UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL

CENTRO DE ESTUDOS E PESQUISAS EM AGRONEGÓCIOS

PROGRAMA DE PÓS-GRADUAÇÃO EM AGRONEGÓCIOS

LIFE CYCLE ASSESSMENT IN BEEF PRODUCTION IN BRAZIL

Clandio Favarini Ruviaro

Porto Alegre, RS

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Autor: Clandio Favarini Ruviaro

Orientador: Prof. Dr. Júlio Otávio Jardim Barcellos

Tese de Doutorado, apresentado ao Programa de Pós-Graduação em Agronegócios da Universidade Federal do Rio Grande do Sul como requisito parcial para a obtenção do título de Doutor em Agronegócios.

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COMISSÃO EXAMINADORA

____

Prof. Dr. Júlio Otávio Jardim Barcellos
UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
Programa de Pós-Graduação em Agronegócios
Orientador

____

Dra. Magda Aparecida de Lima
EMBRAPA – CNPMA

____

Dr. Vinícius do Nascimento Lampert
EMBRAPA - CPPSUL

____

Prof. Dr. Homero Dewes
UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
Programa de Pós-Graduação em Agronegócios

____

Prof. Dr. Luiz Carlos Federizzi
UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
Programa de Pós-Graduação em Agronegócios

Reverência ao destino *(Carlos Drummond de Andrade)*

Falar é completamente fácil, quando se tem palavras em mente que expressem sua opinião.
Difícil é expressar por gestos e atitudes o que realmente queremos dizer, o quanto queremos dizer, antes que a pessoa se vá.

Fácil é julgar pessoas que estão sendo expostas pelas circunstâncias.
Difícil é encontrar e refletir sobre os seus erros, ou tentar fazer diferente algo que já fez muito errado.

Fácil é ser colega, fazer companhia a alguém, dizer o que ele deseja ouvir.
Difícil é ser amigo para todas as horas e dizer sempre a verdade quando for preciso.
E com confiança no que diz.

Fácil é analisar a situação alheia e poder aconselhar sobre esta situação.
Difícil é vivenciar esta situação e saber o que fazer ou ter coragem pra faze (...)

(...) Fácil é mentir aos quatro ventos o que tentamos camuflar.
Difícil é mentir para o nosso coração.

Fácil é ver o que queremos enxergar.
Difícil é saber que nos iludimos com o que achávamos ter visto.
Admitir que nos deixamos levar, mais uma vez, isso é difícil.

Fácil é dizer "oi" ou "como vai?"
Difícil é dizer "adeus", principalmente quando somos culpados pela partida de alguém de nossas vidas...

Fácil é abraçar, apertar as mãos, beijar de olhos fechados.
Difícil é sentir a energia que é transmitida.
Aquela que toma conta do corpo como uma corrente elétrica quando tocamos a pessoa certa (...)

(...) Fácil é chorar ou sorrir quando der vontade.
Difícil é sorrir com vontade de chorar ou chorar de rir, de alegria.

Fácil é dar um beijo.
Difícil é entregar a alma, sinceramente, por inteiro.

Fácil é sair com várias pessoas ao longo da vida.
Difícil é entender que pouquíssimas delas vão te aceitar como você é e te fazer feliz por inteiro.

Fácil é ocupar um lugar na caderneta telefônica.
Difícil é ocupar o coração de alguém, saber que se é realmente amado.

Fácil é sonhar todas as noites.
Difícil é lutar por um sonho.

Eterno, é tudo aquilo que dura uma fração de segundo, mas com tamanha intensidade, que se petrifica, e nenhuma força jamais o resgata.

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À M.T.A.S. que mesmo distante esteve sempre presente e tenho certeza que me auxiliou em cada momento.

À minha esposa Ana Cristina que me incentivou desde o princípio, pelo esforço de, além do seu trabalho, acompanhar sozinha o dia a dia de nossos filhos: Sofia, Michel e João Vitor. Pelo amor e renúncia em vários momentos em que eu estava totalmente absorto em meus estudos e à pesquisa. Pelo companheirismo e carinho dedicado em cada instante em que eu hesitava.

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Aos colegas mais próximos como a Alessandra Ceolin e Fernanda Brandão e, àquele de todos os momentos de discussão, troca de idéias, bons papos, companheiro de viagens, boníssimos assados e maravilhosos vinhos, Miguelangelo Gianezini.

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E, por fim, de maneira especial um muito obrigado ao Prof. Homero Dewes que me ensinou um pouco sobre o que é ciência, como se faz ciência e como se escreve para a ciência mundial (um dos motivos pelo qual esta tese foi redigida em língua inglesa):

“Não adianta escrevermos numa língua em que catedráticos, pesquisadores e cientistas do mundo, não lêem”.

LIFE CYCLE ASSESSMENT IN BEEF PRODUCTION IN BRAZIL [1]

Author: Clandio Favarini Ruviaro

Adviser: Júlio Otávio Jardim Barcellos

ABSTRACT

Brazilian beef production is the second largest in the world and it produced 7.5 million tons carcass weight equivalent in 2011. Production systems are pasture-based, having variable production index and level of technology that increase beef cattle yields. Worldwide demand to set reliable environmental criteria for food and feed products has made consumers more conscious regarding the diversity of products, more attentive to its quality and security, and more concerned with the environmental aspects of production. In this context, this study describes the results of a search for scientific literature and government documents in relation to the application of Life Cycle Assessment (LCA) to agricultural products worldwide, as a way to capture state-of-the-art technology in the field and to identify the trends and drivers for labeling and certification requirements in international markets. In order to remain an important food and feed exporter, Brazil needs to make more efforts to adapt the methodologies of LCA and of Life Cycle Impact Assessment (LCIA) to the peculiarities of the country and to develop a life cycle inventory (LCI) applicable to Brazil's agricultural systems. No doubt, there is a trend in the market for the demand of differentiated food products that leads to the adoption of institutional food certification procedures which provide information to the consumers concerning the composition quality and the environmental amiability of the food. Following these trends in the dynamic market, the traceability of beef cattle production and LCA was addressed as a way to provide a powerful analytical instrument to evaluate the environmental impacts of beef production and strengthen its sustainability in the Legal Amazon region. The LCA is a complementary

[1] Doctoral Thesis in Agribusiness - Agroindustrial Production Chain Analysis, Center for Studies and Research in Agribusiness, Federal University of Rio Grande do Sul, Porto Alegre, Brazil (117p.) August, 2012.

and useful methodology to introduce the concept of the life cycle and allow for suggestions for improvement with an environmental focus. It is necessary to underline the importance of LCA in the beef cattle chain of production because the market is clearly signalling that consumers are demanding products that respect the environment. The joint effort of the production sectors and the government in Brazil to implement and facilitate the process of traceability is key to ensuring a prominent position in the international agribusiness scene. Latter, using an LCA approach, the carbon footprint per functional unit for a typical beef production in southern of Brazil was analyzed and quantified. This was attained defining a typical beef production system and using the scenario options to the required trend in the beef production. The results indicated that the carbon footprint for a cattle farm sampled from the western frontier region of Rio Grande do Sul State, ranged from 18.47–37.18 kg CO_2-e/kg of live weight gain (LWG) for a complete beef system including the contribution of cows, calves, and steers, and from 13.6 to 32.1 Kg CO_2-e/kg LWG excluding pregnant cow emissions. Finally, comprising all studies, it can be concluded that in Brazil continues to lack consolidated studies regarding the development of LCA in agricultural production processes and systems and that there are therefore a large number of possibilities and opportunities to apply this methodology with meaningful results.

AVALIAÇÃO DE CICLO DE VIDA NA PECUÁRIA DE CORTE BRASILEIRA [2]

Autor: Clandio Favarini Ruviaro

Orientador: Júlio Otávio Jardim Barcellos

RESUMO

O Brasil é o segundo maior produtor de carne do mundo e produziu 7,5 milhões de toneladas de equivalente carcaça em 2011. O sistema de produção está baseado na utilização de pastagens, apresentando um variável índice de produtividade e tecnológico que incrementam a produção de carne bovina. A demanda mundial e, um consumidor mais consciente e atento à qualidade e segurança da diversidade de produtos disponíveis no mercado, tem contribuído para o estabelecimento de critérios sustentáveis de produção de alimentos e insumos. Neste contexto, este estudo descreve o resultado de uma pesquisa da literatura científica e dos documentos governamentais relacionados a aplicação da Avaliação do Ciclo de Vida (ACV) à produção agrícola mundial como forma de captar o estado da arte na área e identificar as tendências e mecanismos de rotulagem e certificação de produtos praticados no mercado internacional. A fim de se manter como um importante exportador de alimentos e insumos, o Brasil precisa esforçar-se para adaptar as metodologias de ACV e da avaliação do impacto do ciclo de vida (AICV) às peculiaridades do país e desenvolver um inventário do ciclo de vida (ICV) aplicável aos sistemas agropecuários. Sem dúvida, há uma tendência no mercado pela demanda de produtos agrícolas diferenciados que impulsiona a adoção de procedimentos de certificação institucional que informe aos consumidores sobre a qualidade da composição e da sustentabilidade na produção de alimentos. Seguindo esta tendência dinâmica do mercado, a rastreabilidade na produção de carne e a ACV foram apontados como meios para alicerçar um poderoso instrumento analítico na avaliação dos impactos ambientais e garantir a sustentabilidade da produção de carne bovina na região da Amazônia Legal. A ACV constitui-se em uma metodologia complementar e útil para introduzir o conceito de ciclo de vida e possibilitar sugestões de melhoria com foco no meio

[2] Tese de Doutorado em Agronegócios – Análise de cadeia Produtivas Agroindustriais, Centro de Estudos e Pesquisas em Agronegócios, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brasil (117p.) Agosto, 2012.

ambiente. É necessário destacar a importância da ACV na cadeia produtiva da carne bovina devido ao mercado estar dando sinais claros de que o consumidor esta exigindo produtos que respeitem o meio ambiente. O esforço conjunto dos setores de produção e do governo brasileiro para implementar e viabilizar o processo de rastreabilidade é elemento chave para assegurar ao agronegócio uma posição de destaque no cenário internacional. Por último, usando o enfoque da ACV, foi analisada e quantificada a pegada de carbono por unidade funcional de um típico sistema de produção de carne no sul do Brasil. Isto foi obtido definindo-se 7 cenários de produção de carne a campo de maneira a atender o padrão de terminação dos animais conforme as exigências do mercado. Os resultados indicaram que a pegada de carbono, em uma fazenda produtora de carne bovina na região da fronteira oeste do Rio Grande do Sul, variou entre 18,47 a 37,18 kg CO2-e/kg de ganho de peso, num sistema de produção de ciclo completo incluindo o período de gestação das vacas e, de 13,6 a 32,1 kg CO2--e/kg de ganho de peso, excluindo as emissões das vacas prenhes. Por fim, concluiu-se que no Brasil ainda há deficiência de pesquisas consolidadas em relação ao desenvolvimento e aplicação da ACV em processos e sistemas de produção agrícola e pecuária, portanto, são amplas as possibilidades e oportunidades para a aplicação desta metodologia com resultados significativos.

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LIST OF ABBREVIATIONS

C = Carbon
CH_4 = Methane
CO_2 = Carbon dioxide
COP = Conference of the Parties
CTBE = Brazilian Bioethanol Science and Technology Laboratory
CWE = Carcass weight equivalent
DMID = Dry matter intake digestibility
DMI = Dry matter intake
ECM = Energy corrected milk
EF = Emission factor
EMBRAPA = Brazilian Agricultural Research Corporation
eq. = Equivalent
FCOJ = Frost concentrated orange juice
FU = Functional unit
GHG = Greenhouse gases
GWP = Global warm potential
ha = Hectare
HSCW = Hot Standard Carcass Weight
Ing = Improved natural grass
IPCC = Intergovernmental Panel on Climate Change
ISO = International Standards Organization
LCA = Life Cycle Assessment
LCI = Life cycle inventory
LCIA = Life cycle impact assessment
LW = Live weight
LWG = Live weight gain
MCF = Methane conversion factor
MJ = Megajoule
MWh = Megawatts hour
N_2O = Nitrous oxide
NH_3 = Ammonia
NO_3 = Nitrate
PO_4 = Phosphate
SISBOV = Brazilian Service of Supply Chain Traceability of Cattle and Buffaloes
t = Tonne
Ym = Conversion factor
Yr = Year

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CHAPTER I

1 GENERAL INTRODUCTION

Regardless of the potential economic crises and cyclical conditions associated with the prices of raw materials, commodities and agricultural products, Brazil is experiencing a satisfactory period of technological development and production in agribusiness while expanding its international trade and increasing producers' incomes. However, there is a conflict of information regarding the status of beef production. Topics such as health, environment, product quality and exports are constantly questioned by agents and consumers, generating a diversity of opinions on beef production.

Since 2004, Brazil has become one of the largest beef producers in the world. During this period, there has been a shift in livestock production in the country, with a migration from the Southern and Southeastern regions, where land is more expensive and production is small in scale, to the Midwestern and Northern regions, which are characterised by large-scale production and relatively cheap land that partly originated from deforested areas. However, the expansion of beef production into deforested areas of the so-called Legal Amazon, a conceptual and political-geographical area that expands far beyond the rainforest, has brought serious concerns to this segment of Brazilian agribusiness because international consumers have been led to believe that all Brazilian beef production results from the use of pristine land.

The development of the Brazilian cattle industry involves sustainable production and the rational exploitation of beef cattle, which is mainly performed in pastures under an extensive farming system. The land that is occupied by pastures and intended for beef cattle production is generally marginal when compared to those lands used for grain production. These soils have problems associated with natural fertility, acidity, topography or drainage limitations (ADAMOLI *et al.*, 1986; MACEDO, 2009). Soils better suited for agriculture are occupied by annual grain crops or high-value industrial crops for the production of oil, fibres, resins and sugar, for example. Therefore, it is expected that areas used for beef cattle farming will cause problems related to the productivity and sustainability[3] of meat production. The relevance of debates surrounding the beef production system, the environment in general and, in particular, those related to global warming has finally reached the general public throughout most of the world. The current challenge in agricultural research consists of adopting the concept of sustainable development through innovations in methodologies and research tools to achieve agricultural and livestock production that is in agreement with the principles of sustainability.

It should be noted that any human interference in the production processes creates changes and damages to the original environment, and it is up to man himself to seek ways to maximise the benefits of the production process and minimise the negative effects. The worsening of the greenhouse effect is considered to be among the most serious concerns related to environmental impacts, and this issue has been highlighted due to the size of the cattle herd in the country, which is currently at 205 million heads (IBGE, 2008). Emissions from this sector, mainly carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), are prominent when compared to other emitting sectors of the economy (STEINFELD *et al.*, 2006; IPCC, 2007).

The main strategies for mitigating the emission of greenhouse gases (GHGs) resulting from agricultural and livestock activities consist of reducing the rates of deforestation and the burning of plant material, better land use and strategies for maximising carbon (C) sequestration in the soil and vegetation (VILELA *et al.*, 2005; SEGNINI, 2007; SAWYER, 2008; BERNARDI *et al.*, 2009; URQUIAGA *et al.*, 2010). This increase in the emission of GHGs, and consequent global warming, has led to the search for strategies that aim to reduce the sources of these gases.

In this context, the use of tools with which to analyse the contribution of a certain technology to sustainability and evaluate its environmental impact becomes important (FIGUEIREDO *et al.*, 2007). However, for this change to be successful, the management tools must be appropriate. Therefore, the application of Life Cycle Assessment (LCA) to agriculture

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[3] Sustainability refers to the creation and transformation of products using non-polluting processes and systems that conserve energy and natural resources that and are economically viable, safe and healthy for workers, communities and consumers (VELEVA *et al.*, 2001).

and livestock has been implemented in a relatively new and complex manner, given that this method allows for the evaluation of resource consumption and impacts on the environment associated with a given product, process or activity. LCA also enables the identification and evaluation of opportunities to improve the performance of the process or activity from an environmental perspective (FAVA, 1991; CHEHEBE, 1997).

LCA is a tool for evaluating the environmental impact associated with a product or process, comprising steps that range from the withdrawal of basic raw materials from nature that enter the production system (cradle) to the final disposal of the product after use (grave). To date, studies involving LCA have not been conducted for the various beef production systems in Brazil and the use of LCA in certain production systems characteristic of the state of Rio Grande do Sul have been proposed with the purpose of better exploiting the natural resources of the Pampa biome. We chose to evaluate the complete beef production system of natural and/or cultivated pastures in the summer and winter to estimate the potential environmental impact of beef cattle production, known as the carbon footprint.

The present thesis is divided into 5 chapters. The first chapter presents an introduction to the topic, the proposed objectives and a literature review on LCA. The use of LCA throughout the world and in Brazil is presented in chapter 2. The third chapter addresses the use of LCA in bovine traceability. The fourth chapter discusses the implementation of LCA on a beef cattle farm. The final considerations of the study are presented in chapter 5.

2 OBJECTIVES

2.1 General objectives

To describe the LCA methodology and its use in Brazil, proposing its use for traceability in regions of environmental stress and its practical implementation in a beef cattle farm.

2.2 Specific objectives

a) To estimated the carbon footprint (CO_2 equivalent) generated during animal development in a complete beef production system while consuming natural or cultivated pastures;

b) To identify *hotspots* that will enable the development of strategies to mitigate GHGs;

c) To demonstrate that different grazing systems produce meat with a variable potential for environmental impacts;

d) To estimate the contribution of each stage of animal development to provide elements for subsequent determinations of the carbon footprint of the entire beef production chain.

3 LITERATURE REVIEW

3.1 Life Cycle Assessment

The term LCA was first used in the United States in 1990. The historical designation used for studies of environmental life cycles in the United States since 1970 is "Resource and Environmental Profile Analysis" (REPA) (HUNT and FRANKLIN, 1996).

In 1992, the International Organization for Standardization (ISO) created a technical committee (TC207/SC5) to devise the standardisation of a number of approaches to environmental management, including LCA (TIBOR and FELDMAN, 1996). These standards are currently compiled and published as described below:

a) ISO 14040. Life Cycle Assessment. Principles and Framework (2006).

b) ISO 14044. Life Cycle Assessment. Requirements and Guidelines (2006).

The concept of a life cycle has been extended beyond a simple method for comparing products and is currently seen as an essential component of achieving broader objectives, such as sustainability (CURRAN, 1999). The interconnection of product systems, which are not limited by geographical boundaries, requires the continuous development of the LCA methodology at an international level.

3.1.1 Description of Life Cycle Assessment

LCA refers to the compilation and evaluation of inputs, outputs and potential environmental impacts of a product system throughout its life cycle.

The term "life cycle" refers to the major activities incurred during the course of a product's life-span from its manufacture, use and maintenance to its final disposal, including the purchasing of raw materials required to manufacture the product. Figure 1 illustrates the possible life cycle stages that can be considered in an LCA and the typical inputs/outputs that are measured (USEPA, 2001).

