**UNIVERSIDADE FEDERAL DE SANTA CATARINA**

**DEPARTAMENTO DE ENGENHARIA SANITÁRIA E AMBIENTAL**

**PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA AMBIENTAL**

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**INSTITUT SUPERIEUR DES SCIENCES AGRONOMIQUES, AGRO-ALIMENTAIRES, HORTICOLES ET DU PAYSAGE**

**ECOLE DOCTORALE : VIE AGRO SANTÉ**

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# Effects of intensity and scale of production on environmental impacts of poultry meat production chains

***Life Cycle Assessment of French and Brazilian poultry production scenarios***

Thesis presented in co-supervision, in accordance with terms of cooperation signed and recognized by both universities.

Director: Prof. Dr. Sebastião Roberto Soares - UFSC

Director: Prof. Dr. Michel Bonneau – Agrocampus Ouest

Rennes, December 2011.

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Thesis presented to the Postgraduate Course in Environmental Engineering, Universidade Federal de Santa Catarina to obtain a Ph.D. in Environmental Engineering.

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# Effects of intensity and scale of production on environmental impacts of poultry meat production chains

*Life Cycle Assessment of French and Brazilian poultry production scenarios*

soutenue le « 16 décembre 2011 » devant la commission d'Examen

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To

H. Sônia da Silva
*in memoriam*

“Hail, queen wisdom! May the Lord save thee with thy sister: the pure simplicity!” ... “There is absolutely no man in the whole world who can possess one among you unless he first die.”

“Salut, reine sagesse ! Que le Seigneur te garde, avec ta sœur : la pure simplicité !” ... “Nul homme en ce monde, si d'abord il ne meurt, ne peut posséder une seule d'entre vous.”

“Salve, rainha sabedoria! Que o Senhor te guarde com tua irmã, a pura simplicidade!” ... “Não existe no mundo inteiro homem algum em condições de possuir uma de vós, sem que ele morra primeiro.”

From: “Salutation of the virtues”
by Giovanni di Pietro di Bernardone
also known as **Saint Francis of Assisi**
1182 – 1226

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# ABSTRACT

Currently, livestock production is increasing significantly in response to growing demand, resulting from economic and population growth mainly in emerging economies. Recently, Brazil overtook France as a poultry exporter. The Brazilian poultry sector is booming, resulting in increased poultry density in certain areas of the country. Meanwhile, in France the poultry sector is contracting due to direct competition with emerging economies that can offer the product for the European and Middle East market at a lower cost.

Concern about the environmental impacts associated with poultry production requires the study of poultry production systems, employing appropriate methodologies. Life Cycle Assessment (LCA) is a methodology that provides a solid scientific background to perform a multicriteria quantification of livestock production systems' environmental impacts. The LCA approach uses a concept based on input/output accounting throughout the product life cycle, often revealing that meat production in intensive livestock systems optimizes the use of resources, generating less impact per kg of product than in extensive systems.

The scientific objective of this work is to analyse the effects of "intensity" and "scale" of production on the environmental impacts of poultry production chains through a comparison of contrasting chicken meat production chains. Intensity refers to production practices aiming to increase output per animal and/or unit of land occupied, intensive systems use higher levels of inputs (fertilizer, feed, buildings) than extensive systems. Intensive systems often have a higher density (greater number of animals per m²) than extensive systems. The production scale represents the size of production facilities (buildings) and the number of animals raised on the same farm.

The LCA case study on broiler production systems from Brazil and France confirmed the trend of lower environmental impacts for more intensive systems, but also showed that the transport distance (of both animal feed and meat to the consumer center) had a larger influence on environmental impacts than the production scale.

From an environmental point of view, importing chicken from Brazil rather than producing it in France with Brazilian soybeans, was better with respect to climate change and land occupation, which are both global impacts. With respect to acidification, terrestrial ecotoxicity and energy demand chicken imported from Brazil had larger impacts than the chicken produced in France.

In all studied systems, it was clear that the broiler’s feed production stage contributed most to the environmental impacts of chicken meat production. This study was conducted using an innovative approach for the estimation of impacts caused by soya production in Brazil, since it considered an estimate of deforested area (and its environmental impacts). In addition, the study also showed that in LCA studies involving soybeans from Brazil, we should take into account their region of origin, as different regions have different levels of environmental impacts.

**Keywords:** Life Cycle Assessment (LCA). Environmental impact. Deforestation. Land transformation. Transportation. Soybean. Poultry. Production scale. Production intensity. Label Rouge. Brazil. France.

# RESUME

Actuellement, la production animale est en hausse significative en réponse à une demande croissante, résultant de la croissance économique et démographique principalement dans les économies émergentes. Récemment, le Brésil a dépassé la France comme exportateur de volaille. Le secteur de la volaille au Brésil est en plein essor, ce qui entraîne une forte augmentation de la densité de volailles dans certaines régions du pays. Pendant ce temps, en France, le secteur de la volaille se contracte en raison de la concurrence directe avec les économies émergentes qui peuvent offrir le produit pour le marché Européen et du Moyen-Orient à un moindre coût.

Les préoccupations concernant les impacts environnementaux associés à la production de volailles nécessitent des études des systèmes de production de volailles, utilisant des méthodologies appropriées. L'Analyse du Cycle de Vie (ACV) est une méthodologie qui fournit une base scientifique solide pour effectuer une quantification multicritère des impacts des systèmes de production animale en matière d'environnement. L'approche ACV utilise un concept basé sur la comptabilité d'entrée / sortie au long du cycle de vie du produit, souvent révélateur que la production de viande dans les systèmes d'élevage intensif optimise l'utilisation des ressources, générant moins d'impact par kg de produit que dans les systèmes extensifs.

L'objectif scientifique de ce travail est d'analyser les effets de "l'intensité" et "l'échelle" de la production sur les impacts environnementaux des filières de production de volaille à travers une comparaison de filières contrastées de production de viande de poulet. L'intensité fait référence aux pratiques de production visant à accroître la production par animal et / ou unité de terre occupée. Les systèmes intensifs utilisent des niveaux plus élevés d’intrants (engrais, aliments, bâtiments) que les systèmes extensifs. Les systèmes intensifs ont souvent une densité plus élevée (plus grand nombre d'animaux par m²) que les systèmes extensifs. L'échelle de production représente la taille des installations de production (bâtiments) et le nombre d'animaux élevés sur une même ferme.

L'étude de cas de l'ACV appliquée aux systèmes de production de poulets de chair au Brésil et en France a confirmé les plus faibles impacts environnementaux pour les systèmes plus intensifs, mais a également montré que la distance de transport (des aliments jusqu’à la ferme et de la viande au consommateur) ont eu une influence plus grande sur les impacts environnementaux que l'échelle de production.

D'un point de vue environnemental, l'importation de poulet en provenance du Brésil était préférable à la production de poulet en France avec du soja brésilien, pour les impacts changement climatique et l'occupation des terres, qui sont des impacts globaux. En ce qui concerne l'acidification, écotoxicité terrestre et la demande d'énergie, le poulet importée du Brésil avait des impacts environnementaux plus marqués que le poulet produit en France.

Dans tous les systèmes étudiés, il était clair que l'étape de production d'aliment avait le plus contribué aux impacts environnementaux de la production de viande de poulet. Cette étude a été réalisée en utilisant une approche novatrice pour l'estimation des impacts causés par la production de soja au Brésil, car elle considère une estimation de la superficie déboisée (et ses impacts sur l'environnement). En outre, l'étude a également montré que dans les études ACV impliquant le soja en provenance du Brésil, nous devrions tenir compte de leur région d'origine, comme les différentes régions ont des niveaux d'impacts environnementaux différents.

**Mots-clés :** Analyse du Cycle de Vie (ACV). Impact environnemental. Déforestation. Transformation des terres. Transport. Soja. Poulet. Echelle de la production. Intensité de la production. Label Rouge. Brésil. France.

# RESUMO

Atualmente, a criação de animais tem aumentado significativamente em resposta à demanda que resulta do crescimento econômico e populacional principalmente das economias emergentes. Recentemente, o Brasil ultrapassou a França em exportação de carne de aves. O setor de avicultura encontra-se em plena expansão, aumentando a concentração em determinadas áreas do país. Ao mesmo tempo, na França, este setor encontra-se em contração devido à concorrência direta com países em desenvolvimento que conseguem oferecer o produto para o mercado europeu e oriente médio a custo mais baixo.

Os impactos ambientais associados à produção de aves fazem surgir uma crescente preocupação, que demanda estudos destes sistemas produtivos, com o emprego de metodologias adequadas. A Avaliação do Ciclo de Vida (ACV) é um método que apresenta uma base científica sólida para realizar a quantificação de impactos ambientais de criações de animais. A abordagem da ACV usa um conceito baseado na computação de todas as entradas e saídas ao longo do ciclo de vida de um produto, muitas vezes revelando que a criação em sistemas intensivos otimiza o uso dos recursos, gerando menos impacto por kg de produto do que sistemas extensivos.

O objetivo científico deste trabalho é analisar os efeitos da intensidade e também da escala de produção sobre os impactos ambientais de cadeias produtivas de frango, através da comparação entre cadeias com características contrastantes. A intensidade diz respeito à praticas produtivas que objetivam aumentar as saídas por animal ou por unidade de área ocupada. Sistemas intensivos usam altos níveis de insumos (fertilizantes, alimentos, construções) do que os sistemas extensivos. Sistemas intensivos podem ter uma alta densidade (maior número de animais por m²) do que os extensivos. Já a escala de produção representa o tamanho das instalações e a quantidade de animais criados na mesma propriedade.

Um caso de estudo de ACV aplicada à sistemas de produção de aves no Brasil e na França, confirmou a tendência de menores impactos ambientais em sistemas intensivos, mas também mostrou que a distância de transporte (tanto dos alimentos até as granjas quanto dos frangos até o centro consumidor) têm mais influencia nos impactos ambientais do que a escala de produção.

Do ponto de vista ambiental, importar frangos do Brasil em detrimento aos frangos produzidos na França à base de soja importada do Brasil, é mais vantajoso pelo menos com relação às mudanças climáticas e ocupação de terras, que são ambos impactos globais. Já com relação à acidificação, ecotoxicidade terrestre e demanda de energia, os frangos importados do Brasil apresentam maiores impactos do que os produzidos na França.

Em todos os sistemas estudados, ficou claro que a etapa de produção de ração é a que mais contribui para os impactos ambientais da produção de carne de frango. Este estudo foi realizado usando uma nova abordagem para estimar os impactos da produção de soja no Brasil, por considerar uma estimativa da área desmatada (e seus impactos sobre o meio ambiente). Além disso, o estudo também mostrou que nos estudos de ACV envolvendo soja do Brasil, devemos levar em conta as suas áreas de origem, já que a soja produzida em diferentes regiões tem diferentes níveis de impactos ambientais.

**Palavras-chave:** Avaliação do Ciclo de Vida (ACV). Impacto Ambiental. Desmatamento. Transformação da terra. Transporte. Soja. Frango. Escala de produção. Intensidade de produção. Label Rouge. Brasil. França.

# 1GENERAL INTRODUCTION, ISSUES AND FRAMEWORK

## 1. INTRODUCTION

This work concerns the environmental assessment of chicken production supply chains that represent the situation of the Brazilian and French poultry sector.

This research was driven by the AviTer project, which aimed to study the sustainability of the poultry industry in France and Brazil and involved several institutions, such as EPAGRI (an agricultural research institution in Brazil), INRA (an agricultural research institution in France), Agrocampus Ouest (University of Bretagne, France), among others. With the support of the Graduate Program in Environmental Engineering of UFSC (Federal University of Santa Catarina State, Brazil), whose range of research also involves the impacts of agricultural production in Brazil, came the idea to investigate the impacts of poultry production using Life Cycle Assessment.

The Brazilian poultry sector is in full expansion, increasing the concentration in certain areas of the country. At the same time, in France the poultry industry is in contraction due to direct competition with developing countries that can offer the product for the European and Middle East markets at lower cost. The supply chains in the two countries follow different routes with different environmental impacts.

In food production, the quest for sustainable production models requires knowledge about social, economic and environmental characteristics of the production processes, as well as about the transformation process dynamics of the local ecosystems.

In order to advance towards sustainable poultry production, studies aimed at the rational utilization of natural resources are important. In that sense, this work fits into a kind of scientific investigation that contributes to inform "decision-makers" and to making the information available to society as a whole. So we can say that the determination of the environmental impacts of the poultry production sector, using scientifically accepted methods, contributes to the advancement of the poultry sector by identifying impacts that have not yet been quantified, and contributes to improving methods for environmental assessment.

This research also attempt to contribute to the generation of knowledge on the environmental impacts of animal production systems of different levels of intensity (intensive versus extensive).

Life Cycle Assessment (LCA) is one of many methods developed for the assessment of environmental impacts of production systems. It was initially developed for application in manufacturing industries, but has more recently been used for the analysis of agricultural production, especially for single-crop production systems or processes of food production on industrial scale (Caldeira-Pires *et al.*, 2002). LCA has been considered a viable method for analysing impacts of agricultural systems (van der Werf and Petit, 2002) and therefore we adopted LCA in this study. The poultry industry is the sector of livestock production that best illustrates the current phenomenon of globalization. First, there are only few farms that produce matrices of purebred, including European companies, in the global market. Consequently, these genotypes are available and marketed worldwide. Secondly, the raw materials incorporated into poultry diets can come from any grain production region in the world. This creates a situation of strong competition in the industry (AviTer, 2007). Thus, knowledge about levels of environmental impact caused by the poultry supply chain is relevant to the sustainability of producing regions wherever they are localised in the world.

Poultry production is a source of direct and indirect employment, and thus contributes to developing and maintaining a living rural tissue, which contributes to social advancement. Nonetheless, in Europe there is often a negative perception by the peaple of intensive animal production systems, so the social acceptance of poultry supply chains can be compromised. Therefore one of the current challenges for the French poultry sector is to produce healthy food which is perceived as such by the consumer, respecting the environment and animal welfare standards (AviTer, 2007). In Brazil, this type of concern is not so evident among consumers, and the poultry industry is in clear expansion due to a favourable market situation.

In both cases, the quantification of environmental impacts helps to highlight the major environmental issues in the supply chains studied. For the local comunities it is important to know these impacts. There may be negative consequences, such as acidification and eutrophication of soil and water, but also positive, such as jobs, economic improvement, or use of manure as a fertilizer. For consumers, knowing the environmental impacts associated with the product they consume can affect the acceptance of the product.

According to the project AviTer (AviTer, 2007), it is necessary to apply LCA throughout the supply chain, to identify the economic, environmental and biotechnical aspects that can be improved or to identify obstacles to the sustainable development of the poultry sector.

With regard to the environmental aspects of the poultry production sector, the French legislation is stricter than the Brazilian (Magdelaine and Chesnel, 2005), mainly in limiting levels of nitrogen and phosphorus that can be applied to the soil. Moreover, in France a law was proposed (October 2007) during the so-called "Grenelle de l'Environnement" - a series of participatory meetings held in France in order to elaborate proposals on long-term environmental and sustainable development. This law introduced, among other things, the labelling of all products consumed at a large scale. The label should show, amongst others, the amount of $CO_2$ equivalent emitted in production process, to allow the consumers to consume more "responsibly". A one-year experimental period started from July 1, 2011. Hundreds of products sold on the shelves or over the Internet, come with information detailing their impacts on climate, water, and biodiversity. The main method used for these calculations is LCA. This increases the interest of research using this approach in the area of food production.

Moreover, the Brazilian legislation currently takes into account environmental issues in the production sector. In the 1980s, Brazil established a national environmental policy called "*Política Nacional do Meio Ambiente - PNMA*" described by Law 6.938/81. Under this policy, several other laws and resolutions, focusing primarily on the productive sector, have been created and are being improved over time to protect the environment. Examples of these laws include the resolutions issued by the National Environmental Council – "*Conselho Nacional do Meio Ambiente – CONAMA*" operating in various sectors, such as pollutant emissions and delineation of permanent preservation areas. Likewise, there is the Brazilian Forest Code "*Código Florestal Brasileiro*", which is quite restrictive and protects areas of native forest.

This legislation, however, hasn't been respected, as is revealed in the Statement of Conduct Adjustment - "Termo de Ajuste de Conduta - TAC avicultura Santa Catarina" recently concluded (February 7, 2007) among poultry stakeholders in Santa Catarina state. This term creates the conditions for the poultry producer to progressively adjust to the environmental laws over a period of 5 years, so the farms gradually meet all legal requirements regarding the environment and can receive an operating license during this period. The laws directly involved in the

TAC are: "*Código Florestal – lei 4771/1965 e lei 7803/1989; Normas e Parâmetros para Indústria – Decreto Estadual 14250/1981 SC; Código Sanitário de SC – Decreto 4085/2002; Parâmetros Área de Preservação Permanente – Resolução CONAMA 302 e 303/2002*; *Metodologia para recuperação de Área de Preservação Permanente – Resolução CONAMA 429/2011; Padrões de lançamento de efluentes – Resolução CONAMA 430/2011*".

In addition, important changes occurred in terms of demands from the integrator companies on their integrated poultry farmers, concerning health requirements, imposed by the European market (non-tariff barriers) (AviTer, 2007). These direct influences of legislation on the poultry sector should be considered, even though the sector is strongly articulated through the scheme of vertical integration, involving industries, suppliers and transport.

Thus the determination of environmental impacts for the different supply chains contributes to understanding the current scenarios and may indicate strategies for legislation and actors in the chain, in searching the sustainability of the sector.

## 2. BRAZILIAN AND FRENCH POULTRY INDUSTRIES: GLOBALIZATION APPROACH

Agriculture contributes to the development and maintenance of rural areas both in Europe and in emerging countries (van der Werf and Petit, 2002). In this context, the poultry industry has a particular role, as a profitable and relatively simple activity for farmers, and at the collective level, where the poultry industry can provide jobs and animal protein. However, the production in very heterogeneous basins addresses a globalized market, with rapid transfer of production and processing instruments between production zones. This occurs among a small number of actors for industrial production at a global scale.

In this context, companies can plan their production in geo-strategic terms to ensure their profitability. For example the DOUX Group transferred a large part of their production from the West of France to Brazil. This company, which used to produce only in Europe, currently sells a large portion of its Brazilian products in the European market. A relevant question is to understand how a poultry production basin can become sustainable (van der Werf and Petit, 2002).

In terms of agriculture and sustainable development in Europe, the question has been raised whether European poultry production will continue or whether it will gradually migrate to other parts of the world.

European poultry producers are looking for a model of sustainable agriculture that could be strengthened in order to continue supplying the European market. In Brazil the competitiveness aspects are not the main problem, but the regulatory aspects are very important. In Europe it is particularly interesting for France to strengthen its high quality production systems, since France supplies quality poultry products in Europe, but the current dynamics do not support this development. The American marketing approaches give priority to consumers, while the French marketing seems to be more "producer-oriented", which is reinforced by a health crisis that occurred in the past (Sarrazin, 2000).

This fact is consistent with the views of other authors (Rattner, 1994; Kalemli-Ozcan *et al.*, 2009), who say that the globalization of business and financial activities, driven by the dynamism of international corporations and conglomerates, leads to new forms of interdependence and interaction, but without a real integration of economies and national policies.

## 2.1. LEGAL, SOCIAL AND ENVIRONMENTAL ASPECTS

In terms of environmental criteria, the poultry production systems in Brazil and France are contrasting. In France, according to the size of farms and their locations, they are subject to strict rules regarding waste production and disposal, mainly nitrogen and phosphorus. Additionally, we should take into account the problem of greenhouse gas emissions (Magdelaine, 2008).

In Brazil, concerns about environmental problems are more recent and are now emerging in the South, a region traditionally focused on animal production (Spies *et al.*, 2001). Today, the Brazilian poultry production also grows in the Centre West of the country, a region of major agricultural properties specializing in the production of maize and soybeans, where environmental restrictions are less stringent. So we have a contrasting situation: the vastness of Brazilian territories, even opening new areas of agricultural production and the smaller areas and for which several activities are competing in France.

Social integration is another issue coming to the agenda. The situations are very contrasting between the two countries, even considering that differences between countries are normal. On the one side the poultry industry provides jobs and low-cost animal protein in the two countries. However, for France, there is a system of chicken production that has a positive image with consumers and with the peaple of the production areas (“free-range farming” like “plein air” and “Label Rouge"), while there are also aspects sometimes perceived as negative (environmental impacts associated with intensive production, and welfare of chickens) (ITAVI, 1999).

For Brazil, the massive and rapid development of poultry production in traditional and new areas poses different problems: how can the new production regions adapt? What are the impacts on the use of the land, especially in transport infrastructure, which seems to be a critical point? For the traditional production basins, a question that arises concerns the consolidation and development. The cost of production gives a competitive advantage to Brazilian poultry products, as the resale price per kg of carcass of Brazilian industrial chicken is 45% lower than that of French industrial chicken (Magdelaine, 2008).

There are various explanations for this difference: the workforce is clearly cheaper in Brazil (average of EUR 300 per month for an employee), soybeans and maize are produced locally against massive imports of soybeans in Europe, cost for chicken houses are lower in Brazil and the exchange rate is favourable for Brazilian exports (AviTer, 2007). The consequences of this cost differential are experienced in France where major restructuring of the means of production and processing are observed. Thus, several important slaughterhouses were closed during the last five years. Production is clearly expanding in Brazil and decreasing in France. One of the issues raised by these contrasting scenarios is to know how they will further evolve (AviTer, 2007).

Besides the economic aspects, the sanitary condition of poultry supply chains is fundamental to their sustainability, especially because of non-tariff barriers that affect the market (Laisney *et al.*, 2004). In the past sanitary requirements were higher in France than in Brazil, however, with globalization and increase in Brazilian exports, the market itself began to demand stricter sanitary control. Currently, the southern Brazil enjoys a high status in terms of sanitary control.

Whereas the economic performance of Brazilian and French systems is relatively well documented, currently there is not much quantitative information available about their environmental aspects (Wackernagel *et al.*, 2004).

An important aspect in the sustainable development of a production site is its relative autonomy in terms of food and raw materials resources. The French dependence on external sources of protein (soybeans) for the livestock is questioned, and the intercontinental flows of feed biomass contribute to the generation of animal wastes, which result in considerable environmental impact (AviTer, 2007).

Overall, food autonomy contributes to the sovereignty and the sustainability of production chains in certain territories. This is evident in Europe, where almost 75% of raw materials rich in proteins used for animal feed are imported, mostly from Brazil and the United States (AviTer, 2007). Thus, the European proactive policy of biofuel production appears as a strong opportunity to use the protein-rich co-products, especially those derived from oil crops (rape seed, sunflower) to replace the imported sources, even if the poultry will not be the first user, chronologically speaking. This strategy will have important effects on the development of agro-energy supply chains (Guemene and Lescoat, 2007).

# 3. RESEARCH QUESTIONS AND OBJECTIVES

## 3.1. RESEARCH QUESTIONS

In recent decades the poultry industry has developed and modernized, both in Brazil and in France. Increased productivity due to technological improvements, new models of integration and changes in the market favouring the increase in consumption of chicken meat, are factors that contributed to the growth of the sector in Brazil. Meanwhile, in France, despite the high technological level, the industry has been in decline in recent years due to strong market competition with emerging countries that have a lower cost of production.

Overall, coupled with the growth of production and its concentration in certain regions, there are environmental problems caused by the use of resources and emission of effluents and waste resulting from the production process. Indeed, it is impossible to produce any type of product, food or not, without causing impact on nature. As the environment has a limited capacity to assimilate the impacts caused by the production process, increased production or concentration in certain regions may exceed that capacity, and from this moment the environmental sustainability of the supply chain will be compromised.

Thus, we have on the one hand an idea, a reflection on the production process causing impact on nature, but it is very difficult to quantify this impact. On the other hand, it is known that the chicken production process causes a real environmental impact. The connection between the idea (the impact that may exist) and the reality (the real impact) can be made by seeking a way to effectively assess the impacts caused by the production process, quantifying them and considering these results as an acceptable approximation of reality.

Supply chains can be remarkably different, for example, with respect to the distance between the region producing poultry and the region producing grain and animal feed, the distance between the feed factories and chicken houses, or the distance between chicken houses and the slaughterhouse. But a more striking difference concerns the production intensity of supply chains. Less intensive systems have been gaining acceptance among European consumers, while the conventional intensive systems are increasingly criticized by consumers looking for healthy food. Thus we can formulate a first question: **Do different systems of poultry production (intensive and extensive) cause different environmental impacts? If yes, how large is this difference?** (Research question 1).

A possible element of this question relates to animal welfare, since it is one of the major differences between intensive and extensive systems of production. However, this subject is very difficult to evaluate, especially considering that the strain (genotype) used in intensive farming systems was selected because of its trait of low physical activity (and consequent low energy demand), almost apathetic compared to the strains used in extensive production systems.

There are studies in this area (FAO, 2008; Harper and Henson, 2001) and the results indicate that in the countries of northern Europe consumers of meat and derived products are willing to pay more (regardless of product quality, such as taste, appearance, etc.), for knowing that the animals were produced under good conditions of welfare before being slaughtered. But in the countries of the southern Europe the animal welfare is less of a concern for consumers. For them, product quality and price are the decisive factors. This trend is not likely to change in the medium term.

Each region has its proper characteristics resulting in different levels of sensitivity to environmental impacts. For example, in Santa Catarina State in southern Brazil, the farms are small with little land available to receive manure as fertilizer, and in addition steep slopes complicate the application of manure. Also the technological level is heterogeneous, with few farms being fully automated and with air conditioning, and many having more manual or semi-automatic systems, without air conditioning. In the central-west of the country, the farms are larger, without steep slopes, soil and the local climate allow the use of a larger amount of manure as fertilizer. The technological level is high and homogenous, almost all farms are fully automated and air-conditioned. We can then formulate the following question: **Do small-scale poultry production systems cause more environmental impact than large-scale systems?** (Research question 2). This investigation is interesting, because the pig and poultry industries have made large investments in the central-west region of Brazil searching for economies of scale, but associated environmental issues are rarely considered.

Another concern relates to the origin of the raw material. Part of the soybean used in feed for chickens in France comes from Brazil. So the impacts of soy production (including deforestation) should be considered as part of the impact of the chickens produced in France. According to Patentreger and Billon (2008), 74% of imports of soybeans in France are from Brazil. French soybean production covers only 3% of national consumption. So we can formulate the question: **Do imported chickens from Brazil, fed with locally produced grains cause less (or more) impact than chickens produced in France, using a feed part of which comes from Brazil?** (Research question 3).

A final question that arises in light of the contrasting situations in Brazil and France: **What are the hotspots in each studied supply chain and what are the opportunities for industries to improve their environmental performance?** (Research question 4).

Seeking answers to these research questions was the main objective of this work, presented in the next chapters.

## 3.2. AIM AND OBJECTIVES

### 3.2.1. Aim

The main objective of this thesis is to measure and compare environmental impacts of poultry production in specific settings in Brazil and France, with different levels of intensity and scale, using the multicriteria Life Cycle Assessment method for environmental assessment. The research also seeks to identify the hotspots and the main opportunities for improvement regarding the environmental sustainability of each scenario.

### 3.2.2. Objectives

The objectives were designed to achieve the aim. The objectives of the study and methods of investigation are as follows.

**Objective 1:** to quantify and qualify the environmental impact of supply chains of chickens that are representative of both countries (Brazil and France) and compare the impacts between the production chains. Environmental assessment will take place for a specific set of impact categories.

**Method:** the representative chains were determined in each country considering not only the volume of production, but also the importance of economic, social and environmental impacts in the region where they are. We used the LCA method to quantify the impacts of each scenario. These results allowed answering research questions 1, 2, and 3. We used the tool (software) SimaPro® 7.1 to implement the LCA method. This software allows the creation of basic processes of the product life cycle and for each case it lists all the inputs (consumption of raw materials and natural resources including energy, land, etc.) and all outputs (emissions, waste, etc.) respecting the unit of measurement. The software lists all elementary processes separating them in stages. Thus it was possible to calculate the values for each impact chosen, allowing various types of analysis.

**Objective 2:** identify the main opportunities and threats for each studied scenario , and show how this information can be used to guide the actors towards better environmental performance.

**Method:** the outputs of the LCA were combined, allowing the quantification of the environmental impacts of each process involved in the production of chickens. The results were analysed to identify how the industry can adjust its management practices to minimize the impacts, in agreement with environmental legislation. This provides answers to research question 4.

# 4. SCENARIOS OF POULTRY PRODUCTION

## 4.1. BRAZILIAN POULTRY SCENARIO

The growth of the poultry industry in Brazil has been highlighted in recent years. Along with this growth, its environmental impacts increase. According to the Brazilian Association of Chicken Producers and Exporters (ABEF, 2010), the total chicken production in Brazil increased from 2 million tonnes in 1989 to 12.3 million in 2010. The three southern states, Paraná, Santa Catarina and Rio Grande do Sul, providing on average 54% of the total.

The Figure 1 shows the evolution of the chicken production in the country, showing the difference between the internal and external market.

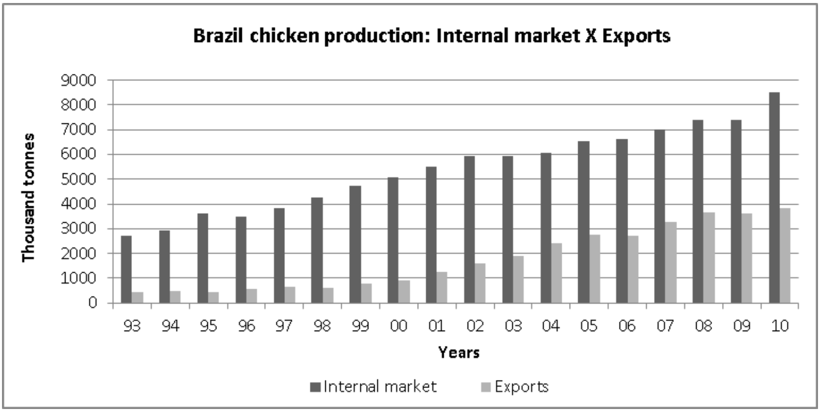

**Figure 1 -** Evolution of chicken production in Brazil. Source: data by ABEF.

In 2006, 2.7 million tons were exported (ABEF, 2010). In 2010, this number rose to 3.8 million tons. Figure 2 shows that the Middle East, the European Union (EU) and Asia are the main destinations for Brazilian chicken. This significant increase in the export of chickens has caused international repercussions. Brazil had a prominent position in recent years, becoming the largest poultry exporter in the world. Its largest market is the Middle East, with the purchase of 1,450 thousand tons in 2010 (ABEF, 2010). The EU, its second largest market, purchased 560 thousand tons. The emergence of avian influenza in some places in Europe has contributed to increase the importation of chicken from Brazil, since this country is free of this disease.

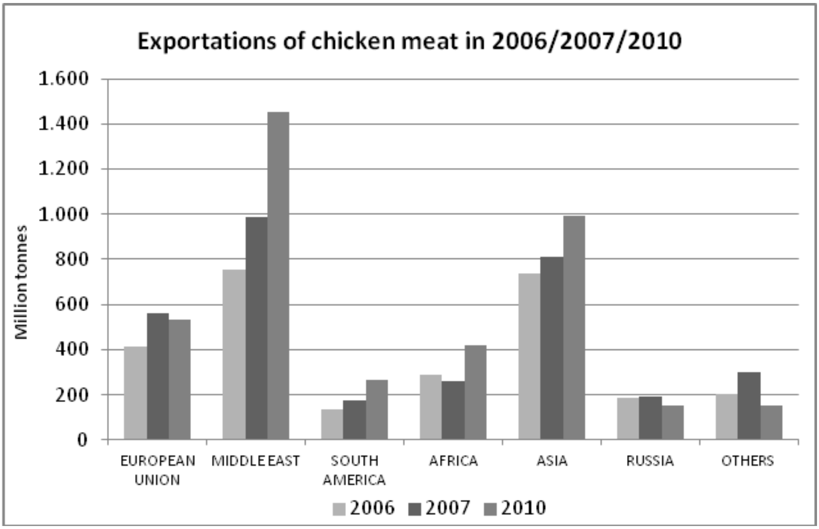

**Figure 2 -** Exportations of chicken meat in 2006 and 2007. Source: Data by ABEF.

The consumption of chicken meat in Brazil increased from 13 kg/capita/year in 1989 to 44.5 kg/capita/year in 2010 (Figure 3).

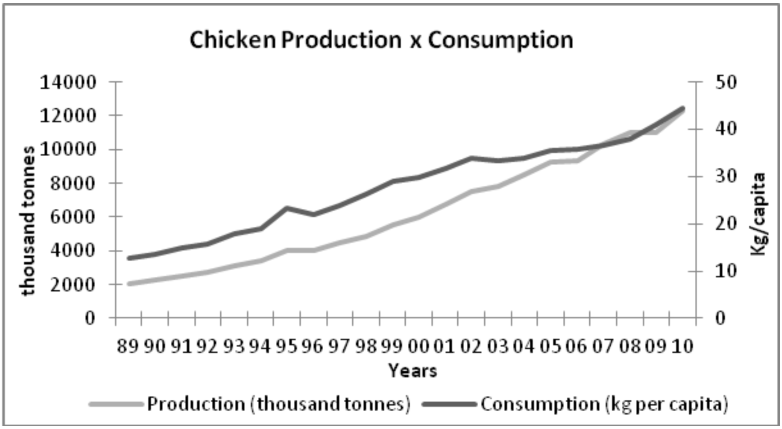

**Figure 3 -** Evolution of chicken production and consumption.
Source: Data by ABEF.

The increased production of chicken has environmental consequences. Like any other product, chicken production presents a series of inputs and outputs. Thus, on the farm there are important aspects like the litter containing feces of chickens, layers of litter, dead birds and other wastes. There is also waste associated with other inputs, such as packaging of veterinary drugs, pest control, cleaning and disinfectant, as well as syringes, remains of implements and equipment. In the slaughterhouse, waste of slaughter and processing of poultry is produced: grease, sewage, viscera, skin, head, feet, feathers, bones and meat. We also need to consider atmospheric emissions and liquid effluents of the industrial process. Among the various stages of production, transportation also involves significant environmental impacts by fossil fuel consumption.

The growth of poultry production in recent years has exacerbated the problems resulting from residues of the different stages of the supply chain and their environmental impact. The environmental degradation has concerned the South of the country due to high volumes of animal waste generated by the industrial poultry, in combination with intensive pig production (Spies *et al.*, 2002). Therefore, a strategic analysis of the environmental impacts is required, considering the contrasting situations in Brazil and France and the available alternatives regarding management.

## 4.2. FRENCH POULTRY SCENARIO

The French production has grown in recent decades thanks to the dynamism of the domestic market and growth in exports to countries of the so called Third World and the Middle East. The development of exports was due to the European policies of support to exports, which aimed to offset high domestic prices for cereals (induced by the Common Market of cereals).

A hallmark of the poultry industry in France is the production of other species that have followed this same pattern of the market. In addition to chicken, turkeys, ducks, geese and peacocks are produced, although in smaller quantities.

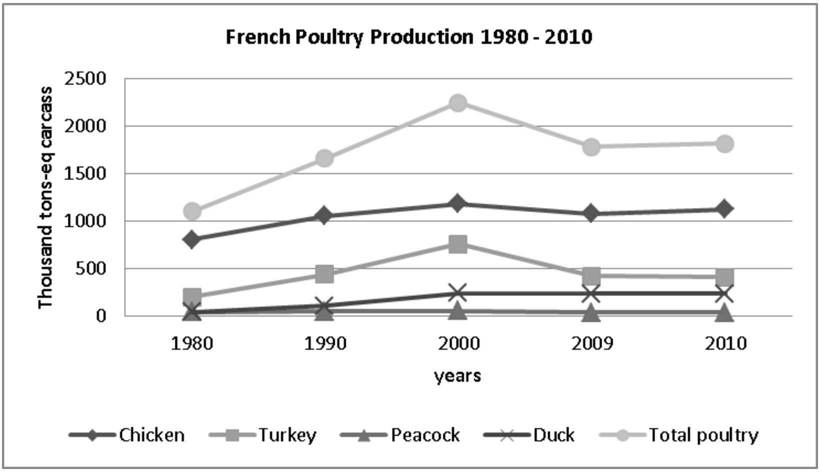

**Figure 4 -** Evolution of French poultry production in thousand tonnes, by poultry species. Source: data from AGRESTE, 2010.

Figure 4 shows that the industry reached its maximum production at the end of the 90s, and then started to decline. Since then, the current picture of French poultry was set, characterized by a structural crisis that has resulted in a reduction in the volume of chicken produced by around 25% (equivalent to 550 tons of carcass). This decline in French production is primarily due to a loss of competitiveness in the light of the sharp reduction of exports extra and intra European Union, and an increase in imports. At the same time, domestic consumption, after reaching a maximum in 2001, stabilized and the market was heavily segmented allowing an increase of imported meat, more in processed meat than whole chickens and less processed products (Magdelaine, 2008).

This decline leads to a weakening of the links in the supply chain and general ageing of the production structure, making it obsolete, in addition to the increase of the competitive deficit in the sector. The export sector in France has been losing ground due the market competition with emerging countries like Brazil. The main buyers of French chicken meat are the EU and Middle East (ME). Figure 5 shows the evolution of French exports.

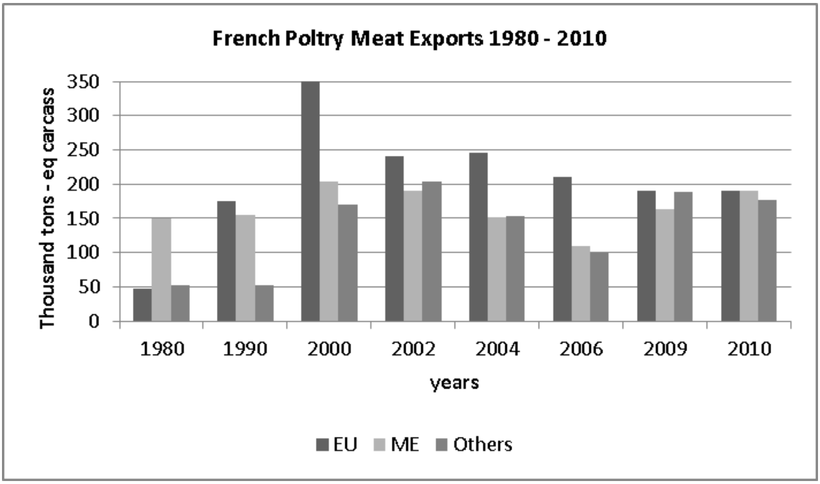

**Figure 5 -** Evolution of French poultry meat exports, in thousand tonnes, for Middle East (ME), Europe Union (EU) and other countries. Source: data from ITAVI 2010.

In France the poultry sector is penalized by its weak position on the international market, and at the same time there is an increasing pressure in terms of regulations (health, environmental, animal welfare), as in other agricultural sectors. Another striking point currently in France is the health context characterized by the threat of a new crisis of avian influenza (Magdelaine, 2008).

In environmental terms, there are many rules, but in general, the incubatory, poultry farms, slaughterhouses and animal feed factories are all classified by their potential for pollution. For each case there are specific requirements on the management of wastewater, and possible treatments. All companies are required to declare their volume of production and distribution of its used water to a Water Agency. The requirements for accumulation of nitrates and other forms of nitrogen in terms of agricultural activities are also very stringent, and allow different limits on each region of the country, according to the concentration of animal production and climate and soil characteristics (ITAVI, 2007).

