Comparative Financial and Environmental Life Cycle Assessment of three South African Pork Production Chains

by

Johannes Christoffel Müller

Thesis presented in partial fulfilment of the requirements for the degree

Master of Science in Agricultural Economics at the University of

Stellenbosch

Stellenbosch University

Department Agricultural Economics

Faculty of AgriSciences

Supervisor: Prof. T.E. Kleynhans

March 2015

Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained herein is my own, original work, that I am the owner of the copyright thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Johannes Christoffel Müller

Date: 3 February 2015

Abstract

The world demand for animal proteins and profit-driven production has led to producing animal proteins intensively. Intensive pork production systems have traditionally had a poor image with the public, because these production systems are associated with environmental pollution. Currently, pigs are produced on highly specialised farms, and are fed concentrated (often imported) pig feed. The resulting higher production and higher animal densities contribute to an increased pollution of water, soil and air. The aim of this study is to determine the energy balance and emissions of three case studies, and to compare these results with their financial performance. The impacts will be recorded in the following impact categories: global warming potential (GWP), acidification potential (AP), eutrophication potential (EP) and Energy Use (EU). The case studies are three typical South African pig production facilities selected by the South African pork producer's organisation (SAPPO). The production inputs, from the feed acquisition to the delivery of one kg of pig at the farm gate, were included. The three farms are located in different areas in South Africa, namely KwaZulu-Natal province (Case study 1), North-West province (Case study 2) and Western Cape province (Case study 3). The functional unit (FU) for this study is defined as 1 kg of South African pig (live-weight) at the farm gate. This study found that the GWP/FU of Case study 2 is 4 and 2 % higher than Case studies 1 and 3 respectively. The EP/FU of Case study 1 is 9 and 6 % higher than Case studies 2 and 3 respectively. The AP/FU of Case study 1 is 4 and 5 % higher than Case studies 2 and 3 respectively. The EU/FU of Case study 3 is 45 % and 16 % higher than Case studies 1 and 2 respectively. The major activities that contributed to the environmental impact categories were the slurry management activity, followed by electricity usage. The financial and environmental performance comparison did show deviations. Therefore, it is recommended that environmental and financial performance measurements be made, in order to create a true reflection of the impacts. The potential for improvement in financial and environmental performance proved to be significant in the productivity of the sow herd, as well as in the management of the piglets. The location of the production facility does not claim to hold have significant environmental or financial implications. Management of the emissions produced by piggeries can offset the impact of the piggery's location.

Acknowledgements

This study would not have been possible without the support, assistance and participation of various individuals and organisations. I would gratefully like to acknowledge the help of following people and institutions:

South African pork producers' organisation (SAPPO), for financial support.

Mr J.L Lombard, for financial support.

Professor T.E. Kleynhans, my supervisor and mentor in this project. I am thankful for his guidance and support throughout this project and for assisting me with advice throughout my student years at Stellenbosch University.

Doctor W.H. Hoffman, for his guidance, friendship and advice throughout my student years at Stellenbosch University.

To my loved ones:

My family, parents and siblings, thank you for your support and belief in me.

All my loyal friends, thank you for your understanding and support.

To my Creator:

Thank You for all Your blessings and all the grace that You have bestowed upon me.

List of abbreviations

AP	Acidification potential
EP	Eutrophication potential
EU	Energy use
FU	Functional unit
GHG	Greenhouse gas
GWP	Global warming potential
ISO	International standards organisation
NFI	Net farming income
LCA	Life cycle assessment
LCC	Life cycle costing
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LW	Life weight
MJ	Mega Joules
SAPPO	South African Pork Producers' Organisation
SW	Slaughter weight
USA	United States of America
UK	United Kingdom
g	Gram
kg	Kilogram
L	Litre
kWh	Kilowatt hour
CO_2	Carbon dioxide

Table of contents

List of tables

List of figures

List of annexures

1 Introduction

The world demand for meat consumption has led to its intensive production. The intensive, concentrated meat production practices place a heavy strain on the environment. No longer, do animals freely graze for food; we feed them in optimally controlled environments for profit-maximising benefits, at the cost of the environment.

In the past decade, the production of pork meat has increased by 18.5 % worldwide. The countries where rapid growth rates have been achieved are Vietnam (65.4 %), Russia (49.6 %), Brazil (27.1 %) and China (24.7 %). During the same period, pork production in the EU has grown by only 5 % (Davies et al., 2014:6).

In South Africa, domestic pork consumption accounted for only 7 % of total meat consumption in 2013. Consumption of pork in South Africa has increased by 53 % over the past decade. The ability of the producers to keep supplying the demand for pork will depend on the availability of resources and the competitiveness of the industry in the global market. Imported products have accounted for a substantial portion of additional consumption during the past decade. Pork imports have grown by over 9 % per annum over the past five years. Imported pork products accounted for 15% of domestic consumption in 2012 (BFAP, 2013:57).

Intensive pork production systems traditionally have a poor image with the public because they are associated with environmental pollution (Basset-Mens & Van der Werf, 2005:140).. Environmental impacts are not always captured in the price of a product. While the world demand for meat, and especially pork, needs to be met, an increasing awareness exists among consumers, researchers and producers about the environmental impacts associated with producing meat. These impacts include the bad odour, water pollution, biodiversity breakdown, global warming and visual pollution. Consumers currently play an important role in most markets because they have more influence on the market than ever before.

The location of the intensive pork production unit requires that production inputs need to be transported to the plant, and the outputs produced at the unit need to be transported to the market place. The location of the pork production unit therefore plays an important role in terms of the environmental impacts generated throughout the production chain.

The aim of this study is to determine the energy balance and emissions (global warming potential, acidification potential, and eutrophication) of three case studies. These case studies are three typical South African pig production facilities, and include inputs and emissions from the mixing and feeding of the feed up to the delivery of one kilogram pig at the farm gate. The three farms are located in different areas in South Africa, namely KwaZulu-Natal province, North-West province and the Western Cape province. The three case studies are compared in terms of their energy balance and emissions performance. The differences are explained, and the impacts of the dominant factors are pointed out. Life cycle assessment will be used to quantify the environmental impacts of the three case studies. It could have been expected that transporting maize, as the major feed input, would have been a major contributor to energy use and emissions. The relative ratios of the three case studies' energy balance and emissions are compared with the relative financial performance of the diesel and electricity inputs. The comparison of the three selected piggeries in terms of financial and economic performance should provide useful information with regard to the impact of the location of the piggery relative to the input sources and pork markets, the impact of infrastructure and of production practices.

Chapter 2 will elaborate on the Life cycle assessment as an environmental impact assessment method. The general framework of Life cycle assessment will also be discussed in this Chapter. An overview of pork production and the relevant literature regarding pork production and Life cycle assessment will be discussed. Chapter 3 the will include the description of the three case studies, as well as the data collected at each case study. The data includes the yearly livestock averages, the feed inputs, the acquisition distance and origin of the feed and the production inputs. These inputs served as the inventory to the Life cycle assessment software that translates the inputs to the various environmental impact categories. In Chapter 4, the Life cycle impact assessment results of the three case studies will be shown. These results will be discussed in Chapter 5. Relevant conclusions and comparisons amongst three case studies will be made. Chapter 6 will include conclusions, recommendations and a summary.

2 Theory and Literature review

This chapter provides an explanation of, and discussion on the methodology of life cycle assessment (LCA) as an environmental quantification method. Also referred to are the origin, goal and purpose, and general framework of the LCA. The aspects of pork production are explained, to lay down a basis for applying the LCA method.

The increased awareness and value of protecting the environment to the human race have led to developing various environmental impact-measuring methods. Life cycle assessment (LCA) is one of these methods that can assist in quantifying environmental impacts and increase awareness of the resultant impacts caused by producing products and delivering services (ISO 14040, 2006:v). LCA has become a renowned methodology when considering environmental impacts. It is a biophysical accounting framework that can be used to characterise the material and energy flows of different activities in a product's or service's life cycle. It also quantifies the contributions of the various activities to resource depletion and emission-related environmental impacts (Pelletier et al., 2010:600). LCA is a method that aims to quantify the potential environmental impacts of goods and services. It and related approaches are essential elements in efforts to make sustainable development a reality (Rebitzer et al., 2004:718). This method has also been used to evaluate the environmental performance of pig production.

LCA expresses two types of environmental impacts during a product's life cycle, namely the use of resources and the emissions emitted. The resources include land usage, water usage, energy usage and fossil fuels. The dominant polluted emissions considered usually include all greenhouse gasses, as well as air and water pollutants; in the case of pork production key pollutants are methane and ammonia (De Vries & De Boer, 2010:2). The general framework of LCA includes the goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation of the results. The processes of calculating the sum of all the costs related to the life cycle of a product is known as life cycle costing (LCC). The three pillars of sustainable development are the environment, economics and social equity. When LCA and LCC are combined, two of these three pillars are represented, namely the environment and economics (Rebitzer et al., 2004:718).

The use of life cycle assessments (LCA) has become widely accepted among researchers who aim to quantify the environmental impacts of intensive animal production. This LCA methodology is used in this study to quantify the environmental impacts of three South African pig production chains. The phases in the life cycle of a typical pork production chain include preproduction, feed production, pig production, slaughterhouse and usage. The preproduction phase includes activities like producing fertilisers, pesticides and seeds. The feed production phase includes producing all the feed and by-products used for the different feeding stages in the production system. This stage has inputs like electricity, water and diesel and outputs like feed and emissions. In the pig production phase the piglets are born, raised and fed until slaughter weight is achieved. This stage has inputs like feed, diesel, electricity and water and outputs of pigs (at slaughter weight), waste water, slurry and transportation.

The aim of this chapter is to familiarise the reader with the origin and development, goal and purpose, general framework, and International Standards Organisation (ISO) requirements of LCA. The literature pertaining to the different stages in the pig's life cycle is reviewed and discussed in this chapter. Previous applications of LCA to intensive farming practices are summarised in order to view the different applications of LCA and their results.

2.1 The origin and development of life cycle assessment

In the early 1970s, LCA emerged as a methodology to address issues such as energy efficiency, raw material consumption and waste disposal. The key drivers of the development of LCA were mainly packaging, waste management, the oil crisis and the energy debate of that specific time (Buamann & Tillman, 2004:79). The norms and standards for applying the LCA methodology were constructed by the ISO to prevent false conclusions. The LCA methodology is described in ISO 14040 (2006:2), as the "compilation and evaluation of inputs, outputs and the potential environmental impacts of a product system throughout its life cycle".

2.2 Goal and purpose of life cycle assessment

The entire life cycle of a product includes extracting raw materials, manufacturing, distribution, transportation, maintenance, recycling, emissions and final disposal (Devers et al., 2012:4). The LCA methodology assists in quantifying environmental impacts and identifying opportunities in a product's life cycle where environmental impact mitigations are possible (ISO 14040, 2006: v). LCA induces more informed decision-making. It also can be used for marketing advantages based on environmental performance. LCA can be used to compare products, processes or services. It can further be used to compare alternative life cycles for a certain product or service, and to identify stages in the life cycle that induce more strain on the environment than other stages. The results point out the segments in a product's or service's life cycle where mitigation opportunities exist (Reckmann et al., 2012:104).

Different approaches to the LCA method exist, namely the cradle-to-grave, gate-to-gate, cradle-to-gate and gate-to-grave approaches. As illustrated in Figure 1, the cradle-to-grave approach includes all the phases of a product's life cycle, from the point of extracting raw material up to the final disposal phase. A gate-to-gate approach determines the environmental impact of a single stage in the production process of a product i.e. from one production phase to another (Devers, et al., 2012:109). The cradle-to-gate approach includes the processes from raw material extraction, through the production phase, up to the gate of the factory. The gate-to-grave approach includes all the processes from the actual consumption or use phase up to its end-of-life phase (everything post production). The latter approach determines the environmental impact of the product once it leaves the production phase.