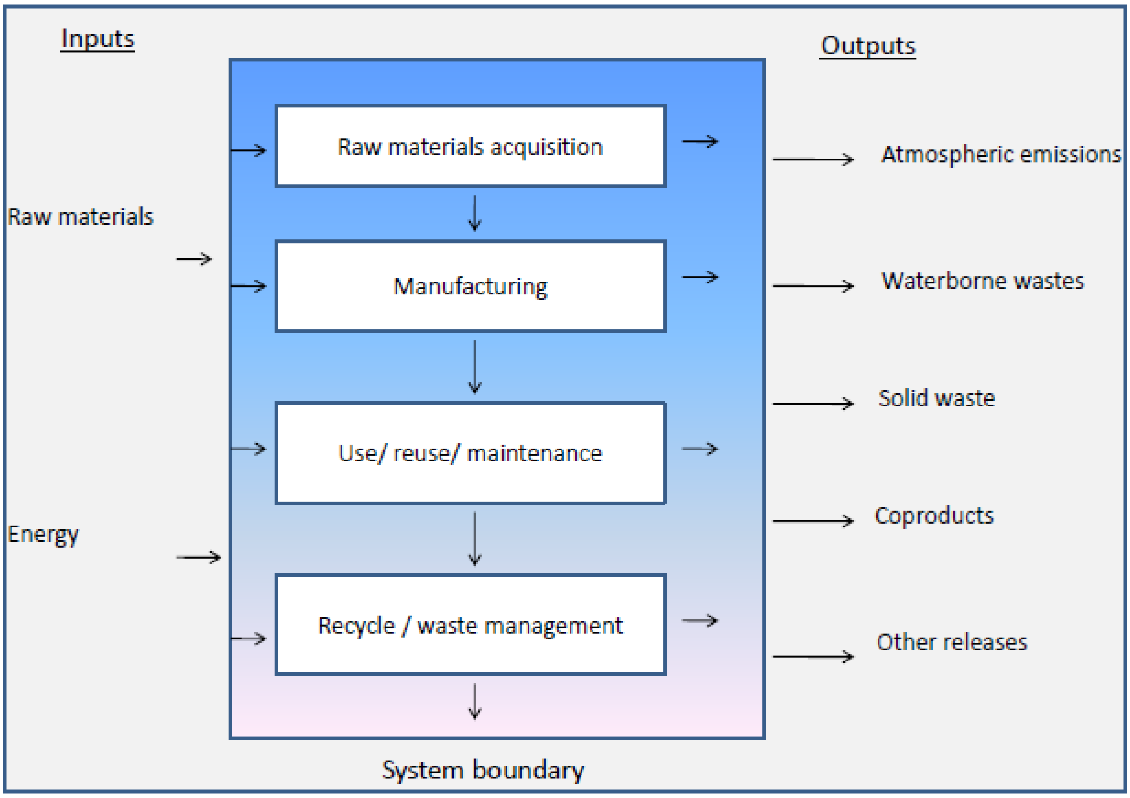

Figure 1 - Life cycle stages of a product (Source: USEPA 2001)

In an LCA study of a product or service, all resource extractions and emissions to the environment are determined, when possible, in a quantitative manner throughout the entire life cycle from their "birth" to their "death" (i.e., "from cradle to grave"). Thus, the potential impacts on natural resources, the environment and human health are evaluated based on these data. Figure 2 shows the typical stages of an LCA study.

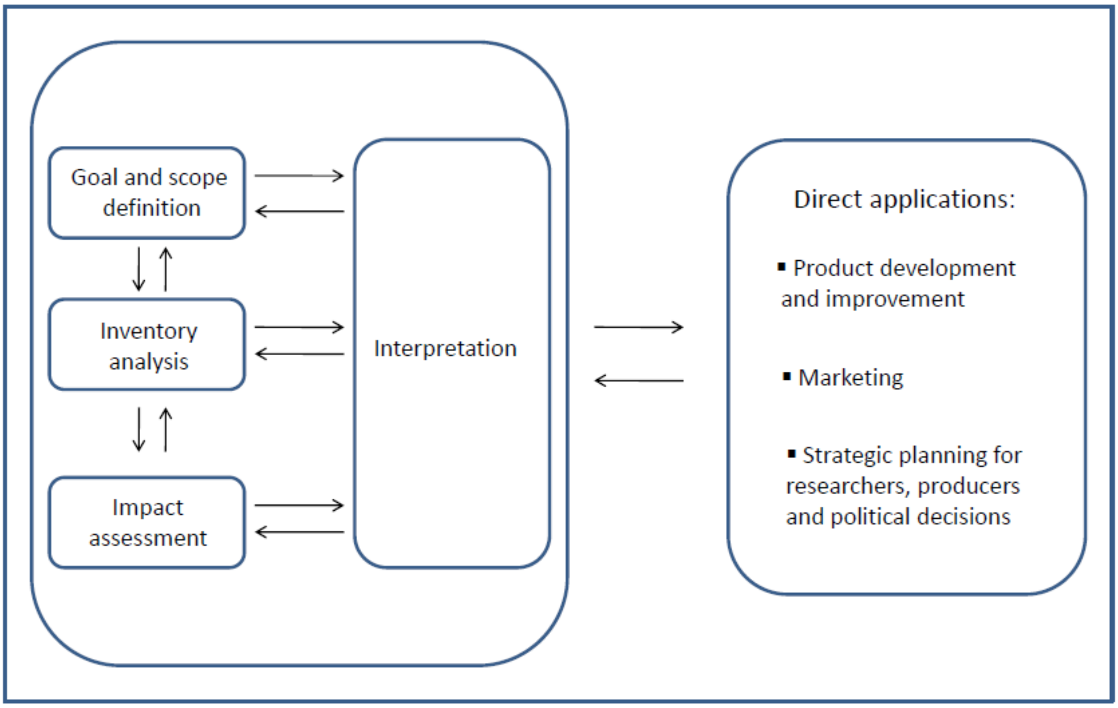

Figure 2 - Stages of a Life Cycle Assessment (Source: adapted from ISO 14040:2006)

a) Definition of Objectives and Scope– Defines and describes the product, process or activity. Establishes the context in which the evaluation is made and identifies the limits and environmental effects to be reviewed for evaluation.

b) Inventory Analysis– Identifies and quantifies the energy, water and materials used and the environmental discharges (e.g., air emissions, solid waste disposal and waste water discharges).

c) Impact Analysis– Analyses the human and ecological effects of using energy, water and materials and the environmental discharges identified in the inventory analysis.

d) Interpretation– Evaluates the results of the inventory analysis and the impact analysis to select the preferred product, process or service with a clear understanding of the uncertainties and assumptions used to generate the results.

The LCA methodology has numerous applications, from product development through eco-labelling and regulation to the definition of priority scenarios and environmental policy.

3.1.2 Advantages of the Life Cycle Assessment approach

Data from an LCA study, together with other information such as cost and performance data, for example, can assist decision makers in selecting products or processes that result in a lower impact on the environment.

The LCA methodology is the only approach that allows for the identification of the transfer of environmental impacts from one environment to the other (e.g., the elimination of air emissions can be performed at the expense of increased waste water emissions) and/or from one life cycle stage to another (e.g., from the phase of raw material acquisition to the phase of product usage).

When developing an LCA study, researchers can implement the following tasks (USEPA, 2001; COLTRO *et al.*, 2007):

a) Develop a systematic evaluation of the environmental consequences associated with a given product;

b) Analyse the environmental balances (gains/losses) associated with one or more specific products/process;

c) Quantify the environmental discharges to the air, water and soil related to each stage of the life cycle and/or processes with the greatest contributions;

d) Assist in the identification of significant exchanges of environmental impacts between life cycle stages and the environment;

e) Evaluate the human and ecological effects of material consumption and environmental discharges to the local community, region and the world;

f) Compare the impacts on ecological and human health between two or more rival products/processes or identify the impacts of a specific product or process;

g) Identify impacts on one or more specific environmental areas of interest.

3.1.3 Limitations of the Life Cycle Assessment methodology

An LCA study does not determine which product or process are most expensive or perform better. Therefore, the information developed in an LCA study should be used as a component in a decision-making process that includes other elements, such as cost and performance analyses (BAUMANN AND TILLMAN, 2004).

An LCA is an important tool for environmental assessments in production chains. A comprehensive systematisation of LCA requirements and steps are contained in the ISO 14040/2006 and ISO 14044/2006 guidelines. Software has been developed for performing LCAs, such as Simapro, Gabi and Humberto, for example. These software have certain advantages, including the following:

a) The moderate convenience and ease of use;

b) The speed in obtaining results due to the decreased time spent on the assessment;

c) The standardisation of databases;

d) The standardisation of the presentation of results and assumed simplifications in addition to the ease of comparing the results obtained with those found in the literature.

However, one of the limitations for its use in Brazil is that LCA software uses databases from systems developed in the United States and Europe, which are applied in contexts quite different from that of Brazil. The use of national data is therefore necessary to ensure the integrity of the results.

3.1.4 The application of Life Cycle Assessments in Agriculture

The application of LCA in agriculture is relatively new. However, several studies outside of Brazil have been conducted for the analysis of agricultural and livestock production (HASS *et al.*, 2001; HOSPIDO *et al.*, 2003; van der WERF *et al.,* 2005; BASSET-MENS *et al.*, 2006; OGINO *et al.*, 2007; BAUMGARTNER *et al.*, 2008; HAVLIKOVA *et al.*, 2008; THOMASSEN *et al.*, 2008; ARSENAULT *et al.*, 2009; CEDERBERG *et al.*, 2009; BAUCHEMIN *et al.*, 2010; NEMECEK *et al.*, 2011).

One of the reasons for the increasing interest in studying the changes caused by agricultural production is due to the fact that this segment is associated with significant environmental impacts. For example, according to Kramer, Moll and Nonhebel (1999), the agricultural sector in the Netherlands is an important source of emission of GHGs, such as CH_4 and N_2O. According to a survey performed by Ruviaro *et al.* (2012), studies conducted in New Zealand, Australia, France, United Kingdom, United States, Canada, Switzerland, Sweden, Japan, Finland, Denmark and Chile, among others, have demonstrated the various levels of the environmental impacts of different production systems in the agribusiness sector.

In Brazil, only 12 articles have been published since 2000 that used the LCA methodology, and a common objective of these studies was the identification of hotspots for process improvement. Efforts have been made to quantify the anthropogenic emissions of GHGs with the primary goal of seeking to meet the commitments made in international forums, e.g., the United Nations Framework Convention on Climate Change. Therefore, the Climate Change Programme has been implemented in the context of agricultural production, under the coordination of the Brazilian Department of Science and Technology, with the purpose of developing the Brazilian inventory of anthropogenic emissions of GHGs.

Therefore, LCA has gained importance as a tool for analysing the environmental impacts of food production and is the focus of studies and research in several countries that aim to standardise their procedures. One such effort is the LCA Net Food, the main objective of which is to develop and support the increased use of the results of LCA studies as a basis for strategic, tactical and operational decisions. This general objective can be divided into four specific goals (OLSSON, 1999):

a) Develop a network of studies on LCA in the food production chain;

b) Assess and report on the state of the art regarding LCA methodologies with an emphasis on failures related to food production chain analysis;

c) Develop a strategic research program focused on the food production chain;

d) Initiate and promote the formation of a European database on LCA related to the food production chain.

It should be noted that many studies conducted in the context of food production have focused on the stages of processing and industrialisation. Only recently have LCA studies focused on the process of agricultural production, especially for annual crop production systems. Studies that include an analysis of the environmental impacts related to the production system as a whole are even less common. There is an urgent need to increase the current knowledge of the environmental consequences of food production while striving for improvements that promote the sustainability of the food production chain (VRIES, 2010; PLACE and MITLOEHNER, 2012).

3.1.5 Necessary adjustments for the use of LCA in agriculture and livestock production

The process of agricultural production, as well as the application of LCA for agricultural products, presents complexities and particularities when compared to the application of LCA to industrial products (HASS, WETTERICH and KÖPKE; KATAJAJUURI and LOIKKANEN, 2001).

According to Olsson (1999), the use of LCA in the food production chain faces specific challenges related to the functional unit, the influences of geographical and climatic changes and the major influence of consumer behaviour, as well as the chain structure for a large number of small-scale production units. These difficulties imply a high variability in the environmental effects and problems associated with data collection.

Special emphasis is given to the data issue because the data collection phases present the greatest time and resource demands in LCA studies and constitute a relatively difficult task. At first, this data collection issue appears to be a paradox because agriculture is the part of the life cycle for which the largest amounts of data are available in the public domain compared to the entire food production chain. However, these data are rarely in a form that allows for the direct correlation with a specific amount of a product, thus requiring additional modelling.

Furthermore, such data present a large extent of variability partly due to the diversity of the production units, where each unit has a different production method, and partly due to the variability of the local production conditions. Finally, these data are not collected in a standardised manner (WEIDEMA and MEEUSEN, 2000; GUINÉE and GORRÉ, 2001).

In summary, the facilitation of data selection, exchange and interpretation in LCA studies is needed, especially for those studies related to the process of agricultural production. Weidema and Meeusen (2000) present the following themes for database modelling, standardisation and development:

a) Data on the use of energy and emissions resulting from the use of fuel in stables, farm machinery, irrigation and drying of products. These data associated with the global warming impact category are derived from CH_4 emissions by the herd, CO_2 emissions from the use of agricultural machinery and equipment, the transport of feed and fertilisers and N_2O emissions derived from the use of synthetic nitrogen fertilisers.

b) Data on the nitrogen cycle and balance, including emissions from animals, stables, manure and crops. The volatilisation of NH_3originating from the use of fertilisers/manure is related to ecosystem acidification. The leaching of NO_3 causes eutrophication and the contamination of ground water. Finally, the emission of N_2O affects the global warming potential.

c) The cycle and balance of other substances, especially phosphorus. The leaching of PO_4 is related to eutrophication.

d) Farm classification aimed at structuring data collection and management. The majority of studies on the potential environmental impacts of agricultural production refer to experimental farms that do not necessarily represent the corresponding production systems (DE BOER, 2003).

Therefore, LCA studies should be conducted in the real environment, i.e., in areas that are representative of the various types of existing production systems and agro-ecological conditions.

When applying LCA for food production chains, there are several important reasons for generating and using information on the origin and characteristics of different food products, including the environmental aspects, particularly due to the trend of intensifying competition in international markets.

In this context, key stakeholders of the food production chain in Finland conducted a joint environmental initiative aiming to develop a database with environmental information. The initial step of this project was a case study of LCA applied to barley production. Among the study's conclusions, emphasis was given to the fact that from a methodological perspective, the use of LCA for agricultural products proved to be more complex than its use in the analysis of conventional industrial products (KATAJAJUURI and LOIKKANEN, 2001).

Regarding livestock production, one of the first LCA studies was performed by Cederberg and Mattsson (2000), who compared the environmental impacts of two dairy farms (a conventional system and an organic system) in Sweden. The incorporation of the concept of life cycle guided the definition of study limits, as shown in Figure 3. This study was conducted during one agricultural year (September of 1996 to August of 1997), and according to the authors, the major differences between the farms were in the following impact categories:

a) Resources: energy, materials and land use.

b) Human health: the use of pesticides.

c) Ecological effects: global warming, acidification, eutrophication, formation of photo-oxidants and a reduction of the ozone layer.

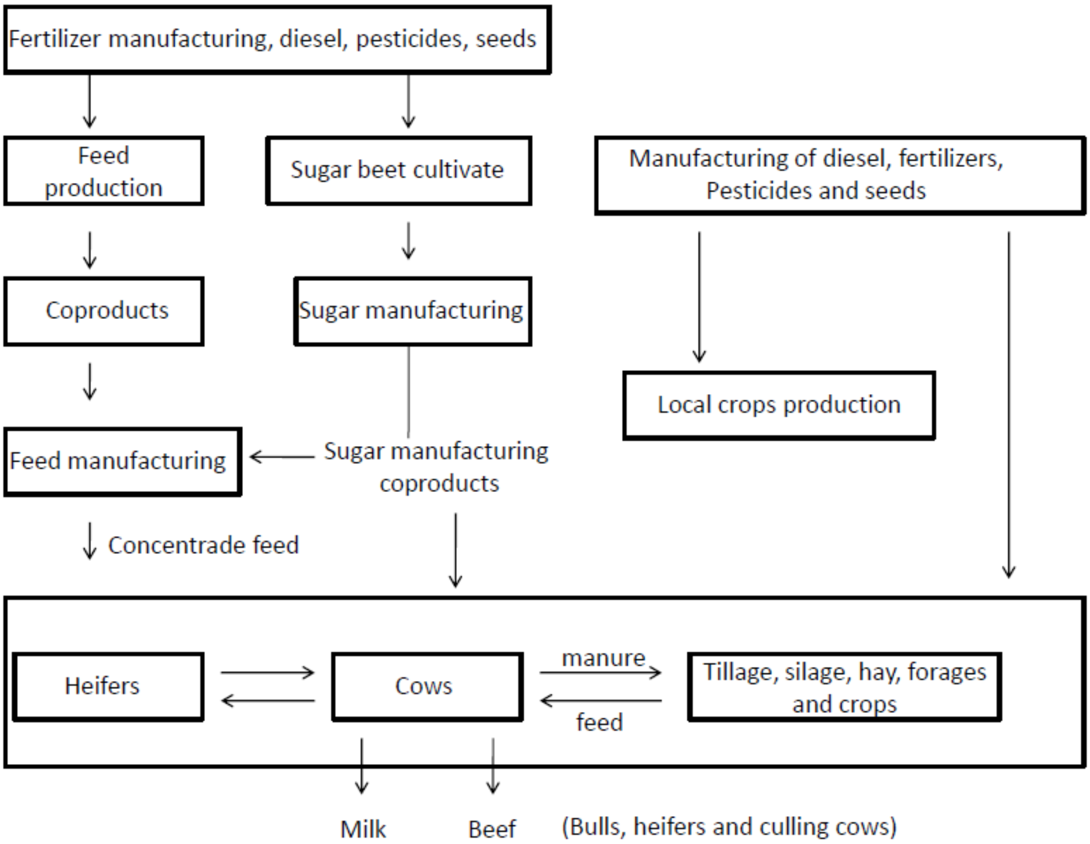

Figure 3 - Life cycle of milk production in organic and conventional farms in Sweden (modified from Cederberg and Mattsson, 2000, p.51).

In the present study, LCA is understood to be a methodology that can be complementary and useful for this purpose by introducing the concept of the life cycle and allowing for suggestions for improvement with an environmental focus. However, it should be clarified that the present study does not aim to identify the environmental impacts occurring in the production system after “the gate”. More precisely, regarding the practical scope, the present study analyses the potential environmental impacts of the livestock production system, given that it is necessary to reconcile two objectives that, at first glance, may be conflicting: environmental impact mitigation and meat production.

3.1.6 Perspectives for the use of LCA in Brazilian agribusiness

Despite the enormous challenge of meeting a 70% increase in food demand by 2050 (FAO, 2009) and doubling of the current meat consumption (FAO, 2006, 2009), agriculture and livestock can contribute significantly towards mitigating this demand (WORLD BANK, 2010). These facts contributed to the institution of a Low-Carbon Agriculture Program (Programa Agricultura de Baixo Carbono – Programa ABC) in 2010 by the Department of Agriculture, Livestock and Food Supply (Ministério da Agricultura, Pecuária e Abastecimento – MAPA), which strives to finance the production of food and bioenergy with a reduction in GHG emissions. A research network entitled Dynamics of Greenhouse Gases in Brazilian Livestock Production (Dinâmica de Gases de Efeito Estufa em Sistemas de Produção da Agropecuária Brasileira – PECUS), led by the Brazilian Agricultural Research Corporation (Empresa Brasileira de Pesquisa Agropecuária – EMBRAPA), was also approved in 2010. The World Bank recently developed a Low-Carbon Study for Brazil, which concluded that the country’s potential to mitigate emissions is strongly related to changes in land use and technological changes in agriculture with an emphasis on deforestation and cattle production (WORLD BANK, 2010).

