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# Assessing economics and environmental issues at farm level: Including specificities on land use change and forest soil carbon storage of an Amazonian typical beef farm

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*Concerns about the land use change and sustainability of beef production are increasing around the world, particularly in the Amazonian region. We intend to improve understanding of economic and environmental issues of a typical Amazonian beef farm at the farm level. We use production cost and profitability analysis to assess farm economics. Employing an original approach we assessed greenhouse gas (GHG) emissions using a Life Cycle Assessment model integrating land-use change (LUC) and Soil Carbon Storage (SCS). We show that the beef farm is profitable only in the short-term. The main hotspots are land opportunity cost and livestock costs. The largest source of GHG emissions from beef production (15 kg $CO_2$ equivalents per kg of live weight produced) comes from enteric fermentation (83%). LUC emissions can double the GHG impact. Therefore, forestland preserved on the Brazilian farm is an important sink of SCS that can compensate all farm GHG emissions. Based on the literature, we conclude that economic failure and the substantial GHG emissions are related to the low productivity of animals and land.*

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## 1. Introduction

The livestock supply chain is commonly recognized for its significant contribution to greenhouse gas (GHG) emissions (Steinfeld et al., 2006) mainly when including emissions from land use change (LUC). On Farm (enteric fermentation) and animal feed production emissions are pointed as the main source of GHG emissions in the livestock sector (Opio et al., 2013). However, beef production systems, when grassland based, can also contribute to carbon sequestration, biodiversity preservation (FAO, 2011). Producing enough food to feed 9.3 billion people in 2050 is also an important challenge for the sector (FAO, 2009). It would require a 158% increase in beef production to meet the growing demands by 2050 (FAO, 2011). Thus, in addition to environmental issues, the sector has important economic and social concerns.

In this context, understanding economic and environmental issues in a sustainable approach has become a major challenge for farmers, advisors, agro-industries and policy-makers. Exploring the relations between economic and environmental issues at the farm level, including regional characteristics, are important in addressing this challenge (Garnett, 2009). Since the Nineties' the Porter hypothesis (Porter, 1991; Porter and van der Linde, 1995) suggests that environmental and economic performance can be achieved together through a "win-win" approach. This hypothesis proposes that pollution is commonly a result of resource waste. Thus, efficient use of resources leads to productivity improvements, with economic and environmental gains. Empirical contributions in the agricultural sector to evaluate and improve farm economic and environmental performance have received major attention (Thomassen et al., 2009).

Therefore, assessing farm's economics is important when addressing sustainable issues. Farm cost and profitability analyses are the most traditional ways to address farm performance. Assessment of farm costs provides an overview of farm expenditures. Sharing the costs among different components of the farm production system (e.g. livestock, labor, depreciation, capital investment, land opportunity cost) allow assessing the weight of different components of total costs and identify hotspots of farm profitability[1].

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[1] Farm profitability is commonly defined as the ability to generate more income than expenses; thus, a profitable farm needs to at least cover its total costs.

Traditional approaches to calculate environmental performance - e.g. Life Cycle Assessment (LCA) - are been revisited and complemented by new concepts. Ecosystem services, land use changes (including forest conversion), soil Carbon stocks (SCS) and the notion of common property resources are emerging concepts on the environmental and ecological performance studies (Carpenter et al., 2009).

Recent studies using LCA for the beef sector has focused great attention on Land Use Changes (LUC) (Flysjö et al., 2012; Persson et al., 2014). This topic is of utmost relevance to the world climate regulation and mainly from regions where these land use changes are underway as Brazil. Cederberg et al. (2011) included LUC emissions in LCA of Brazilian beef cattle making assumptions of LUC and using national average data from forest conversion to pasture in newly deforested land. They predicted a GHG emission per kg of carcass weight of Brazilian Amazonian beef about 25 times higher than as the average GHG emissions for Brazilian beef without LUC accounting. Moreover, including LUC, mainly from native forest conversion to pastureland, in LCA studies is a complex and controversial topic (more information in Kisrchbaum et al., 2012). LCA results have a high influence of the site specificities (Finnveden and Nilsson 2005) mainly in a large country as Brazil. Thus, conclusions of studies based on average data need to be made carefully. In order to better estimate farms' contribution to climate regulation it is important to consider regional and local characteristics in LUC. Targeted analysis at regional and farm level also must be more suitable to propose solutions adapted to the real issues at this level.

The Carbon sequestered and stored in the soil organic matter and roots biomasses – the SCS - are frequently ignored or little discussed in farm LCA studies (Brandão et al., 2013; Petersen et al., 2013). Nevertheless, Lal (2004) and Petersen et al. (2013) emphasize that SCS is expected to have major potential to mitigate agricultural GHG emissions and also provide positive impacts on food security, water quality and biodiversity. The important ecosystem services generated by the SCS of farming systems need to be taking into account in LCA analyses, mainly in Brazilian farms. Actually, the Brazilian National Forest Act No. 4.771 (1965), replaced by Act No. 12651 (2012) determines limits of farmland uses. It requires preserving 20-80% of native forest on farmland. This preserved native forestland cannot be cut and sold. The result is that 87% of Cerrado, 92% of Mata-Atlântica, 99% of Pampas and 98% of Caatinga biomes' natural vegetation are preserved on private farmlands (Sparovek et al., 2011).

The preserved farm native forestland and its soil is a permanent (long-term) carbon stock. Thus, these stocks represent a carbon storage and "avoided carbon emissions to the atmosphere" in comparison with other land uses mainly to traditional agriculture. Still this SCS produces an important ecosystem service contributing to climate regulation by climate change mitigation. Native forestlands are part of the farm land use, and its SCS must be considered in the balance of farm GHG emissions especially in Brazilian LCA studies.

