Sustainability Performance of Soybean and Beef Chains in Latin America

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Thesis

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Contents

Abstract

Livestock production is increasing rapidly as a result of growth in population and incomes and changes in lifestyles and dietary habits. The expansion of livestock production world-wide also has led to a continuous growth in demand for animal feed. This increase in livestock and feed production, not only created economic benefits for chain actors, but also resulted in social and environmental side-effects. More attention is nowadays given to these side effects by the concept of sustainability, also in Latin America (LA). LA stands out as one of the main producing world regions of livestock (i.e. beef) and feed (i.e. soybean).

The overall objective of this thesis, therefore, was to analyze the sustainability performance of soybean and beef production chains in LA. To accomplish this objective, this thesis started by identifying a set of sustainability issues that cover the environmental, economic, and social dimensions of soybean and beef production chains in a LA-EU context, based on stakeholders' survey. Sustainability issues were found to vary across stakeholders' interests: business stakeholders perceived economic issues most important, the majority of the consumers perceived social issues most important, whereas other stakeholders perceived environmental issues to be more important, for both the soybean and beef chains.

Next, the environmental and economic performance of four feeding strategies for beef production in southern Brazil were evaluated, namely: natural pasture (NP), improved pasture (IP), natural pasture and crop residues (CR), and pasture and feedlot (FL). Results showed that IP is a promising system as it results in the best environmental and economic performance of beef production in southern Brazil. Furthermore, the environmental, economic, and social performance of three soybean production systems in southern Brazil were evaluated, namely: conventional production of genetically modified (GM) soybean, conventional production of non-genetically modified (non-GM) soybean, and organic soy bean production. The sustainability assessment of soy bean production systems also captured the uncertainty of key parameters and, therefore, allowed for a comparison of robustness of outcomes. Results revealed that many factors determined the evaluation of GM, non-GM and organic production systems, and none of these systems performed best for all sustainability issues evaluated. Multi-criteria assessment (MCA) has the capability of giving a single overall score per system, by aggregating sustainability scores using relative importance weights provided by stakeholders. Moreover, elicitation of expert opinion could provide a solution for issues which could not be quantified, due to data scarcity or methodological difficulties in sustainability assessments. Validity of expert opinion and robustness of the MCA outcome to uncertainty about scores and weights, however, generally remain unclear. This thesis, therefore, evaluated the validity of scores for sustainability issues obtained from expert elicitation and the robustness of MCA to uncertainty about scores and weights for the case of soybean production. The overall comparison of expert data with data from scientific studies showed that the assessments by experts were consistent for 58% of the pairwise comparisons of the issues with studies reviewed. Hence, there is potential to use expert elicitation as an alternative to extensive data rich methods. Concrete conclusions, however, need further research based on a larger group of experts, with a high degree of knowledge regarding production systems. The simulation results regarding uncertainty of the expert scores and stakeholders' weights, showed a higher variation for the organic soybean production system compared to GM and non-GM production system. In general, relatively little technical expert knowledge and stakeholders' experience about organic systems (compared to other systems), particularly about sustainability issues, might lead to high uncertainty in experts' opinion and stakeholders' perceptions, respectively.

Chapter

1

General Introduction

F. Pashaei Kamali

General background

Population and income growth, along with changes in dietary patterns, are rapidly increasing the demand for livestock products; while globalization is boosting trade in livestock production related inputs and outputs (Gerber et al., 2007). Traditionally, livestock production was based on natural pasture, local fodder, crop residues, and unconsumed portions of household food (Gerber et al., 2007). In the recent past, however, livestock production increasingly depended on feed concentrates (Gerber et al., 2007). For instance, the global consumption of oilseed meals increased from 166 million tons in 1995 to 275.7 million tons in 2010 (MVO, 2011). This rapid growth in demand for livestock products and feed required, created, and is expected to further create benefits for farmers and society. Livestock products, for example, contribute to nutrition security, especially in developing countries where dietary diversity is limited (de Boer, 2011). Livestock also produces leather and wool, creates jobs and income for both livestock and feed producers, provides fertilizer to support crop production, serves as insurance and a source of income for farmers, and conserves the landscape (Otte et al., 2012). It is nowadays also generally acknowledged that livestock production produces harmful environmental impacts such as greenhouse gas emissions, water pollution, and biodiversity loss, and is associated with the transmission of diseases from animals to humans. These impacts may be direct, for example through grazing or housing of animals, or indirect through the expansion of feed production. The current challenge, therefore, is: how can the benefits from livestock and feed production be maintained or increased, while at the same time reducing negative side effects, or in other words, how can the sustainability performance of livestock and feed production improve (Gerber et al., 2013). Sustainability aims to balance the three dimensions of development, namely: environmental, economic, and social development (Figure 1.1) (Vasileiou and Morris, 2006).

Environmental sustainability implies using natural resources in economies or societies at a rate not exceeding their regenerative and absorptive capacity (Hueting and Reijnders, 1998; de Boer, 2012). Environmental sustainability includes issues of climate change, deforestation, biodiversity loss, or water and fossil fuel depletion.

Economic sustainability implies balancing expenditures and revenues so that a system can sustain, including issues such as profitability, volatility, and employment (de Boer, 2012). Social sustainability aims at preserving human and animal wellbeing in the long run. Social sustainability includes issues of food security, food safety, human health and safety, labor rights, animal welfare, and equity (de Boer, 2012).

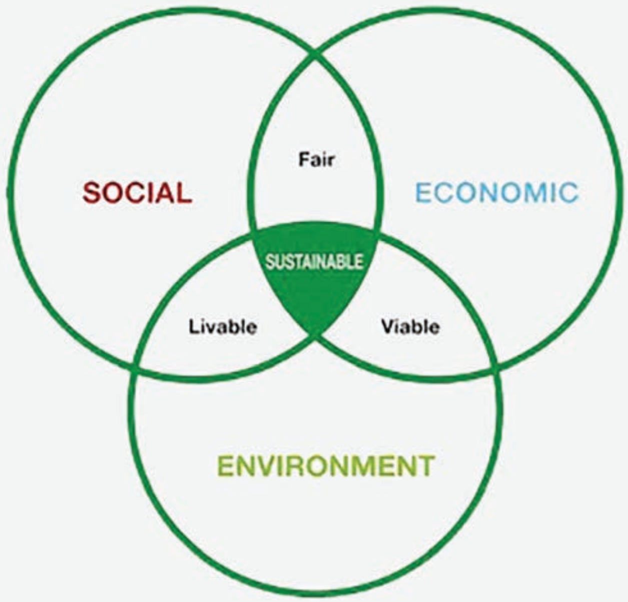

Figure 1.1 Schematic view of sustainability.

One factor that complicates sustainable development of livestock production is their increased complexity due to industrialization, specialization and globalization (de Boer, 2011). Nowadays, different stages of livestock production chains are disconnected and can occur in different areas in the world (de Boer, 2011). Therefore, improving the sustainability performance of global livestock production (including feed production) requires an evaluation of the environmental, economic, and social performance of entire livestock supply chains. Evaluation of the environmental, economic, and social performance of livestock and feed production from a chain perspective could lead to identification of problem areas and options for improving the sustainability performance of chains.

Livestock and feed production in Latin America

Latin America (LA) stands out as a main livestock and feed producing region. Several livestock types are found throughout the region, but beef cattle are particularly important where pasture resources are abundant (FAO, 2012b). Moreover, LA is the leading producer of soybean, one of the main raw materials for the global feed industry (MVO, 2011). The LA beef and soybean sector is to a large extent oriented on exports to markets outside LA. In 2009, the region produced 40% of world's beef exports (FAO, 2012a). Moreover, in 2011, LA produced 60% of world's soybean exports. Of total soybean production 33% is exported directly, while 62% is first crushed inside LA (MVO, 2011).

Beef

Beef cattle production is one of the most important agricultural activities in LA and farms are characterized by operating a large number of animals and extensive pasture. The typical beef production system in LA is grass finished beef. Grass finished beef (sometimes marketed as grass-fed beef) comes from cattle raised on grass their entire lives. Productivity of LA beef cattle is high compared with that of most other developing countries, but is low in comparison with levels achieved in developed countries (FAO, 2012a). Low product prices have made it unprofitable to develop the more costly high-input systems (e.g., feedlot) in LA (FAO, 2012a). Improvements in pasture technology and management have begun to increase productivity during the last two decades; however, in many areas of LA it has been more profitable to expand the area ranched rather than to increase output per hectare (FAO, 2012a). Integrated crop-livestock systems have been adopted recently in LA, using different species sequences, implementation details, and rotation phases between crop and beef farming.

Trade in beef products has historically been an important source of foreign exchange for many LA countries. Led by Brazil, LA has rapidly emerged as the world's largest exporter of beef. The incentives provided by export markets of beef significantly affected the rate and degree of beef development (FAO, 2012a). For instance, Brazil boasts the largest market economy in LA and continues to grow (FAO, 2012a). Brazil exports beef and beef products to over 150 countries, with Russia and the European Union (EU) serving as the main markets. Beef consumption in Argentina is very high as well. Argentina's beef production for 2014 is projected at 2.9 million tons, the highest since 2009.

Soybean

Soybean is the most important crop worldwide for producing oil and feed protein. Approximately 87% of the global soybean production is crushed into roughly 80% meal and 20% oil. Soybean meal is the most important protein source for farm animals. It represents two-thirds of the total world output of protein feedstuffs, including all the other major oil meals and fish meal (MVO, 2011). The global livestock feed industry depends on soybean meal to produce high performance diets (FAO, 2012a). There are two main soybean production systems in LA: the conventional production system which produces genetically modified (GM) or non-genetically modified soybeans (non-GM), and the organic production system (MVO, 2011). GM soybean is a soybean (Glycine max), which has had DNA introduced into it using genetic engineering techniques (Hudson et al., 2013). Roundup Ready soybeans are a series of genetically engineered varieties of glyphosate-resistant soybeans (Azadi and Ho, 2010). Non-GM soybeans are varieties that have not been genetically altered through bioengineering technology. Organic soybeans are produced using pest management and fertilization methods that do not include synthetic compounds (Azadi and Ho, 2010). The production growth in LA was also driven by the increasing use of GM soybeans, whereas organic soybeans have the smallest share of soybean production in LA. The production of soybeans in Argentina is almost entirely GM, and also the cultivation of GM soybeans in Brazil has recently significantly risen up to 75% of the total soy area in 2010. The LA soybean sector is to a large extent oriented on exports to markets outside LA. Brazil and Argentina are the two largest producers and exporters of soybean in LA.

Knowledge gap

Most studies that evaluated soybean and beef production, mainly focused on environmental issues (Pelletier et al., 2008; Beauchemin et al., 2010; Knudsen et al., 2010; Pelletier et al., 2010; Beauchemin et al., 2011; van Middelaar et al., 2013; Dick et al., 2015 a, b). The advantages of such studies are that they provide a great understanding of the environmental impacts, which can help to define improvement strategies. Implementing improvement strategies, however, might affect not only the environment but also other sustainability issues, such as profitability and employment. As a result, not only environmental issues, but also economic and social issues need to be addressed. Moreover, LA countries, particularly Brazil and Argentina, have strong trade relationships with the whole world. These trade relationships create a common interest for stakeholders to cooperate to improve the sustainability of the soybean and beef chains. So far, the number of studies that made a chain level analysis of soybean and beef is limited (Knudsen et al., 2010; Gaitán-Cremaschi et al., 2015). To evaluate the sustainability of soybean and beef production in LA, some aspects should be taken into consideration, as explained below.

First, evaluating sustainability requires defining sustainability issues. In many studies dealing with sustainability, no prescribed procedure is applied to select the set of sustainability issues. Moreover, defining sustainability issues from a whole chain perspective for the soybean and beef production is important, as issues of sustainability emerge at various stages along the production chain (Yakovleva, 2007). An inventory of relevant sustainability issues (i.e., environmental, economic, and social) of soybean and beef production in LA, specifically at chain level, is lacking.

Second, several studies have assessed the potential of various strategies (such as feeding strategies) to reduce the environmental impact of livestock production in different countries (Beauchemin et al., 2010; Wall et al., 2010; Bannink et al., 2011; Bell et al., 2011; Dick et al., 2015a; Ruviaro et al., 2015; van Middelaar et al., 2014a; van Middelaar et al., 2014b; de Vries et al., 2015). However, adoption of alternative feeding strategies might negatively affect farm profitability (Hristov et al., 2013). An assessment of the environmental and economic performance of different feeding strategies for beef production in LA is currently lacking in the literature. The results of such a study are useful for policy makers who wish to design policies to reduce the environmental impact of beef production with only a minimal negative effect on competitiveness.

Third, most studies that focused on evaluation of different soybean production (i.e., GM, non-GM, and organic), focused on the environmental dimension rather than the other sustainability dimensions (Pelletier et al., 2008; Knudsen et al., 2010). Furthermore, most of the studies were based on deterministic input parameters (Pelletier et al., 2008; Knudsen et al., 2010). Studies based on deterministic input parameters do not adequately account for the uncertainty of key variables and ignore the differences in variation of the performance indicators used to compare production systems (Gebrezgabher et al., 2012; Gocsik et al., 2013). A Monte Carlo approach provides insight into the range of outcomes, and therefore provides more complete information to policy makers regarding the performance of various soybean production systems.

Fourth, sustainability assessments are hampered by limited data availability on sustainability issues. Elicitation of expert opinion could provide a solution in such cases and Multi Criteria Assessment (MCA) is a method that allows for using such data in sustainability assessments (van Calker et al., 2005; Reig et al., 2010; Michalopoulos et al., 2013). However, the validity of expert data has not been assessed so far. Also, the robustness of the outcomes of the MCA method to uncertainty about scores elicited from the experts and the weights used for aggregating scores is still lacking.

Objectives of the research

The overall objective of the thesis is to analyze the sustainability performance of soybean and beef production chains in Latin America. Four sub-objectives were defined:

1. To identify a set of sustainability issues that covers the environmental, economic and social dimensions for the soybean and beef chains in the LA–EU context;

2. To assess the environmental and economic performance of four different feeding strategies for beef production in southern Brazil;

3. To evaluate the environmental, economic and social performance of different soybean production systems, namely genetically modified, non-genetically modified, and organic production systems;

4. To evaluate the validity of scores from expert elicitation and the robustness of the multi criteria assessment (MCA) method for sustainability assessments.

Outline of the thesis

The structure of the work and chapters included in the thesis are shown in Figure 1.2. The thesis consists of a general introduction (Chapter 1), four research chapters (Chapter 2-5) and a general discussion (Chapter 6).

Chapter 2 defines a set of sustainability issues that covers the environmental, economic and social dimensions for the soybean and beef production chains in the LA–European context.

Chapter 3 evaluates the environmental and economic performance of alternative feeding strategies for Brazilian beef production.

Chapter 4 evaluates the environmental, economic, and social performance of soybean production systems in Brazil. The stochastic approach gives insight into the range of outcomes and provides more complete information about the performance of various soybean production systems.

Chapter 5 evaluates the validity of scores from expert elicitation and the robustness of the MCA method for sustainability assessments. The study illustrates the approach for the LA soybean production chain.

Chapter 6 discusses the results of the thesis, data issues encountered, implications of the results for policy makers and business stakeholders, and outlines directions for future research. Finally an overview of main conclusions from this thesis is presented.

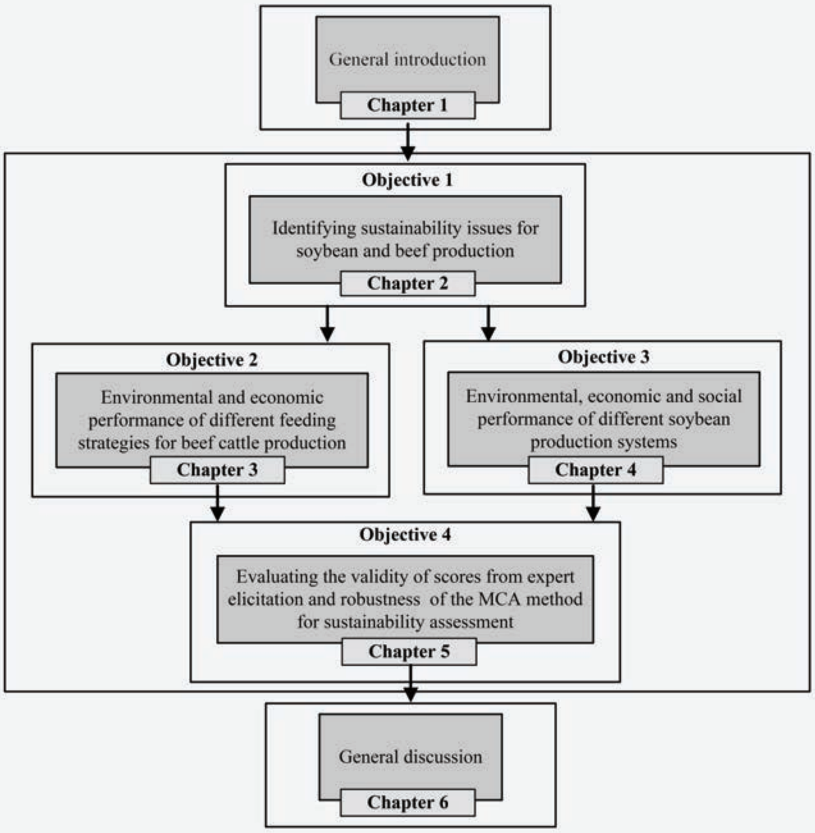

Figure 1.2 Structure of the thesis.

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1

Chapter

2

Identifying Sustainability Issues for Soymeal and Beef Production Chains

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Abstract

The expansion of livestock production throughout the world has led to increased demand for high protein animal feed. This expansion has created economic benefits for livestock farmers and other actors in the chain, but also resulted in environmental and social side effects. This study aims to identify a set of sustainability issues that cover the environmental, economic and social dimensions of soymeal and beef production chains. The method applied combines the results of multiple studies, including a literature review and stakeholder surveys. Stakeholder surveys were conducted for three different interest groups (business, consumers, and other stakeholders) and two geographical regions (Latin America and the European Union). Our results reveal that the selection of issues in most sustainability assessment studies is a relatively arbitrary decision, while the literature also states that identifying issues is an important step in a sustainability assessment. Defining sustainability issues from a whole chain perspective is important, as issues of sustainability emerge at various stages along the production chain, and are found to vary across stakeholders' interests. Business stakeholders, for example, perceived economic issues to be more important, whereas the majority of consumer stakeholders and other stakeholders perceived social and environmental issues, respectively, to be more important. Different education levels, knowledge, and living patterns in various geographical regions can affect the stakeholders' perceptions. The combination of a heterogeneous group of stakeholders and the consideration of multiple chain stages constitutes a useful approach to identify sustainability issues along food chains.

Introduction

The rapid expansion of livestock production has led to increased demand for high protein feed ingredients, such as soymeal (Cavalett and Ortega 2009). This expansion has created economic benefits for livestock farmers and feed producers. However, it has also resulted in numerable side effects, such as the loss of biodiversity, infringements of labor rights, soil and water contamination, and global warming (Cavalett and Ortega 2009; Cederberg et al. 2009; Panichelli et al. 2009; Prudêncio da Silvaa et al. 2010). More attention is now being given to these side effects and this has led to increased interest in the concept of sustainability (Grau and Aide 2008; Lehuger et al. 2009; FAO 2012). Latin American (LA) countries, particularly Brazil and Argentina, are important producers and exporters of soymeal and beef in the world (Sterman and De Felíciob, 2010; USDA-FAS 2010) and have strong trade relationships with the European Union (EU). These trade relationships create a common interest for stakeholders to cooperate to improve the sustainability of the soymeal and beef chains (Euclides 2004; López 2007; Cederberg et al. 2009). Stakeholders in the soymeal and beef chains include farmers, processors, retailers, traders, and consumers. In order to assess sustainability performance along the soymeal and beef chains, we first need to define the relevant issues for the three dimensions of sustainability that are currently acknowledged: environmental, economic, and social (EES) sustainability. Several studies have evaluated EES performance of food products (Hanegraaf et al. 1998; de Boer and Cornelissen 2001; Volk et al. 2004; Mollenhorst et al. 2006; Bokkers and de Boer 2009; Dolman et al. 2012). A few studies focused on defining the issues for sustainability assessment (Mollenhorst and de Boer 2004; van Calker et al. 2005). These studies, however, were restricted to the farm level and did not consider the entire chain. In many studies dealing with sustainability, no prescribed procedure is applied to select the set of sustainability issues. As a result, the selection process of issues is subject to relatively arbitrary decisions, and studies dealing with a similar subject matter or similar geographical entities may use widely different issues. According to the authors' knowledge, defining sustainability issues from a whole chain perspective for the soymeal and beef chains has not yet been reported. A chain perspective is important, as issues of sustainability emerge at various stages along the production chain. This study aims to identify a set of sustainability issues that covers the EES dimensions for the soymeal and beef production chains in the LA–EU context. This study is a part of an EU research project (SALSA)[1]. SALSA is a collaborative project funded by the European Commission under the theme FP7 KBBE 2010–4.

Material and methods

The research design for this study was adapted from different lines of research conducted within the SALSA project. It is a compilation of multiple studies, including a literature review and various stakeholder surveys.

Literature review

A literature review was conducted to define a list of EES issues. The review focused on studies from peer-reviewed scientific journals, and scientific reports from organizations such as FAO (Food and Agriculture Organization) and OECD (Organization for Economic Co-operation and Development). The reviewed literature was categorized as either conceptual or empirical. Conceptual studies focus on the development of a common language, guidelines and frameworks for sustainability assessment, whereas empirical studies derive knowledge from analyzing actual observations or measurements. The databases Scopus and Web of Science and the search engine Google Scholar were used. The search for publications was mainly through structured key words, such as sustainable agriculture, sustainable food supply chain, sustainable soymeal production, sustainable beef production and sustainability issues (attributes, criteria, themes and categories) and frameworks. The literature review was restricted to studies concerning food and agriculture, and which addressed at least two dimensions of sustainability. To facilitate the review process, the Sustainability Assessment of Food and Agriculture systems (SAFA) guidelines

1 Knowledge-based Sustainable vAlue-added food chains: innovative tooLs for monitoring ethical, environmental and Socio-economic impActs and implementing EU-Latin America shared strategies.

were selected as a benchmark. The SAFA guidelines, commissioned by the FAO, define the essential components of sustainable food and agriculture systems along several dimensions. They include EES issues throughout the chain, covering primary production in agriculture, manufacturing, and up to the point of sale to the consumer (FAO 2012). To compare each relevant study with the benchmark, some crucial points should be taken into consideration. First, the term ‘issue’, which is used in this paper, is not a consistent term in the literature. Different studies used different terms such as ‘attitude’, ‘principles’, ‘(sub) themes’ and ‘criteria’. Furthermore, categorization of issues was not similar in all studies. For instance, some studies categorized food quality as an economic issue, while other studies categorized it as a social issue. For this reason, the same categories used in the benchmark study were applied in this study.

Stakeholder survey

Stakeholders in this study are groups that affect, or are affected by, the current and future development of soymeal and beef production. Several stakeholder surveys were performed to explore the perceptions of stakeholders about sustainability issues in the soymeal and beef supply chains. The survey was conducted for three stakeholder groups: business, consumer and other stakeholders. Stakeholders’ surveys were carried out through face-to-face interview (for business stakeholders) and online survey (for consumers and other stakeholders). The methods of survey were selected based on the different characteristics of the stakeholders. For instance, business stakeholders were assumed to largely ignore online questionnaires or to not answer certain questions at all; therefore, they were persuaded to provide answers in face-to-face interviews. Although the survey methods were different across stakeholder groups, content and wording of interview and online survey were very similar. Also, questions in both methods were not ambiguous and were directly relevant to the objectives of the study. Therefore, it was expected that the differences in the methods would not bias the results. Text of interview and online questionnaires are presented in Appendix 2.

Business stakeholders

The business stakeholders' survey was conducted by face-to-face interview, in May 2012, by using semi-structured open-ended questions. Stakeholders originated from Belgium, Brazil, Hungary, Italy, Mexico, the Netherlands and the UK. The countries selected for business stakeholders were representative for soymeal and beef chain in LA and EU. Regarding the soymeal chain, stakeholders included soy farmers and processors, delegates of feed companies, traders, retailers, and consultants. Stakeholders in the beef supply chain were livestock farmers, breeders, delegates of slaughterhouses, meat processors, traders, and retailers. Business stakeholders were either members of the SALSA project or from the personal networks of SALSA members. All interviewed stakeholders were involved in the soymeal and/or beef chains linking LA soymeal and livestock production to EU feed and food industries. Due to the lack of export of Mexican beef, the focus in Mexican interviews was on the domestic market. A checklist of main objectives of the survey was made available to interviewers for guidance during the interviews to explore the concerns, preferences, and needs of business stakeholders. Interviewees discussed the important issues in the soymeal and beef chains based on their perceptions. Furthermore, the interviewees were given the opportunity to suggest new issues. All interviewees were asked to engage in the interviews as experts in the soymeal and/or beef supply chains. In total, there were 29 interviewees for the soymeal chain and 17 interviewees for the beef chain (Table 2.1). Since some of the business stakeholders were multinational, the LA and EU stakeholders were not separated in Table 2.1. Due to the restricted number of business stakeholders in the soymeal and beef chains (i.e., the soy and beef business in LA-EU chains is mostly monopolized by big companies), the sample size was relatively limited. Furthermore, the nature of face-to-face interview by itself limits sample numbers.

Consumer stakeholders

The consumer survey was carried out from April 2012 to June 2012 in Brazil, Italy, Mexico, and the Netherlands. The selected EU countries altogether are responsible for the majority of beef and soymeal imports and consumption in the EU (Kirwan et al., 2005). Moreover, Brazil and Mexico were evaluated for their internal beef consumers. The project partners in each country were responsible for the sampling of the consumers in their related country. They had the responsibility to use a sampling strategy aiming at receiving 125 valid questionnaires representing the population of their targeted country in terms of education, age, sex, and income. An invitation to complete an online questionnaire was distributed by email to the personal networks of SALSA members. The questions were structured as closed-end questions and referred to environmental issues (e.g., climate change, water pollution, soil degradation, land use change, and biodiversity loss), economic issues (e.g., farm profitability and impact on local economy[2]) and social issues (e.g., labor rights and food safety) in the beef supply chain. The description of the issues is presented in Appendix 2 (Table A 2.1). Respondents were asked to assign importance to each issue, using a seven-point Likert scale, where 1 represented 'completely unimportant' and 7 represented 'highly important'. The survey included questions regarding the consumers' motives for choosing beef. The consumer survey was carried out for beef only, as soymeal is not directly bought by consumers and is only used as animal feed. Only respondents who stated that they buy and/or consume beef were eligible to take part in the survey. A total number of 874 questionnaires were successfully completed and returned (Table 2.1). The online questionnaires are presented in Appendix 2

Other stakeholders

The other stakeholder survey was carried out from January 2012 to March 2012 for both the soymeal and beef chains. This survey was conducted using email and contained the same questions regarding sustainability issues as the consumer survey (The online questionnaires are presented in Appendix 2). Respondents were asked to assign importance to EES issues in the soymeal and beef supply chains, a seven-point

2 Local economy in this study refers to local value added along the chain.

Likert scale, where 1 represented 'completely unimportant' and 7 represented 'highly important'. Stakeholders in this group included delegates from environmental and social organizations, universities, and agricultural policy makers in Argentina, Brazil, Mexico, Belgium, Germany, Hungary, Italy and the Netherlands. Other stakeholders' countries were selected based on availability of possible stakeholders representing public institutions as well as civil society organizations, NGOs and institutions developing sustainability standards. Local partners of the SALSA project provided a list of these stakeholders. The stakeholders were working for environmental, social, consumer and animal welfare NGOs, agricultural, environmental and health ministries, institutions developing environmental and/or social standards, fair trade organizations, farmers' and organic farmers' associations, and research centers. Regarding other stakeholders, a big sample size was selected; however, not all of them were willing to answer the questionnaires. A total number of 48 questionnaires were successfully completed and returned (Table 2.1).

Table 2.1 Number of responses for the stakeholder surveys in the soymeal and beef chains.

Stakeholder group	**n**[1]	**Soymeal**			**Beef**		
		Total	LA	EU	Total	LA	EU
Business	46	29[2]	-	-	17[2]	-	-
Consumers	874	-	-	-	874	679	195
Other	48	25	13	12	23	13	10
Total	968	54	13	12	914	692	205

1. Valid number of responses.
2. Soymeal and beef stakeholders representing: feed industry (n=6), production (n=15), processing (n=12), international trade (n=4), retail (n=5) and service (n=4); not separated between LA and EU.

To explore the relative importance of the sustainability issues for consumers and other stakeholders, the frequency distribution of the scores for each issue was used. Since the objective of the paper is to assess which sustainability issues are important, the analyses focused on the frequencies of the scores 6 (important) and 7 (highly important). A Chi-square test of homogeneity of responses was used to make statistical inferences about the variation in responses among stakeholder groups (Petit & van der Werf 2003). The test was carried out to evaluate whether the distribution of all scores (1−7) differed significantly for stakeholder groups across regions.

Results

Outcome of the literature review

The literature review shows the contributions of different studies in defining sustainability issues. The results of the literature review are presented in Table 2.2 Most studies focused at farm level rather than chain level, except for Yakovleva (2007) and Vasileiou and Morris (2006)[3]. The majority of empirical studies focused on environmental issues, with less attention to economic and social issues. Some specific environmental issues, such as biodiversity, were considered by only a few empirical studies, due to the lack of specific and predefined assessment methods. Similarly, animal welfare was addressed by only a few conceptual studies and almost none of the empirical studies addressed welfare along the chain.