## 4.3. SUPPLY CHAIN OF CHICKEN PRODUCTION IN BRAZIL

Brazilian poultry production is “integrated” (or *integração*) (Martins *et al.*, 2007). Therein operations are coordinated vertically by the agribusiness and instruments are used to interfere in the various links in the supply chain. This interference seeks to improve the production systems, modernizing the slaughterhouse and chicken processing as well as enhancing efficiency and logistics of distribution and production of inputs.

Vertical integration is a generic concept, which can be characterized as a combination of several technological processes like production, processing, distribution and sales within the same company. This concept also implies command decision from a single company, corporation, and involves a total or partial ownership of the assets of this company (Carletti Filho, 2005).

### 4.3.1. The vertically integrated system model

The farmer owns a specific structure for the production of chicks with the needed equipment. In this arrangement, the *integrated* farmer’s function is to offer the infrastructure to produce the chick, with his own investment, to the point of slaughter, which is decided by the *integrator* company. In return, the company offers remuneration to the integrated farmer and provides most needs of the business. The company provides the “one day chick”, the feed and technical assistance. The integrated farmer is responsible for the construction of the chicken house, the installation of related equipment in accordance with the requirements of the company to the stage of delivery of the chicken to the slaughterhouse when it reaches the appropriate weight. All transportation needed is provided by the company. Payment is made in accordance with technical indicators defined in the contract (Fernandes Filho, 2004). However, most frequently the company covers the cost of ration, veterinarian and transportation supplies to the farms and poultry to the slaughterhouse (Martins *et al.*, 2007).

### 4.3.2. The links of the chain

The supply chain of poultry production in Brazil consists of four links (Martins *et al.*, 2007):

Link 1 - production of live chicken on the farm. Feed production, its transportation to the chicken house and the supply of chicks are included in this link.

Link 2 - represents the transport of live chicken from the production unit to the processing plant.

Link 3 - is represented by slaughtering and processing of chicken.

Link 4 - refers to the transportation to the seaport and the product loading on ships.

In the link 1, the production occurs in chicken houses with a length varying from 25 to 300 m and a width of 12 m. According to the authors, in the western region of Santa Catarina, based on 1,238 poultry farms sampled, the average age of slaughter was 43 days, average live weight was 2.48 kg, mortality rate was 4.39% and feed conversion was 1.86 kg/kg (quantity of feed to produce 1 kg of live chicken). These rates result in the production of 13,385 birds with a weight of 33,245 kg per batch. The average distance from the feed factory to the poultry farm in the west of Santa Catarina was 42 km. The ingredients used for feed production are basically soybean meal and maize. The maize, which is the main component, is produced and transported over an average distance of 850 km to the feed factory (Spies, 2003).

The most important point in the link 2 is the average distance between each poultry farm and the slaughterhouse. The authors determined an average distance of 95 km (Martins *et al.*, 2007).

Also according to the same authors, at the end of the production cycle, the birds are placed in cages with 8 chickens each, on average (occasionally, more birds can be placed in the cages to facilitate the transport of the batch in 4 trips). The truck used for the transport of live chickens has a capacity of 7.5 tons per trip, corresponding to 396 cages, with a total of 3,168 birds with average weight of 2.38 kg each and total weight of 7,539 kg.

In the link 3, the authors emphasize that in their study, the end product was the whole chicken, although the current industries are capable of producing large quantities of by-products. There is a loss of around 16% corresponding to the viscera, blood, and feathers which are used in the manufacture of by-products. However, to maintain compatibility with other systems in this study, we also consider the withdrawal of the feet, heads, hearts, livers and gizzards, resulting in a carcass yield of 74.6%

Finally the authors describe the link 4 as the stage that includes loading the product in containers, issuance of legal documents (tax and health care) and administrative documents needed for the start of the trip, between industry and the port, storage, processing of documents at the port and ship-loading of the product. The distance considered was 544 km. The load per trip (1 container) was 25 tons.

Meanwhile, other authors give a different description of the supply chain (Vocht, 1996). In this case the author divides the chain in 3 levels: biological chain, nutrition chain and distribution chain. Vieira Junior *et al.* (2006), adopting this division, consider the following flowchart for the supply chain:

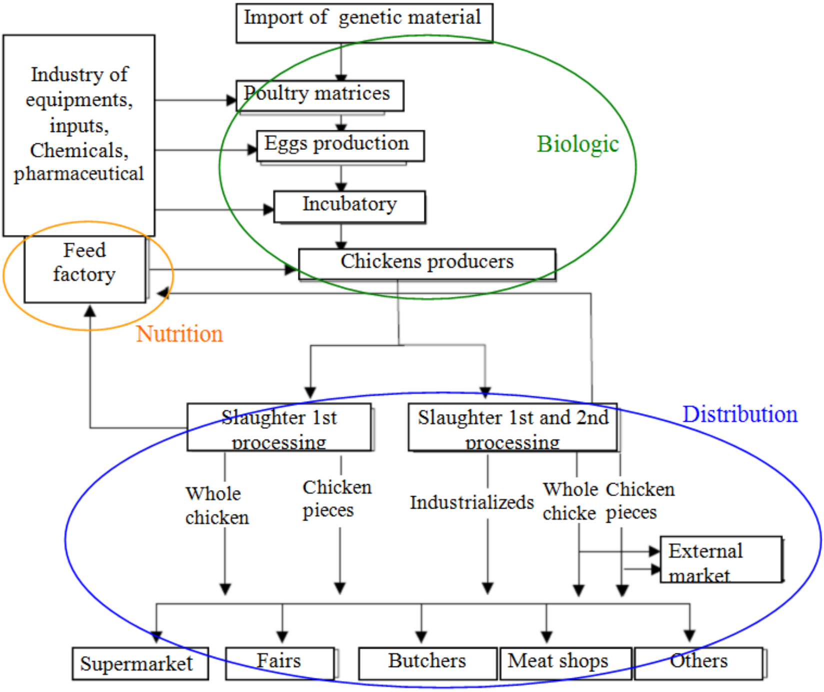

**Figure 6 -** Flowchart for poultry supply chain

The first four boxes in Figure 6 comprise the biological chain: the farms for poultry breeding, the incubatory and the fattening. The term "biological chain" designates the different stages of the production of the broiler chickens (Vocht, 1996). The poultry breeding farms import birds (grandparents) from other countries. The breeds used in production of chicken in Brazil are obtained from crosses between imported grandparents through licensing of technology (Vieira Junior *et al.*, 2006).

The yellow circle represents the nutrition link, it is characterized by the maize and soybean crops and feed processing. In this representation, the maize and soybean crops are embedded in the feed factories. According to the Brazilian Union of Poultry - UBA (http://www.uba.org.br), feed production represents almost 70% of the production costs of chickens. The closer to the grain producing areas, the lower the cost of production, due to reduced transport costs (Vieira Junior *et al.*, 2006). According to the authors, maize is 70% by weight, in composition of feed, while soybean meal represents 15%.

The blue circle represents the distribution link. The starting point in this link is the transport of live chickens from farms to slaughterhouses, which are the key players that make up this supply chain (Vieira Junior *et al.*, 2006). Pharmaceutical companies have an important role in providing mainly antibiotics, among other products.

## 4.4. SUPPLY CHAIN OF CHICKEN PRODUCTION IN FRANCE

Since the 1960s the establishment of the major groups of poultry production was progressively structured around the slaughter link of the supply chain. Integration strategies by slaughterhouses with their upstream processes (hatching, feed) vary widely depending on the company. Some groups have strongly internalized the production of chicken feed, integrating most of their supplies and commercial collaborations are strong and sometimes exclusive.

The integration system characterizes the relationships with industry breeders, but farmers continue to own their building and some of their livestock. Over 90% of farmers are integrated when including cooperative agreements, and about 75% if one excludes them (Magdelaine, 2008).

This vertical integration model works on the basis of very close links between farmers and the integrating company. This company supplies the farmers with their means of production (animal feed), the volume and quality of which are determined depending on the desired output. The company uses the finished products according to a pre–established schedule. The integrator takes the place of the farmer in his prerogatives as head of the company (choice of productions, means to implement, supplier selection, volume and qualities to be produced), but in return, it must bear the burdens imposed, including the remuneration of labour and the market risk, i.e. fluctuations of the price (Magdelaine, 2008).

Many environmental regulations are imposed on the entire poultry supply chain. The French legislation is essentially based on the system of “classified installations”, which affects all segments of the industry chain. Hatcheries, farms, feed mills and slaughterhouses are classified by size, according to their pollution potential. The nomenclature of the ICPE (classified facilities) of 1976 gives specific requirements regarding to the management of their waste, water management, and possible treatments to be implemented. Every company must declare its production volumes and destinations of its wastewater to the Water Agency (ICPE, law n° 76-663 of July, 19 1976).

According to a survey conducted in 2004, there is a high variability of farm size based on different production systems. Half of the broiler farms owned livestock buildings with outdoor runs, with an average farm buildings area of 650 m², the other half of the holdings consist of closed buildings with an average area of 1450 m² (AGRESTE, 2006).

The total average area of farms producing poultry was 51 hectares (ha) in 2000, according to the Agricultural Census, which is higher than the average area of all farm types in France, which reached 42 ha. Poultry farms can be divided into two distinct groups, one gathering specialized farms with a small or very small area (23% of farms were under 10 ha in 2000) and the other involving larger farms (42% of farms over 50 ha in 2000).

Most French poultry farms are not specialized, for 70% of them income from poultry accounted for less than 75% of their total farm income. They represented about 60% of the poultry meat production capacity. These farmers usually have another animal production unit (milk or meat) or produce crops (AGRESTE, 2006).

## 4.5. RESEARCH SITES

Among the objectives of this work is the comparison between intensive and extensive systems, as well as small and large production scale. To this end we seek production systems that fit these criteria.

The “Standard Industrial” is an intensive way of chicken production. This system is characterized by the use of small areas with high population density, and animals can be housed in closed buildings. Intensive livestock operations are also characterised by a small on-farm area dedicated to growing animal feed, resulting in significant reduction of self-reliance of the farmer to feed his animals. Advances in animal nutrition suggest farming in terms of "transformation" of feed in animal growth. The advantage of this type of farming based on production efficiency is that it can provide meat and other products (eggs, milk, leather, wool) at a relatively low cost, allowing accessibility of these foods. In addition, this production is less dependent on weather conditions and has significantly reduced the risks of food-borne microorganisms such as salmonella. In this system, the chickens are mainly fed diets based on grains, it uses strains that allow rapid growth, reaching slaughter weight in around 40 days.

The “Label Rouge” is an extensive (or semi-extensive) way of chicken production. It must meet five specific criteria, tightly controlled and the limits of these criteria can be adjusted over time (Sauveur, 1997):

1 - Use of specific slow-growing strains;

2 - No fat added to diet until 4 weeks of age and total fat content limited to 5%. The food distributed after 28 days of age must contain 75% cereals (and cereals products); animal meal and animal growth promoters are excluded. In addition, the quality of all raw materials is strictly controlled;

3 - Duration of the growth cycle at least 81 days;

4 - Low animal density (11 birds per $m^2$ of building) with an outside run of 2 $m^2$ per animal (at least), should be available no later than at 6 weeks of age;

5 – Severe disqualification rate and extra precautions in conditioning (cooling by immersion of carcasses not allowed).

In addition to these differences in intensity, in Brazil there is a variation of the standard system, which is characterized by a large number of chickens on the same farm, using very homogeneous buildings of a high technical level. In these large scale systems, the facilities are modular, and each farm should have at least four chicken houses of 1,600 $m^2$ each. Considering these differences of intensity and scale, certain locations were studied that represent well the situation of supply chains in France and Brazil. These sites were chosen because they represent most of the production of chicken meat in both countries, as well as the main differences between production systems. One Brazilian system represents a large-scale production system in the Centre West (CW) of the country, the other one a small-scale production in the South (SO). One of the French systems represents a high-quality, semi-extensive poultry production system, known as "Label Rouge" (LR), situated in the Aquitaine region (South-West of France). The other is a standard system (ST), typical for the Bretagne region (West of France). Table 1 synthetizes the systems characteristics.

**Table 1 -** Main characteristics of studied chicken production systems

| Country | Kind of system production | Intensity | Scale | Region | Acronym |
|---|---|---|---|---|---|
| France | Standard industrial chicken | Intensive | Small | West of France, Bretagne | ST |
| | Label Rouge | Extensive | Small | South-west France, Aquitaine | LR |
| Brazil | Standard industrial chicken | Intensive | Large | Centre West of Brazil, Goiás | CW |
| | Standard industrial chicken family | Intensive | Small | South Brazil, Santa Catarina | SO |

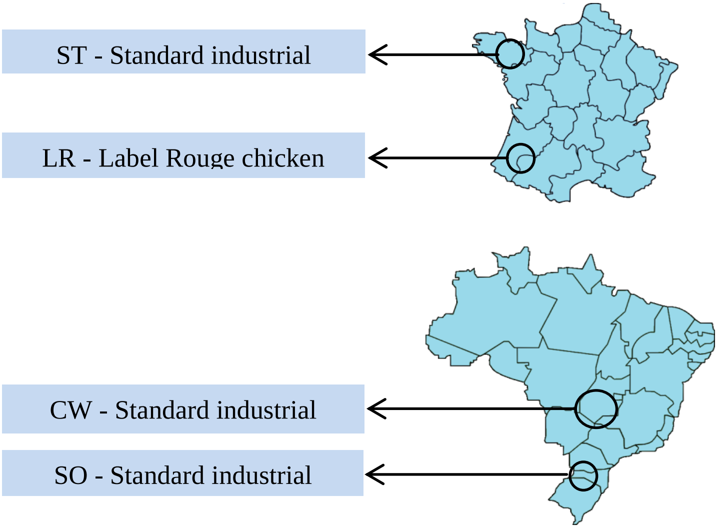

**Figure 7-** Research sites

## 4.6. SOME CHARACTERISTICS OF THE SITES STUDIED

### 4.6.1. France – Standard industrial chicken (ST)

To represent the system of standard industrial chicken in France, we chose the region of Bretagne, which concentrates among the largest quantities of animal production in Europe. In this region, the production of broilers is intended primarily to supply the French domestic market, and then demand from the European Union, and finally the market in other countries.

Bretagne houses around 15 slaughtering and processing industries, involving 95,200 jobs. The poultry production sector comprises 3,000 farms raising poultry (chickens and turkeys) and generates 6,000 direct and indirect jobs. The hatching sector counts about twenty hatcheries (800 employees) and 500 farms specializing in the production of breeding animals. The animal feed sector has forty industrial sites (specialized or not) in compound feed for animal production, and counts about 1,100 employees (CRAB, 2006b)

In this region the French poultry industry has suffered its greatest decline, resulting from a loss of market share to other EU countries and emerging countries, like Brazil (CRAB, 2006a).

### 4.6.2. France - Label Rouge (LR)

This system of poultry farming is common, amongst others, in the South-West of France in the Aquitaine region. Within this region the Label Rouge system is most frequent in the Landes department, which can be considered the cradle of French Label Rouge, knowing that Landes has a strong farmers union (syndicate) tradition. There are 36 million of Label Rouge chickens put in place each year and 1600 poultry producers (AviTer, 2007).

The largest pine forest in France is in this region, near the city of Bordeaux. In the Southern Chalosse area, with less forest, there is a high density of poultry farms. There are two kinds of Labels: Label Landes (that uses “maransines” a kind of movable cabins with 150 m$^2$ surface, maximum), giving it a strong and characteristic image with consumers, although some 400 m$^2$ buildings are used; and the Sud Ouest Label, that uses almost classical buildings (400 m$^2$) (AviTer, 2007).

Within the group of Label Rouge producers in the Landes department we can find three types of poultry producers (Lebreton, 2008):

- Optimists: they represent 50% of total. They have confidence in the system. They are associated in groups of farmers. On average they are 44 years old, and their average farm surface is 54 ha.
- Farmers of obligation: 25% of total, somewhat confident. On average they are 50 years old, and their average farm surface is 41 ha.
- Farmers in abandonment of production: 25%, without confidence. They are 50 years old on average, and their average farm surface is 48 ha.

There are three companies/cooperatives involved in Label Rouge production:

- Maïsadour: 420 poultry farmers; 12 million poultry per year.
- Euralis: 142 poultry farmers; 3.3 million poultry per year.
- Volailles d’Albret: 290 farmers; 6 million poultry per year.

These three operators share a common organization (“Landais” Poultry Farmers Association) to officially manage communication.

### 4.6.3. Brazil - Standard industrial chicken (CW)

This typical large scale chicken production system can be found in Rio Verde. It is located in the Southwest of Goiás state, with an area of 8,415.4 km$^2$ and a density of 13.9 inhabitants per km$^2$. Poultry farms are on average 194 ha. In 1960’s, the region has grown due to the expansion of the agricultural frontier (agriculture and livestock, mainly cattle).

The territory is marked by the diversity of migrants from other Brazilian states and foreign colonies (Russians and Mennonites from the USA). The municipality of Rio Verde is the largest producer of raw materials for livestock feed, primarily maize and soybeans. The COMIGO (Cooperative of Southwest of Goiás) is the major cooperative present in the territory since 1975. Today the region sees the development of other agricultural sectors such as sugar cane.

Poultry farming in Rio Verde has emerged in the late 1990’s with the arrival of the company Perdigão (today, part of BRF- Brasil Foods Company) that came from southern Brazil, with the creation of an agro-industrial centre. The main drivers of this expansion are: agrarian structure favourable to new integration model (medium and large properties), large production of raw materials for animal feed, availability of financing/credit from the Federal Government and public policies of local government; availability and low cost of labour, availability of large areas of land for waste assimilation, favourable climate and the presence of companies related to crop production.

In this zone currently 420.000 birds/day are killed, mostly chicken and chester (heavy chicken) that are destined for export (97%). Each farm has four modular buildings with a surface of 1,600 $m^2$ each (12.8 x 125m). The actors in this territory are the company Perdigão, the integrated producers, the association of integrated producers (AGINTERP), suppliers of raw materials, service providers, governments and banks. The industrial model applied to Rio Verde has a new structure consistent with a small number of farms of a homogeneous high-tech level.

The integrator company manages and owns nearly all stages of poultry production, and provides technical advice, supplying chicks and feed. The integration system is characterized by the partner relationship between the company and the integrated farmer, based on a 12-year contract. The main forces are gathered for the expansion of production in the area.

However, weaknesses have emerged due the fragility of the type of contract and the expansion of the sugar cane area, due to public policies for biofuels in Brazil. This has caused major conflicts in the territories. Thus, the expansion of the poultry in the territory of Rio Verde has reached its limits. Actually, nowadays the company Perdigão does not open new concessions or contracts and stabilizes the sector with 9,200 direct jobs and 27,900 indirect jobs.

### 4.6.4. Brazil - Standard industrial chicken – family (SO)

The Western Region of Santa Catarina state is characterized by small farms (95% under 50 ha), it occupies only 25% of the territory of the state, but produces 55% of its gross value. The region has the largest concentration of pig and poultry farms in Latin America and is the largest exporter of pork and poultry. Moreover, recently in this area the dairy industry began to develop. Social organization has a major impact in the region by the presence of community groups, schools and churches, the “Pastoral Land Commission” (Catholic Church), the movement of landless workers, unions and associations of producers, among other forms of social organization (Silva, 2009).

In the 1970’s, there has been a diversification of pig slaughterhouses into poultry processing and then a concentration in large abattoirs in the 1980’s. The migration of cattle agro-industries to the Midwest of the country (1980’s) preceded the migration of chicken and pigs to that area in the 1990’s. More recently, an important increase of the meat equipment industry occurred in Chapecó (the largest city in western Santa Catarina) with the emergence of regional fairs, diversification of services in the sector and the development of medium sized abattoirs (about 60 thousand head per day). In addition, some agro-industries have increased their investment in the north of the state.

Since the 1970's poultry farming in the state of Santa Catarina has grown from a marginal level to one of its most important economic activities. Operations are characterized by family labour and a farm area of less than 50 ha. The number of buildings per farm varies from 1 to 2 on average, building size is about 1200 m². The technical performance of the farms is very heterogeneous, but the quality of the product is good. According to CEPA (2008), the poultry industry of Santa Catarina directly employs 35,000 people and indirectly over 80,000 people.

In the formation of the gross value of the state’s agricultural production, slaughterhouses are the main activity, with 24% of total (USD 1.013 billion out of $ 4.2 billion). Poultry farming in Santa Catarina produced 2.5% of world production of chickens. About 20% of the national production of chickens comes from the state of Santa Catarina. With a planned production, companies from the Santa Catarina (but currently producing in others states over the country), represent 60% of the domestic market and participate in 70% of Brazilian exports (CEPA, 2008).

## 5. LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) is an impact assessment method based on the use of natural resources and emission of pollutants by the systems studied. In this study, the method is applied as set out in the ISO 14040 standards, with stage of data collection in the field for inventory data and the use of local and institutional data bases. In both France and Brazil, we chose two regions representing contrasting poultry supply chains.

LCA can be defined as a method to compile the inputs and outputs of a production process and to assess the potential environmental impacts of a product through its life cycle (ISO, 2006a). It is a method that analyses systematically any change in the environment, both beneficial and adverse, generated during the whole life cycle of a product, including its design, the extraction of raw materials, its production, transportation, use and final disposal (Fernandes, 2004). According to the EPA (the USA Environmental Protection Agency) Life Cycle Assessment is "a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by compiling an inventory of relevant energy and material inputs and environmental releases; evaluating the potential environmental impacts associated with identified inputs and releases; and interpreting the results."

LCA allows the identification of environmental aspects of a product, process or service and, therefore, allows the identification and quantification of the environmental impacts associates with the processes of a company (Soares and Pereira, 2004).

LCA is divided into four main stages (ISO, 2006a): goal and scope definition, inventory analysis, impact assessment and interpretation. The LCA framework can be represented as in Figure 8 below:

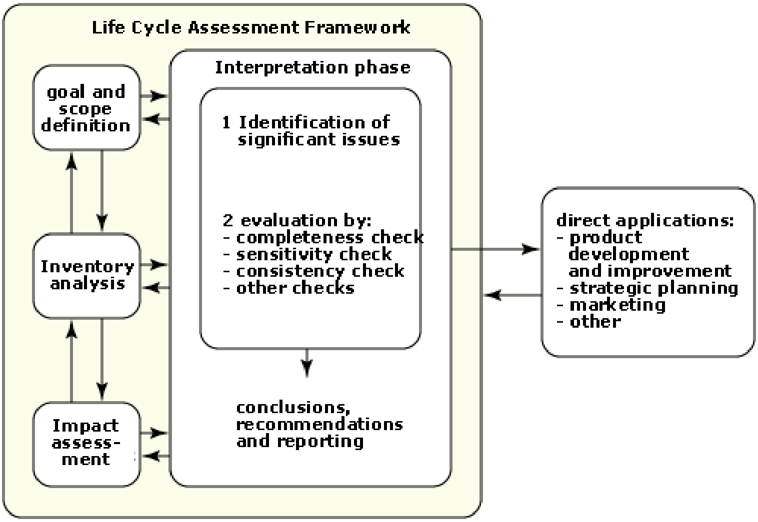

**Figure 8 -** LCA framework. Source : http://labspace.open.ac.uk

Industrial activities have an important impact on the environment, from the extraction of raw materials until the final disposal of waste generated during the production process or after using the products. Environmental management methods, like LCA, allow, in addition to environmental gains, an improvement in the public image, a reduction of environmental risks and costs, and greater respect of the legislation (Soares and Pereira, 2004). Below, the main stages of LCA are presented.

## 5.1. GOAL AND SCOPE

The first step in LCA is the definition of the purpose and scope. This step is the description of the product being studied, and presents the purpose and scope of the study, through the establishment of its limits (Hauschild, 2005). The objective of the study should specify the desired application and the target public to whom results will be reported. At this stage it is important to define the Functional Unit (FU), mainly in comparative studies of different products in order to quantify the system and allow the determination of the reference flows. The definition of the scope and purpose of the LCA should be clear and consistent with its objectives.

## 5.2. LIFE CYCLE INVENTORY

The inventory is basically a compilation of data, it involves the establishment of procedures to calculate inputs and outputs of mass and energy in the process (Fernandes, 2004). The completion of the inventory, in practice, may be difficult to be implemented for a number of reasons, like a lack of available data and the need to estimate data (Chehebe, 1998). Data collected in this stage (measured, calculated or estimated) are used to quantify the inputs and outputs of a unit process.

To be consistent, the inventory of data must be related to the functional unit (FU) established in the previous stage. This is the most laborious step of the LCA and should be done very carefully, because the other stages will be strongly dependent on its quality (Mueller *et al.*, 2004). With this stage we can arrive at a quantitative analysis of environmental impacts.

## 5.3. LIFE CYCLE IMPACT ASSESSMENT

In this stage the flow of materials and energy, identified during the inventory are associated with environmental impacts (Sonnemann *et al.*, 2004). The relevant impact categories are established according to criteria that must be consistent with the objective of the LCA. There are various methods of characterization proposed by researchers. Some methods try to translate some kind of effect on human health. This is the case of the Method EPS - Environmental Priority Strategies, which provides, for example, the following categories: life expectancy, morbidity, potential for growth of crops, potential for production of meat and fish, potential for growth of wood, etc. Other methods emphasize the global impacts, but also consider human health, such as EcoIndicator 99. It combines these categories in quality of the ecosystem (acidification, eutrophication, land use and ecotoxicity), resources (minerals and fossil fuels) and health (carcinogenic, respiratory organic and inorganic, climate change, radiation and ozone layer). According to ISO 14044 (ISO, 2006b), the impact assessment stage comprises mandatory and optional elements. Figure 9 shows these elements.

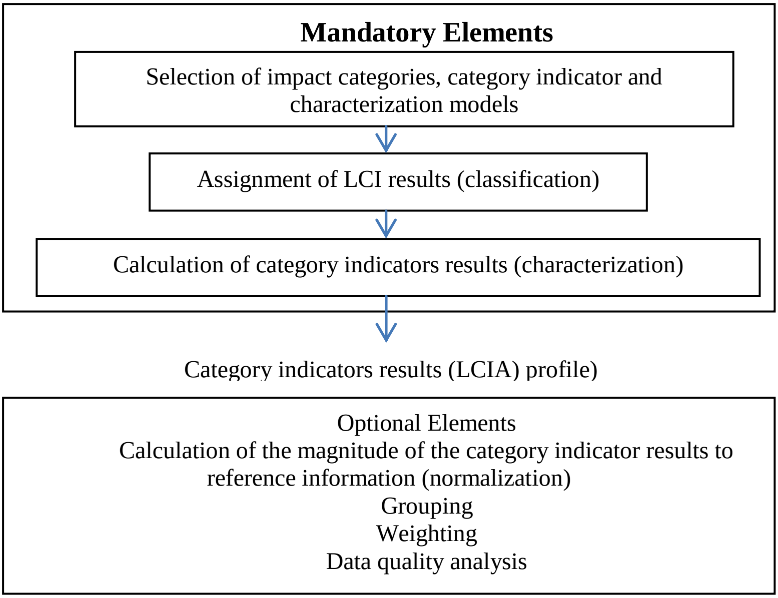

**Figure 9 -** Life cycle impact assessment. Source ISO 14040.

**a) Selection of impact categories** (mandatory)

This involves defining impact categories, the indicators for each category and the characterization method. This selection should be based on scientific knowledge of environmental mechanisms and processes analysed (Chehebe, 1998).

**b) Classification** (mandatory)

It involves a correlation of the results of the inventory (values of consumption of raw materials, emissions, etc.) with the different impact categories, such as ecotoxicity, acidification, climate change and so on. The classification step is qualitative, based on scientific analysis of the environmental aspects.

**c) Characterization** (mandatory)

It means to perform the calculation of the results of indicators for each impact category, through factors and models for characterization. This is a quantitative process.

According to ISO 14044 (ISO, 2006b), the optional elements are normalization, grouping and weighting.

**d) Normalization (**optional**)**

Normalization consists of defining the relative contribution of factors for characterization of a particular category in relation to the total impact for the same category. The normalization factors represent the potential impact of that category (Tolle, 1997). The normalization factor can be external when we know a reference value for a particular category, usually from a previous LCA study. However, there are cases where we do not know an external reference, and it is possible to use an internal value obtained by mathematical normalization.

**e) Weighting (**optional**)**

It means the conversion of the results of indicators for each category to a common scale using numerical factors based on value choices (ISO, 2006b). The different impacts are evaluated according to their severity. According to the result a factor for each impact category is set.

This step can be exemplified as a grouping of impacts as global, regional and local impacts and with high, medium and low priority (Baumann and Tillman, 2004). The aim of this step is to assist the assessment of the environmental performance of a system or product (Haes *et al.*, 2002).

## 5.4. INTERPRETATION

The interpretation step is the review of the study, according to the established goals, namely the analysis of results and the formulation of conclusions and recommendations for minimizing the environmental impacts potentially generated by the system (Graedel, 1998). This phase involves an iterative process of revising the scope of the LCA, as well as the nature and quality of data collected (Frankl and Rubik, 2001). Aspects such as sensitivity and uncertainty are also evaluated (Hauschild, 2005).

The International Organization for Standardization (ISO) established a technical sub-committee (number 5) to write specific rules on LCA. Table 2 shows each document and its respective subject.

**Table 2 -** ISO standards for LCA

| Document | Subject | Year |
|---|---|---|
| ISO 14040 | Management, LCA – principles and framework | 1997 |
| ISO 14041 | Goal and scope definition; inventory analysis | 1998 |
| ISO 14042 | Life cycle impact assessment | 2000 |
| ISO 14043 | Life cycle interpretation | 2000 |
| ISO 14048 | Documentation format | 2002 |
| ISO 14047 | Examples of impact assessment ISO 14042 | 2003 |
| ISO 14049 | Exemples of inventory ISO 14041 | 2000 |
| ISO 14040 | Principles and framework | 2006 |
| ISO 14044 | Requirements and guidelines - contains 41 to 43 | 2006 |

## 5.5. LIMITATIONS

There are uncertainties related to technical parameters and data inventory, given the diversity of production systems, a variety of agricultural possible practices, and the various possible emissions in the light of these variations (Basset-Mens and van der Werf, 2005). In the search for reliable results, the hierarchy of uncertainties, scope definition and sensitivity analysis of LCA are points to consider.

The main problems for the implementation of LCA on agricultural systems are the lack of references on the diversity of existing production systems, and also the complexity of interactions between variables.

# 6. STRUCTURE OF THE THESIS

The thesis project was initiated by a literature review. The information obtained allowed establishing factors, indicators and models of environmental impact assessment applied to poultry production.

The second step included the inventory. From October 2008 to August 2009 a research period was realized at INRA, Rennes (France). During this period, the description of the two supply chains in France was made and data for the inventory were obtained. In sequence, starting in September 2009 a collection of data from the Brazilian supply chains was made, also including field visits to chicken houses and slaughterhouses.

The third step was the implementation of the LCA, to achieve the research objectives. The research results indicated that most of the environmental impacts in each of the supply chains studied resulted from the stage of feed production, especially grains. Therefore special attention was given to grain production systems. As the database that was used for this study (Ecoinvent) considered that part of the grain produced in Brazil uses an area recently occupied by savannah or forest, and knowing that the rate of transformation of natural areas has been reduced due to the action of many sectors of the society in Brazil, attention was also given to the calculation method to estimate the amount of grain that actually comes from these areas as well as estimated emissions from deforestation.

The results were presented in three papers. The first paper deals specifically with the transformation of forest and savannah to arable land for the production of soybean and maize in Brazil. The second paper deals with the impacts connected to different scenarios of soybean production, one of the main components of broiler feed. The third paper compares the supply chains studied, thus characterizing the broiler industry in Brazil and France from an environmental viewpoint.

This thesis was then prepared containing five chapters. The first chapter deals with the general introduction to the work, the next three chapters correspond to the three proposed papers. Finally, the fifth chapter deals with the general discussion and conclusions of the work (Figure 10).

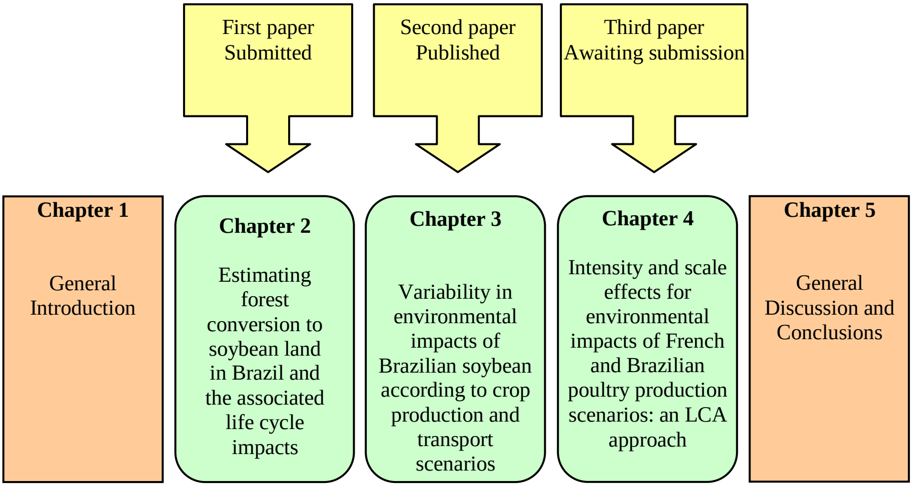

**Figure 10 -** Diagram of the thesis framework

Note: The completion of the LCA requires an inventory of data that can include strategic sensitive information in terms of competitiveness between markets. Hence the information disclosed with this work is limited. These data are confidential and are part of the database used in common with the INRA, UFSC and EPAGRI.

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# ESTIMATING FOREST CONVERSION TO SOYBEAN LAND IN BRAZIL AND THE ASSOCIATED LIFE CYCLE IMPACTS

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## ABSTRACT

In recent decades, the expansion of soybean crops in Brazil to meet domestic and international demand has generated concerns over its environmental impacts. Evaluating impacts of the soy production supply chain by Life Cycle Assessment (LCA) involves an estimation of the area of rainforest and Cerrado (savannah) that is cleared to grow soy. In this study, we evaluated methods used recently to estimate the deforested area and proposed an improved method to estimate land transformation from forest to arable land. We implemented this method in a case study of soybean production to explore the effect of the uncertainty of its parameters on the life cycle impacts of Brazilian soy. Our proposition was based on a study that explored the relationship between cropland expansion and deforestation in Mato Grosso State (Morton *et al.*, 2006) and on easily accessible and annually updated data on soybean area and rainforest and Cerrado clearing. This study showed that, for the 2005-2008 period, the importance of deforestation for soy production in Brazil was highly variable among all regions. For the Centre-West region, we estimated that 1% of total soy production took place on land transformed from rainforest and 3.4% on land transformed from Cerrado. For the South of the country, we estimated that there was no deforestation for soy production. This study showed that deforestation strongly affected overall impacts of soybean production, mainly for cumulative energy demand and climate change, and that per unit area the impact of transformation from rainforest was larger than that of transformation from Cerrado. This work shows that recently used LCA methods used to estimate land transformation from forest can and should be improved.

**Keywords:** soybean, deforestation, life cycle assessment, land transformation.

## 1. INTRODUCTION

The expansion of soybean crops in Brazil is associated with the destruction of the Amazon Biome (rainforest) and the Cerrado Biome (tropical savannah or shrubland) (Steward, 2007). The environmental consequences of deforestation for agricultural expansion (e.g., $CO_2$ emissions and reduced biodiversity) remain a major issue in Mato Grosso and other Brazilian states that are part of the Amazon and the Cerrado Biomes (Figure 1).

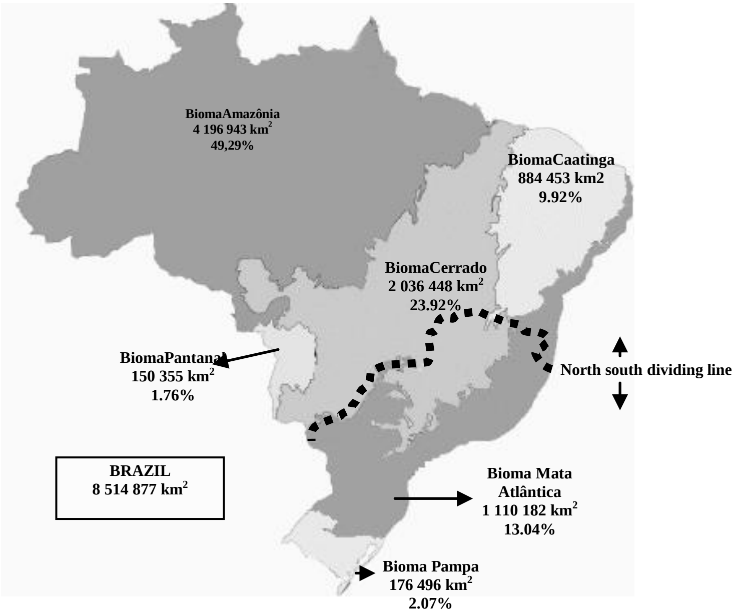

**Figure 1** – Biomes of Brazil. Surface area per biome in km$^2$ and as a percentage of the total surface of Brazil. Source: IBGE (www.ibge.gov.br)

Currently in Brazil, efforts are being made to reduce the environmental impacts of soybean crops. In terms of production technique, no-tillage systems have been widely adopted by producers, reducing losses of soil and use of fertilizers, in particular phosphate (Muzilli, 2000). In terms of policy, soy industry organizations have set up initiatives such as the Soy Moratorium, consisting of a pledge not to commercialize soy produced in the Amazon Biome on land that was cleared of forest after 24 July 2006. However, Brazilian farmers are not free to deforest. All farms in Brazil must have a legal reserve area, also called "Reserva Legal", established by Federal Law 4.771/65 (also called "Código Florestal"), amended by Federal Law 7.803/89, and the "Medidas Provisórias" 2166 and 2167/2001. The size of this reserve is established as a percentage of farm area according to the region where the farm is located, i.e. 80% when the farm is located in the Legal Amazon[1], 35% when the farm is located in the Cerrado biome within the states that make up the Legal Amazon, or 20% in farms located in other regions of the country. Furthermore, in recent years, the Brazilian government significantly increased the efforts to reduce deforestation in the Amazon Biome, making it more difficult for farmers to clear new areas. In 2005, soybeans occupied 2.7% of Brazil’s area and 0.3% of the Amazon Biome area (Jank, 2006). Although deforestation in Brazil has decreased, the problem still persists.

Among the many methods used to evaluate the environmental impacts of farming systems (van der Werf and Petit, 2002), Life Cycle Assessment (LCA) has been shown to holistically quantify and evaluate the resources consumed and environmental emissions at all stages of the life cycle of the product. These stages include the time from the extraction of resources through the production of materials, product parts and the product itself to the use of the product and its reuse, recycling or final disposal (Guinée *et al.*, 2002).

Several studies have assessed the environmental impacts of soybean production in Brazil using the LCA approach (e.g., Cederberg, 1998; Spies, 2003; van der Werf, Petit, and Sanders, 2005; Jungbluth *et al.*, 2007; Cavalett and Ortega, 2009; Lehuger, Gabrielle, and Gagnaire, 2009). In all but one of these studies, Brazilian soybean production was treated as a single scenario, despite the large differences in climate, soils, and sea-port distances existing between and within the main soy production regions in Brazil. Only the study by Jungbluth *et al.* differentiated between two regions within Brazil (North and South).

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[1] According to SUDAM (Superintendência do Desenvolvimento da Amazônia <www.ada.gov.br>), the Legal Amazon is an area that encompasses nine states belonging to the Brazilian Amazon Basin.

Furthermore, it is the only study that considered and quantified the association between soy production and deforestation.

This paper identified a difficulty using updated data in the method proposed by Jungbluth *et al.* for estimating land transformation from Amazon rainforest and Cerrado forest to arable land. We proposed an improved method to make this estimation, and we implemented it in a case study of soybean production to explore the effect of the uncertainty of its parameters on the life cycle impacts of Brazilian soy.