This study aims to contribute to a better assessment of environmental and economic issues at the farm level in regions where beef production is increasing and land use change is controversial. The study analyzes how internal structures of the typical Amazonian beef farm and its ability to use its resources are related to GHG emissions and farm economics. Exploring these relationships, this study examines farm economic and environmental hotspots. We briefly argue for possible ways to improve GHG mitigation and farm profitability from a win-win perspective. By an original methodology in its consideration of the influence of SCS of on-farm preserved forestland, we try to contribute to broaden LCA approaches on the analysis of Brazilian farm's GHG emissions. Data collected directly from farmers allow us to consider local characteristics of Amazonian Brazilian farms. Since no studies relate and combine Amazonian farm economics and GHG emissions at a farm level. This study intends to be a major contribution to methodological and empirical discussion related to this important subject.

## 2. Data and methods

The methodological approach has several steps. First, a typical Amazonian beef farm was established by a focus group. Second, the farm's economic issues were studied through farm production cost and profitability analysis. Then, the farm's net GHG emissions were estimated by LCA model (ISO 14044, 2006) integrating LUC and SCS. We made assumptions to create scenarios to cautiously consider LUC and SCS. Finally, we related farm GHG emissions and costs to farm management and land uses. This enabled us to discover determinants of economic and environmental performance and discuss sustainability issues for a typical Amazonian beef system at the farm level.

### *2.1. The typical farm*

The typical Amazonian beef farm was established according to the Plaxico and Tweeten (1963) method. Many countries use typical farm models for benchmark studies of farming systems, competitiveness, etc. The typical farm represents the size, land use, technical and economic characteristics of most local farms. It is a true representation of local farms. This method helps understand local farming systems, structures and costs; however, generalizations are limited and must be made carefully. More information about standard operating procedures for defining typical farms is also found in Deblitz and Zimmer (2005).

The typical farm established is located in Cáceres City (16.05°S, 57.68°W), Mato-Grosso State, in the Brazilian Legal Amazon region (Figure 1). It is the most important Brazilian beef-cattle region, representing 13.6% of Brazilian herds (IBGE, 2012). The city's mean annual temperature is 25.2°C, mean annual potential evapotranspiration is 1438 mm, and mean annual rainfall is 1347 mm, concentrated mainly in the summer (Embrapa, 2003). It is a sub-humid tropical region (Aw Köppen climate classification) (Embrapa, 2003).

Economic and technical farm data were collected in a focus group with local farmers and experts. The typical farm was established in 2012 by a team from CEPEA (Center for Advanced Studies on Applied Economics). We assembled farm livestock flows (animals' life cycle), livestock weights, technical indices and farm inputs and outputs. Through consensus of focus-group participants, the data for the typical farm were considered as representative characteristics of beef farms in the region.

The typical farm carried out by the focus group covers 1500 ha, composed of 1000 ha of permanent grasslands and 500 ha of permanent reserve of native forest. The farm was established in 1985 and has always produced only beef. The 1000 ha of grassland came from primary forest converted to grassland by slashing and burning in 1985. *Brachiaria decumbens* grass was seeded without addition of fertilizer. Lime was applied only once from 1985-2012 (1 Mg $ha^{-1}$ of dolomitic lime). The typical beef farm has the following characteristics: 400 Nelore cows (*Bos indicus*), a rustic breed adapted to Brazilian conditions. There is no calving period, meaning that the cows calve throughout the year. Mean age at first calving is 36 months. The cows produce 149 female and 149 male calves per year, a birthrate of 74.5%. Each year, 100 older cows of 360 kg are sold to the slaughterhouse and replaced by 100 heifers (replacement rate = 26%). Forty-one heifers of 320 kg are sold to other farms. One hundred forty four bulls are fattened to 490 kg and sold to a slaughterhouse each year. Achieving this weight takes an average of 974 days. They have a daily weight gain (after a birth weight of 30 kg) of 0.47 kg. The total mass of animals sold per year on this typical farm is 120,253 kg. Mean carcass yield is 50%. Thirteen animals die or disappear each year on the farm. Details of the farm animals' life cycle are presented in Figure 2. Assuming 450 kg per animal unit (AU), the farm has a stocking rate of 0.83 AU $ha^{-1}$. Animals are fed grass, along with addition of mineral salt. CEPEA estimated grass consumption of the cow-calf animals as 9321 Mg of grass per year and of fattening animals as 3679 Mg per year. They also estimated the total digestible nutrients of the grass as 61.5 % and 57.9%, respectively. Herbage availability is seasonal, and the quality and quantity of grass is mainly limited to the dry season. The pasture was kept under semi-continuous grazing during the entire period. Herbage stocks are not measured on the farm. The farm has no rotational grazing system. The animals are moved to new paddocks only when the forage availability is too low.

### *2.1. Production costs and profitability assessments*

The farm's economic issues were studied through a farm production cost and profitability analysis, as in Matsunaga et al. (1976). This method is often used in CEPEA and other Brazilian studies (Barros et al., 2009; Siqueira et al., 2013). Farm "effective operational costs" (EOC), or cash costs, include all expenditures during the year. EOC considers variable costs, taxes and mandatory union contributions. "Total operational costs" (TOC) is composed of EOC plus farmer labor payments and linear depreciation of infrastructure and machinery. Annual linear depreciation equals the ratio of acquisition value minus scrap (cut-off) value to product lifetime in years:

$$\boldsymbol{Linear\ depreciation} = \frac{\boldsymbol{Acquisition\ value - Scrap\ value}}{\boldsymbol{Lifetime\ of\ item\ (yr)}}$$

Farm total cost (TC) is the sum of TOC, return on invested capital and the land opportunity cost. The land opportunity cost includes the price of renting land in this region. Van

Passel et al. (2007) consider the use of opportunity costs a key for assessing farm economic sustainability. The return on invested capital equals the mean of acquisition and scrap values multiplied by 0.06, the minimum annual interest rate (6%) of Brazilian savings accounts:

$$\boldsymbol{Return\ on\ capital} = \left(\frac{\boldsymbol{Acquisition\ value} + \boldsymbol{Scrap\ value}}{\mathbf{2}}\right) \times \mathbf{0.06}$$

Farm's return is the income obtained from animals sold during the year. To better understand typical farm economic issues, we also broke farm costs down into different components of the farm system: livestock expenditures, labor, depreciation, capital investment and land opportunity cost.