For the economic dimension, profitability is the primary goal of all businesses, and without profitability a business will not survive in the long run (FAO 2012). The literature review confirmed that profitability is considered by most of the studies as the main economic issue (Table 2.2). Most studies focused on profitability, rather than on other economic issues, such as vulnerability. For the social dimension, most of the conceptual studies covered the complete set of issues. Some issues, such as equity and cultural diversity, were addressed by only a few empirical studies, likely due to the lack of predefined assessment methods.

Outcomes of the interviews with business stakeholders

An overview of the perceptions of business stakeholders about sustainability issues is

3 These two studies were conducted for the UK chain level and not the international chain level.

Table 2.2 Key sustainability issues addressed by the reviewed literature.

Benchmark: **SAFA guideline**	**Description**
Environmental	
Atmosphere	Air pollution, climate change
Water	Water quality, water quantity
Land	Soil organic matter, physical structure, chemical quality, land degradation and desertification
Biodiversity	Habitat diversity and connectivity, Ecosystem integrity, Wild biodiversity, Agricultural biodiversity, Threatened species
Material and energy	Non-renewable resources, Energy supply, Eco-efficiency, Waste disposal
Animal welfare	Freedom from stress, Species-appropriate conditions
Economic	
Investment	Internal investment, Community investment, Long-ranging investment
Vulnerability	Stability of supply, Stability of marketing, Liquidity and insurance, Employment, Stability of production
Product safety and quality	Product information, Traceability, Food safety, Food quality
Local economy	Value creation, Local procurement
Social	
Decent livelihood	Wage level, Capacity building
Labor rights	Employment, Forced labor, Child labor, Freedom of association and bargaining, Working hours
Equity	Non-discrimination, Gender equality, Support to vulnerable people
Human health and safety	Physical and psycho-social health, Health resources, Food security
Cultural diversity	Indigenous knowledge, Food sovereignty

1. Conceptual studies: 1. Smith and McDonald (1998), 2. DEFRA (2002), 3. van Cauwenbergh (2007), 4. UNEP/SETAC (2009), 5. Eurostat (2009), 6. EEA (2005), 7. OECD (2008), 8. GRI (2011), 9.UNECE/ Eurostat/ OECD (2013).

2. Empirical studies: 10. Hanegraaf et al. (1998), 11. de Boer and Cornelissen (2001), 12. Mollenhorst and de Boer (2004), 13. Van Calker et al. (2005), 14. Vasileiou and Morris (2006), 15. Yakovleva (2007), 16.Muel et al. (2008), 17. Sydorovych and Wossink (2008), 18. Bokker and de Boer (2009), 19. Dolman et al. (2012), 20. Michalopoulos et al. (2013).

	Conceptual studies[1]	Empirical studies [2]
	1, 2, 3, 4, 5, 6, 7, 8, 9	10, 12, 14, 16, 17, 18, 19, 20
	1,2, 3, 4, 5, 6, 7, 8, 9	10, 11, 12, 13, 14, 15, 16, 17,18, 19, 20
	1,3, 4, 5, 6, 7, 9	10, 11, 12, 13, 14, 16, 17, 18, 19, 20
	1,3, 4, 5, 6, 7, 8, 9	10, 13, 16, 17, 20
	1,2, 3, 4, 5, 6, 8, 9	10, 11,12, 14, 15, 16, 17, 18, 19, 20
	2	11, 12, 13, 14, 16, 17, 18, 19
	2, 8, 9	
	1,3, 5, 7, 8, 9	11, 12, 13, 14, 15, 16, 17, 18, 19, 20
	1, 2, 3, 8, 9	11, 12, 13, 14, 17, 18, 19, 20
	2, 3, 5, 8	14, 17, 16, 20
	1, 2, 3, 4, 5, 7, 8, 9	12, 14, 15, 16, 17, 19, 20
	4, 5, 7, 8, 9	10, 11, 13, 15, 16, 17, 18, 19
	3, 4, 5, 7, 8, 9	15
	1, 2, 3, 4, 5, 7, 8, 9	11, 12, 13, 17, 18, 20
	1, 2, 3, 4, 7, 8	

presented in Table 2.3. The × shows the issues that were perceived by business stakeholders as important issues. For the environmental dimension, LA business stakeholders perceived natural land use change (e.g., deforestation) and the loss of biodiversity as important issues in the soymeal chain, while water quantity was regarded as an important issue in the beef chain. In contrast, EU business stakeholders gave utmost attention and importance to animal welfare in the beef chain. Brand owners and retailers, especially considered animal welfare as a critical issue in their ethical trading strategy. EU business stakeholders mentioned that, due to media and non-governmental organizations' campaigns, consumers are more aware of animal welfare and link it to the brand and the meat company. Therefore, animal welfare is very important for EU business stakeholders. Most of the LA producers indicated that considering animal welfare is part of their daily management, as it directly affects productivity (Table 2.3).

Regarding the economic dimension, both LA and EU business stakeholders identified long-run profit prospects as the most important economic issue in the soymeal and beef chains. Adding value to the local economy was considered by LA business stakeholders as an important issue for the soymeal chain. Hiring local staff and purchasing inputs locally were mentioned by several LA respondents as important aspects of local economic development. Brazilian family farmers indicated that they have limited opportunities for local value creation in the global soymeal market. These farmers mostly sell their harvest through middlemen, while most value is added by the multinational integrated crushing and trading companies and the European feed companies (Table 2.3).

Considering the social dimension, feed companies stressed the importance of feed safety. Most feed companies and retailers have contracts for the segregation of products, in order to be able to trace back different flows of soymeal (GM, non-GM, certified and non-certified). Both LA and EU business stakeholders in the beef chain perceived food safety and traceability as important issues. Several food safety crises in Europe have resulted in more stringent regulations and more vigilant consumers. In this context, nearly all interviewed business stakeholders stated that they work with national or international standards, certification schemes, and labels. These standards, schemes, and labels guarantee good husbandry practices and hygienic slaughter and transport conditions (Table 2.3).

Table 2.3 Perception of business stakeholders on the importance of sustainability issues in the soymeal and beef chains.

Dimension & Issues	**Soymeal**		**Beef**	
	LA	EU	LA	EU
Environmental				
Atmosphere				
Water quality				
Water quantity			×[1]	
Soil quality				
Agricultural land use change				
Natural land use change	×			
Biodiversity	×			
Material				
Energy				
Waste disposal				
Animal welfare				×
Suggested environmental issue				
Economic				
Profitability	×	×	×	×
Local economy	×			
National economy				
Social				
Labor rights				
Food safety	×			×
Working conditions	×	×	×	×
Decent livelihood		×		×
Suggested social issues				

1. Issues that were perceived as important by business stakeholders.

LA business stakeholders, in both the soymeal and beef chains, stated that offering decent jobs and working conditions can contribute to local economic development. EU business stakeholders shared a common view that working conditions should be respected within the companies. Social activists and human rights organizations are increasingly putting pressure on companies to respect the rights and decent livelihoods of the workforce in LA countries. This may partially account for the concern for the working conditions and decent livelihoods of their workforce, which was expressed by LA business stakeholders.

In addition to the EES issues, soymeal traders also mentioned concerns about certification. They considered the market as the biggest risk for certified products, as certification is guided by the market. If certification is demanded, the companies will comply with all necessary legislation. The fluctuation of demand, however, makes farmers reluctant to adopt certification. Soymeal producers stated that they are not interested in certification and sustainable practices, unless there is a long-term guarantee for certified soymeal. Furthermore, they stated that certification is linked more to issues in the social and environmental dimensions of sustainability, rather than the economic dimension.

Outcomes of the consumers' survey

Frequency analysis of the consumer survey is presented in Table 2.4. Concerning environmental issues, most of the LA and EU respondents perceived water quality as (highly) important. Regarding economic issues, the national economy was perceived as (highly) important by 68% of LA respondents, whereas EU respondents focused on the local (i.e., LA) economy (59%). With respect to social issues, most of the LA and EU respondents perceived food safety as (highly) important. Relatively fewer respondents perceived energy as (highly) important for both LA (49%) and EU (45%). Results in Table 2.4 show that most of the sustainability issues were perceived to be (highly) important by the majority of respondents, for both LA and EU. Chi-square test results, however, showed that the difference in underlying distributions of total scores (1–7) was statistically significant for LA and EU respondents for most issues

(P<0.05), with the exception of local economy, labor rights and food safety (P≥0.05). This implies that LA and EU respondents had different perceptions concerning the importance of most sustainability issues.

Table 2.4 Frequency (%) of perceived importance of sustainability issues by consumers.

	Beef		
	LA (n[1]=679)	EU (n[1]=195)	Chi square
Dimensions & Issues	Importance [2] %	Importance %	P value[3]
Environmental			
Atmosphere	57	54	0.011
Water quality	**73**[4]	**64**	0.000
Water quantity	65	52	0.000
Soil quality	71	55	0.000
Agricultural land use change	61	51	0.000
Natural land use change	69	61	0.000
Biodiversity	70	60	0.000
Material	61	52	0.001
Energy	49	45	0.001
Waste disposal	67	62	0.001
Economic			
Profitability	62	55	0.018
Local economy	64	**59**	0.321
National economy	**68**	45	0.000
Social			
Labor rights	74	71	0.357
Food safety	**82**	**79**	0.052

1. Valid number of responses.
2. Percentage of respondents who scored the issue as important or highly important (score 6 and 7).
3. If P<0.05 the result is statistically significant.
4. Bold numbers indicate the highest frequencies for each dimension.

Outcomes of the other stakeholders' survey

Frequency analysis of the survey of other stakeholders is presented in Table 2.5. Concerning environmental issues in the soymeal chain, most of the LA respondents perceived biodiversity as (highly) important, whereas most of the EU respondents perceived soil quality as (highly) important. For the beef chain, a high percentage of the LA respondents perceived water quality as (highly) important, while the majority of the EU respondents perceived both soil quality and biodiversity as (highly) important. Regarding economic issues in the soymeal chain, local economy was perceived by most of both LA and EU respondents as (highly) important, and most of LA respondents also perceived national economy as (highly) important. For the beef chain, a high percentage of the LA respondents perceived profitability as (highly) important, whereas half of the EU respondents perceived all three economic issues (i.e., profitability, local economy and national economy) to be important or highly important. With respect to social issues in the soymeal chain, a high percentage of both LA and EU respondents perceived labor rights as (highly) important, and the majority of EU respondents also perceived food safety as (highly) important. For the beef chain, a high percentage of both LA and EU respondents perceived food safety as (highly) important, and most of the EU respondents also perceived labor rights as (highly) important.

Relatively fewer respondents in both LA (38%) and EU (50%) perceived waste disposal as (highly) important for the soymeal chain. For the beef chain, very few LA respondents (15%) perceived material as (highly) important. Relatively fewer EU respondents (30%) perceived agricultural land use change as (highly) important for the beef chain. The Chi-square test showed that no significant differences existed in the distribution of scores (1–7) between LA and EU respondents ($P \geq 0.05$), for both the soymeal and beef chains. This implies that for the group of other stakeholders, the sustainability issues had similar importance for LA and EU stakeholders (see Table 2.5).

Table 2.5 Frequency (%) of perceived importance of sustainability issues by other stakeholders.

	Soymeal			Beef		
	LA (n=13)	EU (n=12)	Chi square	LA (n=13)	EU (n=10)	Chi square
Dimension & Issues	Importance[1] %	Importance[1] %	P value[2]	Importance[1] %	Importance[1] %	P value[2]
Environmental						
Atmosphere	46	75	0.105	46	70	0.504
Water quality	69	67	0.124	**62**[3]	60	0.316
Water quantity	54	75	0.495	46	60	0.499
Soil quality	85	**100**	0.374	54	**80**	0.687
Agricultural land use change	46	58	0.639	46	30	0.291
Natural land use change	77	58	0.250	54	70	0.859
Biodiversity	**92**	75	0.664	54	**80**	0.206
Material	46	83	0.195	15	50	0.214
Energy	76	73	0.630	23	50	0.596
Waste disposal	38	50	0.364	50	60	0.418
Economic						
Profitability	46	75	0.293	**54**	**50**	0.605
Local economy	**62**	**83**	0.477	39	**50**	0.753
National economy	**62**	67	0.236	46	**50**	0.125
Social						
Labor rights	**69**	**75**	0.402	31	**60**	0.396
Food safety	54	**75**	0.854	**54**	**60**	0.392

1. Percentage of respondents who scored the issue as important or highly important (score 6 and 7).
2. If $P<0.05$, the result is statistically significant.
3. Bold numbers indicate the highest frequencies for each dimension.

Discussion and conclusions

The literature review revealed that research has mainly focused on measuring sustainability issues in the food and agriculture sector, with only a few studies focused on defining issues (Mollenhorst and de Boer 2004; van Calker et al. 2005). Regardless of whether the studies addressed either the measurement or definition of sustainability issues, very few studies considered sustainability at the chain level. The literature review showed that not all issues are relevant and applicable to all sectors. Relevance of sustainability issues across studies varies because of differences between agricultural sectors (e.g., the issue of animal welfare is specific for livestock) and because sustainability issues emerge at various levels (i.e., farm level versus chain level). Since issues can emerge at different levels, it is important to include all stakeholders along the chain in the process of identifying and defining issues. For studies that measure sustainability performance in agricultural systems, the choice of issues is also determined by the ability to define quantifiable methods and measurable indicators for each issue. At chain level, this is particularly difficult for issues such as biodiversity.

The literature review provided a general perspective about sustainability issues in food and agriculture. The surveys of different stakeholder groups enhanced these findings and gave insight into the EES issues that are particularly important for the soymeal and beef chains. The results of the surveys suggest that a mix of EES issues was perceived to be important by the majority of stakeholders in the soymeal and beef chains. The following issues were perceived by stakeholders to be important for the soymeal chain: water quality, biodiversity, soil quality, local economy, national economy, food safety, labor rights and working conditions. The following issues were perceived by most stakeholders to be important for the beef chain: water quality, biodiversity, profitability, local economy, national economy and food safety. The results of this study cannot easily be compared with other literature, as the specific applications of other studies differ from this study. For instance, Sydorovych and Wossink (2008) defined sustainability issues for any land-related agricultural production, and van Calker et al. (2005) defined sustainability issues specific to dairy farms, while our study aimed to define sustainability issues specifically for soymeal and beef chains. Although individual issues vary for the three studies, some similarities between issues were observed. All three studies identified profitability as the most important issue for economic sustainability, safety of products and working conditions for social sustainability, and water quality and biodiversity for environmental sustainability. These issues, however, are not necessarily independent; biodiversity, for example, is affected by emission of greenhouse gases and eutrophication of water (Mollenhorst and de Boer 2004; van Calker et al. 2005).

Grouping stakeholders in various meaningful ways (e.g., geographical features and common interests) is helpful to observe contrasts in opinions of different groups (Vasileiou and Morris 2006). The geographical feature was found to be an important factor affecting the results of our survey. In the consumer survey, significant differences in the perceived importance of sustainability issues were found between LA and EU respondents. Many factors can potentially cause such differences, such as different education levels and different living patterns.

A comparison of the three different groups of stakeholders, grouped by common interests (business, consumer and other stakeholders) and ignoring regional differences revealed that economic issues tend to take precedence over social and environmental issues for stakeholders in the business group. These stakeholders indicated that economic issues are their main interest, while social and environmental issues were mainly regarded as requirements to be satisfied, as they were often set by compulsory regulations or voluntary collaboration; this was mentioned by Vasileiou and Morris (2006) as well. In contrast to business stakeholders, most respondents in the consumer survey appeared to place relatively more importance on social issues. The stakeholders classified as other stakeholders were different again, this group perceived environmental issues to be more important. These contrasts between stakeholders from different interest groups show that stakeholders in a particular group (e.g., stakeholders in the soymeal chain) do not necessarily share the same concerns or have unified opinions or priorities.

It is difficult to obtain a representative sample of stakeholders, due to the large number of stakeholders involved in the LA-EU soymeal and beef chains. This may restrict the generalization of the results. The exploratory nature of the interviews with business stakeholders allowed participants to touch upon a variety of issues regarding sustainability. Due to the level of expertise of the respondents and the broad range of organizations considered, the patterns identified in the interviews provided a meaningful overview of the perceptions and awareness of sustainability issues for business stakeholders. However, the non-probabilistic nature of the sample of consumers, along with the sample bias related to the online questionnaire, imply that the results of this survey cannot be generalized. The respondents were consumers from households with internet access, well-educated and relatively affluent. A similar situation applies for the survey carried out among other stakeholders. The small sample of stakeholders might imply that results cannot necessarily be generalized to other stakeholders or communities. Furthermore, the sampling technique in this survey might have affected the sample representativeness. Since the survey was performed using email, the questionnaires were not accessible to everyone and only stakeholders from the networks of the project members could participate in the survey.

This survey was applied to soymeal and beef chains and the results are useful for defining a set of appropriate sustainability issues, which can then be used to evaluate the performance of these two chains. The approach used in this study can be applied to other food and agricultural sectors and other countries as well. The EES issues mainly focus on the performance of issues; there is little attention given to the transition to sustainability. To address the transition to sustainability, especially when the value chain and stakeholders' relationships are considered, the focus should be on the relationships and interdependencies of identifiable sustainability dimensions (Kemp and Parto 2005). This became apparent from the results of business stakeholders survey (business stakeholder's concern regarding standards and certification schemes). The relationships among EES dimensions can be facilitated through governance issues. Governance issues could be added to EES issues in future studies, as they play an important role in improving the performance of sustainability.

2

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Appendix 2

Table A 2.1 Description of issues.

Issues	Description
Climate change	Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity (IPCC 2006).
Water quality	Water quality refers to pollution of water that would threaten the health of humans and ecosystems (FAO 2012).
Water quantity	Water quantity is the overall water use directly or indirectly from all sources (tap, river, well) (FAO 2012).
Soil quality	Soil quality refers to several factors, including soil organic matter, physical structure, chemical quality and land degradation or desertification (FAO 2012).
Agricultural land use change	Agricultural land use change refers to land shifting from one type of agricultural land to another type, for example from grassland to cropland or from one type of cropland to another cropland (FAO 2012).
Natural land use change	Natural land use change refers to permanent removal of any type of natural land, such as forest, and conversion to agricultural land (FAO 2012).
Biodiversity	Biodiversity is the diversity of ecosystems, of species in these ecosystems, and of the genome within these species (FAO 2012).
Material	Material refers to total material use (raw materials, associated process materials, semi-manufactured goods) in the production process (FAO 2012).
Energy	Energy refers to the direct and indirect energy use, including the energy consumed during the extraction of raw materials, manufacturing and disposal of the raw and auxiliary materials and processing (FAO 2012).
Waste disposal	Waste disposal refers to disposal of the total amount of waste and hazardous waste generated per unit produced (FAO 2012).
Profitability	Profitability is the difference between the value of goods and services produced by a farm and the costs or resources used in their production (van Calker et al., 2005).
Local economy	Local economy not only refers to local economic development but also to opportunities which are provided for all local residents to obtain decent work at the local level (FAO 2012).
National economy	National economy refers to the financial processes of a country, and is concerned with, and affected by such things as gross domestic product, imports and exports and government policy (FAO 2012).
Labor rights	Labor rights or employees' rights are a group of legal rights and claimed human rights having to do with labor relations between employees and employers (FAO 2012).
Food safety	Food safety refers to any contamination of food with potentially harmful substances (FAO 2012).

Business stakeholders' survey

Company background

Nature of business

Sustainability: general

Is your company dealing with sustainability issues? What are the main reasons for this?

- Is your company dealing with domestic driven or export oriented sustainability?
- Are your clients/consumers concerned about sustainability? Reasons for demand of sustainability? Who undergoes pressure?
- How far down in the supply chain is your brand linked to sustainability?
- (hidden products: soy for feed)
- Why should you and your business be concerned about sustainability in the soy chain? (if possible: link to image of the soy chain)
- What are the most important sustainability **issues/problems** in soy and beef chains?
    - » Main environmental issues?
    - » Main economic issues?
    - » Main social issues?

Certification

Is your company a supplier/producer of certified soy?

- Which standards or certification schemes your company has? (Individual initiative or not?)
- Why are you certified? (Product differentiation or compliance? Motivation?)
- What is the type of contract? (Mass balance/book and claim/segregation?)
- Does your company have chain of custody certification, or certificate trading?
- Are the certified products aimed for the mainstream or niche market?
- Did your company apply for certification voluntarily?
- Are you aware of other certification schemes?
- Are you pro/against certification? (or you think it is better to have a political solution to the issue of sustainability?)

- On which sustainability (environmental, economic, social, governance) dimensions your certification is applicable?
- Should standards focus more or less on your opinion? Which one specifically?
- What are your preferences regarding sustainability dimensions (environmental, economic, and social)?
- What are the problems of other stakeholders for compliance to standards?
- Do you think small stakeholders are able to comply with the standards or certification schemes? Why (not)? What are the bottlenecks?
- Have the standards changed in time? What the trend has been? Is there pressure from certain groups?
- Do you think the standards too restraining? Do you think they should be harmonization towards one standard?
- Did you see any improvement in sustainability through the introduction of these standards? (Company level or in the entire chain?)

Amount of soy imported/exported by your company yearly?

- What is the amount of certified soy purchased by your company yearly from Latin America (in tons)?
- What is the amount of non-certified soy purchased by your company yearly from Latin America (in tons)?
- What is the export share of your company to China/EU-> evolution – impact on the demand for certified soy?
- Are there other stakeholders importing soy?
- Is your company interested in separate streams GMO/non-GMO?

Costs/premium

- What are the costs and risks (problems) for your business to engage in sustainability standards/certification?
- Do you feel you get adequate/appropriate compensation for these efforts? (Price premium?)
- Are you able to pass on the pressure on sustainability (and the costs) to the other stakeholders in the chain upstream and downstream? Can you let them pay for your efforts (downstream) or do you pay extra (upstream)?

- Are you willing to pay extra for certified soy?

Other

- How is your relation with the other business stakeholders in the soy/beef sector?
- Has your sector been influential in setting the standards in favor of your sector? Why (not)?
- How are the power relations in the soy/beef chain? How have they been evolved?
- What are the acceptable levels of environmental impact in your opinion?
- What are acceptable levels of social impact in your opinion?

Consumer survey

Dear Madam or Sir,

As part of the European Commission funded research project SALSA ("Knowledge-based sustainable value-added food chains: innovative tools for monitoring ethical, environmental and socio-economic impacts and implementing EU-Latin America shared strategies"), the Research Institute of Organic Agriculture (FiBL), in Switzerland is conducting a consumer survey on beef.

We would greatly appreciate if you could complete the questionnaire, which will take about 15 minutes. We guarantee that all your information and personal data will be kept confidential.

In this questionnaire we are interested in your personal opinion. Please answer each question with the answer that best reflects your opinion. If in doubt, your spontaneous and instinctive first answer is usually a good guide. There is no incorrect answer.

Thank you very much for taking part in this survey!

Q1. Are you responsible or co-responsible for food shopping in your household?

- □ Yes
- □ No

Q2a. Do you personally buy beef?

- □ Yes (→ go to Q2b)
- □ No (→ go to Q2c)

Q2b. How frequently did you buy beef within the last four weeks?

□ every day
□ twice a week
□ once a week
□ twice a month
□ less often

Q2c. Do you consume beef?

□ Yes (→ go to Q2d)
□ No (→ go to Q2e)

Q2d. How frequently did you consume beef within the last four weeks?

□ every day
□ twice a week
□ once a week
□ twice a month
□ less often

Only if Q2c is NO → Q2e. Why do you not consume beef?
(multiple answers are possible)

□ I am vegetarian because of
□ animal welfare concerns
□ negative environmental impact of animal / beef production
□ health concerns
□ I do not like beef
□ I cannot afford beef
□ other (please specify):

If Q2a and Q2c is NO: "This survey focuses mainly on aspects of beef, since you do neither buy nor consume beef, we thank you very much for your participation."
→ **[Thank respondent and close interview]**

If Q2a is YES → go to Q3a

Q3a. Do you buy organic food?

□ yes → go to Q3b
□ no → go to Q4

Q3b. How do you identify organic products?

(ATTENTION NOTE FOR Interviewer: Do not show possible answers since answers should come from the respondents. Check whether the answers given by the respondents are right (part A) or wrong (Part B). Multiple answers are possible).

Part A			**Part B**		
Through…		*satisfying*			*not satisfying*
Organic food label	□		Animal products produced in free range e.g. free range beef	□	
Products sold at organic food shops / at organic farms / at organic farmers' markets	□		Products from home production / from relatives	□	
Logo of the certification body	□		Products sold at farms / at farmers' markets	□	
Code number / name of the certification body	□		Other (please specify): ____________________	□	

(If none of the replies in Part A are mentioned answers are to be considered as:

Not satisfying □ → go to question 4

If one or more replies in Part A: go to question Q3c.

Q3c. (only if Q3a & Q3b = yes) How frequently did you buy organic food within the last four weeks?

- □ (almost) never
- □ seldom
- □ occasionally
- □ frequently
- □ practically/almost always

Q4. What motives are important to you when you choose meat/beef? Please evaluate the following motives on a 7-point scale from 1= extremely unimportant to 7= extremely important, assuming that you have information on the following aspects at the point of sale.

MOTIVES	[1] Extremely unimportant	[2] Very unimportant	[3] Moderately unimportant	[4] Neither important nor unimportant	[5] Moderately important	[6] Very important	[7] Extremely important	I don´t know
Price	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Taste	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Beef color	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Food Safety (traceability, strict quality control)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
No hormones and antibiotics residues	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
No residues of e.g. pesticides	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
No GMO	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Regional production	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Geographical origin	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Protection of the environment	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Protection of biodiversity	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Preservation of local cultural landscape	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Short transport distances	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
No deforestation of rain forest	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
No air freighting	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Reduced CO_2 emissions	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Organic production	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Animal welfare	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Pasture raised animals	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Animals transported and slaughtered following ethical principles	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Fair prices to farmers	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Support of local economy	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Good working conditions for farm workers	[1]	[2]	[3]	[4]	[5]	[6]	[7]	

The following part of the questionnaire deals with the relevance of different impacts on the sustainability along the beef supply chain. A supply chain consists of all activities associated with the flow and transformation of goods: from raw materials extraction, through to the end user, as well as the associated information flows. The beef supply chain includes different stages from “field to fork”.

Throughout this questionnaire we will refer to the beef supply chain starting in Latin America and exporting to the EU. → *[only displayed for studies in EU]*

Q5. The different production, processing and distribution stages along the beef supply chain have environmental, social and economic impacts. Below is a list of such impacts. How important is it to you that these single impacts are addressed/ solved? Please evaluate the following impacts on a 7-point scale from 1=extremely unimportant to 7=extremely important.

IMPACT	[1] Extremely unimportant	[2] Very unimportant	[3] Moderately unimportant	[4] Neither important nor unimportant	[5] Moderately important	[6] Very important	[7] Extremely important	I don´t know
Amount of energy used	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on air quality (greenhouse gas production)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on water quality (pollution and eutrophication)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Amount of water used (water footprint)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on soil quality (fertility, degradation, erosion)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Amount of mineral resources used (non-renewable energy)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Amount of waste produced (e.g. packaging)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on land use change within agriculture (e.g. monocultures)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	

IMPACT	[1] Extremely unimportant	[2] Very unimportant	[3] Moderately unimportant	[4] Neither important nor unimportant	[5] Moderately important	[6] Very important	[7] Extremely important	I don´t know
Impact on land use change, from natural land to agriculture (e.g. deforestation of rain forest)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on biodiversity (change of wildlife or plants)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on labor rights, including child labor (International Labor Organization ILO core conventions)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on human health (food safety and food security)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Value added in local chain and community (e.g. local soy processing)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on farm income	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on national economy	[1]	[2]	[3]	[4]	[5]	[6]	[7]	

Other stakeholders survey (soy)

SALSA: Knowledge-based sustainable value-added food chains

As part of the European Commission funded research project SALSA (“Knowledge-based sustainable value-added food chains: innovative tools for monitoring ethical, environmental and socio-economic impacts and implementing EU-Latin America shared strategies”), the Research Institute of Organic Agriculture (FiBL), in Switzerland, is conducting a stakeholder survey on the sustainability of the soy supply chain.

In order to identify challenges and opportunities to improve mainly the environmental sustainability along the soy supply chain, your experiences and suggestions are important to us. We would greatly appreciate if you could complete the online questionnaire, which will take about 20 minutes. We guarantee that all your information and personal data will be kept confidential. In appreciation for your participation, we will be glad to send you a copy of our final report containing the survey's results.

Thank you in advance for your cooperation and time effort. Should you have any questions or comments, please do not hesitate to contact us.

There are 17 questions in this survey

Part 1: General information of your organization

1. Please provide the name of the organization/department you represent

2. What is the main activity of your organization/department?

Please choose **only one** of the following:

- Environmental non-profit organization
- Social non-profit organization
- Agricultural policy ministry/department/agency
- Environmental policy ministry/department/agency
- Health and consumption policy ministry/department/agency
- Environmental and/or social standards developer
- Consumer non-profit organization
- Animal welfare non-profit organization
- Fair trade organization
- Farmers' association
- Organic farmer's association
- Other

3. In which country is your office located?

Part 2: Relevance of different impacts/ issues along the soy supply chain

This part of the questionnaire deals with the relevance of different impacts/ issues on the sustainability along the soy **supply chain**. A supply chain consists of all activities associated with the flow and transformation of goods: from raw materials extraction, through to the end user, as well as the associated information flows. The soy supply chain includes different stages:

- cultivation of soybeans
- drying

- transport (including trading)
- processing (into soybean meal, soybean oil or soy protein products)
- distribution
- consumption

Throughout this questionnaire we will refer to the soy supply chain starting in Latin America and exporting to the EU.

