i,j,t)} R_{(c,i,j,t)} f_{(c,i,j,t)} \tag{2}$$

where 28 is the GWP_{100} factor, and 10^{-9} is used to convert kg to Tg. Finally, we calculated the GE (Tg-CO_{2e}/year) emitted in year t as the sum of the M and E maps.

The CC and PC variables estimate the quantity of calories and protein produced in the region. These nutrients might be used for animal supplementation or for other purposes. We selected the three main feed crops used in the country for analysis: maize, soybean and sugarcane. To estimate the production (in metric tons) of each crop per pixel (i, j) in a year (t), we multiplied the crop productivity (in metric ton/ha) by the crop planted area (in ha) maps of Dias et al. [11]. Next, we multiplied the three production maps—soy (P^{so}), maize (P^{ma}) and sugarcane (P^{su})—by the dry matter fraction (d_c). The energy content (e_c) and protein content (p_c) were then used to convert dry matter values into calorie and protein values, respectively. The values of d_c, e_c, and p_c are given in Table 1 and are typical of Brazilian crops. Finally, the values for the protein (PC) and calorie (CC) maps were calculated according to Equations (3) and (4), respectively:

$$PC_{(i,j,t)} = 10^{-3}\left(P^{so}_{(i,j,t)} d^{so}_c p^{so}_c + P^{ma}_{(i,j,t)} d^{ma}_c p^{ma}_c + P^{su}_{(i,j,t)} d^{su}_c p^{su}_c\right) \tag{3}$$

$$CC_{(i,j,t)} = 0.239 \times 10^{-6}\left(P^{so}_{(i,j,t)} d^{so}_c e^{so}_c + P^{ma}_{(i,j,t)} d^{ma}_c e^{ma}_c + P^{su}_{(i,j,t)} d^{su}_c e^{su}_c\right) \tag{4}$$

Table 1. Values for dry matter fraction, energy content, and protein content of crops.

	Dry Matter (d_c) * (Fraction)	Energy Content (e_c) * (MJ/kg of Dry Matter)	Protein Content (p_c) * (as a Fraction of Dry Matter)
Maize	0.88	13.6	0.105
Soy	0.90	14.3	0.420
Sugarcane	0.23	9.10	0.0430

* Values obtained from Cardoso et al. [28].

In Equation (3), the conversion factor 10^{-3} is the result of multiplying 10^6 (used to convert tons to g) and 10^{-9} (used to convert g to Gg). In Equation (4), the factor 0.239 is used to convert joules (J) to calories (cal). The factor 10^{-6} is the result of multiplying 10^3 (used to convert tons to kg), 10^6 (used to convert MJ to J) and 10^{-15} (used to convert cal to Pcal).

2.3. Mapping of Large Slaughterhouses and Definition of Influence Zones

Beef slaughterhouse production data is usually classified information. To identify large slaughterhouses for the study, we first searched for those registered at the Federal Inspection Service (SIF—Sistema de Inspeção Federal). Registration is a condition for trading across states and exporting. Slaughterhouses not registered at SIF can sell only inside the state and thus are assumed to be small. To georeference the locations of slaughterhouses, we looked for each unit on Google Maps through the addresses reported to the Department for Inspection of Animal Products (DIPOA—Departamento de Inspeção de Produtos de Origem Animal) of the Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA—Ministério da Agricultura, Pecuária e Abastecimento). Other information, such as the opening or closing date, was collected from the National Register of Legal Entities (CNPJ—Cadastro Nacional de Pessoa Jurídica); registration with CNPJ is legally required to start business activities in Brazil. To restrict the analysis only to large units, we selected only slaughterhouses with slaughter capacity greater than 40 head/hour (classes MB1, MB2 and MB3, according to MAPA ordinance number 82 of 27 February 1976).

We found 144 slaughterhouse units with SIF registration in Amazonia and the Cerrado, including 61 that qualify as large units (42% of the total, Figure 2). As our analysis aims to determine the impact of the large slaughterhouses, ideally, the analyzed units should have been operating for close to half of the 2000–2013 study period, so that a "former" period can be compared to a "latter" period of similar duration. Thus, we selected slaughterhouses with a starting year for operations (y_{os}) between 2004 and 2008. Only 12 slaughterhouses satisfy this condition and could thus be used. The selected units are presented in Table 2, and their locations are shown in Figure 2.

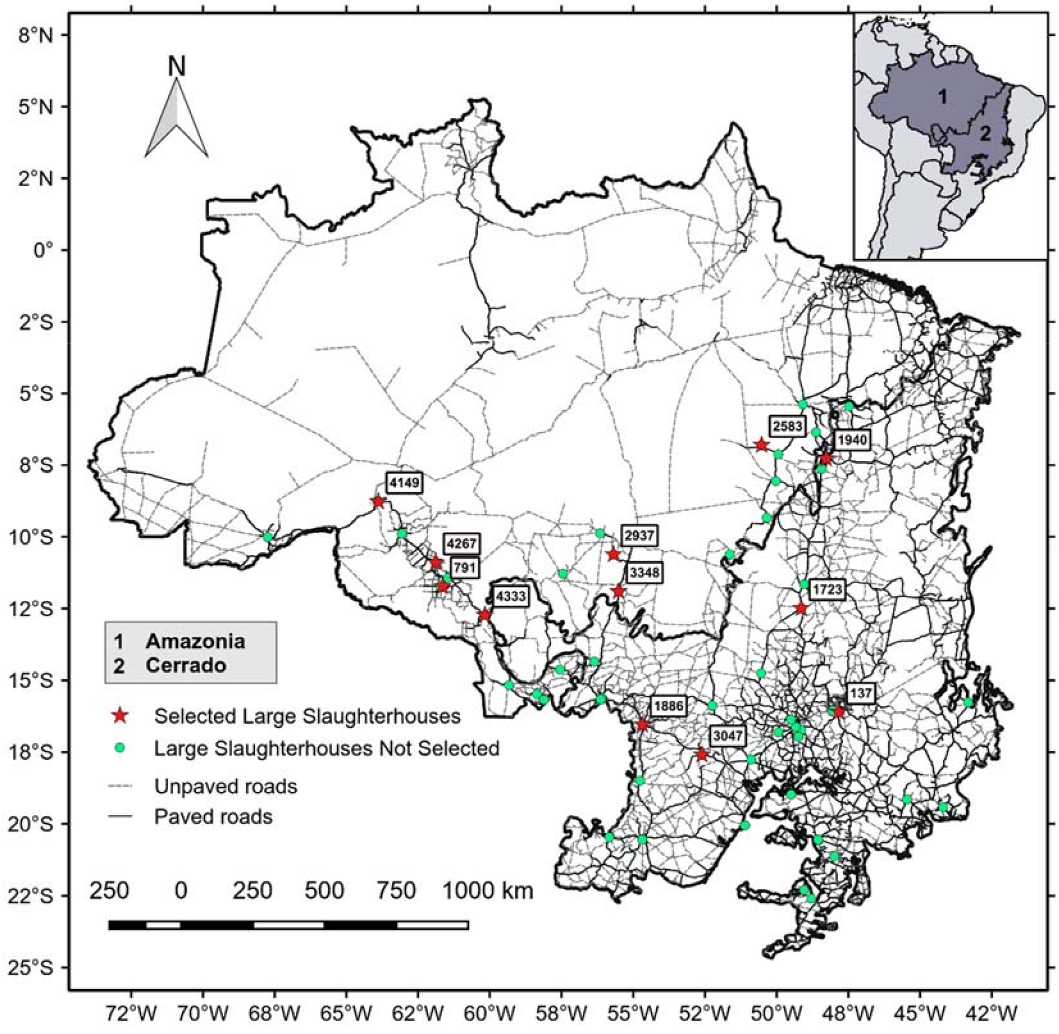

Figure 2. Locations of selected large slaughterhouses and large slaughterhouses that were not selected. Solid and dashed lines represent paved and unpaved roads, respectively.

Table 2. Characteristics of selected slaughterhouses.

SIF Code	Class *	Year of Operation Start (y_{os})	Latitude (°)	Longitude (°)	State	Biome
791	MB1	2006	11°43′ S	61°39′ W	Rondônia	Amazonia
3348	MB1	2004	11°54′ S	55°30′ W	Mato Grosso	Amazonia
3047	MB2	2006	17°36′ S	52°36′ W	Goiás	Cerrado
137	MB3	2008	16°06′ S	47°49′ W	Goiás	Cerrado
1723	MB3	2004	12°29′ S	49°08′ W	Tocantins	Cerrado
1886	MB3	2006	16°33′ S	54°40′ W	Mato Grosso	Cerrado
1940	MB3	2007	7°16′ S	48°16′ W	Tocantins	Amazonia/Cerrado
2583	MB3	2008	6°48′ S	50°31′ W	Pará	Amazonia
2937	MB3	2005	10°37′ S	55°41′ W	Mato Grosso	Amazonia
4149	MB3	2004	8°42′ S	63°55′ W	Rondônia	Amazonia
4267	MB3	2004	10°54′ S	61°53′ W	Rondônia	Amazonia
4333	MB3	2004	12°43′ S	60°10′ W	Rondônia	Amazonia

* MB1 are units with slaughter capacity greater than 80 head/hour and storage capacity greater than 20 t/day; MB2 are units with slaughter capacity greater than 80 head/hour that may or may not have storage capacity; and MB3 are units with slaughter capacity between 40 and 80 head/hour that may or may not have storage capacity.

We define the slaughterhouse influence zone as the likely cattle supply area around a slaughterhouse. We delimited the influence zone of each slaughterhouse unit by determining the distance that could realistically be traveled by a cattle truck. We assumed a maximum travel time of 8 h, which is the maximum travel time tolerated by cattle [29]. To select the truck routes, we used the Brazilian road network for 2010 prepared by the National Logistics and Transportation Plan (PNLT—Plano Nacional de Logística e Transporte). To account for vehicular speed limits, we assigned different velocities for each part of the route. In Brazil, the maximum permissible truck speeds are 90 km/h on paved roads and 60 km/h on unpaved roads (Law number 9503/1997 modified by Law number 13,281/2016).