## 2. MATERIALS AND METHODS

### 2.1. ESTIMATION OF LAND TRANSFORMATION

Jungbluth *et al.* (2007) estimated the type of land use before the establishment of a crop. For soy produced in Brazil, three preceding land use types are distinguished; these are arable land, tropical rainforest and Cerrado. The authors estimated land transformation from rainforest and Cerrado to arable land from the average annual increase of Brazilian soy area from 2000-2004 while also considering that some of the rainforest had been transformed to pasture. Therefore, they estimated that, for the period of 2000-2004 over the entirety of Brazil, on average 3.2% of total land used for soy had been transformed from rainforest in the year preceding the planting of the soy crop; this value was 5.2% for Cerrado. For the North of Brazil (Figure 1) they estimated that 6.0% of total land was transformed to soy from rainforest and 6.2% from Cerrado while for the South of Brazil these numbers were 0% and 4.2%, respectively.

Whereas the rate of increase of soybean area was high from 2000-2004, soybean area slightly decreased from 2004-2008 (Figure 2). Using data from 2004-2008, the approach proposed by Jungbluth *et al.* (2007) would consider that soybean crops did not contribute to deforestation during this period. However, recent studies showed that soybean crops were still grown on recently deforested areas, but to a lesser degree than before (ABIOVE, 2008). Therefore, the approach proposed by Jungbluth *et al.* cannot be used to estimate land transformation for crops with a stable or decreasing area of cultivation.

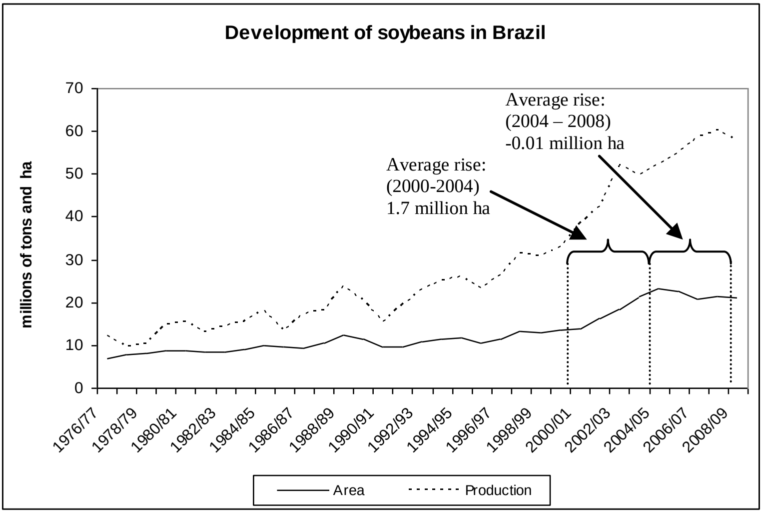


**Figure 2** – The area of soybean crops and total soybean production in Brazil from 1976-2008. Data from CONAB (www.conab.gov.br)

## 2.2. OBSERVATION OF DEFORESTATION AND CROPLAND EXPANSION

Morton *et al.* (2006) combined field observations with satellite-based data on annual deforestation and vegetation phenology to describe the fate of large (> 25 ha) forest clearings in Mato Grosso State in the North of Brazil. This work was based on data for the 2001-2004 period when the rate of expansion of the soybean area was highest (Figure 2). The authors used vegetation phenology information from the Moderate Resolution Imaging Spectroradiometer, or MODIS (http://modis.gsfc.nasa.gov), and two years of field surveys to establish spatial and temporal patterns of land use after deforestation. Most forest area was converted to pasture, and 14% was converted to cropland (Figure 3).

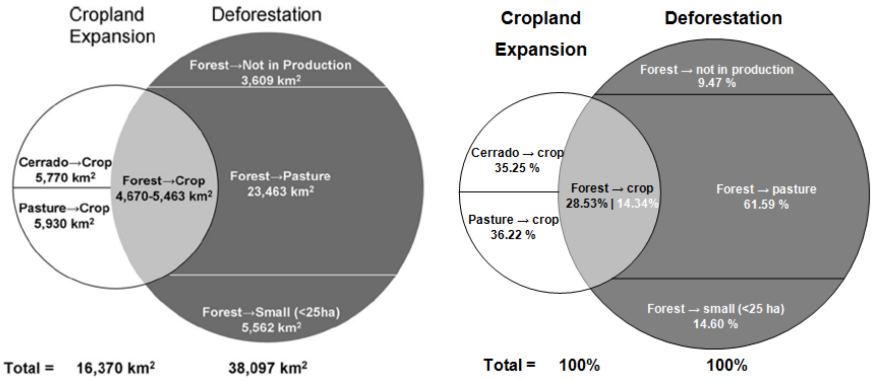


**Figure 3** - Relationship between cropland expansion and deforestation in Mato Grosso, Brazil, cumulative data for 2001–2004. Original results from Morton *et al.* (2006) (left) and the same information expressed as percentages (right).

Source: Morton *et al.* (2006).

This study revealed that the transition from forest to cropland occurred rapidly as >90% of clearings for cropland were planted in the first year after deforestation (Morton *et al.*, 2006). In the 2001-2004 period analyzed by Morton *et al.* (2006), soybean crops represented 70% of the total arable area in Mato Grosso State, but this proportion recently slightly decreased to 67% (Conab, 2009), with soybean losing ground mainly to maize (Figure 4). According to agricultural census data, soybean cropland expansion in Mato Grosso in the same period, i.e., 2001-2004 (Conab, 2009), was greater than total cropland expansion according to Morton *et al.* (2006); however, this is because most fields produce two crops per year (Morton *et al.*, 2006). The authors found a relationship between mean annual soy price (2001-2004) and area deforested for cropland ($R^2 = 0.72$), so it is reasonable to assume that cropland expansion was principally driven by soybean production.

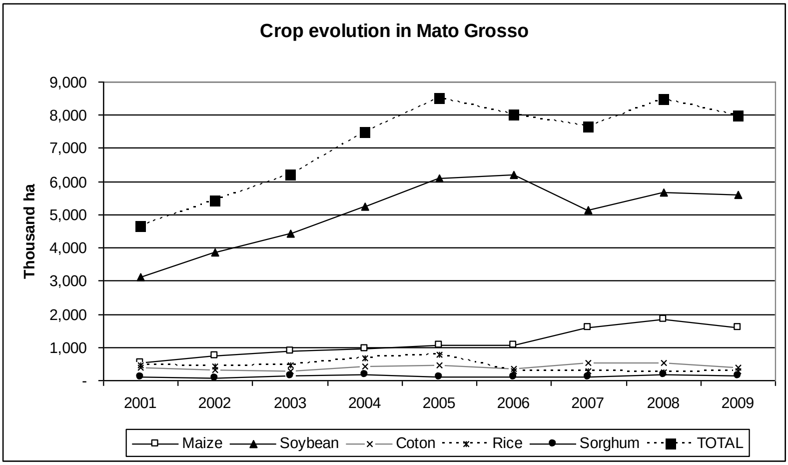


**Figure 4 –** Arable crop surfaces (Conab, 2009) in Mato Grosso State, Brazil, 2000-2008.

## 2.3. A NEW PROPOSITION

In the approach proposed by Jungbluth *et al.* (2007), calculations to estimate land transformation were based on the average rise of the soybean area over the preceding five years. This approach implies that if, as in recent years (Figure 4), soybean area does not increase, then there will be no transformation of rainforest or Cerrado to cropland. This is not necessarily true because although the soy area may remain stable or decrease, part of the soy may have shifted to newly cleared rainforest or Cerrado.

We propose to resolve this problem by using satellite imagery data to identify deforestation and subsequent land use and consistently extrapolate this information to the study area to link it to the total soy crop area. We used data from Morton *et al.* (2006) to estimate the fate of newly deforested land in Mato Grosso from 2005-2008 and extrapolated these results to other soy-producing states in which deforestation occurs using the official data on deforested surfaces in the Legal Amazon rainforest (PRODES, 2009), which are easily accessible and updated annually. To estimate the soybean area planted in each state, we used the data from "Companhia Nacional do Abastecimento (CONAB)" from the National Supply Company, as they are also easily accessible and updated annually.

### 2.3.1. Land transformation from rainforest

**Table 1 -** Legal Amazon deforestation and area planted in soybeans, in thousand ha, from 2005 to 2008.

| | State/Year | 2005 | 2006 | 2007 | 2008 | Average | % |
|---|---|---|---|---|---|---|---|
| **Legal Amazon deforestation** | Acre | 59.2 | 39.8 | 18.4 | 22.2 | 34.9 | 2.5 |
| | Amazonas | 77.5 | 78.8 | 61.0 | 47.9 | 66.3 | 4.7 |
| | Amapá | 3.3 | 3.0 | 3.9 | - | 2.6 | 0.2 |
| | Maranhão | 92.2 | 65.1 | 61.3 | 108.5 | 81.8 | 5.8 |
| | Mato Grosso | 714.5 | 433.3 | 267.8 | 325.9 | 435.4 | 30.8 |
| | Pará | 573.1 | 550.5 | 542.5 | 518.0 | 546.0 | 38.7 |
| | Rondônia | 324.4 | 204.9 | 161.1 | 106.1 | 199.1 | 14.1 |
| | Roraima | 13.3 | 23.1 | 30.9 | 57.0 | 31.1 | 2.2 |
| | Tocantins | 27.1 | 12.4 | 6.3 | 11.2 | 14.3 | 1.0 |
| | **TOTAL** | **1 884.6** | **1 410.9** | **1 153.2** | **1 196.8** | **1 411.4** | **100.0** |
| **Legal Amazon Soybean area** | Acre | - | - | - | - | - | - |
| | Amazonas | 2.8 | 1.9 | - | - | 1.2 | 0.0 |
| | Amapá | - | - | - | - | - | - |
| | Maranhão | 375.0 | 382.5 | 384.4 | 421.5 | 390.9 | 5.9 |
| | Mato Grosso | 6 105.2 | 6 196.8 | 5 124.8 | 5 675.0 | 5 775.5 | 86.8 |
| | Pará | 69.0 | 79.7 | 47.0 | 71.1 | 66.7 | 1.0 |
| | Rondônia | 74.4 | 106.4 | 90.4 | 99.8 | 92.7 | 1.4 |
| | Roraima | 20.0 | 10.0 | 5.5 | 15.0 | 12.6 | 0.2 |
| | Tocantins | 355.7 | 309.5 | 267.7 | 331.6 | 316.1 | 4.7 |
| | **TOTAL** | **7 002.1** | **7 086.8** | **5 919.8** | **6 614.0** | **6 655.7** | **100.0** |

Source: deforestation data - PRODES (2009); soybean data - Conab (2009).

From 2005-2008, Mato Grosso represented 87% of the Legal Amazon soybean area and 31% of the deforested area in the Legal Amazon (Table 1). According to Morton *et al.* (2006), from 2001-2005 14% of the deforested area in Mato Grosso was turned into cropland for soy production. Assuming that this holds true for the period of 1988-2008, we calculated the newly deforested area used for soy production for each year of this period and expressed this as a percentage of the total soy area (Table 2). From 1988-2004, the soy area transformed from rainforest varied, according to our estimation, between 2.5 and 7.6% with an average value of 3.8%. For the 2000-2004 period, this approach yielded an average value of 3.2%. Because from 2001-2004 50% of soy produced in the north of Brazil originated from Mato Grosso (Conab, 2009), it makes some sense to compare this number to the estimated 6% of rainforest transformed to soy area proposed for 2000-2004 by Jungbluth *et al.* for the north of Brazil. From 2005-2008, our estimate for land transformation from rainforest for Mato Grosso varied between 0.7% and 1.6% with an average value of 1% (Table 2), i.e., 1% of total soybean area in this state consisted of land transformed from rainforest in the preceding year. According to Table 2, if the considered period was 2006-2008, the result would be 0.833%; from 2007-2008 it would be 0.75% or 0.8% if considering only the last year (2008). To avoid underestimation, we used the 2005-2008 period.

Obviously, these estimated values are uncertain, but, given the lack of data, we considered them to be reasonable approximations. We used the average value of 1% as our best estimate for land transformation from rainforest to arable land for soybean in Mato Grosso for 2005-2008, and we used 0.7% (the lowest value for 2005-2008) and 3.5% (the average for 1988-2008) for a sensitivity analysis of our results to the value for land transformation from rainforest.

From 2005-2008, the non-Mato Grosso Legal Amazon area comprised 13% of the soybean area and 69% of the deforestation in the Legal Amazon (Table 1). In the Legal Amazon, apart from Mato Grosso, deforestation mainly occurred in Para (39%), Rondonia (14%), Maranhao (6%) and Amazonas (5%) (Table 1). These four states' contribution to the soy area of the Legal Amazon is 1%, 1%, 6% and 0%, respectively (Table 1), so, in these states, soy can hardly have contributed to deforestation, except in Maranhao. For Maranhao we assumed, for lack of data, that the values for land transformation from forest estimated for Mato Grosso (1%, 0.7% and 3.5%) applied. For all other Legal Amazon states we decided to assume 0% land transformation from rainforest to arable land for soybean production.

**Table 2 –** Soybean area, deforested area, estimated soybean area transformed from rainforest, % of total soybean area transformed from rainforest, Mato Grosso, 1988-2008.

| Year | A<br>Soybean area[1]<br>(thousand ha) | B<br>Deforested area[2]<br>(thousand ha) | C = B * 0.14<br>Estimated soybean area transformed from rainforest<br>(thousand ha) | D = C/A * 100<br>% of total soybean area transformed from rainforest<br>(%) |
|---|---|---|---|---|
| 1988 | 1 375.0 | 514.0 | 72.0 | 5.2 |
| 1989 | 1 708.2 | 596.0 | 83.4 | 4.9 |
| 1990 | 1 503.0 | 402.0 | 56.3 | 3.7 |
| 1991 | 1 100.0 | 284.0 | 39.8 | 3.6 |
| 1992 | 1 452.0 | 467.4 | 65.4 | 4.5 |
| 1993 | 1 713.4 | 622.0 | 87.1 | 5.1 |
| 1994 | 1 996.0 | 622.0 | 87.1 | 4.4 |
| 1995 | 2 295.4 | 1039.1 | 145.5 | 6.3 |
| 1996 | 1 905.2 | 654.3 | 91.6 | 4.8 |
| 1997 | 2 095.7 | 527.1 | 73.8 | 3.5 |
| 1998 | 2 600.0 | 646.6 | 90.5 | 3.5 |
| 1999 | 2 548.0 | 696.3 | 97.5 | 3.8 |
| 2000 | 2 904.7 | 636.9 | 89.2 | 3.1 |
| 2001 | 3 120.0 | 770.3 | 107.8 | 3.5 |
| 2002 | 3 853.2 | 789.2 | 110.5 | 2.9 |
| 2003 | 4 419.6 | 1040.5 | 145.7 | 3.3 |
| 2004 | 5 240.5 | 1181.4 | 165.4 | 3.2 |
| 2005 | 6 105.2 | 714.5 | 100.0 | 1.6 |
| 2006 | 6 196.8 | 433.3 | 60.7 | 1.0 |
| 2007 | 5 124.8 | 267.8 | 37.5 | 0.7 |
| 2008 | 5 675.0 | 325.9 | 45.6 | 0.8 |
| AVERAGE | | | | 3.5 |
| TOTAL | - | 13 230.6 | 1 852.3 | |

[1] Source: Conab (2009).

[2] Source: PRODES (2009).

### 2.3.2. Land transformation from Cerrado

To estimate land transformation from Cerrado to cropland we could not use an approach similar to the one for land transformation from rainforest to cropland because annual data on Cerrado clearing were not available. We therefore examined two hypotheses in a sensitivity analysis:

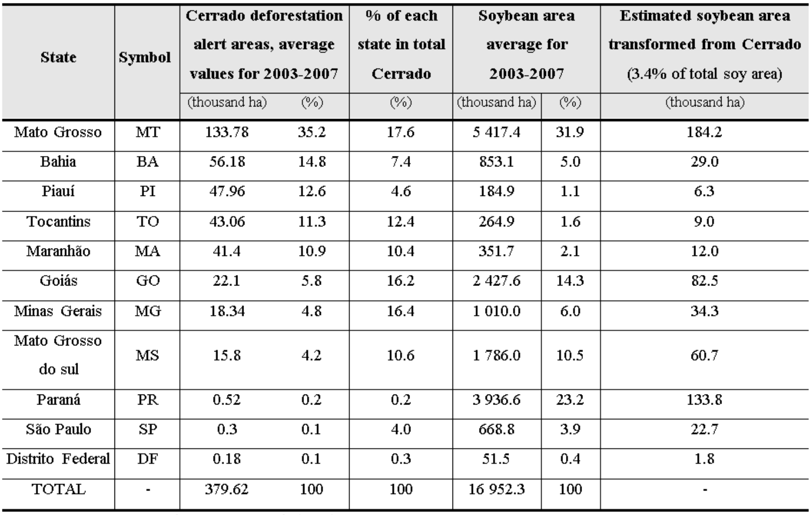
1. Continued Cerrado clearing. We assumed that the data for land transformation from Cerrado to cropland for soybean production by Morton *et al.* (2006) for the 2001-2004 period were valid for the 2005-2008 period for Mato Grosso, and they could be extrapolated to other states where Cerrado biome occurs.

2. Zero Cerrado clearing. We assumed that the stabilization of the soybean area had reduced the transformation of Cerrado to cropland for soybean production to an insignificant level and used a value of 0% for land transformation from Cerrado.

To implement the first hypothesis, we used the 2001-2004 data from Fig. 3 in Morton *et al.* (2006) to calculate the ratio of cropland transformed from Cerrado over cropland transformed from rainforest, i.e., 5770/5463 = 1.056. For the 2001-2004 period, the average % of soy area transformed from rainforest was 3.225% (Table 2). We then estimated the 2001-2004 period average % of soy area transformed from Cerrado as 3.225 * 1.056 = 3.4%.

These hypotheses for transformation from Cerrado are uncertain, but the two hypotheses probably describe the actual situation. To extrapolate this to the other states in which Cerrado occurs, we used data from LAPIG (2008) on Cerrado “alert areas”. These alert areas were obtained from the intersection of several satellite images to estimate the deforestation of the Cerrado. However, as only a small number of randomly selected cases have been validated through a comparison with more precise images and in the absence of validation through field surveys, the expression “alert areas” or “possible clearing areas” was used.

**Table 3 –** Cerrado deforestation alert areas, area of Cerrado biome, soybean area and estimated soybean area transformed from Cerrado per state.



| State | Symbol | Cerrado deforestation alert areas, average values for 2003-2007 | | % of each state in total Cerrado | Soybean area average for 2003-2007 | | Estimated soybean area transformed from Cerrado (3.4% of total soy area) |
|---|---|---|---|---|---|---|---|
| | | (thousand ha) | (%) | (%) | (thousand ha) | (%) | (thousand ha) |
| Mato Grosso | MT | 133.78 | 35.2 | 17.6 | 5 417.4 | 31.9 | 184.2 |
| Bahia | BA | 56.18 | 14.8 | 7.4 | 853.1 | 5.0 | 29.0 |
| Piauí | PI | 47.96 | 12.6 | 4.6 | 184.9 | 1.1 | 6.3 |
| Tocantins | TO | 43.06 | 11.3 | 12.4 | 264.9 | 1.6 | 9.0 |
| Maranhão | MA | 41.4 | 10.9 | 10.4 | 351.7 | 2.1 | 12.0 |
| Goiás | GO | 22.1 | 5.8 | 16.2 | 2 427.6 | 14.3 | 82.5 |
| Minas Gerais | MG | 18.34 | 4.8 | 16.4 | 1 010.0 | 6.0 | 34.3 |
| Mato Grosso do sul | MS | 15.8 | 4.2 | 10.6 | 1 786.0 | 10.5 | 60.7 |
| Paraná | PR | 0.52 | 0.2 | 0.2 | 3 936.6 | 23.2 | 133.8 |
| São Paulo | SP | 0.3 | 0.1 | 4.0 | 668.8 | 3.9 | 22.7 |
| Distrito Federal | DF | 0.18 | 0.1 | 0.3 | 51.5 | 0.4 | 1.8 |
| TOTAL | - | 379.62 | 100 | 100 | 16 952.3 | 100 | - |

Source: LAPIG, 2008; Soybean area: Conab (2009).

From 2003-2007, Mato Grosso presented 35.2% of probable Cerrado clearing and 31.9% of the soybean area in the states where Cerrado occurs. In the non-Mato Grosso Cerrado area, clearing mainly occurred in Bahia (14.8%), Piauí (12.6%), Tocantins (11.3%), Maranhão (10.9%) and Goiás (5.8%) (Table 3). However, we considered that soybean production may have contributed to clearing Cerrado in all states concerned due its ease and the preference of farmers for this type of land clearing. Table 3 reveals that our estimation for soybean area transformed from Cerrado is inferior to “alert areas” in the northern states, i.e., Bahia, Piauí, Tocantins and Maranhão. This seems reasonable because the area transformed from Cerrado is put to other uses (other crops, pasture) besides soybean production (Brossard & Barcellos, 2005; Carvalho, 2006). However, our estimation is higher than “alert areas” in the other states, including states with the largest area of soybeans, such as Mato Grosso, Goiás and Paraná. We decided to keep our estimate because as in the case of Center-West states where Cerrado is predominant, the difference is of the same magnitude. In the case of Paraná, our estimate is much larger than the “alert areas”. However, as the amount of Cerrado is very small in the states of Paraná, São Paulo and Distrito Federal, we assumed that 0% of the soy area was transformed from Cerrado, and for all other states concerned we assumed that the value estimated for Mato Grosso (3.4%) applied.

### 2.4. ASSESSING IMPACTS OF LAND TRANSFORMATION FOR DIFFERENT SCENARIOS

To run a sensitivity analysis, we used the software SimaPro® and the Ecoinvent® database. To assess the impacts, we used the CML 2001 (baseline) method (Guinée *et al.*, 2002). First, we performed an LCA of soybean production in the center-west region always using the same amounts of inputs and yield, assuming 3.4% of transformation from Cerrado and varying the percentage of transformation from rainforest according to the hypotheses described in section 2.3.1 (0.7, 1.0 and 3.5% of soybean area). Next, we performed the same LCA, assuming 1% transformation from rainforest and varying the percentage of transformation from Cerrado according to the hypotheses described in section 2.3.2 (0 and 3.4% of soybean area).

In both cases, the functional unit was 1 ton of soybeans (13% moisture) delivered to regional storage at 40 km of the farm. We considered the impacts associated with the production and use of agricultural machines and diesel, the transport of crop inputs to the farm over a distance of 350 km and the transport of soybeans within the farm and to local storage for drying over a distance of 40 km. We also considered the production of pesticides and production and use of chemical fertilizers. We did not include farm buildings due to lack of data.

Data describing the crop production practices for soybean production in the center-west were based mainly on field surveys from official research organizations (EPAGRI, EMBRAPA and IMEA), production cooperatives (Cooper CAROL and COMIGO) and producers associations (APROSOJA). In short, we assumed a no-tillage system and fertilization using chemical fertilizer only, as these are the most common practices in the center-west region. The data used to calculate emissions for the different parts of the product system were based on the methodology proposed by IPCC (IPCC, 2006) and Ecoinvent® (Nemecek & Kägi, 2007). However, we used emission factors for Brazil where appropriate. These emission factors were found in publications from public research organizations (EMBRAPA and EPAGRI) and

Brazilian universities. Tables 4 and 5 show the main inputs and emissions for soybeans produced in the center-west.

**Table 4 –** Main inputs per ha for soybean production in the center-west of Brazil

| Inputs | Unit | Amount |
|---|---|---|
| Yield (87 % dry matter) | kg/ha | 2 791 |
| Diesel (total) | l/ha | 94.6 |
| Agricultural machinery | kg/ha | 18.7 |
| Seed | kg/ha | 55 |
| Lime | kg/ha | 1 800 |
| Chemical fertilizer | kg/ha (2-20-20) | 450 |
| Transport inputs to farm | km | 350 |
| Transport soybeans to storage | km | 40 |
| Pesticides | kg/ha | 9.05 |
| metalaxil-M (10 g/l) | kg/ha | 0.01 |
| glyphosate (360 g/l) | kg/ha | 1.44 |
| 2,4 D (480 g/l) | kg/ha | 0.48 |
| cipermetrin (200 g/l) | kg/ha | 0.02 |
| methamidophos (600 g/l) | kg/ha | 0.30 |
| epoxiconazole (50 g/l) | kg/ha | 0.03 |
| cyproconazole (80 g/l) | kg/ha | 0.02 |
| others pesticides | kg/ha | 0.43 |
| Total pesticide active ingredient | kg/ha | 2.73 |
| Transformation from arable | $m^2$/ha | 9 778.4 |
| Transformation from trop. rainforest | $m^2$/ha | 51.3* |
| Transformation from Cerrado | $m^2$/ha | 170.3* |
| Transformation to arable | $m^2$/ha | 10 000 |
| Occupation, arable | $m^2$a/ha | 5 000 |

Note: * the values shown in the table are equivalent to 1% of the transformation from tropical rainforest and 3.4% of the transformation from Cerrado, but they vary according to the hypothesis of the sensitivity analysis (see section 2.4).

**Table 5** - Main emissions per ha for soybean production in the center-west of Brazil.

| Emissions | Unit | Amount |
|---|---|---|
| N-$NH_3$, air | kg/ha | 2.3 |
| N-$N_2O$, air | kg/ha | 0.6 |
| N-NOx, air | g/ha | 0.025 |
| N-$NO_3$, water | kg/ha | 15.0 |
| $PO_4$ water | kg/ha | 3.0 |
| Cd, soil | g/ha | 10.5 |
| Cr, soil | g/ha | 15.8 |
| Cu, soil | g/ha | 0 |
| Ni, soil | g/ha | 17.4 |
| Pb, soil | g/ha | 52.0 |
| Zn, soil | g/ha | 0 |

Impacts of the transformation of tropical rainforest to arable land were assessed according to Jungbluth *et al.* (2007), as implemented in the Ecoinvent® v2 database. This involved a process for clear-cutting primary forest that allocates resources (wood, energy in biomass and land) and emissions from wood burning and land transformation to the provision of agricultural land. In this process, the original value of carbon dioxide emission from land transformation was 12 kg/m$^2$ (120 ton/ha). This emission corresponds to an estimated 20% of the above-ground biomass which is burnt; the remaining 80% is ignored in this approach. In order to better conform to current practice with respect to the consideration of $CO_2$ emissions resulting from land transformation, we decided to adopt a value of 74 kg/m$^2$ (740 ton/ha), as recommended in PAS 2050 (2008) and in agreement with several authors (Searchinger *et al.*, 2008; Lapola *et al.*, 2010; Cederberg *et al.*, 2011).

Although Jungbluth *et al.* (2007) estimated the transformation of Cerrado to arable land, these data were not actually taken into account in an impact assessment in the Ecoinvent database. According to Reijnders & Huijbregts (2008), the transformation of tropical rainforest to arable land yields 7.5 times more greenhouse gas emissions than the transformation of Cerrado to arable land. We used these data to assess the impacts of transformation of Cerrado by adapting the approach proposed by Jungbluth *et al.* for the transformation of tropical rainforest.

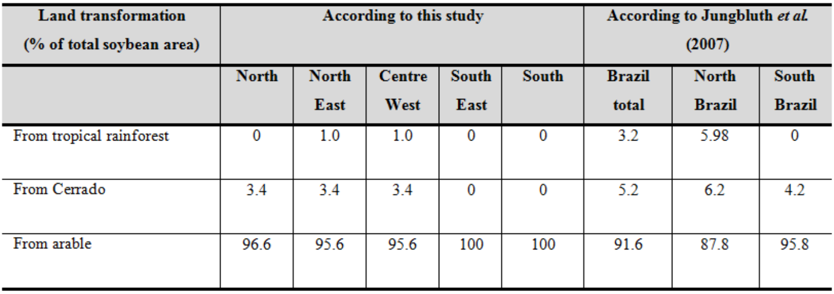
This means that for all impact categories, we assume that the impacts per m$^2$ of cleared Cerrado is 7.5 times smaller than the impacts per m$^2$ of rainforest. As we assume a value of 74 kg $CO_2/m^2$ emissions for tropical rainforest, which means that the value assumed for the Cerrado was 9.87 kg $CO_2/m^2$.

## 3. RESULTS AND DISCUSSION

### 3.1. IMPLEMENTATION OF VALUES FOR LAND TRANSFORMATION

To implement scenarios for soybean crops, we used a combination of values for the soybean area transformed from rainforest (0% or 1%) and for the soybean area transformed from Cerrado (0% or 3.4%) for each of Brazil's five regions (IBGE: www.ibge.gov.br) (Table 6).

**Table 6** – Land transformation values in % for soybean crops in different regions of Brazil for 2005-2008 as estimated in this study compared to values proposed by Jungbluth *et al.* (2007).



| **Land transformation (% of total soybean area)** | **According to this study** | | | | | **According to Jungbluth *et al.* (2007)** | | |
|---|---|---|---|---|---|---|---|---|
| | **North** | **North East** | **Centre West** | **South East** | **South** | **Brazil total** | **North Brazil** | **South Brazil** |
| From tropical rainforest | 0 | 1.0 | 1.0 | 0 | 0 | 3.2 | 5.98 | 0 |
| From Cerrado | 3.4 | 3.4 | 3.4 | 0 | 0 | 5.2 | 6.2 | 4.2 |
| From arable | 96.6 | 95.6 | 95.6 | 100 | 100 | 91.6 | 87.8 | 95.8 |

North states: AC, AM, AP, PA, RO, RR, TO; North-east states: MA, PI, CE, RN, PB, PE, AL, SE, BA; Center-west states: MT, MS, GO, DF; South-east states: MG, ES, RJ, SP; South states: PR, SC, RS. North Brazil: North, north-east and center-west; South Brazil: South-east and south.

Compared to Jungbluth *et al.* (2007), our values for transformation from rainforest and Cerrado were lower, reflecting the recent stabilization of the soybean area and decrease in deforestation in Brazil. Moreover, our regionalization approaches differed. Whereas our approach proposed estimations for each of Brazil’s five regions, Jungbluth *et al.* (2007) presented results for North Brazil (consisting of

North, North-East and Centre-West regions) and South Brazil (consisting of South-East and South regions). In their final calculations for soybean production, Jungbluth *et al.* (2007) considered average percentages of transformation for Brazil.

To calculate environmental impacts using the LCA approach, it is necessary to express these percentages of land transformation in terms of surface-per-mass of product, or $m^2$-per-kg of product. For these calculations, we followed the approach proposed by Jungbluth *et al.* (2007) by applying our percentages of land transformation (Table 6). Because the Centre-West and South regions produce more than 85% of all Brazilian soybeans, only these regions are presented in Table 7.

**Table 7** – Comparison of estimations of land transformation and occupation per kg of soybean: Centre-West and South Brazil (according to this study) and Brazil (according to Jungbluth *et al.*, 2007).

| Item | Unit | Centre West | South | Brazil | Observation |
|---|---|---|---|---|---|
| Yield | kg/ha | 2 791 | 2 535 | 2 544 | A<br>Data from Conab (2009) |
| Transformation from tropical rainforest | m$^2$/kg soy | 0.018 | 0 | 0.062 | B = 10000 / A * % in Table 4 * 0.5 |
| Transformation from cerrado | m$^2$/kg soy | 0.061 | 0 | 0.10 | C = 10 000 / A * % in Table 4 * 0.5 |
| Transformation from arable | m$^2$/kg soy | 3.504 | 3.945 | 3.77 | D = (10 000 / A * % in Table 4) + B + C |
| Transformation to arable | m$^2$/kg soy | 3.583 | 3.945 | 3.93 | E = B + C + D |
| Occupation, arable, not irrigated | m$^2$a/kg soy | 1.791 | 1.972 | 1.97 | F = 10 000 / A * 0.5 |

The factor 0.5 in the calculations of Table 7 reflects the use of the same area for two successive crops within a year, i.e., six months for the soybean crop (Fearnside, 2001; Deconto *et al.*, 2008). This implies that one should allocate the other half of the environmental impact to any other crop planted in the first year following deforestation in the same area.

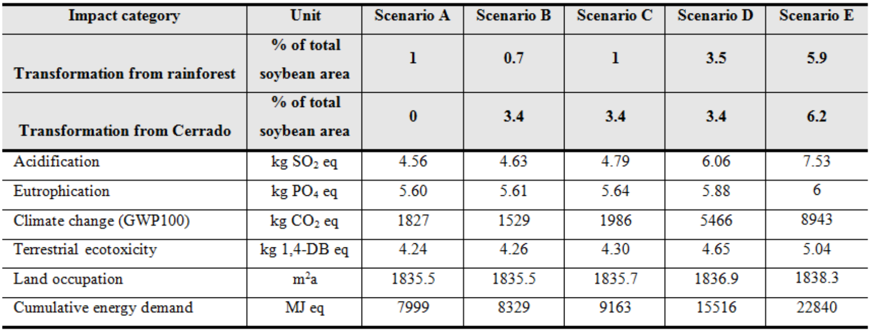
Compared to the estimations according to Jungbluth *et al.* (2007) for the whole of Brazil, our estimations for the two principal soy producing regions in Brazil were lower for the Centre-West, in particular for rainforest (0.018 instead of 0.062 $m^2$/kg) and were zero for the South because in this region, deforestation occurred long ago, and the remaining areas are now protected more strongly (Table 7). It is important to notice that the level of soybean yield considered directly affected these values.

For future estimates, Tables 2 and 3 should be updated. Data on Amazon deforestation can be obtained from PRODES (2009), areas with soybeans can be obtained from Conab (2009) and data to estimate the Cerrado deforestation can be obtained from LAPIG (2008). However, data from Morton *et al.* (2006) to estimate the proportion of deforestation for soy crop should be used only if more recent information of similar quality is not available.

## 3.2. SENSITIVITY ANALYSIS

The results of the sensitivity analysis were summarized in four scenarios defined by assumptions for the percentage of soybeans grown on land transformed from rainforest and Cerrado (Table 8). Scenario A represented the lowest level of land transformation, with 1% transformed from rainforest and no Cerrado clearing. Scenario B represented a moderate situation, with 0.7% transformed from rainforest and 3.4% from Cerrado. Scenario C represented our best estimate of reality, i.e., 1% transformed from rainforest and 3.4% from Cerrado. Scenario D represented the highest level of land transformation, with 3.5% transformed from rainforest and 3.4% from Cerrado. We also presented a fifth scenario (E) with the transformation values proposed by Jungbluth *et al.* (2007) for the North of Brazil. For this scenario E, as for the scenarios A-D, we used the value of 74 kg/m2 for $CO_2$ emissions from land transformation, rather than the value of 12 kg/m$^2$, as originally used by Jungbluth et al (2007) in their calculations (see section 2.4). The scenario E does therefore not correspond to the original process in the Ecoinvent database used for Brazilian soybeans, but to the process as described in this paper for soybean production in Centre-West of Brazil, just changing the proportions of area transformed from rainforest (5.9%) and from Cerrado (6.2%).

**Table 8** – Environmental impacts according to scenarios of transformation from rainforest and Cerrado to arable land for 1 ton of soybeans produced in the Centre-West of Brazil.



| **Impact category** | **Unit** | **Scenario A** | **Scenario B** | **Scenario C** | **Scenario D** | **Scenario E** |
|---|---|---|---|---|---|---|
| **Transformation from rainforest** | **% of total soybean area** | **1** | **0.7** | **1** | **3.5** | **5.9** |
| **Transformation from Cerrado** | **% of total soybean area** | **0** | **3.4** | **3.4** | **3.4** | **6.2** |
| Acidification | kg $SO_2$ eq | 4.56 | 4.63 | 4.79 | 6.06 | 7.53 |
| Eutrophication | kg $PO_4$ eq | 5.60 | 5.61 | 5.64 | 5.88 | 6 |
| Climate change (GWP100) | kg $CO_2$ eq | 1827 | 1529 | 1986 | 5466 | 8943 |
| Terrestrial ecotoxicity | kg 1,4-DB eq | 4.24 | 4.26 | 4.30 | 4.65 | 5.04 |
| Land occupation | $m^2a$ | 1835.5 | 1835.5 | 1835.7 | 1836.9 | 1838.3 |
| Cumulative energy demand | MJ eq | 7999 | 8329 | 9163 | 15516 | 22840 |

For eutrophication, terrestrial ecotoxicity and land occupation, the maximum difference between the scenarios A, B, C and D (Table 8) was less than 8.5%, showing that these impacts were not very sensitive to our hypotheses on land transformation. Acidification was more sensitive to these hypotheses, reaching almost 24% difference between the maximum and minimum values of these four scenarios. The climate change impacts and cumulative energy demand were strongly affected by our hypotheses on land transformation from forest, reaching maximum differences between scenarios of 46% and 51%, respectively. Unsurprisingly, the results were more sensitive to variations in the % transformation from rainforest (scenarios B, C and D) than to variation in the % transformation from Cerrado (scenarios A and C). One should keep in mind, however, that our estimation of the impacts of transformation from Cerrado being seven times smaller than that of the transformation from rainforest were based on the estimation of $CO_2$ emissions according to Reijnders & Huijbregts (2008). More detailed data on the impacts of Cerrado deforestation would be useful.

Compared to scenarios A, B, C and D, the scenario E (proportions of transformation according to Jungbluth *et al.*) showed much higher values for cumulative energy demand and climate change (Table 8). Relative to our scenario with the highest level of impact (D), it had 63% and 47% greater impact for climate change and cumulative energy demand, respectively. Relative to scenario C (our best estimate) it had 350% and 149% higher values for climate change and cumulative energy demand, respectively. These numbers showed that it is very important to have recent and reliable estimates for the area transformed from forest to soybeans because the influence of environmental impacts was very strong.

This sensitivity analysis also revealed that it was important to have a good estimate of transformation from Cerrado, but that an estimate for transformation from rainforest had a much greater effect on the results.

### 3.3. RECOMMENDATIONS

In this study, we consider that the full impact of recent deforestation (the last two growing seasons) is on the annual crop (soybean) planted at the time. This approach, while highlighting the need to not use forest areas for production of annual crops, can be criticized and considered socially unjust, because it does not dilute the impact over the years. So it may be interesting for future researchers to consider dividing this impact over 20 years, for example. We must consider in this case that although the annual impact would be reduced dramatically, the area deforested up to 20 years ago should also be considered (not only the area recently cleared), as it would still have deforestation effects.

## 4. CONCLUSIONS

Although it is difficult to estimate the amount of forest that is transformed into arable land for crops in Brazil, this estimate is necessary to assess the environmental impacts of soybeans and other crops produced in Brazil. This study has shown that, for 2005-2008, the importance of deforestation for soy production in Brazil was highly variable depending on the region of the country. In particular, a major difference existed between the center-west and south regions. In the south of Brazil, deforestation occurred long ago, and the remaining areas are strongly protected. For the center-west we estimated that 1% of soy production in the region took place on land transformed from tropical rainforest, and 3.4 % occurred on land transformed from Cerrado. These values were less than those estimated by Jungbluth *et al.* (2007) for the 2001-2004 period. This difference reflected the recent stabilization of the soybean area and the decrease in deforestation as well as a more appropriate approach that considers differences in the levels of deforestation among Brazil's five regions and in the estimation of soy grown on deforested land.

This study showed that considerations of deforestation and land clearing associated with soybean strongly affected the estimated impacts of soybean production and that the impact of transformation from rainforest was much greater than that of transformation from Cerrado. The eutrophication, terrestrial ecotoxicity and land competition impacts were not affected much by the proportion of land transformed from forest, and acidification was moderately affected. Climate change and cumulative energy demand were strongly affected by assumptions regarding land transformation from forest.