The current trends in terms of the number of publications, channelling resources for research, governmental demands and generation of a growing volume of organised data on GHG flow suggest that the use of LCA to quantify the potential environmental impact of products from agricultural and livestock production and to support public policy will be an area of intense development in the near future.

Brazil continues to lack consolidated studies regarding the development of LCA and life cycle inventories of production processes and systems for the balancing of GHGs and other environmental impact categories. However, several groups from national institutions (e.g., EMBRAPA, the University of São Paulo, Brazilian Bioethanol Science and Technology Laboratory and the Federal University of Rio Grande do Sul) have made consistent progress in the evaluation of emission factors based on national data as well as the evaluation and reparameterisation of process models developed abroad using national databases.

In addition, there has been recent progress towards the production of integrated models for scenario projection and assessment at a national level. Furthermore, the integration of dynamic mathematical models in methods of Life Cycle Assessment in Brazilian cattle production should soon be possible. However, a basic condition for this to occur is the construction of geographical databases of biophysical conditions, land use, prices and infrastructure. Although the technological conditions exist in the country, the time required for constructing these tools is unknown because such tasks depend on the substantial mobilisation of human and capital resources (Barioni *et al.*, 2011).

CHAPTER II

LIFE CYCLE ASSESSMENT IN BRAZILIAN AGRICULTURE FACING WORLDWIDE TRENDS[4]

Clandio F. Ruviaro, Miguelangelo Gianezini, Fernanda S. Brandão, César A. Winck, Homero Dewes.

Abstract

Worldwide demand to set reliable environmental criteria for food and feed products has brought Life Cycle Assessment (LCA) methodologies to agribusiness. This paper describes the results of a search for scientific literature and government documents regarding the application of LCA to agricultural products worldwide, as a way to capture state-of-the-art technology in the field and to identify the trends and drivers for labeling and certification requirements in international markets. Considering the status of Brazilian agriculture, it would be necessary to adapt the LCA tools to the peculiarities of this country's environmental and technological context, regarding the ability to follow current trends in the application of LCA as a tool for analysis of the environmental impact. In Brazil, any effort to develop specific methodologies for both Life Cycle Inventory and Life Cycle Impact Assessment is urgently needed for the country to remain among the leaders of food and feed exporters and would be appreciated by consumers worldwide.

Keywords: sustainability, agribusiness, decision-making, environment, supply chain, certification

1 Introduction

In recent years, the debate about environmental sustainability has broadened to include the impact of agricultural production. The increasing worldwide demand for food, feed and renewable energy sources requires new knowledge about production systems to make them acceptable under the sustainability criteria.

Faced with such complex needs, researchers around the world have developed different research tools for the analysis of the life cycle of products to measure the impacts caused by

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their respective production processes, and have proposed improvements in all stages of production to boost environmental performance as a whole (Guinée *et al.,* 2001; Cederberg & Mattson, 2000). Among the assessment tools currently available, the LCA is a method for integral assessment of the environmental impact of products, processes and services (Thomassen *et al.,* 2008).

The LCA includes analysis of the extraction and processing of raw materials as well as, product manufacture, transport, distribution, use, reuse, maintenance, recycling and disposal of discards. LCA allows a comprehensive view of the various impacts on the environment, enabling the identification of suitable measures from a sustainable development prospective (Chehebe, 1997; Jensen, 1997; Graedel, 1998).

The soaring worldwide demand to set reliable environmental criteria for food and feed products has brought LCA methodologies to agribusiness as a way to support the decision-making processes regarding agriculture and food production technologies. In this sense, the Kyoto Protocol (2005), the Intergovernmental Panel on Climate Change, IPCC (2007), and the United Nations Climate Change Conference, COP (2009), have played a major influence.

As a major exporter of food and feed products, Brazil is a country highly concerned with environmental and food safety issues of international relevance associated with agricultural production and the food processing industry. Brazil is the largest South American country with an area of 8,514,876 km^2 and with a population of more than 190 million (IBGE, 2010). The country leads the world in the production of oranges, sugarcane, and coffee, and it is also one of the major producers of soybeans, corn and beef (FAO, 2009).

This paper presents the results of a search for scientific literature and government documents regarding the application of LCA to agricultural products worldwide, as a way to capture state-of-the-art technology in this field and to identify the trends and drivers for labeling and certification requirements in international markets. We contrasted the data on LCA for agricultural products from worldwide sources with the published documents from Brazilian sources. We found that the world literature on the subject is still relatively scarce and refers to a limited list of products, namely dairy products, tomatoes, apples, nectarines, citrus products, potatoes, olives, wheat, rice, soybeans, maize, sugarcane, biomass, biodiesel, biomethanol, forage, beef, fish, pigs, poultry, sheep, wool, eggs, forests and wood. The Brazilian sources refer to ethanol, sugarcane, biofuels, agricultural machinery manufacture, coffee, soybeans, orange juice, poultry, aquiculture, and oysters.

1.1 Approaches to the assessment of the life cycle of agricultural and livestock products

LCA is an important tool for environmental evaluation of production chains. This methodology is widely used and recognized worldwide by researchers and technicians and allows many applications in productive systems. A comprehensive systematization of the requirements and steps of the LCA is contained in the standards ISO 14040:2006 (ISO, 2006a) and ISO 14044:2006 (ISO, 2006b).

In agricultural production, the application of LCA is of marked relevance in all the production chains, and its importance can be seen in the following market externalities: a) consumers demand environmentally friendly products and are willing to pay more for them, b) the producers who are not able to demonstrate that their produce is grown in a sustainable way, have difficulties in accessing important markets, and c) environmental criteria are being gradually added by countries to their import requirements for agricultural products.

Therefore, only agricultural products that have their production chain properly managed are fully accepted in local or global markets, and for management to move towards environmental control, agriculture requires objective measurements of reliable indicators similar to other production systems.

Another aspect that can be controlled by LCA methodology is the efficiency of a production chain, which partially depends upon the production scale, the technologies used, and the organization of producers facing the industry.

Because agricultural production is highly diversified worldwide, both in cultural and biophysical terms, application of a standard and widely accepted methodology for analysis of environmental impacts of local agricultural production is very difficult and highly controversial, although urgently needed.

The application of LCA in agriculture progresses worldwide, although it still has to evolve to incorporate some additional sustainability dimensions, such as offensive odors, animal welfare and aesthetic aspects, among others.

Considering this scenario, some limitations of the LCA methodology can be mentioned: a) the failure to consider and/or include all the relevant impacts on the production (use of soil and water, indirect changes in the use of the soil and the ecological competition among products); b) the difficulty to consider the reduction of soil use when production is classified as ecological (organic, natural, biodynamic, among others); c) the lack of a broader approach (such as the Integrated Environmental Assessment, IEA); and d) the current inability to consider the large number of existing categories of environmental impacts that make the decision-making process more difficult.

1.2 LCA in Brazil

According to MAPA (Ministry of Agriculture, Brazil), agribusiness accounts for 33 % of Gross Domestic Product (GDP) and 42 % of total Brazilian exports (MAPA, 2010a). Recent studies show that the total area of crops in the country should increase from 60 million hectares in 2010 to 70 million in 2020. Brazil will have a 37 % increase in grain production (soybeans, corn, wheat, rice and beans), equivalent to 48 million tons by 2020. Growth is also expected in the same period for meat production (38 % beef, pork and chicken), sugar (48 %), and milk (24 %) (MAPA, 2010b). What is remarkable is that conditions exist to permit even further growth. The well-known Brazilian potential to produce food due to potentially arable land and the availability of water and renewable energy (such as hydroelectric power), places the country in a prominent position in the global market as one of the major food suppliers for the world in coming years.

However, to meet the new consumer demands for certification and labeling of agricultural products, it is critical that Brazilian institutions, both academic and governmental, watch for the trends of international markets in using the LCA methodologies and take the needed steps to qualify local institutions to perform those analytical procedures properly (Caldeira-Pires *et al.,* 2002; Coltro, 2007; Barbosa *et al.,* 2008).

In other words, the LCA of agricultural products should consider the peculiarities of each country within its analysis context. Therefore, we must know how to apply this methodology properly according to the peculiarities of the different regions of Brazil, to provide both basic scientific knowledge and support for management and for environmental education (Souza *et al.,* 2007; Mourad *et al.,* 2007). Moreover, there is a need to establish institutional policies with local pertinence, in terms of environment and sustainable production.

2 Methods

A preliminary document search showed that the analytical procedures and units used in LCA analysis differed according to the products and origins of the publications. Against this background, a literature review was performed on the LCA studies published in the last ten years. The data were obtained from scientific literature and government documents regarding the application of LCA to agricultural products worldwide. Furthermore, we contrasted the LCA data on agricultural products from worldwide sources with the published documents from Brazilian sources (Fig. 4).

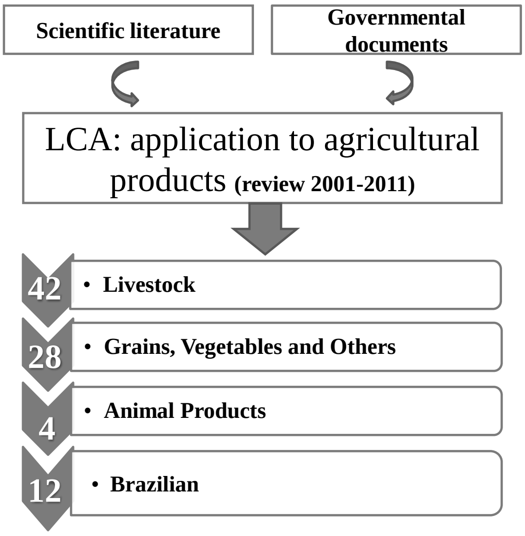


Figure 4 - Flowchart of the search with the numbers of documents analyzed.

3 Results

Apparently, the world is a long way from establishing general protocols that would take into account local conditions while providing valuable comparisons between countries and agricultural products and production systems, useful in supporting official international trade, uni- or multi-lateral requirements, and consumer decision making. Considering the status of Brazilian agriculture, it would be necessary to adapt the LCA tools to the country's environmental peculiarities and technological context, to keep up with current trends in the application of LCA methodology for analysis of the environmental impact of food and feed products. So far, there are only a few studies on adaptation of the descriptive factors related to various critical categories, such as biodiversity, land use, and water use. Regarding the Life Cycle Inventory (LCI), no national database is yet open to access, either related to agriculture or to other sectors of industrial activity, in spite of current efforts in this direction.

Tables 1, 2 and 3 list the LCA reports according to the respective country of application, agriculture products, theme, functional units, selected conclusion, year of publication, and authors. In Table 4, the variables include theme, goal, functional unit, selected results, year of publication, and authors.

Table 1 - International applications of LCA methodology on livestock production according to the year of publication

Country	Agriculture Products	Theme	Functional Units	Selected Conclusion	Year	Author (s)
Ireland	Milk	Compare two standard methodologies, IPCC method and LCA, for quantifying GHG emissions from dairy farms	kg CO_2 eq., kg-1 milk; kg CO_2 eq., kg-1 MS; t CO_2 eq., ha-1	Expressing emissions per ha does not appropriately reflect the effect different dairy systems can have on milk production. The LCA approach must be integrated into the existing IPCC framework to identify production systems with a net reduction in global GHG emissions	2011	O'Brien *et al.*
Ireland	Milk	An evaluation of LCA of European milk production	Undefined	Simplified LCA may not help provide efficient mitigation strategies for environmental problems	2011	Yan *et al.*
New Zealand /Sweden	Milk and co-products	Investigate different methodologies of handling co-products in LCA or CF studies	1 kg energy-corrected milk (ECM)	There was a small difference in calculated average CF value at the farm gate for New Zealand and Swedish milk production	2011	Flysjo *et al.*
Spain	Milk	LCA and DEA methodologies used to perform eco-efficiency assessment of a high number of dairy farms	Dairy farm	Combined LCA and DEA provided valuable results to benchmark both operational and environmental parameters	2011	Iribarren *et al.*
Switzerland	Integrated and organic farming systems	Assessment of integrated and organic farming systems for crops and forage production to compare environmental performance and potentials	Cultivated hectare per year; currency unit; physical units (kg of dry matter and MJ net energy)	There is considerable room for environmental optimization of Swiss farming systems	2011a	Nemecek *et al.*
Switzerland	Extensive and intensive production systems	Reduction of environmental impacts of extensive farming systems	Cultivated hectare per year; currency unit; physical units (Kg of dry matter and MJ net energy)	Detailed eco-efficiency analysis could help in reducing production systems' environmental impacts	2011b	Nemecek *et al.*

Australia	Wheat, sheep meat and wool	Global warming contributions	CO_2 eq./kg of wheat, sheep meat and wool produced from mixed pasture, wheat and sub-clover	Wool GHG emissions are higher than wheat and sheep meat. Enteric and manure decomposition CH_4 emissions accounted for a significant portion of total emissions from sub clover and mixed pasture production, while N_20 is the major emission from wheat production	2010	Biswas *et al.*
Australia	Red meat beef	Accounting for water use in red meat production	Delivery of 1 kg of HSCW meat to the processing works product gate for wholesale distribution	Approach can be applied to other agricultural systems; results not suggested as industry averages	2010	Peters *et al*.
Austria	Livestock	Emissions accounting for production and consumption of livestock system	Carbon emissions (CO_2 and CH_4)	FCA and LCA methods are effective to estimate direct carbon emissions from domestic livestock and combustion of fossil fuels in processes of product manufacturing and transportation	2010	Gavrilova *et al.*
Canada	Beef	Estimation of GHG emissions from beef production	CO_2 eq. Kg $^{-1}$	Following mitigation of GHG emissions, beef production should focus on enteric CH_4 production from mature beef cows. The cow–calf production system also has many ancillary environmental benefits, allowing use of grazing and forage lands, preserving soil carbon reserves and providing ecosystems services	2010	Bauchemin *et al.*
Spain	Fish	Combination of LCA and data envelopment analysis (DEA) in fisheries	kg CO_2 eq.	Approach facilitates interpretation of results of multiple LCAs for some fisheries and carries synergistic effects	2010	Vázquez-Rowe *et al.*
United States	Beef	Comparison between models of different beef production strategies	GJ, GHG (tonnes CO_2 eq.); eutrophying emissions (tonnes of PO_4 eq.); ecological footprint (ha)	Beef production,feedlot or pasture-based, generates lower edible resource returns on the material/energy investment relative to other food production strategies	2010	Pelletier *et al.*

Brazil/USA /Canada	Soybeans and beef	GHG emissions of soybeans and beef production in the Amazon basin of Brazil	Carbon liability embodied in soybeans and beef (Tg CO_2 eq.)	Study requires calculating emissions from deforestation, life-cycle analysis of agricultural systems and allocating emissions between producers and consumers	2009	Zaks *et al.*
Brazil / Sweden	Beef	LCI of GHG emissions and use of land and energy in Brazilian beef production	1 kg of Brazilian beef at the farm-gate, as carcass eight equivalent; 1 kg of Brazilian beef exported as bone-free beef	The use of energy in Brazilian beef production is very low, a tenth of European production. Brazilian land use is higher than in the EU	2009	Cederberg *et al.*
Canada	Milk	Environmental impacts of typical pasture and confinement operations	1,000 kg milk at farm gate	The transition to full confinement does not result in environmental benefits	2009	Arsenault *et al.*
France/ Greece	Fish	Environmental impacts of different production systems of carnivorous fish	1 tonne of live fish weight	Global warming and the availability of fish resources, climate change and net primary production use impact freshwater raceways, sea cages and inland re-circulating systems	2009	Aubin *et al.*
New Zealand	Milk	Global warming and milk production	GWP (/ kg milk)	A probabilistic framework provides information on the differences between technological options	2009a	Basset-Mens *et al.*
New Zealand	Milk	Eco-efficiency in intensification scenarios	kg CO_2 eq.; kg PO_4 eq.; kg SO_2 eq.; MJ; m^2.year; and kg/ha	Comparison NZ x European needs validation	2009b	Basset-Mens *et al.*
Norway/UK/ Canada/Chile	Fish	Global-scale Life Cycle Assessment of a major food commodity, farmed salmon	Emissions per unit production	Impacts were lowest for Norwegian production in most impact categories and highest for UK farmed salmon	2009	Pelletier *et al.*
Czech Republic	Livestock	Environmental and health impact of dairy cattle livestock and manure management	Impacts per year, per hectare and per liter milk production	Selected characterization factors combined with information on study regions are useful in an assessment of the environmental and health impact of dairy	2008	Havlikova *et al.*
European Union	Livestock	Life Cycle Assessment of feeding livestock with European grain legumes	1 kg of animal product	Measures have to be taken to reduce the environmental burden of feedstuff production by choice of origin of feedstuffs and improvement in the productivity of the system	2008	Baumgartner *et al.*

Finland	Chicken meat	Life cycle phases in broiler chain by Finnish 'Eco-Benchmark'	1,000 kg	Grain production has the higher impact on the food chain	2008	Katajajuuri *et al.*
France	Cow and goat	Analyzes the environmental impacts of regional dairy chains to identify improvement options	1,000 kg milk; Ha of land occupied	Farm operations have more impact than farm inputs. Transport of products to retailers has more impact than those of dairy plants	2008	Kanyarushoki *et al.*
Global - Germany	Beef	Local and global meat production related to environmental and economic aspects	One kilogram of ready-to-cook beef	Adoption of "Ecology of Scale" theory to support demand	2008	Schlich *et al.*
Netherland	Milk	Conventional and organic milk production	kg of milk	Relative performance varies within categories of environmental impact	2008	Thomassen *et al.*
Netherland	Organic eggs	Integral environmental impact of the organic egg production chain	One kg of organic egg	Concentrate production is the key cluster to climate change, eutrophication and energy use	2008	Dekker *et al.*
Sweden	Beef	Synthesizes and expands upon existing data on the contribution of farm animal production to climate change	CO_2 eq.GHG emissions per kilogram of beef	Immediate and far-reaching changes in current animal agriculture practices and consumption patterns are both critical and timely if GHGs from the farm animal sector are to be mitigated	2008	Koneswaran, G. & Nierenberg, D.
Japan	Beef cattle	Environmental impacts of beef cow-calf system	One marketed beef calf	Shortening calving intervals and increasing the number of calves per cow reduced environmental impacts in all of the categories	2007	Ogino *et al.*
Canada	Beef cattle	Influences of handling treatment on nutrient levels and mass balance estimates of feedlot manure	Various	Handling manure changes nutrient availability	2006	Larney *et al.*
France	Pigs	Uncertainty and variability	g PO_4 eq. /kg pig; g CO_2 eq. /kg pig, g SO_2 eq. /kg pig	Farmer practices may affect the final result more than production modes	2006	Basset-Mens *et al.*
Ireland	Beef	GHG emissions from sucker-beef production	kg CO_2 kg LW yr^{-1}	Comparing beef x dairy emissions revealed the potential for reduction by adopting alternative management	2006	Casey, J. W. & Holden, N. M.