However, it is not possible to adopt these speeds as the average. The high center of gravity of loaded trucks, the poor condition of Northern Brazilian roads [30] and the necessity for stops are some of the factors limiting driving speeds. Thus, we assumed an average speed of 10 km/h for distances traveled until reaching a paved or unpaved road, 20 km/h for distances traveled on unpaved roads and 40 km/h on paved roads. We also delimited intermediary zones spanning travel distances of 2 h, 4 h and 6 h to determine whether the influence on surrounding areas varies with distance from the slaughterhouse unit.

2.4. Definition of Control Zones

In this study, we also delimited control zones to determine whether the responses of the study variables occurred only in the influence zones. The control zones were chosen from areas outside the influence of any of the slaughterhouses selected for this study. The control zones could not be in areas around other slaughterhouses with slaughter capacity up to 40 head/hour that opened before 2000. We also excluded areas with indigenous lands and conservation units to avoid the effects of conservation measures. The control zones are of the same size as the average size of the 8 h-influence zones, and, in the absence of a y_{os}, we chose 2006 to separate the former and latter periods.

2.5. Data Analysis

We analyzed the changes in five variables, two related to environmental sustainability (land use change rate (ΔLU) and GHG emissions (GE)) and three related to cattle ranching intensification (protein from crops (PC), calories from crops (CC), and stocking rate (SR)). To determine whether the changes really were associated with the start of slaughterhouse operations, we performed two tests, T1 and T2 (Figure 3).

In the first test (T1), we tested for change inside the slaughterhouse influence zone (denoted by superscript S). We used a Wilcoxon paired test to compare the former period (denoted by subscript

F) with the latter period (denoted by subscript L), where the former period included the years from 2000 to y_{os}, and the latter period the years from y_{os} to 2013. Each variable was tested against its own alternative hypothesis (Ha). To be considered a promoter of intensification, the slaughterhouse would need to demonstrably influence the ranchers to increase their stocking rate and use calorie and protein supplementation. By the same token, to be considered a promoter of sustainability, the slaughterhouse would influence ranchers to reduce vegetation suppression and GHG emissions. For the two variables related to environmental impacts, we tested whether the slaughterhouses' start of operation is associated with decreased ΔLU (Ha : $\Delta LU_L^S < \Delta LU_F^S$) and GE (Ha: $GE_L^S < GE_F^S$). For the three variables related to intensification, we tested whether the slaughterhouses' start of operation is associated with regionally increasing the feed supply's PC (Ha: $PC_L^S > PC_F^S$) and CC (Ha: $CC_L^S > CC_F^S$) and the stocking rate SR (Ha: $SR_L^S > SR_F^S$). We tested these hypotheses for all influence zone sizes (transportation radius up to 2 h, 4 h, 6 h and 8 h). In the absence of a significant response ($p > 0.05$) in T1, no significant change could be reported in that variable (null hypothesis: Ho), and we would therefore conclude that the slaughterhouse operation had no impact on that variable.

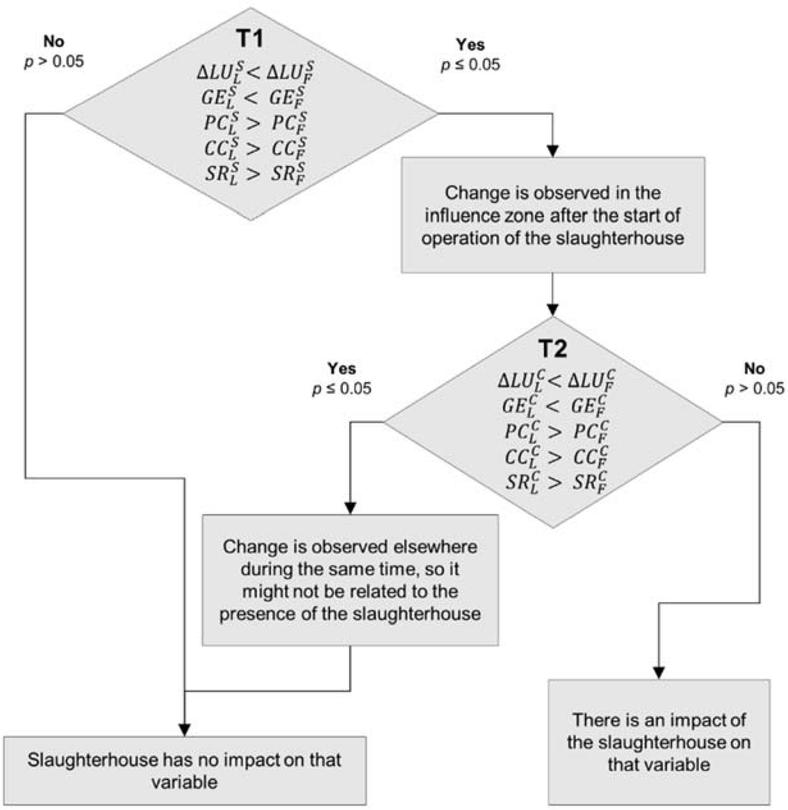

Figure 3. Flow diagram illustrating the analysis.

In the case of a significant response in any of the influence zones in T1, we used a second test (T2) to determine whether this response occurred only in the influence zones in this period (and not in the control zones). In T2, we performed a Wilcoxon paired test with the same hypotheses in the control zones (denoted by superscript C). That is, we tested whether there was a decrease in ΔLU (Ha : $\Delta LU_L^C < \Delta LU_F^C$) and GE (Ha: $GE_L^C < GE_F^C$) and an increase in the PC (Ha: $PC_L^C > PC_F^C$), CC (Ha: $CC_L^C > CC_F^C$) and SR (Ha: $SR_L^C > SR_F^C$) observed within the control zones between these time periods. A significant response ($p \leq 0.05$) in T2 means that the change in this variable was also observed elsewhere in the biome, outside of the influence zones, so it might not be directly related to the slaughterhouse. An opposite or neutral response ($p > 0.05$) means that the change observed in T1 occurred only in the slaughterhouse influence zone, and, in these cases, we would conclude that the slaughterhouse had an impact on the variable.

3. Results

3.1. Influence and Control Zones

Figure 4 shows the 12 influence zones obtained. The average sizes of the influence zones for travel times up to 2 h, 4 h, 6 h and 8 h are 0.43 Mha, 1.7 Mha, 4.1 Mha and 7.3 Mha, respectively. As the delimited extents were based on the travel time of a truck, the sizes of the influence zones vary according to the road network present near each slaughterhouse.

Due to the proximity between the slaughterhouse units, there are overlaps in some influence zones. However, just two zones (4267 and 791) have more than 50% of the 8 h zone shared by both (Figure 4). As the overlap starts at the 4 h travel time, we decided to keep the units separated instead of joining them so that the analysis has the same number of units per size of influence zone. In addition, the zones under the influence of slaughterhouses identified by SIF codes 1940, 3348 and 4333 extend over both biomes. However, just the 1940 SIF code unit was considered in both biome analyses, as a large percentage of its 8 h area is in the Cerrado biome (60% of the 8 h zone). Thus, five slaughterhouses were evaluated for the Cerrado, and eight for the Amazon.

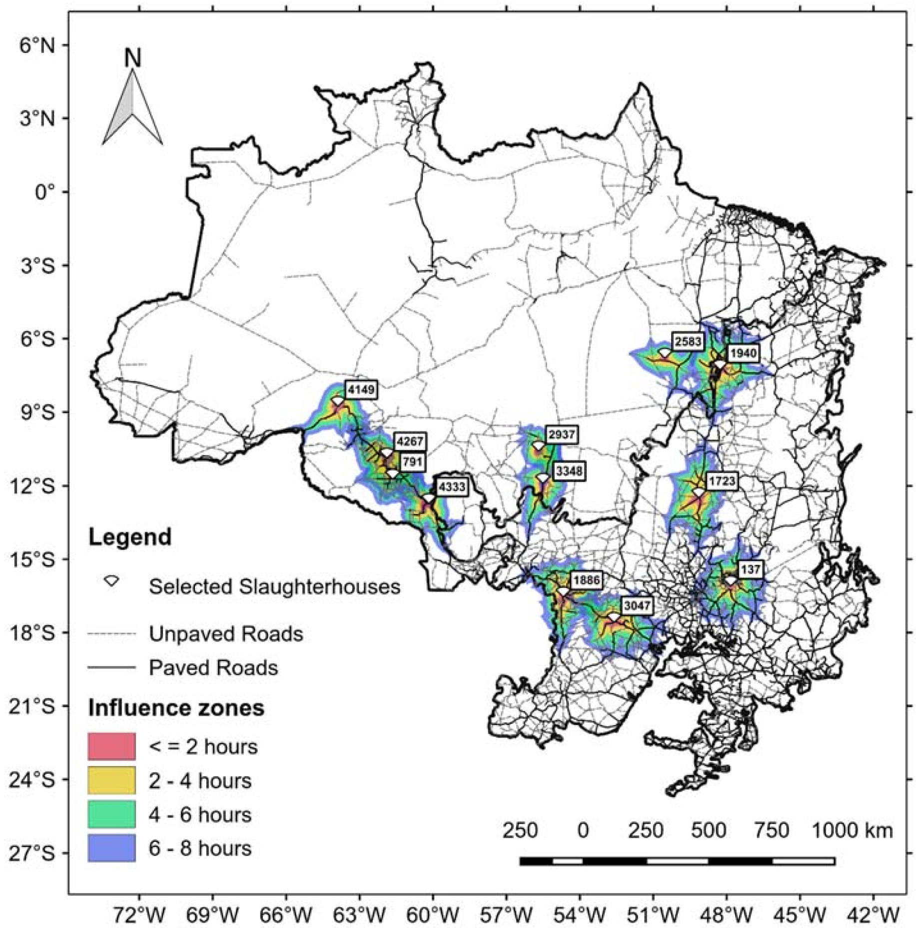

Figure 4. Locations of selected large slaughterhouses and their influence zones. Solid and dashed lines represent the paved and unpaved roads, respectively.

When choosing the control zones, first we excluded 340 Mha in both biomes, 70% in conservation units and indigenous lands and 30% in areas under the influence of selected slaughterhouses and slaughterhouses with y_{os} before 2000. We chose eight control areas in the Amazon and five control areas in the Cerrado (Figure 5). The selected zones have an average size of 7.3 Mha, the same as the average size of the 8 h influence zones.