This work showed that the only LCA study that takes into account deforestation in the assessment of impacts of soybean production (Jungbluth et al., 2007) was based on data from an atypical period and that the method proposed to estimate land transformation from forest should and can be improved. The expansion of the soybean area and the rate of deforestation have declined since the 2001-2004 period. As a consequence, the Ecoinvent data for Brazilian soybeans are now outdated and can be improved.

## 5. ACKNOWLEDGEMENTS

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# VARIABILITY IN ENVIRONMENTAL IMPACTS OF BRAZILIAN SOYBEAN ACCORDING TO CROP PRODUCTION AND TRANSPORT SCENARIOS[2]

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## ABSTRACT

Soybean production and its supply chain are highly dependent on inputs such as land, fertilizer, fuel, machines, pesticides and electricity. The expansion of this crop in Brazil in recent decades has generated concerns about its environmental impacts. To assess these impacts, two representative chains supplying soybeans to Europe were identified: Centre-West (CW) and Southern (SO) Brazil. Each supply chain was analyzed using Life Cycle Assessment methodology. We considered different levels of use of chemical and organic fertilizers, pesticides and machinery, different distances for transportation of inputs and different yield levels. Because transportation contributed strongly to environmental impacts, a detailed study was performed to identify the routes used to transport soybeans to seaports. Additionally, we considered different levels of land occupation and land transformation to represent the impact of deforestation in the CW region. Environmental impacts were calculated for 1000 kg of soybean up to and including the delivery to Europe at the seaport in Rotterdam, at 13% moisture. Overall results showed that the impacts are greater for CW than for SO for all

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[2] This chapter corresponds to an article that was published in the Journal of Environmental Management (v.91, n.9, p. 1831-1839, set 2010, DOI: 10.1016/j.jenvman.2010.04.001). However, the text of this chapter differs from the published paper, as some modifications were made, due to the new value of $CO_2$ emissions from land transformation, as discussed in Chapter 2, Section 2.4 - Assessing the impacts of land transformation for different scenarios. The text presented here corresponds to the text of the publication, with the exception of highlighted text. The authors intend to submit corrections to the published article to the Journal of Environmental Management, soon after the thesis defence.

impact categories studied, including acidification (7.7 and 5.3 kg $SO_2$ eq., respectively), climate change (2,120 and 510 kg $CO_2$ eq.), cumulative energy demand (12,634 and 6,999 MJ) and terrestrial ecotoxicity (4.9 and 3.1 kg 1,4-DB eq.), except eutrophication and land occupation. The same trend was observed for the crop-production stage. Efforts to reduce chemical fertilizers and diesel consumption can reduce $CO_2$ emissions. Although deforestation for crop production has decreased in recent years, the contribution of deforestation to climate change and cumulative energy demand remains significant. In the CW scenario deforestation contributed 68% to climate change and 20% to cumulative energy demand. Results also showed that although there are different transportation options in Brazil, the current predominance of road transport causes severe environmental impacts. In CW, road transport contributed 9% to climate change and 24% to cumulative energy demand, while in SO it contributed 12% and 15% to these impacts, respectively. Improvements in the logistics of transportation, giving priority to rail and river transport over road transport, can contribute significantly to reducing greenhouse gas emissions and decreasing energy use. Future studies involving Brazilian soybeans should take into account the region of origin as different levels of environmental impact are predicted.

**Keywords:** life cycle assessment (LCA), soybean, environmental impact, transportation.

## 1. INTRODUCTION

The rapid growth of soybean production in Brazil began in the 1960s, and in less than 20 years, soybean became Brazil’s most important grain crop. Since the 1970s, the increase in global demand for protein has expanded international trade of soybean products. This resulted in changes in Brazilian economic policies, such as creating a favorable exchange rate to improve competitiveness of exports.

Southern Brazil, especially the states of Paraná and Rio Grande do Sul, has the longest tradition of soybean production. Since 1990, however, soybean production has increased in the Central-West region of Brazil, including the Cerrado (tropical savanna) biome and the states of Goias, Mato Grosso do Sul and Mato Grosso.

Soybean production and its supply chain are highly dependent on inputs such as land, fertilizer, fuel, machines, pesticides and electricity. The expansion of soybean crops in Brazil has been associated with destruction of the Amazon rainforest and the Cerrado biome (Lehuger *et* *al*., 2009). Also, the nutrients exported with the Brazilian soybean cannot be recycled in the same area due to the distance. In Europe, the nitrogen and phosphorus that are associated with intensive livestock production, which often uses Brazilian soybean as a source of protein, are important environmental concerns (Oenema *et al*., 2007).

Efforts have been made in Brazil to reduce the environmental impacts of soybean crops. In terms of production techniques, no-tillage systems that reduce soil erosion and the use of fertilizers and pesticides have been widely adopted by producers (Cavalett and Ortega, 2009). In terms of policies, initiatives put in place by soybean industry organizations such as the Soy Moratorium have pledged to not trade soybeans produced in the Amazon biome on land that was cleared after July 24th, 2006. In recent years, the Brazilian government has also significantly increased efforts to reduce deforestation in the Amazon biome.

Few studies exist on the environmental impacts of Brazilian soybeans using the Life Cycle Assessment (LCA) approach. Furthermore, in such studies (Cederberg, 1998; Spies, 2003; van der Werf *et al*., 2005; Jungbluth *et al*., 2007; Cavalett and Ortega, 2009; Lehuger *et al*., 2009), Brazilian soybeans are treated as a single-source product despite large differences in climate, soil type and transport means and distances for different production regions within Brazil. This is the first LCA study of Brazilian soybeans aimed to examine Brazil’s two primary production regions. In both regions, the impacts of several crop-production scenarios and routes for export were assessed.

## 2. MATERIAL AND METHODS

### 2.1. ASSESSMENT METHODOLOGY

The environmental impacts of supply chains from Brazil’s two major soybean production regions, South (SO) and Centre-West (CW), were evaluated according the LCA approach (ISO, 2006). We studied the life cycle of soybean production up to and including the delivery of soybeans to Europe at the seaport in Rotterdam, Netherlands. The functional unit (FU) was 1000 kg of soybeans at 13% moisture. To consider the impacts associated with energy supply, resource extraction, material supply, chemicals, agricultural machines, and transport we used the Ecoinvent® database. This database was developed by the Swiss

Centre for Life Cycle Inventories, a joint initiative of several institutes and departments and is supported by Swiss Federal Offices. Although the majority of processes in this database are representative of Switzerland and Europe, we consider that the production of raw materials, manufactured goods and transport are very similar in Brazil, allowing us to use the processes unchanged. However, some processes (electricity, limestone, diesel combustion and grain drying) were adapted to better represent the Brazilian reality.

## 2.2. MODELING

### 2.2.1. Production stage

For SO and CW, we considered the transport of crop inputs to the farm to be 250 and 350 km, respectively, and the transport of soybeans within the farm and to local storage for drying to be 20 and 40 km, respectively. We did not include buildings due to lack of data, but buildings were previously shown to have only minor (0-2%) environmental impacts on arable crop production (van Zeijts and Reus, 1996).

In the soybean growing area, we considered that pig slurry use partly substituted for chemical fertilizer use. However, the resource consumption and emissions associated with pig slurry production and delivery were not included, as these were allocated to pig production.

In Brazil, two major factors distinguish production modes for soybean: tillage system and fertilizer type. At least 80% of Brazilian soybean crops are produced with zero-tillage systems (Antunes, 2008), both in the CW and SO. Although pig slurry is not the most common fertilizer for soybean crops, the impacts of its use differ substantially from those of chemical fertilizer and were therefore considered in this study.

We estimated the total amount of slurry produced in both regions using data from the Brazilian Institute of Geography and Statistics (IBGE, 2009), Oliveira (1993), CONAB (2009) and Konzen (2008). Assuming that all pig slurry available was applied to soybean crops, we set the maximum percentage of the soybean crops that could be fertilized with slurry. This figure represents a maximum because in practice slurry is also used for other crops. We assumed that 40% of this maximum would actually receive slurry. This corresponded to 3.6% of the total SO soybean crop area. For CW, this corresponded to less than

0.8% of total soybean crop area, and we considered this amount to be negligible.

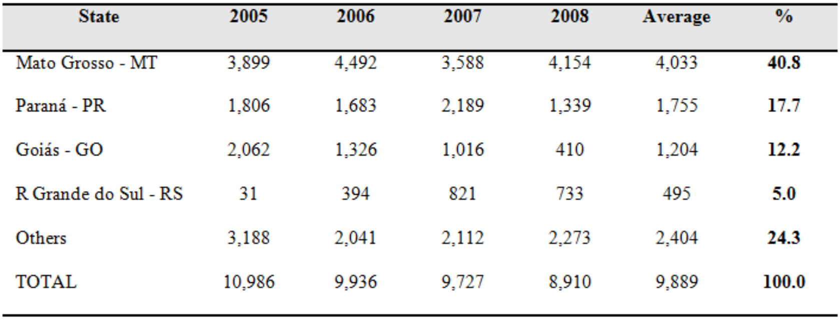
### 2.2.2. Drying and storage

The next stage of production includes pre-cleaning, drying, cleaning and storage. Heat for grain drying comes primarily from wood (85%; Marques, 2006). The remainder comes from natural gas, liquefied petroleum gas and diesel oil. According to EMBRAPA (2004), soybeans should be harvested at approximately 18% moisture. For ideal storage and transport, moisture should be 13% or less (EMBRAPA, 2004; Silva, 2004). According to Errera *et al.* (2002), the energy required for this stage is equivalent to 168 MJ per ton of soybeans at 13% moisture and 2.34 MJ of electricity. Silva (2006) reported a total energy cost of 168-291 MJ per ton of soybeans. Spies (2003) used 468 MJ (from wood) per ton of soybeans at 13% moisture. Marques (2006) used 279 MJ (from wood) per ton of soybeans and 3.222 MJ of electricity (0.288 MJ for pre-cleaning, 1.584 MJ for drying, 0.047 MJ for cleaning and 1.303 MJ for storage). For this study, we used the values proposed by Marques because these data are the most recent and the research was well detailed. To assess the impact of this decision on the final result and thus validate the data chosen, we conducted a sensitivity test, using the maximum (468 MJ) and minimum (168 MJ) values quoted by the authors above. In the final results, the variation obtained in all impact categories studied was less than 1%, except for total cumulative energy demand, where we found 3% of variation for CW and 6% for SO.

### 2.2.3. Transportation routes

We estimated the amount of soybeans passing along different routes (road, rail and waterway), creating scenarios for comparison. Based on data from the Brazilian Ministry of Development, Industry and Foreign Trade (MDIC), we identified the states that contributed most to the export of soybeans to the European Union (EU) over the last four years. We established the mean amount exported by each state (**Table 1**) and decided to focus on the four states that contributed most (Mato Grosso, Paraná, Goiás and Rio Grande do Sul). These four states export 76% of all Brazilian soybeans exported to the EU.

**Table 1 –** Soybean exports (thousand tons) from Brazil (by state) to the European Union from 2005 to 2008.



| State | 2005 | 2006 | 2007 | 2008 | Average | % |
|---|---|---|---|---|---|---|
| Mato Grosso - MT | 3,899 | 4,492 | 3,588 | 4,154 | 4,033 | **40.8** |
| Paraná - PR | 1,806 | 1,683 | 2,189 | 1,339 | 1,755 | **17.7** |
| Goiás - GO | 2,062 | 1,326 | 1,016 | 410 | 1,204 | **12.2** |
| R Grande do Sul - RS | 31 | 394 | 821 | 733 | 495 | **5.0** |
| Others | 3,188 | 2,041 | 2,112 | 2,273 | 2,404 | **24.3** |
| TOTAL | 10,986 | 9,936 | 9,727 | 8,910 | 9,889 | **100.0** |

Source: MDIC, 2008.

Using the same database (from MDIC), we determined the quantity of soybeans exported to the EU from each Brazilian seaport according to its state of origin. Using the regional division of each state by IBGE, which groups municipalities according to their geographic position, rail and road maps and data from the Strategic Development Corridor Project (GEIPOT, 2000), we identified the regional centers of distribution for road, rail and river ports. Similarly, we obtained the distance from each exporting municipality to regional centers by road, rail and river. Finally, we obtained the distance between each regional center (by rail, road and river) and each main port that exports soybeans to the EU.

Furthermore, we identified the primary possible routes and assessed the percentage of soybeans transported by road, rail and waterway. According to the National Plan for Logistics and Transport from MDIC, this percentage was 58% by road, 25% by railway[3] and 13% by waterway in 2006. Using these data, we adjusted the amounts to identify the main routes and their contribution to soybean export to the EU. Finally, we calculated for each state, and for the main routes, the weighted mean of the distances covered by each transport mode.

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[3] According to the National Agency for Land Transport (Agência Nacional de Transporte Terrestre), of 29,700 km of railroad in Brazil, less than 4% are electrified. Thus, we assumed that diesel locomotives were used.

## 2.3. EMISSIONS FROM CROP PRODUCTION

Due to short intervals between successive crops (a field generally produces two crops per year) and the use of minimum-tillage systems and cover crops, the levels of nitrate loss are low in Brazil. Based on the levels of nitrate loss found by Brazilian researchers (Basso, 2003; Giacomini et al., 2007; Moreira et al., 2004), we considered the loss of nitrate for SO to be 20 kg $N\text{-}NO_3$ $ha^{-1}$ for a no-tillage system and 25 kg $ha^{-1}$ for a tillage system. We also considered the loss of nitrate for CW to be 15 kg $N\text{-}NO_3$ $ha^{-1}$ for a no-tillage system and 20 kg $ha^{-1}$ for a tillage system. These values were established considering lower nitrate loss in a no-tillage system compared to a conventional system, and weather conditions (rain coinciding with the low soil cover period) causing more nitrate loss for SO than for CW.

Emissions of $N\text{-}N_2O$ into air were estimated according to IPCC Volume 4 (2006). We considered N from mineral fertilizer and pig slurry, as well as N from the mineralization of crop residues (above and below ground). Indirect $N\text{-}N_2O$ emissions associated with volatilization and the amount of $N\text{-}N_2O$ produced from leaching and runoff of N inputs to managed soils were estimated according to IPCC (2006) and the emission factors proposed by Cantarella *et al.* (2008) and Basso *et al.* (2004). Emissions of $N\text{-}NO_x$ into air were estimated based on the amount of $N_2O$ emitted and applying an emission factor of 0.21, as suggested in Ecoinvent® Report 15 (Nemecek and Kägi, 2007).

Emissions of P into water were estimated according to Ecoinvent® Report 15 (Nemecek and Kägi, 2007). For this purpose, soil loss was estimated for each scenario based on EMBRAPA recommendations and data from several authors (Cogo *et al.,* 2003; Hernani *et al*., 1999; Lima, 2005).

To assess emissions into soil, we calculated a mass balance by considering the concentrations of heavy metals in fertilizers and the amounts exported in harvested grain. For the concentration of heavy metals in lime, we used data from Amaral *et al*. (1992). For concentrations of P in fertilizer, we used data from Campos *et al*. (2005). For concentrations of urea and potassium chloride, we used data obtained in Europe (Nemecek and Kägi, 2007). Concentrations of heavy metals in pig slurry were obtained from Mattias (2006), and concentrations of heavy metals in grain were obtained from Nemecek and Kägi (2007).

## 2.4. LAND USE

Land occupation and transformation were estimated according to Ecoinvent® Report 17 (Jungbluth *et al.*, 2007), which distinguishes three land use types preceding establishment of soybean crops in Brazil: arable land, transformation from rainforest and transformation from Cerrado. In our study, the processes in the Ecoinvent® database have been update to better represent the current Brazilian situation. Jungbluth *et al.* (2007) estimated land transformation from tropical rainforest and Cerrado from the mean annual increase of Brazilian soybean area during 2000-2004. The authors estimated that, in 2004, 3.2% of land used for soybean production in Brazil was transformed from rainforest and 5.2% was transformed from Cerrado. For northern Brazil, they estimated that 6.0% of land for soybean production was transformed from rainforest and 6.2% was transformed from Cerrado. For the south, they estimated that 0% of land was transformed from rainforest and 4.2% was transformed from Cerrado. While the average annual increase in soybean area was 1,700,000 ha during 2000-2004, the soybean area slightly decreased between 2004 and 2008 (CONAB, 2009). Using these data, the approach proposed by Jungbluth *et al.* (2007) would suggest that soybean crops did not contribute to the clearing of rainforest or Cerrado during this period. However, recent studies have shown that soybean crops are still grown on recently deforested areas, but less than previously (ABIOVE, 2008). We therefore used a different method to estimate land transformation for soybean production. This method is based on data for Mato Grosso, which represented 87% of the soybean area and 31% of the deforestation in the Legal Amazon region during 2005-2008.

According to Morton *et al.* (2006), 14% of deforested area in Mato Grosso was transformed to cropland for soybean production during 2001-2005. Assuming that this holds for the 2005-2008 period and using recent data on deforested surfaces in the Legal Amazon rainforest (PRODES, 2009), we estimated the newly deforested area used for soybean production for each year during this period and expressed this as a percentage of the total soybean area. For the states with the CW scenario, we found an average value of 1% for the 2005-2008 period. We therefore assumed for the CW scenario that 1% of land used for soybean production was transformed from rainforest.

To estimate land transformation from Cerrado to soybean area, we extrapolated data from Morton *et al.* (2006) for 2001-2004 in Mato Grosso to other states within the Cerrado biome. This yielded a value of

3.4% for land transformation from Cerrado to soybean production in the CW scenario. In the states with the SO scenario, tropical rainforest and Cerrado do not exist. We therefore assumed 0% of land transformation from rainforest or Cerrado.

### 2.5. CHARACTERIZATION FACTORS

We based our analysis on the CML 2001 (baseline) method[4] and added the following categories: land occupation (originally "land competition") from CML 2001 (all categories) version 2.04 and Total Cumulative Energy Demand version 1.05. For climate change (originally "Global Warming Potential 100 - GWP100"), which is expressed in kg of $CO_2$ equivalents, we updated values of characterization factors (per Forster *et al.*, 2007) for biogenic methane (new value 25) and nitrous oxide (new value 298).

To represent environmental impacts of soybeans, we present results for the following impact categories: *acidification*, *eutrophication*, *climate change*, *terrestrial ecotoxicity*, *land occupation* and *total cumulative energy demand.* A description of the CML 2001 method can be found in PRé Consultants (2008), and a list of all substances and their respective characterization factors can be found in PRé Consultants (2007).

## 3. RESULTS

### 3.1. IMPACTS OF SOYBEAN CROP PRODUCTION

We considered several scenarios for soybean production up to and including local storage (section 2.2.1). We present results for two "weighted mixes" of scenarios that represent the CW and SO regions: (i) for CW, the mix was 80% "no tillage, chemical fertilization" and 20% "conventional tillage, chemical fertilization"; (ii) for SO, the mix was 77.1% "no tillage, chemical fertilization" , 19.3% "conventional tillage,

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[4] CML 2001 (baseline) version 2.04 is a characterization method developed by the Centre for Environmental Studies (CML), University of Leiden, Netherlands. This method elaborates the problem-oriented (midpoint) approach. The CML Guide provides many impact assessment categories, from which we selected some that were relevant for regions of soybean production.

chemical fertilization”, 2.9% “no tillage, pig slurry” and 0.7% “conventional tillage, pig slurry.”

Overall, CW soybeans had higher impacts per ton than SO soybeans, especially for acidification (4.6 and 2.5 kg $SO_2$ eq., respectively), climate change (1860 and 338 kg $CO_2$ eq., respectively), terrestrial ecotoxicity (4.2 and 2.6 kg 1,4-DCB eq., respectively) and total cumulative energy demand (7,991 and 3,913 MJ, respectively).

Relative to SO, climate change was five times as large in CW, primarily due to deforestation and transport (of crop inputs and of grains to the storage site). Cumulative energy demand in CW was also twice as large as in SO. Again, this difference was primarily due to deforestation and transport, but was also due to the use of more fertilizers in the CW Cerrado areas.

For acidification, the contribution of field emissions was higher in CW than in SO. This was due to higher emissions of $SO_2$ as a result of greater diesel consumption. Terrestrial ecotoxicity was 38% higher in CW, which was primarily due to emissions of heavy metals to soil associated with chemical fertilizer production.

## 3.2. IMPACTS OF SOYBEANS DELIVERED AT ROTTERDAM

This section presents the impacts of soybeans delivered to Rotterdam, including crop production, drying and all transport stages. Results are for two weighted mixes of scenarios that represent the mean for the CW and SO regions. Soybeans from the two regions showed little difference for eutrophication and land occupation, while values for acidification, climate change, terrestrial ecotoxicity and cumulative energy demand were larger for CW than for SO.

Eutrophication was similar for SO and CW soybeans. In both regions, the crop production phase contributed most (80% in SO and 70% in CW), particularly due to nitrate leaching (20 and 15 kg $ha^{-1}$ in SO and CW, respectively). Land occupation per ton was higher in SO than in CW as a result of differences in soybean yields (2,535 and 2,791 kg $ha^{-1}$ in SO and CW, respectively). Climate change per ton of soybeans was 2120 kg $CO_2$ eq. for CW and 510 for SO. Cumulative energy demand was 12,630 MJ for CW and 7,000 for SO (**Figure 1**).

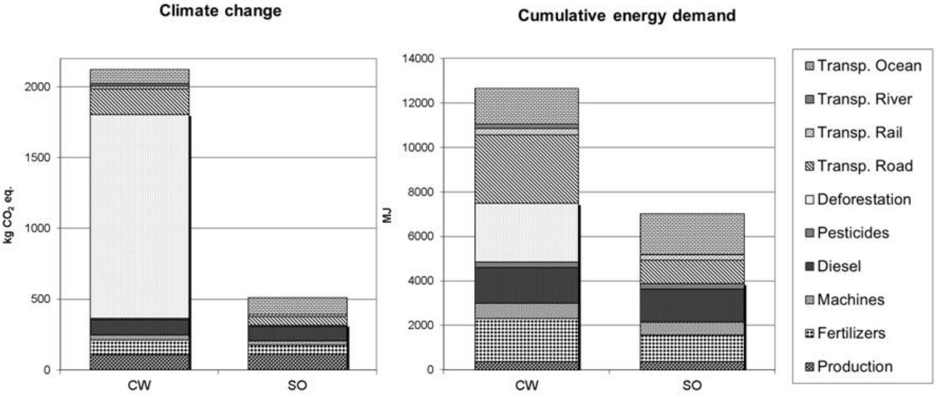


**Figure 1 –** Climate change and cumulative energy demand for one ton of soybeans produced in Center West (CW) or South (SO) Brazil, and delivered at Rotterdam.

Two major factors caused the differences in climate change and energy demand between the two regions: road transport and deforestation. The distance traveled by road was much higher in CW than in SO. In CW, road transport contributed 8.6% to climate change and 24% to cumulative energy demand, while in SO it contributed 12% and 15% to these impacts, respectively. Deforestation for soybean planting occurs in CW, contributing 68% to climate change and 20% to energy demand. Relative to CW, climate change was 76% lower in SO, and cumulative energy demand was 44% lower in SO (**Figure 1**).

For acidification, the contribution of field emissions, was higher for CW due to higher consumption of diesel and fertilizers, at delivery to Rotterdam acidification per ton was 7.7 kg SO2 eq. in CW and 5.3 in SO (**Figure 2**).

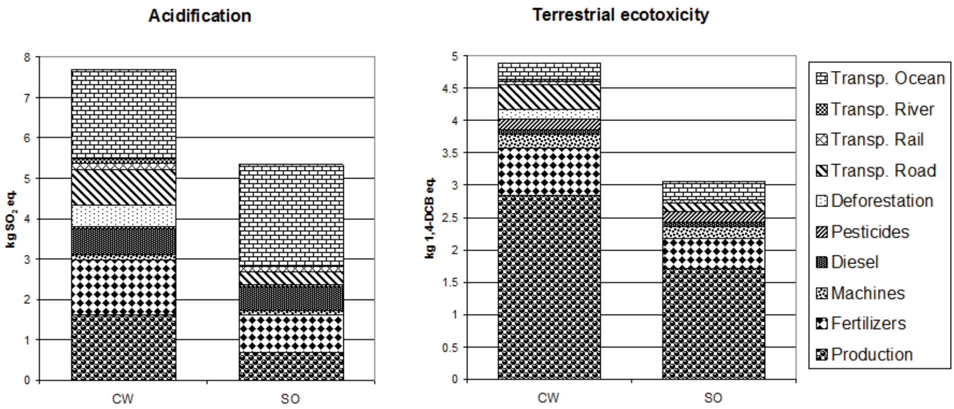


**Figure 2** – Acidification and terrestrial ecotoxicity for one ton of soybeans produced in Center West (CW) or South (SO) Brazil, and delivered at Rotterdam.

Terrestrial ecotoxicity per ton of soybeans was 4.8 kg 1,4-DCB eq. in CW and 3.0 kg 1,4-DCB eq. in SO. Heavy metals from chemical fertilizers contributed most to this impact (**Figure 2**).

The CW and SO weighted mixes of scenarios are presented in Table 2. These weighted mixes represent an average of the main export routes for the two major soybean production areas in Brazil. A table presenting the characteristics and impacts of the scenarios making up the weighted mixes is available online as supplementary information.

**Table 2 –** Environmental impacts for one ton of soybeans delivered at Rotterdam according to scenarios of origin and the mode and distance of transport to seaports in Brazil for CW and SO weighted mixes.

| **Scenarios** | **Distances** | | | **Impact Categories** | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Road | Railway | Waterway | Acidification | Eutrophication | Climate change | Terrestrial ecotoxicity | Land occupation | Cumulative energy demand |
| | (km) | (km) | (km) | (kg SO$_2$ eq.) | (kg PO$_4$ eq.) | (kg CO$_2$ eq.) | (kg 1,4-DB eq.) | (m$^2$ yr$^{-1}$) | (MJ) |
| CW weighted mix | 1,101 | 393 | 289 | 7.7 | 6.8 | 2120.4 | 4.9 | 1,890 | 12,634 |
| SO weighted mix | 317 | 341 | 22 | 5.3 | 6.9 | 510.2 | 3.1 | 2,070 | 6,999 |

GO (Goiás) and MT (Mato Grosso) routes were used to calculate CW values, while PR (Paraná) and RS (Rio Grande do Sul) routes were used to calculate SO values. Considering climate change and cumulative energy demand, the routes “MT, Sorriso, Porto Velho, Manaus/Itacotiara” and “PR, Ponta Grossa, Paranguá” represented the highest and lowest levels of impact, respectively.

Climate change was 2,187 and 474 kg of $CO_2$ eq. per ton of soybeans for Sorriso and Ponta Grossa, respectively, while cumulative energy demand was 13,440 and 6,394 MJ, respectively. In both cases, most of the difference was due to deforestation, which was present only in the Sorriso scenario, and to road transport, which was much higher in Sorriso.

Acidification was 7.8 kg $SO_2$ eq. per ton of soybeans for Sorriso and 5.0 kg $SO_2$ eq. per ton of soybeans for Ponta Grossa. Field emissions contributed more in Sorriso due to more intensive use of machines, but the primary contribution for Sorriso was from road transport, which was much higher than that for Ponta Grossa. Terrestrial ecotoxicity was also higher for Sorriso than for Ponta Grossa (4.9 and 3.0 kg of 1,4-DB eq., respectively). The higher impacts for Sorriso results from deforestation and road transport.

The origin of soybeans within the Brazilian territory strongly affects their environmental impacts. Therefore, in future LCA studies of Brazilian soybeans, this variability of production and transport scenarios should be taken into account.

## 3.3. CONTRIBUTION OF LIFE CYCLE STAGES AND SUBSTANCES TO IMPACTS OF SOYBEAN EXPORTATION

Although we have assessed the impacts of many routes for Brazilian soybean exports to Rotterdam, for the purpose of interpretation, we only considered the CW and SO “weighted mixes.”

Transport to Rotterdam added 15% (CW) to 40% (SO) to the climate change and cumulative energy demand of Brazilian soybeans. Acidification increased by 40% in CW and 53% in SO. Due to transport, eutrophication increased in both scenarios by 5%, terrestrial ecotoxicity by 15% and land occupation by 3%. Thus, the transport stage significantly contributed to climate change, cumulative energy demand and acidification. Transport also contributed to terrestrial ecotoxicity, eutrophication and land occupation to a lesser extent.

### 3.3.1. Climate change and Cumulative energy demand

$CO_2$ was the most important contributor to climate change for both regions. This was primarily due to transport and deforestation (the latter only in CW) (Table 3), but was also due to diesel consumption. However, $N_2O$ also contributed significantly to this impact, resulting primarily from nitrate loss in the crop production stage.

**Table 3 -** Contribution of emitted substances and resources to climate change and cumulative energy demand for one ton of soybeans produced in Center West or South Brazil and delivered at Rotterdam.

| Scenario | Stages of life cycle | Climate change (kg $CO_2$ eq.) | | | | | Cumulative energy demand (MJ) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **$CO_2$** | **$N_2O$** | **$CH_4$** | **Others** | **Total** | **Oil** | **Gas** | **Coal** | **Bio-mass** | **Others** | **Total** |
| Center West average | Crop production [1] | 2.0 | 105.6 | 0.1 | 0.1 | **107.8** | 12 | 4 | 10 | 322 | 18 | **366** |
| | Fertilizers | 98.9 | 0.9 | 5.0 | 0.6 | **105.4** | 539 | 649 | 302 | 23 | 418 | **1,931** |
| | Machines | 30.5 | 0.2 | 1.9 | 0.8 | **33.4** | 218 | 99 | 188 | 4 | 185 | **693** |
| | Diesel | 104.8 | 1.1 | 1.5 | 0.3 | **107.7** | 1,486 | 64 | 23 | 1 | 24 | **1,597** |
| | Pesticides | 9.2 | 0.1 | 0.5 | 0.0 | **9.8** | 88 | 78 | 40 | 2 | 48 | **255** |
| | Deforestation | 1,385.2 | 8.5 | 24.1 | 22.5 | **1,440.3** | 0 | 0 | 0 | 2,631 | 0 | **2,631** |
| | Transp. Road | 172.9 | 1.6 | 6.2 | 0.9 | **181.6** | 2,489 | 226 | 163 | 5 | 195 | **3,078** |
| | Transp. Rail | 18.9 | 0.2 | 0.4 | 0.2 | **19.7** | 235 | 18 | 23 | 1 | 23 | **300** |
| | Transp. River | 13.3 | 0.3 | 0.3 | 0.0 | **13.9** | 151 | 12 | 17 | 1 | 15 | **196** |
| | Transp. Ocean | 97.8 | 0.8 | 1.8 | 0.4 | **100.8** | 1,188 | 105 | 140 | 5 | 154 | **1,591** |
| | **TOTAL** | **1,933.5** | **119.3** | **41.8** | **25.8** | **2,120.4** | **6,407** | **1,254** | **904** | **2,994** | **1,079** | **12,638** |
| South average | Crop production[1] | 2.0 | 110.0 | 0.1 | 0.1 | **112.2** | 12 | 4 | 10 | 322 | 18 | **366** |
| | Fertilizers | 61.8 | 0.6 | 3.0 | 0.4 | **65.8** | 340 | 352 | 203 | 16 | 275 | **1,186** |
| | Machines | 25.7 | 0.2 | 1.6 | 0.7 | **28.2** | 179 | 83 | 160 | 4 | 156 | **582** |
| | Diesel | 97.0 | 1.0 | 1.4 | 0.3 | **99.7** | 1,375 | 59 | 21 | 1 | 22 | **1,478** |
| | Pesticides | 9.5 | 0.1 | 0.5 | 0.0 | **10.1** | 87 | 84 | 42 | 2 | 50 | **265** |
| | Transp. Road | 58.2 | 0.6 | 2.1 | 0.3 | **61.2** | 836 | 76 | 55 | 2 | 66 | **1,035** |
| | Transp. Rail | 16.4 | 0.1 | 0.3 | 0.2 | **17.0** | 204 | 16 | 20 | 1 | 20 | **261** |
| | Transp. River | 1.0 | 0.0 | 0.0 | 0.0 | **1.0** | 11 | 1 | 1 | 0 | 1 | **14** |
| | Transp. Ocean | 111.4 | 0.9 | 2.1 | 0.5 | **114.9** | 1,354 | 119 | 159 | 5 | 176 | **1,813** |
| | **TOTAL** | **383.0** | **113.5** | **11.1** | **2.5** | **510.1** | **4,398** | **794** | **671** | **353** | **784** | **7,000** |

[1] Crop production includes grain drying.

For CW, 8% of emissions contributing to climate change came from road transport, which contributed almost 3 times more to overall emissions in CW than in the SO.

Climate change per ton of transported soybeans was 0.117 kg $CO_2$ eq. per km by road, 0.050 kg $CO_2$ eq. per km by rail (diesel locomotives) and 0.046 kg $CO_2$ eq. per km by river. Cumulative energy demand was 1.990 MJ by road, 0.765 MJ by rail and 0.657 MJ by river. These numbers indicate that prioritizing transport by river and rail rather than by road can help to reduce impacts.

### 3.3.2. Acidification and Eutrophication

$SO_2$ was the most important contributor to acidification impacts for both regions due to the production of fertilizers and transoceanic transport (Table 4). $NO_x$ emissions resulted primarily from road and transoceanic transport, with a minor contribution from crop production. $NH_3$ contributed to acidification, primarily due to field emissions in CW and the use of 2-20-20 chemical fertilizer, which contains 2% nitrogen as urea, 20% $P_2O_5$ and 20% $K_2O$. Although the amount of nitrogen is small, its high volatility results in an important contribution to $NH_{3-}$ emissions.

**Table 4** - Contribution of emitted substances to acidification and eutrophication for one ton of soybeans produced in Center West or South Brazil and delivered at Rotterdam.

| Scenario | Stages of life cycle | Acidification (g $SO_2$ eq.) | | | | Eutrophication (g $PO_4$ eq.) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $SO_2$ | $NO_x$ | $NH_3$ | TOTAL | $PO_4$ | $NO_3$ | $NO_x$ | $NH_3$ | Others | TOTAL |
| Center West mean | Crop production[1] | 5.1 | 21.9 | 1,599.1 | **1,626.1** | 1,732.9 | 2,590.3 | 5.7 | 349.8 | 2.4 | **4,681.1** |
| | Fertilizers | 1,155.4 | 170.6 | 28.2 | **1,354.2** | 1,360.1 | 0.4 | 44.4 | 6.2 | 9.0 | **1,420.1** |
| | Machines | 99.8 | 29.8 | 2.7 | **132.3** | 6.4 | 0.1 | 7.7 | 0.6 | 2.1 | **16,9** |
| | Diesel | 187.6 | 449.4 | 1.3 | **638.3** | 0.3 | 0.0 | 116.9 | 0.3 | 10.3 | **127.8** |
| | Pesticides | 48.6 | 8.4 | 0.2 | **57.2** | 0.4 | 0.0 | 2.2 | 0.0 | 0.7 | **3.3** |
| | Deforestation | 97.8 | 131.8 | 296.1 | **525.7** | 0.0 | 0.0 | 34.3 | 64.8 | 0 | **99.1** |
| | Transp. Road | 227.3 | 644.6 | 4.1 | **876.0** | 3.7 | 0.2 | 167.6 | 0.9 | 11.7 | **184.1** |
| | Transp. Rail | 34.1 | 124.3 | 0.6 | **159.0** | 0.6 | 0.0 | 32.3 | 0.1 | 1.7 | **34.7** |
| | Transp. River | 24.0 | 75.8 | 0.4 | **100.2** | 0.3 | 0.0 | 19.7 | 0.1 | 1.1 | **21.2** |
| | Transp. Ocean | 1,522.4 | 670.9 | 15.7 | **2,209.0** | 1.1 | 0.1 | 174.4 | 3.4 | 8.4 | **187.4** |
| | **TOTAL** | **3,402.1** | **2,327.5** | **1,948.4** | **7,678.0** | **3,105.8** | **2,591.1** | **605.2** | **426.2** | **47.4** | **6,775.7** |
| South mean | Crop production[1] | 5.1 | 34.4 | 647.0 | **686.5** | 1,546.2 | 3,743.5 | 8.9 | 141.5 | 2.4 | **5,442.5** |
| | Fertilizers | 804.5 | 114.1 | 6.4 | **925.0** | 962.3 | 0.3 | 29.7 | 1.4 | 5.7 | **999.4** |
| | Machines | 83.8 | 25.2 | 2.2 | **111.2** | 5.5 | 0.1 | 6.5 | 0.5 | 1.8 | **14.4** |
| | Diesel | 173.7 | 416.1 | 1.2 | **591.0** | 0.3 | 0.0 | 108.2 | 0.3 | 9.6 | **118.4** |
| | Pesticides | 50.0 | 8.7 | 0.2 | **58.9** | 0.4 | 0.0 | 2.3 | 0.0 | 0.7 | **3.4** |
| | Transp. Road | 76.4 | 217.0 | 1.4 | **294.8** | 1.2 | 0.1 | 56.4 | 0.3 | 4.0 | **62.0** |
| | Transp. Rail | 29.5 | 107.9 | 0.5 | **137.9** | 0.6 | 0.0 | 28.0 | 0.1 | 1.5 | **30.2** |
| | Transp. River | 1.8 | 5.6 | 0.0 | **7.4** | 0.0 | 0.0 | 1.5 | 0.0 | 0.1 | **1.6** |
| | Transp. Ocean | 1,734.6 | 764.5 | 17.9 | **2,517.0** | 1.2 | 0.1 | 198.8 | 3.9 | 9.6 | **213.6** |
| | **TOTAL** | **2,959.4** | **1,693.5** | **676.8** | **5,329.7** | **2,517.7** | **3,744.1** | **440.3** | **148.0** | **35.4** | **6,885.5** |

[1] Crop production includes grain drying.

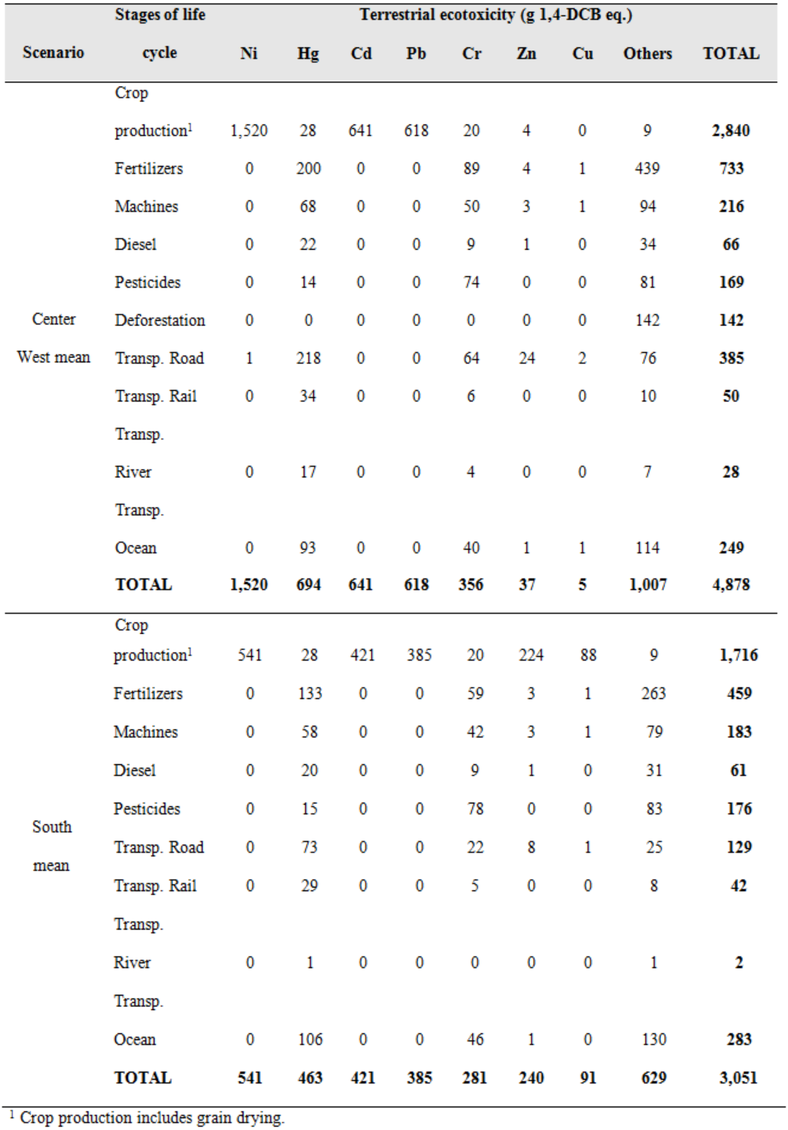
Eutrophication was similar in CW and SO (Table 4). For CW, $PO_4$ was the most important contributor to eutrophication, primarily due to crop production (phosphate lost in soil erosion) and fertilizer production. These levels were slightly lower for SO as less soil was lost and use of fertilizers was less intensive (Table 4). In SO, $NO_3$ contributed most to eutrophication. This was primarily due to nitrate leaching in crop production.