European Union	Livestock	Compares tools for environmental assessment and recommends indicators for benchmarking	Kg/product or kg/ha	Organic vs. conventional milk production and three pig production systems give different results, depending on the basis of the indicators	2005	Halberg *et al.*
France (Bretagne)	Pig	Environmental impacts on the production of concentrated feed associated with the production and on-farm delivery of concentrated feed for pigs	1,000 kg of feed; 1,000 kg of ingredients	Decreased environmental burdens by optimizing the fertilization of crop-based ingredients, by reducing concentrations of Cu and Zn in the feed, and by using wheat-based rather than maize-based feeds	2005	van der Werf *et al.*
Ireland	Milk	GHG and the intensity of milk production	One kg of ECM; land area	Moving toward extensive production could reduce emissions	2005	Casey, J. W. & Holden, N. M.
Japan	Livestock	Environmental impacts of concentrate feed supply systems on industry	PA tons/year; Di tons/year; Fij MJ/tons of feed; GAj tons/MJ; Li GWh/tons of feed; MA tons/GWh; feed i; and fuel j	Livestock industry could join in emissions trading by reducing CO_2 producing equivalents	2005	Kaku *et al.*
Japan	Beef	Environmental impacts of beef-fattening system and effects of feeding length	One beef animal	A shorter feeding length resulted in lower environmental impacts, such as global warming and acidification	2004	Ogino *et al.*
Sweden	Dairy cattle	Perform an LCI of milk production from conventional and organic dairy farms	One kg of energy corrected milk at the farm gate	The organic farms had lower use of fossil energy, P and K, and pesticides, but larger land use. High production per cow and the use of input resources can reduce the environmental impact	2004	Cederberg, C. & Flysjo, A.
New Zealand	Milk	Dairy farm, grazing and forage land	Volume of milk (m^3)	Nitrogen fertilizer increased production and economic efficiency but decreased environmental efficiency	2003	Ledgard *et al.*
Spain	Milk	Total life cycle of production and processing of milk to quantify the environmental impact	1 liter of packaged liquid milk ready to be delivered	Applications of improvement actions in milk production can lead to a maximum reduction of the global normalized impact	2003	Hospido *et al.*
Sweden	Milk and beef	Organic milk production with different methods of handling co-products	One kg ECM; One kg bone-free meat	Milk and beef production systems are closely connected	2003	Cederberg, C. & Stadig, M.

United Kingdom	Pig waste	Environmental benefits of livestock manure management practices and technology	1,000 kg pork weight	Using an anaerobic digester shows few overall benefits due to the fugitive losses of methane. However, if these can be eliminated, the global warming potential from waste management is reduced close to zero	2003	Sandars *et al.*
Germany	Systems of grassland farms	Environmental impacts of eighteen grassland farms in three different farming intensities	Whole farm	Organic production promotes biodiversity	2001	Haas *et al.*

Table 2 - International applications of LCA methodology on grain production, vegetables, and others according to the year of publication

Country	Agriculture Products	Theme	Functional Units	Selected Conclusion	Year	Author (s)
Italy	Wine	Evaluates the environmental performances of four high quality wines for carbon labeling	0.75 L bottle of wine	Vineyard-planting phase has a significant impact on the wine CF; thus, it has to be considered in the life cycle, while in literature, it is frequently omitted. On the contrary, the pre-production phase did not present a relevant impact	2011	Bosco *et al.*
China	Biodiesel	Energy cost of rapeseed-based biodiesel alternative energy in China	MJ/kg, MJ/unit	There is potential to improve the apparently negative energy balance for biodiesel from rapeseed oil in China by increasing the average yield of rapeseed or decreasing the energy inputs of nitrogen fertilizers	2011	Chen & Chen
Sweden	Biomass	Environmental study of production of propionic acid in a biorefinery system based on agricultural by-products	One kg of propionic acid at the factory gate	The use of industrial by-products as raw materials in biorefinery systems appears to be an attractive option to produce bio-based hemicals, both from an environmental and an economical point-of-view	2011	Ekman & Böejesson
Sweden	Biomass	Scenarios for supply of the entire demand of power and heat of a rural village	One year supply of heat and electricity to a modern village of 150 households	The biomass-based scenarios reduce greenhouse gas emissions considerably compared to the scenario based on fossil fuel but have higher acidifying emissions.	2011	Kimming *et al.*

Spain	Tomato	Determine agricultural and environmental differences of four cultivation options characterized by greenhouse or open-field cultivation using compost plus mineral fertilizers or only mineral fertilizers	One tonne of commercial tomatoes produced	Replacement of a fraction of the mineral fertilizers dosage with compost appears to be a good agronomical solution for tomato crops for growth in both open-fields and greenhouses	2011	Martínez-Blanco *et al.*
USA	Woodchips for bioethanol	Among the many lignocellulosic feedstocks, woodchips are viewed as one of the most promising feedstocks for producing liquid transportation fuels	Production of 4 m^3 of hardwood chips	Harvesting and woodchips processing stage and transportation to the facility stage emit large amount of environmental pollutants compared to other life cycle stages of ethanol production	2011	Neupane *et al.*
Italy	Citrus-based products	Environmental impacts of citrus production and transformation processes to identify the most significant issues and suggest options for improvement	1 Kg of each final citrus-based product	Sensible variations in energy and environmental performances of final products. Benefits that state the improvement of products' eco-profile, by reusing purified water used for irrigation, using the railway mode for delivery of final products, and adopting efficient technologies in pasteurization and concentration of juice	2010	Beccali *et al.*
Italy	Nectarine orchard	Application of Ecological Footprint Analysis	gha t^{-1} nectarines produced	Validation of the system is needed before the application at grower level. Ecological indicator based on EFA may provide the required introduction of an environmental verification system for food production	2010	Cerutti *et al.*
Italy	Biofuel	Discuss limits and constraints of the LCA to perform quantitative assessments as requested by the current supporting policies in the biofuel area	CO_2 eq. (kg(MWh$_e$)	LCA studies should always provide the bias of the calculations because this range of variation in the LCA results could be significantly greater than the initially set quantitative targets, and therefore, the whole investigation would be at risks for inconsistency	2010	Chiaramonti, D. & Recchia, L.

Chile	Sunflower and rapeseed	To quantify and compare the environmental impacts and energy and water demand for cultivation of sunflower and rapeseed	One tonne of seeds per year	Evaluation of environmental impacts indicated that in Chilean conditions, rapeseed has a better environmental profile than sunflowers. Sunflowers have a higher impact in 9 of the 11 impact categories evaluated, with values between 1.2 and 39 times higher	2010	Iriarte *et al.*
Brazil, Denmark, China, and the USA	Wheat	Life cycle inventory modeling of land use induced by crop consumption using wheat as an example	Kg eq./ ha	Wheat consumption in different countries result in different land use consequences due to differences in trade patterns, which are governed by transport and trade costs, among other factors	2010	Kløverpris *et al.*
China/ Denmark	Organic soybeans	The environmental impacts of organic and conventional production of soybeans	One tonne of organic soybean produced in China and delivered in Denmark	The organic soybean has a lower environmental impact compared to the conventional soybean	2010	Knudsen *et al.*
Switzerland	Forest	The impact of climatic factors on land use as determined by the CO_2 transfers between vegetation/soil and atmosphere	Carbon quantities per hectare for land transformation and land occupation and their time weighting	The quality of available data on carbon content in vegetation and soil, on carbon transfers to air due to particular land use types, and on the duration of stay of carbon in the air is still limited and needs improvement	2010	Müller-Wenk, R. & Brandão, M.
Australia	Sugarcane production	Quantify the environmental impacts of sugarcane products	One tonne of raw sugar; one tonne molasses; one kWh electricity; and one MJ anhydrous fuel ethanol	Potential uncertainty can be higher in Australian sugarcane products due to the nature of the cane processing system, the variability in sugarcane growing, and the approach taken for assigning impacts to multiple products from sugarcane processing	2010	Renouf *et al.*
Germany	Wood	Environmental burdens of cultivation of fast-growing tree species on agricultural land and subsequent energetic conversion in comparison to the fossil energy system	One oven dry tonne of poplar chips; MJ power; MJ heat; and MJ FT diesel	Utilization of the same amount of short-rotation poplar chips for heat and power production causes fewer environmental impacts than its use for FT diesel	2010	Roedl, A.

European Union	Rapeseed oil and palm oil	Local and global alternative for meeting the increasing oil demand	One tonne refined vegetable oil	Palm oil tends to be environmentally preferable to rapeseed oil within all impact categories except global warming, biodiversity and ecotoxicity, where the difference is less pronounced and where it is highly dependent on assumptions regarding system delimitation in the agricultural stage	2010	Schmidt, J. H.
China	Rice	Examines the environmental impact of the rice production system	One tonne of rice produced	Reducing nitrogen fertilizer intensity and increasing efficiency are key points to control LCA environmental impacts of rice, decreasing resource consumption and emissions	2010	Wang *et al.*
Canada	Greenhouse tomatoes	Explores one approach to assessing social issues in supply chain - LCA	$100 of tomatoes from a large greenhouse	LCAA may serve as an aid for discussions of how current and popular CSR indicators may be integrated into a supply chain model	2009	Andrews *et al.*
Italy	Rice	Analyzes improvement scenarios concerning alternative rice farming and food processing methods: organic and upland farming and parboiling	One kg of refined rice packed and delivered to the supermarket	Organic and upland farming have the potential to decrease impact per unit of cultivated area. Due to the lower grain yields, environmental benefits per kg of the final products are reduced in the case of upland rice production and almost cancelled for organic rice	2009	Blengini, G.A. & Busto, M.
Brazil/ Netherlands	Sugarcane	Comparative LCA on gasoline and ethanol as fuels, and two types of blends of gasoline with bioethanol, all used in a midsize car.	Power to wheels for 1 km driving of a midsize car	Driving with ethanol fuels is more economical than gasoline and economically more attractive. The outcomes depend on the assumed price for crude oil and technological development	2009	Luo *et al.*
Argentina	Biodiesel	Environmental impact of soybean-based biodiesel production for export	1 km driven with diesel by a 28 t truck	Environmental impact is influenced by land use change, the BNF and the use of fertilizers, as well as applied pesticides, the soybean production method, the use of methanol and the transport system	2009	Panichelli *et al.*

China	Biomethanol	The biomethanol rice straw production process involves thermodynamic, economic, and environmental performance	1,000 kg of biomethanol	Rice straw to produce methanol is beneficial for both utilization of agricultural waste and improvement in the environment	2009	Xiao *et al.*
Denmark/ Argentina	Soybean meal	The purpose of the study was to estimate the environmental consequences of soybean meal consumption using a consequential LCA approach	One kg of soybean meal produced in Argentina and delivered to Rotterdam Harbor	Consequential LCAs are quite easy to handle, even though it has been necessary to include production of palm oil, rapeseed and spring barley because these production systems are affected by the soybean oil co-product	2008	Dalgaard *et al.*
Belgium	LCA of biofuels	The environmental benefits of using biofuels	100 km covered with a midsize and recent car	Rapeseed methyl ester allows a considerable improvement in environmental performances compared to fossil diesel, while ethanol from sugar beets offers a more limited benefit compared to petrol	2008	Halleux *et al.*
Spain/ Global	Apples	How the international trade of fresh apples concerned environmental, economic and social impacts	One ha of orchard; one kg of fresh apples; m^3/ha; kg N; kg P_2O_5; and Kg K_2O	Multivariate analysis can be used to select the most important indicators regarding economic, social and environmental aspects of apple production and trade	2008	Soler-Rovira, J. & Soler-Rovira, P.
Germany	Biomass	Ecological optimization of biomass cultivation	Kg of harvested product	There is no cultural method preferable for biodiesel. Organic agriculture was better for integrated production of energy using wheat, corn and soybeans	2007	Kagi *et al.*
Italy	Sunflower oil	Evaluates the use of sunflower oil on farms to meet their internal energy requirements	One ha	Biofuel is not yet competitive because no free market exists for it, but it represents a practical way to avoid the shift of economic benefits from agriculture to industry, as occurs with biodiesel production	2006	Riello *et al*
France	Agriculture	Analyzes 12 indicator-based approaches to assessing the environmental impact at the farm level to propose a set of guidelines for the evaluation or development of such methods	Various	The method should be validated with respect to (a) the appropriateness of its set of objectives relative to its purpose and (b) its indicators	2002	van der Werf, H.M.G. & Petit, J.

Table 3 - International applications of LCA methodology on animal products according to the year of publication

Country	Agriculture Products	Theme	Functional Units	Selected Conclusion	Year	Author (s)
USA	Organic dairy	LCA of a large-scale, vertically integrated organic dairy in the USA	One L of packaged fluid milk	Improvements in data quality with respect to feed production and methane emissions are required before more definitive comparisons can be made between agricultural production methods	2011	Heller *et al.*
Germany	Organic milk	Environmental impacts of different types of organic dairy farms	Whole farm	Environmental impact assessment analyzing only global impact categories of climate impact and energy consumption leads to different conclusions than an overall analysis that also takes categories with regional and local impact into account	2010	Müller-Lindenlauf *et al.*
New Zealand / UK	Dairy	Comparative energy and greenhouse gas emissions of New Zealand's and the UK's dairy industry	CO_2 emissions; energy emissions	NZ is still more efficient at dairy production than the UK even when other emissions are accounted for	2007	Saunders, C. & Barber, A.
New Zealand	Dairy - lamb - apple	Food Miles – Comparative Energy/Emissions Performance of New Zealand's Agriculture Industry	Energy use and CO_2 emissions associated with production and transport	NZ products compare favorably with lower energy and emissions per tonne of product delivered to the UK compared to other UK sources. In the case of dairy, NZ is at least twice as efficient and for sheep meat, four times as efficient. The CO_2 emissions per tonne of apples produced are also higher in the UK than in NZ	2006	Saunders *et al.*

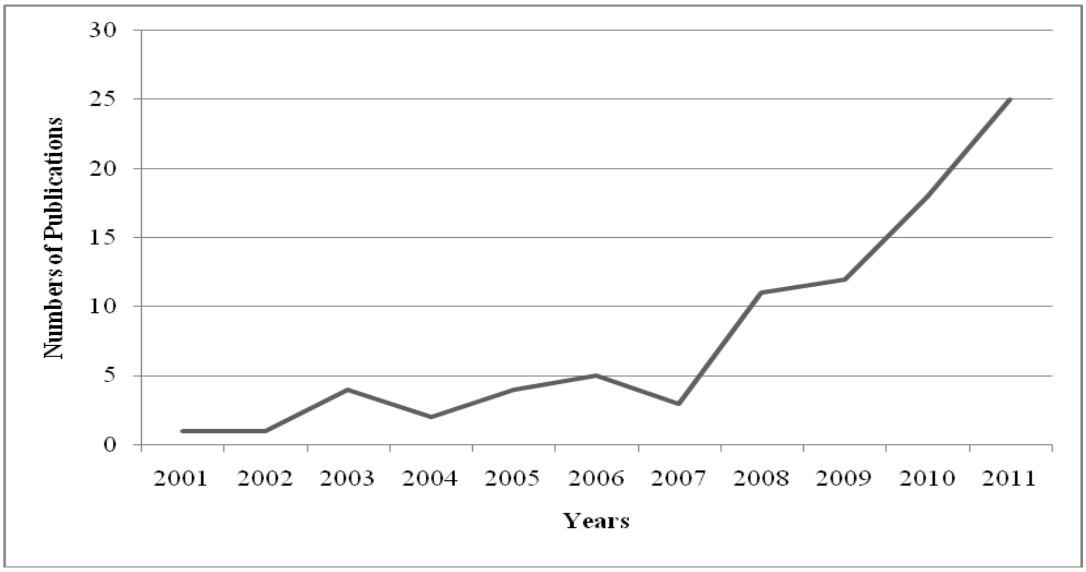
Table 4 - Applications of LCA methodology in Brazilian agriculture according to the year of publication

Theme	Goal	Functional Units	Results	Year	Author (s)
Issues to consider, existing tools and constraints in biofuel sustainability assessments	Contributes to the development of a framework for sustainability indicators as a tool for performance assessment	Various	Brazilian biofuel programs demonstrate the feasibility of a sustainable method for renewable fuels utilization	2011	Lora *et al.*

Life Cycle Assessment of Brazilian sugarcane products: GHG emissions and energy use	Assess the life cycle energy use and GHG related to cane sugar and ethanol, considering bagasse and electricity surpluses as co-products	KJ/kg and CO_2 eq./kg	Advantages of sugarcane products compared to beet sugar produced in Europe	2011	Seabra *et al.*
Comparison of the ecological footprint and a life cycle impact assessment method for a case study on Brazilian broiler feed production	Compares the different interpretations that can be obtained from CML 2001 and Ecological Footprint, using a case study of four scenarios of broiler feed production in Brazil	Supply ration to feed broilers on farm	Ecological Footprint is not suitable for the agricultural sector because misleading decisions can be taken as a result of neglecting some important environmental impacts for this economic sector	2011	Alvarenga *et al.*
Material flow determination through agricultural machinery management	Suggests an arrangement of existing models to determine material flow in agricultural production systems	Volume and mass units	Existing models to determine material flow are applicable for general as well as for local or specific scenarios because they are based on the physical demand of agricultural mechanized operations	2010	Romanelli, T. L. & Milan, M.
Variability in environmental impacts of Brazilian soybeans according to crop production and transport scenarios	Evaluates the environmental impacts of supply chains from Brazil´s two major soybean production regions	1,000 kg of soybeans at 13% humidity	The mode of transport chosen and the distance to be traveled strongly influence environmental impacts. Assessments involving soybeans from Brazil should take into account the region of origin, as different regions have different levels of environmental impacts	2010	Prudêncio da Silva *et al.*
Greenhouse gas emissions in the life cycle of ethanol: estimation in agriculture and industrializatio n stages in Minas Gerais, Brazil	Estimates of greenhouse gas emissions (CO_2, CH_4 e N_2O) in the stages of agriculture and sugarcane industrialization for the production of ethanol in mills	One ha of cultivated land per year	GHG emissions in the phases of agriculture and industrialization of sugarcane for ethanol production are mainly due to the burning of plants, fuel consumption, the release of N_2O in the soil and the consumption of lime and fertilizer	2010	Garcia, J. C. C. & Sperling, E. von
The Life Cycle Assessment of fuel ethanol as 100% of the vehicle fuel from sugarcane in Brazil	LCA of the fuel ethanol from sugarcane in Brazil, assessing the environmental impact potentials	10,000 km run in a urban area by a car with a 1,600 cm³; 1,000 kg of ethanol	Fuel ethanol lifecycle contributes to all the impacts analyzed. The main causes are nutrient application, burning in harvesting, and the use of diesel	2009	Ometto *et al.*

Energy use in the life cycle of frozen concentrated orange juice	Presents the aspects of energy use for FCOJ produced in two orange-growing regions	1,000 kg of FCOJ	The Global Warming Potential of FCOJ is related to 70% of the total energy (non-renewable energy)	2009	Coltro *et al.*
Brazilian poultry: a study of production and supply chains for the accomplishment of a LCA study	Describes two current supply chains of poultry production emphasizing the distance of transportation as a predominant factor	One tonne live weight chicken and one tonne frozen chicken	The potential impacts of frozen chicken delivered to the port could be quite different between two chains given the distance between each and the main port used as a route for export	2008	Prudêncio da Silva *et al.*
Life Cycle Inventory for a Brazilian oyster production system	Raises data of entries and exits at all stages of the life cycle of the oysters to provide grounds for a future LCA analysis	A dozen oysters consumed	There is a high consumption of water (both fresh and salt), and also high emission of CO_2, high total solids (in wastewater) and solid waste as oyster's shells	2008	Alvarenga *et al.*
Sustainable development in aquiculture: methodology and strategies	Introduces a reflection about the strategies of interconnection of the aquaculture in the human-environmental context	Undefined	LCA can be used in environmental licensing	2007	Eler, M.N. & Millani, T.J.
Environmental Profile of Brazilian Green Coffee	Presents the LCI of green coffee production to obtain detailed production inventory data	1,000 kg of green coffee destined for export	Supplies results for a better correlation of agricultural practices and potential environmental impacts	2006	Coltro *et al.*

Figure 5 shows that the number of publications on LCA applied to agriculture rose markedly from the year 2007 and onwards, when governments and public opinion started to ask for more transparency of the environmental impacts of industrial activities as a result of international agreements, such as Kyoto Protocol, COP and IPCC.