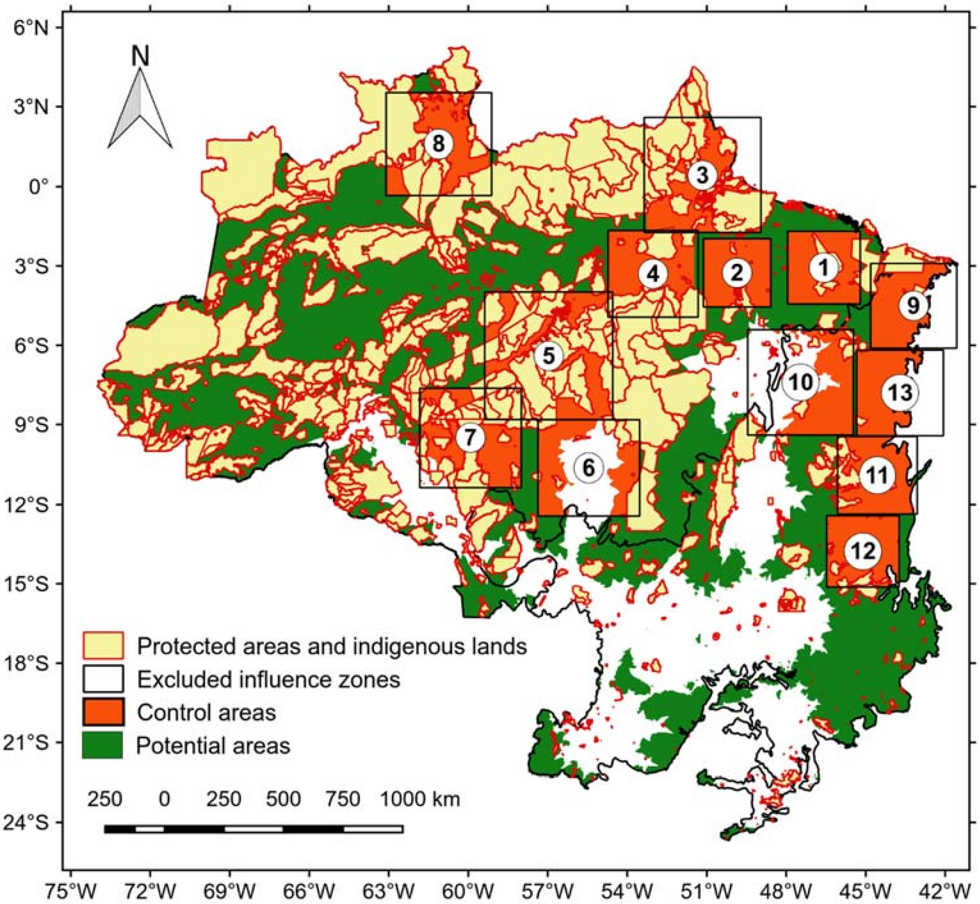

Figure 5. Locations of the control zones. The black squares indicate the zone limits. Green areas indicate areas with the potential to be control zones. White areas indicate influence zones of selected slaughterhouses and slaughterhouses with y_{os} before 2000.

3.2. Statistical Analysis

In the following sections, we show the results for each influence zone and control zone, separated by variable. Negative differences indicate a decrease in the variable analyzed with time.

3.2.1. Environmental Impact Variable: Land Use Change Rate (ΔLU)

Table 3 shows ΔLU_F and ΔLU_L results for the influence zones and the control zones. The first test (T1), a Wilcoxon paired test, determines whether there is a decrease in ΔLU inside the influence zones after the slaughterhouse start of operation. In Amazonia, there is a decrease in ΔLU in all influence zone sizes (travel times up to 2 h, 4 h, 6 h and 8 h), with similar values of probability (p = 0.004, Table 4). These results across the various sizes of the influence zones indicate that the distance from the slaughterhouse unit does not influence ΔLU. Results from T2 show that the decrease of ΔLU also occurs inside the control zones (p = 0.008, Table 4). The similar responses in both the slaughterhouse influence zones and the control zones during the same period indicate that the decrease of ΔLU might be not related to the slaughterhouse presence.

Table 3. Former and latter period values for land use change rate (ΔLU, in ha/year) for each influence zone and control zone.

	2 h		4 h		6 h		8 h			Control	
SIF Code	ΔLU_F^S (ha/year)	ΔLU_L^S (ha/year)	ΔLU_F^S (ha/year)	ΔLU_L^S (ha/year)	ΔLU_F^S (ha/year)	ΔLU_L^S (ha/year)	ΔLU_F^S (ha/year)	ΔLU_L^S (ha/year)	**Control Code**	ΔLU_F^C (ha/year)	ΔLU_L^C (ha/year)
791	6557.552	2387.213	28,446.332	8836.650	61,395.094	19,953.500	92,905.984	30,894.844	1	80,372.484	47,051.168
3348	9407.771	1465.027	34,195.277	7676.226	82,200.266	18,956.490	137,136.984	42,684.102	2	81,378.305	53,318.988
3047	946.861	1135.288	5235.697	5093.823	14,266.354	11,852.601	25,618.500	21,087.488	3	15,819.864	16,464.074
137	250.060	735.411	1786.634	3959.375	7293.791	11,791.568	17,400.232	25,362.859	4	59,520.324	46,821.258
1723	1816.823	1779.501	9388.703	8416.078	22,971.779	19,033.506	36,794.273	31,167.559	5	59,506.941	50,930.031
1886	1868.623	1362.502	9610.937	5900.309	20,900.621	12,623.756	35,851.840	22,329.553	6	117,978.461	46,430.785
1940	1576.978	1439.517	10,806.022	8332.689	26,263.994	18,966.988	55,317.758	35,559.426	7	105,355.867	38,125.027
2583	2439.150	563.163	9376.688	2705.178	23,052.080	7771.413	42,548.234	14,280.646	8	30,946.521	19,714.889
2937	781.155	469.791	5982.479	2420.442	22,798.094	8578.547	56,155.816	18,531.934	9	35,776.426	38,022.645
4149	4107.312	2648.438	18,282.762	11,317.136	39,151.117	24,151.670	79,550.453	41,369.051	10	39,928.773	36,683.539
4267	3596.003	1793.645	24,930.428	8992.448	64,370.426	20,787.986	122,377.789	38,633.922	11	34,875.188	35,362.727
4333	7961.677	3783.414	22,355.818	10,142.759	47,414.707	18,169.438	76,847.141	27,719.873	12	29,021.994	36,196.199
									13	22,420.396	32,550.551

Table 4. Results of Wilcoxon paired tests for T1 and T2 for land use change rate (ΔLU). T1 tests whether the introduction of large slaughterhouses was associated with the reduction of ΔLU in the influence zones (Ha: $\Delta LU_L^S < \Delta LU_F^S$). T2 tests whether reduction of ΔLU also occurred in the control zones (Ha: $\Delta LU_L^C < \Delta LU_F^C$).

	Latter Values–Former Values (ΔLU)						
		T1 $\left(\mathbf{Ha:}\ \Delta LU_L^S < \Delta LU_F^S\right)$				T2 $\left(\mathbf{Ha:}\ \Delta LU_L^C < \Delta LU_F^C\right)$	
	SIF Code	**2 h (ha/year)**	**4 h (ha/year)**	**6 h (ha/year)**	**8 h (ha/year)**	**Control Code**	**Control (ha/year)**
Amazonia	791	−4170.339	−19,609.682	−41,441.594	−62,011.140	1	−33,321.316
	3348	−7942.744	−26,519.051	−63,243.776	−94,452.882	2	−28,059.317
	1940	−137.461	−2473.333	−7297.006	−19,758.332	3	644.210
	2583	−1875.987	−6671.510	−15,280.667	−28,267.588	4	−12,699.066
	2937	−311.364	−3562.037	−14,219.547	−37,623.882	5	−8576.910
	4149	−1458.874	−6965.626	−14,999.447	−38,181.402	6	−71,547.676
	4267	−1802.358	−15,937.980	−43,582.440	−83,743.867	7	−67,230.840
	4333	−4178.263	−12,213.059	−29,245.269	−49,127.268	8	−11,231.632
	Median	−1839.173	−9589.343	−22,262.968	−43,654.335		−20,379.192
	p	0.004 *	0.004 *	0.004 *	0.004 *		0.008 *
Cerrado	3047	188.427	−141.874	−2413.753	−4531.012	9	2246.219
	137	485.351	2172.741	4497.777	7962.627	10	−3245.234
	1723	−37.322	−972.625	−3938.273	−5626.714	11	487.539
	1886	−506.121	−3710.628	−8276.865	−13,522.287	12	7174.205
	1940	−137.461	−2473.333	−7297.006	−19,758.332	13	10,130.155
	Median	−37.322	−972.625	−3938.273	−5626.714		2246.219
	p	0.500 ^{NS}	0.156 ^{NS}	0.156 ^{NS}	0.156 ^{NS}		0.906 ^{NS}

* Indicates significant at 5% level. ^{NS} Indicates not significant at 5% level. SIF code 1940 is used in the analyses of both biomes.

In the Cerrado, T1 shows no decrease in ΔLU (Table 4). This indicates that the slaughterhouses had no impact on ΔLU inside the slaughterhouse influence zones. Although a drop in ΔLU is observed in most of the influence zones, due to the small size of the sample, the response is not significant. By comparison, the T2 test shows interesting results: most of the control zones show increases in ΔLU. Of the five control zones, four show increases in ΔLU in the latter part of the study period (p = 0.906, Table 4).

3.2.2. Environmental Impact Variable: Total Greenhouse Gas Emissions (GE)

Table 5 shows GE_F and GE_L results for the influence zones and control zones. In the Amazon, T1 results show that there is a significant reduction of GE after the slaughterhouses' start of operation. As occurred with tests for ΔLU, all zones show the same level of significance, which demonstrates the absence of a distance influence (p = 0.004, Table 6). The similar responses between ΔLU and GE were already expected because of the large contribution of land use emissions to the total emissions. After finding a significant response in the 8 h influence zone for T1, WE used T2 to compare this result with the response in control areas outside the slaughterhouse influence zones. As occurred with ΔLU, T2 results confirm that the decrease of GE also occurred in the control zones (p = 0.008, Table 6). The T1 and T2 responses demonstrate that the change is observed both inside and outside of the influence zones during the same period, so the decrease of GE might be unrelated to the slaughterhouse presence.