4. The different production, processing and distribution stages along the soy supply chain have environmental, social and economic impacts. Below is a list of such impacts. How important is it to you that these single impacts are addressed/ solved?

IMPACT	[1] Extremely unimportant	[2] Very unimportant	[3] Moderately unimportant	[4] Neither important nor unimportant	[5] Moderately important	[6] Very important	[7] Extremely important	I don´t know
Amount of energy used	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on air quality (greenhouse gas production)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on water quality (pollution and eutrophication)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Amount of water used (water footprint)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on soil quality (fertility, degradation, erosion)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Amount of mineral resources used (non-renewable energy)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Amount of waste produced (e.g. packaging)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on land use change within agriculture (e.g. monocultures)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on land use change, from natural land to agriculture (e.g. deforestation of rain forest)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on biodiversity (change of wildlife or plants)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	

IMPACT	[1] Extremely unimportant	[2] Very unimportant	[3] Moderately unimportant	[4] Neither important nor unimportant	[5] Moderately important	[6] Very important	[7] Extremely important	I don´t know
Impact on labor rights, including child labor (International Labor Organization ILO core conventions)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on human health (food safety and food security)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Value added in local chain and community (e.g. local soy processing)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on farm income	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on national economy	[1]	[2]	[3]	[4]	[5]	[6]	[7]	

Other stakeholders survey (beef)

SALSA: Knowledge-based sustainable value-added food chains

As part of the European Commission funded research project SALSA ("Knowledge-based sustainable value-added food chains: innovative tools for monitoring ethical, environmental and socio-economic impacts and implementing EU-Latin America shared strategies"), the Research Institute of Organic Agriculture (FiBL), in Switzerland, is conducting a stakeholder survey on the sustainability of the beef supply chain.

In order to identify challenges and opportunities to improve mainly the environmental sustainability along the beef supply chain, your experiences and suggestions are important to us. We would greatly appreciate if you could complete the online questionnaire, which will take about 20 minutes. We guarantee that all your information and personal data will be kept confidential. In appreciation for your participation, we will be glad to send you a copy of our final report containing the survey's results.

Thank you in advance for your cooperation and time effort. Should you have any questions or comments, please do not hesitate to contact us.

There are 17 questions in this survey

Part 1: General information of your organization

1. Please provide the name of the organization/department you represent.

2. What is the main activity of your organization/department?

Please choose **only one** of the following:

- Environmental non-profit organization
- Social non-profit organization
- Agricultural policy ministry/department/agency
- Environmental policy ministry/department/agency
- Health and consumption policy ministry/department/agency
- Environmental and/or social standards developer
- Consumer non-profit organization
- Animal welfare non-profit organization
- Fair trade organization
- Farmers' association
- Organic farmer's association
- Other

3. In which country is your office located?

Part 2: Relevance of different impacts along the beef supply chain

This part of the questionnaire deals with the relevance of different impacts on the sustainability along the beef supply chain. A supply chain consists of all activities associated with the flow and transformation of goods: from raw materials extraction, through to the end user, as well as the associated information flows. The beef supply chain includes different stages:

- Beef cattle breeding (farm)
- transport (including trading)
- processing (slaughtering)

- distribution
- consumption

Throughout this questionnaire we will refer to the soy supply chain starting in Latin America and exporting to the EU.

*For the survey conducted in Mexico: Throughout this questionnaire we will refer to the beef supply chain for domestic consumption (in Spanish).

4. The different production, processing and distribution stages along the beef supply chain have environmental, social and economic impacts. Below is a list of such impacts. How important is it to you that these single impacts are addressed/ solved?

IMPACT	[1] Extremely unimportant	[2] Very unimportant	[3] Moderately unimportant	[4] Neither important nor unimportant	[5] Moderately important	[6] Very important	[7] Extremely important	I don´t know
Amount of energy used	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on air quality (greenhouse gas production)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on water quality (pollution and eutrophication)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Amount of water used (water footprint)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on soil quality (fertility, degradation, erosion)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Amount of mineral resources used (non-renewable energy)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Amount of waste produced (e.g. packaging)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on land use change within agriculture (e.g. monocultures)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on land use change, from natural land to agriculture (e.g. deforestation of rain forest)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	

IMPACT	[1] Extremely unimportant	[2] Very unimportant	[3] Moderately unimportant	[4] Neither important nor unimportant	[5] Moderately important	[6] Very important	[7] Extremely important	I don´t know
Impact on biodiversity (change of wildlife or plants)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on labor rights, including child labor (International Labor Organization ILO core conventions)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on human health (food safety and food security)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Value added in local chain and community (e.g. local soy processing)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on farm income	[1]	[2]	[3]	[4]	[5]	[6]	[7]	
Impact on national economy	[1]	[2]	[3]	[4]	[5]	[6]	[7]	

2

Chapter 3

Environmental and Economic Performance of Feeding Strategies for Brazilian Beef Production

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Submitted

Abstract

Beef production in Brazil increasingly competes for natural resources and is a main contributor to the emission of pollutants to the environment. Beef producers can improve their environmental performance by adopting alternative feeding strategies. The adoption of alternative feeding strategies, however, might negatively impact farm profitability. The objective of this study was to evaluate the economic and environmental performance of four feeding strategies for beef production in southern Brazil. Based on the feeding strategies we defined four beef farming systems: (1) farming system based on natural pasture as a feeding strategy (NP); (2) farming system based on improved pasture as a feeding strategy (IP); (3) farming system based on natural pasture and crop residues as a feeding strategy (CR); (4) farming system based on natural pasture and feedlot as a feeding strategy (FL). Environmental indicators used to compare the farming systems were global warming potential (GWP), fossil energy use, and land occupation per kilogram live weight (LW). The economic indicator was operating profit per farm. The IP system had lower GWP (10.0 kg CO_2-eq. kg^{-1} LW) and land occupation (18.5 m^2 kg^{-1} LW) compared with the other systems, whereas its fossil energy use (9.9 MJ.kg^{-1} LW) was higher. IP had the highest operating profit (1,765,000 R$. $farm^{-1}$) of the four systems. Operating profit in the CR system (1,380,000 R$. $farm^{-1}$) was mainly from crop production (89%). Beef production with crop residues is at the expense of the more profitable crop production, which makes adoption unlikely in southern Brazil. The CR system had a higher GWP (27.8 kg CO_2-eq. kg^{-1} LW) compared to NP (27.3 kg CO_2-eq. kg^{-1} LW). The operating profit of the FL system (169,000 R$. farm-1) was similar to the operating profit of NP (163,600 R$. $farm^{-1}$). The outcomes of this research suggest that IP is a promising system to improve both the environmental and economic performance of beef production in southern Brazil.

Introduction

Sustainable production of animal-source food has emerged at the top of the global policy agenda for two main reasons. First, the demand for animal-source food is expected to increase due to population growth and changes in dietary patterns (Geber et al., 2007). Second, production of animal-source food, such as beef, increasingly competes for natural resources and contributes to emissions of pollutants to the environment (Steinfeld et al., 2006; Gerber et al., 2013).

Brazil is one of the world's main producers of beef and faces the above-described challenges (Pashaei Kamali et al., 2014). A number of studies have evaluated the environmental impact of Brazilian beef production (Cederberg et al., 2009; Dick et al., 2015a; Ruviaro et al., 2015). Ruviaro et al. (2015) reported that beef production is responsible for over 50% of national greenhouse gas (GHG) emissions in Brazil. Several studies have assessed the potential of various strategies to reduce the environmental impact of livestock production in different countries (Beauchemin et al., 2010; Wall et al., 2010; Bannink et al., 2011; Bell et al., 2011; van Middelaar et al., 2014a; van Middelaar et al., 2014b; de Vries et al., 2015; Dick et al., 2015a; Ruviaro et al., 2015). Two studies focused specifically on Brazilian beef production (Dick et al., 2015a; Ruviaro et al., 2015). These studies proposed several animal husbandry practices and farm management strategies to reduce the environmental impact of beef production.

The feeding strategy is one of the main farm management strategies affecting the environmental performance of beef production (Beauchemin et al., 2008). However, adoption of alternative feeding strategies might negatively affect farm profitability (Hristov et al., 2013). Any strategy that requires additional investments, which do not generate a positive net present value of cash flows is likely to be rejected by livestock producers (Beauchemin and McGinn, 2008; Hristov et al., 2013). Hence, there is a need to consider both environmental and economic performance in analyzing the impact of alternative strategies. Examples of this approach include Wall et al. (2010), van Middelaar et al. (2014b), and de Vries et al. (2015). van Middelaar et al. (2014b), for instance, investigated the cost-effectiveness of feeding strategies to reduce GHG emissions from Dutch dairy farming. An assessment of the environmental and economic performance of different feeding strategies for beef production is currently lacking in the literature. The results of such a study are useful for policy makers who wish to design policies to reduce the environmental impact of beef production with only a minimal negative effect on competitiveness. The objective of this study was to assess the environmental and economic performance of different feeding strategies for beef production in southern Brazil. The four feeding strategies investigated in this study are: cattle fed on pasture under natural conditions, cattle fed on fertilized pasture improved with winter grasses and legumes, cattle fed on crop residues and pasture, and cattle raised on pasture and finished in a feedlot. These feeding strategies are currently used in southern Brazil.

Material and methods

Characteristics of the feeding strategies and related farming systems

Quantification of the environmental and economic performance of feeding strategies requires the definition of the beef production systems (Figure 3.1). We defined the following beef production systems: (1) farming system based on natural pasture as a feeding strategy (NP); (2) farming system based on improved pasture as a feeding strategy (IP); (3) farming system based on natural pasture and crop residues as a feeding strategy (CR); (4) farming system based on natural pasture and feedlot as a feeding strategy (FL). These four beef production systems were chosen to reflect the current practice in southern Brazil. Beef production in southern Brazil relies on the management of natural pasture as the main source of animal feed (Ruviaro et al., 2015). The natural pasture system represents the traditional production system in southern Brazil (Dick et al., 2015a; Ruviaro et al., 2015). Improved natural grassland or pasture is a relatively new beef production system that is becoming popular in southern Brazil. This innovation is expected to increase production and profit, and reduce damage to environment. Although the innovation is promoted by governmental extension agencies, the adoption rate has been low (Borges et al., 2014). Integrated crop-livestock systems have been adopted recently in several regions of Brazil. These production systems are arranged in various ways that differ in the species sequence, implementation details, and rotation phases between crop and livestock farming. Feedlots are not common in Brazil; in 2008 around 2.7 million animals, corresponding to 6.7% of slaughtered animals in Brazil, were fed in feedlots (Ferraz and Felício, 2010).The general farm characteristics of the four farming systems were based on data provided by EMBRAPA[1] (Table 3.1). They were obtained by EMBRAPA from an expert panel consisting of beef production experts (Malafaia et al., 2014; Pereira et al., 2014). The expert panel provided data for the natural pasture system in southern Brazil in 2012. This data covered the main characteristics of cattle farms in this region, e.g., average farm size, slaughter age and slaughter weight, calving rates, and pasture type. The system-specific data for IP, CR, and FL were based on literature (Table 3.1).

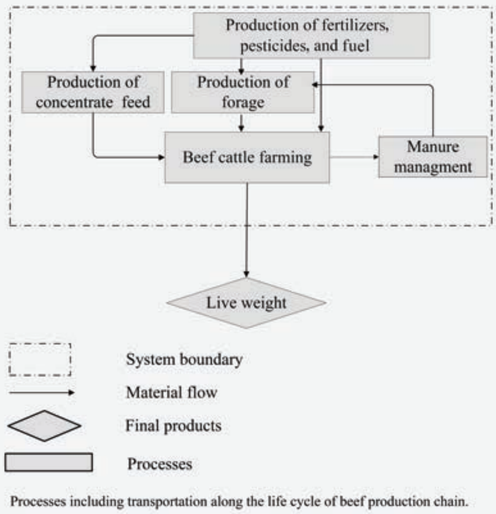

Figure 3.1 System boundary (cradle-to-farm gate) representation of a beef production system and corresponding feed and forage production.

1 EMBRAPA: Brazilian Enterprise for Agricultural Research.

The first farming system analyzed was NP. The main feature of this system is the use of large areas of land with little or no subdivision, where cattle graze continuously throughout the year without feed supplementation. In southern Brazil, natural pasture is dominated by Paspalum, Axonopus, Briza, and Bromus species, sparse shrubs, and trees (Dick et al., 2015a). Beef production and farm inputs were computed on an annual basis. Based on the EMPRAPA data, we assumed that the NP system had an area of 1200 hectare (ha) that the herd had an annual calving rate of 70%, and that 20% of the calves were retained as replacement heifers. The average slaughter weight was 420 kg for females and 440 kg for males. We assumed that all manure is deposited on pasture, as housing is not utilized for beef production in Brazil. We further assumed that the farming systems were all focused on the export market, which prohibits the use of growth hormones, and therefore that growth hormones are not used. Feed intake from pasture was calculated by multiplying the area under pasture by the dry matter (DM) production per hectare and the efficiency of pasture utilization (Table 3.1). The stocking rate was calculated from Dick et al. (2015a); pasture production was 3.0 ton DM ha^{-1} $yr^{-1}$and pasture utilization efficiency was 50% (Dick et al. 2015a; Dick et al. 2015b) (Table 3.1).

The second farming system was IP. This system is similar to NP, except for its pasture characteristics. The natural pasture was assumed to be improved by the introduction of winter grasses (ryegrass and oat) and legumes (clover and birdsfoot trefoil). This improves the seasonal DM production and nutritional value of pasture (Dick et al., 2015a). Using clover decreases nitrogen (N) fertilizer requirements, as clover has a symbiosis relation with nitrogen-fixing bacteria. In this farming system, phosphorous (P) fertilizer (50 kg ha^{-1}. yr^{-1}), potassium (K) fertilizer (65 kg ha^{-1}. yr^{-1}), and lime (333 kg.ha^{-1} yr^{-1}) are applied, but irrigation is not applied (Dick et al., 2015a). The stocking rate was calculated from Dick et al. (2015a); pasture production of IP was assumed to be 11.5 ton DM ha^{-1} yr^{-1} and pasture utilization efficiency was 70% (Dick et al. 2015a; Dick et al. 2015b). All other assumptions were the same as for the NP.

The third farming system was CR, where cattle are fed on crop residues. In this system, cattle and crop production are integrated. The area for soybean production was assumed to be 480 ha (40% of 1200 ha) and the area of natural grassland was 720 ha (60% of 1200 ha) (Table 3.1). The annual crop was assumed to be soybean, because soybean is one of the main agricultural products of Brazil (MVO, 2011). In the CR system, cattle graze on natural pasture from October until March (rainy season) and after March (when the soybeans are harvested) cattle are additionally fed on soybean residues. Soybean residues include leaves, stems, and pods left after harvest (ADF, 2012). Other characteristics of CR are the same as for NP.

Table 3.1 General farm characteristics of the four farming systems.

Description	NP[1]	IP[2]	CR[3]	FL[4]
Area pasture (ha)	1200[5]	1200[5]	720	1200[5]
Pasture type	Native[5]	Improved[6]	Native	Native
Area crop land (ha)	-	-	480[6]	-
Yield soybean residues (ton DM. ha^{-1})	-	-	2.4[7]	-
Pasture production (ton DM .ha^{-1}. yr^{-1})	3[5]	11.5[6]	3[5]	3[5]
Efficiency of pasture utilization (%)	50[6]	70[6]	50[6]	50[6]
Calf mortality rate (% yr^{-1})	4[5]	1[6]	4[5]	4[5]

1. Natural pasture.
2. Improved pasture.
3. Integrated crop-pasture; cattle fed on crop residues.
4. Feedlot pasture.
5. Source: EMBRAPA.
6. Source: Dick et al. (2015a).
7. Source: Computed based on Pashaei Kamali et al. (2015).

Utilization efficiency of natural pasture and soybean residues were assumed to be equal. We assumed that the net energy (NE) content and feed intake per head of cattle were the same in NP and CR. Stocking rate in the CR system was subsequently calculated as the feed production in CR divided by feed production in NP, multiplied by the stocking rate of NP. Soy residues yielded 2.4 ton DM ha^{-1} yr^{-1}, assuming a soybean yield of 3.5 ton DM ha^{-1} yr^{-1} (Pashaei Kamali et al., 2015) and a harvest index of 0.60 (Pedersen and Lauer, 2004). The NE content of soybean residues and

3

the efficiency of pasture utilization were assumed to be the same as in the NP system, because the digestibility of natural pasture (47%) (Dick et al., 2015a) is close to the digestibility of soy leaves (53%), stems (35%), and pods (48%) (Rasby et al., 2014). Soybean residue intake per hectare was multiplied by 480 ha to calculate total soy residue intake.

The fourth farming system was FL, in which cattle first graze natural pasture and are subsequently finished in a feedlot. FL has the same characteristics as NP, except that the feedlot is added to the farming system. Cattle are introduced to the feedlot around 18 months of age, having a live weight (LW) of approximately 280 to 290 kg. Cattle usually stay in the feedlot for 120 days. Culled reproductive cattle are also assumed to be fattened in the feedlot for 120 days (Ferraz and Felício, 2010). Feedlots use concentrate feed composed mainly of maize, soybean meal, and sorghum (Ferraz and Felício, 2010). The percentages of each type of feed (i.e., maize, soybean meal, and sorghum) in the concentrate feed were assumed to be equal. We assumed that the stocking rate on natural pasture in this farming system is the same as in NP, and additional cattle are kept in the feedlot (Table 3.1). The DM intake from concentrate feed in the feedlot was computed based on a feedlot period of 120 days. Intake of concentrate feed was calculated based on NE requirements for maintenance and growth. NE for maintenance was assumed to be 300 kJ $kg^{-0.75}$ total body weight (TBW). To calculate NE for growth, we assumed that live weight gain in a feedlot was 20% protein and 20% fat (NRC, 2000). NE efficiency was assumed to be 54% for protein accretion, and 74% for fat accretion (MUS, 2015), which resulted in NE requirements of 19.4 MJ kg^{-1} of LW gain. Cattle were assumed to be fed two times the NE requirements for maintenance, and hence NE for maintenance equaled NE for growth (Andrews et al., 2008). Daily NE for growth and maintenance enabled the calculation of daily growth rates. NE requirements were calculated backwards from a slaughter weight of 440 kg LW for males and 420 kg LW for females. NE requirements were subsequently converted into metabolizable energy (ME) requirements following A.R.C. (1965). Total ME requirements were divided by the ME content of maize, soybean meal, and sorghum (MAFF, 1986) to calculate the total intake of concentrate feed in the feedlot (Table 3.2).

Table 3.2 Gross energy (GE), metabolizable energy (ME), and net energy (NE) content of each feed type (MJ. kg^{-1} DM).

Feed	GE[1]	ME[1]	NE
Natural pasture	18.5	7.7	5.2
Soybean residues[2]	18.5	7.7	5.2
Improved pasture	18.5	10.7	6.0[3]
Maize	18.6	13.8	10.6
Soybean meal	17.8	13.4	10.3
Sorghum	18.8	13.2	9.9

1. Source: MAFF (1968).
2. Soybean residues are assumed to have the same GE, ME, and NE values as natural pasture.
3. Calculated from Dick et al. (2015a).

Environmental performance

The environmental impact of beef production was quantified using life cycle assessment (LCA). LCA is a method that evaluates the environmental impacts along the entire life cycle of a product (Guinée et al., 2002). LCA relates the environmental impacts of a defined production system to the functional unit (FU) (Guinée et al., 2002), which is the main product of the analyzed system in quantitative terms, and defined here as one kilogram LW. The system boundary was cradle-to-farm gate (Figure 3.1). The herd consisted of mature females, mature males, and young stock. Cattle were divided into subcategories according to age and sex, as recommended by IPCC (2006) Tier 2. For the detailed computation of each animal subcategory see the Appendix 3.

We evaluated the environmental impact of the four beef production systems in terms of global warming, land occupation, and fossil energy. To assess the impact of a production system on global warming, emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) were quantified. Emissions were summed based on their equivalence factor in terms of CO_2-equivalents (100-year time horizon: 1 for CO_2, 28 for biogenic CH_4, 30 for fossil CH_4, and 265 for N_2O) and expressed per

FU (IPCC 2013). We calculated emissions for the following processes: extraction of raw materials to produce farm inputs (i.e., fertilizers, mineral supplements, fuel, and concentrate feed), manufacturing and distribution of inputs, and all processes on the farm (i.e., seeding, fertilizing, liming, transportation, and on-farm feed production). The following GHG emissions were calculated: on farm CH_4 emissions from cattle and manure; direct N_2O emissions from managed soils (from the application of fertilizer, crop residues, and manure deposition during grazing); indirect N_2O emissions from N leaching, runoff, and volatilization; and GHG emissions from energy combustion from on-farm and off-farm processes.

Enteric CH_4 emission was estimated at herd level based on the ME content and neutral detergent fiber (NDF) content of the diet (Ellis et al., 2007). CH_4 emissions from manure were estimated separately for each animal subcategory and were based on volatile solid production, according to the Tier 2 method proposed by IPCC (2006), taking into account the GE intake of the animal and the digestible energy (DE) content of the diet. DE of feed was computed based on ME content, which was assumed to be 82% of DE content (NRC, 2000). GE and ME content of pasture and concentrate feed were obtained from literature (MAFF, 1986; NRC, 2000) (Table 3.2). Direct and indirect N_2O emissions were based on animal subcategory and computed according to the Tier 1 method proposed by IPCC (2006). Emissions related to the production of inputs (e.g., fertilizers, mineral salt, ryegrass, and clover seed) were calculated using the Ecoinvent database (Ecoinvent, 2013). Emissions related to the production of antibiotics, medicines, machines, and buildings were excluded, due to their negligible contribution (Cederberg and Mattsson, 2000). Emissions related to the application of limestone and emissions related to field work (e.g., cultivation, harvesting, and other field operations) were calculated based on IPCC (2006). Emission factors related to transportation (e.g., transportation of inputs to the farm) were calculated using IPCC (2006) and the average distance per ingredient was based on the country of origin (Prudêncio da Silva et al., 2010). Emissions related to land use change (e.g., deforestation) or carbon sequestration were not considered in this study due to a lack of reliable data for the four farming systems. GHG emissions related to the production of soybean meal were based on Pashaei Kamali et al. (2015) and GHG emissions related to maize production were calculated from van Middelaar et al. (2013). GHG emissions related to sorghum production were based on FeedPrint[2]. The main input parameters for each farming system are presented in Table 3.3. Details on formulas and emission factors are provided in the Appendix 3.

Table 3.3 Input parameters for the four farming systems.

Input parameters	**NP**[1]	**IP**[2]	**CR**[3]	**FL**[4]
Seeds ($kg.\ ha^{-1}.yr^{-1}$)	-	Ryegrass: 20 Clover: 5	56	-
P fertilizer ($kg.\ ha^{-1}.yr^{-1}$)	-	50[5]	76	-
K fertilizer ($kg.\ ha^{-1}.yr^{-1}$)	-	65[6]	76	-
Lime ($kg.\ ha^{-1}.yr^{-1}$)	-	333[7]	2000	-
Mineral supplement ($g.\ head^{-1}.day^{-1}$)	49	49	49	49
Pesticides ($kg.\ ha^{-1}.yr^{-1}$)	-	-	6.5	-
Maize ($ton.\ yr^{-1}$)	-	-	-	32
Soybean meal ($ton.\ yr^{-1}$)		-	-	32
Sorghum ($ton.\ yr^{-1}$)	-	-	-	32

1. Natural pasture.
2. Improved pasture.
3. Integrated crop-pasture; cattle fed on crop residues.
4. Feedlot pasture.
5. In IP phosphorous (P) fertilizer is applied every two years.
6. In IP potassium (K) fertilizer is applied every two years.
7. In IP lime is applied every six years.

Land occupation was measured as the area in square meters per year ($m^2.\ yr^{-1}$) used for the production of one kilogram of LW. In the NP and IP systems, only pasture

2 FeedPrint (Carbon FootPrint of Animal Nutrition), version 2013.03. The calculation tool FeedPrint calculates greenhouse gas emissions of feed raw materials during their complete life cycle.

land is used. In CR, cattle graze on pasture (720 ha) for half of the year and the other half of the year cattle graze on both crop land and pasture land (1200 ha); land occupation in CR was adjusted accordingly. In FL, cattle graze on natural pasture and are additionally fed concentrate feed. Off-farm land area is required for the production of concentrate feed. Pasture area and land area for production of concentrate feed were summed to calculate land occupation. For the calculation of land area used for concentrate feed production, soybean yield was assumed to be 3.0 ton ha^{-1} (Pashaei Kamali et al., 2015), maize yield was assumed to be 3.2 ton ha^{-1}, and sorghum yield was assumed to be 3.8 ton ha^{-1} (Ecoinvent, 2007).

We estimated fossil energy use related to primary energy use only, expressed in mega joules (MJ) per kilogram LW. We calculated fossil energy use for the production and transportation of system inputs and the operation of machinery for field operations. Fossil energy was calculated for the production and transport of the following inputs: seeds, fertilizers, limestone, concentrate feed, and fuel. Fossil energy required for the construction of buildings and agricultural machineries was ignored due to a lack of data and its small contribution to total fossil energy use (Pradhan et al., 2008). Fossil energy coefficients for fertilizers, lime, mineral supplements, ryegrass, clover, and fuel, were based on the Ecoinvent database (Ecoinvent, 2013). Fossil energy used for the production of soybean meal was based on Pashaei Kamali et al. (2015), fossil energy use for the production of maize was based on Kim et al. (2014), and fossil energy use for the production of sorghum was based on Cai et al. (2013). More details on the formulas and energy coefficients are provided in the Appendix 3.

Allocation

In a multiple output situation, the environmental impact of a system has to be allocated to the various outputs. We used economic allocation, implying that the environmental impact is allocated to the various products based on their relative economic value. In FL, multiple output situations occurred in the production process for concentrate feed. Feed ingredients could originate from crops directly, in the case of maize and sorghum, or from the industrial processing of crops, in the case of soybean meal.

Feeds derived from industrial processing are often by-products from the biofuel or food industry (van Middelaar et al., 2013). The CR had two outputs, soybean and beef cattle. As soybean residues have no economic value in Brazil, the environmental impact of soy production was fully allocated to soybeans (ISO 14043, 2000).

Economic performance

Operating profit was used as the indicator for economic performance. Total operating profit is an indicator of the relative success of a farm operation in terms of its ability to meet short-term financial obligations (McBride and Greene, 2009). Operating profit was calculated for each farming system as total revenue minus operating costs minus depreciation (Hillier et al., 2010). Revenues and operating costs differed across the four farming systems. Revenues for NP, IP, and FL are derived from beef production only; however, revenues for CR are derived from beef and soybean production. We estimated the following operating costs for beef production: costs related to veterinary services, which include vaccination and medicines, fuel, lubricants, electricity, maintenance, operating interest, insurance, and hired labor. Additional costs for the IP system were ryegrass and clover seeds, fertilizers, extra fuel for application of inputs, and transportation. Additional costs for the CR system were related to soybean production, i.e., soybean seeds, fertilizers, pesticides, fuel for input application, and road transportation. For FL, additional costs were associated with feedlot maintenance and the cost of purchasing and transporting concentrate feed, which was bought at market and transported to the farm. Input prices were average prices during the period 2010–2014, and were obtained from IndexMundi[3] and IBGE[4] (Table 3.4). Operating profit was evaluated at farm level as well as per kilogram LW. Details on the operational costs for each system are provided in the Appendix 3.

3 IndexMundi is a platform containing data concerning selected attributes and characteristics of countries, including detailed country statistics, charts, and maps compiled from multiple sources.

4 The Brazilian Institute of Geography and Statistics is the agency responsible for statistical, geographic, cartographic, geodetic, and environmental information in Brazil.

Table 3.4 Prices of farm inputs and outputs (average of 2010-2014)[1].

Inputs/output	**Price**	**SD[2]**
Beef (R$.kg^{-1} LW)	3.70	0.81
Soybean (R$.kg^{-1})	0.94	0.15
Maize (R$.kg^{-1})	0.50	0.07
Soybean meal (R$.kg^{-1})	0.85	0.20
Sorghum (R$.kg^{-1})	0.45	0.08
P fertilizer (R$.kg^{-1})	0.71	0.06
K fertilizer (R$.kg^{-1})	0.74	0.10
Lime (R$.kg^{-1})	0.19	0.00
Fuel (R$.lit^{-1})	1.52	0.27
Labor (R$.hr^{-1})	1.35	0.08

1. Prices for inputs and outputs were based on IndexMundi and IBEG database.
2. Standard deviation, rounded to two decimal places.