(*until August 2011)

Figure 5 - Evolution of publications on LCA in agricultural products for the period of 2001-2011*

4 Discussion

As in LCA studies of other industrial products and sectors, the reports on LCA of agricultural products put emphasis on comparison of different production systems, e.g., organic versus conventional, extensive versus intensive, small versus large scale, and traditional versus advanced systems. Both the environmental burden and productivity are referred to by LCA methodology that uses multiple functional units to express them, such as the mass of the final products (kg), the energy content of food products (kJ), the cultivation area (ha), and the unit of livestock, among others. In several studies, the LCA methodology is complemented by other approaches that together are more effective in evaluating the environmental impact of the system or the product analyzed.

The studies and their conclusions are quite heterogeneous, as one would expect considering the extreme diversity in technological and biophysical terms of the agricultural systems analyzed. Any extension of the conclusions of one study to another region of the world or to another production system would be inappropriate. This is particularly relevant for Brazil compared to other countries and considering the huge regional differences inside its borders. With the current inexistence of any Brazilian LCA inventory, interregional or international comparisons are very difficult.

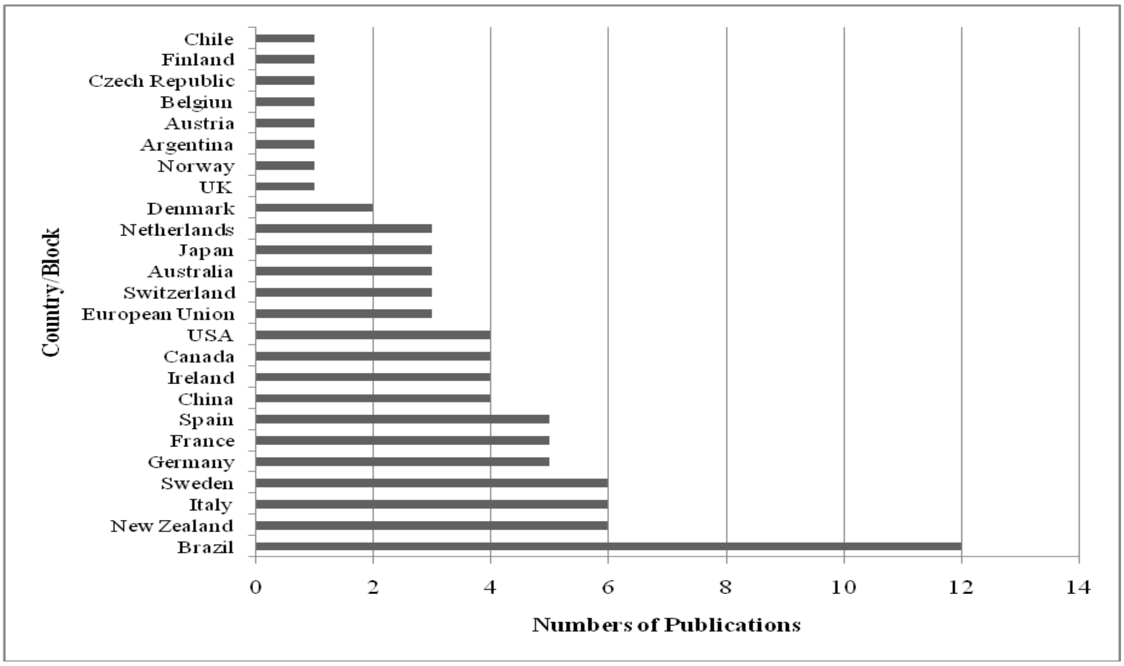


Figure 6 - Geographic distribution of LCA agricultural studies in the world (including livestock, grains, vegetables, animal products) 2001-2011 (until August 2011)

Figure 6 shows that so far, most of the studies have focused on European agriculture. Since 2006, reports on Brazilian agriculture have also achieved noticeable numbers with frank expansion.

The soaring number of publications on Brazilian agriculture mirrors the economic relevance of this sector for the country and the widespread concerns regarding how the environmental impact of this sector affects the access of Brazilian agricultural products in international markets. As one can follow in several recent governmental, agribusiness and academic forums and meetings (e.g., http://www.congressodacarne2011.com.br/; www.ciclodevida.ufsc.br/congresso, http://www.feicorte.com.br/index.php?p=noticias_view&id=1, http://www.biodieselbr.com/eventos/biodiesel.htm, http://www.abag.com.br/index.php?apg=cong_visor&ncong=2011), LCA has been considered one of the preferential approaches to support the decision-making process for establishing appropriate governmental policies and technological choices.

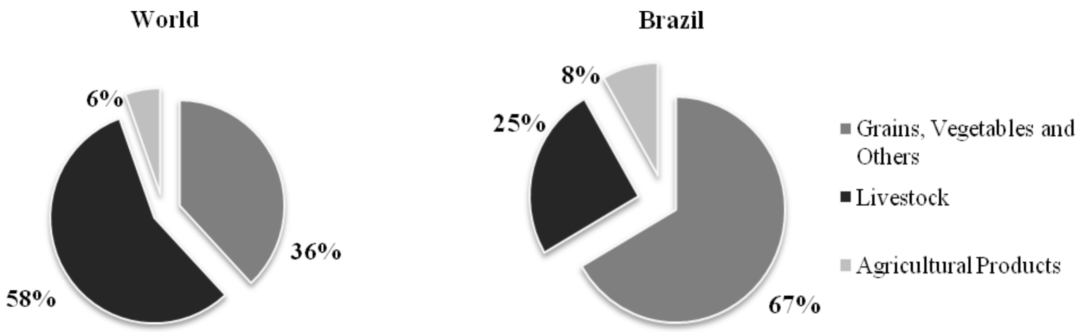


Figure 7 - Distribution of different studies on LCA according to the type of agricultural product (world and Brazil)

In world reports, but not in Brazilian reports, livestock outnumbers grains, vegetables and diversified agricultural products (Fig. 7). This is probably a result of European concerns regarding animal greenhouse gas emissions (GHG), food safety, traceability, and production costs.

In Brazil, production and export of grains play a central role in the formation of the national GDP, which may explain why grain LCA studies predominate. In addition, grains cover large areas of land and form a base for the poultry and swine agro-industrial food chains. Studies on sugarcane and biomass production, both related to expansion of land use and to the growing biofuel industry, tend to gain relevance in the group. Livestock production will certainly demand more research to create an inventory on animal GHG emissions applicable to tropical and subtropical regions.

5 Conclusions

The literature search on LCA provides a comprehensive overview of the various environmental impacts caused by agricultural production in different countries and offers the potential to help in directing the sustainable production of food and other agricultural products.

In Brazil, the application of LCA methodology in the field of agribusiness is still in its infancy. It would be in the interest to the economy of the country to promote the use of such techniques for the assessment of potential environmental impacts to meet the growing demand for answers to questions regarding the sustainability of agricultural production in food-exporting countries.

Brazil can implement solutions for environmental issues related to agriculture with the help of institutional arrangements among universities, industries and government agencies to promote science and innovation for a sustainable agricultural production. International research shows how much can be done. For Brazil to remain an important food and feed exporter, efforts are needed both to adapt the methodologies of LCA and of Life Cycle Impact Assessment, LCIA, to the peculiarities of the country and to develop an LCI applicable to Brazil's agricultural systems. There are certainly many opportunities for local efforts to promote related advanced education, human resources training, infra-structure, and institutional growth.

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CHAPTER III

MARKET-ORIENTED CATTLE TRACEABILITY IN THE BRAZILIAN LEGAL AMAZON[5]

Clandio Favarini Ruviaro, Júlio Otávio Jardim Barcellos and Homero Dewes

Abstract

Purpose – The purpose of this paper is to note the importance of market orientation in agribusiness and to describe the relevance of market-oriented traceability in the export of beef from the Brazilian Legal Amazon.

Design/methodology/approach – The study is of a descriptive nature. The study uses bibliographic references and secondary data to discuss bovine traceability in the context of deforestation of the Brazilian Legal Amazon and its consequences for international beef trade. Analysed data include those related to the Amazon Region. The following aspects are considered: deforestation dynamics, consumer demands, the volume of exported meat, and traceability as a prerequisite for meat export based on the market orientation theory.

Findings – The results indicated that, according to market orientation, beef certification is a prerequisite for meat produced in the Brazilian Amazon Region for maintaining and expanding a sustainable share of the international markets without the burden of presumptive deforestation.

Practical implications – The findings markedly affect primary beef production in the region analysed. The local production systems are forced to adapt to the demands of consumers who are anxious to be assured that the environmental footprint of livestock produced is mitigated worldwide, particularly in the Brazilian Amazon.

Originality/value –Concerns regarding the environmental impact of animal production are crucial in the promotion of sustainability of agriculture production. The major drivers of sustainability in agriculture are the demands of the food market. In this paper, we applied the concept of market orientation and derived the need to apply traceability in animal production in one of the most scrutinised areas of the world in terms of environmental risks.

Keywords- Agribusiness, beef production, sustainability, LCA, Life Cycle Analysis, cattle, supply chain, consumer choice.

Paper type- Research paper

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1 Introduction

The traceability of food has been pivotal for food security. By knowing the origin, the way it is produced, and the path of the components of a food species, we can find the possible sources of food anomalies and control quality in all steps of production. Traceability of food allows one to entrust error responsibility and to claim in mitigation any negative impact of its production and distribution. This same concept of food traceability is currently used to trace the environmental impact of food production as well. In this way, consumers can choose food of lower environmental impact, and society as a whole can demand specifically localised, cleaner, and sustainable agriculture.

In this sense, the growing concerns related to food security and environmental impact must be taken into account when seeking to expand business opportunities. This kind of market demand for differentiated food products leads to the adoption of institutional food certification procedures, which provide information to the consumers concerning the composition quality and the environmental amiability of the food.

These trends in the dynamic market cause changes in the agribusiness sector. Consumers are becoming more conscious of the diversity of products and more attentive to their quality and security, as well as the environmental aspects of their production.

Since 2004, Brazil has been the world's largest cattle breeder for beef for human consumption. To maintain this position or win new market niches, it is necessary to observe the market orientation requirements of this industrial sector.

Adaptation to the market is characterised as one of the greatest demands on companies. The demand is particularly great in agribusiness, due to the greater risk and smaller predictability inherent in agriculture activities. "Market orientation" is an organisational culture that generates the behaviour necessary to create a superior value for consumers and a sustainable competitive advantage for the organisation.

Consumers concerned with reducing the environmental footprint of the agro-industry hope the negative influence of livestock production in the Amazon rainforest will be minimal or non-existent. The expansion of beef production into the deforested areas of the so-called Legal Amazon, a political-geographical area that expands far beyond the rainforest, brings serious concerns to this segment of Brazilian agribusiness. International consumers are led to think that all Brazilian beef is produced on pristine land.

A major misconception is that all of the Legal Amazon is incompatible with livestock production. The reckless, unplanned deforestation practiced in the past has been gradually abandoned because it is not sustainable over time. The old predatory livestock production systems are losing ground to models of production with environmental responsibility. Economic interest and preservative and conservative beliefs are integrated into acceptable production processes for the region. The environmental issues are serious, particularly for people concerned with economic activities in the Amazon. People are looking for ways to promote sustainable livestock in harmony with environmental considerations.

Traceability requires local assessment of the environmental quality of production. Life Cycle Assessment (LCA) methodology provides a powerful analytical instrument to evaluate the environmental impacts of beef production and strengthen its sustainability (ISO, 2006). Cattle traceability – required by the main importing countries – and LCA practices are prerequisites for Brazil. The country can then properly address the origin and characteristics of its beef and remain competitive in the international markets without the burden of Amazon rainforest deforestation.

This paper aims to describe traceability as an answer to market orientation in beef production in the Brazilian Legal Amazon region.

2 Theoretical background

2.1 Market Orientation Theory

The market orientation theory focuses on market research as a strategic way to increase organisational performance. Studies have described market orientation as having three behavioural components: customer orientation, competitor orientation, and inter-functional coordination. These should be the axes of the company when establishing the relationship between market orientation and business performance (Kohli and Jaworski, 1990, Narver and Slater, 1990). This concept goes beyond consumer-oriented marketing practices. It includes analysing the behaviour of competitors and coordinating actions within the organisation that affect performance.

Market orientation takes into account both current and potential customers by the evaluation of market information early and systematically (Slater, 2001). The adoption of market orientation-based strategies is a possible source of competitive advantage that can differentiate a company from its competitors and lead to superior organisational performance (Kirca and Hult, 2009).

One conceptual model with respect to external market orientation is credited toCadogan *et al.* (1999). This kind of orientation towards the international market complements the work of Kohli and Jaworski (1990) and Narver and Slater (1990). It adds an integrative dimension called the coordination mechanism, which includes activities associated with the generation of information, internal dissemination of information, and the formulation of responses to the external market.

Many studies are focused on evaluating the positive relationship between the constructs of market orientation and organisational performance (Cano *et al.*, 2004, Steinman *et al.*, 2000, Urdan, 2004) either by sales growth indicators (Narver and Slater, 1990) or by the number of exports (Cadogan *et al.*, 2003). It appears that the positive relationship between market orientation and organisational performance also exists between external market orientation and international performance (Cadogan *et al.*, 2003, Macera and Urdan, 2004, Rose and Shomam, 2002).

The opening of international markets and the expansion of Brazilian agribusiness exports have been essential for the growth of this economic sector. Despite the existing literature on external market orientation, studies focused on Brazilian agribusiness products are still emerging. This is most likely because the analysts of this sector are focused more on production than on the market itself. It is possible for production managers to start focusing on the agribusiness market, following some changes in strategy and marketing practices of the organisations involved (Beverland and Lindgreen, 2007).

2.2 Traceability

The International Organization for Standardization (ISO, 2007) defines traceability as "The ability to follow the movement of a feed or food through specified stage(s) of production, processing and distribution”.

Several traceability systems have been established in Europe, North America and elsewhere that define traceability as the ability to track consumer products over production and distribution channels, facilitating quality control and possible withdrawal of the product from the market.

Effective traceability provides a safety net where any unanticipated adverse effect can be determined. Traceability and certification are basic tools for guaranteeing the origin and the quality of products and of agro-industrial processes. Traceability depends on a complex information system, starting with the production of raw materials (Portelle *et al.*, 2000, Cochoy, 2001).

For firms, certification raises the quality of their processes, products or services, improves their competitiveness, and allows exporting companies to comply with the technical requirements of international trade (Zeidan *et al.*, 2011). Traceability is of growing importance in the beef production chain; however, its implementation is hindered by a lack of chain coordination between many producers, the heterogeneity of firm sizes with different levels of capitalisation, and the diversity of cattle breeds (Marques *et al.*, 2005).

2.3 Life Cycle Assessment

The LCA methodology has been used to evaluate the environmental profile of alternative agricultural products and food processing methods. According to the ISO (2006), an LCA comprises four main stages: goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation of the results. This methodology consists of a detailed compilation of all the environmental inputs (material and energy) and outputs (air, water, and solid emissions) at each stage of the life cycle. LCA in beef production could improve the safety of the meat based on the Food Traceability System. In Brazil, the collected data for beef production through LCA provide solid information to the Brazilian Service of Supply Chain Traceability of Cattle and Buffaloes (SISBOV) databases concerning farmer, location, land use, bovine species, yield, production area, crop production, and N, P, and K (MAPA, 2004).

Some important international studies have focused on the feasibility of LCA applications in agriculture (Crosson *et al.*, 2011b, Ruviaro *et al.*, 2012). Detailed research reports address the life cycle of the most important livestock production systems. Some researchers have used the LCA methodology to investigate the total environmental impact of beef production, such as Place and Mitloehner (2012a), Pelletier *et al.* (2010), Koneswaran and Nierenberg (2008b) and Casey and Holden (2006). In addition, Cederberg *et al.* (2009b) performed an LCA of beef cattle production using data obtained from Brazilian livestock farms to identify the variability in environmental impacts among different systems of beef cattle breeding. Although some have studied he LCA of beef cattle (Beauchemin *et al.*, 2010, Peters *et al.*, 2010, Ogino *et al.*, 2007), there is no connection between the LCA data and sustainability and market-orientation cattle traceability. We consider the adoption of LCA methodology as a way to analyse the local environmental impact of agriculture production and embed food traceability.

3 Methodology

The present study is of a descriptive nature and uses bibliographic references and secondary data. The search for references was carried out initially using Web of Science, Scopus and other databases. The objectives were to find international publications dealing with the subject, analyse how it is currently being discussed in the international academic community, and determine what publications are the most relevant, who are the main authors are, and what queries and analyses they carry out.

Documents were searched using databases developed by Brazilian institutions, such as the Livestock Directory – ANUALPEC, the Ministry of Agriculture, Livestock, and Food Supply –

MAPA, the National Institute for Space Research – INPE, and the Brazilian Institute for Geography and Statistics – IBGE.

Analysed data were related to the Amazon Region and considered aspects such as the amount of exported meat, deforestation dynamics, consumer demands, and traceability as a prerequisite for meat exports based on the market orientation theory.

4 Results and discussion

4.1 Delimitation of the Brazilian Legal Amazon

The Legal Amazon covers 522 million hectares encompassing 61% of the Brazilian territory, including the states of Acre, Amapá, Amazonas, Mato Grosso, Pará, Rondônia, Roraima, and Tocantins, and part of the state of Maranhão (Figure 8). Twelve percent of Brazil's population lives in the region. Land encompassed by the Legal Amazon is responsible for 5% of the GNP and 10% of it is rural property, most of which is single-family held, with respective areas under 100 hectares (SUDAM, 2010).

Figure 8 - Geographical coverage of Legal Amazon.
Source: SUDAM (2010).