### *2.3. LCA to assess GHG emissions*

LCA is widely used to assess GHG emissions and environmental impacts of livestock production at the farm level (Garnett, 2009; Thomassen et al., 2009; Siqueira et al., 2013). LCA (ISO 14044, 2006) has four steps: goal and scope definition, inventory analysis, impact assessment and interpretation of results. The scope of this study is "cradle-to-farm gate" (Figure 3) for a period of one year (2012). All emissions after the animals leave the farm (post-gate) were not analyzed in this study. Animal medicine, mineralized salt, and grass seed were excluded because of the lack of LCA inventory data for them. For the same reasons, machinery, equipment and buildings were excluded because farms have a low input system (e.g. minimum of infrastructure and agricultural machinery). These excluded annual emissions are unlikely to significantly change potential impacts of the whole farm (Cederberg et al., 2009; Gac et al., 2010; Thomassen et al., 2009), mainly in extensive farming systems.

In the second and third steps we calculated all direct emissions (on farm) and indirect emissions (outside of the farm due to input production and transportation). To estimate direct GHG emissions, we used the methods, equations and emission factors of the Intergovernmental Panel on Climate Change Tiers 2 (IPCC, 2006). This method allowed us to consider regional and local characteristics when estimating GHG emissions. We included indirect emissions of fuel production and transportation using the references of Nemecek and Kägi, (2007).

The farm GHG emissions ($CO_2$, $N_2O$ and $CH_4$) were expressed as $CO_2$ equivalents ($CO_2e$) over a 100-year time horizon. Characterization factors of $N_2O$ and $CH_4$ were based on their Global Warming potentials: 298 and 25, respectively (IPCC, 2007). The GHG emissions are shown in kg $CO_2e$. Total GHG emissions from beef production were divided by the total mass (kg) of animals weight gain at the farm-gate. This enabled us to show the GHG emissions per kg of live weight (LW) of the livestock at the farm-gate (kg $CO_2e$ kg $LW^{-1}$), in agreement with Dollé et al. (2011) and Dick et al. (2014). These results are considered as the farm's gross GHG emissions per kg LW.

### *2.4. Farm net GHG assessment: integrating LCA with different scenarios of land-use change and Soil Carbon Storage*

To help us better understand Amazonian beef-farm environments, we included LUC and SCS in the net GHG emission analysis of a typical farm. Including carbon emissions from LUC in LCA calculations is an important issue because LUC from agricultural expansion represents a significant portion of global GHG emissions (Brandão et al., 2013; Flysjö et al., 2011). LUC can increase or decrease SCS. Therefore, considering SCS in a farm GHG balance is difficult because it depends on many assumptions (Brandão et al., 2013; Flysjö et al., 2011; Petersen et al., 2014). Supported by available literature, we adopted the three following assumptions about LUC emissions and SCS.

First, the effect of converting native ecosystems to pasture on soil carbon stocks of Brazilian biomes shows contrasting results depending on the pasture management applied (Maia et al., 2009). Changes in land use can cause it to become either a source or sink of atmospheric carbon, depending on management practices (Bayer et al., 2006; Bustamante et al., 2006; Carvalho et al., 2010; Carvalho et al., 2014). There is still no consensus on whether soil carbon stocks of low-productivity and degraded pastures decreases. This lack of consensus is most likely due to the great difficulty and subjectivity in determining the degree of pasture degradation (Maia et al., 2010). In this study we use the reference value of Carvalho et al. (2014), who measured a net loss of 0.54 Mg C $ha^{-1}$ $yr^{-1}$ in the soil of native forest converted to and used as a *Brachiaria decumbens* pasture for 23 years. They used a reference for carbon stock present in the 0-30 cm layer of soil under native vegetation in Amazonian and Cerrado biomes. It is important to emphasize that pasture in their study had low forage productivity, no fertilizer applied and continuous grazing. In brief, their study was performed in the same biome as ours and had similar grassland establishment and management as those on our typical farm.

Second, as mentioned above, the 20-80% of native forest on farmland cannot be cut and sold. Therefore, the forestland soil is considered as a permanent carbon stock that can offset GHG emission into the atmosphere. Some studies show Amazon forest soil carbon stocks between 90-360 Mg C ha$^{-1}$ in the 0-30 cm layer of soil (Amezquita et al., 2008; Cerri et al., 2006). The forestland soil effectively reached an equilibrium state, their carbon flux is zero. But, a soil with crop production does not have the same carbon stocks than forestland. We argue that these stocks play an important role on the nature and need to be included in the estimation of net farm GHG assessment of Brazilian farms. So, we propose to annualize no emitted carbon due to forest conservation for included it on net farm GHG assessment. This hypothesis is very important to better understand environmental issues at a farm level and to dress politics issues.