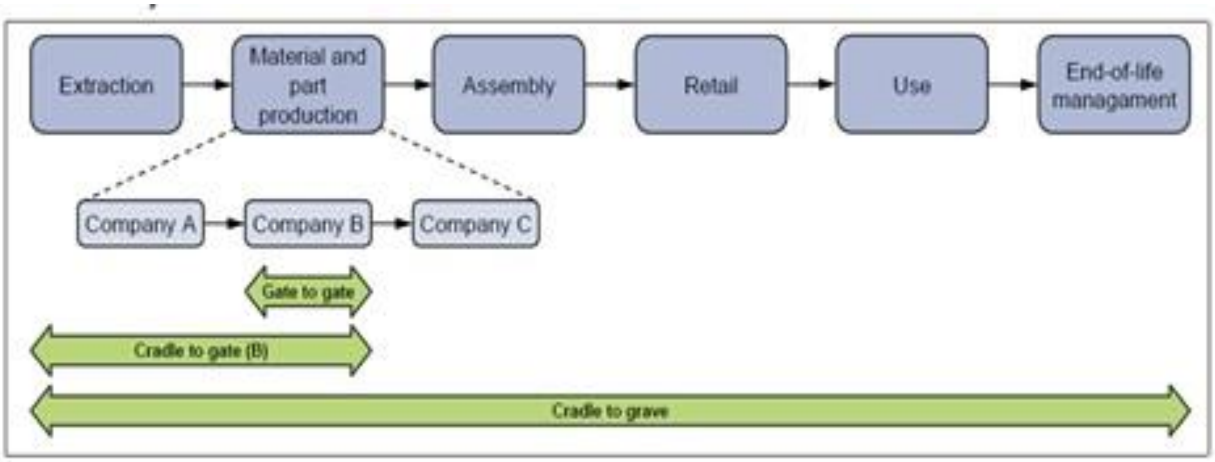


Figure 1: Cradle-to-gave, cradle-to-gate and gate-to-gate illustration of a complete life cycle

Source: Gyetvai, 2012:2.

When an LCA is performed, the ISO 14044 requirements are applied (ISO 14040, 2006:11). Not all the environmental effects can be attributed to the FU. The allocation process requires that co-products in the production chain be identified. Co-products can also be waste products in the production chain, and therefore, a ratio between waste and co-products must be determined (ISO 14040, 2006:14).The allocation of input and output data needs to be clearly stated and explained. When the inputs and outputs of a unit's process have been allocated, they need to add up to the same value as before the allocation. A sensitivity analysis is required to assure that the allocations are correct and to show what the consequences would have been if a different allocation approach were taken (ISO 14044, 2006:14). The LCA general frameworks as set by the ISO requirements are discussed next.

2.3 Life cycle assessment general framework

The LCA method is a systematic approach that includes four stages, namely goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpreting the results (see Figure 2). These stages are addressed accordingly. The stages interact and depend on the stated goal and scope of the proposed study. Although they interact and are related, it is necessary to discuss each phase separately, and their functions in tandem.

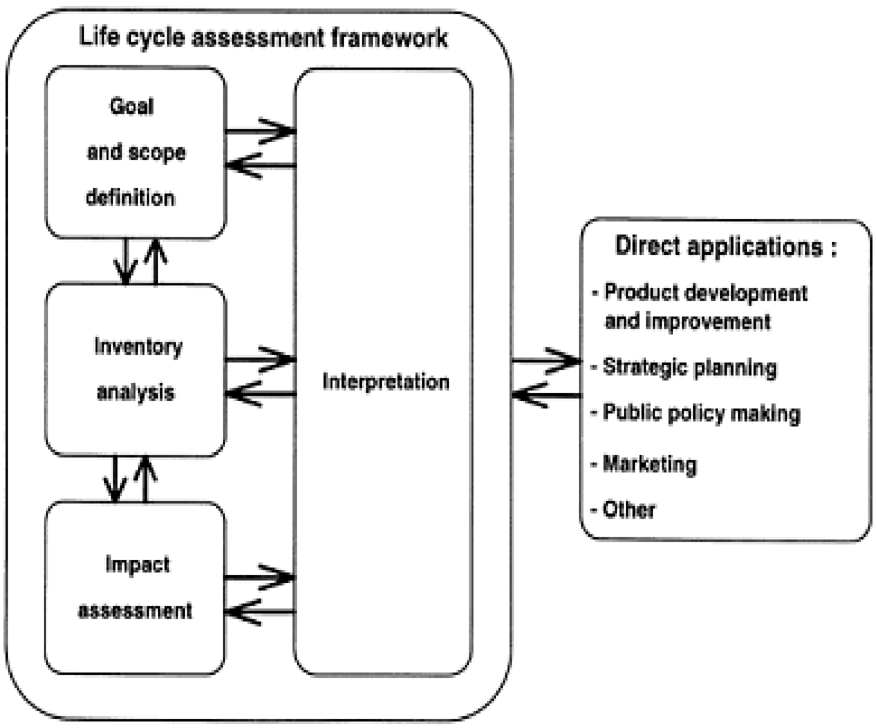


Figure 2: Life cycle assessment framework

Source: ISO 14040, 2006:8.

2.3.1 Goal and scope definition phase

Defining the goal and scope is the first phase of an LCA. When defining the goal of the intended application, the reason for carrying out the study, the proposed audience, and whether or not the results of the study are to be used in comparative assertions need to be disclosed to the public (ISO 14044, 2006:7). ISO 14040 (2006:7) requires that when defining the scope of a study, it must include the product system, the functions of the product system, the functional unit (FU), the system boundaries, allocation procedures, data requirements, limitations, and data quality requirements.

On completing the goal, and deciding on the products and system to be used, the FU must be defined. The functions must be clearly specified in the scope of the LCA. The FU is a quantitative measure expressing the functions that goods and services provide. In order to provide a reference to which all inputs and outputs can be normalised, the FU must be clearly defined and consistently applied throughout the study (ISO 14044, 2006:8). The FU must also be measurable and quantitative, for all other modelled flows of the system to be related. Different types of FUs exist, including input-unit-related, output-unit-related, unit of agricultural land and year. The FU provides a reference to which the input and output process data are normalised (Von Doderer, 2012:24).

The reference flow must be specified and defined after choosing the FU. A reference flow is the measure of product components and materials needed to fulfil the function, as stated in the FU of the study. The system boundary declares which phases of the product life cycle are part of the system, and which phases are not (Devers et al., 2012:6). Cut-off criteria specify the amount of material, energy flow, or level of environmental significance associated with the unit processes of the product system are to be excluded from the study (ISO 14044, 2006:4). When choosing the system boundary, various life cycle stages, unit processes and flows must be taken into consideration, i.e., acquiring raw materials; inputs and outputs of the manufacturing, distribution and production; use of fossil fuels; use and maintenance of the products; disposal of process water and products; recovery of used products; manufacturing of ancillary materials; and additional operations, such as, lighting and heating. The system boundaries must be clarified according to different dimensions, namely geographical, technical, natural and time boundaries.

The next phase of an LCA is the life cycle inventory phase.

2.3.2 Life cycle inventory phase

The second phase of the LCA framework is the LCI. This phase includes compiling and quantifying inputs and outputs for a given product system throughout its life (Sangwon & Huppes, 2005:688). These inputs and outputs may include the use of natural resources, such as land, water and fossil fuels. The use of these resources may release emissions into the air, water and land associated with the system (Von Doderer, 2012:26). The flow chart, Figure 3, illustrates this phase. As seen in Figure 3, there are critical phases within this LCI phase regarding the handling of data.

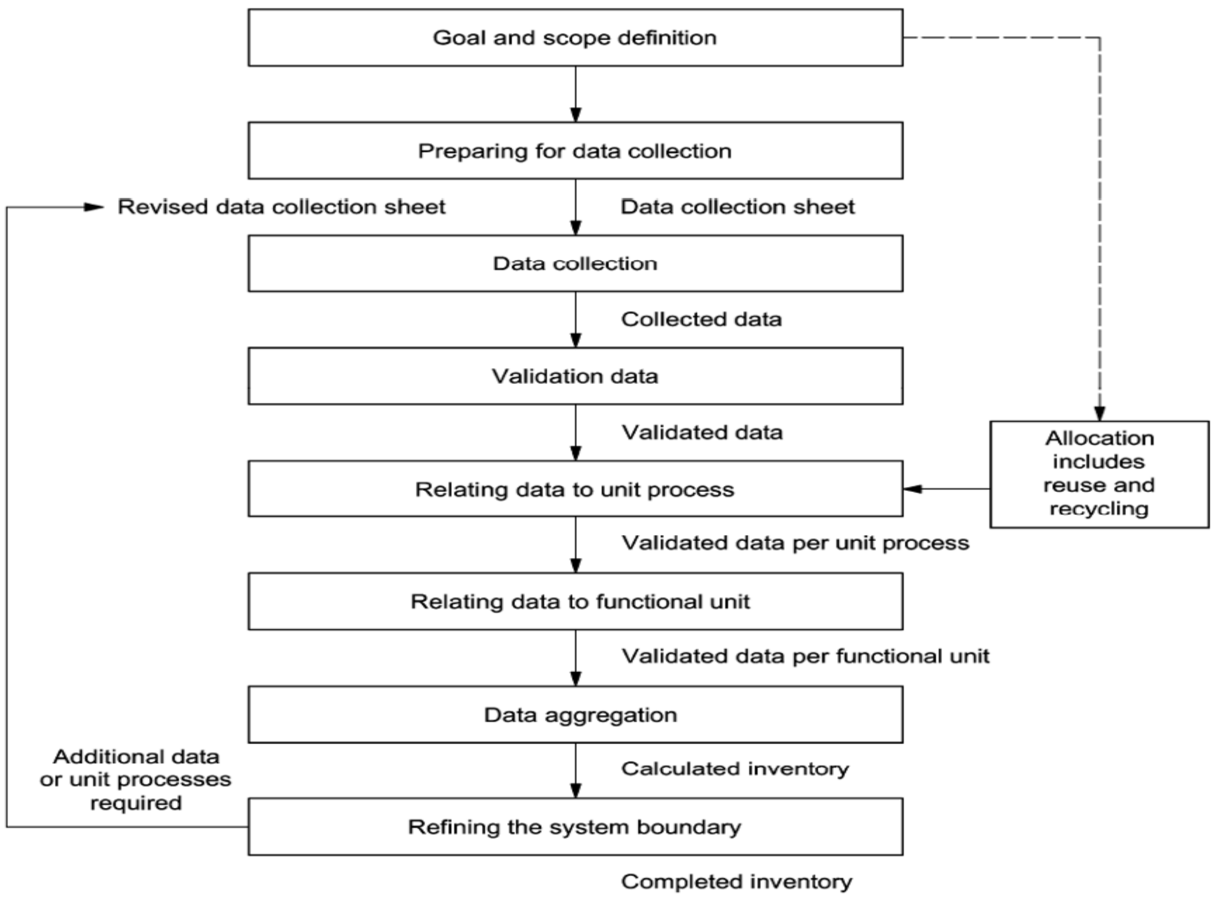


Figure 3: Life cycle inventory

Source: ISO 14044, 2006:12.

2.3.3 Life cycle impact assessment phase

The third phase of an LCA is the life cycle impact assessment phase (LCIA); this phase aims to evaluate the importance of the potential environmental burdens. The LCIA also involves associating inventory data with specific environmental impact categories and category indicators, to clarify these impacts (ISO14040, 2006:14). The LCIA also has limitations; for example, the limited development of characterisation models, setting the system boundaries which may not encompass all possible unit processes for a product and the limitations in collecting inventory data for each impact category (ISO 14040, 2006:15). Spatial differentiation also needs to be considered, as all the impacts caused by an emission depend on the quantity of the substance emitted, the properties of the substance, the receiving environment and the characteristics of the emitting source. Climate change and stratospheric ozone depletion impact indicators are global impact categories: they are independent of where the emissions occur and do not have spatial differences (Devers et al., 2012:27). The elements of the LCIA are illustrated in Figure 4.