The low cost of land, cheap labour, and other socioeconomic characteristics have promoted the expansion of livestock breeding in Legal Amazon, making it a highly lucrative activity. Favourable soil and climate conditions also contribute to the expansion of beef cattle production in the region (Ribeiro *et al.*, 2005).

4.2 Deforestation in Legal Amazon

The Amazon plays a vital role in global climate stability and the preservation of the planet's biodiversity. One of the threats to this unique ecosystem is the expansion of agriculture and livestock breeding over the forest. Technological development and the development of public policies such as the Low Carbon Agriculture Program, announced by the Brazilian government in 2010, may enable the creation of sustainable environmental projects for preserving this ecosystem.

According to Table 5, the annual deforested area in the Legal Amazon increased between 2000 and 2004. There was a reduction in this rate following this period until 2007, partially as a result of unfavourable exchange rates for exports combined with governmental action to repress illegal land exploitation in the state of Mato Grosso. In 2008, there was a new increase in the annual deforested area. In 2009, deforestation was reduced due to governmental initiatives such as the Climate Change and Energy Program. With this initiative, the federal government and the UNO mitigated greenhouse gases emissions by reducing wood extraction practices and agriculture, which are responsible for 58% of the emissions of these gases (WWF and Allianz, 2009, Suassuna, 2009).

Table 5 - Yearly deforestation index per State in the Legal Amazon (km²/year).

State/Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Acre	547	419	883	1078	728	592	398	184	254	167	259	271
Amazonas	612	634	885	1558	1232	775	788	610	604	405	595	526
Amapá	0	7	0	25	46	33	30	39	100	70	53	51
Maranhão	1065	958	1085	993	755	922	674	631	1271	828	712	365
Mato Grosso	6369	7703	7892	10,405	11,814	7145	4333	2678	3258	**1049**	**871**	**1126**
Pará	6671	5237	7510	7145	8870	5899	5659	5526	5607	**4281**	**3770**	**2870**
Rondônia	2465	2673	3099	3597	3858	3244	2049	1611	1136	482	435	869
Roraima	253	345	84	439	311	133	231	309	574	121	256	120
Tocantins	244	189	212	156	158	271	124	63	107	61	49	40
Legal Amazon	**18226**	**18165**	**21651**	**25396**	**27772**	**19014**	**14286**	**11651**	**12911**	**7464**	**7000**	**6238**

Source: INPE, 2011

The state of Pará is where the greatest amount of deforestation has happened and it is responsible by 70% of the deforestation occurred in Legal Amazon. INPE measurements include areas that undergo complete deforestation and areas that are under progressive degradation (INPE, 2011).

In Figure 9, an increase in the deforested area per year in the Legal Amazon between 2000 and 2004 can be observed. There was a reduction in index between 2004 and 2007, partially due to adverse export exchange rates and the Curupira Operation, a governmental action aimed at repressing illegal land exploitation in the state of Mato Grosso.

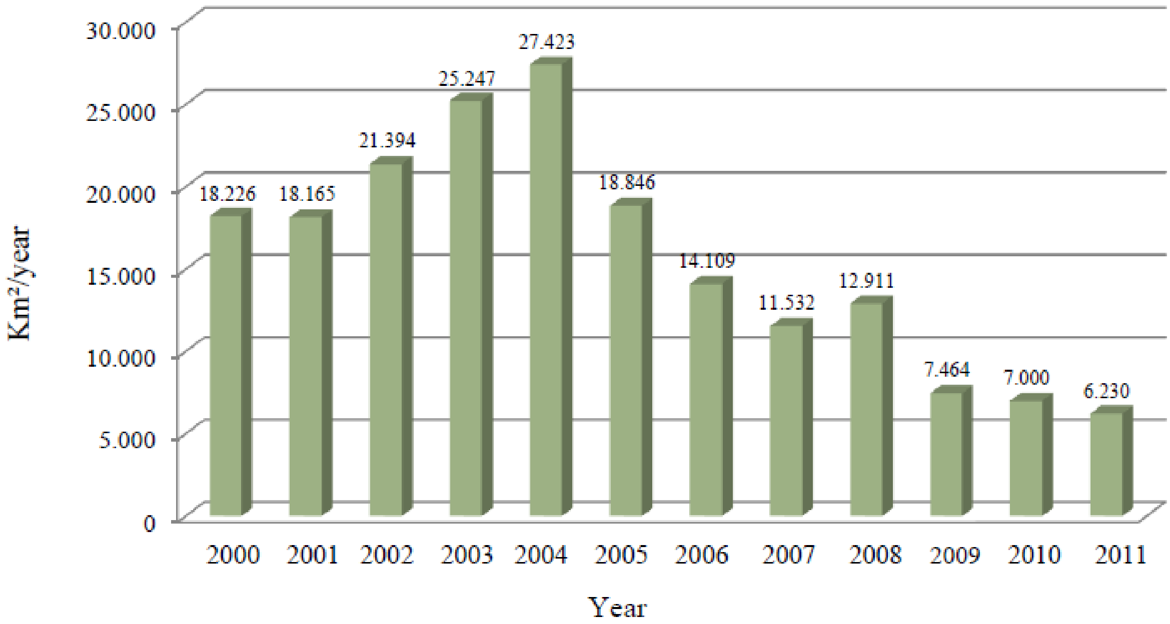

Figure 9 - Annual deforestation area in Legal Amazon between 2000 and 2011.

Source: INPE (2011)

The latest surveys (INPE, 2011) indicate that deforestation in the Amazon reached an area of 6230 km^2 squared between August 2010 and July 2011, a decrease of 11% over the period between August 2009 and July 2010. This is the smallest annual deforested area since the Prodes system (Project Monitoring Deforestation in the Amazon) began to monitor deforestation over 90% of the Legal Amazon in 1988.

4.3 Beef production and export in the Brazilian Legal Amazon

Brazilian beef cattle farming has been characterised by poor management and a resistance to technological innovation (Barcellos *et al.*, 2005). The sector's stagnation until the mid-1990s was the result of the extensive cattle production model, which was rooted in a facilitated access to new land. The cattle herds were used as a capital reserve in times of high inflation and as a strategic approach for consolidating the country's new frontiers in agriculture (Fortes and Yassu, 2008).

In the first decade of this century, this picture has changed. With political and economic stability, Brazil was able to develop its productive potential and consolidate its position as a worldwide food supplier. Livestock agribusiness has expanded, while a professionalization was initiated inside (management, nutrition, health, genetics and management) and outside (slaughter, processing and distribution) the farm (Malafaia *et al.*, 2008).

Brazilian bovine herds had as many as 190.9 million heads in an area of 175 million ha in 2011. Of these herds, 79% was for meat and 21% was for milk production. Brazil is one of the two major producers of beef in the world, producing7.6 million tons of carcass weight equivalent (CWE) per year. Brazil is a major beef exporter, with 1.79 million tons of CWE per year commercialised (Agriculture, 2009, ANUALPEC, 2011).

These numbers represent the economic result of the growth of cattle breeding – although it is not fully consolidated and its environmental consequences are not yet fully known – associated with the expansion of the Brazilian agricultural frontier.

In the fifteen years between 1997 and 2011, it was observed that the expansion of this agriculture frontier, especially in the Center-West and North regions, has resulted in cattle herd growth of approximately 40%. It must be highlighted that much of this expansion occurred in the legally and environmentally complex areas of the Brazilian Legal Amazon, where herd expansion was 178%.

Consolidated breeding areas of the Southeast migrated into new areas in the Center-West and North regions. There was also a small effort in technology use and investment to breed more cattle in the same area (Brasil. Ministério da Agricultura, 2007). In this case, the negative impact on productivity appears in the "stocking rate" (0.76 AU/ha), which is small compared to other countries and below the real potential of Brazilian agriculture and animal production. If this ratio were 1AU/ha, the herd would reach 230 million heads without any need to expand land use.

Based on these data, an increase in management professionalism may overcome these issues at first. In a second stage, it becomes necessary to turn attention to other production practices to raise livestock yield to a more productive level.

Current Brazilian beef production is 7.5 million tons of CWE, of which approximately 23.91% of the total volume is exported (1.79 million ton CWE). In the last ten years (2001-2011), beef exports have increased 227.5% (ANUALPEC, 2011). This is summarised in Table 6.

Table 6 - Cattle herd, total beef production, and exports in Brazil from 2001 to 2011.

Year	Cattle herd (million animal units)	Total production (million tons of CWE)	Exports (million tons of CWE)
2001	170.3	6.754	789
2002	172.2	6.952	929
2003	175.0	7.159	1.208
2004	176.1	7.577	1.630
2005	175.1	8.151	1.857
2006	169.9	8.600	2.100
2007	167.5	7.783	2.194
2008	169.8	7.328	1.829
2009	173.2	7.618	1.611
2010	174.1	7.778	1.547
2011	190.9	7.505	1.795

Source: ANUALPEC, 2011.

In Table 6, an increase in cattle herd and beef production in Brazil may be observed; in 2011, it surpassed 190 million animal units. According to data from IBGE, the cattle herd in the Legal Amazon grew 270% between 1990 and 2008, from 13.9 million heads (animal units; 9.4% of the country's total) to 51.8 million heads (30.5% of the total).

Expansive growth in meat exports from the Legal Amazon occurred between 2001 and 2009, from 6% (10 thousand ton CWE) to 22% (354.4 thousand ton CWE) of the country's total (ANUALPEC, 2010) . This was mainly due to the introduction of traceability processes starting in 2002.

This growth drew attention from environmental defence organisations and from the Brazilian government itself. The Brazilian government was concerned with the reduction of deforestation in new areas for pasture because the six states with the greatest herd expansions between 1990 and 2008 were all in the Legal Amazon. Emphasis was on the state of Mato Grosso (more than 17 million units), Pará (11.3 million), and Rondônia (9.8 million). The states of Tocantins (3.45 million), Maranhão (2.7 million), and Acre (2.05 million) were also of concern (IBGE, 2011).

4.4 Consumer demands

The focus on consumer demands gains importance in a global economy, which is driven by companies that compete in international markets with global strategies. The intrinsic quality assurance of their products or services, or the compliance to health and safety requirements, is increasingly sought by consumers and by the stakeholders of the production chains. Changes are occurring in the coordination of supply chains to ensure final product quality, which depends upon each step of the production processes.

In the European Union – one of the main markets for Brazilian beef – consumers consider it important to have information about the geographical origin of the animal, its feeding conditions, and the environmental impact of cattle-raising activities and to have all that information assured by the procedures of meat certification (Table 7).

Table 7 - European consumer requirements related to beef consumption.

	Not important	Of little importance	Important	Indispensable
Meat of known brand	21%	31%	33%	11%
Know animal's breed	23%	25%	39%	10%
Know the animal's geographic origin	21%	17%	44%	16%
Know the animal's nutritional conditions	18%	18%	43%	17%
Vendor's suggestion (butcher)	14%	13%	46%	25%
Quality certification	2%	9%	50%	33%

Source: Adapted from Eurobarometer (2012).

It is thus evident that the business equation – previously determined by companies that had authority over prices, type and quantity of products – is now controlled by the consumer and consumer necessities and preferences (Cadogan and Diamantopoulos, 1995, Carfantan and Brum, 2006).

This has led the retail sector, controlled by large supermarket chains, to learn about these consumer preferences in detail, especially in developed countries. The retail sector sets the rules in this market and establishes specific conformity standards for its suppliers. Retailers follow the market orientation, which allows superior understanding and satisfaction of customers (Day, 1994).

In this sense, traceability is a pre-requisite for meat exportation for more selective markets such as the European Union. The European Union is an important market for any meat exporting country, be it by the volume of its purchases, by the better rewards paid or by the validation such exports represent to other markets. Among the countries that integrate Mercosur, a multilateral commercial block in South America, Argentina and Uruguay track 100% of the beef exported and their sales are concentrated in the European Union (Table 8).

Table 8 - Cattle herd, total beef production, exports and exports/production ratios in Argentina and Uruguay from 2008 to 2011.

	2008		2009		2010		2011	
	Argentina	Uruguay	Argentina	Uruguay	Argentina	Uruguay	Argentina	Uruguay
Cattle herd (million animal units)	54.260	11.950	49.057	11.828	48.656	11.150	49.655	11.225
Total production (million tons of CWE)	3.150	535	3.375	580	2.60	575	2.05	580
Exports (million tons of CWE)	423	361	655	376	300	380	300	390
Exports/production (%)	13.43	67.47	19.41	64.83	11.54	66.09	16.63	67.14

Source: USDA (2011)

On the other hand, Brazil is currently making efforts to implement and improve its system of traceability to increase its market share. Despite the economic crisis, the European Union continues to demand higher value-added and tracked products.

Until recently, the European Union acquired 25% of Brazilian frozen boneless beef exports, which corresponds to 38% of the income obtained by selling this product on the international market. Nevertheless, the European Union reduced its purchases from Brazil by 80% due to nonconformities in the Brazilian system of bovine traceability. This led to a migration of the production surplus to markets with low profitability, such as Russia and Egypt (Pereira *et al.*, 2011).

The requirements for traceability and the definition of high-quality meat hamper Brazilian exports and result in a greater effort from all sectors of the supply chain to meet the demands of the consumer market.

Table 9 shows the participation of major beef exporting states and the states of the Amazon between 2004 and 2009 by volume. It is evident that the state of São Paulo has always been the largest exporting Brazilian state; however, the expansion of exporting plants and areas authorised for export in recent years is causing a shift in exports to other states that fall into this dynamic.

Table 9 - Participation (%) of selected Brazilian states in beef exports (ton), 2004-2009.

States	2004	2005	2006	2007	2008	2009
Mato Grosso	4.43	6.75	13.15	13.98	13.38	13.23
Rondônia	0.67	1.48	3.32	6.33	7.17	4.34
Tocantins	0.56	0.59	1.58	0.92	1.07	1.75
Pará	0.02	0.05	0.64	0.79	0.69	1.79
Acre	-	-	-	-	-	0.04
Maranhão	0.01	-	-	-	0.08	0.22
São Paulo	70.96	60.34	48.60	48.86	44.12	39.91
Goiás	7.10	8.21	14.73	14.90	12.53	12.91
Mato Grosso do Sul	4.73	9.77	1.72	2.4	7.62	10.48
Rio Grande do Sul	4.91	5.64	8.38	4.71	4.70	4.40
Minas Gerais	1.91	3.01	6.06	5.78	5.52	7.02
Santa Catarina	0.31	0.63	0.21	0.19	0.26	0.35
Others states	4.39	3.53	1.61	1.14	2.46	3.56
Total	100	100	100	100	100	100

Source: ABRAFRIGO (2011)

In Brazil, the Amazonian states expanded the most in the meat exports. In 2004, the states of Mato Grosso, a Legal Amazonian state, and Rio Grande do Sul, which is not an Amazonian state, had a similar percentage of total beef exports; however, Rio Grande do Sul had a drop of 4.66% per year while Mato Grosso grew 24.20% per year. The state of Pará increased the most in its share of Brazilian exports, by 139.41% per year, followed by Rondonia at 52.28% per year, Mato Grosso at 24.20% per year, Tocantins at 21.93% per year, Goiás at 12.97% per year and Mato Grosso do Sul at 10.72% per year.

Among the Legal Amazonian states, exports to the European Union are allowed only in the state of Mato Grosso. This is because traceability is required; Mato Grosso is the only region of the Amazon registered with the Brazilian Service of Supply Chain Traceability of Cattle and Buffaloes (SISBOV).

According to MAPA, in 2008 there were 180 properties accredited to trade meat *in natura* to the EU. In 2012, there are 1948 properties. Currently, 21% of these properties are in the Amazon (all 404 are in Mato Grosso state), although they are not exporting to the EU.

In agribusiness, this reality is reflected in new demands in the productive sectors, as well as for its managers. Sustainable livestock production has the following prerequisites: adequate use of natural resources, investment in technologies that guarantee productivity and revenues, training and capacitating human capital and the effective use of information.

An efficient traceability system, deforestation monitoring, sustainable policies and investment in technology coupled with sustainable development ideas make it possible to obtain consistent results. These results include a significant reduction of deforestation in the Amazon and the capability of the Brazilian beef industry to answer to the demands of import markets.

In this context, the farmer is essential part of establishing appropriate conditions to meet the dictates of the international market for new consumer demands in relation to information products.

4.5 LCA in Beef Cattle Production

In important beef producing and exporting countries, there is an increased application of LCA methodology to qualify local cattle production systems. This has been reported previously (Ruviaro *et al.*, 2012) and is summarised in Table 10. Brazil must follow this trend.

Table 10 - International applications of LCA methodology on beef cattle production according to the countries

Country	Agriculture Products	Author (s)
Australia	Beef	Ridoutt *et al.* (2012)
Australia	Red meat beef	Peters *et al.* (2010)
Canada	Beef	Beauchemin *et al.* (2010)
United States	Beef	Pelletier *et al.* (2010)
Brazil/USA/Canada	Beef/soybeans	Zaks *et al.* (2009)
Brazil/Sweden	Beef	Cederberg *et al.* (2009b)
Global - Germany	Beef	Schlich *et al.* (2008)
Sweden	Beef	Koneswaran and Nierenberg (2008b)
Japan	Beef cattle	Ogino *et al.* (2007)
Canada	Beef cattle	Larney *et al.* (2006)
Ireland	Beef	Casey and Holden (2006)
Japan	Beef	Ogino *et al.* (2004)
Sweden	Beef/milk	Cederberg and Stadig (2003)

Source: based on Ruviaro *et al* (2012)

Although there are numerous international reports on the measurement of greenhouse gases emissions from agricultural products and associated mitigation issues, there are few studies linking the LCA methodology to the beef cattle chain of production and its traceability. The LCA is a complementary and useful methodology to introduce the concept of the life cycle and allow for suggestions for improvement with an environmental focus.

It is necessary to underline the importance of LCA in the beef cattle chain of production because the market is clearly signalling that consumers are demanding products that respect the environment. Trade and economic barriers are being replaced with social and environmental barriers.

5 Conclusion

Brazil was one of the first countries outside of the European Union to begin the process of cattle traceability. Several normative acts were published that defined the Brazilian System of Identification and Certification of Bovine and Buffalo – SISBOV (MAPA, 2004). The measure was adopted to improve the control of origin and destination of the animals from producer to final consumer, contributing to the reduction of underground meat exportation and improving the quality of the meat exported.

Traceability has strategic importance for strengthening the chain of beef cattle production in Brazil for exports. The Brazilian Government worked with slaughterhouses, and beef exporters looked to unify and regulate the environmental and social development of the meat production chain across the legal Amazon Region.

For the domestic and export markets, there are several commercial initiatives, understandings, agreements, contracts, partnerships, certification, and other terms that require some type of control system in livestock production. These issues could be worked out in conjunction with traceability to develop common procedures that meet the greatest possible number of trade requirements simultaneously.

The Brazilian cattle industry seeks to produce efficiently and comply with this new and current demand for quality meat. A globalised economy that emphasises competitiveness and requires the availability of low cost products and better quality for consumers places pressure on production.

The joint effort of the production sectors and the government in Brazil to implement and facilitate the process of traceability is key to ensuring a prominent position in the international agribusiness scene.