Sensitivity analysis

A sensitivity analysis was conducted to investigate the sensitivity of environmental and economic performance to different parameters of beef production. The effect of a 10% increase or decrease in one parameter on environmental and economic performance was examined, while all other parameters were kept constant. Parameters used for the sensitivity analysis were: calving rate, stocking rate, pasture utilization efficiency, and pasture DM production. We chose these parameters as they have been shown to substantially affect environmental and economic performance. Ramsey et al. (2005), for example, showed that calving and stocking rate affect the profitability of beef production and Pelletier et al. (2010) demonstrated that pasture utilization efficiency was an important factor affecting the environmental performance of beef production in the United States. Furthermore, pasture utilization efficiency and pasture DM production were shown to be important factors affecting the environmental performance of beef production in Brazil (Dick et al., 2015b; Ruviaro et al., 2015).

Results and discussion

Total NE intake at farm level in the IP system was higher than in NP, CR, and FL (Table 3.5). This higher NE intake in IP resulted from a higher NE content of improved pastures, a higher DM production per hectare, and a higher efficiency of pasture utilization compared with other systems (Table 3.3). The low ME and NE content of soybean residues in CR (Table 3.3) is explained by the high lignin content (Rasby et al., 2014), which is the indigestible cell wall component of the plant. Hence, total NE available for cattle in CR was lower than in NP, because DM production per hectare was also lower for soybean residues than for natural pasture (Table 3.3). The NE content of concentrate feed in FL was higher than the NE content of feed in other systems (Table 3.2). Cattle in FL, however, were fed this concentrate feed for only 120 days. Low NE content of pasture in NP and CR may have led to a relatively low LW gain, and consequently a higher slaughter age compared to IP and FL (Table 3.5). IP had the highest LW production; this system therefore had the highest FE, followed by FL, NP, and CR (Table 3.5).

Global warming potential

The global warming potential (GWP) of the IP system (10.0 kg CO_2-eq.kg^{-1} LW) was lower than the GWP of FL (23.9 kg CO_2-eq.kg^{-1} LW), NP (27.3 kg CO_2-eq.kg^{-1} LW), and CR (27.8 kg CO_2-eq.kg^{-1} LW) (Table 3.6). Differences in GWP between farming systems were caused mainly by differences in the quantity and quality of feed (i.e., DM production, NE content, and pasture utilization efficiency) consumed by cattle. de Vries et al., (2015). Found that high quality diets led to a reduction in finishing time and consequently decreased GHG emissions of beef production. Our study shows that the production system with the best quality diet (IP) could decrease GHG emission by approximately 60% compared to NP. Higher quality diets could increase growth rates and reduce beef cattle CH_4 and manure N_2O emissions, both of which are key contributors to GHG emissions (Casey and Holden, 2006; Pelletier et al., 2010).

Table 3.5 Stocking rate, average age at slaughter, number of slaughter cattle, net energy (NE), dry matter (DM), live weight (LW), and feed efficiency (FE) for the four farming systems.

	NP[1]	IP[2]	CR[3]	FL[4]
Stocking rate ($AU.ha^{-1}$)[5]	0.5	2.2	0.4	0.5[6]
Average age of slaughter (months)	36	24	36	24
Total number of slaughtered cattle (heads yr^{-1})	133	1508	121	172
Total DM pasture intake (ton DM yr^{-1})	1800	9660	1080	1800
Total DM crop residues intake (ton DM yr^{-1})	-	-	560	-
Total DM of concentrate feed (ton DM yr^{-1})	-	-	-	95
NE from pasture (TJ[7]. yr^{-1})	9.3	58.7	5.6	9.3
NE from crop residues (TJ. yr^{-1})	-	-	2.9	-
NE from concentrate feed (TJ. yr^{-1})	-	-	-	1.0
Total NE (TJ. yr^{-1})	9.3	58.7	8.5	10.3
LW herd (ton)	57.2	648.6	52.1	74.0
FE[8] (kg LW. ton^{-1} DM)	31.8	61.7	31.8	39.0

1. Natural pasture.
2. Improved pasture.
3. Integrated crop-pasture; cattle fed on crop residues.
4. Feedlot pasture.
5. Animal unit per hectare (i.e., the number of animals per unit area).
6. Excludes cattle present in feedlot.
7. Terra Joule.
8. Feed efficiency.

Further analysis of the GHG emissions in the different farming systems showed that enteric fermentation accounted for the highest percentage of GHG emissions, followed by N_2O emissions from crop residues, N_2O from manure, and CH_4 from manure

(Figure 3.2). CO_2 from mineral supplements and from fossil fuel had the smallest share of total GHG emissions. Emissions related to the production of concentrate feed in FL accounted for only 3% of total GHG emissions, due to the short period of feed supplementation (Figure 3.2).

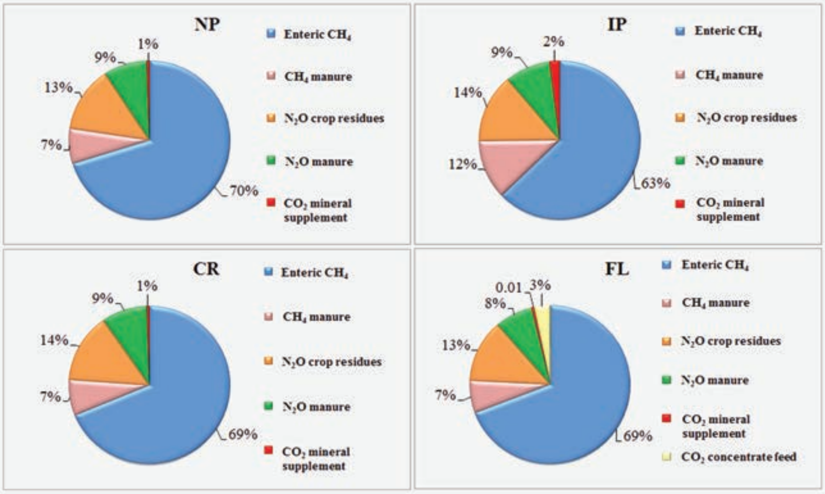

Figure 3.2 Relative contribution (%) of the main sources of greenhouse gas emissions in the four beef production systems. NP: natural pasture; IP: improved pasture; CR: cattle fed on crop residues; FL: Feedlot, pasture.

The comparison of LCA results with other studies is difficult because LCA studies differ in terms of the system boundary, functional unit, allocation methods, and the characterization of the processes observed (de Vries and de Boer, 2010). Comparison of our results with other studies in Brazil, however, show that our estimates of GWP for NP and IP are similar to those reported by Dick et al. (2015a) for NP (22.5 kg CO_2-eq. kg^{-1} LW) and IP (9.2 kg CO_2-eq. kg^{-1} LW) in the south of Brazil. This similarity was expected, as we adopted some of the system characteristics from this study. Ruviaro et al. (2015) reported 18.7 kg CO_2-eq. kg^{-1} LW for an IP in Brazil. This study, however, assumed application of N fertilizer, which increases GHG emissions.

Cederberg et al. (2011) reported 28 kg CO_2-eq.kg^{-1} carcass weight (CW) for IP in the Legal Amazon region in Brazil, which is equivalent to 14 kg CO_2-eq. kg^{-1} LW, assuming a dressing percentage of 50%. It is worth noting that the production system described by Cederberg et al. (2011) was different in terms of soil, weather conditions, management, pasture, animal genetics, and other factors compared to southern Brazil. Overall, the GHG emissions for NP and IP calculated in this study fall within the range of GHG emissions estimated in other studies for farming systems in southern Brazil.

Estimates of GWP for suckler beef in Europe and Canada range from 12.6 to 13.6 kg CO_2-eq. kg^{-1} LW (Casey and Holden, 2006; Nguyen et al., 2010; Beauchemin et al., 2011). Pelletier et al. (2010) reported 19.2 kg CO_2-eq. kg^{-1} LW for pasture and hay-finished beef and 16.2 kg CO_2-eq. kg^{-1} LW for feedlot-finished beef in the United States. Our estimate of GWP for beef in the IP system is comparable to the estimated GWP from beef produced in Europe, Canada, and the United States, whereas the other three systems have higher GWP. The dominant beef production system in Brazil is an extensive system (NP). Compared with NP, where cattle are slaughtered at an age of 3 to 4 years (Ruviaro et al. 2015), in European beef production systems cattle are slaughtered between 18 and 24 months (Casey and Holden, 2006; Nguyen et al., 2010). This implies, assuming the same slaughter weights, cattle grow faster due to more intensive farming systems. This can slightly decrease the GWP of the beef production system in Europe. The differences in GWP between this study and European beef production systems may therefore be related to slaughter age, calving rate, duration of feedlot phase, type of pasture, and concentrate feed.

Land occupation

Results show that the IP system had the lowest land occupation per kilogram LW produced, whereas NP had the highest land occupation (Table 3.6). The higher occupation of land per kilogram LW in NP is mainly due to the low productivity of natural pastures, which allows only low stocking rates. In IP, however, the high productivity of pastures enables higher stocking rates and consequently higher LW, which results in lower land occupation. In the CR system, 40% of the land was completely allocated to crop production during half of the year; hence, the total land occupation in this farming system was lower than for NP. In the FL system, using a feedlot in the last 120 days of the production period leads to an increase in total LW and consequently lower land occupation. Concentrate feed only accounted for 2.3% of total land occupation in this farming system. Lower land occupation, as a consequence of higher productivity, results in a lower pressure associated with the use of natural areas such as forest.

Table 3.6 Environmental and economic performance of different farming systems.

Performance indicators	Unit	NP[1]	IP[2]	CR[3]	FL[4]
GWP[5]	kg CO_2-eq. kg^{-1} LW	27.3	10.0	27.8	23.9
Land occupation	m^2. kg^{-1} LW	209.9	18.5	184.3[6]	166.0
Fossil energy use	MJ.kg^{-1}LW	2.1	9.9	2.1	8.0
Operating profit	R$. $farm^{-1}$	163,600	1,765,000	1,380,000[7]	169,000
Operating profit (kg LW)	R$.$kg^{-1}$ LW	2.8	2.7	2.8	2.2

1. Natural pasture.
2. Improved pasture.
3. Integrated crop-pasture; cattle fed on crop residues.
4. Feedlot pasture.
5. Global warming potential.
6. Under the assumption that 40% of the land for soybeans (in the second half of the year soybeans are harvested and cattle use that land as pasture land) is allocated to beef production.
7. Operating profit per farm in CR includes soybean operating profit. Operating profit for cattle farm was 140,000 R$ (11%); operating profit for soybean farm was 1,240,000 R$ (89%).

The values for land occupation in this study are similar to those found by Dick et al. (2015a) for NP (235 m^2 kg^{-1} LW) and IP (21 m^2 kg^{-1} LW). The results of our study show that land occupation in Brazil is substantially higher than in European beef production systems. In this regard, Nguyen et al. (2010) reported 42.9 m^2. kg^{-1} CW (21.5 m^2. kg^{-1} LW) as the mean value for land occupation for EU suckler beef systems. de Vries and de Boer (2010) reported land occupation of 49 m^2 for the production of 1 kg edible beef (25 m^2. kg^{-1} LW) in Europe. The higher land occupation in NP compared to Europe implies that land is inefficiently used in current beef production using natural pasture in Brazil (Cederberg et al., 2009). Our results also differ from estimates for the United States. For instance, Capper et al. (2012) reported 98.7 m^2. kg^{-1} CW (i.e., 49.3 m^2. kg^{-1} LW) for suckler cattle fed on grass in the United States, which is much lower than in the Brazilian system. Moreover, Pelletier et al. (2010) reported land occupation for beef production systems in the United States to be approximately 120 m^2. kg^{-1} LW for pasture, 98 m^2. kg^{-1} LW for backgrounding/feedlot, and 84 m^2. kg^{-1} LW for feedlot. These values are slightly lower than in the Brazilian system. Differences in the absolute values for land occupation in studies evaluating similar systems might occur because of differences in the methodological choices made in an LCA, such as differences in the system definition and method of allocation.

Fossil energy use

Fossil energy use in beef production was very low (Table 3.6). Fossil energy use was the highest in IP due to the production and application of fertilizers. Following IP, FL also had higher energy use compared with NP and CR. Production of concentrate feed was the major component of fossil energy use in this farming system. Our results show that NP and CR had low fossil energy use, with a value of 2.1 MJ. kg^{-1} LW for both these systems. NP is a low-input farming system; whereas concentrate feed production in FL requires fossil energy inputs for operation of farm machinery, pesticide and fertilizer production, fertilizer application, crop processing, and transportation. The IP system is also quite distinct from natural pasture in terms of both inputs and DM production, and requires fossil energy input for fertilizer production, fertilizer application, and seeding.

The estimates for fossil energy use in this study are similar to those reported by Cederberg et al. (2009) for Brazilian beef production (2.0 MJ. kg^{-1} LW versus 2.1 MJ. kg^{-1} LW in this study). The use of fossil energy in beef production systems in Brazil is low compared to Europe. European beef production requires approximately ten times more fossil energy compared to Brazilian beef production in natural pasture

(Cederberg et al., 2009; Nguyen et al., 2010). Generally, the higher the amount of concentrate feed, the higher the use of fossil energy (Pelletier et al. 2010).

Operating profit

IP was more profitable than NP, CR, and FL at farm level (Table 3.6). Hence, adoption of the IP system could improve the operating profit of the farm in comparison to NP, which is the traditional and widely-used production system in southern Brazil. Variable costs for the IP system exceeded those for NP due to higher requirements for labor, machinery, and especially fertilizer. The increase in variable costs, however, did not exceed the increase in total revenue of the farm due to higher productivity. Nevertheless, the transition process was not accounted for in this study, which may imply lower returns on investment than indicated here (Rueda et al., 2003). Moreover, operating profit of the IP system per kilogram LW was lower than for the NP and CR systems (Table 3.6), due to the relatively high variable costs per kilogram LW.

Due to the integration of crops and cattle in the CR system, this farming system was economically competitive with all farming systems at farm level, except for IP. CR, however, was similar to NP in terms of profitability expressed per kilogram LW (Table 3.6), because the soybean component of the farm accounted for most (89%) of the operating profit of CR. Cattle have access to soybean residues in the period from April until September. Cultivating a second crop after soybean is, therefore, not possible due to the presence of cattle. Given the large contribution of soybean production to the operating profit and the prices for grains (Table 3.4), we expect that cultivating a second crop will result in a higher operating profit than beef production from crop residues. CR may thus not be economically attractive in southern Brazil, where climate conditions enable farmers to cultivate two crops per year. The CR system may have more potential in regions where only one crop can be cultivated per year. In general, CR led to efficient use of land (40% of the land is used for crop cultivation during half of the year) and labor.

FL had a slightly higher operating profit than NP at farm level, but operating profit was lowest per kilogram LW compared to the other farming systems (Table 3.6). In

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FL, concentrate feed costs accounted for 42% of total variable costs (Figure 3.3). The high cost of concentrate feed increased the total costs, and consequently decreased the operating profit compared to IP and CR. Therefore, supplementing concentrate feed to increase cattle productivity might not be an economically viable option in Brazil, given the current relative prices of beef and concentrate feed.

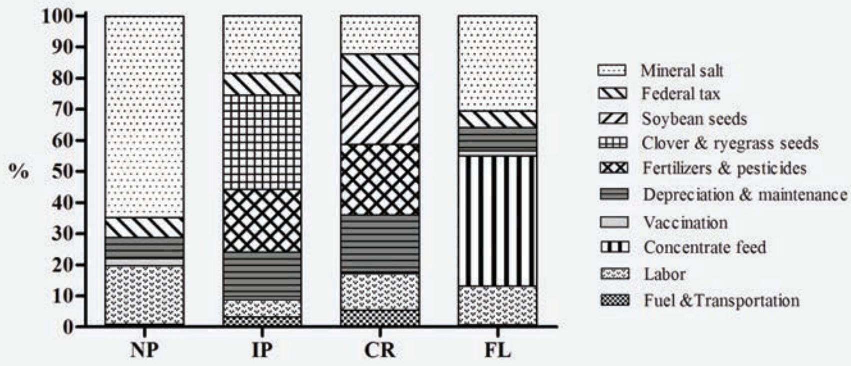

Figure 3.3 Percentage of each cost in total operating costs for the four farming systems.

In line with our findings, results of other studies have also shown that IP is more profitable than NP (Bouton, 2007; Borges et al., 2014). Our results also support the suggestion of Sulc and Tracy (2007) that CR has the potential to be profitable and can enhance the production efficiency of the farm. Our results are also consistent with Ramsey et al. (2005) and Pacheco et al. (2014), who showed that variable costs, such as feed costs, make the largest contribution to the total cost of FL.

Sensitivity analyses

The effects of a 10% change in the selected beef production parameters on the environmental and economic performance of the different farming systems are presented in Table 3.7. The parameters have different effects on the environmental and economic performance of beef production. Overall, changes in calving rate had more impact on GWP and fossil energy than on the other performance indicators (Table 3.7). Changes in pasture DM production, pasture utilization efficiency, and stocking rate had a greater effect on land occupation and operating profit than the on the other performance indicators. Pellitier et al. (2010) found a similar effect for pasture utilization efficiency. They showed that low pasture utilization (e.g., 30% compared to 60%) increases GWP, fossil energy use, and land occupation. In this regard, Ruviaro et al. (2015) also found similar effects and showed that a modification in the quality and quantity of feed, expressed in the variability of DM, can alter the GWP. Dick et al. (2015b) showed a similar effect for calving rate, in their study a scenario with a high calving rate had lower GWP.

Policy implications

In this section we discuss the policy implications of our results and highlight the advantages, disadvantages, and challenges of the different farming systems. We also identify future research that would provide useful information to further assist policy makers in identifying economically and environmentally attractive feeding strategies. In commercial agriculture, profitability is often one of the most important determinants of the adoption of alternative farming systems (Vellinga et al., 2011; Hristov et al., 2013). Our results demonstrate that IP could substantially improve the economic performance of farms. Borges et al. (2014), however, has shown that the adoption rate of improved pastures is low in Brazil. A lack of knowledge and skills for pasture improvement and the unavailability of qualified technical assistance are the main reasons for the low rate of adoption of improved pastures (Borges et al., 2014). To make IP a common farming strategy, more farm-level research is needed to fully evaluate the transition dynamics from NP to IP.

The results show that IP has a high potential to not only increase farm profitability, but also to improve the environmental performance of beef production. In the IP system, GWP and land occupation per kilogram LW were lowest, whereas fossil energy use

Table 3.7 Sensitivity analysis results (% deviation).

		GWP[1]			
Parameters	Increase/decrease	NP[3]	IP[4]	CR[5]	FL[6]
Calving rate	+10%	-3.4	-4.5	-3.4	-3.9
	-10%	+4.1	+5.5	+4.2	+4.8
Pasture/feed DM[7]	+10%	-0.9	-4.4	-1.0	-0.7
	-10%	+1.3	+2.7	+1.8	+0.3
Pasture utilization efficiency	+10%	-0.9	-4.4	-1.3	-1.6
	-10%	+1.3	+2.7	+2.2	+2.0
Stocking rate	+10%	-0.7	-1.1	-7.4	-0.8
	-10%	+1.1	+1.3	+7.5	+0.3

1. Global warming potential.
2. Sensitivity analysis of operating profit was performed per farm.
3. Natural pasture.
4. Improved pasture.
5. Integrated crop-pasture; cattle fed on crop residues.
6. Feedlot pasture.
7. Dry matter.

per kilogram LW was higher than in all the other systems (Table 3.6). Feed efficiency of cattle has a large effect on GWP. Although cattle are able to survive on relatively low quality pasture due to their unique digestive system, low quality feed results in considerable CH_4 and N_2O emissions (Pelletier et al., 2010). Improving pasture quality in the IP, therefore, decreased total GWP. As proposed by Cederberg et al. (2009) and Elferink and Nonhebel (2007), such an improvement may control the expansion of beef production in ecosystems where there is a clear interest in preserving nature (Strassburg et al., 2014). Thus, more intensive use of land in IP may discourage land clearing, which could lead to less biodiversity loss off-farm. A land-sparing strategy such as IP, however, may lead to a decline in on-farm biodiversity. In a land-sharing strategy, such as NP, the relationship between yields and within-farm biodiversity could be positive or neutral, such that agro-ecological management methods could lead to adequate output while enabling more species to coexist within pasture areas

	Land occupation				Fossil energy use				Operating profit[2]			
	NP	IP	CR	FL	NP	IP	CR	FL	NP	IP	CR	FL
	-3.3	-4.1	-3.1	-1.3	-0.3	-3.8	-0.4	-3.8	+4.2	+5.5	+0.4	+5.4
	+3.7	+4.7	+3.7	+0.6	+0.7	+4.7	+0.9	+4.7	-4.8	-6.2	+0.5	-6.1
	-8.7	-4.8	-6.1	-8.4	-1.2	-7.6	-1.2	-2.4	+9.1	+11.3	+8.3	+10.2
	+11.7	+4.1	+7.0	+7.3	+0.2	+5.2	-0.2	+3.7	-10.1	-6.7	-9.9	-9.1
	-8.6	-4.5	-7.2	-6.1	-0.8	-4.7	-0.3	-2.7	+9.4	+11.3	+8.0	+10.2
	+11.7	+4.1	+7.0	+4.4	+0.1	+2.8	+0.1	+1.8	-10.1	-11.3	-8.8	-9.0
	-0.8	-9.1	-0.6	-0.2	-0.2	-0.1	-9.6	-7.7	+10.0	+13.0	+9.5	+11.0
	+0.3	+11.1	+0.2	+0.3	+0.3	+0.2	+10.0	+5.4	-10.0	-13.0	-9.7	-11.1

(Egan and Mortensen, 2012). Unfortunately, farm-level data on biodiversity were not available for this research, so we were unable to compare the four different systems in this respect.

The results show that CR had a higher economic return than IP when expressed per kilogram of LW, implying that the per unit contribution margin was higher in CR than in IP. CR was the second most profitable system when operating profit was expressed per farm (following IP). According to Hendrickson et al. (2008), one of the primary benefits of CR is its economic return, i.e., farmers adopt integrated crop-beef production in Brazil to improve the profitability of their farms. Moreover, diversifying production is also a way of reducing the risk for farmers of market fluctuations (Hendrickson et al., 2008). Our results, however, show that the higher economic return in this system was related mostly to the soybean component of the farm, whereas the cattle component had the lowest operating profit compared to the other systems. In the

CR system, the productivity of cattle did not increase by grazing soybean residues, as we assumed that the feed utilization efficiency and NE content are the same for natural pasture and soybean residues. Studies with alternative crops (such as oats), however, found that integrated crop-cattle systems were more productive than natural pasture (ADF 2012). Although CR may be economically attractive, this system requires an increase in management, knowledge, and skills because of the need to understand the interactions between crop and livestock (Hendrickson et al., 2008).

Supplementation of cattle with concentrate feed in FL allows the animal to grow faster and shortens the fattening period. Increased cattle productivity, hence, led to a reduction in overall GWP and land occupation compared with NP (Table 3.6). The analysis of operating profit, however, indicated that the increase in cattle performance from dietary supplementation did not increase operating profit substantially. Concentrate feed costs significantly affect the total cost of production, and consequently the profitability of the FL system. Profitability of FL, therefore, was only marginally higher than NP at farm level. Although the FL system may be a viable option from an economic point of view, it also requires highly developed skills and knowledge. Moreover, small changes in the prices of beef and concentrate feed may substantially affect the profitability of this system. We assumed that the beef price was equal across the four farming systems. However, it should be noted that the feed consumed by cattle can modify beef quality (Andrae et al., 2001) and consequently the beef price. These two factors (feed and beef quality) are inevitably linked because different feed types vary in nutrient composition. Therefore, future research should also analyze beef quality in different farming systems. Such an analysis was beyond the scope of this paper.

A more comprehensive evaluation of other environmental and economic issues related to beef production in different farming systems was not possible in this study because the necessary data (such as data on land use change and biodiversity) were not available. Future research should focus on collecting data to support a broader analysis of environmental and economic performance.

Conclusions

The objective of this study was to assess the environmental and economic performance of different feeding strategies in southern Brazil. The results show that IP improves the environmental and economic performance of beef production under current conditions. CR improves the economic performance, but the environmental performance of this system was not better than NP. FL results in a small improvement in environmental and economic performance. Our results suggest that IP is the most promising strategy for improving the environmental and economic performance of beef production in southern Brazil. Further research is needed to determine the social and economic implications of a transition to more intensive beef production systems and to evaluate this strategy across a broader range of environmental and economic issues.

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Appendix 3

Herd composition (based on IPCC Tier 2)

Table A 3.1 Farm model and herd proposition.

	NP[1]	CR[2]	IP[3]	FL[4]
Pasture size (ha)	1200	720	1200	1200
Slaughter age (month)	36	36	24	23.8
Stocking rate (%)	0.51	0.46	2.208	0.51
Total number of cattle (farm level, excluding feedlot)	609	554.7	2649.6	609
Overall mortality (%)	2	2	2	2
Replacement rate (%)	20	20	20	20
Calving rate (% yr-1)	70	70	70	70
Mortality rate of new born (%)	4	4	1	4
Number of female calf (0-1 yr)	66.5	60.6	377.1	86.0
Number of male calf (0-1yr)	66.5	60.6	377.1	86.0
Number of female calf (1-2 yr)	66.5	60.6	377.1	84.3
Number of male calf (1-2 yr)	66.5	60.6	377.1	84.3
Number of female (heifer)(2-3 yr)	66.5	60.6	0.0	0.0
Number of male (steer) (2-3 yr)	66.5	60.6	0.0	0.0
Total number of slaughtered cattle every year	132.9	121.1	1508.3	172.1
Live weight (kg)	57165	52083	648586	73993
Carcass percent (%)	51	51	51	51
Male cattle weight to go slaughterhouse (kg)	440	440	440	440
Female cattle weight to go slaughterhouse (kg)	420	420	420	420

1. Natural Pasture.
2. Integrated crop-pasture; cattle fed on crop residues.
3. Improved pasture.
4. Feedlot pasture.

Environmental performance

Table A 3.2 Equations, tables and references used for quantification of environmental indicators.

Emissions	Equation	Table	Reference
Methane emission from enteric fermentation	7b	Table 5	Ellis et al. (2007)
Direct N_2O emission from manure management	10.25	-	IPCC (2006)
N losses due to volatilization	10.26	10A-2, 10A,4, 10A-8, 10-22	IPCC (2006)
Indirect N_2O emission due to volatilization of N from manure management	10-27	11.3	IPCC (2006)
N losses due to leaching from manure management system	10.28	-	IPCC (2006)
Indirect N_2O emission due to leaching from manure management	10.29	11.3	IPCC (2006)
Direct N_2O emissions from managed soils	11.1	11.1	IPCC (2006)
Lime	11.12	-	IPCC (2006)
Off road transportation	3.3.1	3.3.1	IPCC (2006)
Road transportation	3.2.1	3.2.1	IPCC (2006)
Crop residues	11.6 , 11.10	2.6, 11.2, 11, 7	IPCC (2006)
Atmospheric deposition of N volatilized	11.9	11.3	IPCC (2006)
Leaching and run off	11.10, 11.5, 11.8	11.3, 11.5	IPCC (2006)

Table A 3.3 Emission factors.

Production of fertilizers	Emission	Unit	Reference
P_2O_5	2.13	Kg CO_2-eq., per kg P_2O_5	Ecoinvent- 2013
K_2O	0.905	Kg CO_2-eq., per kg K_2O	Ecoinvent- 2013
Lime	0.0372	Kg CO_2-eq., per kg $CaCO_3$	Ecoinvent- 2013
Roundup (Glyphosate)	11.6	Kg CO_2-eq.	Ecoinvent- 2013
Pesticides unspecified	11.1	Kg CO_2-eq.	Ecoinvent- 2013
Phosphate rock	0.318	Kg CO_2-eq., per kg P_2O_5	Ecoinvent- 2013
Diesel	0.602	Kg CO_2-eq.	Ecoinvent- 2013
Ryegrass & clover mixture	0.266	Kg CO_2-eq.	Ecoinvent- 2013

Table A 3.4 Energy coefficients.

Soybean plantation phase energy inputs	Energy content (MJ/kg or liter)	Unit	Reference
Seeds	4.47	MJ/kg seed	Ecoinvent- 2013
P fertilizer	30.06	MJ/kg P_2O_5	Ecoinvent- 2013
P fertilizers (Phosphate rock organic)	4.47	MJ/kg P_2O_5	Ecoinvent- 2013)
Potassium chloride	14.69	MJ/kg K_2O	Ecoinvent- 2013
Lime (CaO)	0.49	CaO (lime)	Ecoinvent- 2013
Pesticides unspecified	196	MJ/kg	Ecoinvent- 2013
Diesel	57.7	(MJ/kg diesel)	Ecoinvent- 2013
Glyphosate	192.3	(MJ/kg)	Ecoinvent- 2013
Ryegrass & clover mixture	1.41	(MJ/kg)	Ecoinvent- 2013

TableA 3.5 Unit conversions.

Diesel density (kg/liter)	0.84
1kWh= MJ	3.6

Economic performance

Table A 3.6 Related costs in each farming systems.