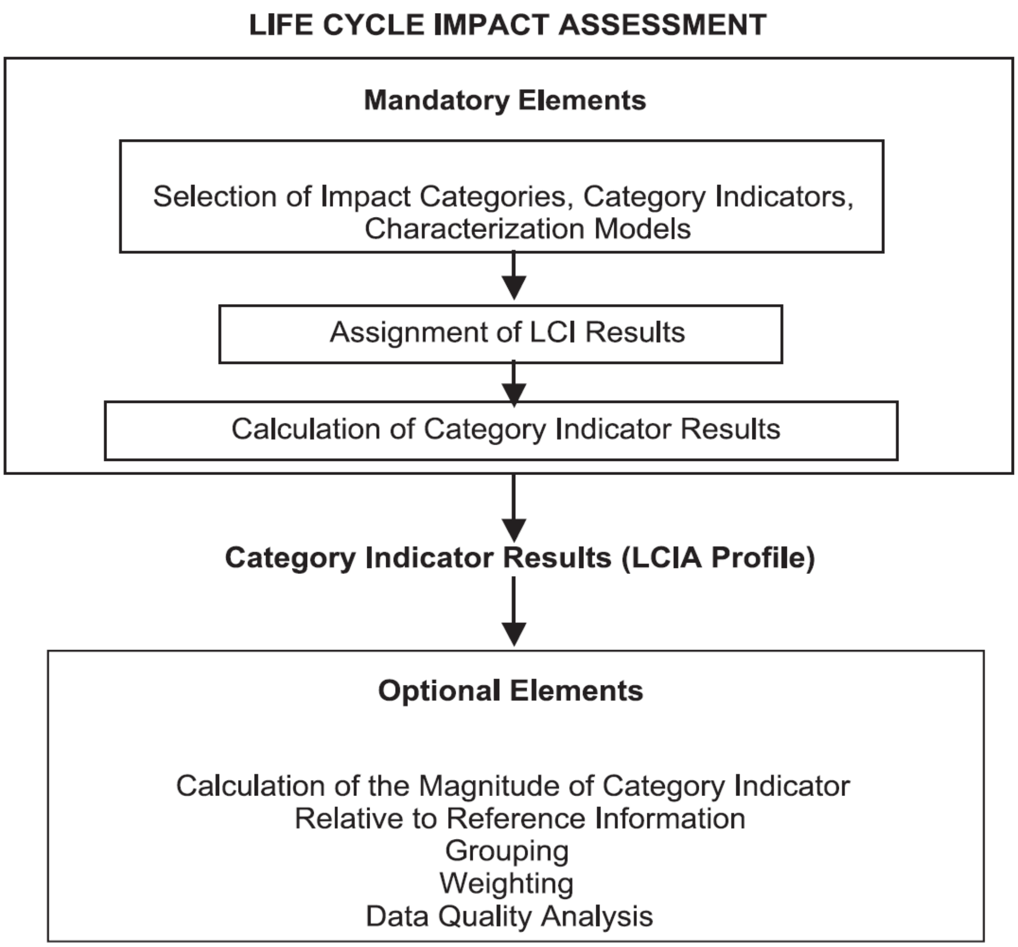


Figure 4: Elements of the LCIA phase

Source: ISO 14040, 2006:14.

Impact category is the class representing environmental issues of concern to which life cycle inventory analyses results may be assigned; for example, global warming potential (GWP), acidification potential (AP) and energy use (EU) (ISO 14040, 2006:5). Environmental impacts are described by Baumann and Tillman (2004:131) using three categories, namely, resource use, human health and ecological consequences. This by no means indicates the complexity of environmental impacts. A single pollutant's primary effect can lead to many other secondary effects or vice versa. Figure 5 indicates different channel flows for a single emission can lead to impacts in different impact categories.

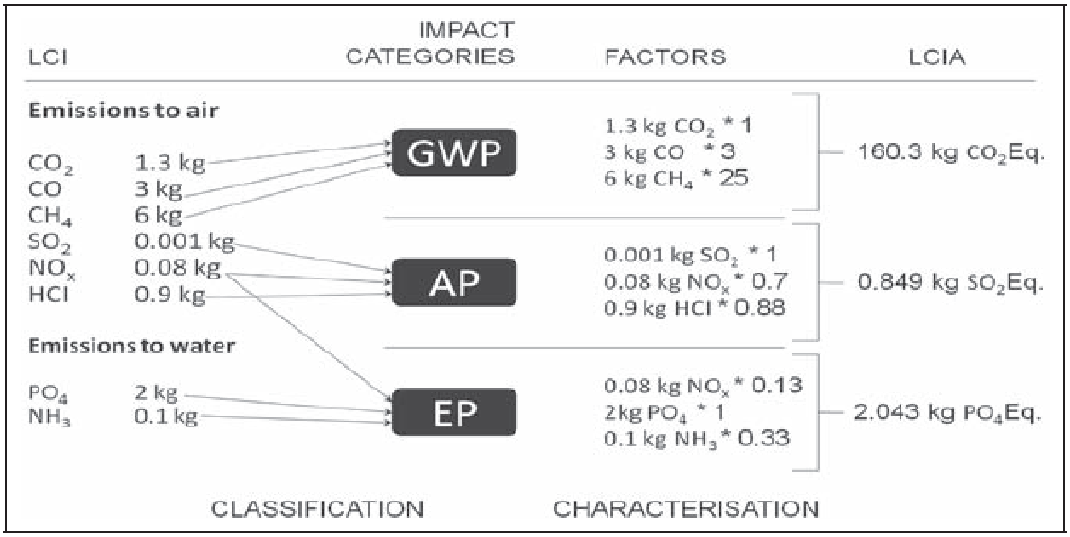


Figure 5: Classification and characterisation of environmental impacts

Source: Gabi, 2014.

There are a large number of impact categories in terms of which the performance of a system can be expressed. Reckman et al. (2012:103) list the main impact categories relevant for environmentally assessing pork production. Based on their example, Table 2 provides a summary of the main impact categories that were used in LCA of pork production.

Table 1: Proposed list of impact categories for pig farming

Impact Category	**Indicators**
1. Global warming potential (GWP)	Emissions of CO_2, CH_4 and N_2O
2. Acidification (AP)	Emissions of NH_3 and NO_x
3. Terrestrial eutrophication	Emissions of NO_x and NH_3
4. Aquatic eutrophication	N-discharge into watercourses (NO_3), (NH_4); P-losses through erosion and interflow, and surface run-off
5. Use of resources (energy use, EU)	Use of primary energy; use of other resources (e.g. fertiliser)
6. Quality of drinking water	N-discharge into watercourses; pesticides discharged into watercourses
7. Eco toxicity	Pesticides discharged into the ecosystem; discharges of antibiotics and feed additives into the ecosystem

Source: Reckman et al., 2012:103.

Global warming potential (GWP), acidification potential (AP), eutrophication potential (EP) and energy use (EU) are the impact categories chosen for this LCA study. A description, summary and unit of measurement for the four impact categories are discussed next.

Global warming potential (GWP)

Greenhouse gasses (GHG) are known for their ability to enhance the radiative forcing in the atmosphere. These GHGs absorb and emit radiation, and can lead to higher temperatures in the atmosphere. GWP measures take into account all the emissions of GHGs, like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), which cause an increase in temperature. GWP is calculated over a hundred years in accordance with the specifications set out in "CML CML2001 - Dec. 07, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]" (Baumann and Tillman, 2004:149). Figure 6 provide an illustration of the Greenhouse effect.

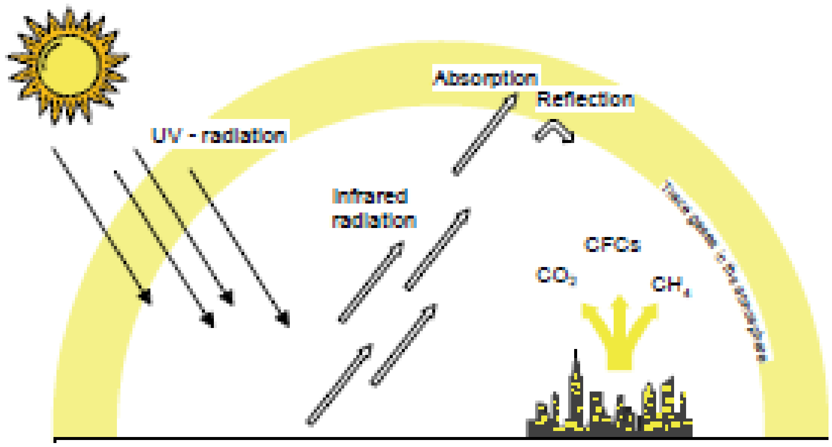


Figure 6: Illustration of the Greenhouse Effect

Source: Baitz et al., 2013:139.

Eutrophication potential (EP)

Eutrophication is the high quantity of nitrogen (N) and phosphorus (P) levels that result mainly from the run-off of agricultural water and the disposal of urban waste. The aquatic environment subsequently absorbs the run-off elements and causes environmental change. Emissions of these elements to the air are also taken into account in EP. These elements have one thing in common, which is the consumption of oxygen in their nearby environment. The reduction of oxygen causes lower levels of it in the water, and this has an effect on aquatic ecosystems. This results in the excessive growth of plants like algae in rivers and causes a sever reduction in water quality and animal populations. The algae prevents the sunlight from reaching the lower depths of the water's surface, which leads to lower photosynthesis and less oxygen produced (Gabi, 2009:60).

Eutrophication is a phenomenon that can influence both terrestrial and aquatic ecosystems. Since different ecosystems are limited by different nutrients, actual eutrophication varies geographically (Baumann & Tillman, 2004:156). All the impacts that lead to EP are converted with the CML method into Kg of PO_4 equivalents (Gabi, 2009:60). EP is illustrated in Figure 7.

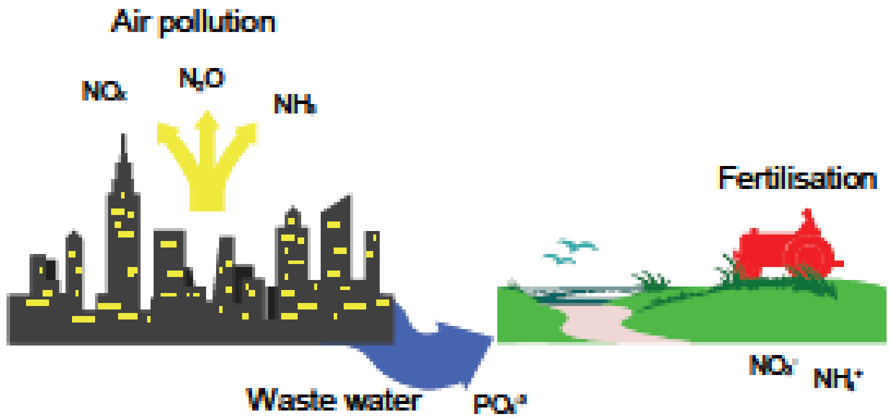


Figure 7: Illustration of the Eutrophication potential

Source: Baitz et al., 2013:139.

Acidification potential (AP)

Acidification potential calculates the loss of the nutrient base (calcium, magnesium, potassium) in an ecosystem, and its replacement by acidic elements caused by atmospheric pollution. Pollutants like SO_2, NO_x, HCl and NH_3 are the main pollutants that cause AP. All these pollutants have a common characteristic, which are that they form acidifying H+ ions. Acidic gasses like SO_2, NO_x and NH_3 react with water in the atmosphere, and have the potential to form acids like H_2SO_4 and HNO_3. The occurrence of rain, fog, snow, and dew are ways in which acid deposition takes place. Dry acid particles can be broken down when they is exposed to moist tissue (e.g. in the lungs). The reaction of the soil and water that are exposed to the acid causes its pH levels to decrease. Low pH levels can cause damage and eventually the death of ecosystems. Other negative effects are the breaking down of building materials such as metals and natural stones. The impact varies according to the area where the acid deposition takes place and to the environment's buffering capacity against the acid (Baumann & Tillman, 2004:155). AP is measured in kg of SO_2 equivalents. AP is illustrated in Figure 8.

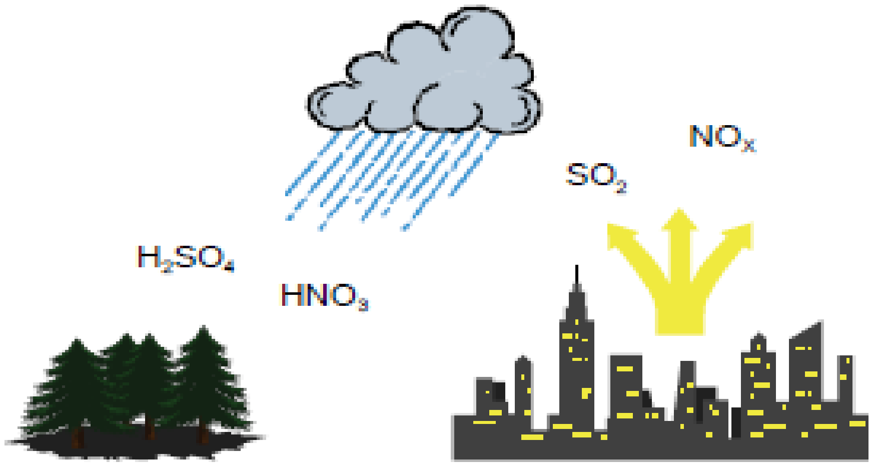


Figure 8: Illustration of Acidification potential

Source: Baitz et al., 2013:139.

Energy use (EU)

The resources used to generate energy have become scares. Various ways to generate sufficient and economically viable energy have been developed. Energy has become an important input in production systems across all sectors. The total energy usage of the pig production chain is a way of measuring its efficiency in using renewable and non-renewable power. All the energy after the production phase of the inputs, up to the point of the delivery of the FU at the farm gate are accounted for in this study. The results are expressed in MJ equivalents (Wegener Sleeswijk et al., 1996:41).