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CHAPTER IV

DIFFERENCES IN CARBON FOOTPRINT OF BEEF PRODUCTION DUE TO VARIATIONS BETWEEN PRODUCTION SYSTEMS IN A BRAZILIAN SOUTH FARM[6]

Abstract

The carbon footprint of beef production is one of the most widely discussed environmental issues within the current agricultural community due to its association with climate change. The goals of this study were to evaluate, by Life Cycle Assessment, the potential impact of beef production systems upon the environment and to estimate the carbon footprint of beef cattle production on a farm in the Western Frontier region of Rio Grande do Sul State. Aberdeen angus beef-bred cattle were assigned to one of seven *scenarios*: I) natural grass; II) improved natural grass; III) natural grass plus ryegrass; IV) improved natural grass plus sorghum; V) ryegrass and sorghum pasture; VI) intensified natural grass; and VII) intensified natural grass with supplement. The carbon footprint varied with the *scenario* and ranged from 18.47 to 37.18 kg CO_2-e/kg live weight gain (LWG) for the complete beef production system, including the contributions of cows, calves, and steers. Excluding emissions from pregnant cows, the carbon footprint ranged from 13.6 to 32.1 Kg CO_2-e/kg LWG. The differences in estimated carbon footprint resulting from feed and method of calculation indicate that it is necessary to be prudent when extrapolating or comparing the obtained values among studies. It is important to recognise that the values cannot be extended to take into account the relative biodiversity of different Brazilian regions.

Keywords: Life Cycle Assessment, GHG, livestock, meat, environment, consumer, sustainability

1. Introduction

Beef cattle production is one of the most important agricultural activities in the world, characterised by large numbers of animals and extensive pasture. The Brazilian herd has 205 million head occupying 170 million hectares of pasture, according to the most recent census of the Brazilian Institute of Geography and Statistics (IBGE, 2008).

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In the state of Rio Grande do Sul, there are approximately 13.2 million head of cattle occupying 11.7 million hectares, which is approximately 53.7% of the total area of the state (IBGE, 2008). The beef production relies on the management of natural pasture as the main source of animal feed. These grasslands have high biodiversity and are characterised by high production and quality during the spring and summer and low production and quality in the autumn-winter, when it is necessary to use cultivated pastures or supplementation.

This seasonal efficiency combined with the media constantly highlighting beef cattle in general as a major source of emission of greenhouse gases, has generated actions to reduce its dimensions or minimise its negative impacts. Emissions from cattle are attributed to production processes that involve the inputs (CO_2 and N_2O) and production itself. Regarding the latter, (a) methane emissions (CH_4) are produced through enteric fermentation and manure, and (b) nitrous oxide emissions (N_2O) are emitted by faeces and urine. There is also the possible use of nitrogen fertilisers in pastures. Among these greenhouse gases, the most important is methane (Steinfeld et al., 2006; Beauchemin et al., 2008).

In Brazil, approximately 70% of methane emissions are derived from cattle production (MCT, 2010). Most of the methane has its origin in enteric fermentation and is a normal result of digestion in ruminant animals. It represents, in part, the inefficient capture of energy contained in animal feed. The use of techniques such as intensification of activity through appropriate management of the pastures and improved quality of food supplied to animals mitigates the production of greenhouse gases (O'Hara *et al.*, 2003; McAllister *et al.*, 2011; Cohn *et al.*, 2011; Bungenstab, 2012).

Therefore, better pasture management, supplementary feeding practices, the substitution of forage for food containing less fiber, adequate sanitary control, integrated management of animal wastes, and the genetic improvement of the performance of the animals are techniques that may improve livestock productivity and reduce emissions linked to beef cattle production (Wilkins and Hump, 2003; Boadi *et al.*, 2004; Pedreira *et al.*, 2004, Barioni *et al.*, 2007; Oliveira *et al.*, 2007; Segnini *et al.*, 2007).

The aim of this study was to quantify and analyse the greenhouse gas (GHG) emissions (as carbon footprint) per functional unit (FU) for a typical south Brazilian beef production system. To attain this required (a) defining a *typical* beef production system operating in South Brazil; (b) defining the system boundary and functional unit; and (c) using the dietary and *scenario* options employed in South Brazilian beef production that may lead to reduced GHG emissions. Contribution to climate change associated with 7 different production systems was evaluated using an LCA approach (Curran, 1996; Guinée *et al.*, 2001). The original use of the LCA study was to associate default data provided by IPCC (2007) for CO_2, CH_4, and N_2O emissions related to feed and animal dung with those now available in Brazil from EMBRAPA (MCT, 2010; Lima *et al.*, 2012).

2. Material and Methods

2.1 Definition of the production system

This study was conducted at a farm in the Western Frontier region of the state of Rio Grande do Sul, Brazil. This region has the largest beef cattle herd (3,285,590 head), approximately 22.2% of the total cattle herd in this state (IBGE, 2008). The climatic classification is wet subtropic Cfa in Koeppen classification (Koeppen, 1948). The average precipitation is 1598 mm yr, without dry season. The average annual temperature is 19.8C. Cattle are bred extensively, forage on natural and cultivated pasture with variable stocking rates and are responsible for most of the meat production in the region.

In addition to natural grass, other pastures for beef cattle feed include improved natural grass (a mixture of natural grass, ryegrass and clover), ryegrass and sorghum. All the farmed animals are of the *Bos taurus* breed (Aberdeen angus). It was assumed that calves are weaned at approximately 180 days and that from this period onwards, they graze on grass. From 180 days to when the fattening weight is attained, the animals are allowed to graze on grass according to the *scenario*s defined forward (described in item 2.5). The animal fattening weight was 430 kg live weight for all *scenarios*. The data used (average of 6 years from 420 animals) reflect the reality of cattle farms with varied production systems in the region.

2.2 The system boundary and functional unit

The system boundary is defined by the GHG emissions associated with South Brazilian beef production from "cradle to farm-gate". The LCA of the production systems included natural grass, cultivated forages (natural grass plus ryegrass and clover, ryegrass, or sorghum), natural grass supplemented with proteinic-energetic mineralised salt and the resources used to produce these components (e.g., diesel and fertilisers), and all transportation, including the transport of components to the farm where they were consumed by the herd. Data concerning resource use and emissions associated with the production and delivery of several requirements for forage cultivation (fertilisers, diesel, and agricultural machinery) were obtained from the Ecoinvent database, version 3.0 (Nemecek *et al.*, 2007).

The model includes the physical limits of the beef unit and associated activity: emissions associated with nitrogen fertiliser production, transportation and application; emissions associated with animals; and emissions associated with the diesel used for agricultural work on the ranch. The following GHG sources were considered: on-farm CH_4 emissions from cattle and manure; on-farm N_2O emissions from manure and soils; and run-off and volatilization of indirect N_2O emissions. The emissions associated with the production of medicines and pesticides are excluded due to absence of data (Cederberg and Mattsson, 2000). CO_2 from enteric fermentation was excluded from the study because this enter a cycle comprising the uptake of atmospheric carbon by crops followed by a return to the atmosphere through animal respiration (IPCC, 2007). Thus, this gas is considered neutral with respect to GHG emissions. In this study, the functional unit (FU) used for all flows within the system studied was “1 kg live weight gain (LWG) at the farm gate”. This functional unit serves as the measure of the performance of a production system to which all inputs and outputs are related.

2.3 Impact category

The global warming potential (GWP) over a 100-year time horizon was used to determine the contribution of CO_2, CH_4 and N_2O to the greenhouse effect (IPCC, 2007). Carbon footprint was estimated by the average of regional beef using a standardised method of LCA (ISO, 2006a; ISO, 2006b) to calculate the environmental impact of a product from a life cycle perspective. Carbon footprint estimation through Life Cycle Assessment (Crosson *et al.*, 2011) considers the resources used in production, as well as the production of gases during the production process and from production to consumption (Peters *et al.*, 2010). All calculations were performed in Excel using the LCA software tool SimaPro 7.3.2 (PRéConsultants, 2010). These gases have different global warming potential when converted to carbon dioxide equivalents. Each kg of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) released to the atmosphere is equivalent to 1 kg, 21 kg and 298 kg of carbon dioxide, respectively. The analysis of carbon footprint identifies areas where emissions may be reduced by improved efficiencies, estimates the amount and breakdown of GHG emissions and provides a mechanism to track efforts in improving efficiencies and reducing emissions.

2.4 Emission factors

Enteric methane emissions were calculated using the equations from IPCC (Dong *et al.*, 2006). Input data in this model are the animal live weights and were used to estimate the energy required for maintenance, beef yield to estimate the energy required for production, energy content in feed intake, and proportions of roughage feed and crude protein in the total dry matter intake (DMI) (NRC, 2000; Dong *et al.*, 2006).

Emission factors (EFs) for N_2O from dung were based on data from Primavesi *et al.* (2012). Over the duration of each life cycle stage in all production systems, the environmental inventory was limited to emissions of enteric CH_4, emissions from N (urea), and emissions from manure. The emissions from animals were calculated according to the data from chapter 10 of the IPCC (Dong *et al.*, 2006) using equation 10.21, 10.23, 10.24, 10.25 and Table 10.17. Methane emissions from manure and excreta deposited on the field during grazing were calculated according to Tier II protocols from the IPCC guidelines (IPCC, 2007). The emission factors and methane conversion factors (MCFs) were calculated following Tier II protocols and adjusted following the analysis protocols in Lima *et al.* (2006) and MCT (2010). Tier II protocols were employed to calculate the enteric methane emissions because of the sensitivity of emissions to the production system and the importance of methane emissions to overall GHG emissions in beef cattle production. In this study, a 6% conversion factor (Ym) was applied to the pasture data (Johnson and Johnson, 1995, Dong *et al.*, 2006, Primavesi *et al.*, 2012). The production of manure was calculated based on DMI with digestibility varying according to the forage type in each production system (Valadares Filho *et al.*, 2010; Peripolli *et al.*, 2011).

Direct emissions of nitrous oxide (N_2O) from soil and EF values were calculated as recommended by the IPCC (2007) with adjustments as in Alves *et al.* (2012) using equation 11.2 and 11.5 from chapter 11 using the measured nitrogen intake and nitrogen retained. The nitrogen applied to soil as fertiliser was calculated as nitrogen in urea, as recommended by SBCS (2004). The nitrogen in excreta was calculated as the total amount of N in feed dry matter intake (DMI) minus the amount of N in beef (calves and growth). The indirect emissions of N_2O caused by volatilization of NH_3 and leaching of nitrate (NO_3) were estimated using EF values according to the IPCC (2007).

2.5 *Scenario*s for carbon footprint estimation

*Scenario*s were developed using Angus beef-bred animals utilised in typical South Brazilian beef production systems as castrated males. The system was then modified to consider the life cycle from pregnant cows (281 days) to fattened steers with a 430 kg final live weight in all *scenario*s (Table 11). *Scenario I* analysed animals in natural grass for a period of 840 days. In *Scenario II*, the animals grazed on improved natural grass for 510 days. In *Scenario III*, the animals grazed on natural grass for 510 days plus 159 days on ryegrass. In *Scenario IV*, the animals grazed on improved natural grass for 360 days plus 125 days on sorghum. In *Scenario V*, the animals grazed on cultivated ryegrass and sorghum for 502 days. In *Scenario VI*, the animals grazed on natural grass supplemented with proteinic-energetic mineralised salt for 510 days. In *Scenario VII*, the animals grazed on natural grass supplemented with proteinic mineralised salt for 660 days.

Table 11 - Schedules of the live weight, live weight gain, duration from calving to fattening and stock rate of each *scenario*.

		Age, mo					
	Scenario	6	12	18	24	30	
Live weight, *kg*	I	165	195	280	325	430	
	II	190	330	430	-	-	
	III	165	195	280	430	-	
	IV	190	330	430	-	-	
	V	190	330	430	-	-	
	VI	220	260	430			
	VII	220	260	360	430	-	
DMID, *kg/d*	I	1,02	1,84	2,42	3,36	3,37	
	II	1,50	3,57	4,83	-	-	
	III	1,02	1,84	2,42	5,59	-	
	IV	1,15	3,58	4,83	-	-	
	V	1,10	3,47	4,99	-	-	
	VI	1,31	2,49	3,77	-	-	
	VII	1,31	2,49	3,15	4,45	-	
							total
Live weight gain, *kg*	I	133	30	85	45	105	398
	II	158	140	100	-	-	398
	III	133	30	85	150	-	398
	IV	158	140	100	-	-	398
	V	158	140	100	-	-	398
	VI	188	40	170	-	-	398
	VII	188	40	100	70	-	398
Period, *d*	I	180	150	180	150	180	840
	II	180	180	150	-	-	510
	III	180	150	180	159	-	669
	IV	180	180	125	-	-	485
	V	180	180	142	-	-	502
	VI	180	150	180	-	-	510
	VII	180	150	180	150	-	660
							means
Live weight supported, *kg/ha*	I	397	397	397	397	397	397
	II	716	716	716	-	-	716
	III	397	397	397	930	-	530
	IV	716	716	1150	-	-	861
	V	930	930	930	-	-	930
	VI	380	380	380	-	-	380
	VII	380	380	388	380		382

3. Results and Discussion

Evaluation of strategies for mitigation and adaptation usually occurs at scales at which interventions can be performed (the production system, region or country). Recent publications have used Life Cycle Assessments to determine all or a portion of the GHG emissions from measured inputs and outputs over beef production systems (Schils et al., 2007; Avery and Avery, 2008; Veysset et al., 2010; Sejian et al., 2011; McAllister et al., 2011; Dollé et al., 2011; Cederberg et al., 2011; Beauchemin et al., 2011; Place and Mitloehner, 2012). The application of and comparisons among existing LCA can be limited due to differences in goals, system boundaries or functional units. Creating LCA models that account for different management strategies and technology is critical, as there is increasing consumer interest in sustainable beef production and there is a need for a complete analysis of these different systems.

In this study, the estimated carbon footprint of one cattle farm in the Western Frontier region of Rio Grande do Sul State ranged from 18.47 to 37.18 kg CO_2-e/kg LWG (Table 12) for a complete beef system including the contributions of cows, calves, and steers. Excluding emissions from pregnant cow, the estimated carbon footprint ranged from 13.6 to 32.1 Kg CO_2-e/kg LWG.

The results indicate that when viewed on an equal live-weight production basis, *scenario I* (natural grass), with 37.18 kg CO_2-e/kg LWG, is more greenhouse gas intensive than *scenario V* (cultivated ryegrass and sorghum), with 18.47 kg CO_2-e/kg LWG. The least CO_2-e emitting production systems were *scenario V* and *II*, with 18.47 and 18.67 CO_2-e/kg of LWG, respectively, producing fattened animals in 485 and 510 days, respectively. These results are close to those reported by Phetteplace *et al.* (2001), who estimated 15.5 kg CO_2-e/kg live weight for calf-to-beef systems. Our results are also similar to estimates by Casey and Holden (2006) and Veysset *et al.* (2010) of 11 and 15 kg of CO_2-e/kg of live weight gain, respectively. Hacala and Le Gall (2006) estimate a carbon footprint between 11.33 and 14.69 kg CO_2-e/kg live weight in three suckler systems. Studies evaluating the carbon footprint of beef production in Japan (Ogino *et al.*, 2004), Sweden (Koneswaran and Nierenberg, 2008) and Brazil (Cederberg *et al*., 2009), have also reported similar values of total GHG emissions as in the current study, ranging from 22,8 kg of CO_2-e/kg of beef to 32.3 kg of CO_2-e/kg of beef.

Table 12 - Summary of the calculated CO_2 equivalent inputs from each growth stage of each *scenario*.

				Age, mo				total	excluded pregnancy cow
	Scenario	Cow	0 - 6	6 - 12	12- 18	18 - 24	24 - 30	emissions	emissions
CO_2 equivalent, *kg CO_2 e/live weight gain*	I	4,87	3,51	8,07	5,52	8,55	6,66	37,18	32,31
	II	4,87	3,34	3,83	6,63	-	-	18,67	13,80
	III	4,87	3,51	8,07	5,52	3,80	-	25,77	20,90
	IV	4,87	3,34	8,07	6,49	-	-	22,77	17,90
	V	4,87	3,48	3,78	6,34	-	-	18,47	13,60
	VI	4,87	2,20	8,05	5,18	-	-	20,30	15,43
	VII	4,87	2,20	8,05	6,03	7,78	-	28,93	24,06

The highest CO_2-e emissions were from *scenario*s *I* and *VII*. These produced 37.18 and 28.93 kg CO_2-e/kg LWG, respectively, with fattening periods of 840 and 660 day, respectively. These *scenario*s had the lowest dry matter intake digestibility (DMID) of 48%. Among all grassland-based cattle farms, those production systems with DMID from 52 to 59 % achieved the lowest CO_2-e emissions and highest feed conversion rate. This means that they generate lower CH_4 and N_2O emissions per production system. The high values of approximately 27 kg of CO_2-e per kilogram of body weight gain, scaled with intensity of production, were reported in a study by Nguyen *et al.* (2010).

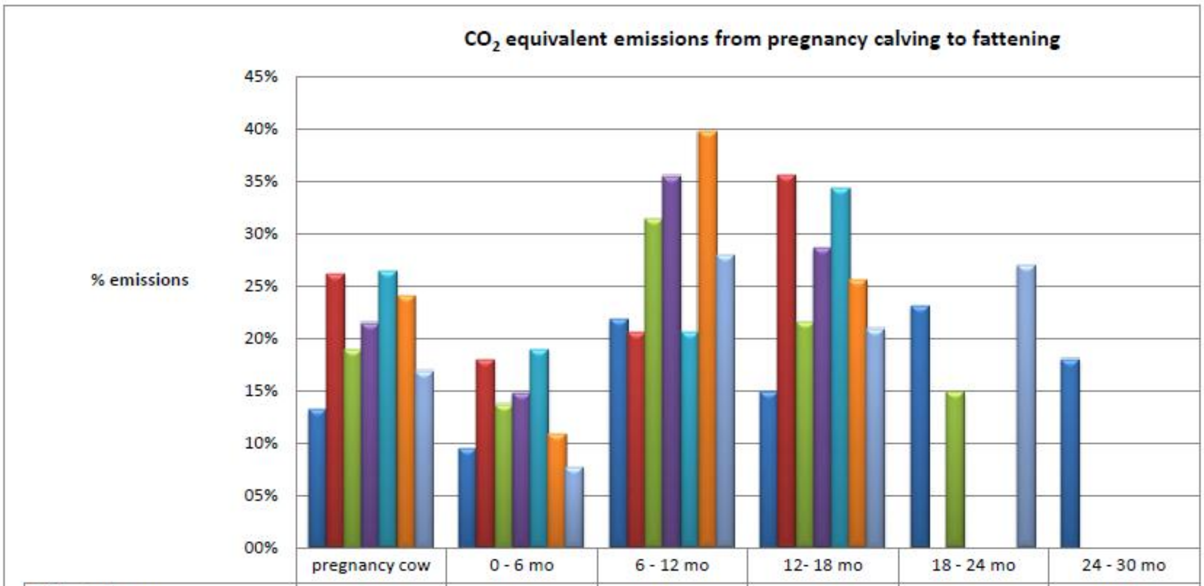
Importantly, it is necessary to consider the relative intensity of the production system, the stocking rate (number of animals raised and produced per hectare) and the kilogram of body weight gain obtained per hectare as the main drivers of the greenhouse gases emissions. The most intensive production systems, those with *scenarios* II, IV, V and VI with 510, 485, 485 and 510 days for producing fattened animals and a stocking rate of 716, 861, 930 and 380 kg/ha, respectively, are the lowest CO_2-e emitting *scenarios* (Table 11).