Third, we propose the choice of time horizons to annualize this carbon stocks and to turn it in SCS yearly. The choice of time horizon over which carbon flows into or out of the soil is aggregated has a huge impact on LCA results (Petersen et al., 2013). In a literature review, Brandão et al. (2013) conclude that the carbon-flow time horizon used to account for SCS in climate-change impact assessments are not purely science-based and include value judgments. Petersen et al. (2013) suggest a time horizon of 100 years for comparability with the calculation of potential climate change in LCA studies. Based on models and studies conducted around the world, the IPCC suggests that 20 years would be the average time required for the soil reach a new steady state of Carbon (C) accumulation when conservation management with high biomass input is adopted (IPCC, 2007).

Similar to Soussana et al. (2010), we converted C to $CO_2$ using the most commonly used conversion factor of 3.667, which is based on the mass-conversion principle. Our assumptions were important when constructing scenarios for LUC emissions and SCS estimates. Due to lack of consensus in the literature, the following scenarios were constructed:

- Scenario 1: Assuming a time horizon of 100 years (Petersen et al., 2013; Schmidinger and Stehfest, 2012) and GHG emissions of 0.54 Mg C ha$^{-1}$ yr$^{-1}$ for primary forest converted to grassland;

- Scenario 1.1. With a forest soil carbon stock of 90 Mg C $ha^{-1}$ (× 3.667 ÷ 100 years we obtain the forest soil carbon storage (FSCS) of 3.30 Mg $CO_2$ $ha^{-1}$ forest $yr^{-1}$);

- Scenario 1.2. With a forest soil carbon stock of 225 Mg C $ha^{-1}$ (× 3.667 ÷ 100 years we obtain a FSCS of 8.25 Mg $CO_2$ $ha^{-1}$ forest $yr^{-1}$);

- Scenario 2: Assuming the IPCC (2006) 20-year time horizon and a Forest soil carbon stock of 90 Mg C ha (× 3.667 ÷ 20 years we obtain a FSCS of 16.50 Mg $CO_2$ $ha^{-1}$ forest $yr^{-1}$);

- Scenario 2.1. Assuming that after 20 year all C for LUC was losses and the soil reach a new state. So, there are no LUC emissions from forest converted to grassland after 20 years;

- Scenario 2.2. Assuming current net GHG emissions of 0.54 Mg C $ha^{-1}$ $yr^{-1}$ for primary forest converted to grassland.

In each scenario, $CO_2$ emissions from LUC were added to those from beef production, and the FSCS were subtracted from them to obtain farm net GHG emissions:

$$\boldsymbol{Net\ farm\ GHG\ emissions = \left(GHGb\ + LUC_x - FSCS_y\right)}$$

Where: LUC= land use change, FSCS (Forest Soil Carbon storage), x = annual emission scenario, y = annual storage scenario, GHGb = Green House Gases from beef production.

## 3. Results

### *3.1. Farm economics*

Values for the typical farm in 2012 were R$392,844.60 for total costs, R$266,760.60 for total operational costs, R$126,084.00 for effective operational costs and R$231,037.90 for total income[2]. The results suggest that the farm is profitable only in the short-term. The total income of R$231,037.90 is sufficient to pay the cash cost or effective operational costs (R$126,084.00). The farm is not profitable in the medium/long-term, however, because the total income covers only 59% of total costs. In other words, the farm's total income is too low to cover depreciation, farmer labor costs, opportunity cost and the 6% return on capital investment per year. This indicates that the farm is not able to fund itself. Because renewing farm production structures requires external funding, the farm is not economically efficient in the long-term. Breaking down

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[2] Mean exchange rate for 1 US$ in 2012 = 1.76 R$ (CEPEA, 2012)

Total costs into expense categories identifies those that are the most important. The two highest expenses are land opportunity costs and livestock expenses, which represent 68% of TC (Table 1). Returns on capital investment, deprecitation and labor costs represent 15%, 12% and 5% of TC, respectivily.

### *3.3. GHG emissions from beef production*

The farm's beef production generated 1805 Mg $CO_2$e of GHG emissions. When this amount is shared by the total of live weight at the farm-gate in 2012 (120.253 Mg) we obtain an emission of 15.0 kg $CO_2$e kg$^{-1}$ LW. Almost 100% of farm GHG came from on-farm activities (direct emissions). Only 0.23% derived from indirect emissions. Breaking down the farm's direct GHG emissions, animal enteric fermentation contributed most to farm GHG emissions (83%), followed by animal excreta (16%) and combustion of fossil fuels (1%) (Figure 4).

### *3.4. Farm net GHG emissions according to scenarios of land-use change and SCS*

For scenario 1, farm emissions from converting primary forest to grassland is 1980 Mg $CO_2$e yr$^{-1}$ (Table 2). Adding farm GHG from LCA (1805 Mg $CO_2$e) to them equals 3785 Mg $CO_2$e yr$^{-1}$ (31.5 kg $CO_2$e kg$^{-1}$ LW yr$^{-1}$). For scenario 1.1 (FSCS = 3.3 Mg $CO_2$e ha$^{-1}$ yr$^{-1}$), total farm FSCS per year equals 1650 Mg $CO_2$e yr$^{-1}$. Subtracting the FSCS from all GHG emissions we obtain net GHG emissions of 17.8 kg $CO_2$e kg$^{-1}$ LW. For scenario 1.2 (FSCS = 8.25 Mg $CO_2$e ha$^{-1}$ yr$^{-1}$), total farm FSCS equals 4125 Mg $CO^2$e yr$^{-1}$. Subtracting this FSCS from all GHG emissions yielded net GHG emissions of -2.8 kg $CO_2$e kg$^{-1}$ LW.