2.3.4 Interpreting results

In this phase of the LCA, the results from the inventory analysis and impact assessment are considered together, or in the case of LCI studies, the inventory analysis only. The interpretation phase must deliver results that are consistent with the goal and scope. The interpretation should also reach conclusions, explain limitations and give recommendations (ISO, 14040, 2006:16). In this phase, the data in the LCI and LCIA are analysed in order for conclusions to be made. The main objective of the life cycle interpretation phase is to analyse the results, reach conclusions, provide recommendations and illustrate results so that they are transparent to the intended audience.

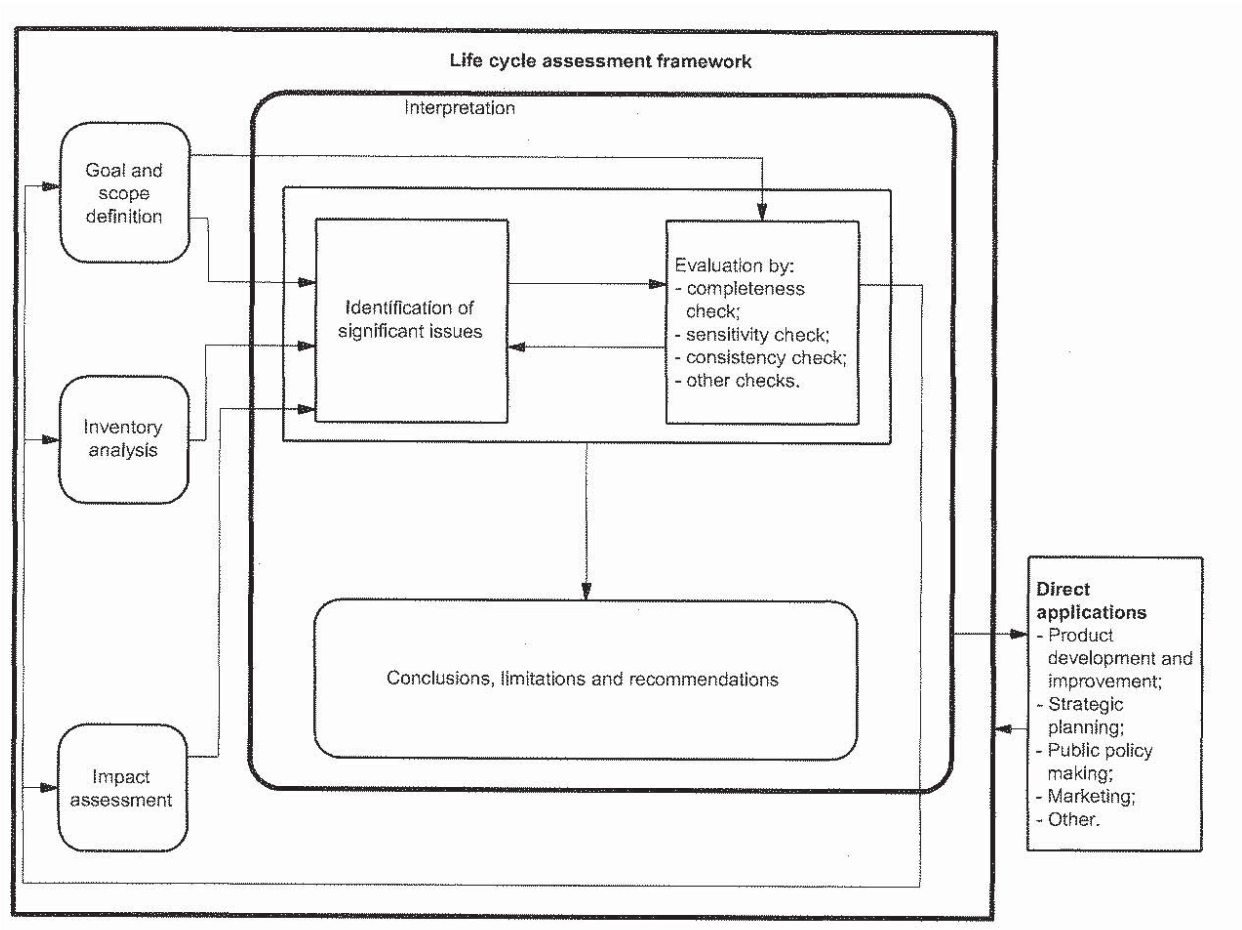


Figure 9: Relationships of the elements within the interpretation phase with the other phases of LCA

Source: ISO 14044, 2006:24.

2.4 Life cycle costing

While life cycle costing (LCC) is not the primary focus of this research, it is included to give the reader a greater and more comprehensive understanding of the various facets of LCA. The process of calculating the sum of all the costs related to the life cycle of a product is known as LCC. The LCC approach calculates the future costs and benefits of a project and, by discounting them to their present value, the economic value of a project can be assessed. In order to achieve the objectives of LCC, the following elements must be considered: initial capital costs, life of the asset, the discount rate, operating and maintenance costs, disposal cost, information and feedback, uncertainty, and sensitivity analysis (Woodward, 1997:337-338). When LCA and LCC are combined, two of the three pillars of sustainability are represented, namely the environment and economics (Rebitzer, 2004:718).

The LCC method also focuses on including the costs of the following phases: acquisition, installation, operation, maintenance, refurbishment and disposal (Luo et al., 2009:1614). Demolition and recycling costs were left outside the boundary of traditional accounting systems; therefore, the goal of the LCC method is to incorporate this problem (Glutch & Baumann, 2004:571).

2.5 Pig farming and its environmental impacts

In this section the literature on pig production is discussed, to create a more comprehensive understanding of all the factors determined for pork production. The use of life cycle assessments in intensive animal production, and particularly in pig production chains, is referred to for completeness.

The use of LCA has become a widely accepted tool among researchers who aim to quantify the environmental impacts of intensive animal production. A typical life cycle of pork production is illustrated in Figure 10. The phases in this production chain include the preproduction, feed production, pork production, slaughterhouse and use phases. The preproduction phase includes activities like producing fertilisers, pesticides and seeds. The feed-producing phase includes producing all the feed and by-products used for the different feeding stages in the life cycle of the pig. The pig production phase includes piglet production, farrowing, finishing, wastewater treatment and manure management. The slaughterhouse and usage phases include slaughtering, packaging and processing the meat, transportation, and usage and disposal of the packaging and remains. For the purpose of this review, the life cycle is categorised in three stages, namely the feed acquisition and mixing activities (2.5.1), the farming activity (2.5.2) and the post-production stage (2.5.3).

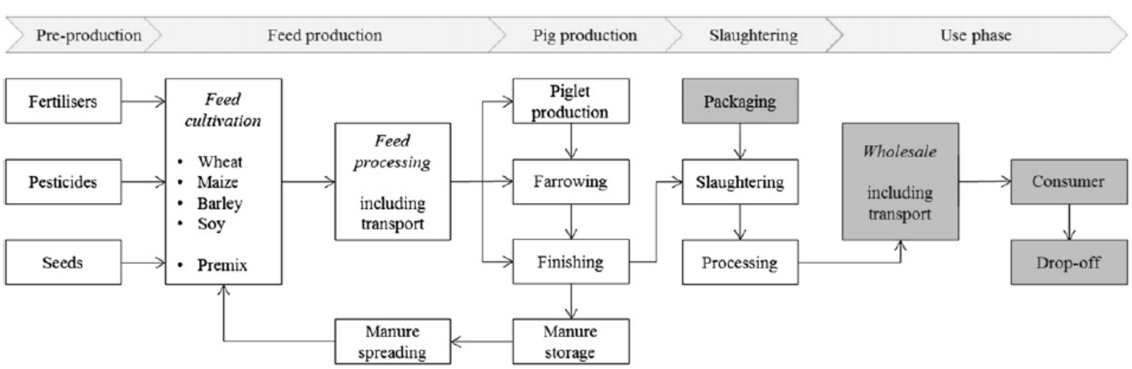


Figure 10: Life cycle stages of a typical pork production chain

Source: Reckmann et al., 2012:105).

2.5.1 Producing and transporting feed

An important part of the environmental impact of intensive pig production takes place outside the pig farm and is related to the production, processing, transport, storage and mixing of the feed. Pork production depends heavily on concentrated feed ingredients. Due to climatic factors, not all the feed can be produced in the same area, and some of it must be transported over great distances (Dolman et al., 2012:144).

Research has established that one kg of feed delivered to piggeries produces an EP of between 3.8 and 9.38 g of PO_4 eq, a GWP of between 472 g and 792 g of CO_2 eq, and that it has an EU of between 3.3 and 6.1 MJ, depending on the feed composition. A feed mix containing mainly co-products required higher energy usage and lower terrestrial ecotoxicity than feeds consisting mainly of non-processed crop-based ingredients (Basset-Mens et al., 2005:174). The growing and processing of the pig's diet has the largest influence on resource usage. Feed efficiency is also a critical control point for the success of a production chain (Lammers et al, 2011:1).

Mineral phosphorous and copper are used as supplements and growth-promoting agents in a pig's diet, among other substances like soybean meal and grain. A concentration of copper remains in the manure, because only a small portion of the copper is retained in the meat. If the manure is applied to soil, the copper is released into the soil and water. This is a harmful component, and is toxic to aquatic life (Nguyen et al., 2012:169). The environmental burdens, management and disposal of slurry are discussed in detail in Section 2.5.2.2.

Producing pigs relatively efficiently converts feed protein into meat products. The efficiency of this conversion rate depends heavily on the type of feed and the genetics of the pigs. The content of feed for animal consumption generally includes wheat, barley, soybean, maize and peas, which are not processed before their incorporation in the feed (Basset-Mens et al., 2005:165). A pig's diet consists of different raw materials, but the main components of the mixture are wheat, barley, maize and soy. Supplements such as calcium carbonate and lysine are also added to the feed mix (Reckmann et al., 2013:588). The major part of this off-farm impact results from cultivating and transporting the dry feed components (Dolman et al., 2012:149). An LCA case study completed on Western Cape pork production in South Africa found that the maize content of the total feed ration was 60 %. Transporting this maize occurred mainly by road over 1 200 km from the maize-producing areas of South Africa. The results illustrated that the GWP is significantly affected by the transportation distance of the maize content (Devers et al., 2012:117).

Raw material inputs to animal feeds can travel long distances and still outcompete other locally produced substitutes, due to factors including farming subsidies, different tax rates, resource availability and infrastructure. In Reckman et al. (2013:588), soy was imported from Brazil to the harbour at Rotterdam in the Netherlands (9 700 km), and then transported with trucks to its destination in Germany (412 km).

Comparatively speaking, producing and providing feed contributes the majority of the environmental impacts for the cradle-to-farm gate life cycle of a US broiler poultry supply chain. In poultry feed mix, where maize has a mass content of 70 % of the ration, it contributed on average 40 % of the environmental impacts to produce one tonne of broiler feed. Soybean meal comprises 20 % of the feed mix, and results in 12 % of the environmental impacts. Further results found that producing fertiliser has the highest impact on energy use and ozone depleting emissions in producing crops (Pelletier, 2008:69).

Similar comparisons can be made for producing feed for cattle farming. The on-farm feed production in conventional dairy farming systems contributes 90 % of eutrophication potential in the life cycle. This result is high because of the use of artificial fertilisers and manure in the feed production activity (Guerci et al., 2013:301). In a cradle-to-gate LCA of beef production, the main contributor to energy use as well as ecological footprint is the production of feed (Pelletier et al., 2010:383).

Several authors recommend mitigation strategies in producing and using feed in pig farming. A low feed intake and a feeding ration with a high proportion of wet by-products improves the environmental performance. Larger production farms that tend to feed a higher proportion of by-products outperform other farms on economic, environmental and societal criteria. The environmentally best-performing farms have a lower feed intake per functional unit (Dolman et al., 2012:152). The environmental impacts of pig feed are lower if the number of other feedstuff increases in the mix. In a study of pig production in Europe, Basset-Mens et al., (2005:170) found that maize-based feed required 33 % more energy than wheat-based feed. This number certainly differs among countries with conditions that favour maize production. If no maize is produced in the region, it must be either transported or imported at an additional cost to the environment.

Copper and zinc are supplements that are added to a pig's diet. Copper is used as a performance-enhancing and growing agent, and as an anti-bacterial agent in the animals gut. Zinc is also a type of supplement in a pig's diet, used to enhance the control of post-weaning scours (Petersen et al., 2007:183).