Table 5. Former and latter period values for greenhouse gas emissions (GE, in Tg-CO_{2e}/year) for each influence zone and control zone.

	2 h		4 h		6 h		8 h			Control	
SIF Code	GE_F^S (Tg-CO_{2e}/year)	GE_L^S (Tg-CO_{2e}/year)	GE_F^S (Tg-CO_{2e}/year)	GE_L^S (Tg-CO_{2e}/year)	GE_F^S (Tg-CO_{2e}/year)	GE_L^S (Tg-CO_{2e}/year)	GE_F^S (Tg-CO_{2e}/year)	GE_L^S (Tg-CO_{2e}/year)	**Control Code**	GE_F^C (Tg-CO_{2e}/year)	GE_L^C (Tg-CO_{2e}/year)
791	4.8	2.5	19	8.2	38	17	57	24	1	59	36
3348	5.6	0.93	20	4.4	44	11	70	24	2	58	39
3047	0.35	0.35	1.9	1.7	5.1	4.4	10	9.3	3	6.1	7.0
137	0.14	0.19	0.86	1.1	3.2	3.9	7.3	8.8	4	42	34
1723	0.50	0.55	2.3	2.4	5.9	5.6	10	9.6	5	37	32
1886	0.96	0.84	3.3	2.7	6.0	4.7	9.6	7.6	6	64	28
1940	1.0	0.87	6.1	4.2	14	9.4	28	16	7	69	27
2583	1.9	0.58	7.6	2.9	18	7.8	33	14	8	18	11
2937	0.73	0.53	4.1	2.3	14	6.9	30	13	9	15	16
4149	2.3	1.4	9.5	5.6	22	13	46	24	10	7.7	6.8
4267	3.0	2.0	18	9.1	43	19	78	31	11	9.3	9.4
4333	4.2	2.1	12	5.7	25	11	41	18	12	7.3	8.3
									13	3.9	5.4

Table 6. Results of Wilcoxon paired tests for T1 and T2 for greenhouse gas emissions (GE). T1 tests whether the introduction of large slaughterhouses was associated with the reduction of GE in the influence zones (Ha: $GE_L^S < GE_F^S$) T2 tests whether reduction of GE also occurred in the control zones (Ha: $GE_L^C < GE_F^C$).

Latter Values–Former Values (GE)								
		T1 $\left(\text{Ha}: GE_L^S < GE_F^S\right)$				T2 (Ha: $GE_L^C < GE_F^C$)		
	SIF Code	2 h (Tg-CO_{2e}/year)	4 h (Tg-CO_{2e}/year)	6 h (Tg-CO_{2e}/year)	8 h (Tg-CO_{2e}/year)	Control Code	Control (Tg-CO_{2e}/year)
Amazonia	791	−2.3	−11	−22	−33	1	−23
	3348	−4.7	−15	−33	−46	2	−19
	1940	−0.13	−1.9	−4.8	−12	3	0.94
	2583	−1.3	−4.6	−11	−19	4	−7.8
	2937	−0.20	−1.8	−7.1	−17	5	−4.4
	4149	−0.90	−3.8	−8.4	−22	6	−36
	4267	−0.95	−8.8	−24	−47	7	−42
	4333	−2.1	−5.9	−14	−23	8	−7.6
	Median	−1.1	−5.3	−12	−23		−13.6
	p	0.004 *	0.004 *	0.004 *	0.004 *		0.008 *
Cerrado	3047	0.0010	−0.16	−0.69	−1.0	9	0.86
	137	0.048	0.28	0.71	1.5	10	−0.92
	1723	0.046	0.075	−0.27	−0.70	11	0.14
	1886	−0.12	−0.65	−1.2	−2.0	12	1.0
	1940	−0.13	−1.9	−4.8	−12	13	1.6
	Median	0.0010	−0.16	−0.69	−1.0		0.86
	p	0.406 NS	0.219 NS	0.156 NS	0.156 NS		0.969 NS

* Indicates significant at 5% level. NS Indicates not significant at 5% level. SIF code 1940 is used in the analyses of both biomes.

In the Cerrado, T1 results show a nonsignificant response for the reduction of GE inside the slaughterhouse influence zones. As occurred in Amazonia, the GE results are very similar to the ΔLU results. In addition, for transportation distances up to 4 h, emissions due to enteric fermentation appear to have a greater influence on the total emitted. In comparison to what was observed for ΔLU, where two units show increases inside the influence zones up to 2 h and one up to 4 h, for GE, three units (SIF codes 3047, 137 and 1723) show increases in GE inside the zones up to 2 h, and two (SIF codes 137 and 1723) in the zones up to 4 h. According to the analysis framework, the T2 test is not necessary in the case of negative responses up to 8 h. As was the case with ΔLU analyses, T2 results looking at GE show that the increases also occur inside the control zones (p = 0.969, Table 6).

3.2.3. Intensification Variable: Protein from Crops (PC)

Table 7 shows PC_F and PC_L results for the influence zones and control zones. In Amazonia, T1 results show that there was a change in PC inside the influence zones ($p \leq 0.05$, Table 8). In addition, the decrease of p with the increase of influence zone sizes (up to 2 h, 4 h, 6 h, and 8 h) indicates that distance from the slaughterhouse unit had a likely influence. As T1 results show significant changes in PC in the influence zones, we use T2 to determine whether the changes occurred only inside the influence zones. According to T2 results, the increase of PC also occurred in the control zones ($p \leq 0.05$, Table 8), which implies the absence of slaughterhouse impact on this variable.

Table 7. Former and latter period values for protein from crops (PC, in Gg protein) for each influence zone and control zone.

	2 h		4 h		6 h		8 h		Control		
SIF Code	PC_F^S (Gg)	PC_L^S (Gg)	PC_F^S (Gg)	PC_L^S (Gg)	PC_F^S (Gg)	PC_L^S (Gg)	PC_F^S (Gg)	PC_L^S (Gg)	**Control Code**	PC_F^C (Gg)	PC_L^C (Gg)
791	8.7	15	21	38	36	67	63	1.2×10^2	1	17	37
3348	42	1.1×10^2	2.6×10^2	5.1×10^2	6.2×10^2	1.1×10^3	1.0×10^3	1.8×10^3	2	6.5	18
3047	89	1.2×10^2	3.7×10^2	4.9×10^2	9.3×10^2	1.2×10^3	1.5×10^3	2.0×10^3	3	0.20	1.0
137	32	49	1.5×10^2	2.5×10^2	4.2×10^2	7.2×10^2	7.5×10^2	1.3×10^3	4	14	22
1723	3.3	10	13	36	28	77	55	1.4×10^2	5	2.0	3.1
1886	1.0×10^2	1.5×10^2	3.5×10^2	4.8×10^2	7.1×10^2	9.5×10^2	1.1×10^3	1.4×10^3	6	5.6×10^2	1.3×10^3
1940	1.2	2.5	6.4	14	34	70	87	1.7×10^2	7	78	1.3×10^2
2583	0.20	0.19	1.4	1.4	4.0	4.2	8.5	10	8	4.4	4.4
2937	1.2	2.7	10	25	35	95	78	2.2×10^2	9	28	80
4149	0.17	0.21	0.36	0.57	0.68	1.3	1.6	3.0	10	2.8×10^2	5.6×10^2
4267	1.1	1.1	7.3	10	21	35	32	61	11	3.2×10^2	5.3×10^2
4333	16	37	63	1.3×10^2	1.6×10^2	2.8×10^2	3.4×10^2	5.4×10^2	12	3.2×10^2	5.1×10^2
									13	1.0×10^2	2.7×10^2

Table 8. Results of Wilcoxon paired tests for T1 and T2 for proteins from crops (PC). T1 tests whether the introduction of large slaughterhouses was associated with the increase of PC in the influence zones (Ha: $PC_L^S > PC_F^S$). T2 tests whether the increase of PC also occurred in the control zones (Ha: $PC_L^C > PC_F^C$).

Latter Values–Former Values (PC)							
		T1 (Ha: $PC_L^S > PC_F^S$)				T2 (Ha: $PC_L^C > PC_F^C$)	
	SIF Code	**2 h (Gg)**	**4 h (Gg)**	**6 h (Gg)**	**8 h (Gg)**	**Control Code**	**Control (Gg)**
Amazonia	791	6.3	17	32	59	1	20
	3348	66	2.6×10^2	5.2×10^2	8.3×10^2	2	11
	1940	1.3	7.6	36	83	3	0.78
	2583	−0.011	−0.050	0.19	1.8	4	7.4
	2937	1.5	16	60	1.4×10^2	5	1.1
	4149	0.049	0.21	0.57	1.4	6	7.1×10^2
	4267	−0.032	2.5	14	30	7	51
	4333	21	70	1.3×10^2	1.9×10^2	8	−0.069
	Median	1.4	12	34	71		9.3
	p	0.020 *	0.008 *	0.004 *	0.004 *		0.008 *
Cerrado	3047	32	1.2×10^2	2.8×10^2	4.9×10^2	9	51
	137	17	1.0×10^2	3.0×10^2	5.1×10^2	10	2.9×10^2
	1723	7.0	23	49	88	11	2.1×10^2
	1886	43	1.4×10^2	2.4×10^2	3.5×10^2	12	1.9×10^2
	1940	1.3	7.6	36	83	13	1.7×10^2
	Median	17	1.0×10^2	2.4×10^2	3.5×10^2		1.9×10^2
	p	0.031 *	0.031 *	0.031 *	0.031 *		0.031 *

* Indicates significant at 5% level. SIF code 1940 is used in the analyses of both biomes.

In the Cerrado, based on T1, all sizes of influence zone show an increase in PC after the slaughterhouse start of operation at the same level of significance (Table 8). The T2 results indicate a similar increase of PC occurred inside the control zones ($p \leq 0.05$, Table 8). These similar responses indicate that the large slaughterhouses have no impact on the PC.