For scenario 2, the farm total FSCS is equals 8251 Mg $CO^2$e yr$^{-1}$. For scenario 2.1 we considered that the soil reached a new steady state because primary forest was converted to grassland more than 25 years ago. Thus, the typical farm has no LUC emissions from forest converted to grassland. For scenario 2.1, the farm net GHG emissions are estimated as -6446 Mg $CO_2$e yr$^{-1}$ or -53.6 kg $CO_2$e kg$^{-1}$ LW. For scenario 2.2, we consider that primary forest conversion to grassland emits 0.54 Mg C ha$^{-1}$ yr$^{-1}$.The farm net GHG estimated for the scenario 2.2 is -4465.5 Mg $CO_2$e yr$^{-1}$ or -37.1 kg $CO_2$e kg$^{-1}$ LW.

## 4. Discussion

### *4.1. Technical, economic and environment issues of the Amazonian typical beef farm*

This typical farm of the Amazonian region has extensive farmland use with few inputs, low technology and simplified management (e.g. no rotational grazing, genetic improvement, stalls, machines, or fertilizers) and low stocking rates (0.83 AU $ha^{-1}$ grassland). The typical farm has poorly integrated technical management of the soil-plant-animal system. In other words, it produces little grass amount, mainly due to the lack of fertilization, semi-continuous grazing, and large paddock areas. According to Costa et al. (2006), grassland without fertilizers in this region can provide enough forage for a maximum stocking rate of 0.92 AU $ha^{-1}yr^{-1}$. Then, Cardoso (2001) reported a stocking rate up to 7 AU $ha^{-1}yr^{-1}$ in intensified Brazilian grassland systems. The consequences of low grassland productivity and the farm's resource management are low productivity and poor technical indices the main technical issues of Amazonian beef extensive farm. Examples include: high infertility (26%), low daily weight gain for males (0.47 kg), a long time to reach slaughter weight for males (970 days), and high age of first calving (36 months). These figures are consistent with other studies of beef production systems in Amazonian and Cerrado Biomes. The previously mentioned characteristics are the most common features of Brazilian extensive and low-input beef farms (Barros et al., 2002; Bonjour et al., 2008; Costa et al., 2006; Mazzetto et al., 2015).

The most important economic issue of the Amazonian beef typical farm studied is the lack of profitability in the medium/long-term, mainly because of high land opportunity cost and overall livestock expenditures. Our results corroborate those of Barros et al. (2002), Bowman et al. (2012) who found high land opportunity costs and negative economic results for extensive Amazonian beef farms, especially in cash-crop production regions. They also highlight poor animal management and misuse of farm resources as fundamental issues for farm profitability.

Concerning predicted GHG emissions from beef production (15.0 kg $CO_2e$ $kg^{-1}$ LW), our result agree with the range of 10-20 kg $CO_2e$ $kg^{-1}$ LW found in LCA literature of beef production systems around the Europe (Gac et al., 2010; Leip et al., 2010; Nguyen et al., 2010). The calculated emission also corroborate with emissions found by Dick et al. (2014) for intensive and extensive southern Brazilian beef farms respectively (9.16-22.5 kg $CO_2e$ kg $^{-1}$ LW). In order to make comparable of other studies, we replicate farm results by 1 kg of hot standard carcass weight (HSCW). Considering a carcass yield of 50% of farm' cattle we found emissions of 30 kg $CO_2e$ kg carcass$^{-1}$. The GHG emissions from the Amazonian beef production is also similar to average Brazilian beef GHG emissions (28.2 kg and 41.3 kg $CO_2e$ kg$^{-1}$ carcass) found respectively by Cederberg et al., (2009) and Mazzeto et al (2015). Similar to these studies, we found that enteric fermentation and animal excreta are the two most important GHG emission sources. Compared to European beef systems (Gac et al., 2010; Leip et al., 2010; Nguyen et al., 2010), our typical farm is a low-input farming system and therefore has lower indirect emissions. Emissions from manure storage and spreading do not exist in the Brazilian system. Nevertheless, GHG emissions kg LW$^{-1}$ from European systems is similar to ours. In Europe, the higher beef productivity can in some cases compensates the higher GHG emissions.

Other important environmental issue identified concern LUC from forest to grassland. Given uncertainties and no-linearity in GHG losses after this LUC, results differed according to time horizon and other scenario assumptions (see section 3.4). Except for the Scenario 2.1, the LUC emissions increase in 110% all GHG impacts from beef production of the Amazonian farm. Hence, the farm GHG emissions including GHG from beef production and LUC increase from 30 kg $CO_2e$ kg carcass$^{-1}$ to 63 kg $CO_2e$ kg carcass$^{-1}$. Cederberg et al. (2011) also included emissions from the conversion of forest to pasture in the Amazon per a 20-year time horizon. They found the GHG emissions for Brazilian beef in the range of 44-724 kg $CO_2e$ kg$^{-1}$ carcass weight. Even if our results agree with their range of GHG emissions when including LUC, substantial differences exists between both studies. Cederberg et al. (2011) used average national data and hypotheses for LUC emission allocation based in newly national deforestation dynamics. In contrast, we used regional characteristics for LUC and forest conversion to grassland. Our typical farm is not a newly deforested area, because the deforestation occurred in 1985.

In our study we also propose including an important environmental issue less discussed in the LCA studies: the role of the soil carbon storage on climate changing mitigation. In fact, Brazilian Forest Act states the preservation of 20-80% of farm's land covered by native forest. Thus, this farm features and ecosystem service needs to be considered in LCA analysis. According to the results for all scenarios farm Forest soil carbon storage (FSCS) play an important role on offsetting partially or fully farm GHG emissions from beef production and LUC. Although using different methods to estimate SCS, other studies also found total or partial compensation of GHG emissions by SCS mainly in grass-based beef farming systems in France, Australia and United States of America (Dollé et al., 2011; Gac et al., 2010; Pelletier et al., 2010; Petersen et al., 2013).