The environmental impacts associated with producing and transporting pig feed can be reduced by using fertilisers more efficiently. Using more locally produced feed ingredients and reducing concentrations of copper and zinc in the feed can lower the environmental burden of the feed-providing activity in the life cycle of producing animals (Basset-Mens et al., (2005:170). Less copper and zinc in the feed lowers the harmful amount of it in the manure and, consequently, also in the slurry. Slurry is a mixture of the faeces, urine, strewing material, spilled feed and water, including the water used for cleaning the pig houses (Hjorth et al., 2010:155).

2.5.2 The farming activity

The farming activity consists of all the processes in the life cycle that occur on the farm. This activity includes producing, preparing and mixing the feed, and supplying the feed to the sows, boars and piglets. It also consists of supplying inputs like heating, ventilation, water, and cleaning the premises (Reckmann et al., 2013:588). In this stage the piglets are born, raised and fed until slaughter weight is reached. Specific feedstuffs for each stage of the pig's life are provided. The outputs of this stage are pigs at slaughter weight, slurry and wastewater, among others.

The cleaning of the pig housing includes the removal and disposal of manure. In some cases, the manure also needs to be transported away from the farm. In a grow-to-finish swine production facility, the inputs needed include the following: electricity usage (lighting, ventilation, heating, and feed-auger operations); water for consumption, cleaning, and cooling; manure handling, manure auger operations, manure vehicle transportation and manure pumping for application to the land (Stone et al., 2012:4).

Countries use different resources to generate electricity. A country typically uses the resources that it has an abundant supply of and combines them with the technology available to generate electricity. It is not always the case that a country will choose the environmentally friendly option to generate electricity, but often rather the financially efficient option. Some countries use a mixture of available resources and technologies to generate their electricity. The most common ways to generate electricity in South Africa are coal combustion. Nuclear energy, solar power, hydro power and wind power are also used to generate electricity, but only contributes around 10 % to the national grid. Therefore, the type of electricity mix used in a country has different impacts on the environment. Electricity generated from coal combustion has a higher environmental impact than electricity generated from renewable energy resources. In the pig-farming activity, electricity is also the key determinant of GWP. Electricity is used for heating the piglet's environment. Central heating can be used instead of heat bulbs for more efficient use of energy (Devers et al., 2012:116).

Genetics play a very important role in the number of piglets weaned per sow, the quality of meat produced, the amount of feed needed for the pig to add bodyweight and the amount of slurry that the pig produces. The quality of the feed also has a significant effect on the reproductive performance of sows. Therefore, the reproductive performance of sows influences the whole-herd productivity of the production chain (Koketsu & Dial, 1996:1446). The feed conversion factor is the amount of feed needed to add one kg of live weight to an animal. The type of feed mix used for feeding, and the genetics of the animals are major factors in the feed conversion ratio (Devers et al., 2012:126). The feed conversion ratio is an effective and reliable means by which feed efficiency comparisons can be made between production chains. Similar to pig production, improvements to genetic strains in chicken production have also increased the carcass yield and, therefore, decreased the environmental impact of the meat produced (Da Silva et al., 2014:229). Eutrophication is the main environmental impact resulting from the farming activity. The main contributor to this potential is the leaching of nitrogen from pig manure, ammonia emissions to the atmosphere, and phosphate leaching (Devers et al., 2012:118).

Within the farming activity, the pig housing stage and the manure and slurry management occurs. According to the literature, key environmental mitigation possibilities occur in these segments of the production chain. These two stages are discussed separately in the following section.

2.5.2.1 The pig housing stage

The pig housing stage includes the way the pig's pen is designed, and how different technologies are incorporated to provide an optimal 'house' for the pigs. This optimal house differs from one production chain to another, due to climate, feed and water availability, among others.

In Reckmann et al. (2012:108), the pig housing stage contributed (81 %) to GWP. In this study methane was the main contributor to this figure and accounted for 79 % of the GWP. Methane can only be controlled during the transportation and storage of the slurry, so by using low-emission housing systems, and by reducing the mineral content in the feed mix, the excretion of minerals can be reduced.

Numerous heating and lighting technologies exist that can be incorporated to lower the energy demand in the farming process (Devers et al., 2012:126). In the pig-farming activity, improvements can be made by limiting energy use, by using heating that is more efficient.

The way animal housing is designed may have an influence on the physical and chemical characteristics of the slurry produced. Some pig housing facilities are designed with slatted floors that have channels to accommodate transporting the slurry beneath the floor (Hjorth et al., 2010:155).

2.5.2.2 Slurry management

Slurry is a mixture of the faeces, urine, strewing material, spilled feed and water, and the water used for cleaning the pigpens (Hjorth et al., 2010:155). Concentrated animal production often comes with producing excess manure on a small area. Slurry is produced in large amounts and has a low concentration of nutrients; thus the cost of transporting the nutrients from livestock farms with a nutrient surplus to arable farms with a nutrient deficit is high (Moller et al., 2000:223). The nutrients or components thereof that can be found in the manure, slurry, air and water originate from the portion of feed that is not retained by the animal. Therefore, manipulating an animal's diet will have an effect on the nutrients that it will excrete or emit (Petersen et al., 2007:182).

Slurry produced in intensive livestock practices contains P, K and N. The P and Lhave an equivalent fertilisation value to those of mineral fertilisers. However, the lower N content has a lower fertilisation value than those of commercial fertilisers. If the nutrients are applied to the soil at a higher rate than used by plants, the risk of nutrient runoff and leaching occurs. Therefore, the nutrients must be stored or transported to areas were the disposed slurry will not cause the environment any harm (Hjorth et al., 2010:154).

Slurry must often be transported over distances to less vulnerable areas. In the case of the Western Cape province, in South Africa, the solid parts of manure can easily be distributed locally because of the constant demand for it (Devers et al., 2012:119). In the pig housing activity, findings are that treating the slurry is the main contributor to environmental impacts (Reckmann et al., 2012:108).

Quickly and effectively incorporating slurry can minimise the emissions of ammonia (NH_3). The amount of NH_3 emissions can also be reduced by nutritional measures. These measures aim to reduce the amount of nitrogen waste from undigested or catabolised nitrogen waste (Basset-Mens et al, 2005:140).

The slurry of finishing pigs contains the highest nutrient concentration. Excess slurry can place a substantial burden on the environment if not managed correctly. NH_3 is the main substance in the slurry that contributes to impact categories like eutrophication and acidification. This substance is emitted mainly during the slurry storage phase. Methane (CH_4) is also an important impact contributor, and this component is mainly released during the storage of slurry, whether on the farm or to where it is transported. Reducing excess slurry on an area can be achieved by reducing the herd number (Lopez-Ridaura et al., 2008:1303).

Separating the slurry into dry matter and liquid can also lower transportation costs. Various processes on the farm can be used to separate the slurry into liquid and dry matter. The water thus recycled can be used again to lower demand. Methods like mechanical screen separators, sedimentation, centrifugation, biological treatments and reverse osmosis are being used in pig production today (Hjorth et al., 2010:155).

Developed countries in Europe are well established in the use of composting, i.e. aerobic degradation and anaerobic digestion, as a practice for waste management. The outputs of the aerobic degradation and anaerobic digestion are mostly compost, and recycled water. These can be applied to agricultural land for various benefits, but must be carefully managed to avoid the associated impacts. The benefits of this practice include the supply of plant nutrients such as phosphorus and soil organic carbon, and improved soil microbial activity, and may enhance the physical properties of the soil. The negative effect of compost and digestate is that it may contain pollutants such as heavy metals and organic pollutants (Kupper et al., 2014:865).

Separating animal slurry into its liquid and dry matter components is mostly countered by the economic aspect. Commercially intensive animal production chains have the option of incorporating various technologies to improve capturing the benefits of manure, but this is a financial expense that would not necessarily entail financial benefits. Regulations and laws can be enacted to force environmentally friendly production practices. Governments can also make funding available to make incorporating environmentally friendly technologies possible. This would lower the impact on the environment and decrease the amount of heavy metals that would be applied to the soil. There are higher concentrations of copper and zinc in the liquid components of separated pig slurry than in the solids (Popovic et al., 2012:2130).

Over-fertilisation is harmful for the environment and has negative financial implications. Therefore, it is necessary to have suitable manure management systems in place to redistribute the excess nutrients from the animal manure, to optimise their recycling (Holm-Nielsen et al., 2009:5478-5484).

Anaerobic digestion is the degradation and stabilisation of organic materials under anaerobic conditions by microbial organisms, and leads to the formation of biogas and microbial biomass. This method helps to reduce the pollution generated by agricultural and industrial operations, and if the biogas is incorporated into the operations, it serves as an alternative to fossil fuels (Chen et al., 2008:4044).

The use of the decanter centrifuge is claimed to be one of the simplest methods for separating slurry into its solid and liquid fractions. The dry matter content of the solid fraction can vary between 25-35 %, and it contains 60-80 % of the dry matter and phosphorus content of the original slurry but only 20-25 % of the nitrogen and 10-15 % of the potassium. The anaerobic digestion of animal manure has several benefits, namely improving the fertiliser quality, reducing odours and pathogens, and producing a renewable fuel (Holm-Nielsen, 2009: 5478-5484). Anaerobic digestion can further lower the environmental burden of a farm’s manure. With anaerobic digestion, biogas – which is a renewable energy source – can be captured. This biogas can also be used to replace fossil fuels consumed as inputs in the life cycle (Reckmann et al., 2013:594). Other results found that the stage from weaning to slaughtering contributes the most to the various environmental impact categories. The period from weaning to slaughtering the pigs is longer than the piglet production phase (Reckmann et al., 2012:106). To produce one slaughter-ready pig, an average of 19.5 kWh of electricity and 23.9 MJ of energy are required. Transporting 1 000 kg of slurry from in-house to outside storage consumes approximately 4.6 kWh of electricity (Nguyen et al., 2012:172).

The daily production of slurry can be lowered to almost half if the water-to-feed ratio is adjusted from 4:1 to 2:1. The daily production of urine can also be reduced significantly by adjusting the water-to-feed ratio. The study also indicates that the influence of the pig’s pen temperatures on the volume of slurry produced may be more important than previously realised. Pigs that are exposed to higher temperatures (28 to 30 °C) in their housing produce 22 % less slurry and 17 % more dry matter than pigs that are raised in lower temperatures (20 to 22 °C). The reason for this is that the pig's body heat is self-regulated (O'Connell et al., 1997).

Intensive pig production generates one of the dominant emissions that cause environmental pollution, namely ammonia. Ammonia is a compound of nitrogen and hydrogen. Nitrogen excreted via faeces is predominantly incorporated in bacterial protein, which is less susceptible to rapid decomposition. Increasing fibrous feedstuffs in the pig’s diet shifts the nitrogen excretion from the urine to the faeces. This reduces the nitrogen excreted in the urine, which is less environmentally destructive. Nitrogen can also be managed by lowering the amount of it in the pig’s ration, but the nitrogen content must be managed carefully to maintain normal animal performance (Canh et al., 1998:182).

The daily average amount of slurry that a pig generates can vary significantly. The key factors that contribute to the amount of slurry that a pig generates are the quality of the diet, the composition of the diet, the genetic quality of the pig, and the slurry management technique used on the farm. The average daily amount of slurry that a pig weighing ±50 kg produces ranges between 4.5 and 6 kg (Portrjoie et al., 2004:50). The variance in results is due to the different climatic factors and diets fed to the pigs. The average amount of slurry generated by a piglet from 6 up to 20 kg is 600 kg per year, and a fattening pig from 20 kg up to 100 kg generates 2 400 kg per year (Teira-Esmatges et al., 2010:2). A sow with piglets up to 6 kg generates 5 400 kg per year, and a sow without piglets, 2 750 kg per year. These results are based on the following assumptions:

- Each sow stays in farrowing for 56 days per year
- Each sow stays in a gestation barn for gestation control for 309 days per year
- Each sow lactates at least twice per year
- The barn is empty for 7 days after the 20 kg pig leaves it
- Transition lasts for 42 days
- There are 2.2 cycles per sow per year

- Slurry density is 1 029 kg/m^3

A farm that houses approximately 1 200 sows generates 7 344 m^3 of slurry per year. This equates to 6.12 m^3 per sow with piglets of up to 20 kg (Beltran et al., 2014:4). In Table 2 the total amount of slurry generated in a year during each stage of a pig's life cycle is illustrated. It must be kept in mind that the amount of slurry produced can vary significantly among different production chains.

Table 2: Quantity of slurry generated during stages of a pig's life cycle, in one year

Type of animal	**Value (m^3)**
Closed cycle pig	17.75
Pig with piglets up to 6kg	5.10
Pig with piglets up to 20kg	6.12
Replacement pigs	2.50
Fattening pigs	2.15
Boar	6.12

Source: Beltan et al., 2014:3.