### 3.3.3. TERRESTRIAL TOXICITY AND LAND OCCUPATION

In this study, we considered pesticide use, including its stages of production and transport. However, we did not take into account the toxic impacts of pesticide application in the field due to the lack of a satisfactory method to assess the fate and toxicity of pesticides. For the CW scenario, pesticide use was 2.5 kg $ha^{-1}$ of active substance or 0.89 kg $ton^{-1}$ of soybeans. For the SO scenario, pesticide use was 2.1 kg $ha^{-1}$ or 0.83 kg $ton^{-1}$ of soybeans.

For terrestrial ecotoxicity, emissions of heavy metals contributed most (Table 5). However, the contribution for zinc and copper in crop production stages in the SO scenario mix was due to higher concentrations of these elements in pig slurry, which was used in a scenario making up 3.6% of this mix (section 2.2.1).

**Table 5** - Contribution of emitted substances to terrestrial ecotoxicity for one ton of soybeans produced in Center West or South Brazil and delivered at Rotterdam.



| Scenario | Stages of life cycle | Terrestrial ecotoxicity (g 1,4-DCB eq.) Ni | Hg | Cd | Pb | Cr | Zn | Cu | Others | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| Center West mean | Crop production[1] | 1,520 | 28 | 641 | 618 | 20 | 4 | 0 | 9 | **2,840** |
| | Fertilizers | 0 | 200 | 0 | 0 | 89 | 4 | 1 | 439 | **733** |
| | Machines | 0 | 68 | 0 | 0 | 50 | 3 | 1 | 94 | **216** |
| | Diesel | 0 | 22 | 0 | 0 | 9 | 1 | 0 | 34 | **66** |
| | Pesticides | 0 | 14 | 0 | 0 | 74 | 0 | 0 | 81 | **169** |
| | Deforestation | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 142 | **142** |
| | Transp. Road | 1 | 218 | 0 | 0 | 64 | 24 | 2 | 76 | **385** |
| | Transp. Rail | 0 | 34 | 0 | 0 | 6 | 0 | 0 | 10 | **50** |
| | Transp. River | 0 | 17 | 0 | 0 | 4 | 0 | 0 | 7 | **28** |
| | Transp. Ocean | 0 | 93 | 0 | 0 | 40 | 1 | 1 | 114 | **249** |
| | **TOTAL** | **1,520** | **694** | **641** | **618** | **356** | **37** | **5** | **1,007** | **4,878** |
| South mean | Crop production[1] | 541 | 28 | 421 | 385 | 20 | 224 | 88 | 9 | **1,716** |
| | Fertilizers | 0 | 133 | 0 | 0 | 59 | 3 | 1 | 263 | **459** |
| | Machines | 0 | 58 | 0 | 0 | 42 | 3 | 1 | 79 | **183** |
| | Diesel | 0 | 20 | 0 | 0 | 9 | 1 | 0 | 31 | **61** |
| | Pesticides | 0 | 15 | 0 | 0 | 78 | 0 | 0 | 83 | **176** |
| | Transp. Road | 0 | 73 | 0 | 0 | 22 | 8 | 1 | 25 | **129** |
| | Transp. Rail | 0 | 29 | 0 | 0 | 5 | 0 | 0 | 8 | **42** |
| | Transp. River | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | **2** |
| | Transp. Ocean | 0 | 106 | 0 | 0 | 46 | 1 | 0 | 130 | **283** |
| | **TOTAL** | **541** | **463** | **421** | **385** | **281** | **240** | **91** | **629** | **3,051** |

[1] Crop production includes grain drying.

Nickel was the most important contributor to terrestrial ecotoxicity for CW and SO (Table 5). This was due to the use of chemical fertilizers, which contain heavy metals as contaminants.

For each ton of soybeans produced, land occupation in the crop production stage was 1,835 m² $year^{-1}$ for CW and 2,017 m² $year^{-1}$ for SO. Adding the impacts of transport to Rotterdam, these values increased by 2.8 and 2.5%, respectively. Agriculture obviously requires more land than industrial and transport activities. The difference in land occupation between the two scenarios analyzed in this study can be explained by the assumed soybean yields (2,791 and 2,535 kg $ha^{-1}$ for the CW and SO scenarios, respectively).

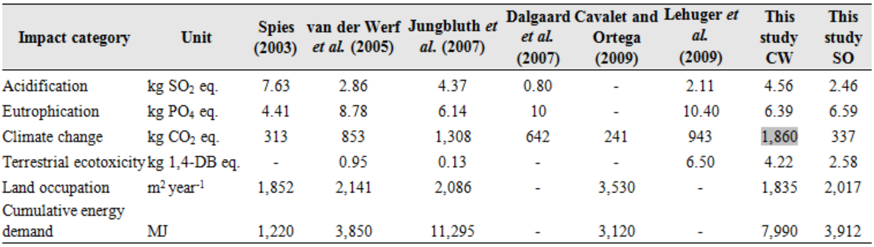
# 4. DISCUSSION

## 4.1. COMPARISON WITH PREVIOUS STUDIES

Brazil is a large country with significant variations in soil, vegetation cover, climate and transport infrastructure. These variations result in differences in agricultural production potential and transport routes. Soybeans are cultivated in many regions of the country, especially in South and Central West Brazil. These two regions together produce more than 80% of the nation’s soybeans. Soybean production scenarios for these two regions differ markedly. In CW, soybean production results in the clearing of Amazon forest and Cerrado, whereas such clearing does not occur in SO. Input use for soybeans in the Cerrado region (predominant in CW) is higher than in SO, and transport distances for crop inputs (350 km in CW and 250 km in SO) and grain (40 km in CW and 20 km in SO, on average) to regional storage facilities are larger in CW than in SO.

Results from previous LCA studies of Brazilian soybean production show large variability (Table 6). The methods of these studies (e.g., system definition, estimation of emissions and characterization factors) differed, which likely contributed to this variability in results. The predicted impacts of CW and SO soybeans fall within the range of values from previous studies, except for those of terrestrial ecotoxicity. This except is due to higher concentrations of heavy metals in the chemical fertilizers used in Brazil (Table 6).

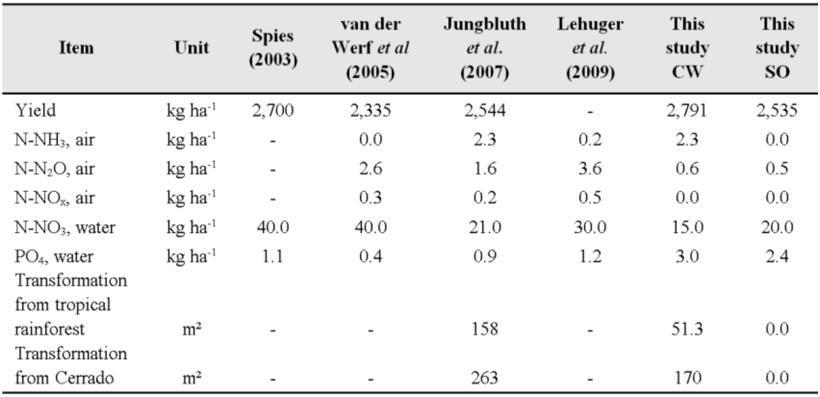
**Table 6** - Environmental impacts at the farm gate or local storage facility for one ton of soybeans produced in Brazil according to different authors[5].



| Impact category | Unit | Spies (2003) | van der Werf *et al.* (2005) | Jungbluth *et al.* (2007) | Dalgaard *et al.* (2007) | Cavalet and Ortega (2009) | Lehuger *et al.* (2009) | This study CW | This study SO |
|---|---|---|---|---|---|---|---|---|---|
| Acidification | kg $SO_2$ eq. | 7.63 | 2.86 | 4.37 | 0.80 | - | 2.11 | 4.56 | 2.46 |
| Eutrophication | kg $PO_4$ eq. | 4.41 | 8.78 | 6.14 | 10 | - | 10.40 | 6.39 | 6.59 |
| Climate change | kg $CO_2$ eq. | 313 | 853 | 1,308 | 642 | 241 | 943 | 1,860 | 337 |
| Terrestrial ecotoxicity | kg 1,4-DB eq. | - | 0.95 | 0.13 | - | - | 6.50 | 4.22 | 2.58 |
| Land occupation | $m^2$ $year^{-1}$ | 1,852 | 2,141 | 2,086 | - | 3,530 | - | 1,835 | 2,017 |
| Cumulative energy demand | MJ | 1,220 | 3,850 | 11,295 | - | 3,120 | - | 7,990 | 3,912 |

For some of the studies listed in Table 6, data for yields and field emissions were available (Table 7). This information shed some light on the methodological differences. Contrary to previous studies, this study used the latest recommendations (IPCC, 2006) for the estimation of $N_2O$ emissions and thus did not consider biologically fixed nitrogen, leading to lower values for $N_2O$ emissions (Table 7). Compared to previous studies, our value for $NO_3$ emissions is rather low, whereas our value for $PO_4$ emissions is high.

**Table** 7 – Yield and substances emissions in the crop production phase for soybeans produced in Brazil according to different authors.



| Item | Unit | Spies (2003) | van der Werf *et al* (2005) | Jungbluth *et al.* (2007) | Lehuger *et al.* (2009) | This study CW | This study SO |
|---|---|---|---|---|---|---|---|
| Yield | kg $ha^{-1}$ | 2,700 | 2,335 | 2,544 | - | 2,791 | 2,535 |
| N-$NH_3$, air | kg $ha^{-1}$ | - | 0.0 | 2.3 | 0.2 | 2.3 | 0.0 |
| N-$N_2O$, air | kg $ha^{-1}$ | - | 2.6 | 1.6 | 3.6 | 0.6 | 0.5 |
| N-$NO_x$, air | kg $ha^{-1}$ | - | 0.3 | 0.2 | 0.5 | 0.0 | 0.0 |
| N-$NO_3$, water | kg $ha^{-1}$ | 40.0 | 40.0 | 21.0 | 30.0 | 15.0 | 20.0 |
| $PO_4$, water | kg $ha^{-1}$ | 1.1 | 0.4 | 0.9 | 1.2 | 3.0 | 2.4 |
| Transformation from tropical rainforest | $m^2$ | - | - | 158 | - | 51.3 | 0.0 |
| Transformation from Cerrado | $m^2$ | - | - | 263 | - | 170 | 0.0 |

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[5] Comparing the data in Table 6 with those in Table 8, Chapter 2, one should consider that here we present results for two "weighted mixes" including tillage or no tillage, chemical or organic fertilization, while in Chapter 2, the scenario is confined to no-tillage system with chemical fertilizers, only.

Moreover, the approach used by Jungbluth *et al.* (2007) resulted in a value of 158 $m^2$ of deforestation per ha of soybean, while our approach yielded a value of 51 $m^2$. This explains the large difference between the two approaches in terms of climate change and cumulative energy demand impacts (Table 6).

The different scenarios for soybean crops in Brazil have different levels of impacts. Although there are differences in the approaches of various authors, the results of this study indicate that it is necessary to consider the source region of soybean crops to obtain more reliable estimates of environmental impacts.

## 4.2. HOT SPOTS AND RECOMMENDATIONS

### 4.2.1. Environmental hot spots and recommendations

The results of this study indicate that environmental burdens associated with the production and transport of soybeans can be decreased, especially for the CW scenario. Stopping deforestation is clearly the most urgent action. While other impacts related to deforestation, such as loss of biodiversity and social problems (Cavalett and Ortega, 2009), have not been considered in this study, 68% of climate change impacts came from deforestation in CW. Furthermore 21% of cumulative energy demand impacts came from deforestation, demonstrating the strong influence of deforestation on impacts of the soybean supply chain.

Improving the logistics of transport, especially for the CW scenario, is another important action that could reduce impacts substantially as most soybeans in Brazil are still transported by road. As shown in section 3.3.1, transport by road contributes 2.5 to 3 times more to climate change and cumulative energy demand than transport by river or rail.

The climate change impact has two main sources: $CO_2$ from deforestation, transport and diesel combustion and $N_2O$ from direct and indirect field emissions (Table 3). Therefore, optimization of fertilization and use of farm machinery (to avoid unnecessary diesel consumption) can contribute to decreased climate change impacts.

Likely for economic motives, the 2-20-20 fertilizer (section 3.3.2) is widely used in CW to fertilize soybeans. The use of a 0-20-20 fertilizer, however, probably would not affect crop yield, but would eliminate ammonia emissions, thus reducing acidification and eutrophication. Although there may be some advantage in using a small quantity of nitrogen to improve crop establishment, the effect is small and probably not worth the environmental burden. In addition, there are several studies that show no increase in soybean yield when using chemical nitrogen fertilizer (Albareda, Rodríguez-Navarro, and Temprano 2009; Barker and Sawyer 2005; Bergamin et al. 2007; Diaz, Pedersen, and Sawyer 2009; Schmitt et al. 2001).

Other practices that may reduce impacts further include soil conservation practices to prevent erosion, improvement of production techniques to increase yield and integrated management of diseases and pests to minimize pesticide use.

### 4.2.2. Methodological hot spots and recommendations

To assess the environmental impacts from cleared forest and Cerrado areas, we modified the approach proposed by Jungbluth *et al.* (2007) and used more recent data to estimate land transformation from rainforest and Cerrado to soybean production. We feel confident that these estimates are reasonable given the current availability of data. In the future, however, these calculations should be updated as new studies are implemented in this area.

As $NO_3$, $NH_3$ and $N_2O$ are majors contributors to the environmental impacts of agricultural systems, future studies will need to consider the possibility of improving estimates of their emission from fields. Our estimate of $NO_3$ leaching was based on studies of Brazilian crops (section 2.3) that reported a low level of nitrate loss. Because nitrate loss is a major contributor to eutrophication and climate change, we feel that additional data on nitrate loss in soybean fields under a range of pedo-climatic and crop management conditions would help to improve the assessment of the contribution of nitrate loss to the impacts of soybean production.

Our approach to estimate $PO_4$ emission into water (section 2.3) was strongly affected by soil loss. Due to the lack of data, we used values from recent studies of soil loss and from expert opinions. More precise information on the emissions of $PO_4$ and soil loss may allow a better estimation of eutrophication.

This study shows that it is no longer possible to consider a single scenario for the production and transportation of soybeans from Brazil. As shown in Table 2, according to the origin and transport route, the impacts of soybeans exported to Rotterdam may differ by more than 100%. These differences are especially true for climate change and cumulative energy use, which dramatically changes the consequences of transporting soybeans from different regions of the country. It is essential that this variability be taken into account in future studies.

## 5. CONCLUSIONS

Brazil is a large country with a wide range of pedo-climatic conditions and production practices that affect agricultural production and its environmental impacts. This is illustrated by our comparison of soybean production impacts for Brazil’s two major production regions, the Central West and South. Although the intensity of input use by itself contributes significantly to these impact differences, other factors, such as deforestation and geographical location (distance and means of transport), contribute even more.

The various routes of transport considered in this study show higher levels of impacts for CW than SO for all impact categories examined except eutrophication and land occupation. The same trend was observed for the crop production stage.

In the crop production stage, optimization of the use of fertilizers and machinery can significantly reduce $CO_2$ emissions. The use of fertilizers without nitrogen, or at least nitrogenous fertilizers not based on urea, will contribute to a reduction in $NH_3$ and $N_2O$ emissions.

Although deforestation for cropland has decreased in recent years, the contribution of deforestation to climate change and cumulative energy demand remains significant. Therefore, efforts to halt deforestation should continue.

For acidification and cumulative energy demand, the transport phase is responsible for almost 40% of impacts in CW and approximately 30% of impacts in SO. This shows that for soybeans produced in Brazil and exported to Europe, the transport stage has a strong influence on impacts. Our study showed that although there are different possibilities of transportation in Brazil, the current predominance of road transport causes severe environmental impacts.

The scenarios of different transport routes with higher and lower impacts assessed in this study show differences on the order of 30-78%, depending on the impact category. This suggests that both the mode of transport chosen and the distance to be traveled strongly influence environmental impacts. In this sense, the geographical location of CW is unfavorable for export. However, for both CW and SO, improvements in transportation logistics that give priority to rail and river transport instead of road transport can significantly contribute to reducing greenhouse gas emissions and decreasing consumption of energy resources.

The most important contribution of this paper to the LCA field is the conclusion that future studies involving soybeans from Brazil should take into account the region of origin, as different regions have different levels of environmental impacts.

## 6. ACKNOWLEDGEMENTS

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# 8. ANNEX

**Table 8 - Supplementary** – Environmental impacts for one ton of soybeans delivered at Rotterdam according to scenarios of origin and the mode and distance of transport to seaports in Brazil for the states of Goiás (GO), Mato Grosso (MT), Paraná (PR) and Rio Grande do Sul (RS) and for CW and SO weighted mixes.

| **Scenarios State of origin, route, (port Brazil)** | **Distances** | | | **Impact Categories** | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Road | Rail-way | Water-way | Acidifi-cation | Eutrophica-tion | Climate change | Terrestrial ecotoxicity | Land occupation | Cumulative energy demand |
| | (km) | (km) | (km) | (kg $SO_2$ eq.) | (kg $PO_4$ eq.) | (kg $CO_2$ eq.) | (kg 1,4-DB eq.) | ($m^2$ $yr^{-1}$) | (MJ) |
| GO, Goiania, (Santos/Paranagua) | 713 | 435 | 546 | 7.7 | 6.8 | 2110 | 4.8 | 1,890 | 12,195 |
| GO, Goiania, (Vitoria) | 233 | 1,843 | 0 | 7.6 | 6.8 | 2086 | 4.8 | 1,890 | 11,787 |
| GO, Rio Verde, (Santos/Paranagua) | 1,090 | 0 | 0 | 7.6 | 6.7 | 2109 | 4.8 | 1,889 | 12,259 |
| GO, Rio Verde, São Simão, Anhembi, Cesar Neto, (Santos) | 283 | 351 | 759 | 7.5 | 6.7 | 2063 | 4.7 | 1,890 | 11,406 |
| GO, south of GO, Uberlandia, (Vitoria) | 1,203 | 0 | 0 | 7.4 | 6.7 | 2111 | 4.8 | 1,889 | 12,312 |
| MT, Diamantino - (Santarem) | 1,768 | 0 | 0 | 7.5 | 6.8 | 2169 | 4.9 | 1,890 | 13,259 |
| MT, several cities, (Manaus/Santos/Vitoria) | 1,120 | 785 | 1 | 7.8 | 6.8 | 2146 | 4.9 | 1,890 | 12,822 |
| MT, Parecis, Porto Velho, (Manaus) | 1,185 | 0 | 1,056 | 7.6 | 6.8 | 2152 | 4.9 | 1,892 | 12,863 |
| MT, Rondonopolis, Alto Taquari, (Santos) | 267 | 1,262 | 0 | 7.6 | 6.7 | 2072 | 4.8 | 1,889 | 11,572 |
| MT, Rondonopolis, (Paranagua) | 1,586 | 0 | 0 | 7.9 | 6.8 | 2172 | 5.0 | 1,890 | 13,288 |
| MT, Rondonopolis, (Santos) | 1,436 | 0 | 0 | 7.8 | 6.8 | 2150 | 4.9 | 1,889 | 12,937 |
| MT, Sorriso, Porto Velho, (Manaus/Itacotiara) | 1,475 | 0 | 1,056 | 7.8 | 6.8 | 2187 | 5.0 | 1,892 | 13,442 |
| PR, Cascavel, (Paranagua) rail | 72 | 679 | 0 | 5.3 | 6.9 | 495 | 3.0 | 2,070 | 6,711 |
| PR, Cascavel, (Paranagua) road | 666 | 0 | 0 | 5.3 | 6.9 | 530 | 3.1 | 2,070 | 7,376 |
| PR, Guarapuava, (Paranagua) rail | 26 | 416 | 0 | 5.1 | 6.9 | 476 | 3.0 | 2,070 | 6,418 |
| PR, Guarapuava, (Paranagua) road | 388 | 0 | 0 | 5.2 | 6.9 | 498 | 3.0 | 2,070 | 6,822 |
| PR, Ponta Grossa, (Paranagua) rail | 75 | 256 | 0 | 5.1 | 6.8 | 474 | 3.0 | 2,069 | 6,394 |
| PR, Ponta Grossa, (Paranagua) road | 289 | 0 | 0 | 5.1 | 6.8 | 486 | 3.0 | 2,069 | 6,625 |
| RS, Cachoeira do Sul, (Rio Grande) | 257 | 0 | 227 | 5.4 | 6.9 | 505 | 3.0 | 2,070 | 6,896 |
| RS, Cruz Alta, (Rio Grande) | 409 | 120 | 212 | 5.6 | 6.9 | 528 | 3.1 | 2,070 | 7,281 |
| RS, Lagoa Vermelha, (Rio Grande) | 490 | 0 | 121 | 5.5 | 6.9 | 527 | 3.1 | 2,070 | 7,291 |
| RS, Passo Fundo, (Rio Grande) | 180 | 669 | 5 | 5.6 | 6.9 | 519 | 3.1 | 2,070 | 7,108 |
| RS, Santa Maria, (Rio Grande) | 271 | 242 | 0 | 5.5 | 6.9 | 508 | 3.0 | 2,070 | 6,960 |
| RS, Santo Angelo, (Rio Grande) | 457 | 163 | 87 | 5.6 | 6.9 | 530 | 3.1 | 2,070 | 7,328 |
| CW weighted mix | 1,101 | 393 | 289 | 7.7 | 6.8 | 2120.4 | 4.9 | 1,890 | 12,634 |
| SO weighted mix | 317 | 341 | 22 | 5.3 | 6.9 | 510.2 | 3.1 | 2,070 | 6,999 |

# INTENSITY AND SCALE EFFECTS FOR ENVIRONMENTAL IMPACTS OF FRENCH AND BRAZILIAN POULTRY PRODUCTION SCENARIOS: AN LCA APPROACH

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## ABSTRACT

This study compared environmental burdens of two poultry production systems in Brazil and two in France. One Brazilian system represents large-scale production in the Centre-West (CW) of the country, the other one small-scale production in the South (SO). One of the French systems represents an extensive poultry production system, known as "Label Rouge" (LR), the other is a standard system (ST). The life cycle assessment was performed using the CML characterisation method. The main functional unit adopted was 1 ton of chicken cooled and packaged, ready for distribution. For the systems and impacts studied, production scale did not affect environmental impacts, but production intensity did. The extensive Label Rouge system had the largest values for all impacts studied. This resulted principally from the high feed conversion ratio of this production system (3.09 kg of feed per kg of live weight) in conjunction with the fact that the feed production stage contributed most to overall impacts.

***Keywords*:** Production scale, Production intensity, Poultry, Life Cycle Assessment, Brazil, France, Label Rouge

## 1. INTRODUCTION

Globally, Brazil and France are major producers and consumers of chicken meat. Brazil recently overtook France in export of chickens, and the Brazilian poultry sector is in full expansion, increasing the

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number of chicken farms in several regions of the country. At the same time, in France the poultry industry is in decline due to competition with products from emerging economies that offer the product for the European and Middle Eastern markets at a lower price. The different characteristics of Brazil and France with respect to human and natural resources, climate, topography, geographical distribution, have led to the establishment of different supply chains. The supply chains in the two countries follow different routes, which may result in different environmental impacts.

In Southern Brazil, a traditional region of pig and poultry production (Spies, 2003), both the government and the population are increasingly concerned about the environmental impacts of these activities. Today, Brazilian poultry is also produced in the Centre-West of the country, a region with large farms specialized in the production of maize and soybeans, and where environmental impacts from agriculture are a lesser concern, mainly due to the lower spatial density of its pig and poultry production.

According to Magdelaine (2008), in France, given the size of farms and their spatial concentration, poultry production is submitted to restrictive rules with regard to acceptable levels of nitrogen, and more recently, restrictions are being defined on the levels of phosphorus as well. In France another major issue is the contribution of the sector to greenhouse gas emissions. The increased concern with environmental problems may lead to a significant increase in costs in the poultry sector (Magdelaine and Chesnel, 2005).

We have a striking contrast here: on the one hand the great Brazilian territory with the potential of intensifying production in many areas and of opening up new areas for agricultural production, and with a poultry sector in full expansion, and on the other hand numerous activities competing for a limited area in France with the poultry industry in contraction due to the competition with emerging countries.

Poultry production is a typical example of globalization, as it is easy to outsource, and uses inputs from different parts of the globe. This generates an intense competition between the various producing regions. The growth of poultry production at world level is a very significant phenomenon in food production. This phenomenon deserves a full review, involving the entire product life cycle, to identify all environmental aspects involved.

This study compares environmental burdens of four poultry production systems, two from Brazil and two from France, using a Life Cycle Assessment (LCA) “cradle to gate” approach. One Brazilian system represents large-scale production in the Centre-West (CW) of the country, the other small-scale production in the South (SO). One of the French systems produces a high-quality chicken in an extensive production system known as "Label Rouge" (LR). This system is situated in the Aquitaine region (South-West of France). The other is a standard system (ST), typical for the Bretagne region (Western France). This paper seeks to assess the impacts of processed whole chicken, packed and cooled at the gate of the slaughterhouse. However, in order to contribute to the understanding of the environmental impacts directly related to the agricultural sector, we also briefly present the results per kg of live weight at the farm gate and per unit (Euro) of economic value at the farm gate.

## 2. MATERIAL AND METHODS

### 2.1. SCOPE OF ANALYSIS

The LCA for the four systems studied begins with the production of inputs and goods used to produce crops, passing through the phases of crop production, grain drying and processing, feed manufacturing, production of chicks, chicken rearing, slaughter, cooling and packaging of whole chicken, including all transport phases, up to the slaughterhouse gate. The production and maintenance of chicken houses and of slaughterhouse buildings and machines were not included. In the grain production stage, we consider that part of the grain is produced with organic fertilization (see the example for soybeans in Chapter 3, item 2.2.1). This implies a reduction in impacts due to avoided production of chemical fertilizer that is no longer used because it was replaced by organic manure. Thus the impact avoided by not using chemical fertilizers is already embedded in the production of grain. As a consequence, in the poultry production stage, we consider that the litter manure leaves the system, to avoid double counting.

Figure 1 show a simplified flow chart of the main processes considered to chicken meat production.

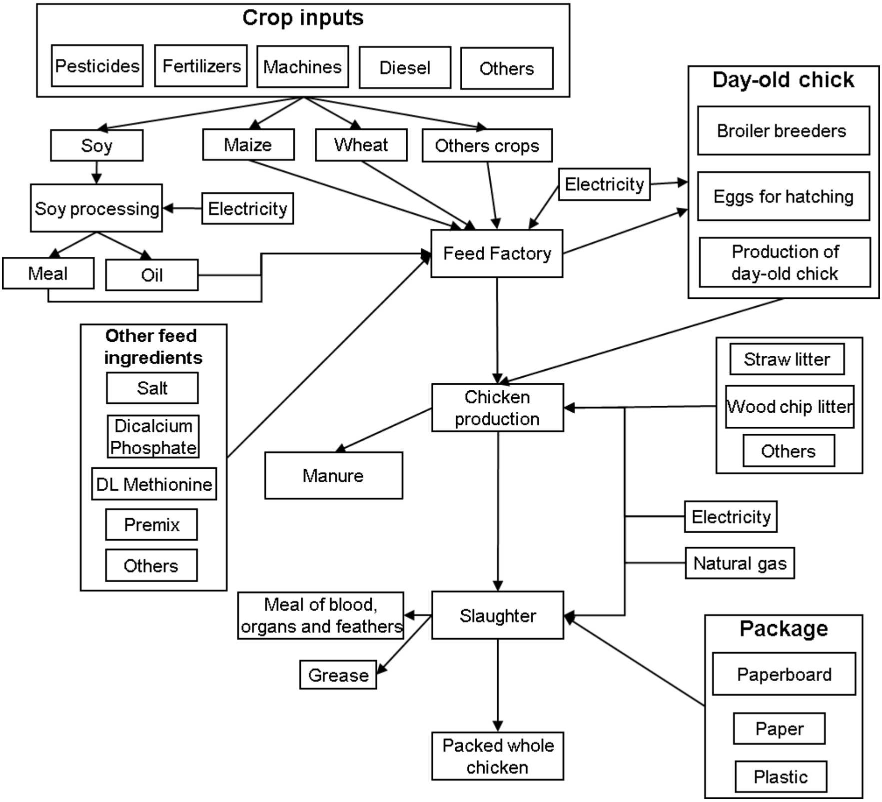

**Figure 1 -** Simplified flow chart of poultry production.
Note: transportation was taken into account among all stages; only the main processes are represented (water is considered but not represented); buildings and their maintenance were not considered in the calculations.

Data for the inventory deforestation, crop production and transport in Brazil were based on data presented in Chapters 2 and 3. For French crops, data on different production practices come from the 2006 AGRESTE database surveys on crop systems. The inventory data for grain drying, soybean processing, transport distances, chicken production and slaughter in Brazil were obtained from EPAGRI (the Santa Catarina state institution for agricultural research), EMBRAPA (the federal institution for agricultural research), AURORA (a poultry and pig production cooperative) and local interviews. In France, data for inventory analysis for feed production were obtained from INRA, UMR-SAS (Rennes), and from Maïsadour (a grain and poultry production company) and from local interviews.

## 2.2. TECHNICAL INDICATORS

Table 1 shows technical performance indicators that characterise the four systems. Label Rouge is the only extensive system studied, the other three are variations of intensive systems. Unlike other systems, there are some specific requirements in this case. The Label Rouge poultry are raised with access to an outdoor area, in accordance with specifications approved by the government. Label Rouge chickens must not be slaughtered before the age of 81 days, must have a minimum of space in the building (max. 11 chicken/m$^2$), access to an outdoor run (2 m$^2$/chicken) and be fed at least 75% of cereals.

**Table 1** - Technical indicators of poultry production systems in the South-West of France (LR - Label Rouge), the West of France (ST - standard), and the South (SO) and Centre-West (CW) of Brazil.

| Indicator | LR | ST | SO | CW |
|---|---|---|---|---|
| Rearing time (days) | 89 | 40 | 42 | 42 |
| Final weight (kg) | 2.26 | 1.92 | 2.48 | 2.40 |
| Density (animals/m$^2$) | 10.9 | 22.0 | 11.7 | 15.0 |
| Mortality (%) | 3.1 | 4.1 | 4.4 | 4.2 |
| Feed conversion (kg/kg) | 3.09 | 1.87 | 1.86 | 1.89 |
| No. of batches per year | 3.1 | 6.0 | 6.4 | 6 |
| Carcass yield (%) | 67 | 70 | 74.6 | 74.6 |
| Price at farm (€/kg) | 1.61 | 0.83 | 0.54 | 0.54 |

Source: LR and ST systems – ITAVI (2003); SO system - Martins *et al.* (2007); CW system - (Carfantan, 2007); Prices LR and ST - Gallot *et al.* (2009); SO and CW Conab (2009).

## 2.3. CROP PRODUCTION STAGE EMISSIONS

Emissions from crop production are highly variable, depending on climate, soil type, farming practice and many other factors. The emissions considered were $NH_3$ to air from chemical fertilizer, $NH_3$ to air from animal manure (and slurry), $NO_3$ and $PO_4$ to water, $N_2O$ and NOx to air and heavy metals to soil.

Regarding $CO_2$ and energy contained in grains, there is general agreement, as expressed for instance by Williams *et al.* (2006), that in steady state nearly all carbon (C) in the grain will rapidly (within one or two years) be emitted to the atmosphere and that therefore the absorption of $CO_2$ by the grain (and the associated $O_2$ emission) can be ignored. Nevertheless, this assumption should be borne in mind by those carrying out LCA studies of downstream processes that use these grains as input. These studies should not debit those systems with $CO_2$ emissions from C contained in the grain and should credit them if the C is stored for a longer period.

In our approach, we consider various scenarios for the production of maize and soybeans for animal feed in Brazil. For the CW scenario, we consider that a small part of the soybean area (and therefore also of the maize area, since a field produces two crops within a year, maize after soybeans) was deforested, i.e. the year preceding the soybean or maize crop it was tropical rainforest or Cerrado. The impacts associated with this deforestation are included in the impacts of maize and soybeans from CW, where the $CO_2$ is the main issue. See Chapters 2 and 3 for details.

### 2.3.1. Nitrate leaching

For the French crops (maize, wheat, rape) nitrate leaching was estimated according to Basset-Mens *et al.* (2006). In both systems studied (ST and LR), we used a national average scenario for the production of these crops. Estimated nitrate losses were: 40 kg/ha of $NO_3$-N for wheat, 70 kg/ha of $NO_3$-N for maize and 40 kg/ha of $NO_3$-N for rapeseed.

In Brazil, due to the short intervals between successive crops (a field generally produces two crops per year) and the use of minimum-tillage systems and cover crops, the levels of nitrate loss are low. Based on the data from the Brazilian researchers Basso (2003); Moreira *et al.* (2004) and Giacomini *et al.* (2007) for soybeans in SO we considered nitrate leaching to be 20 kg $NO_3$-N/ha for a no-tillage system and 25 kg/ha for a tillage system. For maize in SO, $NO_3$-N loss was 10 and 15 kg/ha for tillage and no tillage systems, respectively. For soybeans in CW we considered nitrate leaching to be 15 kg $NO_3$-N/ha for a no-tillage system and 20 kg/ha for a tillage system. For maize in CW, nitrate loss was 10 and 15 kg $NO_3$-N/ha for tillage and no tillage systems, respectively.

### 2.3.2. Ammonia emissions

For all crops we adopted the approach proposed by IPCC (IPCC, 2006). However, the emission factors for French crops (wheat, maize and rape) were based on Nemecek and Kägi (2007). The calculation of emissions of $NH_3$-N is done by multiplying the quantity of mineral nitrogen by an emission factor which is specific for the type of nitrogen fertilizer: this factor is 0.02 for ammonium nitrate and 0.15 for urea. For organic fertilizer, it is necessary to calculate the amount of ammonia nitrogen. This represents about 70% of the nitrogen content of slurry. To estimate the emission of $NH_3$-N at slurry application, we multiplied this amount of ammonia nitrogen by an emission factor of 0.12, according to Nemecek and Kägi (2007). For the Brazilian crops (maize and soybeans) we adopted the same approach, except for the emission factors for organic and mineral fertilizers, for which we identified the most appropriate values based on data for Brazil. Thus the factors used were 0.25 for urea, according to Cantarella *et al.* (2008), and 0.26 for organic fertilizer, according to Basso *et al.* (2004).

### 2.3.3. $N_2O$ emissions

For all crops, emissions of $N_2O$ to air were estimated according to Volume 4, IPCC (2006). We considered N from mineral fertilizer and pig slurry, as well as N from the mineralization of crop residues (above and below ground). Indirect $N_2O$ emissions associated with volatilization and the leaching and runoff of N inputs to managed soils were estimated according to IPCC (2006) for French crops, and the emission factors proposed by Cantarella *et al.* (2008) and Basso *et al.*, (2004) for Brazilian crops. Emissions of $NO_x$ to air were estimated based on the amount of $N_2O$ emitted and applying an emission factor of 0.21, as proposed in Ecoinvent® Report 15 (Nemecek and Kägi, 2007).

### 2.3.4. Phosphorus emissions

Emissions of P into water were estimated according to Ecoinvent® Report 15 (Jungbluth *et al.*, 2007). The key factor to estimate the amount of phosphorus lost by erosion is the amount of soil lost during the crop cycle. For the French crops (both ST and LR systems), we used an average value valid for moderate slopes in

Western Europe (0.24 t/ha/yr). This value results from the PESERA model from the European Soil Bureau ("European Soil Portal - PESERA", 2010). In Brazil, for this purpose, soil loss was estimated for each scenario based on EMBRAPA recommendations and data from several authors (Hernani *et al.* , 1999; Cogo *et al.*, 2003; Lima, 2005). Assumed values for the CW system were: 2 and 10 ton/ha/year for no tillage and conventional tillage, respectively. For the SO system values were 1.5 and 8 ton/ha/year for no tillage and conventional tillage, respectively.

### 2.3.5. Heavy metals emissions

To assess emissions to soil, we calculated a mass balance by considering the concentrations of heavy metals in fertilizers and the amounts exported in harvested grain and through leaching and erosion. For Brazilian systems (CW and SO), to estimate the concentration of heavy metals in lime, we used data from Amaral *et al.* (1992). For concentrations of P in fertilizer, we used data from Campos *et al.* (2005). For concentrations in urea and potassium chloride, we used data obtained in Europe (Nemecek and Kägi, 2007). Concentrations of heavy metals in pig slurry were obtained from Mattias (2006), and concentrations of heavy metals in grain were obtained from Nemecek and Kägi (2007). For the French systems (ST and LR), we used data from Nemecek and Kägi (2007).

## 2.4. POULTRY PRODUCTION STAGE EMISSIONS

Data on greenhouse gas emissions for poultry rearing are available for France but not for Brazil, we therefore used the French values for both systems. Gac *et al.* (2007) provided emission factors for $CH_4$, $N_2O$ and $NH_3$, but for $CH_4$ and $N_2O$ a more recent publication (Dollé *et al.*, 2009) exists. So we used Gac *et al.* (2007) for $NH_3$ and Dollé *et al.* (2009) for $CH_4$ and $N_2O$ emission factors.

The most important emissions result from litter manure. The adopted methodology divides emissions into three stages: the chicken house, the manure storage and the outside area the chicken have access to. The last stage exists only in the LR system.

Emissions from litter manure in the **chicken house**:

- $CH_4$ according to Dollé *et al.* (2009): an emission factor in kg of $CH_4$ per head. For egg hens: 0.053; for pullets: 0.013.

- $NH_3$ according to Gac *et al.* (2007): an emission factor for nitrogen excreted/head/year: 30.4 %.
- $N_2O$ according to Dollé *et al.* (2009): an emission factor in kg of $N_2O$ per head (for egg hens and pullet) or per kg of live weight (for chicken). For egg hens: 0.0164; for pullet: 0.00024; for chicken: 0.128 g of $N_2O$ per kg of live weight.