Costs	NP[1]	IP[2]	CR[3]	FL[4]	Reference
Vaccination (R$/head)	3.3	3.3	3.3	3.3	IBGE, 2011
Veterinary cost (R$/head)	3.62	3.62	3.62	3.62	IBGE, 2011
Depreciation (R$/ha)	0.50%	0.80%	1.00%	0.80%	Expert opinion
Federal sales taxes (INSS/ SAT) percentage from revenue	2.40%	2.40%	2.40%	2.40%	Bowman et al 2012
Transport (R$/head/km)	0.05	0.05	0.05	0.05	IBGE, 2011
Maintenance (percentage of revenue)	2%	2%	2%	2%	Bowman et al 2013

1. Natural pasture.
2. Improved pasture.
3. Integrated crop-pasture; cattle fed on crop residues.
4. Feedlot pasture.

3

Chapter 4

Evaluation of the Environmental, Economic, and Social Performance of Soybean Production Systems in Brazil

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Abstract

Soybean production has a crucial role in the development of Brazilian agriculture and recently became the most important commodity in Brazilian agribusiness. Various soybean production systems exist, which are claimed to differ in terms of sustainability performance. In this regard, evaluation of environmental, economic, and social performance of different soybean production systems in Brazil, by consideration of variability in input parameters, is critically needed. In this context, we evaluated environmental, economic, and social issues for the two main soybean production systems in southern Brazil, the conventional system, which produces genetically modified (GM) or non-genetically modified (non-GM) soybeans, and the organic system. Data were collected for 2012 from three sources: soybean farms in Paraná, Brazil (15 GM, 15 non-GM, and 15 organic farms), the Brazilian Enterprise for Agricultural Research (EMBRAPA), and expert elicitation. Monte Carlo simulation was used to account for the variation in input parameters. Five sustainability issues were evaluated in this study: global warming, land occupation, primary energy use, profitability, and employment. Results revealed that, compared with the GM and non-GM systems, organic systems had a higher probability (77%) to have a lower global warming potential. Land occupation was higher and energy use was lower for organic systems than for the GM and non-GM systems at every level of probability. Concerning profitability, organic systems had a higher probability (60%) to have higher profitability compared with GM and non-GM production, and employment was higher for organic systems at every level of probability. Overall, simulation results of this study illustrated the relatively high level of variation in the environmental, economic, and social performance of organic soybean production systems. Sensitivity analysis based on stepwise regression showed that yield, fuel, fertilizer, and labor had significant effects on performance. This study shows that accounting for variability in key system parameters provides not only insight in the most likely outcomes, but also in the robustness of system performance. This additional information about the robustness of system performance enhances the debate about the sustainability of soybean production systems.

Introduction

Soybean production has a crucial role in the development of Brazilian agriculture and recently became the most important commodity in Brazilian agribusiness (Cavalett and Ortega, 2009; Prudêncio da Silvaa et al., 2010; MVO, 2011). Increased soybean production has been triggered by growing demand worldwide for both soybean meal and soybean oil (MVO, 2011). Soybean production in Brazil mainly occurs in the southern and central western regions. In Paraná, one of the states in the south of Brazil, there are two main soybean production systems, the conventional production system, which produces genetically modified (GM) or non-genetically modified soybeans (non-GM), and the organic production system (MVO, 2011).

These soybean production systems differ in terms of their sustainability performance (Franke et al., 2011). Several studies have found that using GM soybeans positively affects a number of environmental, economic, and social (EES) issues. GM soybean production produces at a lower cost than non-GM soybean production, partly because of lower labor requirements (van Meijl and van Tongeren, 2004; Antoniou et al., 2012). Moreover, GM soybean production has higher productivity, and uses fewer pesticides and herbicides (Azadi and Ho, 2010; Antoniou et al., 2012; Brookes and Barfoot, 2012). Although cultivation of GM crops can improve some environmental aspects, concerns regarding the negative impacts of using GM products are increasing (Azadi and Ho, 2010). Araujo et al. (2003), for instance, found that more carbon dioxide was released from soils to which glyphosate had been added, a product commonly used in the cultivation of GM soybeans, compared to soils without added glyphosate. Organic production is gradually being perceived as a possible alternative to address the concerns about GM production (Stolze et al., 2000; Delate, 2003; Pimentel et al., 2005). Pelletier (2008) showed that organic production of Canadian canola, corn, soybeans, and wheat had a lower cumulative energy demand and lower emission of greenhouse gases than their conventional counterparts. Organic production, however, has been criticized as being inefficient compared to conventional production systems due to lower yields (Nemecek et al., 2011; Seufert et al., 2012; Tuomisto et al., 2012). Another criticism is that organic products are usually more expensive than conventional products (McBride and Greene, 2009). In addition, organic crop systems substitute chemicals with field operations and labor, which make them less practical on large scale farms (McBride and Greene, 2009).

In this regard, several studies have compared the environmental and economic performance of different production systems by using empirical data (Mollenhorst et al., 2006; Thomassen et al., 2008; Bokkers and de Boer, 2009; McBride and Greene, 2009; Knudsen et al., 2010) and census or national statistical data (Oude Lansink et al., 2002; Pelletier et al., 2008; Serra et al., 2008; Leinonen et al., 2012). A number of these studies accounted for variation of outputs and inputs within and between systems (Mollenhorst et al., 2006; Serra et al., 2008; Thomassen et al., 2008; Leinonen et al., 2012). However, so far only Leinonen et al. (2012) have accounted for stochasticity in the input parameters. Studies based on deterministic input parameters do not adequately account for the uncertainty of key variables and ignore the differences in variation of the performance indicators used to compare production systems (Gebrezgabher et al., 2012; Gocsik et al., 2013). Furthermore, studies that evaluate the social performance of different systems are still lacking. This study aims to evaluate EES issues of different soybean production systems using a stochastic approach based on Monte Carlo simulation. This approach gives insight into the range of outcomes and therefore provides more complete information to policy makers about the performance of various soybean production systems.

Material and methods

The selection of EES issues relevant for soybean production systems was based on the study of Pashaei Kamali et al. (2014). We selected only those issues that were geographically relevant (e.g., water deprivation was excluded because soybeans are not irrigated in Brazil), quantifiable, and for which data were available. The EES issues that resulted were global warming, land occupation, primary energy use, profitability, and employment. Data were collected by EMBRAPA[1]for the year 2012

1 EMBRAPA: Brazilian Enterprise for Agricultural Research.

from soybean farms in Paraná in Brazil (i.e., 15 GM, 15 non-GM, and 15 organic farms). Data were gathered specifically for this study, either by visiting farms directly or by phone calls. The selected farms for data gathering were representative of soybean production in south Brazil and were relatively homogeneous farms. Data were validated by comparing them with available data in IBGE[2] for different municipalities (IBGE 2013). IBGE data represent average quantities and prices across farms at the municipality level.

Environmental performance

The environmental impact of soybean production systems was evaluated using life cycle assessment (LCA). LCA is a method that evaluates the environmental impact along the entire life cycle of a product (Guinée, 2002). LCA relates the environmental impacts of the defined production system to the functional unit (FU) (Guinée et al., 2002), which is the main product of the analyzed system in quantitative terms. In this study, the FU is defined as one ton of GM, non-GM, or organic soybeans[3]. The system boundary is from cradle-to-farm gate. Processes included are the extraction of raw materials to produce farm inputs, the processing, manufacturing and distribution of these inputs, and all the processes on the soybean farm until the moment the soybeans are ready to be sold at the farm gate (Figure 4.1). Environmental impacts related to production and maintenance of buildings and machinery were not included because the contribution was assumed to be minor (IPCC, 2006; Pradhan et al., 2008). To assess the impact of a production system on global warming, we quantified emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Emissions were summed based on their equivalence factor in terms of CO_2-equivalents (100-year time horizon: 1 for CO_2, 30 for CH_4, and 265 for N_2O) and expressed per FU (IPCC, 2013). To assess the global warming potential (GWP) of soybean production, the following activities are of importance: (1) production and application of system inputs (e.g.,

2 The Brazilian Institute of Geography and Statistics.

3 All computations were carried out based on the dry matter of soybeans (Appendix 4).

fertilizers, limestone, pesticides, and energy resources); (2) cultivation and harvesting of crop products; (3) transport of unprocessed and processed products between all activities up to the farm gate; and (4) off-road transportation (i.e., use of machinery and tractors for cultivation, harvesting, and other field operations). Emissions related to the production of inputs (e.g., production of fertilizers, limestone, pesticides and energy resources) were based on the Ecoinvent database (Ecoinvent, 2013). Emissions were based on international averages, as there are no country specific emission factors available for the production of these inputs in Brazil. Emissions related to seed production were not included in this study due to lack of data. Emissions related to the application of limestone and emissions related to field work (e.g., cultivation, harvesting, and other field operations) were calculated based on IPCC (2006). The amount of nitrogen (N) from crop residues was also based on IPCC (2006). Emissions related to transportation (e.g., transportation of inputs to the farm) were based on IPCC (2006), and the average distance per ingredient was based on the country of origin (Prudêncio da Silva et al., 2010). Emissions related to land use change (e.g., deforestation) were not considered in this study because soybean production in Paraná has not been directly related to deforestation (Prudencio da Silva et al., 2010). Co-product allocation was not required in this study, since the systems do not have multiple outputs. For the detailed formulas, references of formulas and emission factors see the Appendix 4.

The physical occupation of land area was measured as the area used for the production of one ton of soybeans during one year, expressed in square meters per year ($m^2.yr^{-1}$). In the calculations related to land occupation it was assumed that soybeans are cultivated for a period of six months per year. A lower value for land occupation indicates that a production system has a higher productivity. Primary energy use for producing one ton of soybeans was estimated based on the energy consumption per phase and expressed in megajoules (MJ). The energy required to produce soybeans included the energy used to produce system inputs (i.e., seeds, fertilizers, limestone, pesticides, and energy sources) and the energy used for the transportation of inputs and for field operations (fuel and electricity to operate agricultural field equipment). The energy coefficients were based on the Ecoinvent database (Ecoinvent, 2013). For the detailed formulas and energy coefficients see the Appendix 4.

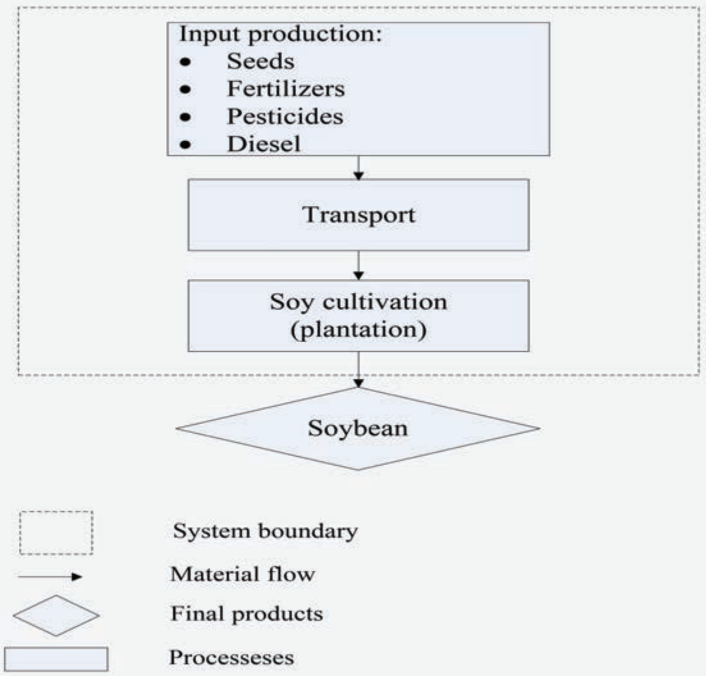

Figure 4.1 System boundary.

Economic performance

To evaluate economic performance, operating profit was used as an indicator for profitability. It was quantified as total revenue minus operating costs minus depreciation (Hillier et al., 2010). Operating costs were the costs related to seeds, fertilizers, pesticides, fuel, lubricants, electricity, repair, maintenance, operating interest, insurance, hired labor, and transportation. Total operating profit is an indicator of the relative success of operations in terms of their ability to meet short-term financial obligations (McBride and Greene, 2009).

Social performance

Social sustainability was defined in this study as the quantity of employment[4] and was expressed as the number of working hours per hectare per day. Working hours is an indicator that captures the employment capacity in such a way that makes employment comparable across various contexts (Salz et al., 2005). Labor in this study refers to all categories of employees on the farm; it includes full-time, part-time, and casual labor.

Stochastic simulation

Several methods have been proposed for identifying and quantifying uncertainty in LCA and economic studies (Gocsik et al., 2013; Herrmann et al 2014; Groen et al. 2014). The most commonly used method in stochastic analysis is the Monte Carlo (MC) simulation (Groen et al. 2014). MC is a technique that combines information on the distribution of different stochastic variables by running multiple iterations to provide insight into the range of possible outcomes and the likelihood or probability of these outcomes. Moreover, correlations and other relations and dependencies of data can be modeled by MC simulation. In addition, MC simulation can show the sensitivity of the outcomes to input variables (Ghasemi et al., 2012). Monte Carlo simulation was conducted using @Risk, an add-in in MS Excel (Microsoft Corporation, Redmond, WA). Once the essential variables (indicators) were selected, characterization of the probability distributions was carried out. Probability distributions were defined for technical variables. The MC simulation model used in this study was based on data collected on 15 GM, 15 non-GM and 15 organic farms. We calculated the mean and standard deviation (SD) for the three farm types and these values were used as input variables in the Monte Carlo simulation. Normal distributions are commonly used

4 Work quality (i.e., working condition) was not evaluated in this study, due to lack of data.

to model input and output variables (e.g., Gebrezgabher et al. 2012). Testing for normality was not possible due to data limitations. For the variables for which farm data were lacking, the probability distribution of a variable was defined using expert opinion assuming a triangular distribution with parameters reflecting the minimum, most likely, and maximum values. Experts were selected from SALSA[5] project partners and EMBRAPA Soja in Paraná. All input and soybean (as output) prices for different production systems were considered deterministic, implying that prices differed between but not within different production systems. This assumption is realistic because farms were located in the same state and prices of inputs in regional markets hardly vary within a specific year. Cost of depreciation was considered to be deterministic, as depreciation in soybean production is negligible (due to no-tillage system, off-farm storage facilities, which are not part of our system, and use of machinery for other crops), and has a small impact on profitability. The costs of certification and the price premiums were also considered to be deterministic, as they are constant within a specific year for all farms in each system. All these parameters (i.e., the mean and standard deviation of real input parameters) fed the Monte Carlo, which gave the results in the form of a probability distribution around the mean values. The model input variables along with their units of measurement are listed in Table 4.1 (technical variables) and Table 4.2 (input and output prices). The functional forms for the stochastic variables are shown in Table 4.1. Further details about the methods and data, which are not discussed in the main text are available in the Appendix 4.

Sensitivity analysis

The sensitivity analysis was carried out to identify the input variables which had high effect on the outcomes. This is a common motivation for sensitivity analysis (Saltelli et al., 2008). The sensitivity analysis was performed in @Risk using multivariate stepwise regression analysis. A multivariate regression analysis was run for each

5 Knowledge-based Sustainable vAlue-added food chains: innovative tooLs for monitoring ethical, environmental and Socio-economic impActs and implementing EU-Latin America shared strategies (EU-FP7).

iteration, with the output of interest as the dependent variable and the simulated values of each stochastic variable as independent variables. In the multivariate regression sensitivity analysis, stepwise selection criteria were performed by varying one input parameter across the possible range while holding the other input parameters constant at their mean values. As the variables are measured in different units of measurement, it is difficult to compare coefficients. One solution is to estimate regression models using standardized variables, which are metric-free. The output of this sensitivity analysis is presented as standardized coefficients or β coefficients. The regression coefficients were standardized by computing Z scores for each of the variables. Before fitting the multiple regression equation, all variables were standardized by subtracting the mean value and dividing by the standard deviation (SD) (Ghasemi et al., 2012). The β coefficient indicates the number of SDs the output will change, given a one SD change in the input (assuming all other variables are held constant). With regard to price data, price changes across years were approximated in the sensitivity analysis by considering the effect of a ten percent change (increase/decrease) in input prices while keeping other parameters and prices constant. The results of the sensitivity analyses help decision-makers to define opportunities to improve sustainability by identifying the variables with the highest impact on outputs. In other words, sensitivity analyses can help to identify critical control points, prioritize additional data collection or research. For the detailed formulas of sensitivity analysis see the Appendix 4.

Table 4.1 Stochastic technical variables used in the simulation model and their respective units, distributions, and key parameters.

			GM[1] (n[2]=15)	Non-GM[3] (n=15)	Organic (n=15)
Variable	**Unit**	**Distribution type**	**Parameters[4]**	**Parameters**	**Parameters**
Yield	$Kg.ha^{-1}.\ yr^{-1}$	Normal	Mean: 3560 SD[5]: 347	Mean: 3541 SD: 381.9	Mean: 2665 SD: 520.8
Seeds	$Kg.ha^{-1}.\ yr^{-1}$	Normal	Mean: 56 SD: 3.2	Mean: 56 SD: 3.4	Mean: 66 SD: 3.6
P fertilizer[6]	$Kg\ ha^{-1}.yr^{-1}$	Normal	Mean: 76 SD: 8.2	Mean: 76.6 SD: 7.9	Mean: 38 SD: 4
Manure[7]	$Kg\ ha^{-1}.yr^{-1}$	Normal	NA[8]	NA	Mean: 38 SD: 4
K fertilizer[9]	$Kg\ ha^{-1}.yr^{-1}$	Normal	Mean: 76 SD: 8.2	Mean: 76 SD: 8.4	Mean: 66 SD: 8.2
Lime	$Kg\ ha^{-1}.yr^{-1}$	Triangular	Minimum: 1500 Most likely: 2000 Maximum: 2000	Minimum: 1500 Most likely: 2000 Maximum: 2000	Minimum: 1500 Most likely: 2000 Maximum: 2000
Pesticides	$Kg\ ha^{-1}.yr^{-1}$	Normal	Mean: 5.53 SD: 0.72	Mean: 6.53 SD: 0.81	NA
Fuel	$L.\ ha^{-1}.yr^{-1}$	Triangular	Minimum: 30 Most likely: 45 Maximum: 60	Minimum: 40 Most likely: 50 Maximum: 60	Minimum: 30 Most likely: 35 Maximum: 40
Labor	$Person.ha^{-1}$	Normal	Mean: 0.06 SD: 0.04	Mean: 0.08 SD: 0.02	Mean: 0.97 SD: 0.53

1. Genetically modified.
2. Number of Farms.
3. Non-genetically modified.
4. Parameters for the Normal distributions were obtained from the analysis of data from 15 GM, 15 non-GM, and 15 organic farms in Paraná in 2012. Parameters for the Triangular distributions were obtained from expert opinion.
5. Standard deviation.
6. Single super phosphate, triple super phosphate and phosphate rock were considered as phosphate (P) fertilizer in the conventional system.
7. Phosphate rock and manure were considered as P fertilizer in the organic system.
8. Not applicable.
9. Potassium chloride was considered as potassium (K) fertilizer in both systems.

Table 4.2 Deterministic variables used in the simulation model: input and output prices in 2012.

		GM[1]	Non-GM[2]	Organic
Variable	**Unit**	**Value**	**Value**	**Value**
Soybeans	R\$[3].kg^{-1}	1.05	1.05	1.05
Price premium	%	0	7	50
Seeds	R\$.kg^{-1}	3.00	3.00	3.60
P fertilizer	R\$.kg^{-1}	1.00	1.00	0.40
Manure	R\$.kg^{-1}	NA[4]	NA	0.11
K fertilizer	R\$.kg^{-1}	1.24	1.24	1.24
Lime	R\$.kg^{-1}	0.08	0.08	0.08
Pesticides	R\$.kg^{-1}	0.83	0.83	NA
Glyphosate	R\$.kg^{-1}	14.64	NA	NA
Labor[5]	R\$.hr^{-1}	1.40	1.40	1.40
Diesel	R\$.litre^{-1}	2.20	2.20	2.20

1. Genetically modified.
2. Non-genetically modified.
3. Brazilian Real, 1 USA dollar equals to 2.25 Brazilian Real.
4. Not applicable.
5. Labor includes all types of Labor (i.e., full time, part time, and casual).

Results

Environmental, economic, and social performance

Table 4.3 shows the results of the simulated EES performance for the three soybean production systems. Figure 4.2 presents the simulation results in the form of Cumulative Distribution Functions (CDF). The CDF gives the probability of having

Table 4.3 Simulation[1] results for the environmental, economic, and social performance of one ton of soybeans for the GM, non-GM, and organic production systems.

Performance indicator	Unit[2]	GM[3]		Non-GM[4]		Organic	
		Mean	SD[5]	Mean	SD	Mean	SD
Environmental							
GWP [6]	kg CO_2-eq.ton^{-1}	277.77	21.40	278.18	21.14	270.96	33.13
Land occupation	m^2.yr^{-1}.ton^{-1}	1711.47	165.94	1724.16	186.14	2376.76	521.11
Primary energy use	MJ.ton^{-1}	3075.57	329.90	3149.28	329.62	2149.21	360.48
Economic							
Profitability	R$.ton^{-1}	517.94	116.08	533.14	115.94	593.4	374.10
Social							
Employment	hr.ha^{-1}day^{-1}	0.29	0.19	0.24	0.08	3.98	1.68

1. 5000@Risk iterations.
2. All results are per ton of soybeans, except employment (per hectare).
3. Genetically modified.
4. Non-genetically modified
5. Standard deviation.
6. Global warming potential.

an output less than or equal to a given value on the horizontal axis. The CDF extends the insight into EES performance by showing the whole range of possible outcomes. The results for GWP demonstrate that organic systems had a higher probability (77%) to have a lower GWP per ton soybeans than the GM and non-GM systems (Figure 4.2). Organic systems showed a better mean performance for GWP (2.5%), but also a higher SD than the GM and non-GM systems (Table 4.3). Concerning land occupation, results demonstrate that organic systems scored higher at every level of probability compared with GM and non-GM. In other words, land occupation per ton soybeans was higher for organic production compared to GM and non-GM soybean production (on average 27%) irrespective of the variation in input parameters (Table

4.3). This means that organic production was less productive than the GM and non-GM systems. The results for energy use show that organic production used less energy per ton soybeans (29-32%) at every level of probability compared to GM and non-GM production (Table 4.3). Concerning profitability, results show that organic systems had a higher probability (60%) to have a higher profitability per ton of soybeans than the GM and non-GM systems (Figure 4.2). Organic production showed a better mean performance of profitability (11-15%), but again, also a higher SD (higher financial risk) compared to the GM and non-GM systems (Table 4.3). In terms of employment, results show that organic systems had higher employment at every level of probability compared to the GM and non-GM systems. Organic systems required, on average, more working hours per hectare per day compared to the GM and non-GM systems (Table 4.3). Although the performance of the different systems varied across the EES issues in this study, overall the simulation results showed a higher variation for organic systems in all EES issues of this study, which is also reflected in the higher SD-values (Table 4.3).

Sensitivity analyses

Table 4.4 presents the β coefficients for the multivariate regression analysis of the effect of the stochastic variables on the results for GWP, land occupation, energy use, profitability, and employment for each production system. A β coefficient of 0 indicates that no significant relationship exists between the input and output, whereas a β coefficient of 1 or -1 indicates a 100% correlation between the input and output, i.e., a 1 or -1 SD change in the input results in a 1 SD change in the output. A positive coefficient indicates that this input has a positive impact, implying that increasing this input will increase the output. A negative coefficient implies that increasing this input will decrease the output. When the correlation between the independent variables is zero or very low, the standardized regression coefficient is equal to the correlation coefficient and the β values are confined to the bounds of (-1, 1). However, if there are two or more independent variables that are correlated positively or negatively, then β values may exceed these bounds (Ghasemi et al., 2012).

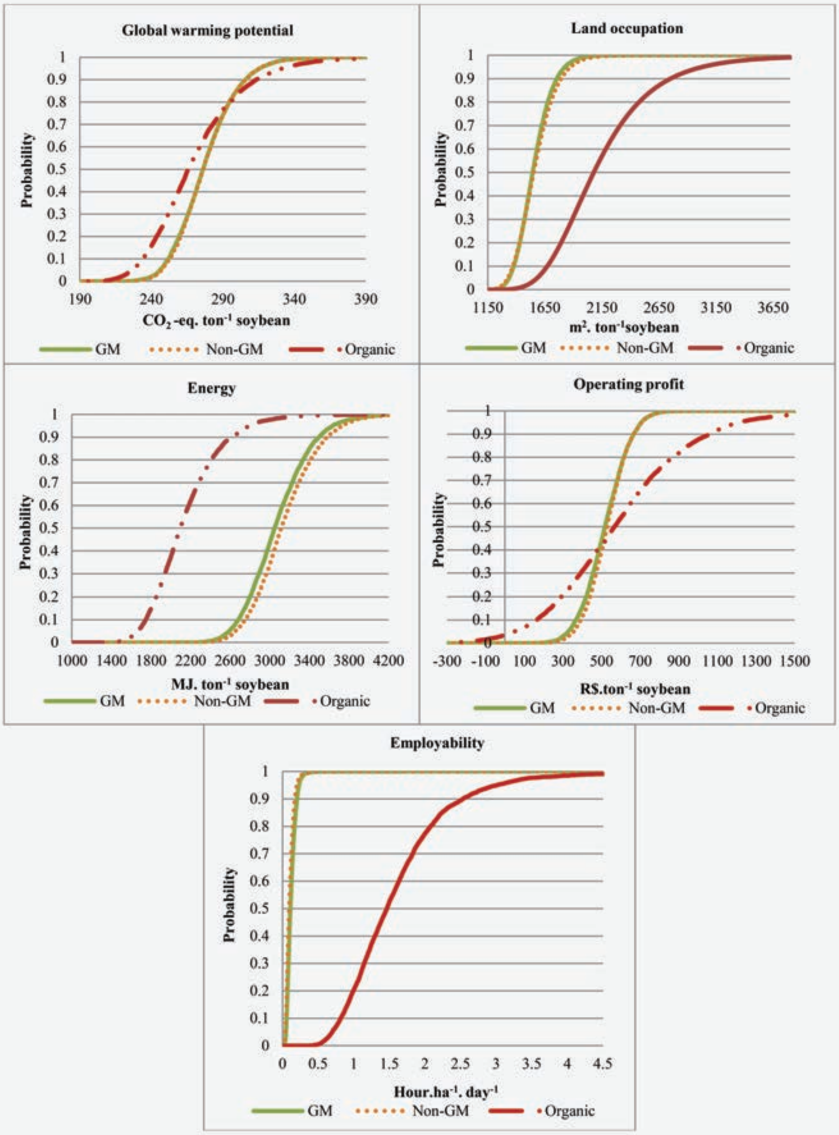

Figure 4.2 Cumulative Distribution Function of EES performance for GM, non-GM, and organic soybean production.

Table 4.4 Multivariate stepwise regression coefficients for the effect of technical inputs on environmental, economic and social performance.

Stochastic variables	Beta coefficients				
	GWP[1]	Land occupation	Energy	Operating profit	Employment
GM[2]					
Yield	-0.92	-0.99	-0.91	0.85	-
Seeds	-	-	0.02	-0.02	-
P fertilizers	0.13	-	0.24	-0.03	-
K fertilizers	0.06	-	0.12	-0.02	-
Lime	0.22	-	0.16	-0.03	-
Pesticides	0.15		0.17	-0.07	
Fuel	0.26	-	0.28	-0.03	-
Labor	-	-	-	-0.51	F[3]: 0.93 P[4]: 0.38 C[5]: 0.00
Non-GM[6]					
Yield	-0.94	-0.99	-0.92	0.94	-
Seeds	-		0.03	-0.02	-
P fertilizers	0.14	-	0.23	-0.03	-
K fertilizers	0.06	-	0.12	-0.02	-
Lime	0.22	-	0.16	-0.03	-
Pesticides	0.13	-	0.15	-0.08	-
Fuel	0.18	-	0.19	-0.3	-
Labor	-	-	-	-0.32	F: 0.94 P: 0.35 C: 0.00

Organic					
Yield	-0.95	-0.99	-0.95	0.38	
Seeds	-	-	0.02	-0.01	
P fertilizers	0.02	-	0.02	-0.01	
K fertilizers	0.05	-	0.15	-0.02	
Lime	0.19	-	0.14	-0.01	
Pesticides	-	-	-	-0.01	
Fuel	0.08	-	0.12	-0.01	
Labor	-	-	-	-0.95	F: 0.88 P: 0.39 C: 0.32

1. Global warming potential.
2. Genetically modified.
3. Full-time labor.
4. Part-time labor.
5. Casual Labor.
6. Non-genetically modified.

The results of the sensitivity analysis show that environmental performance was most responsive to changes in yields for all three soybean production systems. Following the yield, the environmental performance of all types of soybean production was sensitive to the amount of lime and fuel used. Regarding profitability, GM and non-GM production were most sensitive to yield followed by labor cost. Organic production was most sensitive to labor cost followed by yield. Overall, the sensitivity analysis showed that yield, fuel, fertilizers, and labor had the highest impact on EES performance for the different soybean production systems.

The effects of a ten percent increase and decrease in input prices on profitability are presented in Table 4.5. Profitability in GM, non-GM, and organic production systems was most sensitive to changes in the output price (soybean). For GM and non-GM systems, following the soybean price, profitability was most sensitive to the price of P fertilizers. In contrast, for organic systems, soybean price was followed by labor cost, which was clearly linked to the labor intensive production in this system.