2.5.3 Post production

This phase includes processes like slaughtering, processing, packaging, cooling, transporting and distributing the product. In these processes inputs like diesel for generating heat, electricity, fuel, water, and packaging materials are included. This phase in the production chain is responsible for emissions to the air and water (Reckmann et al., 2013:589).

The greatest relative differences between countries in the slaughterhouse and pig-farming activities are due to differences in diesel composition and energy generation. In a study that evaluated a cradle-to-grave LCA for pork production, the transportation of the final product to the domestic market accounted for less than 1% of the total GHG emissions. In a cradle-to-gate LCA, results have shown that transporting the final product from South Africa to the EU via shipping, accounts for less than 8% of the total emissions (Devers et al., 2012:126). Reckmann et al. (2012:106) confirm that the slaughterhouse does not have a great impact on the total emissions for the cradle-to-grave LCA, but accounts for only 6% of the overall CO_2-equivalents.

Most studies do not include minor inputs like laundry detergents, cleaning supplies and disinfectants (Stone et al., 2012:4).

2.6 Conclusion

This chapter served as a review of the LCA method, and explains how LCA can be applied as an environmental impact assessment method. It also gave an overview of how LCA is applied in animal production practices. A typical cradle-to-grave life cycle of pork production comprises of the fertiliser and feed production, and associated transportation; the mixing of the feed; the pig-farming and slaughterhouse activities; and the usage phase. In pork production, it has been found that the key areas for mitigating environmental impacts are the production of feed, the distance of transportation, and the feed conversion ratio. The type and quality of the feed, and the genetics of the pigs also have a significant effect on the environmental performance of the pig production chain. Overall, there are numerous strategies and technologies to reduce the environmental impacts of existing production chains. These are subsequently discussed further.

3 Methods and Data

Against the background of the literature reviewed on LCA and the general pork production chain in Chapter 2, this chapter elaborates on achieving the aim of the study. It also includes the goal and purpose of the study, life cycle inventory (LCI), life cycle impact assessment (LCIA) and the life cycle interpretation. The goal and scope of the study describe the system boundaries and the three selected case studies. The life cycle inventory section includes all the processed data that was collected for each case study. The life cycle impact assessment section explains the methods that were used to convert the data into the selected impact categories. The life cycle interpretation section explains how the consistency, sensitivity and completeness checks were done in the Gabi software program.

3.1 Goal and scope definition

3.1.1 Goal and purpose of the study

The aim of this study is to determine the energy balance and emissions of three pork farms, which serve as the case studies bases for the LCA. The three case studies are compared in terms of their energy balance and emission performance. The dominant factors and weak points in the various production chain segments are pointed out. In the LCA a model of the production chain is built, and data for the case study is modelled and converted into the FU of one kilogram of live-weight pig over a period of one year.

The intended audiences for this study are the following:

- SAPPO SA, The South African Pork Producers' Organisation.
- Policy makers
- Producers
- Investors

Figure 11 provides the outline of the system boundaries set for each activity. The model constructed in the Gabi software provides a more comprehensive explanation of the boundaries for each activity within each production chain. These models can be viewed in Annexures, 1-3.

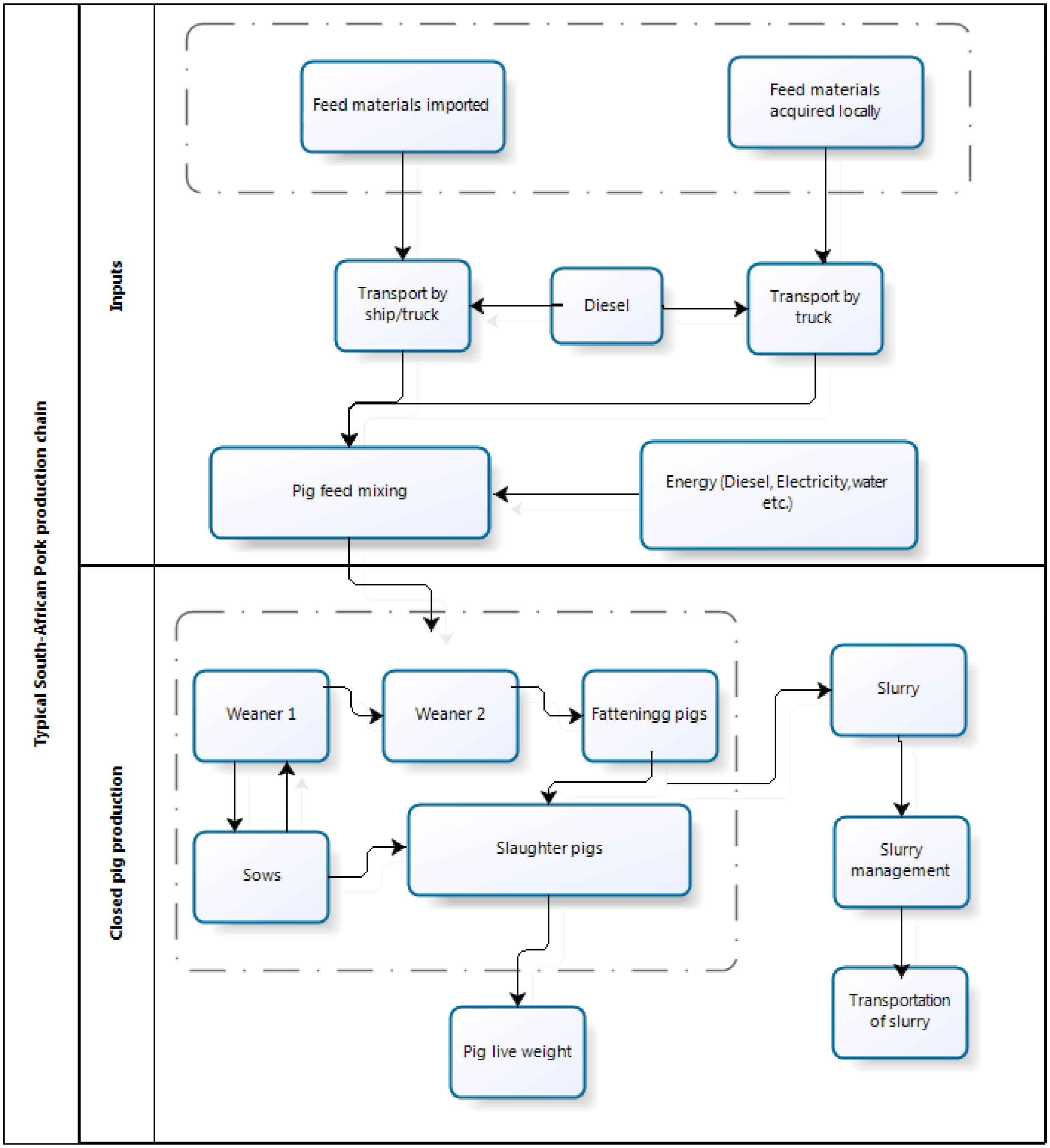


Figure 11: Technical system boundary for a typical pork production chain

Source: Own creation by Bizagi process modeller.

3.1.2 Scope of the study

3.1.2.1 Description of the three case studies

For the purpose of the study, three typical pig-farming practices were selected in South Africa. Data for the three pig-farming practices to be used for modelling purposes and to evaluate their environmental performance were collected during field trips. The three case studies are of farrow-to-finish production farms. This means that the weaners are born and raised on the farm until they reach their slaughter weight. Some weaners are retained to replace sows that are slaughtered. The replacement rate of sows and the proportion of own sow replacement can be seen in Table 6, Table 14 and Table 21. Brief descriptions of the three case studies follow.

Case study 1 (KZN)

The KwaZulu-Natal production chain procures all of its feed inputs from local producers. Feed is delivered in bulk and is mixed on the farm into different rations. Each stage of the pig's life requires a particular feed ration. The production chain does not include a slaughtering facility, and ends when pigs are sold at their live weight. Water is used as an input in the pig's diet, in cleaning the pig's pen, and as a medium to transport the slurry to the separating plants. The slurry management technique used on the farm consists of a deep-pit, slatted-floor system. The slurry is transported to a separating plant, were the liquid and solids are separated. The slurry then flows into two storage dams. The first dam is an anaerobic dam, where the fermentation takes place. The second dam is an aerobic dam. In this dam the nitrogen rich water is stored. The liquids from the second dam are subsequently used to irrigate grass fields for grazing by sheep and cattle. The solids are transported to vegetable producers in the surrounding areas. Electricity is used as an input for mixing the feed, pumping water and providing light. No added source of heat is provided in the pig's pen.

Case study 2 (NW)

The North West province production chain also buys all feed ingredients in bulk and mixes its own rations on the farm for each stage in the pig's life. Additional premix feed is bought for the piglets but accounts for only a small proportion of the total feed input. This production chain has a slaughtering facility, and ends when pigs are slaughtered and processed. Electricity is used as an input for mixing feed, pumping water and for lighting. Water is used as an input in the pig's diet, for cleaning the pig’s pen and for transporting the slurry to manure storage and separating dams. The slurry management technique used on the farm comprises a deep-pit slatted-floor system, with flush-channel management. The slurry is transported to a separating plant, where the liquid and solids are separated. The separating plant comprises two dams. The first dam is an anaerobic dam, where the fermentation takes place. The second dam is an aerobic dam. In this dam the nitrogen rich water is stored. The liquids from the second dam are used to irrigate grass fields. The solids from the separating plant are transported to a vegetable enterprise. Data for the slaughtering facility were excluded from the totals, because this study covers only the production chain up to the farm commodity produced, before processing.

Case study 3 (WC)

The Western Cape province production chain uses a feed supplier for all the feed inputs used in the system. The feed supplier mixes the different rations at the feed mill. Data for the feed and mixing thereof was obtained from the feed supplier. This production chain starts when piglets are born, continues as they are raised and fed, and ends when they reach their slaughter weight. The production chain does not have a slaughtering facility, and stops where the live-weight pigs are sold. The slurry management technique consists of a separating plant, were the solids and the liquids are separated. The liquid flows to two storage dams. The first dam is an anaerobic dam, where the fermentation takes place. The second dam is an aerobic dam. In this dam the nitrogen rich water is stored. The liquids from the second dam are used to irrigate grass fields for grazing by sheep and cattle. The solids are transported to vegetable producers in the surrounding areas.

3.1.2.2 System boundaries

As discussed in Section 2.3.1, the system boundary states which phases of the product's life cycle are included in the system and which are excluded. In order to enable a good comparison among the case studies, the system boundaries among them need to be identical. Cut-off criteria like cradle-to-grave, gate-to-gate, cradle-to-gate, or gate-to-grave are used to describe the system boundaries.

3.1.2.3 Functional unit

As mentioned in section 2.3.1, the functional unit (FU) provides a reference to which all the input and output process data of the system can be normalised. The FU also provides the basis on which the final results are presented. The FU for this study is defined as 1 kg of pig at live weight.

3.1.2.4 Allocation

Not all the environmental effects can be attributed to the FU. The allocation process requires that co-products in the production chain be identified. Co-products can also be waste products in the production chain, and therefore, a ratio between waste and co-products must be determined (ISO 14040, 2006:14). In this LCA of pork production, examples of co-products are soy oil from producing soy meal and the pig's intestines, which can be used for producing animal feed, among others. With the system boundaries set as they are, the co-products like soy oil and pig intestines are excluded from the life cycle. The lack of data in this LCA were the cause of some of the co-products produced not being included. However, different impacts are allocated for the co-products that are produced. The allocations to different products can be done according to various methods, such as according to mass, cost, or energy (ISO 14044, 2006:15). Allocation was done according to mass, since most data requiring allocation was specified in terms of mass in this study. Figure 12 illustrates an example of an allocation method.

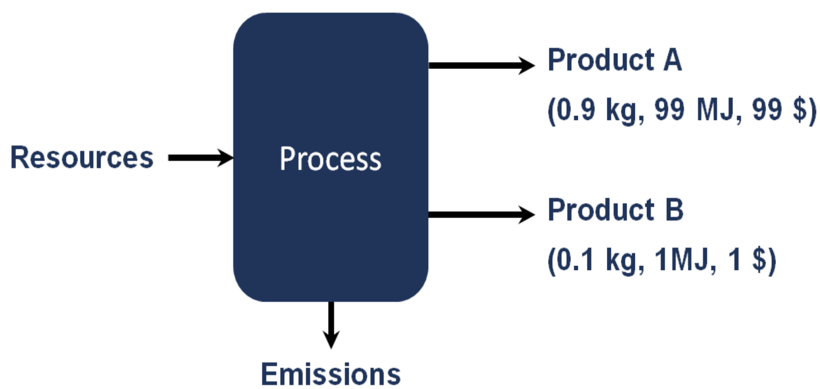


Figure 12: Allocation method

Source: Gabi, 2014.