Emissions from litter manure on **storage:**

- $CH_4$ according to Dollé *et al.* (2009): an emission factor in kg of $CH_4$ per head. For egg hens: 0.1; for pullet: 0.04.
- $NH_3$ according to Gac *et al.* (2007): an emission factor for nitrogen excreted/head/year: 9.5 %
- $N_2O$ according to Dollé *et al.* (2009): an emission factor in kg of $N_2O$ per head (for egg hens and pullet) or per kg of live weight (for chicken). For egg hens: 0.0003; for pullet: 0.0006; for chicken: 0.262 g of $N_2O$ per kg of live weight.

Emissions from litter manure **outside the chicken house:**

- $NH_3$ according to Gac *et al.* (2007): an emission factor for nitrogen excreted/head/year: 10.7%
- $N_2O$ according to Dollé *et al.* (2009): an emission factor of 0.0019 g of $N_2O$ per kg of live weight.

Table 2 summarizes the emissions for each system.

**Table 2 -** Estimated gaseous emissions for the animal production stage, in kg of gas per ton of poultry live weight for four systems: the South-West of France (LR – Label Rouge), the West of France (ST - standard), and the South (SO) and Centre-West (CW) of Brazil.

| Emission | LR | ST | SO | CW |
|---|---|---|---|---|
| $CH_4$ | 5.79 | 6.95 | 5.24 | 5.42 |
| $N_2O$ | 0.42 | 0.51 | 0.39 | 0.40 |
| $NH_3$ | 21.48 | 11.28 | 8.51 | 8.79 |

## 2.5. SLAUGHTERHOUSE STAGE

We assumed that the variation was small between the slaughtering systems within a country, so we collected data from one abattoir in Brazil and one in France. We assumed that the impacts of this stage were the same for both Brazilians systems, and also for the two French systems. For the transport of live poultry to the slaughterhouse we considered 40 km for the two French systems, 60 km for CW and 95 for SO.

Electricity use was 0.67 kWh/ton of slaughtered chicken in France and 0.37 kWh in Brazil. In the French systems 7 liters of fuel oil were spent per ton of chicken slaughtered and 25.3 $m^3$ of natural gas. In Brazil 0.04 liters of fuel oil and 0.37 $m^3$ of firewood were used per ton of slaughtered chicken.

The packaging materials were separated into plastic (polyethylene), paper and cardboard. In France, the chickens were packed in individual trays, covered with a plastic wrap and including an individual label. Secondary packaging consisted of a cardboard box. In Brazil the chickens are usually sold in two forms of transport packaging: cardboard boxes, with 18 kg capacity or plastic bags with 30 kg capacity. Per ton of slaughtered chicken, LR and ST used 10.2 kg of plastic, 2.6 kg of paper and 10.1 kg of cardboard. CW and SO used 7.5 kg of plastic, 0.8 kg of paper and 12.8 kg of cardboard.

Main emissions considered for the slaughterhouse stage were BOD (6.5 kg per ton of slaughtered chicken in Brazil and 8.1 in France), suspended solids (7.7 kg/ton in Brazil and 5.3 in France), organic substances (0.2 kg/ton in France and 0.4 in Brazil) and sewage for treatment (11.4 $m^3$/ton of slaughtered chicken in both countries).

## 2.6. CHARACTERIZATION FACTORS

The four systems were analyzed from the environmental point of view, using LCA. In this approach, the impact assessment stage involves transforming the inventory information into measures of environmental impact and consists of classification and characterization as mandatory steps. The classification stage assigns the emissions or uptakes to one or more impact categories. The characterization stage quantifies the impacts using methods that are currently most suitable for global impacts such as climate change or ozone layer depletion. These methods also address effects for local or regional impacts, such as acidification, terrestrial ecotoxicity or eutrophication.

We based our analysis on the CML 2001 (baseline) method[6]. We added the Land Occupation category (originally “land competition”) from the CML 2001 (all categories) 2:04 version and we added the Total Cumulative Energy Demand version 1.05. For Climate Change (originally “Global Warming Potential 100 - GWP100”) we updated values of characterization factors according Forster *et al.* (2007) for methane (new value 25) and nitrous oxide (new value 298).

We present results for the following impact categories: *acidification* expressed in sulfur dioxide ($SO_2$) equivalent, *eutrophication* expressed in phosphate ($PO_4$) equivalent, *climate change* expressed in carbon dioxide ($CO_2$) equivalent, *terrestrial ecotoxicity* expressed in 1.4 dichlorobenzene (1.4DB) equivalent, *land occupation* expressed in square meter year ($m^2a$) and *total cumulative energy demand* expressed in mega Joules (MJ). A description of the CML 2001 method can be found in PRé Consultants (2008), and a list of all substances and their respective characterization factors can be found in PRé Consultants (2007).

### 2.6.1. Functional Units (FU)

The main functional unit adopted was 1 ton of chicken cooled and packaged, ready for distribution, at the slaughterhouse gate. However, we also present results for two other functional units, amongst others to facilitate the comparison with other published results. These functional units are ton of live weight at the farm gate, and unit (Euro) of economic value at the farm gate.

To estimate this last FU, we use two different approaches: first, we assume the average **price** of live chickens in 2009 as the economic value indicator. Second, we assume the average **added value** in 2009 as the economic value indicator.

**Price:** According to Gallot *et al.* (2009) the price of ST and LR chicken was € 831 and € 1607 per ton of live weight respectively, showing a large appreciation in the market for the high quality LR chicken. In Brazil, prices per ton of live weight were € 539 for SO and € 542 for CW (prices according to CONAB (2009) and Euro exchange rates from “Banco Central do Brasil” (2009)). These data show that the

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[6] CML 2001 (baseline) version 2.04 is a characterization method developed by the Centre for Environmental Studies (CML), University of Leiden, Netherlands. This method elaborates a problem-oriented (midpoint) approach. The CML Guide provides many impact assessment categories, from which we selected some that were relevant for regions of poultry production.

local price paid for chicken is similar for the Brazilian intensive systems (SO and CW), higher for the French intensive system (ST) and much higher for the extensive system (LR).

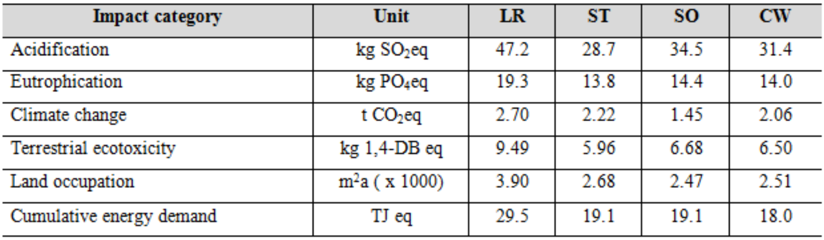
**Added Value:** as a simple way to estimate the added value, we deduct the cost of production (recorded by research institutions) from the estimated price of live chickens. According to ITAVI (2009, *apud* FranceAgriMer, 2011), the cost of production of ST and LR per ton of live weight in 2009 was € 670 and € 1136, respectively, resulting in an estimated added value of € 161 for ST and € 471 for LR per ton of live weight. In Brazil, according to EMBRAPA (2011) the cost of production in 2009 was € 950 and € 887 for CW and SO respectively, resulting in an estimated added value of € 345 and € 322. The added values estimated in this way show that the Brazilian systems have similar added values but are higher than the added value of the French intensive system (ST). The extensive system (LR) has more added value than all the others.

# 3. RESULTS

## 3.1. IMPACTS OF LIVE CHICKEN PRODUCTION

Results are first presented for live chickens at the farm gate (Table 3). The Label Rouge (LR) system clearly differed from the three intensive systems, as it had the largest values for all impacts studied. The three intensive systems had quite similar results for eutrophication, terrestrial ecotoxicity, land occupation and cumulative energy demand. For acidification ST had the lowest value and SO the highest. For climate change ST (2.22) and CW (2.06) presented similar values, whereas SO (1.45) presented a much lower value.

**Table 3** - Environmental impacts for 1 ton of live chicken at the farm gate produced in the South-West of France (LR – Label Rouge), the West of France (ST - standard), the South (SO) and the Centre-West (CW) of Brazil.



| Impact category | Unit | LR | ST | SO | CW |
|---|---|---|---|---|---|
| Acidification | kg $SO_2$eq | 47.2 | 28.7 | 34.5 | 31.4 |
| Eutrophication | kg $PO_4$eq | 19.3 | 13.8 | 14.4 | 14.0 |
| Climate change | t $CO_2$eq | 2.70 | 2.22 | 1.45 | 2.06 |
| Terrestrial ecotoxicity | kg 1,4-DB eq | 9.49 | 5.96 | 6.68 | 6.50 |
| Land occupation | $m^2$a ( x 1000) | 3.90 | 2.68 | 2.47 | 2.51 |
| Cumulative energy demand | TJ eq | 29.5 | 19.1 | 19.1 | 18.0 |

## 3.2. IMPACTS OF PROCESSED CHICKEN PRODUCTION

Besides the production of live chicken on-farm, this study also considered the next step, when the birds are transported to the slaughterhouse, where they are killed and processed. In this case the functional unit was a ton of slaughtered chicken, cooled and packaged at the slaughterhouse gate. Table 4 shows the main results.

**Table 4** - Environmental impacts for 1 ton of chicken cooled and packaged at the slaughterhouse gate produced in the South-West of France (LR – Label Rouge), the West of France (ST - standard), and the South (SO) and Centre-West (CW) of Brazil.

| Impact category | Unit | LR | ST | SO | CW |
|---|---|---|---|---|---|
| Acidification | kg $SO_2$eq | 69.4 | 40.5 | 45.9 | 41.8 |
| Eutrophication | kg $PO_4$eq | 29.9 | 21.0 | 20.5 | 19.9 |
| Climate change | t $CO_2$eq | 4.02 | 3.18 | 1.95 | 2.75 |
| Terrestrial ecotoxicity | kg 1,4-DB eq | 14.22 | 8.69 | 9.40 | 9.16 |
| Land occupation | $m^2$a ( x 1000) | 5.78 | 3.82 | 3.55 | 3.60 |
| Cumulative energy demand | TJ eq | 46.4 | 30.0 | 31.7 | 30.1 |

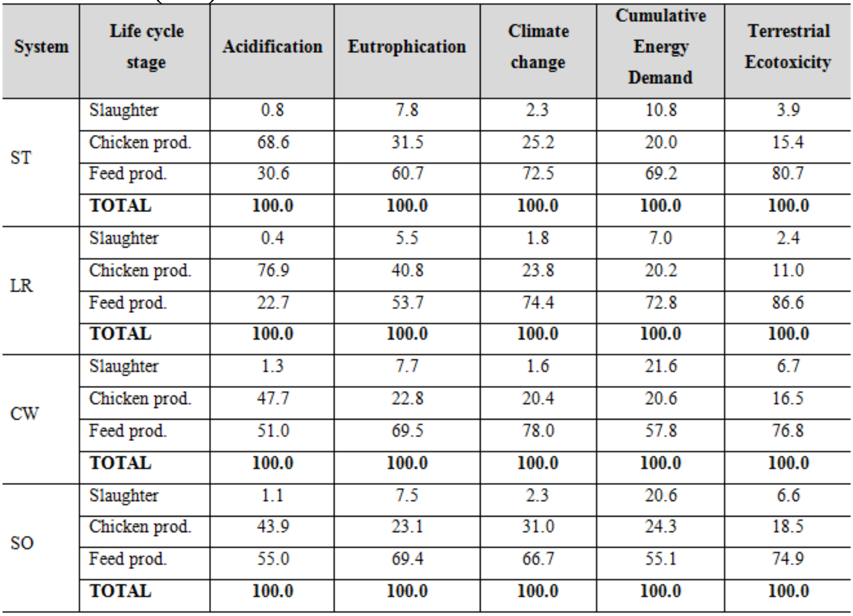
The Label Rouge system had the largest values for all impacts studied and thus clearly differed from the three intensive systems, as was found for impacts at the farm gate. One aspect contributing to this contrast is the carcass yield at slaughter, it was approx. 67% in the LR system and higher than 70% in the other three systems.

Among the intensive systems, the French ST system had somewhat lower values for acidification and terrestrial ecotoxicity. For land occupation the French system had slightly higher values than the two Brazilian systems. Regarding climate change, the CW presented 14% less impact than ST, while SO had 39% less impact than LR.

## 3.3. CONTRIBUTIONS OF LIFE CYCLE STAGES AND SUBSTANCES

The contribution of life cycle stages to overall impacts may vary according to impact category and production system (Table 5). We considered three main life cycle stages here: i) feed production (including crop production, transport and processing into feed), ii) poultry production and iii) slaughtering (including the transport of the chickens to the slaughterhouse).

**Table 5 -** Contribution (in %) of the three main life cycle stages to the environmental impacts of 1 ton of chicken cooled and packaged at the slaughterhouse gate, produced in the South-West of France (LR – Label Rouge), the West of France (ST - standard), and the South (SO) and Centre-West (CW) of Brazil.



| System | Life cycle stage | Acidification | Eutrophication | Climate change | Cumulative Energy Demand | Terrestrial Ecotoxicity |
|---|---|---|---|---|---|---|
| ST | Slaughter | 0.8 | 7.8 | 2.3 | 10.8 | 3.9 |
| | Chicken prod. | 68.6 | 31.5 | 25.2 | 20.0 | 15.4 |
| | Feed prod. | 30.6 | 60.7 | 72.5 | 69.2 | 80.7 |
| | **TOTAL** | **100.0** | **100.0** | **100.0** | **100.0** | **100.0** |
| LR | Slaughter | 0.4 | 5.5 | 1.8 | 7.0 | 2.4 |
| | Chicken prod. | 76.9 | 40.8 | 23.8 | 20.2 | 11.0 |
| | Feed prod. | 22.7 | 53.7 | 74.4 | 72.8 | 86.6 |
| | **TOTAL** | **100.0** | **100.0** | **100.0** | **100.0** | **100.0** |
| CW | Slaughter | 1.3 | 7.7 | 1.6 | 21.6 | 6.7 |
| | Chicken prod. | 47.7 | 22.8 | 20.4 | 20.6 | 16.5 |
| | Feed prod. | 51.0 | 69.5 | 78.0 | 57.8 | 76.8 |
| | **TOTAL** | **100.0** | **100.0** | **100.0** | **100.0** | **100.0** |
| SO | Slaughter | 1.1 | 7.5 | 2.3 | 20.6 | 6.6 |
| | Chicken prod. | 43.9 | 23.1 | 31.0 | 24.3 | 18.5 |
| | Feed prod. | 55.0 | 69.4 | 66.7 | 55.1 | 74.9 |
| | **TOTAL** | **100.0** | **100.0** | **100.0** | **100.0** | **100.0** |

For acidification, the contribution of the feed production stage is above 50% for both Brazilian systems (51% and 55% for CW and SO respectively) while in both French systems, the largest contribution comes from the chicken production stage (77% and 69% for LR and ST, respectively), leaving a contribution equal to or less than 30% for the feed production stage (Table 5).

For eutrophication, the LR system presented a contribution of 54% for the feed production stage and of 41% for chicken production (Table 5). This contrasts with the intensive systems in Brazil, where feed production contributed 70% and chicken production 23%. ST, the French intensive system, had an intermediary profile, with feed and chicken production contributing 61 and 32%, respectively. For climate change, feed production contributed 67-78%, while chicken production contributed 20-31%. Feed production contributed 55-73% to cumulative energy demand, 94-98% to land occupation and 75-87% to terrestrial ecotoxicity.

### 3.3.1. Climate change and cumulative energy demand

In the four systems, $CO_2$ contributed most to climate change (Figure 2), followed by $N_2O$ and $CH_4$.

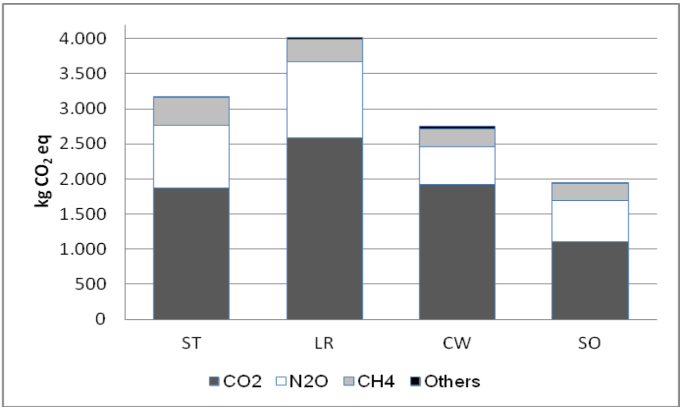


**Figure 2 -** Greenhouse gas contributions to climate change for 1 ton of chicken cooled and packaged at the slaughterhouse gate produced in the South-West of France (LR), the West of France (ST), and the South (SO) and Centre-West (CW) of Brazil.

For all systems except CW, approximately 83% of $CO_2$ emissions resulted from crop production due to fossil fuel use and transport between stages. CW was the only system presenting a significant contribution (19%) of $CO_2$ emissions resulting from due to deforestation. The $CO_2$ emissions of the SO system were lower than those of the French systems. $N_2O$ emissions also contributed significantly, in particular from the crop production stage (70% on average), but also from the poultry housing (24% on average).

Table 6 and 7 show the main substances and resources contributing to climate change and cumulative energy demand, for the three major life cycle stages. Feed production contributed much to climate change, it accounted for more than 67% of the total $CO_2$-eq. emitted.

The climate change impact of these poultry supply chains was significantly affected by feed transport, which contributed 12% for SO, 3% for CW, 5% for LR and 4% for ST (Table 6). In the two French systems, soybeans were the largest contributors to climate change, followed by maize. In Brazil, maize was the major contributor to climate change. The slaughter stage contributed least (about 2%) to climate change for all systems.

For cumulative energy demand (Table 7) again, feed production contributed most. However, the contribution of feed production to energy demand was larger for the two French systems (approx. 71%), than for the Brazilian systems (57%).

The slaughter stage made a major contribution to energy demand (about 22%) for the two Brazilian systems, due to the amount of firewood used. For the French systems the slaughter stage contributed about 9% to energy demand, mainly due the use of natural gas and packaging (Table 7).

**Table 6 -** Contributions of processes and main substances for three major life cycle stages to climate change for 1 ton of chicken cooled and packaged at the slaughterhouse gate, produced in the South-West of France (LR – Label Rouge), the West of France (ST - standard), and the South (SO) and Centre-West (CW) of Brazil, in kg of $CO_2$-eq.

| Life cycle stages | | France Standard (ST) | | | | | France Label Rouge (LR) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $CO_2$ | $N_2O$ | $CH_4$ | Others | TOTAL | $CO_2$ | $N_2O$ | $CH_4$ | Others | TOTAL |
| Slaughter | Heat from wood | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | **0** |
| | Heat from natural gas | 9 | 0 | 4 | 0 | **13** | 9 | 0 | 4 | 0 | **13** |
| | Paper Board | -3 | 0 | 1 | 0 | **-2** | -3 | 0 | 1 | 0 | **-2** |
| | Other slaughter stages | 55 | 1 | 6 | 0 | **62** | 55 | 1 | 6 | 0 | **62** |
| Chicken Production | Chicken house[1] | 0 | 213 | 243 | 0 | **456** | 0 | 184 | 212 | 0 | **396** |
| | DOC | 67 | 39 | 15 | 1 | **122** | 70 | 41 | 16 | 1 | **128** |
| | Propane | 151 | 0 | 2 | 0 | **153** | 332 | 0 | 5 | 0 | **337** |
| | Electricity | 2 | 0 | 0 | 0 | **2** | 2 | 0 | 0 | 0 | **2** |
| | Transport chicken | 44 | 1 | 2 | 0 | **47** | 69 | 1 | 2 | 1 | **73** |
| | Other chicken production stages | 0 | 20 | 1 | 0 | **21** | 0 | 21 | 1 | 0 | **22** |
| Feed production | Maize | 180 | 247 | 8 | 1 | **436** | 458 | 421 | 26 | 3 | **908** |
| | Soybean meal | 748 | 56 | 20 | 11 | **835** | 953 | 52 | 17 | 14 | **1.036** |
| | Soybean oil | 22 | 2 | 1 | 0 | **25** | 0 | 0 | 0 | 0 | **0** |
| | Palm oil | 60 | 21 | 59 | 2 | **142** | 0 | 0 | 0 | 0 | **0** |
| | Wheat | 123 | 233 | 7 | 1 | **364** | 145 | 226 | 6 | 1 | **378** |
| | Feed transport | 118 | 5 | 8 | 1 | **132** | 121 | 50 | 15 | 1 | **187** |
| | Other feed stages | 298 | 59 | 8 | 2 | **367** | 369 | 87 | 19 | 1 | **476** |
| **TOTAL** | | **1.874** | **897** | **385** | **19** | **3.175** | **2.580** | **1.084** | **330** | **22** | **4.016** |

| Life cycle stages | | Brazil Centre West (CW) | | | | | Brazil South (SO) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $CO_2$ | $N_2O$ | $CH_4$ | Others | TOTAL | $CO_2$ | $N_2O$ | $CH_4$ | Others | TOTAL |
| Slaughter | Heat from wood | 7 | 4 | 2 | 3 | **16** | 7 | 4 | 2 | 3 | **16** |
| | Heat from natural gas | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | **0** |
| | Paper Board | -4 | 0 | 1 | 0 | **-3** | -4 | 0 | 1 | 0 | **-3** |
| | Other slaughter stages | 28 | 1 | 4 | 0 | **33** | 28 | 1 | 4 | 0 | **33** |
| Chicken Production | Chicken house | 0 | 156 | 178 | 0 | **334** | 0 | 151 | 172 | 0 | **323** |
| | DOC | 34 | 20 | 8 | 0 | **62** | 63 | 36 | 14 | 1 | **114** |
| | Propane | 83 | 0 | 1 | 0 | **84** | 83 | 0 | 1 | 0 | **84** |
| | Electricity | 21 | 0 | 6 | 0 | **27** | 18 | 0 | 5 | 0 | **23** |
| | Transport chicken | 49 | 0 | 2 | 0 | **51** | 56 | 0 | 2 | 0 | **58** |
| | Other chicken production stages | 0 | 0 | 0 | 0 | **0** | -1 | 0 | 0 | 0 | **-1** |
| Feed production | Maize | 884 | 237 | 23 | 12 | **1.156** | 255 | 279 | 13 | 1 | **548** |
| | Soybean meal | 230 | 82 | 12 | 4 | **328** | 226 | 81 | 12 | 4 | **323** |
| | Soybean oil | 418 | 28 | 10 | 7 | **463** | 66 | 27 | 3 | 1 | **97** |
| | Palm oil | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | **0** |
| | Wheat | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | **0** |
| | Feed transport | 87 | 1 | 3 | 1 | **92** | 215 | 2 | 7 | 2 | **226** |
| | Other feed stages | 91 | 7 | 6 | 4 | **108** | 90 | 7 | 6 | 4 | **107** |
| **TOTAL** | | **1.928** | **536** | **256** | **31** | **2.751** | **1.102** | **588** | **242** | **16** | **1.948** |

As Table 7 shows the contribution analysis for cumulative energy demand.

**Table 7 -** Contributions of processes and main resources for three major life cycle stages to cumulative energy demand for 1 ton of chicken cooled and packaged at the slaughterhouse gate, produced in the South-West of France (LR – Label Rouge), the West of France (ST - standard), and the South (SO) and Centre-West (CW) of Brazil, in MJ.

| **Life cycle stages** | | **France Standard (ST)** | | | | | | **France Label Rouge (LR)** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Oil** | **Gas** | **Coal** | **Biomass** | **Others** | **TOTAL** | **Oil** | **Gas** | **Coal** | **Biomass** | **Others** | **TOTAL** |
| Slaughter | Heat from wood | 0 | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | 0 | **0** |
| | Heat from nat. gas | 7 | 1.220 | 5 | 0 | 5 | **1.237** | 7 | 1.220 | 5 | 0 | 5 | **1.237** |
| | Paper Board | 44 | 34 | 43 | 292 | 39 | **452** | 44 | 34 | 43 | 292 | 39 | **452** |
| | Other slaughter stages | 743 | 379 | 121 | 78 | 231 | **1.552** | 743 | 379 | 121 | 78 | 231 | **1.552** |
| Chicken Production | Chicken house[1] | 0 | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | 0 | **0** |
| | DOC | 419 | 298 | 94 | 70 | 844 | **1.725** | 438 | 311 | 98 | 73 | 882 | **1.802** |
| | Propane | 2.207 | 96 | 36 | 1 | 39 | **2.379** | 4.841 | 211 | 79 | 3 | 85 | **5.219** |
| | Electricity | 5 | 8 | 14 | 2 | 288 | **317** | 5 | 9 | 15 | 2 | 301 | **332** |
| | Transport chicken | 625 | 56 | 36 | 1 | 51 | **769** | 969 | 86 | 56 | 2 | 79 | **1.192** |
| | Others LW stages | 236 | 77 | 21 | 444 | 44 | **822** | 247 | 81 | 23 | 464 | 46 | **861** |
| Feed production | Maize | 1.257 | 1.457 | 349 | 28 | 659 | **3.750** | 1.351 | 4.857 | 1.009 | -76 | 3.813 | **10.954** |
| | Soybean meal | 3.107 | 1.109 | 502 | 1.303 | 595 | **6.616** | 3.445 | 163 | 468 | 1.464 | 263 | **5.803** |
| | Soybean oil | 73 | 27 | 13 | 44 | 16 | **173** | 0 | 0 | 0 | 0 | 0 | **0** |
| | Palm oil | 339 | 180 | 101 | 233 | 41 | **894** | 0 | 0 | 0 | 0 | 0 | **0** |
| | Wheat | 1.060 | 810 | 236 | 22 | 292 | **2.420** | 1.520 | 744 | 208 | 21 | 228 | **2.721** |
| | Feed transport | 832 | 735 | 176 | 225 | 396 | **2.364** | 2.218 | 1.735 | 363 | 346 | 1.246 | **5.908** |
| | Other crop stages | 639 | 2.135 | 169 | 119 | 1.480 | **4.542** | 1.570 | 3.831 | 356 | 56 | 2.581 | **8.394** |
| **TOTAL** | | **11.593** | **8.621** | **1.916** | **2.862** | **5.020** | **30.012** | **17.398** | **13.661** | **2.844** | **2.725** | **9.799** | **46.427** |

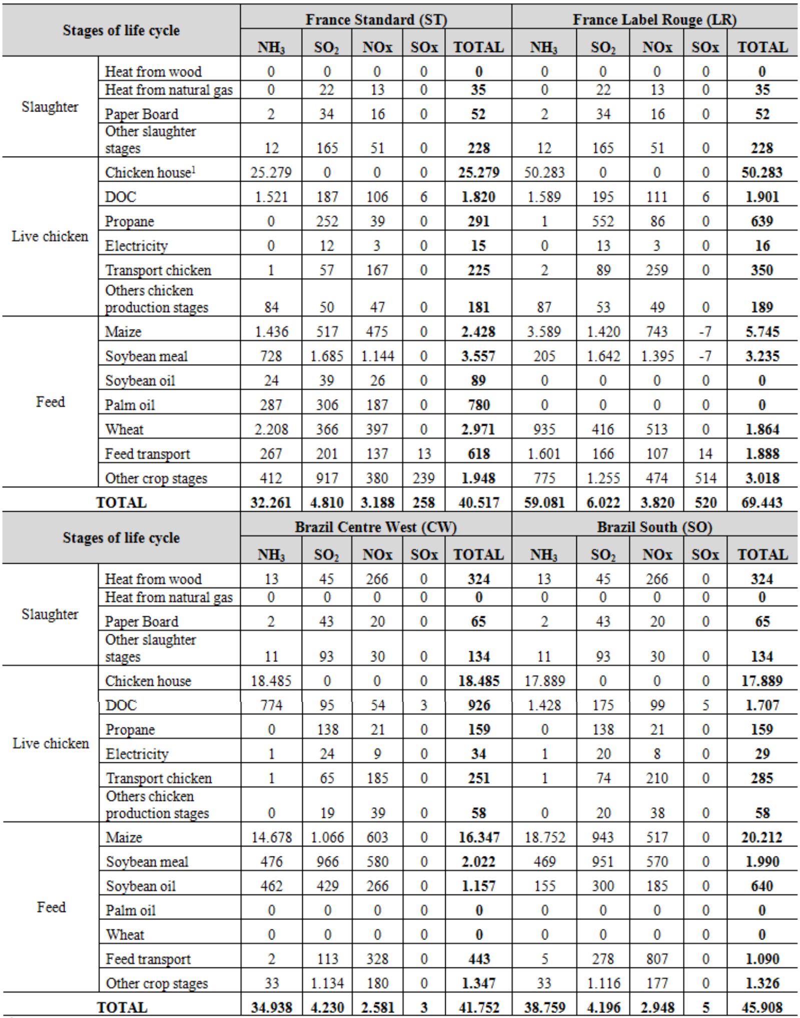
| **Life cycle stages** | | **Brazil Centre West (CW)** | | | | | | **Brazil South (SO)** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Oil** | **Gas** | **Coal** | **Biomass** | **Others** | **TOTAL** | **Oil** | **Gas** | **Coal** | **Biomass** | **Others** | **TOTAL** |
| Slaughter | Heat from wood | 106 | 26 | 41 | 4.824 | 141 | **5.138** | 106 | 26 | 41 | 4.824 | 141 | **5.138** |
| | Heat from nat. gas | 0 | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | 0 | **0** |
| | Paper Board | 55 | 43 | 54 | 370 | 49 | **571** | 55 | 43 | 54 | 370 | 49 | **571** |
| | Other slaughter stages | 317 | 254 | 84 | 10 | 147 | **812** | 317 | 254 | 84 | 10 | 147 | **812** |
| Chicken production | Chicken house | 0 | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | 0 | **0** |
| | Propane | 1.210 | 53 | 20 | 1 | 21 | **1.305** | 1.210 | 53 | 20 | 1 | 21 | **1.305** |
| | Electricity | 39 | 68 | 32 | 20 | 423 | **582** | 33 | 59 | 27 | 17 | 363 | **499** |
| | Transport chicken | 709 | 65 | 45 | 2 | 52 | **873** | 807 | 74 | 51 | 2 | 60 | **994** |
| | Other stages | 126 | 18 | 22 | 2.365 | 26 | **2.557** | 119 | 19 | 26 | 3.079 | 30 | **3.273** |
| Feed production | Maize | 1.999 | 1.824 | 453 | 1.203 | 493 | **5.972** | 1.940 | 2.110 | 427 | -1 | 461 | **4.937** |
| | Soybean meal | 1.857 | 1.313 | 478 | 693 | 572 | **4.913** | 1.827 | 1.292 | 471 | 682 | 563 | **4.835** |
| | Soybean oil | 791 | 409 | 177 | 858 | 217 | **2.452** | 596 | 318 | 138 | 225 | 165 | **1.442** |
| | Palm oil | 0 | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | 0 | **0** |
| | Wheat | 0 | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | 0 | **0** |
| | Feed transport | 1.230 | 109 | 72 | 3 | 97 | **1.511** | 3.026 | 269 | 178 | 6 | 238 | **3.717** |
| | Other feed stages | 546 | 402 | 157 | 1.018 | 462 | **2.585** | 538 | 396 | 154 | 1.002 | 454 | **2.544** |
| **TOTAL** | | **9.198** | **4.736** | **1.683** | **11.402** | **3.130** | **30.149** | **10.968** | **5.193** | **1.759** | **10.282** | **3.485** | **31.687** |

[1] = For the LR system, chicken house also includes the outdoor area.

### 3.3.2. Acidification and eutrophication

Contributions for acidification impacts are shown in Table 8.

**Table 8 -** Contributions of processes and main resources for three major life cycle stages to acidification for 1 ton of chicken cooled and packaged at the slaughterhouse gate, produced in the South-West of France (LR - Label Rouge), the West of France (ST - standard), and the South (SO) and Centre-West (CW) of Brazil, in g $SO_2$-eq.



| **Stages of life cycle** | | **France Standard (ST)** | | | | | **France Label Rouge (LR)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **$NH_3$** | **$SO_2$** | **NOx** | **SOx** | **TOTAL** | **$NH_3$** | **$SO_2$** | **NOx** | **SOx** | **TOTAL** |
| Slaughter | Heat from wood | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | **0** |
| | Heat from natural gas | 0 | 22 | 13 | 0 | **35** | 0 | 22 | 13 | 0 | **35** |
| | Paper Board | 2 | 34 | 16 | 0 | **52** | 2 | 34 | 16 | 0 | **52** |
| | Other slaughter stages | 12 | 165 | 51 | 0 | **228** | 12 | 165 | 51 | 0 | **228** |
| Live chicken | Chicken house[1] | 25.279 | 0 | 0 | 0 | **25.279** | 50.283 | 0 | 0 | 0 | **50.283** |
| | DOC | 1.521 | 187 | 106 | 6 | **1.820** | 1.589 | 195 | 111 | 6 | **1.901** |
| | Propane | 0 | 252 | 39 | 0 | **291** | 1 | 552 | 86 | 0 | **639** |
| | Electricity | 0 | 12 | 3 | 0 | **15** | 0 | 13 | 3 | 0 | **16** |
| | Transport chicken | 1 | 57 | 167 | 0 | **225** | 2 | 89 | 259 | 0 | **350** |
| | Others chicken production stages | 84 | 50 | 47 | 0 | **181** | 87 | 53 | 49 | 0 | **189** |
| Feed | Maize | 1.436 | 517 | 475 | 0 | **2.428** | 3.589 | 1.420 | 743 | -7 | **5.745** |
| | Soybean meal | 728 | 1.685 | 1.144 | 0 | **3.557** | 205 | 1.642 | 1.395 | -7 | **3.235** |
| | Soybean oil | 24 | 39 | 26 | 0 | **89** | 0 | 0 | 0 | 0 | **0** |
| | Palm oil | 287 | 306 | 187 | 0 | **780** | 0 | 0 | 0 | 0 | **0** |
| | Wheat | 2.208 | 366 | 397 | 0 | **2.971** | 935 | 416 | 513 | 0 | **1.864** |
| | Feed transport | 267 | 201 | 137 | 13 | **618** | 1.601 | 166 | 107 | 14 | **1.888** |
| | Other crop stages | 412 | 917 | 380 | 239 | **1.948** | 775 | 1.255 | 474 | 514 | **3.018** |
| **TOTAL** | | **32.261** | **4.810** | **3.188** | **258** | **40.517** | **59.081** | **6.022** | **3.820** | **520** | **69.443** |

| **Stages of life cycle** | | **Brazil Centre West (CW)** | | | | | **Brazil South (SO)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **$NH_3$** | **$SO_2$** | **NOx** | **SOx** | **TOTAL** | **$NH_3$** | **$SO_2$** | **NOx** | **SOx** | **TOTAL** |
| Slaughter | Heat from wood | 13 | 45 | 266 | 0 | **324** | 13 | 45 | 266 | 0 | **324** |
| | Heat from natural gas | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | **0** |
| | Paper Board | 2 | 43 | 20 | 0 | **65** | 2 | 43 | 20 | 0 | **65** |
| | Other slaughter stages | 11 | 93 | 30 | 0 | **134** | 11 | 93 | 30 | 0 | **134** |
| Live chicken | Chicken house | 18.485 | 0 | 0 | 0 | **18.485** | 17.889 | 0 | 0 | 0 | **17.889** |
| | DOC | 774 | 95 | 54 | 3 | **926** | 1.428 | 175 | 99 | 5 | **1.707** |
| | Propane | 0 | 138 | 21 | 0 | **159** | 0 | 138 | 21 | 0 | **159** |
| | Electricity | 1 | 24 | 9 | 0 | **34** | 1 | 20 | 8 | 0 | **29** |
| | Transport chicken | 1 | 65 | 185 | 0 | **251** | 1 | 74 | 210 | 0 | **285** |
| | Others chicken production stages | 0 | 19 | 39 | 0 | **58** | 0 | 20 | 38 | 0 | **58** |
| Feed | Maize | 14.678 | 1.066 | 603 | 0 | **16.347** | 18.752 | 943 | 517 | 0 | **20.212** |
| | Soybean meal | 476 | 966 | 580 | 0 | **2.022** | 469 | 951 | 570 | 0 | **1.990** |
| | Soybean oil | 462 | 429 | 266 | 0 | **1.157** | 155 | 300 | 185 | 0 | **640** |
| | Palm oil | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | **0** |
| | Wheat | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | **0** |
| | Feed transport | 2 | 113 | 328 | 0 | **443** | 5 | 278 | 807 | 0 | **1.090** |
| | Other crop stages | 33 | 1.134 | 180 | 0 | **1.347** | 33 | 1.116 | 177 | 0 | **1.326** |
| **TOTAL** | | **34.938** | **4.230** | **2.581** | **3** | **41.752** | **38.759** | **4.196** | **2.948** | **5** | **45.908** |

[1] = For the LR system, chicken house also includes the outdoor area.

For the French systems the largest contribution to acidification came from the chicken production stage (Table 8), in particular from chicken house emissions (69% for ST and 77% for LR). The largest absolute value for acidification (69.4 kg of $SO_2$–eq. per ton of chicken at the slaughterhouse gate) also came from the LR system. This resulted to a large extent from the emission of ammonia from the droppings of birds, both in and outside the chicken house.

In the Brazilian systems, although the largest contribution to acidification also came from chicken house emissions (48% for CW and 44% for SO), there was a larger contribution from maize production, due the use of nitrogen fertilizer (39% for CW, 44% for SO).

For French systems the slaughter stage contributed on average 7% to eutrophication, chicken production contributed on average 36% and feed production 57% (Table 9). For Brazilian systems, contributions to eutrophication were higher for the feed production stage (69%), leaving 23% for the chicken production stage and 8% for the slaughter stage.

For all systems, emissions from the chicken house and from the use of fertilizers were the main contributors to eutrophication. The absolute emission values were similar for the three intensive systems (from 19.9 to 21.0 kg $PO_4$-eq. per ton) and higher for the extensive system (29.9 kg $PO_4$ eq. per ton).