### *4.2. Relating economics, environmental and technical results and proposing improvment options*

We found that economic and environmental hotspots of a typical Amazonian Brazilian beef farm are both related with low farm productivity issues. Our results corroborate assertions that farms' economic and environmental performances can share the same critical points (Thomassen et al., 2009; van Passel et al., 2007). Likewise these authors, we also identified that low animal productivity and less efficient animal feeding are important economic and environmental issues in livestock production. Cederberg et al. (2009, 2011), Opio et al. (2013) and Mazzetto et al. (2015) also found a positive relation between low indices of herd productivity, lower farm productivity and higher emissions per kg CW.

Increasing individual animal productivity by providing higher-quality feeds is the most relevant strategy for mitigation options in systems with low-quality feed (Hristov et al., 2013, Mazzetto et al., 2015). Mazzetto et al., (2015), studying intensification of Brazilian farming systems found that improved pasture and herd management can reduced the GHG emissions per kg of beef from 2% to 57%. Adopting simple techniques for grassland and animal management without many inputs requirements can improve environmental and economic results (Cederberg et al., 2009, Dick et al., 2014; Mazzetto et al., 2015). Increased productivity by improving pasture and herd management can reduce GHG emissions without major changes in the level of farm inputs (Cederberg et al., 2009, 2011; Dick et al., 2014, Mazzetto et al., 2015). Adopting paddocks, using rotational grazing and improving animal supervision are good and simple adopting practices.

Additional intensification practices can also be implemented. For example, a small and reasonable amount of fertilization can help restore system mineral exported in the beef to improve soil fertility; however, this requires more inputs. Other studies on poorly managed grassland farms conclude that crop-pasture rotation is a suitable strategy for improving farm productivity while reducing GHG emissions (Carvalho et al., 2014). However, adopting crop rotation demands major changes in the livestock production system.

Several studies demonstrated that well-managed grasslands in the Amazon increase soil carbon stocks in 2.7 to 6.0 Mg $ha^{-1}$ in comparison with those under primary forest (Cerri et al., 2006; Maia et al., 2009; Neill et al., 1997). Improving grassland management and productivity and preserving primary forests are important for compensating farm GHG emissions and mitigating climate change. Lal (2004) concluded that soil carbon sequestration is a truly win–win strategy for farmers and society. Opio et al. (2013) also highlight the important role of grass-based livestock systems in clime change regulation. Improving grassland restores degraded soils, increases biomass production, purifies surface and ground waters, and reduces the rate of atmospheric $CO_2$ enrichment by offsetting emissions due to fossil fuel use (Lal, 2004).

Policy strategies that combine GHG mitigation and improvements in food security are good insights for the livestock sector (Garnett, 2009). There are wide margins for such improvements in developing regions. Recently, the Brazilian government has encouraged low-carbon agriculture through economic improvements at the farm level (Bowman et al., 2012; de Gouvello et al., 2010). The government program envisions moderate intensification of cattle production as beneficial to reduce pastures erosions, enteric emissions and mainly avoid new deforestation. It is also envisioned as a means to increase productivity and profitability of Brazilian livestock production. That Government Policy has been supported by the ABC credit program[3] and also by increasing research on better management systems that incorporates efficiently-managed pasture or integrates crops with livestock systems (Bowman et al., 2012; de Gouvello et al., 2010).

### *4.3. Methodological insights*

Farm profitability and cost analysis are powerful methods for analyzing farm economic hotspots. Analyzing the costs of several components of the farm production system and relating those to farm technical data is crucial for understanding farm economic issues. We agree with Garnett (2009) and Van Passel et al. (2007) about the key role of opportunity costs in farm sustainability

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[3] More information at http://www.wri.org/www.wri.org/publication/ghg-mitigation-brazil-land-use-sector

analyses. Evaluating and understanding opportunity costs allowed us to address important issues related to land use and production system profitability and to compare other possibilities for managing land and money. One limit of cost and profitability analysis is its static nature. Price volatility and external shocks can change the interpretation of farm profitability and cost composition structures.

Concerning framework used to assess environmental issues, likewise other authors (Gac et al., 2010; Leip et al., 2010; Nguyen et al., 2010) we consider that LCA is a powerful tool to quantify farm environmental impacts. This methodology allowed us to identify the main sources (hotspots) of farm GHG emissions. However, likewise Ruviaro et al. (2012), we recognize that methodological improvements are necessary to adapt GHG emissions in LCA to the characteristics of Brazilian systems. In order to make our results comparable to the cited literature about GHG emissions we used the former values we used former value of IPCC 2007 for Global Warming potentials. Nevertheless we have Global Warming potentials of $N_2O$ and $CH_4$ update for 265 and 28 respectively (IPCC, 2013).

Including LUC and Soil Carbon Storage (SCS) in LCA and in GHG analyses are important ways to improve the assessment of farms' environmental issues (Brandão et al., 2013; Flyjo et al., 2012; Petersen et al, 2014). This topic is of utmost relevance to the world climate regulation and mainly from regions where these land use changes are underway as Brazil. Nonetheless this is a complex subject with no current consensus. We agree with Petersen et al. (2013) that the assumptions and methods used in LUC and SCS assessment lead to different results and conclusions in GHG-emission assessments. Similarly to Cederberg et al. (2011) and Petersen et al. (2013), we found that LCA results and conclusions are highly influenced by time horizon over which LUC is considered. Assuming a 100- or 20-year time horizon to carbon flows can substantially change predicted LUC emissions. Thus, using a variety of scenarios and assumptions to integrate carbon storage and LUC into GHG assessment is a prudent approach in LCA.