With the production chain defined and illustrated, its outputs are expressed in various impact categories, with reference to the FU.

3.1.2.5 Impact categories

The environmental performance of all three case studies is recorded in the following impact categories: global warming potential (GWP), acidification potential (AP), eutrophication potential (EP) and energy usage (EU). The environmental performance of all three case studies will be done separately to allow for a comparison among them. A further discussion on the chosen impact categories for this study is given in Section 3.3, in this chapter.

3.1.3 Limitations

The environmental impacts of the production of buildings and machinery were excluded from the study. The production facilities of all three case studies have similar fixed improvements and tangible assets. Pesticides and disinfectants were not included in this LCA because their total impact on the impact categories chosen is negligible.

The environmental impacts of producing the feed were not taken into consideration in this study. Only a small amount of feed was imported from other countries. The environmental impacts of acquiring the feed were taken into consideration in this study.

3.1.4 Gabi software

The Gabi 6 software program was used to calculate the environmental impacts. This software is maintained and supplied by PE International. PE International also provides the Gabi 2012 databases, which assisted in translating inputs and outputs into environmental impacts, as well as the different impact categories. The information in the database is based on know-how resulting from PE International’s long-term co-operation with the industry as well as on familiarity with the patent, technical and scientific literature. Gabi automatically tracks all material, energy and emission flows. The databases are the primary sources of data within the software. These contain all of the datasets, plans, processes and balances for each project that has been started. According to Gabi (2009), it is the most comprehensive, up-to-date life cycle inventory database available.

3.2 Life cycle inventory

Three typical South African pig production chains were identified as case studies for this study. In order to make comparisons among the three cases, the system boundaries needed to be similar. The system boundaries are discussed in Section 3.1.2.2. The pig production chain consists of three main activities, namely, feed acquisition and mixing, pig farming and manure management.

Data were collected mainly through interviews on the farm and from the literature. The following section includes all the various inputs and outputs of the three case studies that were collected to serve as the inventory for the LCA.

3.2.1 Case study 1: KwaZulu-Natal

3.2.1.1 Feed acquisition and mixing activity

In this case study, bulk feed is purchased from various local feed producers. The mixing of the feed into different rations is done on the farm. This case study uses nine different feed rations, namely, Creep Feed, Link Feed, Weaner, Grower 1, Grower 2, Grower 3, Finisher Mix, Dry Sow and Boar Mix, and Lactating Sow. The weighted average of the different raw material components used in the different rations was calculated in order to get a total for the amount of each component used during the year. Table 3 provides a summary of the weighted average of each raw material component that was used in the different feed mixes for this case study. The figures in this table indicate the weighted average of all the feed components rations used on the farm for a period of one year. It is evident that maize is dominant at $^{2}/3$ of the total feed ration, soybean and wheat bran is next important- these three together making up 95 % of the feed ration by mass.

Table 3: Weighted average of the different raw material components used as feed in Case study 1 for a period of one year

Feed component	**Total raw material consumed (Tons/year)**	**Relative contribution %**
Yellow maize	2 521	67.38
Soybean meal	651	17.41
Wheat bran	386	10.32
Feed lime	48	1.27
Lacto pig mix	26	0.7
Fish meal	18	0.5
Monocalcium phosphate (MCP)	16	0.42
Salt	16	0.42
Acid pro	0.5	0.012
Remainder	58	1.55
TOTAL minus Remainder	3 683	98.45
TOTAL	**3 741**	**100**

Other inputs, like water, are added to the ration in the various stages of the pig's diet. Electricity is also used in the feed-mixing process. The raw materials used in this scenario are all produced in South Africa and are transported in bulk by road, with trucks, to the mixing plant, which is located on the farm.

The inputs included within the system boundaries of this activity are listed below. Table 4 provides a summary of the inputs for the production chain in Case study 1. Due to the lack of data capturing of the producers, the data could not be divided between the two production activities, namely, the feed acquisition and mixing activity, and the pig-farming activity. Therefore, the inputs and outputs for this case study show results for both activities. With regard to acquisition, Table 5 provides an illustration of the acquisition distance of the main feed components up to the farm gate.

Table 4: Summary of the production inputs in the feed acquisition and mixing activity for Case study 1 in one year

Input	**Value**	**Unit of measure**
Feed	3 741	Tonne
Water	*	KL
Electricity	48 000	kWh
Fuel (diesel)	*	L

* = No data

Table 5: Acquisition distance of the main feed components for Case study 1

Feed component	**Average distance to farm (Km)**	**Origin**
Yellow maize	205	NW
Soybean meal	75	KZN
Wheat bran	75	KZN
Fish meal	75	KZN
Feed lime	160	KZN

- **Outputs for feed acquisition and mixing activity**

The outputs of this activity are the environmental emissions resulting from acquiring the various feed components, and producing the feed. This amount of feed produced serves as an input for the next stage in the production chain, namely, the pig-farming activity. The following activity in the production chain is that of pig farming. A brief description of this activity, as well as a summary of the data captured for this activity will follow.

3.2.1.2 Pig-farming activity

This activity involves the actual farming of the pigs. This farm has its own sows to produce piglets, which are then raised and fed until they reach slaughter weight. Water is used as an input in the pig's diet, as is cleaning the pig's pen and transporting the slurry to manure storage and separating dams. The slurry management technique used on the farm consists of a deep-pit slatted-floor system. The manure is transported to a separating plant, where the liquid and solids are separated. The liquids are then pumped onto cattle grazing fields. Electricity is used as an input for mixing the feed, pumping water and providing light. No added source of heat is provided in the pig's pen. Table 6 provides an illustration of the livestock data and its performance for Case study 1.

Table 6: Yearly average of livestock numbers and performance

Livestock Information	**Value**
Number of sows	625
Number of gilts	100
Sow, live-weight (kg)	209
Sow, carcass-weight (kg)	157
Sow mortality (%)	1
Total sows sent to abattoir/year	315
Cycles per sow and year	2.31
Average time of gestation period	114.9
Replacement rate of sows (%)	50
Fraction of own sow replacement (%) *	100
Piglets born per sow per year	25.5
Piglets weaned per sow per year	23.1
Pre-weaning mortality (%)	9.9
Post-weaning mortality (%)	3%
Total number of piglets born per litter	11.6
Piglets born alive per litter	11
Piglets born dead per litter	0.6
Piglets weaned per litter	9.9

*Farm retains sows that are used for breading.

The inputs for this activity include water for animal consumption, cleaning the pig's pen and flushing the manure channels. Further inputs are feed; diesel, for transporting the feed on the farm; and electricity, for pumping water. A summary of the inputs for Case study 1 for the part of production chain under study are illustrated in Table 7.

Table 7: Yearly inputs for the pig-farming activity of Case study 1

Input	**Value**	**Unit of measure**
Feed	3 741 000	kg
Water	31 800 000	L
Electricity	113 000	kWh
Fuel (diesel)	24 000	L

- **Outputs of the pig-farming activity of Case study 1**

The outputs of this activity include the emissions generated from the production chain, the slurry produced and the live-weight pigs. Animal manure is also an output during this stage, and is captured as slurry. Slurry is a mixture of manure, urine and the wastewater from the pig's pen. The slurry management technique used on the farm consists of a deep-pit slatted-floor system, with flush-channel management. The manure is transported via channel drains to an anaerobic separating plant, were the liquid and solids are separated. The liquids are then pumped onto cattle grazing fields.

Due to a lack of data, the actual amount of slurry and its composition were not available. These figures were obtained from the literature. A farm that houses approximately 1 200 sows generates 7 344 m^3 of slurry per year. This accounts for 6.12 m^3 per sow with piglets up to 20 kg. Fattening pigs, which are fed from 20 kg up to 100 kg produce 2.15 m^3 of slurry per year. A piglet with a body weight of between 20 and 50 kg produces an amount of 1.80 m^3 slurry per year, and a pig weighing between 50 kg and 100 kg produces 2.50 m^3 of slurry per year. The pig production chains under study produce mainly fattening pigs. The farming methods used in all three case studies are fairly typical, and are similar to the farming methods described in Beltran et al. (2014:4).

Table 2, in Section 2.5.2.2, provides a breakdown of the amount of slurry produced at each stage of the pig's life cycle. The density factor of the slurry is 1 029 kg/m^3. The total amount of slurry produced per pig in a year was obtained from the literature. Based on the following assumptions, the slurry of the whole farm is calculated.

Assumptions:

- 10 piglets per sow per birth
- Farm accommodates sows, and raises piglets from birth up to 100 kg
- ((6.12 m^3 x the number of sows) + (2.15 m^3 x number of sows x piglets per sow per year)) x slurry density

Therefore, the amount of slurry produced in this case study in one year is equal to:

- ((6.12 x 625)+ (2.15 x 625 x 10)) x (1.029)

  = (3 825 +13 438) x 1.029

  = 17 764 tons

Table 8: Total outputs of the pig-farming activity of Case study 1

Output	**Value**	**Unit of measure**
Pigs (live-weight)	1 350 500	kg
Slurry	17 764 000	kg

Table 9: Total production inputs and outputs of Case study 1

Inputs	**Values**	**Unit of measure**
Feed	3 741 000	kg
Water	31 800 000	l
Electricity	161 000	kWh
Fuel (diesel)	24 000	l
Outputs		
Pigs (live-weight)	1 350 500	kg
Slurry	17 764 000	kg

3.2.2 Case study 2: North-West province

3.2.2.1 Feed acquisition and mixing activity

In this case study, bulk raw material is bought from local producers, which is then mixed on the farm into the various feed rations. This production chain uses eight different feeding rations. Electricity is mainly used as an input in this activity for mixing feed and pumping water. Water is used as an input in the pig's diet, cleaning the mixing plant and as a medium to transporting the slurry to the separating plant. Table 10 provides a summary of the total inputs for this activity. The amount and relative contribution of each raw material that was used during the year is illustrated in Table 11.

Table 10: Summary of the production inputs for the feed acquisition and mixing activity

Input	**Value**	**Unit of measure**
Feed	11 494 000	KG
Water	*	L
Electricity	*	kWh
Fuel (diesel)	*	L

** Data not available.*

Table 11: Weighted average of the feed components of different rations for Case study 2

Feed component	**Total raw material consumed (Tons/year)**	**Mass %**
Yellow maize	7 414	64.5
Soybean meal	1 916	16.67
Wheat bran	1 459	12.69
Fish meal	159	1.39
Feed lime	143	1.25
Molasses	98	0.85
Lacto pig mix	89	0.76
Monocalcium phosphate (MCP)	75	0.65
Salt	3	0.03
Remainder	138	1.21
TOTAL minus Remainder	11 356	98.79
TOTAL	**11 494**	**100**

Maize, soybean and wheat are the dominant constituents of the rations used in this case study. Table 12 illustrates the acquisition distances for the main feed components and the origins thereof.

Table 12: Acquisition distance of main feed components for Case study 2

Feed component	**Average distance to farm (Km)**	**Origin**
Yellow maize	20	NW
Soybean meal	570	KZN
Bran	250	GP
Fish meal	1 200	WC
Feed lime	550	NC
Molasses	570	KZN

- ## Outputs for feed acquisition and mixing activity

The outputs of this activity are the environmental emissions resulting from the acquisition and the total amount of feed that is transferred to the next activity, namely, the pig-farming activity. The next activity in the production chain is the pig-farming activity. The following section covers the data captured for the pig-farming activity of Case study 2. A brief description of this activity, as well as a summary of the data captured for it will follow.

3.2.2.2 Pig-farming activity of Case study 2

This activity includes the actual farming of the pigs. This farm has its own sows to produce piglets, which are then raised and fed until they reach slaughter weight. The slurry management technique used on the farm consists of a deep-pit slatted-floor system and flush-channel management. The manure is transported to a separating plant, from where the liquid and solids are separated. The liquids are then pumped onto cattle grazing fields. The solids are transported to the agriculture land of vegetable producers for fertilization. Electricity is used as an input in this activity, to provide heat during the wintertime, for pumping water and for providing light. Water is used as an input in the pig's diet, in cleaning the pig's pen, and as a medium to transport the slurry to manure storage and separating dams. Further inputs are feed, diesel for transporting the feed on the farm, and electricity for pumping water. Table 14 gives an illustration of the livestock and its performance in Case study 2.