3.2.4. Intensification Variable: Calories from Crops (CC)

Table 9 shows CC_F and CC_L results for the study influence zones and control zones. In Amazonia, T1 shows that there is an increase in CC in all influence zone sizes (up to 2 h, 4 h, 6 h and 8 h). As occurred with PC, there is an influence of distance from the slaughterhouse, with p decreasing along with increase of zone size. T2 shows that the increase in CC between the two time periods also occurs inside the control zones ($p = 0.020$, Table 10). The similar responses in T1 and T2 indicate that the increase of CC might not be related to the slaughterhouse presence.

Table 9. Former and latter period values for calories from crops (CC, in Pcal) for each influence zone and control zone.

	2 h		4 h		6 h		8 h			Control	
SIF Code	CC_F^S (Pcal)	CC_L^S (Pcal)	CC_F^S (Pcal)	CC_L^S (Pcal)	CC_F^S (Pcal)	CC_L^S (Pcal)	CC_F^S (Pcal)	CC_L^S (Pcal)	**Control Code**	CC_F^C (Pcal)	CC_L^C (Pcal)
791	0.13	0.24	0.33	0.58	0.53	1.0	0.84	1.6	1	0.47	0.77
3348	0.39	1.2	2.4	5.6	5.8	12	10	20	2	0.17	0.32
3047	1.1	1.8	4.4	7.4	11	18	18	30	3	0.0067	0.015
137	0.45	0.74	2.1	3.6	5.3	9.7	10	17	4	0.29	0.33
1723	0.037	0.10	0.15	0.36	0.34	0.78	0.75	1.7	5	0.057	0.070
1886	1.1	1.7	3.7	5.7	7.3	11	11	17	6	5.4	14
1940	0.016	0.029	0.092	0.17	0.47	0.82	1.1	1.9	7	0.77	1.3
2583	0.0063	0.0058	0.043	0.039	0.11	0.11	0.22	0.22	8	0.070	0.056
2937	0.017	0.031	0.11	0.28	0.37	1.0	0.80	2.4	9	0.80	1.7
4149	0.0052	0.0055	0.011	0.015	0.021	0.030	0.048	0.067	10	3.0	6.1
4267	0.034	0.033	0.18	0.22	0.38	0.58	0.52	0.93	11	3.3	5.6
4333	0.16	0.41	0.62	1.5	1.6	3.2	3.4	6.0	12	3.8	5.8
									13	1.1	2.9

Table 10. Results of Wilcoxon paired tests for T1 and T2 for calories from crops (CC). T1 tests whether the introduction of large slaughterhouses was associated with the increase of CC in the influence zones (Ha: $CC_L^S > CC_F^S$).T2 tests whether the increase of CC also occurred in the control zones (Ha: $CC_L^C > CC_F^C$).

	Latter Values–Former Values (CC)						
		T1 (Ha: $CC_L^S > CC_F^S$)				T2 (Ha: $CC_L^C > CC_F^C$)	
	SIF Code	**2 h (Pcal)**	**4 h (Pcal)**	**6 h (Pcal)**	**8 h (Pcal)**	**Control Code**	**Control (Pcal)**
Amazonia	791	0.10	0.26	0.45	0.79	1	0.30
	3348	0.78	3.2	6.6	11	2	0.14
	1940	0.012	0.073	0.35	0.86	3	0.0085
	2583	−0.00056	−0.0043	−0.0065	−0.0022	4	0.037
	2937	0.014	0.17	0.67	1.6	5	0.013
	4149	0.00027	0.0034	0.0090	0.019	6	8.8
	4267	−0.0012	0.045	0.20	0.40	7	0.58
	4333	0.26	0.86	1.6	2.7	8	−0.014
	Median	0.013	0.12	0.40	0.82		0.090
	p	0.039 *	0.012 *	0.008 *	0.008 *		0.020 *
Cerrado	3047	0.76	3.0	7.3	13	9	0.90
	137	0.28	1.5	4.3	7.9	10	3.1
	1723	0.063	0.21	0.43	0.91	11	2.3
	1886	0.58	1.9	3.8	5.9	12	2.1
	1940	0.012	0.073	0.35	0.86	13	1.8
	Median	0.28	1.5	3.8	5.9		2.1
	p	0.031 *	0.031 *	0.031 *	0.031 *		0.031 *

* Indicates significant at 5% level. SIF code 1940 is used in the analyses of both biomes.

In the Cerrado, T1 shows that there is an increase in CC (Table 10). All influence zones show a significant response in T1, which indicates a change occurred after slaughterhouse start of operation. As the response of the 8 h influence zone is significant, we use T2 results to determine whether the observed result also occurred inside the control zones. The T2 results do indicate an increase of CC in the control zones ($p \leq 0.05$, Table 10), which means that the increase of CC might be unrelated to the slaughterhouse presence.

3.2.5. Intensification Variable: Stocking Rate (SR)

Table 11 shows SR_F and SR_L results for the study influence zones and control zones. In Amazonia, T1 results indicate that SR is not impacted by the slaughterhouse start of operation, with all sizes of influence zone showing nonsignificant responses for the change ($p > 0.05$, Table 12). As T1 is negative, T2 is not necessary to prove the impact of the slaughterhouse. However, contrary to the results for the slaughterhouse influence zones, the control zones show a significant increase in the SR between time periods ($p \leq 0.05$, Table 12).

Table 11. Former and latter period values for stocking rate (SR, in head/ha) for each influence zone and control zone.

	2 h		4 h		6 h		8 h		Control		
SIF Code	SR_F^S (head/ha)	SR_L^S (head/ha)	SR_F^S (head/ha)	SR_L^S (head/ha)	SR_F^S (head/ha)	SR_L^S (head/ha)	SR_F^S (head/ha)	SR_L^S (head/ha)	**Control Code**	SR_F^C (head/ha)	SR_L^C (head/ha)
791	2.023	1.915	1.990	1.855	1.946	1.856	1.936	1.873	1	0.981	1.073
3348	0.717	0.753	0.867	0.915	1.066	1.117	1.194	1.240	2	1.204	1.554
3047	0.875	1.002	0.953	1.055	0.968	1.059	1.033	1.124	3	0.249	0.286
137	1.011	1.257	0.866	1.143	0.821	1.119	0.886	1.184	4	1.452	1.504
1723	0.811	1.060	0.858	1.181	0.845	1.144	0.834	1.115	5	1.342	1.684
1886	1.543	2.033	1.130	1.433	0.980	1.186	0.921	1.073	6	1.458	1.588
1940	0.984	1.043	0.993	1.081	1.025	1.146	1.024	1.150	7	1.589	2.018
2583	2.532	2.672	1.817	1.774	1.628	1.522	1.509	1.423	8	0.584	1.453
2937	2.085	1.850	1.913	1.744	1.782	1.719	1.708	1.728	9	0.968	1.267
4149	1.347	1.668	1.407	1.604	1.421	1.691	1.577	1.902	10	0.656	0.905
4267	1.826	1.925	1.835	1.971	1.866	2.014	1.855	2.036	11	0.653	0.974
4333	1.237	1.075	1.756	1.721	1.869	1.815	1.794	1.821	12	0.612	0.936
									13	0.512	0.530

Table 12. Results of Wilcoxon paired test for T1 and T2 for stocking rate (SR). T1 tests whether the introduction of large slaughterhouses was associated with the increase of SR in the influence zones (Ha: $SR_L^S > SR_F^S$). T2 tests whether the increase of SR also occurred in the control zones (Ha: $SR_L^C > SR_F^C$).

		Latter Values–Former Values (SR)					
		T1 (Ha: $SR_L^S > SR_F^S$)				T2 (Ha: $SR_L^C > SR_F^C$)	
	SIF Code	**2 h (Head/ha)**	**4 h (Head/ha)**	**6 h (Head/ha)**	**8 h (Head/ha)**	**Control Code**	**Control (Head/ha)**
Amazonia	791	−0.108	−0.135	−0.090	−0.063	1	0.092
	3348	0.036	0.048	0.051	0.046	2	0.350
	1940	0.059	0.088	0.121	0.126	3	0.037
	2583	0.140	−0.043	−0.106	−0.086	4	0.052
	2937	−0.235	−0.169	−0.063	0.020	5	0.342
	4149	0.321	0.197	0.270	0.325	6	0.130
	4267	0.099	0.136	0.148	0.181	7	0.429
	4333	−0.162	−0.035	−0.054	0.027	8	0.869
	Median	0.048	0.007	−0.002	0.037		0.236
	p	0.473 NS	0.371 NS	0.320 NS	0.125 NS		0.004 *
Cerrado	3047	0.127	0.102	0.091	0.091	9	0.299
	137	0.246	0.277	0.298	0.298	10	0.249
	1723	0.249	0.323	0.299	0.281	11	0.321
	1886	0.490	0.303	0.206	0.152	12	0.324
	1940	0.059	0.088	0.121	0.126	13	0.018
	Median	0.246	0.277	0.206	0.152		0.299
	p	0.031 *	0.031 *	0.031 *	0.031 *		0.031 *

* Indicates significant at 5% level. NS Indicates not significant at 5% level. SIF code 1940 is used in the analyses of both biomes.

In the Cerrado, all sizes of influence zone show an increase in SR after the start of operation of the slaughterhouses studied (p = 0.031, Table 12). According to T2, the control zones have the same results as the influence zones (p = 0.031, Table 12). These similar responses indicate that the large slaughterhouses are not directly responsible for SR increases in their influence zones in the Cerrado.

4. Discussion

Regarding the hypothesis that large slaughterhouses promote sustainable agricultural development and cattle ranching intensification, we expected to find significant reductions in variables that measured environmental impact (ΔLU and GE) and increases in variables that measured intensification (PC, CC, and SR) after the start of slaughterhouse operations. In Amazonia, the results show that there is a significant decrease in ΔLU and GE inside the slaughterhouse influence zones. However, since the same change happened in the control zones, this decrease might not be caused directly by the slaughterhouse presence, and might instead be part of the downward trend of deforestation over the period between 2004 and 2013 [31,32]. For agricultural intensification variables in Amazonia, PC and CC show a significant increase in both the influence and control zones, while SR does not show change in the areas under slaughterhouse influence. In the Cerrado, results for all variables are similar in the control and influence zones. Nonsignificant decreases in ΔLU and GE and significant increases of PC, CC, and SR are observed in the control zones as well as the influence zones.