Soil carbon storage is an important ecosystem service provided by farms (Power, 2010) . Farm Soil Carbon Storage playing an important role in global carbon stocks avoiding and compensating GHG emissions, regulating the climate, water infiltration, preserving the biodiversity and other functions. We highlight the importance of considering SCS in GHG, LCA or other environmental analysis of agricultural sector. More, SCS is a key factor on the understanding of environmental issues of Brazilian agriculture. In fact, Brazilian Forest Act states the preservation of 20-80% of farm's land covered by native forest. These preserved forestland in large SCS sink. Our methodology tries to support the value of farm preserved native forestland integrating farm Forest Soil Carbon Storage (FSCS) in LCA studies is an original. Considers FSCS of Brazilian farms is needed for understanding the real issues of farm native forest preservation and reduces deforestation pressures. It is also essential to valorize one of the multiple functions of farm forests and for supporting international negotiation about global warming through the Brazilian law.

An important methodological issue is the scale at which data are recorded and analyzed. Use regional and local farm data can be appropriate for integrating system characteristics, correctly addressing the real environmental issues and proposing adapted solutions. Analysis at the macro level can obscure the diverse reality of beef production systems and lead to mistaken interpretations. Avoiding generalization is also essential to reduce uncertainty when considering the characteristics of local farms LUC.

Finally likewise Chatterton et al. (2014), our study shows that combining LCA and economic analyses is a valuable way to better understand and assess environmental and economic issues of livestock farms. Relating these results to farm technical characteristics and existing technical knowledge about livestock systems helps identify potential win-win strategies for livestock farm sustainability.

## 5. Conclusion

This study intended to improve understanding of environmental and economic challenges of a typical Amazonian beef farm at the farm level. We proposed an original methodological approach to consider characteristics of Brazilian farm systems at the farm level using Life Cycle Assessment (LCA) standards that included land-use change (LUC) and Soil Carbon Storage (SCS). Since Brazilian farms are legally obligated to preserve of 20-80% of native forest on their land, forests are a part of farmland, and their SCS should be considered in the farm Green House Gases (GHG) balance. Not considering the entire system and SCS can lead to misunderstanding beef farm environmental issues and their contribution to climate regulation. We show that combining LCA (including LUC and SCS) with cost and profitability analysis helps interpret how farm internal structures and resource use are related to economic performances and GHG emissions. This approach also identifies farm economic and environmental hotspots and improves understanding of sustainability issues of an Amazonian beef farm. Applying this methodology to other typical farms in other Brazilian states and regions, while at the same time considering other environmental impacts, are key elements for proceeding with this analysis.

Our typical farm has characteristics similar to those found in the literature for most Amazonian beef farms: low input use and poor animal and grassland management. The farm's most important economic issue is the lack of profitability in the medium/long-term, which is mainly due to the high land opportunity cost and overall livestock expenditures. The main GHG emission results mostly reveal issues related to enteric fermentation and animal excreta. Regarding LUC and net GHG emissions, conversion of primary forest to grassland produced GHG emissions and losses of SCS. Therefore, the part of the farm preserved as native forest represents a large carbon stock that can compensate for GHG emissions of beef production. Preserving forestland at a farm level is important to reduce farm carbon footprints and mitigate global warming. The preserved forestland is also important for biodiversity conservation, water infiltration, and other ecological and social services. Thus, preserve and valorize this forestland, mainly in the Amazonian region, is a major policy issue. Substantial improvements in grassland management are beneficial for confronting economic and GHG issues.

Finally, the paper reveals that economic and GHG issues of a typical Amazonian beef farm are not necessarily opposed. They have similar determinants: the low productivity of land and animals. Based on available knowledge about grassland management and livestock performance, we conclude that win-win strategies can occur that improve farms' economic and environmental performances. Addressing the hotspots by improving farm grassland and animal management is a promising initial measure.

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## Tables and Figures

**Table 1**. Contribution of expenses subcategories based on CEPEA data.

| Group | Percentage of Total Cost |
|---|---|
| Livestock * | 31 |
| Labor | 5 |
| Depreciation (infrastructure and machinery) | 12 |
| Return on capital investment (without livestock) | 15 |
| Land opportunity cost | 37 |

* Medicines and others annual expenditures related to animals and return on capital invested on the livestock

**Table 2**. Greenhouse gas (GHG) balance of a typical Brazilian beef farm according to different scenarios of time horizon and carbon storage

| | **GHG from beef production** | **Land-use change** | **Forest soil carbon storage** | **Farm net GHG** | **Farm net GHG** |
|---|---|---|---|---|---|
| | Mg $CO_2$e $yr^{-1}$ | Mg $CO_2$ $yr^{-1}$ | Mg $CO_2$ $yr^{-1}$ | Mg $CO_2$e $yr^{-1}$ | kg $CO_2$e $kg^{-1}$ live weight |
| **Scenario 1** | | | | | |
| **1.1** | 1805 | 1980 | 1650 | 2135 | 17.8 |
| **1.2** | 1805 | 1980 | 4125 | -340 | -2.8 |
| **Scenario 2** | | | | | |
| **2.1** | 1805 | 0 | 8251 | -6446 | -53.6 |
| **2.2** | 1805 | 1980 | 8251 | -4466 | -37.1 |

**Scenario 1:** Time horizon of 100 years and net GHG emissions of 0.54 Mg C $ha^{-1}$ $yr^{-1}$ for primary forest converted to grassland.