**Table 9 -** Contributions of processes and main resources for three major life cycle stages to eutrophication for 1 ton of chicken cooled and packaged at the slaughterhouse gate, produced in the South-West of France (LR – Label Rouge), the West of France (ST - standard), and the South (SO) and Centre-West (CW) of Brazil, in g of $PO_4$-eq.

| **Stages of life cycle** | | **France Standard (ST)** | | | | | | **France Label Rouge (LR)** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **$NH_3$** | **$NO_3$** | **$PO_4$** | **NOx** | **Other** | **Total** | **$NH_3$** | **$NO_3$** | **$PO_4$** | **NOx** | **Other** | **Total** |
| Slaughter | Heat from wood | 0 | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | 0 | **0** |
| | Heat from nat. gas | 0 | 0 | 0 | 4 | 0 | **4** | 0 | 0 | 0 | 4 | 0 | **4** |
| | Paper Board | 0 | 2 | 17 | 4 | 6 | **29** | 0 | 2 | 17 | 4 | 6 | **29** |
| | Other stages | 3 | 147 | 1.384 | 13 | 54 | **1.601** | 3 | 147 | 1.384 | 13 | 54 | **1.601** |
| Live chicken | Chicken house[1] | 5.530 | 0 | 0 | 0 | 0 | **5.530** | 10.999 | 0 | 0 | 0 | 0 | **10.999** |
| | DOC | 333 | 260 | 108 | 28 | 21 | **750** | 348 | 272 | 113 | 29 | 22 | **784** |
| | Propane | 0 | 0 | 14 | 10 | 15 | **39** | 0 | 1 | 30 | 22 | 33 | **86** |
| | Electricity | 0 | 0 | 6 | 1 | 0 | **7** | 0 | 0 | 6 | 1 | 0 | **7** |
| | Transport chicken | 0 | 0 | 12 | 43 | 3 | **58** | 0 | 0 | 18 | 67 | 5 | **90** |
| | Others LW stages | 18 | 165 | 21 | 12 | 14 | **230** | 19 | 172 | 22 | 13 | 14 | **240** |
| Feed | Maize | 314 | 3.042 | 368 | 124 | 317 | **4.165** | 871 | 4.672 | 1.050 | 200 | 93 | **6.886** |
| | Soy meal | 159 | 1.364 | 1.359 | 298 | 26 | **3.206** | 131 | 1.827 | 1.860 | 369 | 31 | **4.218** |
| | Soy oil | 5 | 46 | 45 | 7 | 1 | **104** | 0 | 0 | 0 | 0 | 0 | **0** |
| | Palm oil | 63 | 424 | 19 | 49 | 75 | **630** | 0 | 0 | 0 | 0 | 0 | **0** |
| | Wheat | 483 | 1.790 | 213 | 103 | 145 | **2.734** | 204 | 1.850 | 252 | 133 | 153 | **2.592** |
| | Feed transport | 8 | 53 | 19 | 5 | 4 | **89** | 178 | 138 | 75 | 15 | 7 | **413** |
| | Other crop stages | 140 | 797 | 701 | 130 | 57 | **1.825** | 170 | 940 | 628 | 123 | 115 | **1.976** |
| **TOTAL** | | **7.056** | **8.090** | **4.286** | **831** | **738** | **21.001** | **12.923** | **10.021** | **5.455** | **993** | **533** | **29.925** |

| **Stages of life cycle** | | **Brazil Centre West (CW)** | | | | | | **Brazil South (SO)** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **$NH_3$** | **$NO_3$** | **$PO_4$** | **NOx** | **Other** | **Total** | **$NH_3$** | **$NO_3$** | **$PO_4$** | **NOx** | **Other** | **Total** |
| Slaughter | Heat from wood | 3 | 1 | 15 | 69 | 24 | **112** | 3 | 1 | 15 | 69 | 24 | **112** |
| | Heat from nat. gas | 0 | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | 0 | **0** |
| | Paper Board | 0 | 3 | 22 | 5 | 8 | **38** | 0 | 3 | 22 | 5 | 8 | **38** |
| | Other stages | 2 | 133 | 1.185 | 8 | 52 | **1.380** | 2 | 133 | 1.185 | 8 | 52 | **1.380** |
| Live chicken | Chicken house | 4.043 | 0 | 0 | 0 | 0 | **4.043** | 3.913 | 0 | 0 | 0 | 0 | **3.913** |
| | DOC | 169 | 132 | 55 | 14 | 11 | **381** | 312 | 244 | 101 | 26 | 20 | **703** |
| | Propane | 0 | 0 | 8 | 6 | 8 | **22** | 0 | 0 | 8 | 6 | 8 | **22** |
| | Electricity | 0 | 0 | 14 | 2 | 0 | **16** | 0 | 0 | 12 | 2 | 0 | **14** |
| | Transport chicken | 0 | 0 | 14 | 48 | 3 | **65** | 0 | 0 | 16 | 55 | 4 | **75** |
| | Others LW stages | 0 | 0 | 0 | 10 | 1 | **11** | 0 | 0 | 0 | 10 | 1 | **11** |
| Feed | Maize | 3.211 | 1.585 | 1.836 | 157 | 23 | **6.812** | 4.102 | 1.417 | 1.417 | 135 | 24 | **7.095** |
| | Soy meal | 104 | 2.698 | 1.730 | 151 | 22 | **4.705** | 103 | 2.655 | 1.702 | 148 | 22 | **4.630** |
| | Soy oil | 101 | 620 | 716 | 69 | 9 | **1.515** | 34 | 881 | 562 | 48 | 7 | **1.532** |
| | Palm oil | 0 | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | 0 | **0** |
| | Wheat | 0 | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | 0 | **0** |
| | Feed transport | 0 | 1 | 23 | 85 | 6 | **115** | 1 | 2 | 56 | 210 | 14 | **283** |
| | Other crop stages | 7 | 58 | 574 | 47 | 25 | **711** | 7 | 57 | 565 | 46 | 25 | **700** |
| **TOTAL** | | **7.640** | **5.231** | **6.192** | **671** | **192** | **19.926** | **8.477** | **5.393** | **5.661** | **768** | **209** | **20.508** |

[1] = For the LR system, chicken house also includes the outdoor area.

### 3.3.3. Terrestrial ecotoxicity and land competition

The LR system contributed more to terrestrial ecotoxicity per ton of chicken produced (14.2 kg of 1.4-DB–eq.) than the ST system (8.7 kg of 1.4-DB-eq.). The two Brazilian system had similar values for terrestrial ecotoxicity per ton of chicken produced (9.2 and 9.4 kg of 1.4-DB-eq.). For all systems the feed production stage contributed most to terrestrial ecotoxicity (from 75 to 86%), which resulted from the emissions of heavy metals as contaminants from fertilizers used in crops.

On average, the feed production stage contributed 90% to land occupation (data not shown). This reflects the fact that agriculture requires more land than industrial and transport activities. The differences in land occupation between the four scenarios resulted mainly from differences in feed conversion ratios and crop yield levels among the scenarios. For the main feed ingredients the yields[7] were:

Soybeans: 2791 and 2535 kg/ha for the CW and SO scenarios, respectively; for the two French systems we used a composition of different soybeans scenarios, resulting in 2714 kg/ha. Maize: 6000 and 6600 kg/ha for the CW and SO scenarios, respectively, and 8979 kg/ha for both French systems. Wheat: 7080 kg/ha, only for French systems.

## 3.4. ECONOMIC FUNCTIONAL UNIT APPROACH

Using the functional unit of 1 ton of live weight at the farm gate, LR chicken had much higher impacts than standard chicken (Table 3). However, LR (Label Rouge) chicken is a high-quality product, which is sold at a higher price than the standard chicken from the other systems. This raises the question whether mass of chicken is the appropriate functional unit. So we explored the use of economic value at the farm gate as an alternative functional unit. A simple way to do this is to use the local farm gate price of the product, expressing these in Euros (Table 10).

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[7] Yields are at the reference dry matter contents, i.e. 82% for soybeans, 86% for Brazilian maize, 85% for French maize and 85% for wheat.

**Table 10 -** Environmental impacts for 1000 Euro of live chicken at the farm gate produced in the South-West of France (LR – Label Rouge), the West of France (ST - standard), and the South (SO) and Centre-West (CW) of Brazil.

| Impact category | Unit | LR | ST | SO | CW |
|---|---|---|---|---|---|
| Acidification | kg $SO_2$eq | 29.40 | 34.55 | 64.08 | 57.90 |
| Eutrophication | kg $PO_4$eq | 12.03 | 16.64 | 26.80 | 25.84 |
| Climate change | t $CO_2$eq | 1.68 | 2.67 | 2.69 | 3.80 |
| Terrestrial ecotoxicity | kg 1,4-DB eq | 5.90 | 7.17 | 12.40 | 11.99 |
| Land occupation | $m^2$a ( x 1000) | 2.43 | 3.22 | 4.57 | 4.63 |
| Cumulative energy demand | TJ eq | 18.37 | 23.01 | 35.53 | 33.18 |

Table 10 shows that for this functional unit, among the French systems LR had lower values than ST for all impacts. The two Brazilian systems had similar values for all impacts except climate change, where CW had a much higher value.

Another way to make this economic analysis is to use the added value instead of price. Table 11 shows the results of the environmental impacts from this point of view:

**Table 11 -** Environmental impacts for 1000 Euro of added value of live chicken at the farm gate produced in the South-West of France (LR – Label Rouge), the West of France (ST - standard), and the South (SO) and Centre-West (CW) of Brazil

| Impact category | Unit | LR | ST | SO | CW |
|---|---|---|---|---|---|
| Acidification | kg $SO_2$eq | 100.31 | 178.31 | 107.01 | 90.80 |
| Eutrophication | kg $PO_4$eq | 41.06 | 85.90 | 44.75 | 40.52 |
| Climate change | t $CO_2$eq | 5.72 | 13.77 | 4.49 | 5.96 |
| Terrestrial ecotoxicity | kg 1,4-DB eq | 20.14 | 37.03 | 20.71 | 18.81 |
| Land occupation | $m^2$a ( x 1000) | 8.29 | 16.62 | 7.67 | 7.26 |
| Cumulative energy demand | TJ eq | 62.66 | 118.74 | 59.33 | 52.04 |

Using the added value, the levels of impact increase in the ST system, but as the added value of the two Brazilian systems are closer to LR, this compensates the previous difference somewhat, so that the environmental impact per 1000 Euro of added value is similar between the LR and Brazilian systems, in contrast to that of ST, which is higher.

# 4. DISCUSSION

Most published research regarding the environmental impacts of chicken production focuses on farm-specific emissions from poultry houses or litter management (De Boer *et al.*, 2000; Ullman *et al.*, 2004; Wheeler *et al.*, 2006). In this work, we were concerned with the fact that the production of broilers in a chicken house is but one step in a complex series of interlinked agricultural and industrial activities that together comprise the broiler supply chain. LCA proved to be a suitable tool for this type of global analysis.

As chicken meat production is fundamentally dependent on concentrated feed derived from crop production systems, transportation and processing links these systems to those on the farm itself. According to Pelletier (2008), from a life cycle perspective, upstream feed production processes are responsible for the bulk of macroscale environmental impacts associated with material and energy inputs and emissions along the broiler supply chain.

We confirm these findings and realize that the strong contribution of the grain production stage to the environmental impacts of poultry production is a determining factor associated with the feed-conversion rate of each system as well as its carcass yield at the slaughterhouse stage. This is also according to Williams *et al.* (2006), who claim that poultry and pigs consume high-value feeds and effectively live on arable land, as their nutritional needs are overwhelmingly met by arable crops (produced both in Europe and overseas).

## 4.1. COMPARISON WITH PREVIOUS STUDIES

Chicken live weight is the best unit to compare our results with other studies, as this functional unit is most used in LCA studies of chickens. **Table 12** allows a comparison of our results with those of several other LCA studies on broiler production (Spies, 2003a; Katajajuuri *et al.*, 2008; Pelletier, 2008; Cederberg *et al.*, 2009; Williams *et al.*, 2009; Leip *et al.*, 2010).

Four authors (Spies, 2003; Katajajuuri *et al.*, 2008; Pelletier, 2008; Williams *et al.*, 2009) presented results for acidification, ranging from 16 to 60 kg $SO_2$-eq. per t of broiler live weight. Our values (29-47) are between those by Pelletier (16) and Spies (60) and agree with those by Katajajuuri *et al.* (35) and Williams *et al.* (26-31). The same four authors presented results for eutrophication, ranging from 2.1 to 23 kg $PO_4$-eq. per t of broiler live weight. Our values (14-19) agree with findings by Spies (16) and Williams *et al.* (14-23). Values by Katajajuuri *et al.* (2.1) and by Pelletier (3.9) are much lower than ours. All six studies presented results for climate change, ranging from 1395 to 3430 kg $CO_2$-eq. per t of broiler live weight. Our results (1449-2696) agree with those by Pelletier (1395), Spies (1410), Cederberg (1900), Katajajuuri *et al.* (2079) and Williams *et al.* (1800 and 2000). The value by Leip *et al.* (3430) is higher. Two authors (Katajajuuri *et al.*, 2008; Williams *et al.*, 2009) presented results for land occupation, ranging from 4270-6700 (Williams *et al.*) to 5500 (Katajajuuri *et al.*) $m^2a$ per t of broiler live weight. Our values (2465-3905) are lower. Three authors (Spies, 2003; Katajajuuri *et al.*, 2008; Williams *et al.*, 2009) presented results for energy demand, ranging from 11200 to 16000 MJ per t of broiler live weight. Our values (18000-29500 MJ) are higher.

For acidification, eutrophication and climate change our results were within the range of literature values. It should be noted that for acidification and eutrophication the range of values found in the literature was particularly large. For land occupation our values were below literature values, whereas for energy demand our values were above literature values. For land occupation, although we had no access to the methodological details of other works, it is likely that these authors used lower yield levels for feed crops, resulting in greater land occupation, since the crops are the processes that use most land in the chain analyzed. The reasons for the difference in energy demand is likely to be linked to different methodological details and scope of the life cycle inventory, i.e., what was or was not considered as part of the system. For the specific case of Spies (2003), the energy input values were similar to ours, but the set of database processes used to generate electricity does not seem to have considered the losses during the transmission process.

**Table 12 -** Comparison of the main results of this study with other relevant publications, per ton of live weight[1].

| Study | ystem | Country[2] | Acidification Kg $SO_2$eq | Eutrophication kg $PO_4$eq | limate change g $CO_2$eq | and occup. ²a | Cumul. energy demand MJ |
|---|---|---|---|---|---|---|---|
| Spies (2003) | tandard | BR | 60.4 | 16.4 | 410 | | 14300 |
| Katajajuuri *et al. (*2008) | tandard | FR | 35 | 2.1 | 079 | 500 | 16000 |
| Pelletier (2008) | tandard | US | 15.8 | 3.9 | 395 | | - |
| Cederberg (2009) | tandard | SW | - | - | 330 | | - |
| Williams *et al.* (2009) | tandard | UK | 25.9 | 14 | 800 | 270 | 11200 |
| Williams *et al.* (2009) | ree range | UK | 30.8 | 23.5 | 000 | 700 | 11200 |
| Leip *et al.* (2010) | tandard | EU | - | - | 430 | | - |
| This study – ST | tandard | FR | 28.7 | 13.8 | 216 | 676 | 19118 |
| This study – LR | abel Rouge | FR | 47.2 | 19.3 | 696 | 903 | 29516 |
| This study – CW | tandard | BR | 31.4 | 14 | 058 | 508 | 17977 |
| This study – SO | tandard | BR | 34.5 | 14.4 | 449 | 465 | 19147 |

**1. Functional unit:** t LW=ton of live weight. Williams, Cederberg and Leip *et al.* used carcass weight as functional unit. We transformed carcass weight in live weight, assuming a carcass yield of 70% for standard systems and 67% for the free range system.

**2.Country:** UK=United Kingdom; FR=France; SW=Sweden; BR=Brazil; US=United States; EU=average of several European Union countries

This study has shown the major contribution of feed production to impacts (Table 5). This is in agreement with the findings of Pelletier (2008). However, relative to our results Pelletier found higher contributions from feed production, accounting for 80% of energy demand, 82% of climate change, 98% of ozone depleting emissions, 96% of acidification, 97% of eutrophication for the cradle-to-farm gate production of broiler poultry. Pelletier's system definitions, estimations of emissions or characterization factors may be different from ours, which may have contributed to these differences. However, his work confirms the major contribution of the feed production stage.

It was not possible to know the detailed methodologies for most other studies, but we had access to the details of the work by Spies (2003). His results are different from ours with respect to field emissions. We used more recent recommendations from IPCC (IPCC, 2006) for the estimation of $N_2O$ emissions and thus did not consider biologically fixed nitrogen, whereas Spies did, based on previous IPCC methodology. Thus our work presented lower values for $N_2O$ emissions of soybeans. Furthermore, relative to the work by Spies, our values for $NO_3$ emissions were lower, whereas our value for $PO_4$ emissions was higher.

These differences in results summarized in **Table 12** are probably related to the different methodologies used in each study. Some authors have shown concern about this fact (Roy *et al.*, 2009; Clandio, 2010; Flysjö, 2010), seeking a harmonization for LCA studies in agriculture, which represents a challenge for future work.

## 4.2. SCALE EFFECT

The production scale represents the size and number of production facilities (buildings) and the number of animals raised on the same farm. In this regard, only CW can be characterized as large-scale production, and the other three systems are small scale. The two French systems differ on several points, such the geographic origin of feed ingredients, the age at slaughter and access to an outdoor run. It therefore seems best to analyze the effect of scale of production by comparing the two Brazilian systems, which are very similar, except for the issues presented in Table 13.

**Table 13 -** Characterization of differences between small scale (SO) and large scale (CW) systems.

| Main differences | SO | CW |
|---|---|---|
| Distance from area of crop production to the feed industry | 500 km | 200 km |
| Distance from feed industry to the chicken farm | 42 km | 35 km* |
| Distance from chicken farm to slaughter | 95 km | 60 km |
| Distance from hatchery to chicken farm | 100 km | < 100 km* |
| Size of buildings | 1200 m² x 1 building | 1600 m² x 4 buildings |
| Numbers of animals per batch | 14,040 | 96,000 |
| Feed truck capacity | 13 t/truck | 26 t/truck |
| Chicken truck capacity | 3131 chicken/truck | 7178 chicken/truck |

* Information not based on literature sources but on surveys of relevant stakeholders.

Climate change was higher for CW than for SO (2.75 against 1.95 kg of $CO_2$-eq. per kg of slaughtered chicken, respectively), which resulted from the feed production stage. This mainly results from $CO_2$ emissions associated with land use change, the conversion of a small part of forest and cerrado to crop land that, although it has decreased in the country, still occurs. Once this effect is considered, there is no effect of the scale of poultry production to explain the difference between CW and SO.

The impacts from the feed transport stage were higher for SO than for CW, due to longer transport distances for feed ingredients. The energy demand and $CO_2$ emissions, for example, are 2.4 times higher for the SO system. However, the impacts associated with crop production were higher for CW (higher input use and lower yields), and this partly compensated the effect of shorter transport distances for CW. Anyway, these characteristics are not related to the scale of the production system and the net differences found were small.

For the other impact categories, the difference between the two systems was 2 to 9%. Since the comparison is based on a single case for small and large scale operations, it becomes very difficult to know whether these differences are effects of scale of production or the result of other factors for which the systems differed.

Consequently, this work does not allow any conclusion with respect to the effect of scale of production on the environmental impacts of poultry production systems.

## 4.3. INTENSITY EFFECT

As shown in sections 3.1, 3.2.and 3.3, the extensive system (LR) clearly had 1.3 to 1.7 times larger impacts than the intensive systems for the functional unit of 1 ton of whole chicken cooled and packaged. This can be explained considering that most environmental impacts resulted from the crop production stage. So, the more grain is needed to produce the same amount of live chickens, the larger the environmental impact. LR had the worst feed conversion ratio in comparison with the other systems (3.1 kg of feed per kg of live weight chicken, against from 1.9 for the other systems). In this case, as the other stages of the life cycle did not differ much, the intensive systems required less feed per unit of animal growth, using chicken strains selected for low physical activity, concentrating the energy of ingested food in weight gain. In the extensive system slow growing strains were used, and greater physical activity of animals required more energy, resulting in slower weight gain. Thus a higher feed conversion ratio entailed greater environmental impacts. Here we find that the level of intensity clearly affected impacts per unit of chicken meat produced.

Another important point that affects the results is the carcass yield parameter. Due to the genetic strains used in intensive systems, carcass yield for these systems is higher than in LR. This fact also contributed significantly to the poorer environmental performance of LR when the impacts are compared per ton of chicken slaughtered. Therefore, improvements in carcass yield of the LR system can lead to a substantial improvement of its environmental performance.

## 4.4. ECONOMIC FUNCTIONAL UNIT

A valuable feature of the LCA approach is that once we have completed the inventory data, it is possible to use different functional units for the same product, depending on the focus of the research. While not intending to make an economic analysis in this paper, we have also analyzed the results in a different way, seeking to play up the fact that a significant part of French consumers are willing to pay a higher price for chicken raised in extensive systems due to its superior product quality. For this purpose, we adopted an economic value (1000 Euro - using both price and added value) of chicken live weight at the farm gate as functional unit.

Thus, the results presented by these two FUs represent the environmental impacts related to the value assigned by the market price and added value to the different types of chicken. This creates a new basis for comparison, showing results that are different from those obtained when 1000 kg of live weight is used as the functional unit.

**Price:** Under the price approach, Table 10 shows that for all impact categories analyzed, the LR systems had the lowest levels of impact.

Per ton of LW, we found 1.5 t of $CO_2$-eq. for SO system (Table 3) against 2.7 t for the LR system, i.e; almost two times more impact for the LR system. Assessing per 1000 Euro of LW, we found 2.7 t of $CO_2$-eq. for SO (Table 10) against 1.7 t for LR, i.e. almost 1.5 times more impact for SO. A similar result is found for energy demand. Per ton of LW we found 1.5 times more impact for LR, while per Euro of LW, we found twice more impact for SO than for LR.

Interestingly, when comparing the emission of $CO_2$–eq. per ton of LW between ST and SO, we found 1.5 times more impact for ST system. Whereas comparing per Euro of LW we found the same value for both systems.

**Added Value:** the estimated added value shows a relationship between the systems which is different from the relationship of the price. The added value of ST is the lowest, and the two Brazilian systems are twice the ST, while the LR system has the highest value, reaching three times the ST. This proportion affects the results, so that the environmental impacts for some categories are smaller for both Brazilian systems (acidification, land competition and energy demand). However, for all impact categories, the ST system showed the highest values.

In terms of $CO_2$ emissions, as shown in Table 11, the SO system emits less per 1000 Euros of added value (4.49 t of $CO_2$-eq), followed by the LR system (5.72 t of $CO_2$-eq), then the CW (5.96 t of $CO_2$-eq) and, the most polluting, the ST system, with 13.77 t of $CO_2$-eq. Per t of LW, we found almost two times more impact for the LR system (Table 3), while per 1000 Euro of added value, the LR system is three times higher than SO (Table 11).

Regarding energy demand, the CW system performs better, with 52 TJ per 1000 Euros of added value, followed by SO with 59 TJ, LR with 63 TJ, and ST with 119 TJ (Table 11). Per ton of LW, both systems OS and ST showed almost the same energy demand (Table 3), but per 1000 Euros of added value, system ST showed almost twice the value of that of OS (Table 11).

When we use economic FU (based on estimated price or added value), as all impacts that were expressed per unit mass are divided by a new factor with different values for each system, the results are highly dependent on these adopted values. Therefore, it is clear that the adoption of new FUs results in different rankings of environmental impacts.

## 4.5. HOT SPOTS AND RECOMMENDATIONS

Clearly the largest contribution to the environmental impacts studied in this work during the process of chicken production, came from the feed production stage. This trend was very clear when considering the production of live chickens, and when we added the stage of slaughter and processing, the picture changed little.

An important contribution of the feed production stage to overall impacts is also found by others authors, working with different species. In a comparison of conventional and organic milk production in the Netherlands, Thomassen *et al.* (2008) found that the production of concentrate feeds for conventional dairy farms produced the highest contributions to all impact categories considered. In a similar analysis in Sweden, Cederberg and Mattsson (2000) also identified concentrate feed production, and the use of synthetic fertilizer in feed crop production in particular, as a central factor in the environmental performance of conventional dairy farming. In an analysis of pork production in Sweden, Carlsson-Kanyama (1998) found that the production of concentrate feed contributed 53% of greenhouse gas emissions, and 70% of energy use. Basset-Mens and van der Werf (2005) also found that feed production was an environmental hotspot in pork production.

We found that for poultry feed production, impacts were predominantly associated with the crop production stage rather than with transportation or processing stages. Carbon dioxide and dinitrogen monoxide contributed most to climate change; ammonia and sulfur dioxide contributed most to acidification, while ammonia and nitrate contributed most to eutrophication. The production of nitrogen fertilizer also contributed strongly to climate change and energy demand. This is in agreement with Williams *et al.* (2009) and Pimentel *et al.* (2005).

It is interesting to note that this study revealed that for the two French systems the largest contribution to acidification resulted from the chicken production stage (mainly ammonia emissions in the chicken houses) rather than from the feed production stage, whereas in the two Brazilian systems the largest contribution came from feed production. This resulted from the use of urea as a nitrogen fertilizer for maize in Brazil, since urea has a much higher emission factor for ammonia than ammonium-nitrate, which is the usual nitrogen fertilizer applied in French crops. Therefore, in Brazil, the use of a more efficient nitrogen fertilizer (less volatilization of ammonia) will reduce acidification along the chain.

For the two Brazilian systems, climate change and land occupation impacts were smaller for the SO system (Table 4), due lower impacts in the grain production stage. Feed ingredients of the CW system had larger impacts than those of the SO system, resulting from deforestation and greater transport distances. In the French systems the soy used in the feed comes from Brazil, bringing these impacts with it. So, stopping deforestation for the production of crops in Brazil is an important point to improve the environmental performance of poultry production.

The extensive system examined in this study (LR) had a worse environmental performance for all categories analyzed, per ton produced compared to intensive systems. It is noteworthy that the feed production for both French systems is largely the same, so the slow animal growth and the associated poorer feed conversion of the extensive system explain its higher levels of impact. It is therefore very important to think about ways to produce less impacting feed for chickens reared in extensive system (use of alternative foods, organic farming or other ways to produce feed with less energy consumption and less greenhouse gas emissions) in an attempt to minimize the environmental impacts.

Although not analyzed in this study, the use of organic feed ingredients, which are typically less energy- and emission-intensive due to the absence of synthetic fertilizers in their production (Pelletier *et al.*, 2008), may potentially offer a viable means of reducing the life cycle impacts of broiler production. However, Williams *et al.* (2006) found that, whereas organic field crops and animal products generally consumed less primary energy than their non-organic counterparts due to the use of legumes to fix N rather than fuel to make synthetic fertilizers, poultry was an exception, resulting from the very high efficiency of feed conversion for the non-organic poultry.

## 5. CONCLUSIONS

LCA proved to be a suitable tool for a global analysis of the entire broiler supply chain.

The grain production stage is the largest contributor to the overall environmental impacts along the chicken meat supply production chain. This, associated with feed conversion rate of each system, as well as its carcass yield at the slaughterhouse stage, is a determinant factor in the impacts of chicken production.

We conclude that, per ton of chicken meat produced, and for the impacts studied, the Label Rouge system causes more environmental impacts than the two systems of poultry production typical of Brazil and standard chicken produced in France. Efforts to improve the feed conversion rate, the carcass yield and to reduce the use of fossil fuels in the supply chain can help to improve the environmental performance of such extensive poultry production systems. Care should be taken however to preserve the superior quality of the chicken produced by these systems.

This work did not find differences, for the impacts studied, between large and small scale production systems. However, we found that for systems with different levels of intensity, there is a clear difference when the impacts are related to the amount of chicken meat produced, suggesting that the more intensive the production system, the lower the environmental impact of the entire chain. This results mainly from the efficient feed conversion ratio in the intensive system.

When we changed the FU to relate the environmental impacts to the price or the added value of the chicken at the farm gate, we found completely different results, with the extensive LR system presenting the lowest impacts, when using the price in the FU. These economic functional units takes into account the quality of the product as reflected in its market price or added value. In this work the issue has been addressed only superficially, and we suggest more comprehensive analysis of these aspects in future work.

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## 8. ANNEX

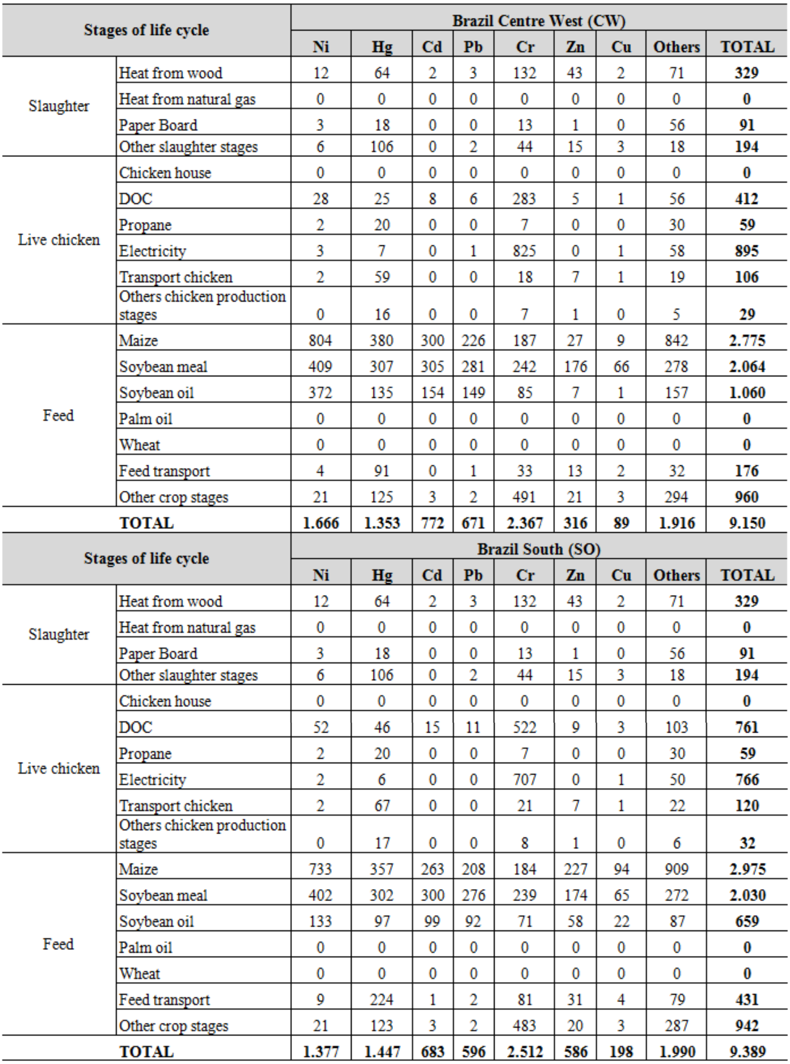
**Table 14 – Supplementary -** Contributions of processes and main resources for three major life cycle stages to terrestrial ecotoxicity for 1 ton of chicken cooled and packaged at the slaughterhouse gate, produced in the South-West of France (LR – Label Rouge) and the West of France (ST - standard), in g of 1,4DB-eq.

| Stages of life cycle | | France Standard (ST) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Ni | Hg | Cd | Pb | Cr | Zn | Cu | Others | TOTAL |
| Slaughter | Heat from wood | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | Heat from natural gas | 0 | 9 | 0 | 0 | 1 | 0 | 0 | 2 | **12** |
| | Paper Board | 2 | 14 | 0 | 0 | 10 | 1 | 0 | 44 | **71** |
| | Other slaughter stages | 7 | 127 | 0 | 2 | 67 | 16 | 3 | 32 | **254** |
| Live chicken | Chicken house[1] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | DOC | 55 | 49 | 16 | 11 | 556 | 9 | 3 | 110 | **809** |
| | Propane | 4 | 36 | 0 | 0 | 13 | 1 | 0 | 56 | **110** |
| | Electricity | 1 | 4 | 0 | 0 | 206 | 0 | 0 | 13 | **224** |
| | Transport chicken | 2 | 46 | 0 | 0 | 17 | 6 | 1 | 16 | **88** |
| | Others chicken production stages | 28 | 14 | 5 | 0 | 12 | 1 | 0 | 46 | **106** |
| Feed | Maize | 372 | 252 | 109 | 22 | 410 | 248 | 54 | 492 | **1.959** |
| | Soybean meal | 619 | 383 | 268 | 257 | 223 | 53 | 16 | 329 | **2.148** |
| | Soybean oil | 20 | 10 | 9 | 9 | 6 | 2 | 1 | 10 | **67** |
| | Palm oil | 19 | 41 | 4 | 1 | 124 | 3 | 1 | 53 | **246** |
| | Wheat | 267 | 140 | 42 | 8 | 107 | 13 | 1 | 507 | **1.085** |
| | Feed transport | 47 | 31 | 15 | 11 | 36 | 10 | 2 | 57 | **209** |
| | Other crop stages | 228 | 183 | 68 | 62 | 295 | 19 | 7 | 438 | **1.300** |
| **TOTAL** | | **1.671** | **1.339** | **536** | **383** | **2.083** | **382** | **89** | **2.205** | **8.688** |

| Stages of life cycle | | France Label Rouge (LR) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Ni | Hg | Cd | Pb | Cr | Zn | Cu | Others | TOTAL |
| Slaughter | Heat from wood | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | Heat from natural gas | 0 | 9 | 0 | 0 | 1 | 0 | 0 | 2 | **12** |
| | Paper Board | 2 | 14 | 0 | 0 | 10 | 1 | 0 | 44 | **71** |
| | Other slaughter stages | 7 | 127 | 0 | 2 | 67 | 16 | 3 | 32 | **254** |
| Live chicken | Chicken house | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | DOC | 58 | 51 | 17 | 12 | 581 | 10 | 3 | 115 | **847** |
| | Propane | 9 | 79 | 0 | 0 | 28 | 1 | 0 | 122 | **239** |
| | Electricity | 1 | 4 | 0 | 0 | 215 | 0 | 0 | 13 | **233** |
| | Transport chicken | 3 | 71 | 0 | 1 | 27 | 9 | 1 | 25 | **137** |
| | Others chicken production stages | 29 | 15 | 5 | 0 | 12 | 1 | 0 | 49 | **111** |
| Feed | Maize | 49 | 837 | 292 | 1 | 3.357 | 38 | 8 | 1.314 | **5.896** |
| | Soybean meal | 801 | 500 | 354 | 348 | 281 | 73 | 21 | 358 | **2.736** |
| | Soybean oil | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | Palm oil | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | Wheat | 314 | 142 | 59 | 4 | 99 | 17 | 2 | 511 | **1.148** |
| | Feed transport | 70 | 100 | 36 | 18 | 255 | 9 | 2 | 164 | **654** |
| | Other crop stages | 187 | 199 | 30 | 9 | 613 | 25 | 8 | 809 | **1.880** |
| **TOTAL** | | **1.530** | **2.148** | **793** | **395** | **5.546** | **200** | **48** | **3.558** | **14.218** |

[1] = For the LR system, chicken house also includes the outdoor area.

**Table 15 – Supplementary -** Contributions of processes and main resources for three major life cycle stages to terrestrial ecotoxicity for 1 ton of chicken cooled and packaged at the slaughterhouse gate, produced in the South (SO) and Centre-West (CW) of Brazil, in g of 1,4DB-eq.



| Stages of life cycle | | Brazil Centre West (CW) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **Ni** | **Hg** | **Cd** | **Pb** | **Cr** | **Zn** | **Cu** | **Others** | **TOTAL** |
| Slaughter | Heat from wood | 12 | 64 | 2 | 3 | 132 | 43 | 2 | 71 | **329** |
| | Heat from natural gas | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | Paper Board | 3 | 18 | 0 | 0 | 13 | 1 | 0 | 56 | **91** |
| | Other slaughter stages | 6 | 106 | 0 | 2 | 44 | 15 | 3 | 18 | **194** |
| Live chicken | Chicken house | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | DOC | 28 | 25 | 8 | 6 | 283 | 5 | 1 | 56 | **412** |
| | Propane | 2 | 20 | 0 | 0 | 7 | 0 | 0 | 30 | **59** |
| | Electricity | 3 | 7 | 0 | 1 | 825 | 0 | 1 | 58 | **895** |
| | Transport chicken | 2 | 59 | 0 | 0 | 18 | 7 | 1 | 19 | **106** |
| | Others chicken production stages | 0 | 16 | 0 | 0 | 7 | 1 | 0 | 5 | **29** |
| Feed | Maize | 804 | 380 | 300 | 226 | 187 | 27 | 9 | 842 | **2.775** |
| | Soybean meal | 409 | 307 | 305 | 281 | 242 | 176 | 66 | 278 | **2.064** |
| | Soybean oil | 372 | 135 | 154 | 149 | 85 | 7 | 1 | 157 | **1.060** |
| | Palm oil | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | Wheat | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | Feed transport | 4 | 91 | 0 | 1 | 33 | 13 | 2 | 32 | **176** |
| | Other crop stages | 21 | 125 | 3 | 2 | 491 | 21 | 3 | 294 | **960** |
| **TOTAL** | | **1.666** | **1.353** | **772** | **671** | **2.367** | **316** | **89** | **1.916** | **9.150** |

| Stages of life cycle | | Brazil South (SO) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **Ni** | **Hg** | **Cd** | **Pb** | **Cr** | **Zn** | **Cu** | **Others** | **TOTAL** |
| Slaughter | Heat from wood | 12 | 64 | 2 | 3 | 132 | 43 | 2 | 71 | **329** |
| | Heat from natural gas | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | Paper Board | 3 | 18 | 0 | 0 | 13 | 1 | 0 | 56 | **91** |
| | Other slaughter stages | 6 | 106 | 0 | 2 | 44 | 15 | 3 | 18 | **194** |
| Live chicken | Chicken house | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | DOC | 52 | 46 | 15 | 11 | 522 | 9 | 3 | 103 | **761** |
| | Propane | 2 | 20 | 0 | 0 | 7 | 0 | 0 | 30 | **59** |
| | Electricity | 2 | 6 | 0 | 0 | 707 | 0 | 1 | 50 | **766** |
| | Transport chicken | 2 | 67 | 0 | 0 | 21 | 7 | 1 | 22 | **120** |
| | Others chicken production stages | 0 | 17 | 0 | 0 | 8 | 1 | 0 | 6 | **32** |
| Feed | Maize | 733 | 357 | 263 | 208 | 184 | 227 | 94 | 909 | **2.975** |
| | Soybean meal | 402 | 302 | 300 | 276 | 239 | 174 | 65 | 272 | **2.030** |
| | Soybean oil | 133 | 97 | 99 | 92 | 71 | 58 | 22 | 87 | **659** |
| | Palm oil | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | Wheat | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | Feed transport | 9 | 224 | 1 | 2 | 81 | 31 | 4 | 79 | **431** |
| | Other crop stages | 21 | 123 | 3 | 2 | 483 | 20 | 3 | 287 | **942** |
| **TOTAL** | | **1.377** | **1.447** | **683** | **596** | **2.512** | **586** | **198** | **1.990** | **9.389** |

# GENERAL DISCUSSION AND CONCLUSION

Poultry production is a typical example of globalization, as poultry can be easily moved and uses inputs from different parts of the globe. This generates an intense competition between the various producing regions. The growth of poultry production at the global level is a very significant phenomenon in food production and involves several stages of its supply chain. Brazilian poultry has supplanted French poultry in several international markets and Brazil is now a major producer of feed ingredients for the production of intensive livestock in the world and it is the leading exporter of beef and chicken (Guemene and Lescoat, 2007).

With this growth, questions are raised about the sustainability of current production systems and about the contribution of poultry production to the sustainable development of producing regions. In this thesis the entire poultry product life cycle was analysed, to know all environmental aspects involved.

The results of this research are dependent on the methodological approach, which in this case represents the situation of the chicken supply chains in a given time. As this productive sector is subject to significant changes in the medium term, it is possible that changes will occur and, if this same methodology were reapplied to the systems, the results could differ. This shows a weakness of this approach. Therefore, it is important to note that in the case of trying to build an analysis that looks forward a few years, it would be necessary to design scenarios with future changes and perform the LCA again. In other words, the results discussed here are only valid for the current situation, noting the limitations of the LCA.

The main objective of this thesis was to measure and compare environmental impacts of poultry production in specific settings in Brazil and France, with different levels of intensity and scale, using the LCA method for environmental assessment. The research also seeks to identify the main opportunities and hotspots regarding the environmental sustainability of each scenario. These objectives were met and the results are summarized in this chapter by answering the research questions that were presented in Chapter 1 (item 3.1, research questions).