The decrease in ΔLU observed both inside and outside the slaughterhouse influence zones in Amazonia demonstrates not slaughterhouse influence, but the power of conservation programs and other policies for forest protection [31,33–35]. In addition to the protection granted by the Brazilian Forest Code and monitoring programs such as the Program for Satellite Monitoring of the Brazilian Amazon Forest (PRODES—Projeto de Monitoramento da Floresta Amazônica Brasileira por Satélite) and the System for Detection of Deforestation in Real Time (DETER—System for Detection of Deforestation in Real Time), the private sector signed ambitious agreements—cattle agreements in 2009 and a Soy Moratorium in 2006 [36]—to further protect the native vegetation. The effective contribution of each measure is difficult to disentangle, but the combined result of these actions was a great success. According to INPE [32] the rate of forest loss in the Brazilian Amazon dropped from more than 2.7 Mha/year in 2004 to an average of 0.6 Mha/year in 2013, reaching the lowest rates since 1988.

Unfortunately, the same did not occur in the Cerrado. The decrease of ΔLU did not happen inside all influence zones. In the control zones, the ΔLU results indicate that there is increased suppression of Cerrado vegetation in areas away from large slaughterhouse influence. This may be linked with the absence of an effective vegetation suppression monitoring system in the biome, and the more permissive New Forest Code, which has allowed more legal suppression since 2012 [35]. Some studies [36,37] have also warned about a possible leakage of agriculture from Amazonia to the Cerrado due to the stricter conservation policies in Amazonia. According to the most recent official data available, 0.725 Mha was suppressed in the Cerrado between 2010 and 2011, which was 12% greater than observed in the previous period (0.647 Mha, between 2009 and 2010 [38]. In addition, a recent report released by Mighty Earth and Rainforest Foundation Norway (RFN) claimed that multinational companies are linked to massive and systematic suppression of native vegetation in areas of Cerrado in MATOPIBA (an acronym created from the first two letters of the states of Maranhão, Tocantins, Piauí and Bahia). The report found that areas operated by the investigated companies had 0.697 Mha of vegetation suppressed from 2011 to 2015 [39].

GE results reflect ΔLU results, as land use emissions dominate GE in both biomes. In Amazonia, even with the increase of cattle between 2000 and 2013 (from 29 to 56 million head), the emissions from enteric fermentation are not enough to exceed the emissions from land use; this result was expected due to the high Amazonian biomass. In the Cerrado, the emissions from enteric fermentation dominate GE in the influence zones up to 4 h. For GE, by contrast with the results observed for ΔLU, three slaughterhouse units showed an increase in the areas of influence up to a 2 h driving radius, and two, in a radius up to 4 h. This response suggests that, in the zones near the slaughterhouses, the native vegetation has already been suppressed for the most part, making the emissions contributions from enteric fermentation more prominent than those from land use change.

The PC and CC results show that there has been an increase in the production of protein and calories in both biomes. In Amazonia, the p calculated for the various influence zone sizes show that the farther the distance from the slaughterhouse, the greater the increase in both variables. The most likely reason for this is that areas closer to these slaughterhouses are dominated by pasture, which is unlikely to be converted to new cropping areas. According to Dias et al. [11], the Amazon and Cerrado experienced expansion of crop area and increase in production in recent decades, especially for soybeans. Considering both biomes, soybean production grew from 7.4 million tons in 1990 to approximately 45.2 million tons in 2010 [11]. As one could expect, our results indicate that the increases of PC and CC are not related to the slaughterhouses' presence. However, the large increases in crop production around slaughterhouses may contribute to future increases in animal feed availability in the region.

The SR results for Amazonia indicate that these pastures have a stable stocking rate probably related to stagnant cattle ranching technology. To complement the discussion about SR, we performed two additional tests. First, we performed a Mann−Whitney test to compare the SR of the control and influence zones before the year of start of operation. In this test, we aimed to verify whether the large slaughterhouses we studied were installed in areas with high values of SR. According to the result (Table 13), before the slaughterhouse start of operation in the Amazon, the SR in the influence zones was greater than the SR observed in the control zones ($p = 0.031$, Table 13). This is an indication that big companies prefer to install slaughterhouse units in areas with high production, to ensure supply to their large processing capacity.

Table 13. Results of Mann-Whitney test comparing SR_F^S and SR_F^C in Amazonia.

Former Period (Ha: $SR_F^S \neq SR_F^C$)			
SIF Code	SR_F^S **(Head/ha)**	**Control Code**	SR_F^C **(Head/ha)**
791	1.936	1	0.981
3348	1.194	2	1.204
1940	1.024	3	0.249
2583	1.509	4	1.451
2937	1.708	5	1.342
4149	1.577	6	1.458
4267	1.855	7	1.589
4333	1.794	8	0.584
Median	1.643		1.273
p	0.031 *		

* Indicates significant at 5% level.

In the second test (Table 14), to verify the stagnation of the SR inside the slaughterhouses influence zones, we performed a Mann–Whitney test to compare the SR of the control and influence zones after the start of slaughterhouse operations. The result shows that in the latter period, the SR values of the control zones are similar to the values in the influence zones (p = 0.328, Table 14). In other words, and considering also the results of Table 12, stocking rate is intensifying at much faster rates away from the large slaughterhouses than closer to them.

Table 14. Results of Mann-Whitney test comparing the SR_L^S and SR_L^C in Amazonia.

Latter Period (Ha: $SR_L^S \neq SR_L^C$)			
SIF Code	SR_L^S **(Head/ha)**	**Control Code**	SR_L^C **(Head/ha)**
791	1.873	1	1.073
3348	1.240	2	1.554
1940	1.150	3	0.286
2583	1.423	4	1.504
2937	1.728	5	1.684
4149	1.902	6	1.588
4267	2.036	7	2.018
4333	1.821	8	1.453
Median	1.775		1.529
p	0.328 ^{NS}		

^{NS} Indicates not significant at 5% level.

Our results also demonstrate that the relationship between SR and ΔLU is not easily defined. After the slaughterhouse start of operation in the Amazon, although ΔLU dropped everywhere, the process of intensification did not start in the influence zones. Through a historical comparison between the US and Brazil, Merry and Soares [18] suggested that Brazilian cattle ranching will intensify as a result of economic conditions and conservation investments (reductions in capital and land subsidies) rather than intensifying in order to produce conservation outputs. In addition, characteristics that facilitate extensive ranching practices need to be discouraged or removed. The relatively easy process of land acquisition—land grabbing and low land prices—accompanied by weak protection laws that facilitates forest clearing for new pasture areas are the main obstacles of intensive ranching profitability, and may continue to be so in the next years [10,40,41].

Finally, the main limitation of this work is related to three assumptions. First, as we assume the zone of slaughterhouse influence extends up to 8 h travel time from a slaughterhouse, we may have excluded pasture areas dedicated to the cow–calf segment of the market. This segment is the main challenge on the pathway to achieving sustainable cattle ranching in Brazil, because it is not monitored or tracked under the current cattle agreements [13]. In addition, nearly all cow–calf production continues to be dependent on extensive grazing systems in the country [9].

Second, we may underestimate the area influenced by slaughterhouses, and therefore the appropriate sizes of the influence and control zones. We do not consider variables such as cattle availability, market access and transportation cost in the zone size estimates. Today, about 49% of active slaughterhouses in Amazonia belong to companies that signed the TAC, corresponding to 70% of slaughter capacity in the biome [19]. Therefore, the similarities observed between the control and influence zones may indicate that small slaughterhouses, which are not considered in this analysis and may be found inside some areas designated as control zones, may affect their supply areas in the same way that large units do.

The third limitation is related to the assumption that only 12 selected slaughterhouses have influence in their respective supply area. As observed in Figure 2, many large slaughterhouses are near the selected ones and they may influence the variables analyzed along with the selected units. We assumed here that the effect of these older slaughterhouses has not changed in time, and the main effect measured is due to the slaughterhouses that started operations in the period of analyses. Only two slaughterhouses do not have other large units near them: SIF 4333 in Amazonia and SIF 3047 in the Cerrado (Figure 2). Although it is not possible to test statistically one slaughterhouse, SIF 4333 has the same direction of change of the set of Amazonia plants for ΔLU, GE, PC and CC at all influence zones (Table 4, Table 6, Table 8, and Table 10) and for SR at the 6 h and 8 h influence zone (Table 12). Similar results are found for SIF 3047 when compared to the Cerrado set, except for ΔLU at the 2 h influence zone. This is an indication of the effectiveness of this assumption.

5. Conclusions

This study investigated the influence of large slaughterhouses on five variables, two related to environment impact (land use change rate and GHG emissions), and three related to cattle-ranching intensification (protein from crops, calories from crops and stocking rate). The results indicate that the changes observed inside the zones influenced by slaughterhouses cannot be attributed to the start of slaughterhouse unit operation in either Amazonia or the Cerrado.

In the Amazon, the environmental impact variables we studied show the same pattern of responses inside and outside the slaughterhouse influence zones—both moving towards reduced environmental impact. The hypothesis that slaughterhouses are leverage points to reduce deforestation and suppression of native Cerrado vegetation is not confirmed, leading us to believe that conservation measures such as a strong monitoring system and more restrictive environmental policies are the main promoters of conservation in Amazonia. In addition, the slaughterhouses seem to have no effect on cattle-ranching intensification. The high stocking rates observed in the period before the slaughterhouses' start of operation indicate that large meatpackers prefer to set up their plants in areas already well established and developed in the biome.

In the Cerrado, the responses of the environmental impact variables both inside and outside the slaughterhouse influence zones indicate that there is considerable conservation work to be done in the biome. The success of sustainable agriculture in the Cerrado still relies on the implementation of conservation measures. In addition, the increase of PC, CC, and SR both inside and outside the influence zones demonstrates that, in the Cerrado, cattle-ranching intensification is a reality, and it is occurring independently of the presence of large slaughterhouses.