Discussion

Comparison with previous studies

This section compares the results of our study with those obtained from other studies[6], both in Brazil and other countries. The comparison of LCA results is generally not straightforward because LCA studies differ in terms of the system boundary, functional unit, allocation methods, and the characterization of the processes observed (Dick et al., 2014; Halberg et al., 2005). Pelletier et al. (2008) and Knudsen et al. (2010) found that organic soybean production in Canada had a lower GWP than conventional soybean production; a similar result was found by Knudsen et al. (2010) for China. Our results are partially consistent with these findings; we found that organic soybean production had a 77% probability of a lower GWP than the conventional production

6 The studies used for comparison did not distinguish between GM and non-GM soybean production, therefore, in this section we have used conventional production to encompass both GM and non-GM production.

systems. The difference between organic and conventional production was slightly higher in the studies by Pelletier et al. (2008) and Knudsen et al. (2010). This difference can be explained by the different assumptions about P fertilizer. In our study, organic P fertilizer was considered to be half manure (which increases N_2O emissions) and half phosphate rock, whereas Pelletier et al. (2008) assumed that only phosphate rock was used. The use of phosphate rock only would lead to a decrease of about two percent in GWP for the organic system in our study. The GWP per unit of soybeans in conventional production was in agreement with Pelletier et al. (2008) and Knudsen et al. (2010).

Table 4.5 Effect of 10% price changes (increasing/decreasing) on profitability

		Profitability changes%		
Prices	**Price changes%**	**GM**[1]	**Non-GM**[2]	**Organic**
Soybean	+10	+16.8	+16.5	+21.0
	-10	-20.2	-19.8	-30.2
Seeds	+10	-0.8	-0.8	-1.0
	-10	+0.8	+0.8	+1.5
P fertilizer	+10	-1.5	-1.6	-0.2
	-10	+1.6	+1.3	+0.1
Manure	+10	NA[3]	NA	-0.1
	-10	NA	NA	+0.2
K fertilizer	+10	-0.5	-0.5	-0.4
	-10	+0.5	+0.5	+0.4
Lime	+10	-0.8	-0.8	-0.9
	-10	+0.8	+0.8	+1.2
Pesticides	+10	-0.9	-0.9	NA
	-10	+0.9	+0.9	NA
Fuel	+10	-0.5	-0.5	0.4
	-10	+0.5	+0.5	+0.8
Labor	+10	-1.4	-1.6	-8.7
	-10	+1.4	+1.58	+8.15

1. Genetically modified.
2. Non-genetically modified.
3. Not applicable.

4

Organic soybean production in our study showed higher land occupation compared with conventional soybean production, a finding consistent with Spies (2003) and Seufert et al. (2012). The values obtained in this study for land occupation are similar to the results found by Spies (2003). Regarding primary energy use, we found that organic soybean production utilized less energy compared with the conventional systems, which is similar to the findings of Pelletier et al. (2008) for Canadian organic soybean production and Knudsen et al. (2010) for Chinese organic production.

Our study showed that organic production had higher costs than conventional soybean production. Our results on costs fall within the range of results from Delbridge et al. (2011) and McBride and Greene (2009). Furthermore, some studies have demonstrated that organic products are more profitable than the conventional ones (Pimentel et al., 2005; McBride and Greene, 2009; Knudsen et al., 2010; Delbridge et al., 2011), which is in line with our findings. Regarding employment, our study showed that organic systems need more working hours per hectare per day. This result is consistent with the studies of McBride and Greene (2009) and Delbridge et al. (2011), who showed that labor requirements are higher in organic systems than in conventional soybean production.

The main difference between this study and other studies is in the methodology; other studies used a deterministic model and did not account for the uncertainty and variability of input parameters. By using a stochastic model, we included this uncertainty and variability, and showed the effect of it on the sustainability performance of different systems. Results showed that differences between systems are not only structural, but also depend on the input parameters that are used, which can be subject to high levels of uncertainty and variability.

The challenges in different soybean production systems

GM crops are often claimed to give higher yields than non-GM varieties. The data used in this study, however, do not support this claim. The yield difference between GM soybeans and non-GM soybeans was negligible. Conventional soybean production (GM and non-GM) is generally found to have a higher yield than organic soybean production (Seufert et al., 2012). The lower yield for organic production is commonly linked to the limited use of fertilizers and no use of pesticides (Seufert et al., 2012). Although in this study the amount of fertilizer used was similar for all three production systems, the yield of the organic system was still lower. The higher yield in GM and non-GM systems might be caused by more efficient use of fertilizers (Seufert et al., 2012). In organic systems, usually one type of P fertilizer was used (i.e., phosphate rock), whereas in the GM and non-GM systems, multiple types of synthetic P fertilizers were used at the same time. Using multiple types of P fertilizers can increase the efficiency of P uptake by the plants, and result in a higher yield (Oliveira Júnior et al., 2011). Therefore, it is possible to have higher yields in GM and non-GM soybean production compared with organic production through the better management of P sources, even with similar amount of fertilizer application in all systems. Lower yield in the organic soybean production system means that more land (i.e., higher land occupation) is required to produce the same amount of soybeans compared to the conventional system. A relatively high land occupation could lead to more widespread deforestation and biodiversity loss, thus potentially undermining the environmental benefits of organic systems (Seufert et al., 2012). Therefore, the main challenge to improve the overall sustainability of organic production systems is to increase yields without creating negative impacts for the environment (Tuomisto et al., 2012).

The use of pesticides in the GM and non-GM production systems is another reason for the higher crop yields in these production systems (Seufert et al., 2012). However, there is increasing concern regarding the impact of the intensive use of pesticides and fertilizers in GM and non-GM production on human health and the environment (e.g., human toxicity, eco-toxicity, and biodiversity). Restrictive use of pesticides in the organic system leads to noticeably lower human and eco-toxicity potential, and at the same time higher biodiversity potential (Hole et al., 2005; Nemecek et al., 2011).The GM technology enables a lower use of pesticides compared with the non-GM system. This can decrease the costs of production. Non-GM soybean production had a higher use of chemicals and consequently slightly higher cost compared with GM production. The price premium (about 7%), allows farmers to achieve similar profit compared with GM production. It was expected that not using fertilizers and pesticides in the organic system would decrease the costs of this system compared to GM and non-GM systems. Most studies, however, that have evaluated the economic performance of organic systems found that the average operating costs for producing organic products are higher (Chavas et al., 2009). The reason that organic soybean production is still more profitable than conventional production is related to the price premiums paid for organic products (Chavas et al., 2009; McBride and Greene, 2009). The assessment of cost differences in the longer term was not carried out in this study. Several studies have shown that additional costs are incurred associated with the transition from conventional to organic production (Hanson et al., 2004; McBride and Greene, 2009). Prices of organic crops might also have greater variability in the future, due to the small-scale nature of the organic market (McBride and Greene, 2009).

The production of organic soybean is subject to additional risks, such as production, marketing, and policy risks. For instance, organic soybean production systems cannot use important risk management techniques, such as the use of pesticides. Instead, organic soybean farmers have to rely more on their management skills, such as timing of planting and harvesting, mechanical cultivation, and the use of insect populations to control pests. In addition, variety of concerns about competition, imports, and over-supply in markets can be marketing risks for organic soybean production. Moreover, organic production is based on strict standards and certification schemes, which would make it more risky (Hanson et al., 2004). These risks may lead to farmers choosing different production systems depending on their underlying risk attitudes (Hanson et al., 2004). Furthermore, size of operation is found to be one of the main factors determining the likelihood of an operation to adopt organic production (McBride and Greene, 2009). Small farms likely view the organic approach as among the few alternatives to improve farm profitability. Larger farms, which usually produce GM and non-GM products, however, likely have a lower incentive to consider alternatives (organic production) because of economies of size (McBride and Greene, 2009). Although critics argue that the labor intensity of organic systems leads to higher product costs and hinders large-scale farms from shifting to organic production (Wood et al., 2006; McBride and Greene, 2009), from a social (employment) point of view this is considered as an advantage of organic systems. Organic production provides relatively more jobs and consequently improves the local economy relatively more compared to mechanized GM and non-GM farms (FAO, 2014). A comprehensive evaluation of all EES issues related to soybean production was not possible in this study, as broadly comparative data were scarce and difficult to access. Collection of the data necessary to undertake a comprehensive evaluation of all issues would require long periods of field research. The need to conduct intensive and time consuming fieldwork, therefore, limited the potential for collecting enough data to support a broad comparative analysis.

Need for uncertainty and sensitivity analysis

Data collection for three different production systems in Brazil was a major issue for conducting this study, as comprehensive data on the three systems were lacking among others due to a relatively low number of non-GM and organic farming systems in Brazil. Low quality and limited data induces the need for uncertainty and sensitivity analyses via, for example, stochastic simulation augmented by sensitivity analysis, which was applied in this study. To our knowledge this study is the most extensive comparison of different soy production systems in Brazil including uncertainty.

Conclusions

The objective of this study was to evaluate the EES performance of GM, non-GM, and organic soybean production in Paraná region in Brazil. In addition to the general comparison of different soybean production systems, the modeling framework used in this study captures the uncertainty in key system parameters, and therefore allows for a comparison of the robustness of outcomes. Furthermore, by using sensitivity analyses we were able to identify the key variables determining the EES performance of soybean production systems. The results of this study revealed that there are many factors to consider in the evaluation of organic, GM, and non-GM production systems, and that there is no simple way to determine a clear winner; this is similar to Seufert et al. (2012) conclusion. We found that organic production outperformed GM and non-GM systems on most of the EES issues studied, but that the latter outperformed with regard to yield efficiency. Finally, we found that the variation in farm inputs had substantial consequences for the EES performance. Therefore, this study demonstrates that using Monte Carlo simulation to account for variation in input parameters provides valuable insight into the distribution of the EES performance of different systems. The improved insight into EES performance provided by this approach enables policy makers and business stakeholders to better address sustainability concerns.

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Appendix 4

Environmental performance

Table A 4.1 Equations, tables and references used for quantification of environmental indicators.

Emissions	Equation	Table	Reference
Urea	11.1, 11.13,11.4	-	IPCC (2006)
Lime	11.12	-	IPCC (2006)
Off road transportation	3.3.1	3.3.1	IPCC (2006)
Road transportation	3.2.1	3.2.1	IPCC (2006)
Biomass burning GM	2.27, 2.14	2.6, 2.5, 2.4	IPCC (2006)
Crop residues GM	11.6 , 11.10	2.6, 11.2, 11, 7	IPCC (2006)
Atmospheric deposition of N volatilized	11.9	11.3	IPCC (2006)
Leaching and run off	11.10, 11.5, 11.8	11.3, 11.5	IPCC (2006)
Dry matter	-	11.2	IPCC (2006)

Table A 4.2 Emission factors.

Production of fertilizers	Emission (kg/kg of fertilizers)	Reference
P fertilizers (per kg P_2O_5)	2.13	Ecoinvent- 2013
Potassium chloride (per kg K_2O)	0.905	Ecoinvent- 2013
Lime (per kg)	0.0372	Ecoinvent- 2013
Roundup (Glyphosate) (per kg)	11.6	Ecoinvent- 2013
Pesticides unspecified (per kg)	11.1	Ecoinvent- 2013
Organic P fertilizer (phosphate rock) (per kg P_2O_5)	0.318	Ecoinvent- 2013
potassium sulphate (K_2SO_4)	1.43	Ecoinvent- 2013
Diesel	0.602	Ecoinvent- 2013

Table A 4.3 Energy coefficients.

Soybean plantation phase energy inputs	Energy content (MJ/kg or liter)	Unit	Reference
Seeds	4.47	MJ/kg seed	Ecoinvent- 2013
P fertilizer	30.06	MJ/kg P_2O_5	Ecoinvent- 2013
P fertilizers (Phosphate rock organic)	4.47	MJ/kg P_2O_5	Ecoinvent- 2013
Potassium chloride	14.69	MJ/kg K_2O	Ecoinvent- 2013
Lime (CaO)	0.49	CaO (lime)	Ecoinvent- 2013
Pesticides unspecified	196	MJ/kg	Ecoinvent- 2013
Diesel	57.7	(MJ/kg diesel)	Ecoinvent- 2013
Glyphosate	192.3	(MJ/kg)	Ecoinvent- 2013

Table A 4.4 Unit conversions.

Diesel density (kg/liter)	0.84
1kWh= MJ	3.6

Sensitivity Analysis

Consider the following regression model with two independent variables:

$$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \varepsilon_i \quad \text{Equation 4.1}$$

where y_i is the dependent variable of the ith subject, x_{1i} and x_{2i} are independent variables of the i^{th} subject, β_0 is the intercept parameter, β_1, and β_2 are population regression coefficients, and ε_i is a residual term, assumed to be normally distributed with mean of zero and constant variance. Equation 4.2 refers to Z number:

$$Z_1 = \frac{x_{1i-}\bar{x}_1}{S_{x1}} \quad \text{Equation 4.2}$$

The associated standardized regression model is presented in Equation 4.3 and 4.4:

$$y_i^* = \beta_1^* Z_1 + \beta_2^* Z_2 + \varepsilon_\iota^* \quad \text{Equation 4.3}$$

$$y_i^* = \beta_1^* \frac{x_{1i-}\bar{x}_1}{S_{x1}} + \beta_2^* \frac{x_{2i-}\bar{x}_2}{S_{x2}} + \varepsilon_\iota^* \quad \text{Equation 4.4}$$

Where $\bar{x}_i$ is mean of regressor and S_x is the standard deviation of regressor.
The least squares estimate of the standardized regression slopes are, equation 4.5 and 4.6:

$$b_1^* = \frac{r_{y1} - r_{12} r_{y2}}{1 - r_{12}^2} \quad \text{Equation 4.5}$$

$$b_2^* = \frac{r_{y2} - r_{12} r_{y1}}{1 - r_{12}^2} \quad \text{Equation 4.6}$$

The regression coefficient b_1^* and b_2^* are called standardized regression coefficient; r_{y1} is the simple correlation coefficient between y and x_1; r_{y2} is the simple correlation coefficient between y and x_2, and r_{12} is the simple correlation coefficient between x_1 and x_2. The standardized regression coefficient for the first independent variable b_1^*, is a function of all the correlation coefficients among the variables. When the inter-correlation between the two independent variables is zero (i.e., $r_{12} = 0$), the standardized regression coefficient, b_1^*, is equal to the correlation coefficient, r_{y1}. If there is a single independent variable or multiple independent variable that are not correlated, then the β values will be confined to the bounds of (-1, 1). However, if there are two or more independent variables that are correlated positively or negatively, then β values may exceed these bounds (Ghasemi et al., 2012). For multiple regression models with more predictors, these formulas are more complex, but the simplification that $b_1^* = r_{y1}$ holds if all the inter-correlation values among the predictors are zero.

4

Chapter 5

Evaluating the Validity of Expert Opinion and Robustness of the Multi Criteria Assessment Method for Sustainability Assessments

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Submitted

Abstract

Sustainability assessments are hampered by limited data availability. Elicitation of expert opinion could provide a solution in such cases, and multi criteria assessment (MCA) is a method that allows for using such data in sustainability assessments. The validity of expert opinion to score the sustainability performance of distinct systems, however, has not been assessed so far. Also, the robustness of the outcomes of the MCA method to uncertainty about scores elicited from the experts and the weights used for aggregating indicator scores has generally not been addressed. The objective of this study was to evaluate the validity of scores from expert elicitation, and the robustness of the MCA method to uncertainty about weights and scores. This has been illustrated for three soybean production systems (i.e., conventional production with either genetically modified or non-genetically modified soybeans, and organic production) in Brazil and Argentina. The validation was carried out by comparing the scores that were obtained using expert elicitation with the values from scientific studies. The robustness of the MCA outcome to uncertainty about the scores and weights was assessed using Monte Carlo simulation. The overall comparison of expert data with data from scientific studies showed that the assessments by the experts were consistent for 58% of the pairwise comparison of the issues with studies reviewed. In conclusion, there is potential to use expert elicitation as an alternative to extensive data rich methods. Concrete conclusions, however, need further research based on a larger group of experts, with a high degree of knowledge regarding production systems. With regard to robustness, outcomes showed higher variation of weighted scores for organic soybean production systems compared to GM and non-GM production system in both Brazil and Argentina. A distribution of the overall MCA scores provides better information to decision makers about the potential range of outcomes.

Introduction

Worldwide, there is an increasing concern about the consequences of economic development, which often goes at the detriment of social progress and environmental protection (Vasileiou and Morris, 2006). This concern finds expression in the concept of sustainability. "Sustainability attempts to balance the three dimensions of development, which define the quality of human life in its broadest sense, namely: environmental, economic, and social, objectives" (Vasileiou and Morris, 2006). More attention is nowadays given to sustainability assessment which underlies decision making about sustainability. Multi Criteria Assessment (MCA) has become increasingly popular in agriculture sustainability studies, due to its ability to address the multi-dimensionality of the sustainability goals (Linkov et al., 2004; Pohekar and Ramachandran, 2004; Mourits et al., 2006; Huang et al., 2011; Michalopoulos et al., 2013). In this regard, a variety of assessment methods has been developed for agricultural systems over the past decades, such as the response-Inducing Sustainability Evaluation (RISE), Indicateurs de Durabilité des Exploitations Agricoles or Farm Sustainability Indicators (IDEA), Sustainability Assessment of Food and Agriculture systems (SAFA), and Sustainability Monitoring and Assessment RouTine (SMART) (Briquel et al., 2001; Grenz et al., 2009; FAO, 2012; Jawtrusch et al., 2013). Measuring the sustainability performance of agricultural systems using these methods, however, requires technical data of which the collection is often costly (in terms of financial resources and time). Elicitation of expert opinion could provide a solution in such a case, and MCA is a method that allows for using such data in sustainability assessments. Furthermore, the MCA has the capability of giving a single overall score by aggregating sustainability scores and using relative importance weights provided by stakeholders. Such an overall score can inform decision makers at the strategic and operational levels about the potential for improving sustainability.

In the particular case of agriculture, a sizeable amount of literature has used MCA to assess sustainability based on expert elicitation of scores for sustainability issues (Sydorovych and Wossink, 2008; Engels et al., 2010; Reig et al., 2010; Michalopoulos et al., 2013). For instance, Engels et al. (2010) used MCA for developing a comprehensive sustainability label for food products, and Reig et al. (2010) used MCA for assessing the sustainability of rice cultivation technologies. These MCA studies suffer from two shortcomings. First, they use expert elicitation to obtain scores but did not evaluate the validity of scores. Clearly, if scores for an issue obtained from expert elicitation are not in line with scores found in scientific literature, then the overall score provided by MCA may be erroneous. Second, existing MCA studies generally did not evaluate the robustness of the MCA outcomes to uncertainty about the scores and weights. Uncertainty about the scores and weights implies a distribution of MCA score, rather than a single value. A distribution of the overall MCA score provides better information to decision makers about the potential range of outcomes.

In the light of the foregoing, the objective of this study is to evaluate the validity of scores for sustainability issues that were obtained using expert elicitation and the robustness of the MCA to uncertainty about the scores and weights. The validation is carried out by comparing the scores that were obtained using expert elicitation with the values from empirical studies. The robustness of the MCA outcome to uncertainty about the scores and weights is assessed using Monte Carlo (MC) simulation. This study uses the case of Latin American (LA) soybean production systems to illustrate the evaluation of the validity of the scores and the robustness of MCA outcomes.

Materials and methods

The research design for this study was based on MCA, literature review and MC simulation.

Multi criteria assessment

One of the most common decision rules in the applied MCA literature involves computing a simple weighted average of all of the performance scores for each alternative (Equation 5.1). Assuming that all issues are defined in terms of performance (higher scores indicate better performance), the alternative system with the highest average overall score is the best. Accordingly, a preference weight must be assigned to each issue that reflects the relative importance of that issue to the decision maker. In this regard, the following steps were taken in this study: (1) selection of key issues (criteria); (2) scoring of issues by experts for different production systems (alternatives); (3) weighting of issues by different stakeholders in each sustainability dimensions; (4) analysis and interpretation of scores and weights based on Equation 5.1 (Linares and Romero, 2000; Mourits et al., 2006).

$$MCA_j = \sum_{ij} W_i * S_{ij} \qquad \text{Equation 5.1}$$

Where MCA is the overall sustainability score for system (j), W is the weight for the issue (i) and S is the score for issue (i) in system (j).

Selection of issues

The first step in MCA is the selection of the sustainability issues. The issues can be selected based on literature and existing sustainability guidelines or frameworks. Relevance of sustainability issues across studies varies because of differences between agricultural sectors (e.g., the issue of animal welfare is specific for animal systems), differences in socio-cultural and geographical context (Cornelissen et al., 2001; Mollenhorst and de Boer, 2004; van Calker et al., 2005; Pashaei Kamali et al., 2015), and because issues emerge at various levels (i.e., farm level versus chain level) (Yakovleva, 2007; Pashaei Kamali et al., 2014). The issues selected in this study for the three sustainability dimensions, namely environmental, economic, and social, were based on the literature, sector and context of the study. We selected only those issues that were considered relevant in LA (e.g., water deprivation was excluded because soybeans are not irrigated in LA), moreover, we selected those issues which are specifically related to soybean production system. The following issues were selected: global warming, energy, land use (land occupation), biodiversity, profitability, barriers to entry into chain (based on economic of scale), employment, working conditions (labor rights and working circumstances), and human health and safety (local community, employees and risk).

Scores

The experts were asked to score the issues for different soybean production systems at the chain level based on an ordinal rating scale ranging from 1 (much worse) to 7 (much better). The chain was defined from farm in LA to harbor in Europe. The production systems for soy were organic and conventional production system which includes the genetically modified (GM), and non-genetically modified (non-GM). The mainstream production system, i.e. GM soybean production, was used as a benchmark, and represented by “4” in the ordinal rating scale. The GM soybean was chosen as a benchmark because it was the mainstream production in LA and it has a higher volume of trade than the other types of soybean (i.e., non-GM and organic soybean). Experts were selected from research institutes and universities and had to be knowledgeable about the GM, non-GM and organic soybean production systems. The knowledge of experts was evaluated based on their scientific publications and scientific reports regarding different production systems. The experts were assumed to have the potential of giving assessments (scores) on the sustainability issues. The experts originated from Argentina, Belgium, Brazil, Hungary, Italy, Mexico and the Netherlands. A total number of 33 questionnaires (i.e., 18 non-GM and 15 organic) were completed. The Mann–Whitney U test for independent random samples was used to compare the differences of scores obtained from experts for different production systems. The experts’ questionnaire is presented in Appendix 5.

Weights

The weights were provided by stakeholders participating in a survey using a written questionnaire. Weights represented stakeholders’ perceptions of the relative importance of sustainability issues as well as sustainability dimensions (i.e., environmental, economic and social) of soybean production system. Stakeholders are defined as any group of people, organized or unorganized, who shared a common interest or stake in a particular issue or system (van Calker et al., 2005). In this study, stakeholders, namely producers, retailers, and traders, were selected from Brazil, and Argentina (Table 5.1). These countries are representative for soybean production in LA (Sterman et al., 2010; USDA-FAS, 2010). Stakeholders included were farmers and processors, representatives of feed companies, traders, retailers, and other business consultants. Stakeholders were either member of the SALSA[1] project or did belong to the personal networks of SALSA members or from the personal networks of the authors.

Table 5.1 Number of responses for stakeholders' survey and percentages per group.

Stakeholders	Total	Producers[1]	Traders[2]	Retailers[3]
	n[4]	Percentage		
Brazil	75	6	13	81
Argentina	20	25	35	40
Total	95	-	-	-

1. Soy producers represent farmers and farm advisors.
2. Traders represent soybean buyers (in some cases big traders have their own processing companies).
3. Retailers represent suppliers of inputs, such as seeds, fertilizers and machinery, and processors.
4. Valid number of responses.

Stakeholders' surveys were conducted face-to-face, online and by email. Questionnaires were translated into Portuguese and Spanish. Surveys were carried out from December 2014 to March 2015 in Brazil and Argentina. The questions were structured as closed-end questions, in which stakeholders were asked several questions about sustainability using a top down approach: starting with sustainability dimensions, and progressing to the issues within each dimension of sustainability. Each dimension of sustainability was given a weight between 0 and 100 (i.e., the stakeholders were asked to divide 100 points across the environmental, economic and social dimensions). Moreover, each of the aforementioned sustainability dimensions comprised several issues, which were

1 Knowledge-based Sustainable value-added food chains: innovative tools for monitoring ethical, environmental and socio-economic impacts and implementing EU-Latin America shared strategies.

presented to the stakeholders who were requested to give a weight between 0 and 100 (i.e., the stakeholders were asked to divide 100 points to environmental issues, 100 to economic, and 100 to social issues). For instance, with regard to the environmental issues, 100 points had to be divided among global warming, energy use, land use and biodiversity. This shows the importance of a specific sustainability issue as perceived by each stakeholder. A total number of 95 questionnaires were completed (Table 5.1). The questionnaires are presented in Appendix 5. A Chi-square test was used to make statistical inferences about the variation of stakeholders' perceptions (relative weights) regarding sustainability dimensions and issues.

Analysis and interpretation of weights and scores

Weights indicate the relative importance of the various issues and are based on stakeholders' perceptions. Higher weights indicate higher importance of the issues or dimensions. Scores indicate experts' opinions regarding the performance of one production system compared to the benchmark system. Scores below the benchmark system indicate that the performance of the production system on that issue is perceived to be lower than that of the benchmark system. In contrast, scores above the benchmark system indicate that the performance of the production system on that issue is perceived to be better than the benchmark system. Joint consideration of weights and scores facilitates the interpretation of the overall performance of sustainability issues in different production systems. The overall single score per production system indicates the system's overall sustainability performance.

Validity and robustness

Comparison of the scores with literature

A literature review was conducted to validate the scores that were obtained using elicitation of expert opinion. The validation was performed by comparing the scores with the values reported by empirical studies, derived from scientific literature. The literature review focused on studies from peer-reviewed scientific journals and scientific reports that compared soybean production systems. In this study, the databases of Scopus and Web of Science as well as the search engine Google Scholar were used. Our search was based on structured key words, such as organic soybean, conventional soybean, sustainable soybean farming, and sustainable soybean production systems. Since the elicitation of expert opinion and stakeholders' perceptions was at the whole chain level, we first focused on studies that evaluated sustainability issues at chain level. However, only a small number of studies appeared to cover the entire chain. We, therefore, extended our review to studies which evaluated sustainability issues at farm level or cradle-to-farm-gate level. This approach appears logical, since main differences in sustainability performance of especially soybean production systems occur at cradle-to-farm-gate (Yakovleva, 2007; Gaitán-Cremaschi et al., 2015). Moreover, post farm stages can be assumed similar for different soybean production systems (i.e., GM, non-GM and organic).

To enable a comparison of literature with scores we defined three selection criteria for inclusion of studies in our review:

- The studies assessed sustainability issues at farm, cradle-to-farm-gate or chain level;

- The studies evaluated at least two distinct soybean production systems based on the classification method , i.e., GM, non-GM and organic;

- The studies addressed at least one dimension or one issue of sustainability.

To compare expert scores with the reviewed studies, first we compared based on the ordering of systems. In this regard, we counted orders of scores and compared the literature based on order counting. More specifically, we counted order percentages, for instance we counted the percentage of the scores (for each sustainability issue) which was higher for organic when we compare with GM. In this regard, we assumed that if more than 50%, of experts gave similar order compared to reviewed studies for an issue, there is consistency regarding that issue. Second we considered the degree to which systems differed. In this case we concluded on consistency in case of a corresponding degree of difference, i.e. significantly different scores accompanied with at least 10% and 20% difference between systems' performance in literature.

Monte Carlo Simulation

MC is a widely used method for translating uncertainty in model inputs into uncertainties in model outputs (results) (Gebrezgabher et al., 2012). In MC simulation, a random value is drawn from the distribution of each input parameter. Next, the model outcome is calculated for the value drawn for all input parameters. The procedure is then repeated N times to generate a distribution of model outcomes. In this study, MC simulation was used to simulate the uncertainty in the scores for the issues that were elicited from the experts and the weights of the issues given by the stakeholders. The number of stakeholders is presented in Table 5.1.

The MC Simulation was conducted using @Risk[2], an add-in in MS Excel (Microsoft Corporation, Redmond, WA). Probability distributions were defined for scores and weights, where a discrete distribution was defined for scores that were obtained using expert elicitation (Table 5.2) and a truncated normal distribution (with values between 0 and 1) was assumed for weights obtained from stakeholders for each issue (Table 5.4). In each iteration, the values for the weights drawn from the normal distribution should add up to 1. To ensure this we first defined a truncated normal distribution for the weights using the means and SD of the stakeholders, i.e. the truncation ensures that all values lie between 0 and 1. Second, in order to prevent that the simulation follows the same order of issues for each iteration resulting in a bias towards the weights of the issues drawn first, we imposed a random order of issues when drawing the parameters in each iteration. The MC simulation provides the distribution of the final scores.

2 5000 iterations.

Table 5.2 The obtained scores from expert elicitation regarding different soybean production systems, frequency of experts ordering systems in the same way, and significant differences across systems.

Sustainability issues	**Scores**			**Order counting (%)**			**Mann-Whitney U test /P value**[1]		
Soybean	GM[2]	Non-GM[3] (n[4]=18)	Organic (n=15)	Non-GM p.b.t[5] organic	GM p.b.t organic	Non-GM p.b.t GM	Non-GM p.b.t Organic	GM p.b.t Organic	Non-GM p.b.t GM
Environmental									
Global warming	4.00	3.26	3.67	40	60	11	0.837	0.358	0.073
Energy	4.00	3.00	3.73	7	46	10	0.372	0.770	0.041
Land use[6]	4.00	3.68	3.60	47	68	26	0.265	0.045	0.012
Biodiversity	4.00	4.21	5.47	20	20	52	0.015	0.004	0.806
Economic									
Profitability	4.00	4.01	4.60	7	40	36	0.451	0.545	0.612
Barriers to entry into chain	4.00	4.16	3.40	60	67	68	0.319	0.216	0.610
Social									
Employment	4.00	4.16	4.67	7	34	56	0.028	0.027	0.012
Working conditions	4.00	4.16	4.33	27	40	50	0.111	0.216	0.066
Human health and safety	4.00	3.68	5.53	6	27	16	0.001	0.001	0.017

1. If $P<0.05$, the result is statistically significant.
2. Genetically modified.
3. Non-genetically modified.
4. Number of respondents.
5. Performed better than.
6. Land use in this study specifically refers to yield.