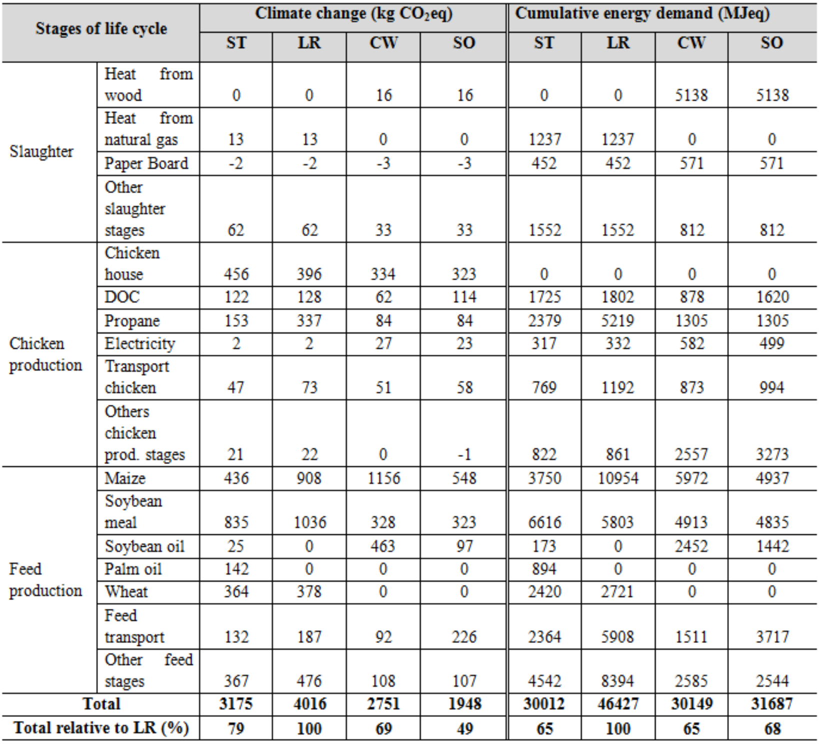
# 1. INTENSITY EFFECTS

Question 1: **Do different systems of poultry production (intensive and extensive) cause different environmental impacts? If yes, how large is this difference?**

To answer this question, the main results were presented in Chapter 4, Table 4, and the detailed results in tables from 6 to 9. As was also shown in Chapter 4, the functional unit strongly affects the results. However, to best answer this question, we will focus on the FU “1 ton of chicken cooled and packaged produced” in each system.

The general answer to the question is: yes, intensity affects impacts. To demonstrate the effect of intensity, we re-present the results in summary form for climate change and energy demand (Table 1).

**Table 1 -** Contributions of processes from three main life cycle stages for Climate change and Cumulative Energy Demand for 1 ton of chicken cooled and packaged at the slaughterhouse gate produced in the –South-West of France (LR – Label Rouge), the West of France (ST - standard), and the South (SO) and Centre-West (CW) of Brazil.



| **Stages of life cycle** | | **Climate change (kg $CO_2$eq)** | | | | **Cumulative energy demand (MJeq)** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **ST** | **LR** | **CW** | **SO** | **ST** | **LR** | **CW** | **SO** |
| Slaughter | Heat from wood | 0 | 0 | 16 | 16 | 0 | 0 | 5138 | 5138 |
| | Heat from natural gas | 13 | 13 | 0 | 0 | 1237 | 1237 | 0 | 0 |
| | Paper Board | -2 | -2 | -3 | -3 | 452 | 452 | 571 | 571 |
| | Other slaughter stages | 62 | 62 | 33 | 33 | 1552 | 1552 | 812 | 812 |
| Chicken production | Chicken house | 456 | 396 | 334 | 323 | 0 | 0 | 0 | 0 |
| | DOC | 122 | 128 | 62 | 114 | 1725 | 1802 | 878 | 1620 |
| | Propane | 153 | 337 | 84 | 84 | 2379 | 5219 | 1305 | 1305 |
| | Electricity | 2 | 2 | 27 | 23 | 317 | 332 | 582 | 499 |
| | Transport chicken | 47 | 73 | 51 | 58 | 769 | 1192 | 873 | 994 |
| | Others chicken prod. stages | 21 | 22 | 0 | -1 | 822 | 861 | 2557 | 3273 |
| Feed production | Maize | 436 | 908 | 1156 | 548 | 3750 | 10954 | 5972 | 4937 |
| | Soybean meal | 835 | 1036 | 328 | 323 | 6616 | 5803 | 4913 | 4835 |
| | Soybean oil | 25 | 0 | 463 | 97 | 173 | 0 | 2452 | 1442 |
| | Palm oil | 142 | 0 | 0 | 0 | 894 | 0 | 0 | 0 |
| | Wheat | 364 | 378 | 0 | 0 | 2420 | 2721 | 0 | 0 |
| | Feed transport | 132 | 187 | 92 | 226 | 2364 | 5908 | 1511 | 3717 |
| | Other feed stages | 367 | 476 | 108 | 107 | 4542 | 8394 | 2585 | 2544 |
| **Total** | | **3175** | **4016** | **2751** | **1948** | **30012** | **46427** | **30149** | **31687** |
| **Total relative to LR (%)** | | **79** | **100** | **69** | **49** | **65** | **100** | **65** | **68** |

The results presented in Table 1 clearly show that the extensive LR system had larger impacts than the other (intensive) systems. Table 1 shows the results only for climate change and energy demand, but the same trend was observed for the other impacts studied. For climate change, intensive systems varied from 49% to 79% of the impact of the LR system. For energy demand, they ranged from 65% to 68% of the impact of LR (Table 1).

## 2. SCALE EFFECTS

Question 2: **Do small-scale poultry production systems cause more environmental impact than large-scale systems?**

The production scale represents the size and number of production facilities (buildings) and the number of animals raised on the same farm. As shown in Chapter 4 (section 4.2), the two Brazilian systems represent a difference in scale of production. However, the differences between the two systems found in this work were attributed to other factors (such as level of inputs used, deforestation that only occurred in one system, different distances among life cycle stages) and not to the difference in scale between the systems. So, per ton of chicken slaughtered, our results showed no relationship between the differences of environmental impacts and the scale of the production systems. However it must be emphasized that this conclusion is valid for this case study, and for the impact categories considered here.

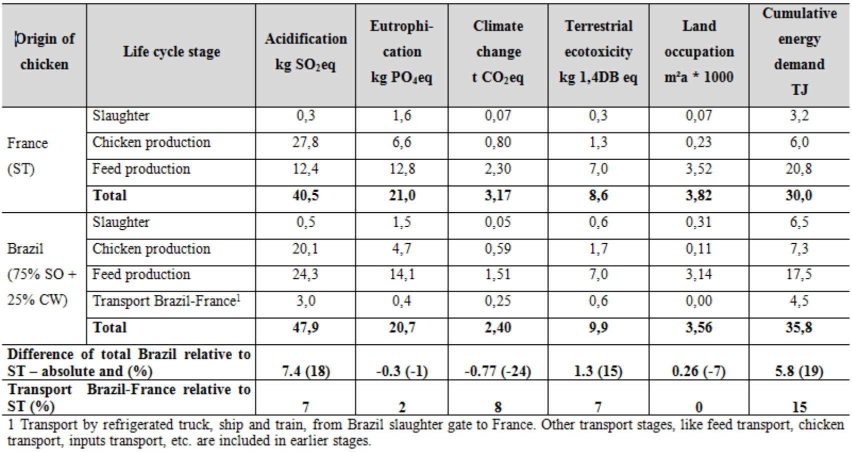
Interestingly, the feed transport stage, although with a smaller difference in distance between the two systems (42 and 35 km for SO and CW, respectively, see Table 13 of Chapter 4), resulted in larger impacts than the transport of chickens. For this stage, the impacts were 59% higher for SO than for CW. However, the difference was not due to the effect of scale, since for the SO system feed transport distance was higher because some of the raw materials for feed (maize and soybeans) came from far away than for CW. Per ton of chicken cooled and packaged produced this difference was most evident for the impacts climate change and energy demand, reaching 12% of the total impacts for SO, for both categories. For the other impacts this stage contributed less than 5%.

## 3. ORIGIN OF THE CHICKEN CONSUMED IN FRANCE

Question 3: Do imported chickens from Brazil, fed with locally produced grains cause less (or more) impact than chickens produced in France, using a feed part of which comes from Brazil?

To answer this question, we use information from Chapter 3, that explored the scenarios of grain production in Brazil, and Chapter 4 that compared the different production systems. Then we ran a comparison, assuming that the chicken produced in France was the intensive system (ST) with a feed made with French ingredients (maize, wheat, and rapeseed) and with soybean from Brazil. For the Brazilian case, chickens were fed mainly with maize and soybeans produced in the region in which the chickens were raised. The bureau of foreign trade of Brazil – SECEX –(“Ministério do Desenvolvimento, Indústria e Comércio Exterior”, 2011) reported that 75% of exports of chicken come from the three southern states of the country. As we have two scenarios (both intensive) that represent the Brazilian situation, we propose a scenario consisting of 75% of SO chicken (considered representative for the three southern states) and 25% of CW chicken, adding to this scenario the transport distances. The distances considered were on average 1370 km from the Centre-West of Brazil to the port of Itajaí, and on average 500 km from the South of Brazil to the same port, in a refrigerated truck. Then, we considered more 9700 km of transoceanic ship to the port of Bordeaux, France, and thereafter, another 500 km of railway, to Bretagne. The results are shown in Table 2.

**Table 2 -** Contributions of the main life cycle stages for six impacts for 1 ton of chicken cooled and packaged produced in France (ST) and 1 ton of chicken cooled and packaged produced in Brazil and delivered in France.



| **Origin of chicken** | **Life cycle stage** | **Acidification kg $SO_2$eq** | **Eutrophi-cation kg $PO_4$eq** | **Climate change t $CO_2$eq** | **Terrestrial ecotoxicity kg 1,4DB eq** | **Land occupation m²a * 1000** | **Cumulative energy demand TJ** |
|---|---|---|---|---|---|---|---|
| France (ST) | Slaughter | 0,3 | 1,6 | 0,07 | 0,3 | 0,07 | 3,2 |
| | Chicken production | 27,8 | 6,6 | 0,80 | 1,3 | 0,23 | 6,0 |
| | Feed production | 12,4 | 12,8 | 2,30 | 7,0 | 3,52 | 20,8 |
| | **Total** | **40,5** | **21,0** | **3,17** | **8,6** | **3,82** | **30,0** |
| Brazil (75% SO + 25% CW) | Slaughter | 0,5 | 1,5 | 0,05 | 0,6 | 0,31 | 6,5 |
| | Chicken production | 20,1 | 4,7 | 0,59 | 1,7 | 0,11 | 7,3 |
| | Feed production | 24,3 | 14,1 | 1,51 | 7,0 | 3,14 | 17,5 |
| | Transport Brazil-France[1] | 3,0 | 0,4 | 0,25 | 0,6 | 0,00 | 4,5 |
| | **Total** | **47,9** | **20,7** | **2,40** | **9,9** | **3,56** | **35,8** |
| **Difference of total Brazil relative to ST – absolute and (%)** | | **7.4 (18)** | **-0.3 (-1)** | **-0.77 (-24)** | **1.3 (15)** | **0.26 (-7)** | **5.8 (19)** |
| **Transport Brazil-France relative to ST (%)** | | **7** | **2** | **8** | **7** | **0** | **15** |

1 Transport by refrigerated truck, ship and train, from Brazil slaughter gate to France. Other transport stages, like feed transport, chicken transport, inputs transport, etc. are included in earlier stages.

For climate change, and land occupation it is better to produce chicken in Brazil and export it to France than to produce the same type of chicken in France. The transport stage contributed only 8% to GHG emissions, and therefore, when imported in France, the Brazilian chicken still had 24% less emissions than the French chicken (Table 2).

An interesting effect occurred for energy demand. On average, the Brazilian chicken consumed almost the same energy per ton of chicken at the slaughterhouse gate regarding French chicken (Table 4, Chapter 4), but due to energy demand for transportation to France, on delivery in France it required 15% more energy than the French chicken.

Acidification was already higher for chicken production scenarios in Brazil, and transportation increased acidification by 7%, reaching 18% more acidifying emissions than the French chicken on delivery in France. A similar phenomenon occurred for terrestrial ecotoxicity.

For the French chicken, about 33% of greenhouse gas emissions resulted from the use of soybean meal from Brazil, as well as 24% of energy demand. It is very likely that these values would be lower if other locally produced protein-rich grains were used, in substitution of Brazilian soybeans, improving thus the environmental performance of the French chicken.

From an environmental point of view, importing chicken from Brazil rather than producing it in France with Brazilian soybeans, was better with respect to climate change and land occupation, which are both global impacts. With respect to acidification, terrestrial ecotoxicity and energy demand chicken imported from Brazil had larger impacts than the chicken produced in France. It is therefore not simple to answer this question. If one considers that climate change is the most important environmental issue, then the import of Brazilian chicken would seem preferable and stopping deforestation in Brazil would strongly reduce the climate change impact of both Brazilian and French chicken.

## 4. HOTSPOTS AND OPPORTUNITIES

Question 4: **What would be the hotspots in each supply chain studied and what are the opportunities for industries to improve their environmental performance?**

As the supply chains are quite similar, most of the hotspots and actions to improve environmental performance apply to all systems. Thus, we present first a few more specific issues for each system, and then we’ll address issues that apply to all of them.

## 4.1. WESTERN FRANCE - STANDARD SYSTEM (ST)

In this system, as can be seen in Tables 6 to 9 of Chapter 4, for the feed production stage soybean meal contributes most to all impacts. This is the main hotspot for this system. Companies operating in this region could decrease the amount of imported soybeans in the feed, seeking a substitution by locally-produced feed ingredients. There is indication that overall impacts of feeds can be reduced by decreasing the use of maize and soybean meal and increasing wheat and co-product content in the feed (Nguyen *et al.*, 2011).

## 4.2. SOUTH-WEST OF FRANCE "LABEL ROUGE" (LR)

This was the only extensive system examined in this study, and, compared to intensive systems, it had a worse environmental performance per ton of chicken produced for all impacts analyzed. One hotspot is the feed conversion ratio. Any improvement of the conversion ratio will decrease all impacts. Other opportunities for the companies operating this system is finding ways to produce less impacting feed, such as using less impacting ingredients, produced by organic farming or other methods requiring less energy consumption and generating less greenhouse gas emissions.

## 4.3. CENTRE-WEST OF BRAZIL (CW)

The largest contribution to all impacts came from maize and soybean production. Although the area deforested each year for growing these crops is declining and actually is relatively small, the associated impacts are very high. This is a hotspot for this system. So, stopping deforestation is an urgent action to improve the environmental performance of this poultry production system. Also, maize production with use of nitrogen fertilizers with less volatilization of nitrogen, rather than the use of urea, can contribute significantly to reducing the climate changes impact. Another important point would be to increase the participation of maize produced with organic fertilization.

## 4.4. SOUTH OF BRAZIL (SO)

As can be seen in Tables 6 and 7 of Chapter 4, feed transport contributed more to climate change and energy demand for this system than for the other systems. Therefore locating feed factories strategically can help to reduce these impacts. Another hot spot concerns maize production, which has a high contribution to all impacts. Likewise the CW system, increasing the area of maize fertilized with organic manure can help reduce the use of and impacts associated with chemical fertilizers.

## 4.5. OVERALL ISSUES

### 4.5.1. Improving feed production

Feed production contributed most to the environmental impacts of the chicken production systems studied in this work. This is in agreement with the results of several authors studying different animal species (Carlsson-Kanyama, 1998; Cederberg; Mattsson, 2000; Basset-Mens; van der Werf, 2005; Thomassen *et al.*, 2008).

Clearly, feed production is a general hotspot in rearing chickens. We also found that for crops used in poultry feed production, impacts were predominantly associated with the agricultural stage rather than with transportation or processing stages. In general, recommendations that may improve the environmental performance of feed crop production will also reduce the impacts of chicken production.

Impacts of feed ingredients can be decreased by producing feed crops in the proximity of chicken production farms, which reduces the need for transportation, as well as through the cultivation of soybeans and maize in sustainable systems, which allows the reduction of impacts associated with chemical fertilizers and pesticides.

As was demonstrate in Chapter 4, nitrous oxide, ammonia and nitrate emissions strongly contributed to climate change, acidification and eutrophication. The production of chemical fertilizers, especially nitrogen fertilizer, further contributed to climate change and energy demand. Thus, the use of chemical fertilizers with lower emissions of ammonia can help reduce environmental impacts during the crop production stage.

Other practices that may reduce impacts further include soil conservation practices and the use of cover crops, to prevent soil erosion and to reduce losses of nitrate. Any production techniques that increase yield, without requiring the use of more inputs will contribute to reducing the impacts per kg of product. Integrated management of diseases and pests is another issue, since it can reduce pesticide use. Likewise, in this work we considered only the use of fossil fuels, but the use of biofuel in the production of grains may change significantly the environmental performance of broiler production. Although there are studies showing that the use of biofuels may worsen the environmental performance of products due to a direct or indirect effect on deforestation (Fargione *et al.*, 2008; Searchinger *et al.*, 2008), it is possible to imagine that, through policies properly implemented for this purpose, biofuels can be produced on land that was deforested for agriculture but then abandoned or in areas of unproductive pastures, where there is no need for further clearing of forests. Within this context, it might be a good alternative to use of biofuel in production of crops for animal feed.

Finally, the improvement of transport logistics, especially for the Brazilian systems, can help improve the performance of broiler production. This contribution is not as significant as the previous ones, but it is important since it is linked to almost all other productive sectors of the country. The Brazilian transport web is typically based on roads, while the environmental impacts of other forms of transport, such as railways and river transport, are much lower.

### 4.5.2. Improving chicken rearing

Tables 8 and 9 of Chapter 4, also showed that the emission of ammonia from the poultry houses is another hotspot for all systems. Practices that contribute to the reduction of ammonia emissions can contribute significantly to reducing acidification and eutrophication impacts. Furthermore, nitrous oxide and methane emissions from chicken houses are very important contributors to climate change (Table 6, Chapter 4).

Thus, practices that reduce gas emissions from poultry houses will also help to avoid environmental impacts. This may include improvement of diets, using a balance of ingredients that improve digestion, as suggested by some authors (Nahm and Carlson, 1998; Williams et al., 1999; Ferket et al., 2002; Nahm, 2002, 2004) and also more appropriate use of genetic strains, seeking the reduction of emissions. The use of additives is a possible way, as demonstrated by McCrory and Hobbs (2001) to reduce ammonia and odour emissions.

In the LCA approach used in this study, the litter leaves the system, but is considered as an input in crop production for the scenarios that use organic fertilizer. The crops thus fertilized required less or none chemical fertilizer, which reduced their impacts. It is important to consider the appropriate use of poultry litter as a fertilizer as a way to reduce the environmental impacts of the poultry production system. The main use of the litter is as fertilizer in the production of crops such as grains, vegetables, sugar cane and others. It can furthermore be used as a substrate in biogas production and direct combustion for power generation.

### 4.5.3. Improving slaughter stage

This stage had the smallest contribution to all impacts (Tables 6-9, Chapter 4). Even so, some general practices may be recommended in order to minimize impacts, such as the proper treatment of the slaughter effluent, water reuse, optimization and use of recyclable materials in packaging and use of renewable sources for energy consumed in the process.

## 5. CHANGING THE APPROACH

When referring to the relationship between environmental impact and intensity of animal production, there is a general notion that intensive production systems, somehow, are more impacting. This notion probably results rather from a focus on the local/regional impacts (eutrophication, odours) than from a systemic assessment of all emissions and resource uses through the entire supply chain, such as LCA can provide.

The results of this study have shown that from the perspective of LCA, intensive livestock production systems caused less environmental impact than the extensive ones, when compared per unit mass of final product. During the interpretation of the results of this work, we felt the need to use other approaches, as was done in Section 3.4 of Chapter 4, when we changed the functional unit to 1000 Euro of chicken live weight at the farm gate (based on price and added-value estimations).

Although there was no time to explore these different approaches in depth, we feel the need to at least suggest as a subject of future research not only the use of different functional units, but also animal welfare, another issue often associated with intensive animal production.

A study conducted in several European countries (United Kingdom, Ireland, Italy, France and Germany) sought to determine and analyze the nature and level of public concern with animal welfare (Harper and Henson, 2001). The results of the qualitative and quantitative studies demonstrated that although consumers were concerned about farm animal welfare, this concern generally was not a priority in food choice. Consumers used animal welfare as an indicator of other, usually more important, product attributes such as food safety, quality and healthiness. Consequently, consumers equated good animal welfare standards with good food standards (Harper and Henson, 2001). Consumers define animal welfare in terms of natural lives and humane deaths. In essence, this means that animals should be reared, fed, housed, reproduced and allowed to behave as close to natural conditions as possible. In this sense, the extensive system studied in this work (LR) is closer to a desirable situation for animal welfare, but when compared against intensive systems by unit mass of the final product, has a worse environmental performance, in the impact categories considered.

Although consumers claim that they are willing to pay more for improved animal welfare, at point of purchase such claims are rarely translated into practice. Indeed, although the majority of consumers report high levels of concern about farm animal welfare, such concerns are rarely translated into behaviour (Harper and Henson, 2001).

Still, there is actually a big difference in price in France between the standard chicken and the Label Rouge chicken. The price difference indicates that the standard and Red Label products are not really products that meet exactly the same functions. The red label product tastes better, so we consider the price (and, alternatively, the added value) as a "proxy" for the function rendered by the product.

Besides these issues, many others appear when one relates the issue of animal welfare to environmental impacts. Some questions are prominent, and relatively easy to tackle, such as ammonia concentration, light level and animal density inside the chicken houses. Other issues are more difficult to change, such as the genetic strains used in intensive systems, which over time selected the most apathetic individuals with little activity, consequently allowing faster growth. This probably is one of the main reasons for the impressive improvement of feed conversion ratio of new strains of chicken.

Many interesting questions arise when it comes to animal welfare, but they were not the focus of this thesis. Therefore we suggest to address these issues in future research, by trying to find ways to qualify and quantify animal welfare, and to express it in a manner which could be covered by the LCA approach.

## 6. CONCLUSION

It is important to develop methods of analysis and appropriate environmental assessment to guide the evolution of society towards sustainable modes of production and consumption (van der Werf and Petit, 2002). This study aimed to contribute to this by quantifying the environmental impacts associated with the production of chicken meat. The main conclusions of this work were:

- Deforestation for cultivation of crops in Brazil is declining. In this work it was estimated that for the Centre-West 1% of soy production took place on land transformed from tropical rainforest the previous year, and 3.4 % occurred on land transformed from Cerrado. These values were lower than those estimated previously by others authors, reflecting the recent stabilization of the soybean area and the decrease in deforestation as well as a more appropriate approach that considers differences in the levels of deforestation among Brazil's five regions and in the estimation of soy grown on deforested land.
- This study showed that considerations of deforestation and land clearing associated with soybean and maize strongly affected the estimated impacts of these crops. Therefore, efforts to halt deforestation should continue. A sensibility analysis showed that eutrophication, terrestrial ecotoxicity and land occupation impacts were not much affected by the proportion of land transformed from forest, and acidification was moderately affected. Climate change and cumulative energy demand were strongly affected by assumptions regarding land transformation from forest.
- For soybean production, the various routes of transport considered showed higher levels of impact for CW than for SO for all impacts examined except eutrophication and land occupation. The same trend was observed for the crop production stage. Another important issue for soybeans, that also applied to maize or other grains, is that in the crop production stage, optimization of the use of fertilizers and machinery can significantly reduce $CO_2$ emissions. The use of

nitrogenous fertilizers not based on urea, will contribute to a reduction in $NH_3$ emissions.

- For soybeans produced in Brazil and exported to Europe, the transport stage has a strong influence on impacts. Results showed that although there are different possibilities of transportation in Brazil, the current predominance of road transport causes major environmental impacts. The scenarios of different transport routes with higher and lower impacts assessed in this study revealed differences of 30-50%, depending on the impact. This suggests that both the mode of transport chosen and the transport distance strongly influenced environmental impacts. In this sense, the geographical location of CW is unfavorable for export. However, for both CW and SO, improvements in transportation logistics that give priority to rail and river transport instead of road transport can significantly contribute to reducing greenhouse gas emissions and energy use.
- In other LCA studies (Jungbluth et al., 2007; Cavalett and Ortega, 2009), Brazilian soybean was modeled as a single production system. However, Brazil is a huge country with great variability of pedo-climatic conditions, which implies differences in the level of inputs and mechanization used in each region, and yield levels. Future LCA studies involving soybeans from Brazil should take into account the region of origin and its associated farmer practices, as different regions have different levels of environmental impacts. This distinction is important not only to give more accuracy to LCA studies, but also serves to guide government policies that could adopt strategies adapted to each region.
- The environmental impacts of the poultry production systems analysed were strongly affected by the crop production stage, as well as by their feed conversion ratio and carcass yield at the slaughterhouse.
- Comparing per mass of chicken meat produced, and for the impacts studied, the Label Rouge system caused more environmental impacts than the two systems of poultry production typical of Brazil and standard chicken produced in France.
- This work didn’t find differences of environmental impact, between large and small scale production systems. However, for systems with different levels of intensity, and when the impacts were related to the amount of chicken meat produced, the intensive production systems had lower impacts than the extensive system.

- Importing chicken from Brazil rather than producing it in France with Brazilian soybeans, was better with respect to climate change and land occupation. With respect to acidification, terrestrial ecotoxicity and energy demand chicken imported from Brazil had larger impacts than the chicken produced in France. If one considers that climate change is the most important environmental issue, then the import of Brazilian chicken would seem preferable.
- When we change the FU trying to relate the environmental impacts the market value of the chicken (based on price estimates), the Label Rouge system presented a better performance for all impacts studied, than the intensive systems. In this work this issue has been the subject of a first exploration, and we suggest a more comprehensive analysis of this question in future work.

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# 8. ANNEX

## 8.1. **ANNEX 1 -** LABEL ROUGE CHICKEN FARM VISIT, REPORT

**Date:** 14 Feb. 2008.
Update: 26 Feb. 2008.

**Local:** Rennes, France – Le Grand Fougeray et Saulnieres

**Time:** Farm 1 - 14:00 PM
Farm 2 - 16:00 PM

**Distance from Rennes:** about 60 Km.

**Participants:**
Airton Spies
Michel Corson
Sebastião Roberto Soares
Thierry Trochet
Vamilson Prudêncio da Silva Jr.

**Objective:** to understand the production system of Label Rouge chicken in France, and to gather some basic information about the differentiating characteristics from conventional chickens.

**Farm 1**
**Owner:** Monsieur Moreou
Location: Le Grand Fougeray
Tel: 06 32 16 94 59
02 99 08 48 90

**General info:**

- The farmer is producing label rouge chickens for 14 years.
- Full time of 4 people is used in this propriety.
- Production system: 4 sheds with 400 m2 (9 x 45) located in two different sites. In one shed he is producing 5,000 peacocks and in the other 3 sheds, 4,400 label rouge chicken in each.
- Each shed has attached free range or grazing area of one ha. (10,000 m2)

- The farm has total area of 140 ha.

**Technical and economics indicators of these label rouge chickens:**

- Weight of on day-old-chicks at arrival on the farm: 40g.
- Mortality rate: 2%
- Age at killing: 81 to 88 days
- Weight at killing: average 2.3 kg (live weight - LW)
- Feed conversion: 3:1 (3 kg of ration per kg of LW).
- Feed is bought in from a cooperative
- Chickens stay inside the shed for 6 weeks and then released every day from sunrise to sunset (9:00 AM to 05:00 PM at least).
- Chickens are weighted weekly to monitor its growth.
- Vaccines and parasite control is made according a pre-established schedule.
- The shed floor is covered with wheat straw and the litter is removed every batch.
- Chickens are fed *ad libitum* with an automatic system.
- Temperature is controlled with gas burners and automatic control of window opening systems.
- Chickens are sold to the cooperatives and prices are set twice a year with a contract.
- All litter manure collected in the sheds is used on the farm to grow crops.
- In the past there were compliance about noise produced by the peacocks. After measuring the intensity of the noise, it was considered acceptable for health standards.
- The farm uses a gas-based gun to produce blasts to scare the crows who attack the peacocks.
- The farmer has no information over the impacts of the manure dropped by the birds directly on the soil.
- The Peacocks are about 20% more profitable then label rouge chickens, despite having a worse feed conversion.

## Some pictures from farm 1:

Fig 1 – Label Rouge building

Fig 2 – First 6 weeks period

JANZÉ

FICHE D'ELEVAGE

Fig 3 – Fiche d'élevage

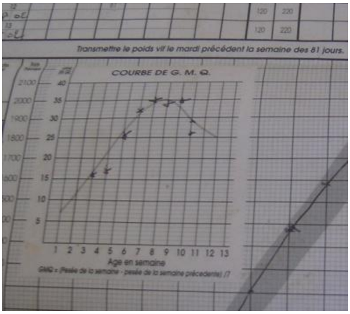

Fig 4 – weight goin control

Fig 5 – Chickens outside shed

Fig 6 – Peacocks outside shed

## Farm 2

**Owner:** Monsieur J. Maine (neighbour Mr. P. Robin)
Local: Le Bain de Bretagne / Saulnieres

**General info:**

- The farmer is producing label rouge chickens for 20 years.
- Full time of 3 people is used in this propriety. The farm has 64 ha, 20 ha used with pasture for dairy cows and 40 ha with grain production and 4 ha used with label rouge chickens.
- Production system: 4 sheds with 400 m2 (9 x 45) located in two different sites. The farm has 4,400 label rouge chicken in each shed.
- Each shed has attached free range or grazing area of one ha. (10,000 m2)
- Chickens are responsible for 60% of total gross income of the farm.
- Chickens are sold with protected geographical indication label under “Le Janzé”.

**Technical indicators of label rouge chickens:**

- Weight of on day-old-chicks at arrival on the farm: 40g.
- Mortality rate: 2%
- Age at killing: 81 to 88 days
- Weight at killing: average 2.5 kg of LW
- Feed conversion: 3:1 (3 kg of ration per kg of LW).
- Feed is bought in from a cooperative, base on wheat, burley and corn and soymeal.
- Chickens stay inside the shed for 6 weeks and then released every day from sunrise to sunset (9:00 AM to 05:00 PM at least, according Label Rouge rules).
- Chickens are weighted weekly to monitor its growth.
- Vaccines and parasite control is made according a pre-established schedule.
- The shed floor is covered with wheat straw and the litter is removed every batch.
- Chickens are fed *ad libitum* with an automatic system.
- Temperature is controlled with gas burners and automatic control of window opening systems. Aproximately 2,000 kg of

gas per year are used. The farmer is currently changing the gas burners for more efficient ones.
- All litter manure collected in the sheds is used on the farm to grow crops.
- The farmer has no information over the impacts of the manure dropped by the birds directly on the soil.

**Economical indicators:**
- Cost of ration: this label rouge production is profitable, however, at moment, the farmer is not populating all the sheds, because the market is over-supplied.
- Cost of ration is 268 euro per ton (based on Feb 2008 data).
- Price for chicken: 1.4 euro per kg LW.
- So, cost of ration production is 2,01 Euros per bird.
- Average price at supermarket for the consumer – whole chicken = 6 euros per kg.
- Other cost estimated: 0,69 euros per bird.
- So, average gross profit per bird is about 0.80 euros.

**Some issues to be considered:**

One shed produces 3 batches per year with 4.400 birds. These 13.200 chickens made up 33,000 kg of LW. They consume 100,000 kg of ration. In addition, 3 layers of straw are brought in.

As chickens spend a significant part of their lives in the field, their waste is dropped directly on that land, which over 20 year of production, may have been overloaded with nutrients.

Label Rouge chicken consume 60% more ration, which requires additional land and natural resources to be produced. Therefore the emissions from corn, soybean, wheat and barley (or other crops) production must be considered.

1,88 kg of ration per kg of LW – conventional system

3 kg of ration per kg of LW – Label Rouge

## Some pictures from farm 2:


Fig 1 – Label Rouge building


Fig 2 – Chickens outside shed


Fig 3 – Litter aspect


Fig 4 – Label Rouge chicken


Fig 5 – Inside shed aspect


Fig 6 – Farmer and technical team

## 8.2. **ANNEX 2 -** MEMOIRE VISITE A MG2MIX – CHATEAUBOURG

**Date:** 30 janvier 2008

**Lieu:** La Basse Haie - 35220 Châteaubourg – France
Tel : 02 99 00 70 34 - FAX : 02 99 00 73 50
E-mail : mg2mix@mg2mix.fr

**Heure:** 10:40h - 12:30h

**Distance de Rennes:** environ 30 Km.

**Participants:**
Denis Chevalier – MG2Mix
Joël Aubin – INRA Rennes, UMR-SAS
Vamilson Prudêncio da Silva Jr – Epagri / Ufsc / UMR-SAS

**Objectif:** contact initial pour obtention de données (en visant la réalisation d'une ACV) sur secteur d'aliments de volaille en France.

Pour commencer, Joël a présenté rapidement l'abordage de la méthode ACV. Ensuite, les informations de Monsieur Denis Chevalier.

Origine du nom de la société : deux partenaires fondateurs : Maurice Gétain, Gérard Maignan (deux « M » et deux « G »).

La société a été créée à 1989, mais l'usine a commencé à fonctionner en 1992.
Il y a deux métiers principales dans la société : fabrication de Premix et vendre du service et de technologie aux fabricants d'aliments.

**Fabrication Premix :**
- vitamines
- oligo éléments
- additif
- anticoccidiens
- extraits de plants
- acides organiques
- etc.

L’objectif c’est valoriser la performance.
Ils n’utilisent plus les « facteur de croissance ».

Ils ont un bâtiment volaille : 450 m² avec 40 cases de 6 m² pour tester e valider sont produit. Espèces : poulet, dinde, caille, canard.

**Vendre de service et techniques aux fabricant d’aliment :**

- formulation
- terrain + visites + conseils
- analyse de résultats techniques

Pour améliorer les formulations et valoriser la performance.
Ils font des analyses chimiques de ingrédients (matière première) d’aliments, par exemple, le blé :
humidité, protéin, énergie, matière grasse, cellulose, mat. organique, aminoacides. Mais aussi pour les autres composants. Aussi ils déterminent A. Aminés, AAT, AA digestible...
Pour faire la formulation précise.

Pour soja, Qualimat fait les analyses.
Maïs : à la récolte.

**Quantité de Premix :**

Pour les volailles, la quantité de Premix varie de 0,25 à 1% :
0,25% - vitamines + oligo éléments
0,5% - vitamines + oligo éléments + additifs (enzymes, anticoccidiens, extraits de plants, etc.)
1% - comme à 0,5% + sel à 0,3%
Anticoccidiens ionophores (issus de fermentation).

**Origine du composant d’aliment :**

Blé et maïs : grande région ouest (Bretagne, Pay de la Loire, Poitou-Charentes)
Les aliment que sont importé arrive par : (ports) :
Sud Bretagne : St. Nazaire – Montoir
Nord France : Ooestende (Belgique)
Sud Ouest : Bordeaux
Sud : Fos - Marseille

Le blé viens d’ici et Charentes.

Dans l’été => blé
À partir Octobre => maïs

**Métal lourd** : Cu 15 ppm en apport par l’aliment.

**Contacts suggérés :**

Le Gouessant (groupe spécialiste nutrition animale) pour consommation d’énergie ;

Fermiers de Loué : usine – Didier Leloup
Yves de la Fouchardière (enthousiaste de l'environnement)

Fermiers de Landes : fabrication d’aliment
M. Laurent Tusek (Landes et Gers)

Doux – abbatoir Châteaulin : poulet export Moyen Orient congelé

LDC – Bruno Mousset (lien producteurs) abbatoirs fédéré
Lambert Dodard
Chancereul
Information sur : frais, transformé
Abattent aussi pour « Fermier de Loué »

Autres firmes service à :
Crevin : Celtic (+ centralis)
Janzé : CCPA

Coralis Cesson Sévigné : volaille label et porc.
Michel à Fougère : volaille, porc ruminant.

## Contrat d'intégration :

Les poulets ici sont abattus avec 2,150 kg et avec un IC = 1,8 (40 jours).

Avec ces indices et en fonction du contrat, le éleveur va recevoir 7 Euro/m² de bâtiment.

Mais le niveau génétique et la qualité de la matière première permettent d'arriver au même poids (2,150) avec une IC = 1,65 (seulement 35 jours.)

Avec ces indices le éleveur va recevoir 10 Euro/m². C'est trop ! Et c'est possible d'éviter ce bon résultat en modifiant (pour pire) la formulation.

## Quelques photo : (récupérées sur site : www.mg2mix.fr)

Accueil et usine (arrière)

Mélangeuse

Système informatique

Mélangeuse

Équipements divers

## 8.3. **ANNEX 3 -** TRAVEL REPORT FOR DATA COLLECTION – AURORA

Participants:

**Vamilson Prudêncio da Silva Jr.**
**Rodrigo Augusto Freitas de Alvarenga**
Departamento de Engenharia Sanitária e Ambiental
Universidade Federal de Santa Catarina

Departure Date: 07/10/09

Return Date: 09/10/09

The purpose of the trip was to complete the inventory data of the LCIA phase of the production of broilers representative of southern Brazil (western Santa Catarina). The missing data refer to the stages of manufacture of feed for broilers, production of fertile eggs and slaughter.

The data will be used for two projects: thesis and dissertation of those students, because it is two different approaches on the same chain.

In 08/10/09 at 8:30h, there was a meeting at the Cooperative "Fach Aurora II" in Chapecó, Santa Catarina. People present: the students Vamilson and Rodrigo, Mr. Carlos Luis Farias, poultry manager and coach of Aurora company, Rodrigo Santana Toledo, responsible for the animal nutrition sector at the same company. At this meeting presentations were made explaining the methodology of Life Cycle Assessment, goal and state of the art of AviTer project (institutional project between Brazil and France related to poultry) and preliminary results of environmental impact analysis of the supply chains studied. It was also explained by the representatives of Aurora company, the flux of several important systems, as feed production, eggs production and slaughter of chickens. At the time, various information has been provided directly by the technicians of Aurora company, and as some items could not be raised immediately, it was agreed that a questionnaire would be fulfilling and submitted next week.

In the afternoon the same day, the plant of slaughter of chickens of Aurora Cooperative was visited, located in the municipality of Quilombo, approximately 60 km from Chapecó. On this visit, the general manager Eng. Antonio Wanzuit Junior accompanied the students Vamilson and

Rodrigo. Similarly some data were collected on site, and, for the remaining information, was agreed that a questionnaire would be sent the next day and Mr. Antonio will send the answers as quickly as possible.

The abattoir has a capacity of about 150000 birds slaughtered per day, currently working close to full capacity. It produces mainly chicken cuts, almost all for export (Middle East and European Union). Blood, feathers, leftover meat and offal are processed into meal and used in Aurora's composition of feed (mostly for other species - pigs). The factory for production of meal works attached to the main plant.

Subsequently, we present some photos of the production line of the slaughterhouse.

**Figure 2:** Aerial view of Aurora slaughter

**Figure 4** – After slaughter and feathers out, chickens go through "chiling" to pre-cooling

**Figure 2:** Reception of live birds, with fans and water sprinklers for temperature control – measures of animal welfare required by buyers

**Figure 5** – Poultry cuts: the main product of the slaughterhouse (although it is also equipped for whole chicken). After cooling, is the removal of viscera (who follow parallel processing line) head, trachea and lungs. In parallel lines, several types of cuts are made (manual and automatic lines).

**Figure 3** – End of first stage: after hanging, stunning, bleeding and plucking, the birds pass through the federal inspection and move on to next step

**Figure 6** – Another view from cuts line.

**Figure 7** – Some chicken parts serve as feedstock for other industrial units, which are handled separately. The chicken cuts sold in trays, are also packed in this sector.

**Figure 8:** Packaging Sector. After passing through the freezing chamber, the other cuts are accommodated in special packaging, pass through metal detectors, inventory control (bar code) and end labeling.

**Figure 9:** Storage yard for wood, for heat generation needed in slaughter (heating water for plucking). In the background, a water tank

**Figure 10:** Reservoirs of water for industrial use

**Figure 11:** Engine room, where are all the electric motors and emergency generator system.

**Figure 13:** Trucks waiting to load.

**Figure 12:** Loading site of packaged goods in the trucks.

**Figure 14:** View from the access road.