In conclusion, there is no evidence that large slaughterhouses have promoted either cattle-ranching intensification or improvements in the sustainability of cattle-ranching activity in the Amazon and Cerrado. The results of our study and the recent failures of some of the cattle agreements show that leaning on slaughterhouses should not be considered a reliable strategy to achieve sustainable beef production. According to Lambin et al. [42], zero-deforestation agreements signed by private sectors may not be sufficient to reduce environmental impacts in commodities supply chain; public and private policies need to complement and reinforce each other to disconnect the link between cattle production and deforestation. In addition, to achieve intensification, it is necessary to improve the ranchers' access to technologies and capital [43,44], as there are still too many cattle farmers in Amazonia and the Cerrado who are engaging in extensive ranching practices associated with low income and high environmental damage.

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Appendix Table with All Abbreviations Used in the Text

ABBREVIATIONS	
AGB	Aboveground biomass
BGB	Belowground biomass
CAR	Cadastro Ambiental Rural (*Rural Environmental Registry*)
CNPJ	Cadastro Nacional de Pessoa Jurídica (*National Register of Legal Entities*)
DETER	Sistema de Detecção de Desmatamento em Tempo Real (*System for the Detection of Deforestation in Real Time*)
DIPOA	Departamento de Inspeção de Produtos de Origem Animal (*Department for Inspection of Animal Products*)
GHG	Greenhouse Gases
GWP	Global Warming Potential
IBGE	Instituto Brasileiro de Geografia e Estatística (*Brazilian Institute of Geography and Statistics*)
INPE	Instituto Nacional de Pesquisas Espaciais (*National Institute for Space Research*)
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land Use, Land Use Change and Forestry
MAPA	Ministério da Agricultura, Pecuária e Abastecimento (*Brazilian Ministry of Agriculture, Livestock and Food Supply*)
MATOPIBA	Acronym created from the first two letters of the states of Maranhão, Tocantins, Piauí, and Bahia
NGOs	Non-Governmental Organizations
PNLT	Plano Nacional de Logística e Transporte (*National Logistics and Transportation Plan*)
PNMC	Política Nacional sobre Mudanças no Clima (*Brazil's National Policy on Climate Change*)
PRODES	Projeto de Monitoramento da Floresta Amazônica Brasileira por Satélite (*Program for Satellite Monitoring of the Brazilian Amazon Forest*)

Appendix Biomass Map and Emissions from Enteric Fermentation

The biomass map of the historic vegetation for Amazonia and the Cerrado is presented in Figure A1. The historic carbon content of native vegetation was 68.7 Pg-C for Amazonia and 10.1 Pg-C for the Cerrado. Estimation of the historic vegetation is a complicated process, and results can vary widely. Our estimate is comprehended in the range calculate by Leite et al. [45] for Amazonia (from 51.3 to 85.5 Pg-C); however, our estimate is about 53% less than the estimate for the Cerrado (from 13.8 to 28.8 Pg-C). The historic carbon content of native vegetation estimated in this study is different from the values reported in Leite et al. [45] because different methodologies and values of carbon stock were used to make the biomass maps. While Leite et al. [45] combined two maps of vegetation types (RadamBrasil and IBGE [25]) and used the values for carbon stock in vegetation from the Second National Communication of Brazil to the UNFCCC, we used the map from IBGE [25] and the data from the Third National Communication.

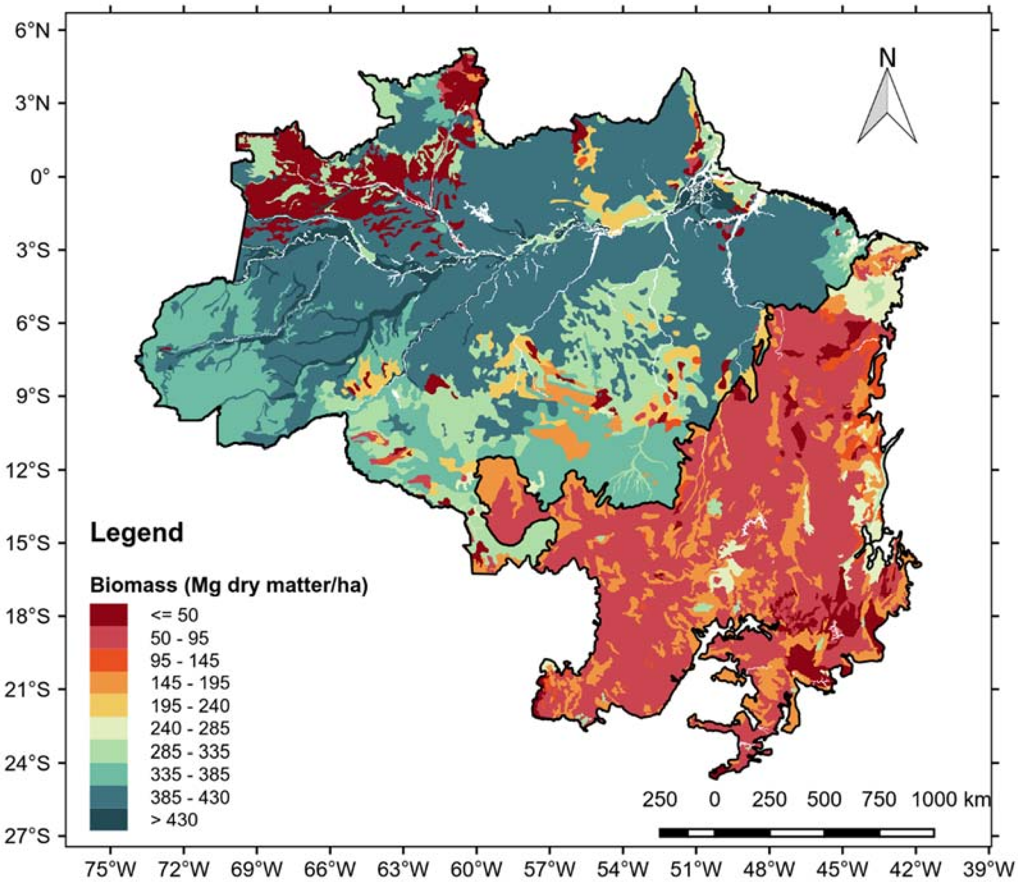

Figure A1. Biomass map for past vegetation of Amazonia and the Cerrado.

Another result is the CH_4 emissions from enteric fermentation. Between 2000 and 2013, the emissions from beef cattle increased in both biomes. Total methane emission by the two biomes in this period amounted to 2.9 Pg-CO_{2e}, about 54% of the total emitted in the country (5.3 Pg-CO_{2e} [2]). Emissions in Amazonia increased about 80% (from 41.7 Tg-CO_{2e} in 2000 to 77.5 Tg-CO_{2e} in 2013). In the Cerrado, emissions increased about 0.09% (from 82.5 Tg-CO_{2e} in 2000 to 90.5 Tg-CO_{2e} in 2013). The increase was bigger in the Amazon than in the Cerrado because of the great increase in number of cattle that occurred in this period.

Our estimates for methane emissions are very similar to other data. According to Azevedo et al. [2], for the states of the Amazon biome, the total amount of methane emitted by enteric fermentation from beef cattle was 1.0 Pg-CO_{2e} for the period, while our estimate was 0.9 Pg-CO_{2e}.

For the states of the Cerrado, Azevedo et al. [2] reported total methane emissions of 2.0 Pg-CO_2-eq for the period, about 35% greater than our estimate of about 1.3 Pg-CO_2-eq. These Cerrado estimates differ because we consider the actual geographic limits of the biome, while the Azevedo et al. [2] value includes total emissions for all Cerrado states, irrespective of how much area within the states is part of the Cerrado biome.

References

1. Ministério da Ciência, Tecnologia e Inovação. *Third National Communication of Brazil to the United Nations Framework Convention on Climate Change*; Ministério da Ciência, Tecnologia e Inovação: Brasilia, Brazil, 2016; Volume III, ISBN 9788588063198.
2. De Azevedo, T.R.; Costa Junior, C.; Brandão Junior, A.; Cremer, M.D.S.; Piatto, M.; Tsai, D.S.; Barreto, P.; Martins, H.; Sales, M.; Galuchi, T.; et al. SEEG initiative estimates of Brazilian greenhouse gas emissions from 1970 to 2015. *Sci. Data* **2018**, *5*, 1–43. [CrossRef] [PubMed]
3. Cohn, A.S.; Mosnier, A.; Havlík, P.; Valin, H.; Herrero, M.; Schmid, E.; O'Hare, M.; Obersteiner, M. Cattle ranching intensification in Brazil can reduce global greenhouse gas emissions by sparing land from deforestation. *Proc. Natl. Acad. Sci. USA* **2014**, *111*, 7236–7241. [CrossRef] [PubMed]
4. Strassburg, B.B.N.; Latawiec, A.E.; Barioni, L.G.; Nobre, C.A.; da Silva, V.P.; Valentim, J.F.; Vianna, M.; Assad, E.D. When enough should be enough: Improving the use of current agricultural lands could meet production demands and spare natural habitats in Brazil. *Glob. Environ. Chang.* **2014**, *28*, 84–97. [CrossRef]
5. Crosson, P.; Shalloo, L.; O'Brien, D.; Lanigan, G.J.; Foley, P.A.; Boland, T.M.; Kenny, D.A. A review of whole farm systems models of greenhouse gas emissions from beef and dairy cattle production systems. *Anim. Feed Sci. Technol.* **2011**, *166–167*, 29–45. [CrossRef]
6. De Oliveira Silva, R.; Barioni, L.G.; Hall, J.A.J.; Matsuura, M.F.; Zanett Albertini, T.; Fernandes, F.A.; Moran, D. Increasing beef production could lower greenhouse gas emissions in Brazil if decoupled from deforestation. *Nat. Clim. Chang.* **2016**, *6*, 493–497. [CrossRef]
7. Mazzetto, A.M.; Feigl, B.J.; Schils, R.L.M.; Cerri, C.E.P.; Cerri, C.C. Improved pasture and herd management to reduce greenhouse gas emissions from a Brazilian beef production system. *Livest. Sci.* **2015**, *175*, 101–112. [CrossRef]
8. Palermo, G.C.; D'Avignon, A.L.D.A.; Freitas, M.A.V. Reduction of emissions from Brazilian cattle raising and the generation of energy: Intensification and confinement potentials. *Energy Policy* **2014**, *68*, 28–38. [CrossRef]
9. Ferraz, J.B.S.; de Felício, P.E. Production systems—An example from Brazil. *Meat Sci.* **2010**, *84*, 238–243. [CrossRef] [PubMed]
10. Bowman, M.S.; Soares-Filho, B.S.; Merry, F.D.; Nepstad, D.C.; Rodrigues, H.; Almeida, O.T. Persistence of cattle ranching in the Brazilian Amazon: A spatial analysis of the rationale for beef production. *Land Use Policy* **2012**, *29*, 558–568. [CrossRef]
11. Dias, L.C.P.; Pimenta, F.M.; Santos, A.B.; Costa, M.H.; Ladle, R.J. Patterns of land use, extensification, and intensification of Brazilian agriculture. *Glob. Chang. Biol.* **2016**, *22*, 2887–2903. [CrossRef] [PubMed]
12. Barreto, P.; Pereira, R.; Arima, E. *A Pecuária e o Desmatamento na Amazônia na era das Mudanças Climáticas*; Instituto do Homem e Meio Ambiente da Amazônia: Belém, Brazil, 2008; ISBN 9788586212260.
13. Gibbs, H.K.; Munger, J.; L'Roe, J.; Barreto, P.; Pereira, R.; Christie, M.; Amaral, T.; Walker, N.F. Did ranchers and slaughterhouses respond to zero-deforestation agreements in the Brazilian Amazon? *Conserv. Lett.* **2016**, *9*, 32–42. [CrossRef]
14. Greenpeace. Eating up the Amazon. Available online: http://www.greenpeace.org/usa/research/eating-up-the-amazon/ (accessed on 16 May 2016).
15. Greenpeace. Slaughtering the Amazon. Available online: http://www.greenpeace.org/international/en/publications/reports/slaughtering-the-amazon/ (accessed on 16 May 2016).
16. Walker, N.; Patel, S.; Kalif, K. From Amazon pasture to the high street: Deforestation and the Brazilian cattle product supply chain. *Trop. Conserv. Sci.* **2013**, *6*, 446–467. [CrossRef]
17. Garcia, E.; Filho, F.S.V.R.; Mallmann, G.M.; Fonseca, F. Costs, benefits and challenges of sustainable livestock intensification in a major deforestation frontier in the Brazilian Amazon. *Sustainability* **2017**, *9*, 158. [CrossRef]