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Results

Scores

Scores obtained by expert elicitation for sustainability issues regarding different soybean production systems, the order counting of scores (%), and the results of Mann-Whitney U test regarding differences in experts' opinions are presented in Table 5.2. Scores represent the means of total scores from expert elicitation. The scores showed that the pairwise comparison of non-GM and organic system based on Mann-Whitney U test was significant only for biodiversity, employment and human health and safety. The pairwise comparison of GM and organic systems showed the difference was significant for land use change, biodiversity, employment and human health and safety. Regarding comparison of GM and non-GM, there was a significant difference regarding energy, land use, employment and human health and safety.

Comparison of scores with literature

We found 19 studies from peer-reviewed scientific journals and scientific reports which assessed the environmental, economic, or social performance of different soybean production systems (Table 5.3). Soybean production systems included in our comparison were located in Europe (Refsgaard et al., 1998; Nemecek et al., 2011), United States (Hanson et al., 1997; Welsh, 1999; Delate et al., 2003; Hanson et al., 2004; Hole et al., 2005; Pimentel et al., 2005a; Hepperly et al., 2006; Mahoney et al., 2007; Cavigelli et al., 2008; Gomiero et al., 2008; Chavas et al., 2009; McBride and Greene, 2009; Delbridge et al., 2011), Canada (Pelletier et al., 2008), China (Knudsen et al., 2010), and Brazil (Gaitán-Cremaschi et al., 2015; Pashaei Kamali et al., 2015). The studies included in the review used different classifications of soybean production systems. The majority of these studies categorized the soybean production systems as either conventional or organic. In most of the reviewed studies, conventional soybean production referred to non-GM soybean production system. McBride and Greene (2009) and Hanson et al. (2004), however, considered both GM and non-GM as conventional soybean in their studies. The mainstream (about 90%) of production system in these two studies, however, was GM, therefore, in the review; we categorized these two studies in the GM category. Most of the reviewed studies focused at farm level rather than chain level. There were only two studies focusing at the whole chain level: Gaitán-Cremaschi et al. (2015) evaluated GM and non-GM soybean meal chain from Brazil to Europe, and Knudsen et al. (2010) evaluated organic and non-GM soybean chain from China to Denmark. The majority of the studies focused on environmental issues and paid less or no attention to economic and social issues. Some specific environmental issues, such as biodiversity, were considered by only a few studies, due to the lack of specific and predefined assessment methods. Furthermore, the number of studies which specifically focused on LA was limited. This is why we expanded our review to other countries as well.

In Table 5.3, within the column 'non-GM vs. Organic' we reviewed studies, which compared non-GM and organic soybean production systems. This column is divided into three subsections: non-GM performs better than (p.b.t.) organic, non-GM performs equal to (p.e.t.) organic, and organic performs better than non-GM based corresponding unit. The numbers within the parentheses represent the performance differences (%) between the systems reported by the preceding literature. For example, study #1 indicated that non-GM performed 1.6% better than organic with respect to land use. Similarly, within the columns 'GM vs. Organic' and 'non-GM vs. GM', studies that compared GM with organic, and non-GM with GM soybean production systems, were reviewed.

Table 5.3 shows that a wide range of values for different issues were reported in the studies for the different production systems (i.e., non-GM, GM, and organic production system). For instance, the difference in GWP of non-GM and organic soybean production range from 3.5% (Pashaei Kamali et al., 2015) to 41% (Knudsen et al., 2010). The variation in different production systems are mostly related to the country of origin, farm size, farm management, and time period of the analyzed system. For instance, studies that evaluated the soybean production system in Brazil had similar results (values) (Gaitán-Cremaschi et al., 2015; Pashaei Kamali et al., 2015). However, the results for Brazil were different from those of the soybean

Table 5.3 Literature comparing different soybean production systems. Numbers within parentheses represent relative differences (%) between systems, as reported in the literature.

	Non-GM[a] vs. Organic		
Issues	Non-GM ***p.b.t.***[c] Organic	Non-GM ***p.e.t.***[d] Organic	Organic ***p.b.t.*** Non-GM
Environmental			
Global warming	-	-	12 (**23**[e]), 15 (**41**), 18 (**3**)
Energy	-	-	2 (**35**), 7 (**32**), 11 (**37**), 12 (**35**), 15 (**54**), 18 (**31**)
Land use[f]	1 (**1.6**), 2 (**23**), 3 (**15**), 7 (**3**), 9 (**12**), 10 (**19**), 11 (**11**), 15(**12**), 16 (**25**), 18 (**25**)	12	-
Biodiversity	-	-	6 (**NA**[g]), 8 (**NA**), 11 (**NA**), 17 (**NA**)
Economic			
Profitability[h]	-	-	1 (**11**), 3 (**2**), 4 (**72**), 9 (**57**), 13 (**85**), 18 (**11**)
Barriers to entry into chain	5 (**NA**)	-	-
Social			
Employment	-	-	5 (**NA**), 18 (**93**)
Working conditions	-	-	-
Human health and safety	-	-	11 (**NA**)

1. Hanson et al. (1997): Pennsylvania, USA, 1991-1995; **2. Refsgaard et al. (1998)**: Denmark; **3.Welsh (1999)**: USA; **4. Delate et al. (2003)**: USA; **5. Hanson et al. (2004)**: USA; **6. Hole et al. (2005)**: USA **7. Pimentel et al. (2005b)**: USA average for 22. years; **8. Hepperly et al. (2006)**: USA; **9. Mahoney et al. (2007)**: Minnesota, USA; **10. Cavigelli et al. (2008)**: Maryland, USA; **11. Gomiero et al. (2008)**: Pennsylvania, USA; **12. Pelletier et al. (2008)**: Canada (hypothetical data based on national average); **13. Chavas et al. (2009)**: Wisconsin, USA; 14. McBride and Greene (2009): USA; **15. Knudsen et al. (2010)**: China; **16. Delbridge et al. (2011)**: Minnesota, USA; **17. Nemecek et al. (2011)**: Europe; **18 . Pashaei Kamali et al. (2015)**: south Brazil (a stochastic approach and the compared values were means of two production systems); **19. Gaitán-Cremaschi et al. (2015)**: Brazil.

GM[b] vs. Organic			Non-GM vs. GM		
GM ***p.b.t.*** Organic	GM ***p.e.t.*** Organic	Organic ***p.b.t.*** GM	Non-GM ***p.b.t.*** GM	Non-GM ***p.e.t.*** GM	GM ***p.b.t.*** Non-GM
-	-	18 (**3**)	-	-	18 (**0.14**), 19 (**1**)
-	-	18 (**43**)	-	-	18 (**2**)
14 (**34**), 18 (**28**)	-	-	-	-	18 (**1**)
-	-	-		-	-
-	-	14 (**25**), 18 (**13**)	18 (**2**), 19 (**6**)	-	-
-	-	-	-	-	-
-	-	14 (**68**), 18 (**93**)	-	-	18 (**17**), 19 (**20**)
-	-	-	-	-	-
-	-	-	-	-	-

a. Non-genetically modified.
b. Genetically modified.
c. Performed better than.
d. Performed equal to.
e. The bold numbers within the parentheses represent the performance differences (%) between the systems, reported by the preceding literature.
f. Land use in this study specifically refers to land occupation (yield).
g. Values not available.
h. Profit of organic system in this study and reviewed literature were without consideration of transition costs.

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production systems in China (Knudsen et al., 2010).

Table 5.4 compares the scores obtained from experts (Table 5.2) with the reviewed studies (Table 5.3). In this regard, the comparison of scores with the reviewed studies revealed that overall pairwise comparison of all production systems were 58% consistent and 42% inconsistent for all scores and reviewed studies. Based on the ordering of production systems we found that scores and literature are substantially consistent, i.e. the same order of performance is found in 87% (non-GM vs organic), 80% (GM vs organic) and 60% (non-GM vs GM) of the issues. Based on degree of difference we find less consistency (Table 5.4), especially when comparing non-GM and organic production. This, however, is also due to scores which had non-significant differences for most of the issues which were compared in the non-GM versus organic pairwise comparison, and also due to a wide range of differences for values reported by reviewed studies.

Regarding consistency in environmental issues in total global warming had 67%, energy 33%, and land use 45% consistency. Regarding economic issues, profitability had a 45% consistency. Regarding social issues, employment had 89% consistency (Table 5.4). It is worth mentioning that for some issues such as barriers to entry into chain, working conditions and human health and safety, the number of studies was rather limited or even lacking. Moreover, for some issues such as biodiversity, barriers to entry into chain and working conditions, studies were only qualitative so we could not consider consistency based on degree of difference at all.

Weights

Relative importance of the weights is presented in Table 5.5. Chi-square test results showed that the difference in the weights given to the environmental, economic, and social dimensions was statistically significant in both Brazil and Argentina ($P<0.05$), this implies that stakeholders had different perceptions concerning the importance of sustainability dimensions both in Brazil and Argentina. The economic dimension was perceived to be the most important dimension in both countries. With regard to the social dimension, both countries were found to have exactly opposite perceptions, i.e., Brazilian stakeholders perceived the social dimension more important than the environmental dimension, while Argentinian stakeholders perceived it just the other way around.

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Table 5.4 Consistency of expert scores and literature.

	Consistency based on ordering of systems		
Soybean	Non-GM[1] vs. Organic	GM[2] vs. Organic	Non-GM vs. GM
Environmental			
Global warming	✓[3]	×[4]	✓
Energy	✓	✓	✓
Land use	×	✓	✓
Biodiversity	✓	-[5]	-
Economic			
Profitability	✓	✓	×
Barriers to entry into chain	✓	-	
Social			
Employment	✓	✓	×
Working conditions	-	-	-
Human health and safety	✓	-	-
Consistency (%)	**87**	**80**	**60**

1. Non-genetically modified.
2. Genetically modified.
3. Scores are consistent with the reviewed studies.
4. Scores are not consistent with the reviewed studies
5. There was not any study or value reported by available studies.

	Consistency based on corresponding degree of difference between systems (i.e., significantly different scores as well as at least a 10% difference in literature)			Consistency based on corresponding degree of difference between systems (i.e., significantly different scores as well as at least a 20% difference in literature)		
	Non-GM vs. Organic	GM vs. Organic	Non-GM vs. GM	Non-GM vs. Organic	GM vs. Organic	Non-GM vs. GM
	×	✓	✓	×	✓	✓
	×	×	×	×	×	×
	×	✓	×	×	✓	×
	-	-	-	-	-	-
	×	×	✓	×	×	✓
	-	-	-	-	-	-
	✓	✓	✓	✓	✓	✓
	-	-	-	-	-	-
	-	-	-	-	-	-
	20	**60**	**60**	**20**	**60**	**60**

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Table 5.5 Weights and relative importance weights for soybean production systems in Brazil and Argentina.

	Weights		**Relative importance (%)**			
	Brazil (n[1]=75)	Argentina (n=17)	Brazil		Argentina	
Sustainability dimensions	Mean	Mean	Mean	Chi Square P value[2]	Mean	Chi Square P value
Environmental	27	33	0.27	0.000	0.33	0.020
Economic	41	40	0.41	0.000	0.40	0.000
Social	32	27	0.32	0.001	0.27	0.000
Sum	100	100	1.00	-	1.00	-
Sustainability issues	Mean	Mean	Mean	SD[3]	Mean	SD
Environmental						
Global warming	27	21	0.07	0.02	0.07	0.04
Energy	23	21	0.06	0.02	0.07	0.03
Land use	25	35	0.07	0.02	0.11	0.05
Biodiversity	25	23	0.07	0.02	0.08	0.04
Sum	100	100	0.27	-	0.33	-
Economic						
Profitability	53	68	0.22	0.05	0.27	0.18
Barriers to entry into chain	47	32	0.19	0.03	0.13	0.15
Sum	100	100	0.41	-	0.40	-
Social						
Employment	41	23	0.13	0.03	0.06	0.04
Working conditions	32	30	0.10	0.02	0.08	0.05
Human health and safety	27	47	0.09	0.02	0.13	0.08
Sum	100	100	0.32	-	0.27	-

1. Valid number of responses.
2. If $P<0.05$, the result is statistically significant.
3. Standard deviation.

Robustness of weighted scores

The overall single score based on equation (5.1) is reported in Table 5.6. In both Brazil and Argentina, the organic system showed a higher overall sustainability score (3.89 and 3.71 respectively) compared to non-GM soybean (3.85 and 3.49 respectively). However, both production systems had lower overall single score compared with GM (4.00) soybean production systems. Overall the simulation results showed a higher variation for the organic soybean production system, which is reflected by the wider confidence interval (Table 5.6).

Discussion and conclusions

MCA is a tool that allows for providing an overall sustainability score by using expert elicitation for the scores of individual issues and stakeholder perceptions for the importance weights of issues. Expert elicitation is particularly useful when data to quantify indicators are scarce. This study validated the expert scores by comparing the scores of different production systems with the existing literature. Furthermore, this study assessed the robustness of the overall score to uncertainty about the importance weights and expert scores.

The comparison of obtained scores from expert elicitation and reviewed studies is currently limited, because not all relevant sustainability issues have been studied. The comparison of expert data with empirical data from the literature showed that the overall consistency was 58% for all pairwise comparisons performed. By increasing the cutoff criteria for consistency based on order counting from 50% to 60%, overall consistency decreases to 54%. The higher degree of inconsistency in some economic and social issues, such as profitability and employment, can be explained by differences in, management, economic, socio-cultural and geographical context of most of the studies which were compared with LA context in this study. For instance in some developed countries the soybean farms are more mechanized and they use substantially less labor (even in organic systems) which leads to lower employment. The inconsistency in some environmental issues such as global warming between

Table 5.6 Mean overall sustainability scores and confidence interval (95%) for different soybean production systems in Brazil and Argentina.

Dimensions and issues	Brazil								
	GM[1]			Non-GM[2]			Organic		
	Mean	CI[3] (95%) LB[4]	CI[3] (95%) UB[5]	Mean	CI (95%) LB	CI (95%) UB	Mean	CI (95%) LB	CI (95%) UB
Environmental									
Global warming	0.29	0.05	0.55	0.24	0.04	0.51	0.27	0.04	0.62
Energy	0.26	0.05	0.51	0.20	0.03	0.48	0.25	0.03	0.60
Land use	0.28	0.07	0.55	0.25	0.04	0.59	0.26	0.05	0.63
Biodiversity	0.27	0.05	0.53	0.29	0.05	0.63	0.35	0.06	0.73
Economy									
Profitability	0.88	0.45	1.28	0.88	0.28	1.63	0.81	0.24	1.57
Barriers to entry into chain	0.75	0.43	1.05	0.77	0.23	1.46	0.71	0.20	1.40
Social									
Employment	0.51	0.17	0.84	0.52	0.16	0.96	0.58	0.16	1.08
Working conditions	0.40	0.12	0.63	0.37	0.10	0.65	0.43	0.10	0.82
Human health and safety	0.36	0.10	0.62	0.31	0.07	0.64	0.45	0.10	0.80
Overall single score	4.01	2.99	4.1	3.85	2.94	4.75	3.89	2.84	4.81

1. Genetically modified.
2. Non-genetically modified.
3. Confidence interval.
4. Lower bound.
5. Upper Bound.

expert scores and literature might partly be attributed to differences in methodological approaches used in the studies, but might also partly reflect differences between soybean production systems in different countries. Experts in our study were specifically asked to give their opinion about sustainability issues in soybean production systems in LA,

	Argentina								
	GM			Non-GM			Organic		
	Mean	CI (95%)		Mean	CI (95%)		Mean	CI (95%)	
		LB	UB		LB	UB		LB	UB
	0.27	0.00	0.72	0.24	0.00	0.65	0.27	0.00	0.82
	0.28	0.00	0.65	0.21	0.00	0.60	0.27	0.00	0.73
	0.40	0.00	0.92	0.37	0.00	1.02	0.38	0.00	1.08
	0.30	0.00	0.73	0.33	0.00	0.84	0.39	0.02	0.86
	1.00	0.00	2.26	1.00	0.00	2.66	0.99	0.03	2.62
	0.64	0.00	1.69	0.66	0.00	2.08	0.61	0.00	2.09
	0.30	0.00	0.69	0.27	0.00	0.77	0.30	0.00	0.85
	0.34	0.00	0.79	0.31	0.00	0.79	0.31	0.00	0.96
	0.47	0.00	1.15	0.43	0.00	1.17	0.60	0.00	1.60
	4.02	2.39	4.30	3.49	2.40	4.68	3.71	2.42	5.05

while reviewed studies related to Europe, Canada, China and USA. For instance, there are some differences regarding type and amount of fertilizers application in soybean production systems in China and Brazil (Knudsen et al., 2010; Pashaei Kamali et al., 2015), which, for instance can lead to different global warming potential. Moreover, the comparison showed that experts are better able to score production systems in case production systems substantially differ (based on scientific evidence); in case of small differences between production systems scoring seems to be more difficult for experts.

The reviewed studies are mostly based on measurable indicators. The expert elicitation in this study, however, was based on issues without taking into account specific indicators. This might decrease the consistency of the scores compared to the reviewed literature. For instance, different indicators can be defined for global warming or working conditions and experts might have scored issues based on their own perceived indicators, according to their operational context.

Although the performance of the different systems varied across the environmental, economic, and social issues in this study, overall the simulation results showed a higher variation of the weighted scores for all issues and for the overall single score of the organic soybean production system. This variation is reflected by the wider confidence interval. The results of this study are partially similar with the findings of the study performed by Pashaei Kamali et al. (2015), in which a relatively high level of variation (higher standard deviation) in the environmental, economic and social performance of organic soybean production systems compared to GM and non-GM was reported. In general, relatively less technical knowledge and relatively limited experience about organic systems (compared to other systems), particularly on sustainability issues, might lead to high uncertainty in experts' opinion and stakeholders' perceptions respectively.

The assessment of the overall sustainability of various production systems is a complex process including several stages, such as selection of experts, identification of the stakeholder groups, selection of issues, and selection of weights that reflect relative importance of individual issues and/or dimensions on the sustainability (Sydorovych and Wossink, 2008). In this study, we focused on evaluation of validity of scores and the robustness of MCA method for sustainability assessment, and not explicitly on the selection of experts, stakeholders and issues. Similar to other MCA methods, which are based on stakeholder perceptions, the results of this study are of a subjective nature reflecting the perceptions of the participated stakeholders. Hence, the overall score does not necessarily reflect the sustainability score for a system as a whole. The scoring of sustainability issues on a 1–7 scale requires detailed expert knowledge on sustainability and impacts of specific production systems. Moreover, for the current study, we surveyed a relatively small group of experts to determine the performance scores of the selected issues. A larger group might make the outcomes less vulnerable to variation among experts. Therefore, further research and practical use of this method should be based on a larger group of experts with adequate knowledge of the production systems assessed. Moreover, when applying the method to relatively new systems on which experts do not have enough knowledge regarding sustainability performances, outcomes may be less reliable. Furthermore, stakeholders' representativeness is essential if this approach is applied to yield insight to decision makers. As a final point, it is worth underlining some limitations of our specific application and of the proposed approach in general. Since our objective was to show how to evaluate validity of the scores and robustness of the MCA outcomes, we did not concentrate on experts' and stakeholders' selection. Hence, the issue of experts' and stakeholders' representativeness in this study remains inexplicable and should be addressed in further research. In conclusion, based on our case study regarding soybean production system, there seems to be potential for the use of expert elicitation in assessing sustainability performance of different production systems as an alternative approach to extensive data-rich methods.

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Appendix 5

Expert survey on scores

Dear ……………… [IN EMAIL]

In a combined project between EU and Latin American partners, the aim is to assess the sustainability of soybean chains from Latin America to the EU. We need your help to assess a list of 10 issues regarding soybean production systems.

The consortium of the project regards you as an expert with regard to sustainable supply chains and we would like to ask you to score the questions included. Scores are on a 1 to 7 scale in which a benchmark chain serves as anchor point. The questions are in the tables below (background information on issues is included as attachment).

This questionnaire is part of the FP7-Salsa project with the following consortium partners from Latin America: Solidaridad, Embrapa, RTRS, Universidad Nacional Autonoma de Mexico, Federal University of Vicosa. Partners from EU countries include Bologna University, Universiteit Gent, FiBL, proQuantis, Campden BRI and Wageningen University.

Sustainability assessment of soybean chains.

The soy chains under consideration are soybean meal chains from Latin America exporting to the Europe. We ask you to provide a score for each of the issues relative to a benchmark chain, which is a mainstream GM soybean meal chain in Latin America, exporting to the Europe.

How do you perceive the performance of organic soybean bean chains operating in LA and exporting to the Europe compared to the benchmark chain with regard to the following indicators? Indicate your preference on the scale from 1 (much worse) to 7 (much better) in which “4” reflects the benchmark chain.

How do you perceive the performance of non-GM soybean chains operating in LA and exporting to the EU compared to the benchmark chain with regard to the following indicators? Indicate your preference on the scale from 1 (much worse) to 7 (much better) in which “4” reflects the benchmark chain.

Issues	1 Much worse	2 Moderately worse	3 Slightly worse	4 BENCH MARK GM soy	5 Slightly better	6 Moderately better	7 Much better
Global warming							
Energy use							
Land use (land occupation)							
Biodiversity							
Profitability							
Barriers to entry in to chain							
Employment							
Working conditions (labor rights, working hours)							
Human health and safety (local community and employees)							

Thank you sincerely for sharing your insights with us.

(Attachment: explanation of selected issues)

Stakeholder survey on weights

Personal information

Name…………………………………………………………

Company/organization name ……………………………….

Company/organization activity …………………………….

Country ……………………………………………………..

Explanation of selected issues

Environmental issues

Global warming (GHG)

Global warming refers to the changing atmospheric composition due to the slowly increasing greenhouse gases. The major sources of GHGs emission in soy production chain are fertilizers in plantation phase, machinery use in plantation phase, energy use (electricity and fuel), land-use changes for plantation, fossil fuel use during soy transportation and fossil fuel use in soy bean processing (oil extraction) and transport of processed soy products.

Energy

Energy refers to the direct and indirect energy (e.g., fertilizers and other energies at farm level, energy (fuel) for transportation and energy (electricity) and fuel in the processing phase (crushing)).

Land use (land occupation)

From a life cycle perspective, 'land use impact' has been used to show the productivity. Higher productivity (yield) decreases land occupation.

Biodiversity

Biodiversity is the diversity of ecosystems, of species in these ecosystems, and of the genome within these species More intensive use of the, chemicals and land for e.g. in soy production may cause a loss of biodiversity.

Economic issues

Profitability

Profitability defined as the difference between the revenue received from the sale of an output and the cost of the used inputs (variable and fixed costs). Accurate cost and profit evaluation are important factors for helping decision makers focus on opportunities for profitability improvements along the chain.

Barriers to entry in to chain

This indicator evaluates the extent to which new participants are able to enter the value chain, so it is referring to issues of participation and inclusion in the value chain. Specific characteristics of the chain that can influence entrance of new participants are: (i) market-characteristics (market concentration, economies of scale, cost-structures, etc.); and (ii) costs and difficulties of compliance with and enforcement of specific legal and extra-legal requirements (related to certification schemes, standards and monitoring).

Social issues

Employment

Employment here refers to job creation and quantity of employment which can be assessed by total working hours. Working hours is an indicator that designates the employment capacity in such a way that makes employability comparable across various contexts.

Working conditions (labour rights, working hours)

Working conditions refer to the working environment and aspects of an employee's, terms and conditions of employment, including wages, benefits and working hours.

Human health and safety (local community and employees)

Health and safety issues, e.g. with regard to chemical hazards, not only refer to the farm's employees but can also refer to the local community, e.g. in case of spraying herbicides.

Questionnaire

What is your perception regarding the importance of the following environmental issues in sustainability performance of the Latin America-Europe soy chain? Allocate 100 points (0 = not important; 100 = very important) among the four environmental issues; the sum must not exceed 100 points.

Environmental	**Points**
Global warming	
Energy use	
Land use	
Biodiversity	
Sum	**100**

What is your perception regarding the importance of the following economic issues in sustainability performance of the Latin America-Europe soy chain? Allocate 100 points (0 = not important; 100 = very important) among the two economic issues; the sum must not exceed 100 points.

Economic	**Points**
Profitability	
Barriers to entry chain (based on economic of scale)	
Sum	100

What is your perception regarding the importance of the following social issues in sustainability performance of the Latin America-Europe soy chain? Allocate 100 points (0 = not important; 100 = very important) among the three social issues; the sum must not exceed 100 points.

Social	Points
Employment	
Working conditions	
Human health and safety (local community and employees)	
Sum	**100**

What is your perception regarding the importance of environmental, economic and social dimensions in sustainability performance of the Latin America-Europe soy chain? Allocate 100 points (0 = not important; 100 = very important) among the three sustainability dimensions; the sum must not exceed 100 points.

Sustainability dimensions	Points
Environmental	
Economic	
Social	
Sum	**100**

Do you like to receive the results of this survey? Yes No

5

Chapter 6

General Discussion

F. Pashaei Kamali

Introduction

Latin American (LA) countries are important producers and exporters of soybean and beef in the world (Sterman et al., 2010; USDA-FAS, 2010). The trade and development of soybean and beef production has created economic benefits for producer countries, but also resulted in negative side effects, such as deforestation, biodiversity loss, infringements of labor rights, and global warming (Cavalett and Ortega, 2009; Cederberg et al., 2009; Prudêncio da Silva et al., 2010). The concept of sustainability is nowadays employed to reveal the side effects of production and to give incentives to producers to reduce side effects (FAO, 2012).The improvement of sustainability of soybean and beef production is a common interest of stakeholders (López, 2007; Dick et al., 2015). Implementation and evaluation of measures to enhance the sustainability of soybean and beef production in LA, has become an important issue for policy and decision makers (López, 2007; Dick et al., 2015). Although there are notable developments in the field of sustainability assessment, there is still limited knowledge regarding the sustainability performance of soybean and beef production chains in LA.

In this regard, the overall objective of the thesis was to analyze the sustainability performance of soybean and beef production chains in LA. This chapter starts with a synthesis of the results. Subsequently, the data issues encountered in this these are discussed. This is followed by the discussion of implications of the results for policy makers and business stakeholders regarding sustainability of soybean and beef production, and an outline of future research. Finally, the main conclusions from this thesis are presented.

Synthesis of the results

In order to assess the sustainability performance of soybean and beef production in LA countries, the following steps were taken (1) the identification and definition of relevant environmental, economic, and social (EES) issues in Chapter 2; (2) quantification of environmental and economic performance of various feeding strategies for beef production in south Brazil in Chapter 3; (3) quantification of EES performance of distinct soybean production systems in Paraná region in Brazil in Chapter 4; (4) an overall assessment of the sustainability performance of soybean production systems in LA in Chapter 5.

Methodological approach

The main methods used in this thesis are summarized in Table 6.1. Identification of sustainability issues was based on a combination of literature review and stakeholders' surveys (Chapter 2). Feeding strategies were defined using literature study and experts opinion (Chapter 3). The performance regarding a selected set of issues was evaluated for different feeding strategies and distinct soybean production systems (Chapter 3 and 4). Life cycle assessment (LCA) was used to evaluate the environmental performance of different feeding strategies and soybean production systems (Chapter 3 and 4). The economic performance of feeding strategies and soybean production systems was evaluated using operating profit (Chapter 3 and 4). The social performance of soybean production systems was evaluated using employment rate and the number of working hours. In case of technical data scarcity, e.g. assessment of biodiversity loss of soybean production systems, we used a Multi Criteria Assessment (MCA) based on expert elicitation and stakeholders' perception (Chapter 5). Moreover, to evaluate the validity of the scores obtained from experts elicitation, we compared these scores with empirical data based on a literature review (Chapter 5). Monte Carlo (MC) simulation was used in Chapter 4 and 5 to evaluate the robustness of the outcomes to uncertainty about the input parameters and stakeholders' perceptions. Moreover, sensitivity analysis was used in chapter 3 and 4 (Table 6.1) to investigate the sensitivity of outcomes to variation in key model parameters. Challenges encountered by using these methods are discussed in the following sections.

Identifying sustainability issues

Sustainability issues emerge at various stages along the production chain, and are

Table 6.1 Methodological approaches of the thesis.