1.1. Forest soil carbon storage of 3.3 Mg $CO_2$ $ha^{-1}$ $yr^{-1}$

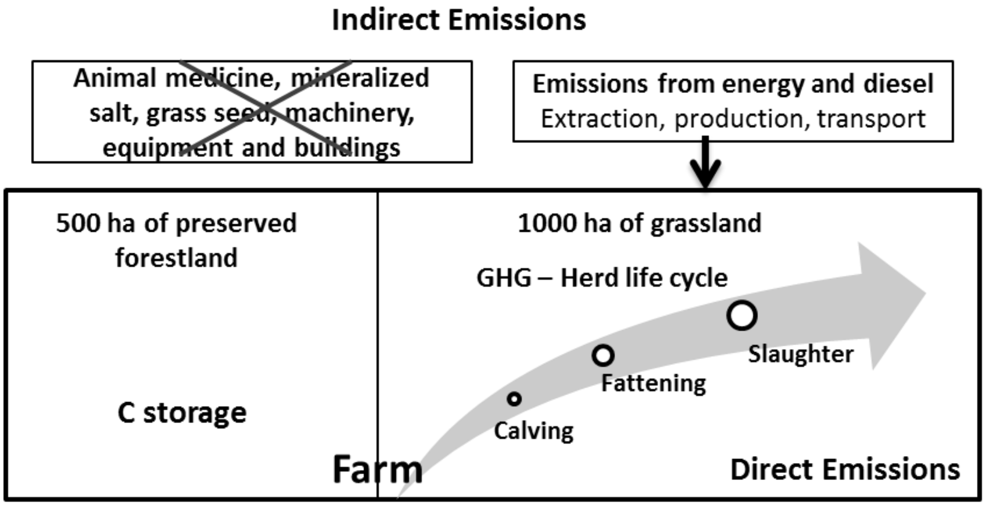
1.2. Forest soil carbon storage of 8.25 Mg $CO_2$ $ha^{-1}$ $yr^{-1}$

**Scenario 2:** Time horizon of 20 years and forest soil carbon storage of 16.5 Mg $CO_2$ $ha^{-1}$ $yr^{-1}$

2.1. No emissions from conversion of primary forest to grassland

2.2. Net GHG emissions of 0.54 Mg C $ha^{-1}$ $yr^{-1}$ for primary forest converted to grassland

**Figure 1**. Location of Cacéres in Mato-Grosso state



**C**- Carbon; **GHG** - Greenhouse gases

**Figure 2.** System boundary

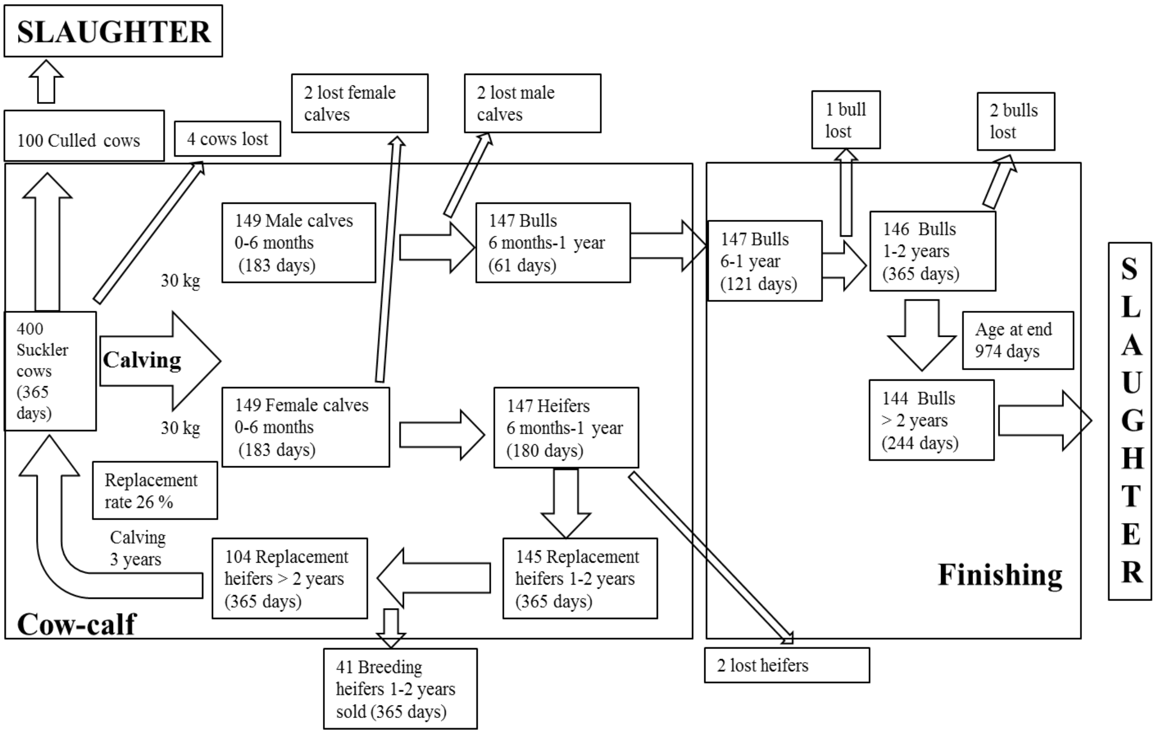


**Figure 3.** Farm animal life cycle

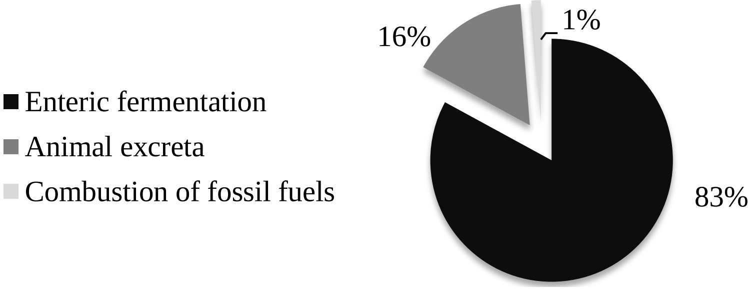


**Figure 4**. Sources of direct greenhouse gas emissions due to beef production from the typical Brazilian beef farm studied.