Scenario VI produces lower emissions (20.3 kg CO_2-e/kg LWG) despite the low DMID (48%). The proteinic-energetic mineralised salt used led to these results because it acts as an amender in the feed conversion rate and reduces the time to achieve the fattening weight (510 days). These results are consistent with those of other studies that have shown that higher quality forage, the use of concentrated, essential oils or increased growth rates reduce methane and nitrous oxide emitted from manure, both of which are key emission gases (Lovett *et al.*, 2005; Casey and Holden, 2006; Benchaar and Greathead, 2011).

Comparisons of these results with previous studies reveal a number of difficulties. First of all, in Brazil there are no studies concerning beef production using Life Cycle Assessment methodology (Ruviaro *et al*., 2012). One very significant problem is the variation in choice of functional unit and time scale among studies. For example, a study of a Japanese beef fattening system (Ogino *et al.*, 2004) estimated a 32.3 kg CO_2-e/kg of beef gain during the fattening of the animal, but this did not include cow emissions for the whole system. Furthermore, it should be noted that the production efficiency in the Japanese cattle system was very different from that in this study.

In another recent study of Brazilian beef cattle, Cederberg *et al.* (2011) estimated a carbon footprint from beef cattle production in the Legal Amazon Region. However, Cederberg *et al.*'s estimates are not adequate for comparison because they assumed calving intervals of 20 months and 3-4 years to fattening. This is an inefficient production system that is used in a specific region and does not represent Brazilian norms. These issues make it difficult to compare the results among studies because of differences in management practices and assumptions regarding the production systems in other countries.

Despite the large differences among studies, reflecting differences in the boundaries of the systems and assumed farming practices, our results agree with those of Pelletier *et al.* (2010). Their study considered a complete beef production system in which the fattening phase (more than 12 months) accounted for less than 36% of the total GHG emissions in the most efficient *scenarios*, similar to *scenarios* II, IV, V and VI of the current study (Figure 10) and are the lowest CO_2-e emitting *scenarios*. The growth phase between calving and 6 months of age accounted for less than 19% of the total CO_2-e emissions in all these *scenarios*.



	pregnancy cow	0 - 6 mo	6 - 12 mo	12- 18 mo	18 - 24 mo	24 - 30 mo
I Natural grass	13,10%	9,44%	21,71%	14,85%	23,00%	17,91%
II Impr. natural grass	26,08%	17,89%	20,51%	35,51%	0,00%	0,00%
III Natural grass, ryegrass	18,90%	13,62%	31,32%	21,42%	14,75%	0,00%
IV Impr. natural grass, sorghum	21,39%	14,67%	35,44%	28,50%	0,00%	0,00%
V Ryeg, Ing, sorg	26,37%	18,84%	20,47%	34,33%	0,00%	0,00%
VI Natural grass suplem 18	23,99%	10,84%	39,66%	25,52%	0,00%	0,00%
VII Natural grass suplem 24	16,83%	7,60%	27,83%	20,84%	26,89%	0,00%

Figure 10 - Summary of CO_2-e emissions (%) for each production system according to the growth stage.

Considering the variation among published studies from the point of view and specific methodology of collection and analysis of data, we recognize that the results from specific regions cannot be used to compare beef production *scenarios* in different regions of the world. Comparison of the various studies emphasises the effect of each production system and variation in efficiency on the estimated environmental impact.

4 Conclusion

Life Cycle Assessments are useful tools for analyzing the carbon footprint of beef. They consider all phases of the production system and allow for comparisons among distinct beef cattle production *scenarios* because the sources of greenhouse gases used in the analyses do not vary among systems.

Our results suggest that some production systems of beef cattle in the western frontier of Rio Grande do Sul have lower GHG emissions. Improvements in pasture quality, genetic selection for animals with high feed conversion rates, promotion of better pasture management, use of additives and establishment of integrated crop-livestock systems are factors for mitigation of the emissions of greenhouse gases.

Although beyond the scope of the current analysis, it would be interesting to assess the comparative greenhouse gas emissions of the pasture-finished beef productions systems in which components of the diet are customised to reduce methane emissions.

Given that it is difficult to assess the carbon footprint of any production system alone, considering the lack of baseline data in Brazil, this study can become a standard for future LCA studies.

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CHAPTER V

It is not the nature of things for any one man to make a sudden, violent discovery; science goes step by step and every man depends on the work of his predecessors….
…Scientists are not dependent on the ideas of a single man, but on the combined wisdom of thousands of men, all thinking of the same problem and each doing his little bit to add to the great structure of knowledge which is gradually being erected.

Sir Ernest Rutherford (1871-1937)

CONCLUSIONS AND IMPLICATIONS

The methodology of evaluating the Life Cycle Assessment presented in this thesis may give an over-view of the various potential impacts induced on the environment, constituting itself a technique of environmental management practiced in many countries with a potential to guide and direct a sustainable development of processes and products. Bibliographic data collected for the study puts in evidence a large spectrum of possibilities for the application of LCA in Brazil to deal with the increasing demand of evaluation systems on environmental impacts.

As observed while perusing existing literature, several LCAs have been applied to the livestock chain around the world, giving evidence that consumers, decision makers and stakeholders in the agri-food sector have become increasingly more aware of the impacts of agricultural production on the environment. However, the use of LCA has previously been hindered by the limited availability of databases concerning the life cycle inventory. More studies related to this matter are necessary to improve the knowledge of the life cycle inventory of agricultural products, infrastructure inputs and processes. These issues have prompted some Brazilian institutions to attempt to develop databases for the agricultural LCA as required to reduce environmental impacts and optimize the food supply chains.

Through its wide and thorough primary representative data, the life cycle inventory, the LCA was proposed as a tool that could be applied to animal traceability and assure the measures for the beef production environmental footprint. Considering, however, the great biodiversity of the Brazilian regions, it is essential to make some adjustments concerning the IPCC methodology for calculating the greenhouse gas emissions within the conditions of tropical and subtropical climate.

Likewise, the results of the research indicate that to obtain an accurate application of the LCA, it is necessary to estimate the flow balance of the greenhouse emissions at the different scenarios and regions. It also means that Brazil, as a major beef producer in the world, needs to develop methodologies, elaborate inventories based in the IPCC Tier 3, allowing, thus, for a more detailed estimate of emissions and removals and calculate the amount of land occupied and the variation of the carbon storage in the soil, since they reflect directly in the results obtained in the LCA.

It was learned that there are not any studies done by Brazilian researchers in regard to the evaluation of the beef cattle using LCA in Brazil. On the other hand, most of the results handled by foreign researchers are not directly comparable to the results presented in this study. A direct comparison with literature values from other LCA studies is difficult due to differences in functional units, project boundaries, and scarcity of detailed information regarding processes or activities that were excluded or included in the other assessments.

At present, a standard approach for a complete beef production system LCA is not available, and therefore, each of those LCAs will differ based on which processes are included and which are not. Therefore, a comparison of this study with the results from other beef LCAs must be prudent because it can potentially lead to misinterpretation of results.

Further, it should be noted that this is a first approximation of the impacts associated with the typical beef production systems by LCA. It is expected that additional studies will address these issues over time, leading to a more accurate approach. However, even in that instance, a lack of uniformity in how beef LCAs studies are conducted may hinder any meaningful ability to compare results between studies.

It is recommended that additional studies be conducted on a number of scenarios in order to improve the accuracy of results and fill in data gaps. Also, further research for more Brazilian-specific emission factor data may be warranted for the next iterations.

At last, "*the systematic way of working with LCA enables communication about large and complex environmental issues. Many find LCA studies somewhat complicated, but this is a case of LCA reflecting the complexities of our world. One must remember that LCA as such is not blame*", (Baumann and Tillman, 2004).

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APENDICES

Apendice I

SimaPro inputs data

		Age, mo					Pregant cow, *281 d*
	Scenario	6	12	18	24	30	
Occupation land,	I	25,1889	25,1889	25,1889	25,1889	25,1889	25,1889
m²/kg live weight supported	II	13,9664	13,9664	13,9664	-	-	25,1889
	III	22,7272	22,7272	22,7272	10,7526	-	25,1889
	IV	13,9664	13,9664	13,9664	-	-	25,1889
	V	10,7527	10,7527	10,7527	-	-	25,1889
	VI	25,1889	25,1889	25,1889	-	-	25,1889
	VII	25,1889	25,1889	25,1889	25,1889	-	25,1889
Gross energy, MJ/kg live weight gain	I	11,7706	78,1696	43,6831	95,9198	49,3319	55,8052
	II	11,0955	27,1989	48,6760	-	-	55,8052
	III	11,7705	78,1696	43,6830	32,8373	-	55,8052
	IV	11,0955	27,1989	40,5633	-	-	55,8052
	V	10,8848	26,2991	37,1881	-	-	55,8052
	VI	10,9949	80,6891	34,5732	-	-	55,8052
	VII	10,9949	80,6891	48,4652	82,2459	-	55,8052
CH_4 enteric, Kg CH_4/kg live weight gain	I	0,15962	0,36660	0,25070	0,38800	0,30252	0,22159
	II	0,14724	0,16967	0,29197	-	-	0,22159
	III	0,15962	0,36660	0,25079	0,16678	-	0,22159
	IV	0,14724	0,16967	0,25907	-	-	0,22159
	V	0,15386	0,15409	0,27463	-	-	0,22159
	VI	0,09978	0,36602	0,23538	-	-	
	VII	0,09978	0,36602	0,27424	0,35352	-	
CH_4 manure management,	I	0,00180	0,00330	0,00290	0,00350	0,00270	0,00203
kg CH4/kg live weight gain	II	0,00163	0,00117	0,00275	-	-	0,00203
	III	0,00186	0,00335	0,00454	0,00089	-	0,00203
	IV	0,00161	0,00117	0,00244	-	-	0,00203
	V	0,00174	0,00087	0,00277	-	-	0,00203
	VI	0,00116	0,00340	0,00216	-	-	
	VII	0,00116	0,00340	0,00251	0,00326	-	
N_2O "N" fertilizer,	I	-	-	-	-	-	-
kg N2O/kg live weight gain	II	0,00072	0,00072	0,00072	-	-	-
	III	0,00000	0,00000	0,00000	0,00059	-	-
	IV	0,00042	0,00042	0,00042	-	-	-
	V	0,00084	0,00084	0,00084	-	-	-
	VI	-	-	-	-	-	
	VII	-	-	-	-	-	
N_2O manure management,	I	0,000018	0,001722	0,000819	0,002192	0,000751	0,002025
kg N2O/kg live weight gain	II	0,000272	0,001521	0,001954	-	-	0,002025
	III	0,000018	0,001722	0,000819	0,002248	-	0,002025
	IV	0,000272	0,001521	0,001587	-	-	0,002025
	V	0,000163	0,001674	0,001164	-	-	0,002025
	VI	-	0,00211	0,000886	-	-	
	VII	-	0,00211	0,00094	0,002051	-	

Apendice II

EQUATION 10.21
CH_4 EMISSION FACTORS FOR ENTERIC FERMENTATION FROM A LIVESTOCK CATEGORY

$$EF = \left[\frac{GE \bullet \left(\frac{Y_m}{100} \right) \bullet 365}{55.65} \right]$$

Where:

EF = emission factor, kg CH4 head-1 yr-1

GE = gross energy intake, MJ head-1 day-1

Ym = methane conversion factor, per cent of gross energy in feed converted to methane

The factor 55.65 (MJ/kg CH4) is the energy content of methane

Apendice III

EQUATION 10.23
CH_4 EMISSION FACTOR FROM MANURE MANAGEMENT

$$EF_{(T)} = \left(VS_{(T)} \bullet 365\right) \bullet \left[B_{o(T)} \bullet 0.67\, kg / m^3 \bullet \sum_{S,k} \frac{MCF_{S,k}}{100} \bullet MS_{(T,S,k)} \right]$$

Where:

EF(T) = annual CH4 emission factor for livestock category *T*, kg CH4 animal-1 yr-1

VS(T) = daily volatile solid excreted for livestock category *T*, kg dry matter animal-1 day-1

365 = basis for calculating annual VS production, days yr-1

Bo(T) = maximum methane producing capacity for manure produced by livestock category *T*, m3 CH4 kg-1 of VS excreted

0.67 = conversion factor of m3 CH4 to kilograms CH4

MCF(S,k) = methane conversion factors for each manure management system *S* by climate region *k*, %

MS(T,S,k) = fraction of livestock category *T*'s manure handled using manure management system *S* in climate region *k*, dimensionless

Apendice IV

EQUATION 10.24
VOLATILE SOLID EXCRETION RATES

$$VS = \left[GE \bullet \left(1 - \frac{DE\%}{100} \right) + (UE \bullet GE) \right] \bullet \left[\left(\frac{1 - ASH}{18.45} \right) \right]$$

Where:

VS = volatile solid excretion per day on a dry-organic matter basis, kg VS day-1

GE = gross energy intake, MJ day-1

DE% = digestibility of the feed in percent (e.g. 60%)

(UE • GE) = urinary energy expressed as fraction of GE. Typically 0.04GE can be considered urinary energy excretion by most ruminants (reduce to 0.02 for ruminants fed with 85% or more grain in the diet or for swine). Use country-specific values where available.

ASH = the ash content of manure calculated as a fraction of the dry matter feed intake (e.g., 0.08 for cattle). Use country-specific values where available.

18.45 = conversion factor for dietary GE per kg of dry matter (MJ kg-1). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock.

Apendice V

EQUATION 10.25
DIRECT N_2O EMISSIONS FROM MANURE MANAGEMENT

$$N_2O_{D(mm)} = \left[\sum_S \left[\sum_T \left(N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)} \right) \right] \bullet EF_{3(S)} \right] \bullet \frac{44}{28}$$

Where:

N2OD(mm) = direct N2O emissions from Manure Management in the country, kg N2O yr-1

N(T) = number of head of livestock species/category *T* in the country

Nex(T) = annual average N excretion per head of species/category *T* in the country, kg N animal-1 yr-1

MS(T,S) = fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S* in the country, dimensionless

EF3(S) = emission factor for direct N2O emissions from manure management system *S* in the country, kg N2O-N/kg N in manure management system *S*

S = manure management system

T = species/category of livestock

44/28 = conversion of (N2O-N)(mm) emissions to N2O(mm) emissions

Apendice VI

Table 10.17
MCF values by temperature for manure management systems

System[a]		MCFs by average annual temperature (°C)																			Source and comments
		Cool					Temperate											Warm			
		≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	≥ 28	
Pasture/Range/Paddock		1.0%					1.5%											2.0%			Judgement of IPCC Expert Group in combination with Hashimoto and Steed (1994).
Daily spread		0.1%					0.5%											1.0%			Hashimoto and Steed (1993).
Solid storage		2.0%					4.0%											5.0%			Judgement of IPCC Expert Group in combination with Amon *et al.* (2001), which shows emissions of approximately 2% in winter and 4% in summer. Warm climate is based on judgement of IPCC Expert Group and Amon *et al.* (1998).
Dry lot		1.0%					1.5%											2.0%			Judgement of IPCC Expert Group in combination with Hashimoto and Steed (1994).
Liquid/Slurry	With natural crust cover	10%	11%	13%	14%	15%	17%	18%	20%	22%	24%	26%	29%	31%	34%	37%	41%	44%	48%	50%	Judgement of IPCC Expert Group in combination with Mangino *et al.* (2001) and Sommer (2000). The estimated reduction due to the crust cover (40%) is an annual average value based on a limited data set and can be highly variable dependent on temperature, rainfall, and composition. When slurry tanks are used as fed-batch storage/digesters, MCF should be calculated according to Formula 1.
	Without natural crust cover	17%	19%	20%	22%	25%	27%	29%	32%	35%	39%	42%	46%	50%	55%	60%	65%	71%	78%	80%	Judgement of IPCC Expert Group in combination with Mangino *et al.* (2001). When slurry tanks are used as fed-batch storage/digesters, MCF should be calculated according to Formula 1.

Apendice VII

There are three tiers to estimate CH_4 emissions from livestock manure.

Tier 1

A simplified method that only requires livestock population data by animal species/category and climate region or temperature, in combination with IPCC default emission factors, to estimate emissions. Because some emissions from manure management systems are highly temperature dependent, it is *good practice* to estimate the average annual temperature associated with the locations where manure is managed.

Tier 2

A more complex method for estimating CH_4 emissions from manure management should be used where a particular livestock species/category represents a significant share of a country's emissions. This method requires detailed information on animal characteristics and manure management practices, which is used to develop emission factors specific to the conditions of the country.

Tier 3

Some countries for which livestock emissions are particularly important may wish to go beyond the Tier 2 method and develop models for country-specific methodologies or use measurement–based approaches to quantify emission factors.

The method chosen will depend on data availability and national circumstances. *Good practice* in estimating CH_4 emissions from manure management systems entails making every effort to use the Tier 2 method, including calculating emission factors using country-specific information. The Tier 1 method should only be used if all possible avenues to use the Tier 2 method have been exhausted and/or it is determined that the source is not a key category or subcategory.

Apendice VIII

EQUATION 11.2
DIRECT N_2O EMISSIONS FROM MANAGED SOILS (TIER 2)

$$N_2O_{Direct}\text{–}N = \sum_i (F_{SN} + F_{ON})_i \bullet EF_{1i} + (F_{CR} + F_{SOM}) \bullet EF_1 \; + \; N_2O\text{–}N_{OS} \; + \; N_2O\text{–}N_{PRP}$$

Where:

EF1*i* = emission factors developed for N2O emissions from synthetic fertilizer and organic N application under conditions *i* (kg N2O–N (kg N input)-1); *i* = 1, …n.

Equation 11.2 may be modified in a variety of ways to accommodate any combination of N source-, crop type-, management-, land use-, climate-, soil- or other condition-specific emission factors that a country may be able to obtain for each of the individual N input variables (FSN, FON, FCR, FSOM, FOS, FPRP).

Conversion of N2O–N emissions to N2O emissions for reporting purposes is performed by using the following equation:

N2O = N2O–N x 44/28

Apendice IX

EQUATION 11.5
N IN URINE AND DUNG DEPOSITED BY GRAZING ANIMALS ON PASTURE, RANGE AND PADDOCK
(TIER 1)

$$F_{PRP} = \sum_T \left[\left(N_{(T)} \bullet Nex_{(T)} \right) \bullet MS_{(T,PRP)} \right]$$

Where:

FPRP = annual amount of urine and dung N deposited on pasture, range, paddock and by grazing animals, kg N yr-1

N(T) = number of head of livestock species/category *T* in the country (see Chapter 10, Section 10.2)

Nex(T) = annual average N excretion per head of species/category *T* in the country, kg N animal-1 yr-1 (see Chapter 10, Section 10.5)

MS(T,PRP) = fraction of total annual N excretion for each livestock species/category *T* that is deposited on pasture, range and paddock12 (see Chapter 10, Section 10.5)