Methodological approach	Chapter 2	Chapter 3	Chapter 4	Chapter 5
Literature review	✓	-	-	✓
Stakeholder survey	✓	-	-	✓
Expert elicitation	-	✓	-	✓
Life cycle assessment	-	✓	✓	-
Economic analysis	-	✓	✓	-
Multi criteria assessment	-	-	-	✓
Monte Carlo simulation	-	-	✓	✓
Sensitivity analysis	-	✓	✓	-

found to vary across stakeholders. To identify all issues relevant for a sustainability assessment, different groups of stakeholders need to be involved, i.e. groups of stakeholders representing society and different stages of the supply chain. Only a few studies involved different groups of stakeholders to identify issues to be included in a sustainability assessment. Mollenhorst and de Boer (2004), for example, combined a brainstorming session and SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis with a heterogeneous group of stakeholders to identify relevant EES issues for egg production in the Netherlands. van Calker et al. (2005) identified and ranked issues based on opinions of experts and stakeholders for Dutch dairy farms. To our knowledge, so far, sustainability issues related to soybean and beef production chains in LA have not been identified in cooperation with stakeholders. To fill this knowledge gap, this thesis identified a set of sustainability issues for soybean and beef production chains in LA-EU context based on a survey among different groups of stakeholders (Chapter 2). We distinguished three groups of stakeholders: (1) business stakeholders, including producers, retailers, and traders, (2) consumers, and (3) other stakeholders, including representatives from environmental and social organizations, universities, and agricultural policy makers. Results revealed that economic issues tend to take precedence over social and environmental issues for stakeholders in the business group. These results are in line with the results of Chapter 5, where business stakeholders perceived higher importance (weight) for the economic dimension compared to the environmental and social dimensions of sustainability. More specifically, results of Chapter 2 and 5 confirmed the importance of economic issues for business stakeholders in soybean and beef production systems. Similar results were found by Mollenhorst and de Boer (2004) for egg production in the Netherlands, Vasileiou and Morris (2006) for potato production in UK, and van Calker et al. (2005) for Dutch dairy farming. In contrast to business stakeholders, consumers placed a relatively higher weight on social issues, such as food (feed) safety, whereas the other stakeholders perceived environmental issues such as biodiversity to be more important (Chapter 2).

The soybean business, consumers and other stakeholders perceived the following issues to be important: water quality, biodiversity, soil quality, local economy, national economy, food safety, labor rights and working conditions. For beef business, consumers and other stakeholders these were: water quality, biodiversity, profitability, local economy, national economy and food safety (Chapter 2).

A comprehensive evaluation of all EES issues was not possible in this thesis, due to the lack of data or methods to quantify issues (Table 6.1). This thesis only included those issues that were quantifiable, and for which data were available. Also, this thesis only included those issues which were relevant to beef and soybean production systems in LA countries and specifically in Brazil. For instance, land use change was not evaluated for soybean production system in Paraná region in Brazil, because soybean production in Paraná was not directly related to deforestation. According to Prudêncio da Silva et al (2010) for the southern part of Brazil (including Paraná), 0% of rainforest land was transformed from rainforest to soybean farms.

Sustainability performance of feeding strategies in beef production

The issues included in the sustainability assessment of various feeding strategies of beef production in Chapter 3 were: global warming, energy use, land occupation and profitability. Global warming was not selected in Chapter 2 by business, consumers and other stakeholders. However, literature suggests that implementing a feeding strategy considerably affects greenhouse gases emissions (GHG) in cattle production (Pelletier et al., 2010; van Middelaar et al., 2014). Beef and dairy cattle supply chains are responsible for about 61% of the global GHG emissions produced by livestock, i.e. 4.6 Gt carbon dioxide equivalent (CO_2-eq.) (Gerber et al., 2013). Ruviaro et al. (2015) reported that In Brazil, beef production is responsible for over 50% of national GHG emissions. Hence, we also selected global warming as a relevant issue. Moreover, land occupation as a proxy to measure productivity of cattle was used for evaluation of different feeding strategies, and, hence we included land occupation in Chapter 3 as well. Mollenhorst and de Boer (2004) also concluded that in addition to stakeholder involvement, reviewing of the literature is required to identify a complete list of EES issues. Biodiversity was not selected in the list of EES issues, since quantifying biodiversity proved difficult from a methodological point of view. Furthermore, Chapter 3 of this thesis attempted to evaluate the feeding strategies in terms of their impact on water quality by invoking the nitrogen (N) and phosphorus (P) balance. However, limited data were available regarding off-farm N and P balance. Specifically, the amount of fertilizer applied during the cultivation of concentrate feed ingredients (soybeans, sorghum and corn) was not available. It was not possible, therefore, to assess the long term effects of feeding strategies on N mining or N accumulation in the water and soil. We identified employment rate as an indicator for local economy; but observed no differences in employment rate between feeding strategies in Brazilian beef production systems. Another issue which was identified by stakeholders was national economy. To evaluate the performance of production systems regarding this issue, we need to link a specific production to the economic performance of country, which requires data and models that link a specific chain to the national economy. Generally, such data are not available. The evaluation of the impact for the national economy was further hampered by the fact that the alternative farming systems based on different feeding strategies are quite new and only a small percentage of Brazil's cattle farms have currently adopted these new systems. Hence, relating specific feeding strategies to the national economy proved impossible. Animal welfare was not in the list of questions of the survey; however, stakeholders had the possibility to suggest issues. Animal welfare was suggested as an issue for sustainability assessment of beef production in LA by the stakeholders that participated in the survey in this thesis. Therefore, we aimed to evaluate the animal welfare based on welfare principles (i.e., good feeding, good housing, good health and appropriate behavior), however, the data related to these welfare principles mostly were not available or were not relevant to LA situation.

The results of Chapter 3 showed from all feeding strategies for beef production evaluated, improved pasture (IP) could substantially improve the environmental and economic performance of the farms. In the IP system, global warming potential and land occupation per kilogram live weight were lowest, whereas fossil energy use per kilogram live weight was higher than in all other systems. The farming system based on crop residues (CR) as a feeding strategy was the second most profitable one. The higher economic return in this system, however, was related mostly to the soybean component of the farm, whereas the cattle component had the lowest operating profit compared to the other systems. Furthermore, this system did not have a better environmental performance compared with natural pasture (NP). The feedlot (FL) system had slightly better environmental performance (in terms of global warming and land occupation) than NP. However, the dietary supplementation did not increase operating profit. The results of Chapter 3 suggest that IP feeding strategy was the best strategy in terms of economic performance and most environmental indicators.

Sustainability performance of distinct soybean production systems

The issues included in the sustainability assessment of the soy bean production systems in Chapter 4 were: global warming, energy, land occupation, profitability and employment. Global warming and energy were not identified as issues for soybean production system by stakeholders (Chapter 2). According to scientific literature, however, conventional crop production systems, i.e., Genetically modified (GM) and non-genetically modified (non-GM) soybean production, consume considerably more energy and emit more GHGs than organic systems (Pelletier et al., 2008; Knudsen et al., 2010; Nemecek et al., 2011). These two issues, therefore, were included also in the evaluation of the sustainability performance of soy bean production systems (Chapter 4). Moreover, many studies criticize organic production as a system with lower yields compared to a conventional system (Azadi and Ho, 2010; Nemecek et al., 2011; Seufert et al., 2012). Although yields are only part of a range of environmental, social and economic benefits delivered by production systems, it is widely accepted that yields affect the sustainability of production once land availability is finite (Seufert et al., 2012). Therefore, land occupation was included in the evaluation of soybean production systems in Chapter 4 as well. As an indicator for local economy, employment provided by each of the production systems was taken. Biodiversity and national economy were not assessed in Chapter 4, for the same reasons as described previously for feeding strategies in beef farming systems. This thesis attempted to evaluate social performance of different production systems using indicators such as working conditions and labor rights. However, in contrast to developed countries such as European countries, in LA and specifically in Brazil, detailed data on working condition in different soybean production systems were lacking.

Evaluation of EES performance of different soybean production systems was carried out in Chapter 4 using a Monte Carlo simulation to reflect the impact of variation in input parameters on the distribution of outcomes. A number of studies accounted for variation of input parameters within and between systems (Mollenhorst et al., 2006; Thomassen et al., 2008; Leinonen et al., 2012). Leinonen et al., (2012), for example, accounted for stochasticity in the input parameters for environmental assessment of broiler production systems. The stochastic analysis of sustainability of soybean production systems gives insight into the range of outcomes and provides more complete information to policy makers about the distribution of the performance of various soybean production systems.

The variation in farm inputs in Chapter 4 substantially affected the EES performance of soybean production systems. Quantification of EES performance of soybean production systems revealed that organic systems had 77% probability to have a lower global warming potential than GM and non-GM systems. Moreover, at every level of probability land occupation was higher and energy use was lower for organic systems than for the GM and non-GM systems. Concerning profitability, organic systems had 60% probability to have higher profitability than GM and non-GM production, and employment at every level of probability was higher for organic systems. No significant differences were observed in the EES performance of GM and non-GM soybean production systems. In contrast to the results of Chapter 3 which allowed for selecting the farming system (based on feeding strategies) with the best environmental and economic performance, the selection of the best performing soybean production system (i.e., GM, non-GM and organic) was not straightforward in Chapter 4. Based on results of Chapter 4, therefore, decision-makers cannot easily choose between different soybean production systems, because EES issues are not all best in one system. MCA has the capability of giving a single overall score per system by aggregating sustainability scores using relative importance weights provided by stakeholders. Due to tradeoffs between scores for various issues, it is necessary to weigh issues and aggregate scores. Hence stakeholders were asked to weight the relative importance of sustainability issues in Chapter 5, in order to determine a final score for sustainability performance. Furthermore, we used elicitation of expert opinion to score the performance for issues which we could not quantify in Chapter 4, due to data scarcity or methodological difficulties. Several studies have used MCA to assess sustainability of agriculture and food production based on expert elicitation of scores (Sydorovych and Wossink, 2008; Engels et al., 2010; Reig et al., 2010; Michalopoulos et al., 2013). However, the scores provided by experts were not validated so far. The overall comparison of expert data with the data from the reviewed studies showed that the experts opinion were consistent with the reviewed studies for 58% of the pairwise comparisons of production systems.

The results of Chapter 5 were partly in line with the results of Chapter 4, i.e., expert elicitation and stakeholders' perceptions regarding different soybean production systems showed that a single overall score of the organic system was higher than the non-GM system. However, the results of Chapter 4 and Chapter 5 were partly inconsistent. The results of Chapter 4 showed that organic soybean production system performed better than GM for most of the issues (i.e., global warming, energy, profitability and employment). Furthermore, results of Chapter 5 showed a higher single overall score (better performance) for GM soybean production system than for organic soybean production system. The results of Chapter 5 were based on a more comprehensive list of sustainability issues than in Chapter 4. This can partly explain the differences between the results of Chapter 4 and 5.

Although the organic soybean production system has a higher probability to perform better than GM and non-GM systems regarding most of the EES issues in Chapter 4, the performance of organic agriculture per unit output or per unit input may not always be advantageous due to the high variation in the EES performance of this system. These findings in Chapter 4 were in line with the results of Chapter 5. More specifically, there was relatively a high level of variation (wider confidence interval) for organic soybean production system for all issues and for the overall single score (obtained from experts scores and stakeholders weights) in Chapter 5. The results of literature review in Chapter 5 confirmed these findings. For instance, the difference in the profitability of organic system compared to other systems varied in the reviewed studies from 2% to 85% and the global warming potential (GWP) varied from 3% to 41%.

Data issues

Several data related challenges were experienced while conducting the research in this thesis. First, sustainability assessment highly draws on input data, and data availability is usually a challenge in sustainability assessments. In this thesis, the lack of data related to the EES issues posed challenges in each research chapter. With respect to LCA data, gaps in the availability of inventory data represents a barrier to LCA practice; data have not yet been assembled specifically for some countries, products, systems, and emissions (e.g., Ecoinvent data for GHGs emission were based on international averages, and there are no country-specific emission factors available for the Brazilian situation). Therefore, in Chapter 3 and 4 only a limited number of EES issues were evaluated. Second, very limited historical data were available for sustainability issues, and essential data are still missing in the Brazil. Data collection for three different production systems in Brazil posed a major challenge in Chapter 4, as comprehensive data on the three systems were lacking among others due to a relatively low number of non-GM and organic farming systems in Brazil. Moreover, evaluation of different production systems in this thesis was based on data from one year. Studies covering only one year may be strongly affected by factors such as weather, market developments, or major pest and disease outbreaks in a given year. This thesis, could partly address these data challenges by using uncertainty analyses via, for example, stochastic simulation (Chapter 4 and 5) and by sensitivity analysis (Chapter 3 and 4). Studies based on deterministic input parameters do not adequately account for the uncertainty of key variables and ignore the differences in variation of the performance indicators used to compare production systems (Gebrezgabher et al., 2012; Gocsik et al., 2013). Therefore, in Chapter 4, we used Monte Carlo simulation to provide insight in the distribution of outcomes (Table 6.1). Moreover, in Chapter 5 we evaluated the validity of expert elicitation of scores and the robustness of the MCA method to uncertainty about the weights and scores (Table 6.1). Accounting for uncertainty about model parameters provides more complete information to decision makers.

Another data issue in this thesis was that generally more information was available for the stage of agriculture rather than post farm stages (e.g., crushing and slaughtering stage), wholesale, retail, and food catering. In Chapter 2, defining sustainability issues for soybean and beef production systems at LA-EU chain level was aimed for. However, finding data for computing all indicators related to the selected issues for all stages of the chains was challenging. For instance, finding data related to processing companies or slaughter houses was difficult and data could not always be obtained. Therefore, Chapter 3 and 4 focused on cradle-to-farm-gate rather than the entire supply chain.

The social dimension of sustainability proved to be especially difficult to measure (Halog and Manik, 2011), in particular because the country specific conditions need to be taken into account (Benoît and Vickery-Niederman, 2010). This is because social impacts are highly site-specific; hence, there are clear challenges to find site-specific social data for farm as well as other stages of the chain. For instance, the aforementioned problem regarding animal welfare issue can highlight this point.

Policy and business implications

Shifting the concept of sustainability from theory to operational for public policies raises significant challenges in terms of measurement (OECD, 2013). "Without issues, indicators, or a quantitative framework, sustainability policies lack a solid foundation on which to advance" (OECD, 2013). This thesis, therefore, tried to define sustainability issues, and evaluated a number of these issues for beef and soybean production systems which gives an overview regarding sustainability performance of soybean and beef production. This overview enables decision makers in these sectors to better anticipate and understand long-term trends and the effect of resource use, and to address stakeholders' expectations. Moreover, the insight into the sustainability issues can be used by policy makers to develop new policies for enhancing the sustainability of soybean and beef chains.

Chapter 3 showed that adoption of alternative feeding strategies to decrease environmental impacts might negatively affect farm profitability (Hristov et al., 2013). Business stakeholders are unlikely to adopt strategies that require investments that do not generate a positive net present value (Beauchemin et al., 2008; Hristov et al., 2013). Improving pasture quality in Chapter 4 decreased the total GWP and land occupation. Moreover, an improved pasture system could substantially improve the economic performance of farms. Therefore, IP is the most promising farming system based on feeding strategies in southern Brazil. The results of Chapter 3, therefore, suggest business stakeholders to adopt IP (as a best feeding strategies). According to Borges et al. (2014), however, the adoption rate to IP is still low in Brazil. These insights provided in this thesis can be used to adjust current policies and to develop new policy initiatives to stimulate the adoption and use of this practice by cattle farmers. Policy makers can promote the adoption of improved pasture through subsidies, loans, and provision of technical assistances to farmers (Borges et al., 2014). Such an improvement may control the expansion of beef production in the ecosystem, and discourage land clearing, where there is a clear interest in preserving nature and biodiversity for policy makers (Cederberg et al., 2011).

Based on the results of Chapter 4 and 5 regarding comparison of GM, non-GM and organic soybean production systems, policy makers and business stakeholders can be provided insight in the distribution of outcomes. The information regarding uncertainty and robustness can assist business stakeholders and policy makers to have more complete information to make better informed decisions. For instance, Chapter 4 reveled that organic system was the most profitable system compared to GM and non-GM soybean production system, however, the production of organic soybeans is subject to higher risks, such as production risks (Chapter 4 and 5).

Future research

The evaluation of the EES issues of soybean and beef production in this thesis mainly focused on the performance in terms of sustainability issues, and the process of sustainable development was not considered. To address this process of sustainable development, especially when the value chain and stakeholders' relationships are considered, the focus should be on the relationships and interdependencies of identifiable sustainability dimensions (Kemp et al., 2005). The relationships among EES dimensions can be addressed through governance issues (FAO, 2012). This became apparent from the results of business stakeholders survey in Chapter 2, where business stakeholders found governance issues (such as standards and certification schemes) important for sustainability of soybean and beef chains. Governance issues could be added to the EES issues in future studies, as they play an important role in improving the performance of sustainability (Kemp et al., 2005; FAO, 2012). In this regard SAFA guidelines defined governance as the fourth dimension of sustainability (FAO, 2012).

As discussed in the previous section, this thesis evaluated a limited number of EES issues of soybean and beef production systems, due to data and methodological challenges. Restricting the analysis to a limited number of sustainability issues allowed for a quantitative evaluation in Chapter 3 and 4. It is obvious that sustainability of beef and soybean production, in particular, and food and feed production, in general, comprises other issues, such as biodiversity, water quality and quantity, land use change, working conditions, etc. For a more complete view of sustainability, stakeholders should start sharing and collecting data more comprehensively, which is often costly (in terms of financial resources and time).

Main conclusions

The main conclusions of this thesis are:

- Economic issues were perceived more important for business stakeholders (Chapter 2 and 5), social issues were perceived more important for consumers (Chapter 2), and environmental issues were perceived more important for other stakeholders in beef and soybean production in LA-EU chain level (Chapter 2).

- A beef production system with an improved pasture (i.e. the natural pasture which was improved by the introduction of winter grasses (ryegrass and oat) and legumes (clover and birdsfoot trefoil)) improves the environmental and economic performance of beef production systems under current conditions, and is the most promising beef production system among the ones evaluated (Chapter 3).

- Sustainability issues emerge at various stages along the supply chain, and their relative importance is found to vary across stakeholders and countries (Chapter 2 and 5).

- Sustainability issues need to be complemented by a literature review, since stakeholders due to their interests, geographical differences, and knowledge do not always define a complete and relevant list of issues (Chapter 2).

- Organic production systems outperformed GM and non-GM systems with a 70% probability for global warming, a 60% probability for profitability, and a 100% probability for energy use and level of employment; non-GM systems outperformed other systems at every level of probability with regard to yield efficiency (Chapter 4).

- There is a relatively higher level of variation in the EES performance of organic soybean production compared to GM and non-GM soybean production systems (Chapter 4 and 5).

- The scores obtained from expert elicitation in our case study for soybean production were consistent with the reviewed studies for 58% of the pairwise comparisons of issues investigated. Therefore, there is potential to use expert elicitation as an alternative to extensive data rich methods. However, further research is needed involving more homogeneous groups of experts, with specific knowledge of EES dimensions of production systems (Chapter 5).

- Integrated sustainability assessment highly draws on input data, and generally is hampered by data availability (Chapter 3, 4, 5).

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6

Summary

F. Pashaei Kamali

Summary

The expansion of livestock production throughout the world has led to an increased demand for high protein animal feed. This expansion has created economic benefits for livestock farmers, feed producers and other actors in the chain. However, there is an increasing debate and concern at international, national, and local levels concerning the consequences of growth in livestock production, which fails to reconcile the often conflicting objectives of the economic growth, social progress, and protection of the environment. More attention is now given to these side effects by the concept of sustainability. In this regard, there is a common interest for stakeholders to cooperate to improve the sustainability of the soybean and beef production. Latin American (LA) countries, particularly Brazil and Argentina, are important producers and exporters of soybean and beef in the world. Although there are notable developments in the field of sustainability assessment, the knowledge regarding sustainability performance of soybean and beef production in LA is still low. Therefore, implementation and evaluation of sustainability of soybean and beef production chains in LA has become a principal objective for policy and decision makers. In this regard, the overall objective of the thesis is to analyze the sustainability performance of soybean and beef production chains in LA.

In Chapter 2, we aimed to identify a set of sustainability issues that cover the environmental, economic, and social (EES) dimensions of soybean and beef production chains. The method applied combines the results of multiple studies, including a literature review and stakeholder surveys. Stakeholders' survey was conducted for three different interest groups (business, consumers, and other) and two geographical regions (LA and the European). Only a few studies involved a heterogeneous group of stakeholders to identify issues to be included in a sustainability assessment. To our knowledge, so far, sustainability issues related to soybean and beef production chains have not been identified in cooperation with stakeholders. To fill this knowledge gap, this chapter identified a set of sustainability issues for soybean and beef production chains in LA-EU context based on stakeholders' survey. Defining sustainability issues from a whole chain perspective is important, as issues of sustainability emerge at

various stages along the production chain, and are found to vary across stakeholders' interests. Business stakeholders, for example, perceived economic issues to be more important, whereas the majority of consumer stakeholders perceived social and other stakeholders perceived environmental issues to be more important. The following issues were perceived by stakeholders to be important for the soybean chain: water quality, biodiversity, soil quality, local economy, national economy, food safety, labor rights and working conditions. For the beef chain these were: water quality, biodiversity, profitability, local economy, national economy and food safety. Different education levels, knowledge, and living patterns in various geographical regions can affect the stakeholders' perceptions. The combination of a heterogeneous group of stakeholders and the consideration of multiple chain stages constitutes a useful approach to identify sustainability issues along food chains.

In Chapter 3, we evaluated the economic and environmental performance of four feeding strategies for beef production in southern Brazil. Based on the feeding strategies, we defined four beef farming systems: (1) farming system based on natural pasture as a feeding strategy (NP); (2) farming system based on improved pasture as a feeding strategy (IP); (3) farming system based on natural pasture and crop residues as a feeding strategy (CR); (4) farming system based on natural pasture and feedlot as a feeding strategy (FL). Environmental indicators used to compare the farming systems were global warming potential (GWP), fossil energy use, and land occupation per kilogram live weight (LW). The results showed that: IP improves the environmental and economic performance of beef production under current conditions; CR improves the economic performance, but the environmental performance of this system was not better than NP; FL results in a small improvement in the environmental and economic performance. The outcomes of this research suggest that IP is a promising system to improve both the environmental and economic performance of beef production in southern Brazil.

In Chapter 4, we evaluated EES issues for the two main soybean production systems in southern Brazil; the conventional system, which produces genetically modified (GM) or non-genetically modified (non-GM) soybean, and the organic system. Data were collected for the year 2012 from three sources: soybean farms in Paraná, Brazil

(15 GM, 15 non-GM, and 15 organic farms), the Brazilian Enterprise for Agricultural Research (EMBRAPA), and the expert elicitation. Monte Carlo (MC) simulation was used to account for the variation in input parameters. Five sustainability issues were evaluated in this study: global warming, land occupation, primary energy, profitability, and employment. In addition to the general comparison of different soybean production systems, the modeling framework used in this study captures the uncertainty in the key system parameters, and therefore, allows for a comparison of the robustness of the outcomes. Furthermore, by using sensitivity analyses we were able to identify the key variables determining the EES performance of soybean production systems. Quantification of EES performance of soybean production systems revealed that organic systems had 77% probability to have a lower global warming potential than GM and non-GM systems. Moreover, at every level of probability land occupation was higher and energy use was lower for organic systems than for the GM and non-GM systems. Concerning profitability, organic systems had a 60% probability to have higher profitability than GM and non-GM production, and employment at every level of probability was higher for organic systems. No significant differences were observed in their EES performance of GM and non-GM soybean production systems. The results of this study revealed that there are many factors to consider in the evaluation of organic, GM, and non-GM production systems, and that there is no simple way to determine a clear winner. Overall, simulation results of this study illustrated the relatively high level of variation in the environmental, economic, and social performance of organic soybean production systems. Sensitivity analysis based on stepwise regression showed that yield, fuel, fertilizer, and labor had significant effects on performance. This study shows that accounting for variability in key system parameters provides not only insight in the most likely outcomes, but also in the robustness of system performance. This additional information about the robustness of system performance enhances the debate about the sustainability of soybean production systems.

In Chapter 5 we used elicitation of expert opinion to deal with the scarce data situation, as sustainability assessments are often hampered by limited data availability. Elicitation of expert opinion could provide a solution in such cases, and multi criteria assessment

(MCA) is a method that allows for using such data in sustainability assessments. The validity of expert opinion to score the sustainability performance of distinct systems, however, has not been assessed so far. Also, the robustness of the outcomes of the MCA method to uncertainty about scores elicited from the experts and the weights used for aggregating indicator scores has generally not been addressed. The objective of this study was to evaluate the validity of expert elicitation of scores, and the robustness of the MCA method to uncertainty about scores and weights. This has been illustrated for three soybean production systems (i.e., conventional production with either GM or non-GM soybeans and organic production) in Brazil and Argentina. The validation is carried out by comparing the scores that were obtained using expert elicitation with the values from scientific studies. The robustness of the MCA outcome to uncertainty about the scores and weights is assessed using MC simulation. The overall comparison of expert data with data from scientific studies showed that the assessments by the experts were consistent for 58% of the pairwise comparisons of the issues with studies reviewed. With regard to robustness, outcomes showed higher variation of weighted scores for organic soybean production systems compared to GM and non-GM production system in both Brazil and Argentina. The evaluation of validity is needed to allow inclusion of expert data in MCA. A distribution of the overall MCA scores provides better information to decision makers about the potential range of outcomes. In conclusion, there is potential to use expert elicitation as an alternative to extensive data rich methods. Concrete conclusions, however, need further research based on a larger group of experts, with a high degree of knowledge regarding production systems.

Chapter 6 provides a synthesis of the results. Subsequently, the data issues encountered in this thesis are discussed. This is followed by the discussion of implications of the results for policy makers and business stakeholders regarding sustainability of soybean and beef production, and an outline of future research. Finally, the main conclusions from this thesis are presented. Based on the results of this thesis, the main conclusions are:

- Economic issues were perceived more important for business stakeholders

(Chapter 2 and 5), social issues were perceived more important for consumers (Chapter 2), and environmental issues were perceived more important for other stakeholders in beef and soybean production in LA-EU chain level (Chapter 2).

- A beef production system with an improved pasture (i.e. the natural pasture which was improved by the introduction of winter grasses (ryegrass and oat) and legumes (clover and birdsfoot trefoil)) improves the environmental and economic performance of beef production systems under current conditions, and is the most promising beef production system among the ones evaluated (Chapter 3).

- Sustainability issues emerge at various stages along the supply chain, and their relative importance is found to vary across stakeholders and countries (Chapter 2 and 5).

- Sustainability issues need to be complemented by a literature review, since stakeholders due to their interests, geographical differences, and knowledge do not always define a complete and relevant list of issues (Chapter 2).

- Organic production systems outperformed GM and non-GM systems with a 70% probability for global warming, a 60% probability for profitability, and a 100% probability for energy use and level of employment; non-GM systems outperformed other systems at every level of probability with regard to yield efficiency (Chapter 4).

- There is a relatively higher level of variation in the EES performance of organic soybean production compared to GM and non-GM soybean production systems (Chapter 4 and 5).

- The scores obtained from expert elicitation in our case study for soybean production were consistent with the reviewed studies for 58% of the pairwise comparisons of issues investigated. Therefore, there is potential to use expert elicitation as an alternative to extensive data rich methods. However, further research is needed involving more homogeneous groups of experts, with specific knowledge of EES dimensions of production systems (Chapter 5).

- Integrated sustainability assessment highly draws on input data, and generally is hampered by data availability (Chapter 3, 4, 5).

Training and Supervition Plan

F. Pashaei Kamali

Training and supervision plan

Description	Institute [1]	Year	ECTS[2]
Discipline-Specific courses			
Sustainable Enterprise & Emerging Theory and Practice	BEC/WUR	2011	0.5
Agriculture business economics	BEC/WUR	2012	6
Advanced agriculture business economics	BEC/WUR	2013	6
Advanced statistics	Mathematical and Statistical Methods Group	2013	6
Scientific writing	Language centre/WUR	2012	2
Improve your writing	Language centre/WUR	2013	1.5
General research related competences			
Introduction course	WASS	2011	1
Writing PhD research proposal	WUR	2011	4
Research Methodology - From topic to proposal	WASS	2012	4
Career related competences/personal development			
Voice matters-Voice and presentation skills training	BEC/WUR	2011	0.5
Interpersonal communication for PhD students	WGS/WUR	2012	0.6
Competence theory and research	ECS/WUR	2012	4
Techniques for writing and presenting a scientific paper	WGS	2012	1.2
Participation PhD meetings	BEC/WUR	2011-2013	2
Social Dutch for employees	Language centre/WUR	2014	3

WASS PhD council, includes Chair, organization of PhD Days and Career events; member of Wageningen PhD Council	WASS	2014-2015	2
Contribution to conferences and seminars			
Conceptual Framework for Extended Life Cycle Assessment of Soy and Beef Chains	International European Forum on System Dynamics and Innovation in Food Networks, 13-17 February, 2012, Innsbruck-Igls, Austria	2012	1.0
Exploring environmental, economic and social performance of GM, non-GM and organic soybean production systems in Brazil	11th Wageningen International Conference on Chain and Network Management, 4-6 June, 2014, Anacapri, Italy	2014	1.0
Evaluation of beef sustainability in conventional, mixed crop-beef, and organic systems	9th International Conference LCA of Food, 8-10 October 2014, USA, San Francisco	2014	1.0
Teaching and Supervising activities			
Supervising MSc and BSc student	BEC-WUR	2012-2014	1.0
Lecture-Sustainability analysis	BRD-WUR	2014	0.5
Tutoring practical sections in the course "Food safety economics"	BEC-WUR	2012-2014	1
Total			**49.8**

1. WASS: Wageningen School of Socila Science; WGS: Wageningen Graduate School; WUR: Wageningen University and research Centre; BEC: Business Economics Group; ECT: Education and Competence Studies Group; BRD: Biomass refinery and Process Dynamics.

2. One ECTS is on average equivalent to 28 hours of study load.

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F. Pashaei Kamali

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Colophon

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