18. Merry, F.; Soares-Filho, B. Will intensification of beef production deliver conservation outcomes in the Brazilian Amazon? *Elem. Sci. Anth.* **2017**, *5*, 1–12. [CrossRef]
19. Barreto, P.; Pereira, R.; Brandão, A., Jr.; Baima, S. *Os Frigoríficos vão Ajudar a Zerar o Desmatamento da Amazônia?* Imazon: Belém, Brazil, 2017; ISBN 9788586212949.
20. Alves-Pinto, H.N.; Newton, P.; Pinto, L.F.G. *Certifying Sustainability: Opportunities and Challenges for the Cattle Supply Chain in Brazil*; Research Program on Climate Change; Agriculture and Food Security (CCAFS): Copenhagen, Denmark, 2010; pp. 1–8.
21. Zu Ermgassen, E.K.H.J.; de Alcântara, M.P.; Balmford, A.; Barioni, L.; Neto, F.B.; Bettarello, M.M.F.; de Brito, G.; Carrero, G.C.; Florence, E.D.A.S.; Garcia, E.; et al. Results from on-the-ground efforts to promote sustainable cattle ranching in the Brazilian Amazon. *Sustainability* **2018**, *10*, 1301. [CrossRef]
22. Barreto, P.; Silva, D. Will cattle ranching continue to drive deforestation in the Brazilian Amazon? In *Environment and Natural Resources Management in Developing and Transition Economies*; Centre of Studies and Research on International Development from the University of Auvergne: Clermont Ferrand, France, 2010; pp. 1–23.
23. Hansen, M.C.; Potapov, P.V.; Moore, R.; Hancher, M.; Turubanova, S.A.; Tyukavina, A.; Thau, D.; Stehman, S.V.; Goetz, S.J.; Loveland, T.R.; et al. High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science* **2013**, *342*, 850–853. [CrossRef] [PubMed]
24. Bustamante, M.; Santos, M.M.D.O.; Shimbo, J.Z.; Cantinho, R.Z.; Mello, T.D.R.B.D.; Oliveira, P.V.D.C.; Cunha, P.W.P.D.M.; Martins, F.D.S.R.V.; Aguiar, A.P.D.; Ometto, J. *Emissões do Setor de uso da Terra, Mudança do uso da Terra e Florestas: Relatório de Referência*; Ministério da Ciência, Tecnologia e Inovação: Brasíla, Brazil, 2015; p. 343.
25. IBGE. Mapa de Vegetação. 2004. Available online: https://mapas.ibge.gov.br/tematicos/vegetacao (accessed on 13 February 2016).
26. Berndt, A.; Lemes, A.P.; Romero, L.A.; Sakamoto, L.S.; Lima, M.A. *De Emissões de Metano por Fermentação Entérica e Manejo de Dejetos de Animais: Relatório de Referência*; EMBRAPA; Ministério da Ciência, Tecnologia e Inovação: Brasília, Brazil, 2015; p. 150.
27. IPCC. IPCC Guidelines for National Greenhouse Gas Inventories. 2006. Available online: https://www.ipcc-nggip.iges.or.jp/public/2006gl/ (accessed on 1 April 2016).
28. Cardoso, E.G. Engorda de Bovinos em Confinamento (Aspectos Gerais). Embrapa, 1996. Available online: https://www.embrapa.br/busca-de-publicacoes/-/publicacao/317195/engorda-de-bovinos-em-confinamento-aspectos-gerais (accessed on 15 April 2018).
29. Da Costa, M.J.R.P.; Quintiliano, M.H.; Tseimazides, S.P. *Boas Praticas de Manejo—Transporte*; MAPA/ACS: Brasília, Brazil, 2013; ISBN 9788579910715.
30. Confederação Nacional do Transporte. Anuário CNT do Transporte—Estatísticas Consolidadas. Available online: http://anuariodotransporte.cnt.org.br/2017/ (accessed on 20 April 2018).
31. Boucher, D. How Brazil has dramatically reduced tropical deforestation. *Solutions* **2014**, *5*, 65–75.
32. Kastens, J.H.; Brown, J.C.; Coutinho, A.C.; Bishop, C.R.; Esquerdo, J.C.D.M. Soy moratorium impacts on soybean and deforestation dynamics in Mato Grosso, Brazil. *PLoS ONE* **2017**, *12*, 0176168. [CrossRef] [PubMed]
33. Nepstad, D.; McGrath, D.; Stickler, C.; Alencar, A.; Azevedo, A.; Swette, B.; Bezerra, T.; DiGiano, M.; Shimada, J.; da Motta, R.S.; et al. Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains. *Science* **2014**, *344*, 1118–1123. [CrossRef] [PubMed]
34. Soares-Filho, B.; Rajao, R.; Macedo, M.; Carneiro, A.; Costa, W.; Coe, M.; Rodrigues, H.; Alencar, A. Cracking Brazil's forest code. *Science* **2014**, *344*, 363–364. [CrossRef] [PubMed]
35. Gibbs, H.K.; Rausch, L.; Munger, J.; Schelly, I.; Morton, D.C.; Noojipady, P.; Soares-Filho, B.; Barreto, P.; Micol, L.; Walker, N.F. Brazil's soy moratorium. *Science* **2015**, *347*, 377–378. [CrossRef] [PubMed]
36. INPE. Instituto Nacional de Pesquisas Espaciais 2013. Available online: http://www.inpe.br/ (accessed on 20 December 2017).
37. Macedo, M.N.; DeFries, R.S.; Morton, D.C.; Stickler, C.M.; Galford, G.L.; Shimabukuro, Y.E. Decoupling of deforestation and soy production in the southern Amazon during the late 2000s. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 1341–1346. [CrossRef] [PubMed]
38. IBAMA Projeto de Monitoramento dos Biomas Brasileiros via Satélite (PMDBBS). Available online: http://siscom.ibama.gov.br/monitora_biomas/ (accessed on 20 December 2017).

39. Bellantonio, M.; Hurowitz, G.; GrØnlud, L.; Yousefi, A. Ultimate Mystery Meat. Available online: http://www.mightyearth.org/mysterymeat/ (accessed on 16 October 2017).
40. Cardoso, D.; Brito, B.; Baima, S.; Siqueira, V. *O Estado da Amazônia Potencial de Arrecadação Financeira com a Regularização Fundiária no Pará*; Imazon: Belém, Brazil, 2018; p. 14.
41. Azevedo-Ramos, C.; Silva, J.N.M.; Merry, F. The evolution of Brazilian forest concessions. *Elem. Sci. Anth.* **2015**, *3*, 000048. [CrossRef]
42. Lambin, E.F.; Gibbs, H.K.; Heilmayr, R.; Carlson, K.M.; Fleck, L.C.; Garrett, R.D.; de Waroux, Y.L.P.; McDermott, C.L.; McLaughlin, D.; Newton, P.; et al. The role of supply-chain initiatives in reducing deforestation. *Nat. Clim. Chang.* **2018**, *8*, 109–116. [CrossRef]
43. Monzoni, M.; Vendramini, A.; Rocha, F.C.; Peirão, P.; Campanili, M.; Sobreiro, A.; Monteiro, A. *Análise dos Recursos do Programa ABC Safra 2016/17*; Centro de Estudos em Sustentabilidade da Fundação Getúlio Vargas (GVces): São Paulo, Brazil, 2017; pp. 1–36.
44. Latawiec, A.E.; Strassburg, B.B.N.; Valentim, J.F.; Ramos, F.; Alves-Pinto, H.N. Intensification of cattle ranching production systems: Socioeconomic and environmental synergies and risks in Brazil. *Animal* **2014**, *8*, 1255–1263. [CrossRef] [PubMed]
45. Leite, C.C.; Costa, M.H.; Soares-Filho, B.S.; Hissa, L.D.B.V. Historical land use change and associated carbon emissions in Brazil from 1940 to 1995. *Glob. Biogeochem. Cycles* **2012**, *26*, 1–13. [CrossRef]