Table 13: Inputs for the pig-farming activity of Case study 2

Inputs	Values	Unit of measure
Feed	11 494 000	Tons
Water	73 000 000	kWh
Electricity	1 412 000	l
Fuel (Diesel)	48 000	

Table 14: Yearly average of livestock numbers and performance

Number of sows	1 787
Number of gilts	345
Sow, live-weight (kg)	213.18
Sow, carcass-weight (kg)	163.08
Sow mortality (%)	0.5
Total sows sent to abattoir per year	936
Cycles per sow and year	2.51
Average time of gestation period	115
Replacement rate of sows (%)*	52
Proportion of own sow replacement (%)	100
Piglets born per sow per year	29.2
Piglets weaned per sow per year	26.7
Pre-weaning mortality (%)	2.6
Post-weaning mortality (%)	2%
Total number of piglets born per litter	13
Piglets born alive per litter	12
Piglets born dead per litter	0.9
Piglets weaned per litter	11.1

* Sows retained to include in the herd for breeding

- **Outputs of the pig-farming activity**

The outputs of this activity include the emissions generated from the production chain, the slurry produced, and the live-weight pigs. Slurry is a mixture of manure, urine and the wastewater from the pig's pen. The slurry management technique used on the farm consists of a deep-pit slatted-floor system, with flush-channel management. The slurry is transported to a separating plant, were the liquid and solids are separated. The liquids are then pumped onto cattle grazing fields. The total amount of slurry produced per pig per annum was obtained from the literature. Based on the following assumptions, the whole farm's slurry is calculated.

Assumptions:

- 10 piglets per sow per birth
- Farm accommodates sows, and raises piglets from birth up to 100 kg
- ((6.12 m^3 x the number of sows) + (2.15 m^3 x number of sows x piglets per sow per litter)) x slurry density.

Therefore, the amount of slurry produced for this case study in one year is equal to:

- ((6.12 x 1 784) + (2.15 x 1 784 x 10)) x (1.029)
  = (10 918 + 38 356) x 1.029
  = 50 703 ton

Table 15: Total outputs for the pig-farming activity for Case study 2

Outputs	Value	Unit of measure
Pigs (live-weight)	4 137 970	kg
Slurry	50 703 000	kg

Table 16: Summary of the total production inputs and outputs for Case study 2

Inputs	**Values**	**Unit of measure**
Feed	11 494 000	kg
Water	73 000 000	l
Electricity	1 412 000	kWh
Fuel (diesel)	48 000	l
Outputs		
Pigs (live-weight)	4 137 970	kg
Slurry	50 703 000	kg

3.2.3 Case study 3: Western Cape Province

3.2.3.1 Feed acquisition and mixing activity

The Western Cape province production chain uses a feed supplier for all the feed inputs in the system. The feed is mixed by the feed supplier at the feed supplier's plant. Data for the feed and mixing thereof were obtained from the feed supplier. This production chain has its own livestock from which piglets are born, raised and fed until they reach their slaughter weight.

The slurry management technique consists of a slatted-floor system, from where the slurry is transported to a separating plant, where the solids and the liquids are separated. Vegetable producers in the nearby area collect the solids at their own cost. Hence, this study is a gate-to-gate LCA, and the transportation of the slurry was not accounted for. The liquid flows from the separating plant into two storage dams. The first dam is an anaerobic dam; the second is an aerobic dam. The liquids from the second dam are used to irrigate grass fields for grazing by sheep and cattle. This production chain has its own sows that produce piglets. The piglets are raised and fed until they reach slaughter weight.

Table 17: Total inputs for the feed acquisition and mixing activity for Case study 3

Input	**Value**	**Unit of measure**
Feed	8 160 000	kg
Water	895 500	L
Electricity	324 800	kWh
Fuel (Diesel)	20 300	L
Coal	600	kg

Table 18: Weighted average of the various raw materials used in Case study 3

Feed component	**Total raw material consumed (Tons/year)**	**Mass %**
Maize	4 380	53.68
Wheat bran	1 719	21.07
Lupines	635	7.78
Soybean meal	503	6.16
Canola oil cake	255	3.13
Local fish	182	2.23
Molasses	100	1.23
Feed lime	67	0.82
Sunflower oil cake	64	0.78
Lucerne	53	0.65
Oat Bran	40	0.50
Salt	23	0.30
Lysine	16	0.20
Remainder	**123**	**1.47**
TOTAL minus Remainder	**8 037**	**98.53**
TOTAL	**8 160**	**100**

Table 19: Acquisition distance of the main feed components for Case study 3

Feed component	**Acquisition distance to farm**	**Origin (Province code)**
Maize	1 200	GP/MP
Wheat bran	50	WC
Lupines	80	WC
Soybean meal	6 950	ARG
Canola oil cake	170	WC
Local fish	60	WC
Molasses	1 500	KZN
Feed lime	150	WC
Sunflower oil cake	6 950	ARG
Lucerne	750	NC
Oat Bran	30	WC
Salt	750	NC
Lysine	1 500	KZN

- **Outputs for feed acquisition and mixing activity**

The outputs of this activity include the emissions resulting from the transportation, acquisition and mixing of the feed. Inputs like water, electricity and diesel are used in this activity. Feed is the output of this activity that transfers to the pig-farming activity as an input.

The next activity in the production chain is the pig-farming activity. The following section covers the data captured from the pig-farming activity for Case study 3. A brief description of this activity, as well as a summary of the data captured will follow.

3.2.3.2 Pig-farming activity of Case study 3

This production chain breeds its own livestock; piglets are born, raised and fed on the farm until they reach their slaughtered weight. The slurry management technique consists of a separating plant, where the solids and the liquids are separated. Thereafter the solids are transported to vegetable producers nearby. The liquid flows into two storage dams. This production chain has its own sows that produce piglets, which are raised and fed until they reach slaughtering weight. A summary of the production inputs for this activity are illustrated in Table 20.

Table 20: Inputs of the pig-farming activity for Case study 3

Input	**Value**	**Unit of measure**
Feed	8 160 000	kg
Water	46 720 000	L
Electricity	1 300 000	kWh
Fuel (diesel)	25 000	L

Table 21: Yearly average livestock numbers and performance of Case study 3

Number of sows	1 275
Number of gilts	390
Sow, live-weight (kg)	140
Sow, carcass-weight (kg)	100
Sow mortality (%)	9
Total sows sent to abattoir per year	575
Cycles per sow and year	2.45
Average time of gestation period	113.8
Replacement rate of sows (%)	48
Proportion of own sow replacement (%)*	100
Piglets born per sow per year	25.50
Piglets weaned per sow per year	24.30
Pre-weaning mortality (%)	4.7
Post-weaning mortality (%)	0.35
Total number of piglets born per litter	10.85
Piglets born alive per litter	10.41
piglets born dead per litter	0.48
Piglets weaned per litter	9.9

***** Sows are retained to include in the herd as breading sows

- ## Outputs of the pig-farming activity

The outputs of this activity include the emissions generated from the production chain, the slurry produced, and the live-weight pigs. Slurry is a mixture of manure and the wastewater from the pig's pen. The total amount of slurry that is produced in a year was obtained from the literature. The slurry management technique used on the farm consists of a deep-pit slatted-floor system, with flush-channel management. The slurry is transported to a separating plant, were the liquid and solids are separated. The liquid is then pumped onto cattle grazing fields. Table 22 provides a summary of the outputs for this activity; Table 23 provides a summary of all the inputs and outputs used in Case study 3.

The total amount of slurry produced per pig in a year was obtained from the literature. Based on the following assumptions, the whole farm's slurry is calculated.

Assumptions:

- 10 piglets per sow per birth
- Farm accommodates sows and raises piglets from birth up to 100 kg live weight.
- (6.12 m^3 x the number of sows) + (2.15 m^3 x number of sows x piglets per sow) x slurry density.

Therefore, the amount of slurry produced in this case study in one year is equal to:

- (6.12 x 1 275)+ (2.15 x 1 275 x 10) x (1.029)
  = (7 803 + 27 413 x 1.029
  = 36 236 ton

Table 22: Total outputs of the pig-farming activity for Case study 3

Outputs	**Value**	**Unit of measure**
Pigs (live-weight)	3 222 995	kg
Slurry	36 236 000	kg

Table 23: Total production inputs and outputs for Case study 3

Inputs	**Values**	**Unit of measure**
Feed	8 160 000	kg
Water	47 615 500	L
Electricity	1 624 800	kWh
Fuel (Diesel)	45 300	L
Coal	600	kg
Outputs		
Pigs (live-weight)	3 222 995	kg
Slurry	36 236 000	kg

All the data collected and recorded for the three case studies is included in this section. The aim of this section is to summarise the data in such a way that it can be included in the Gabi LCA models built for each case study. The life cycle impact assessment is the next step in the LCA framework. The LCA framework is illustrated in Figure 13 below.

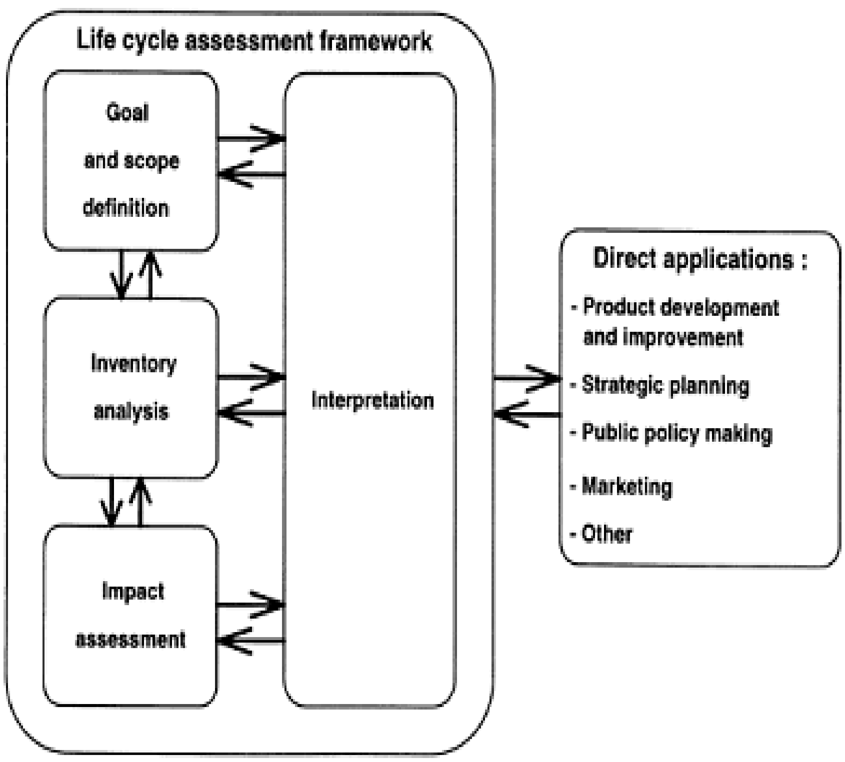


Figure 13: LCA framework

Source: ISO 14040, 2006:8.

3.3 Life cycle impact assessment

The previous section covers the life cycle inventory based on the LCA framework. The LCI section covers all the relevant data collected from fieldwork, interviews and the literature. The data for the inputs and outputs of the various activities throughout the production chain were quantified and processed for purposes of comparison. This section focuses on translating the inventory and environmental loads into impact categories.

The purpose of life cycle impact assessment (LCIA) is to assess a product system's LCI results, to clarify their environmental significance. The LCIA profile provides information regarding the environmental issues, resulting in the inputs and outputs of the production system (ISO1440, 2006:9). The Gabi 6 LCA software program translates inputs and outputs into impact categories. The Gabi program provides several opportunities for calculating impact assessments and providing information for strategic management. The Gabi 6 LCA software package offers a variety of LCIA methods, namely, CML 2001, Eco indicator 95, EDIP 2003, Impact 2002+ and TRACI. In this study the CML 2001 method is used. This method was developed by the Centre of Environmental Science ('Centrum Milieukunde Leiden' or CML) at the University of Leiden in the Netherlands. The CML 2001 data is based mainly on European conditions; data for other countries was supplied mainly by Pe-international GmbH. The CML 2001 is an impact assessment collection method used within the Gabi databases. The CML 2001 restricts quantitative modelling to the relatively early stages in the cause-effect chain, in order to limit uncertainties and group the LCI results in midpoint categories, according to themes. These themes represent common effects such as climate change and ecotoxicity.

Impact category is the class representing environmental issues of concern to which life cycle inventory analysis results may be assigned, for example, global warming potential (GWP), acidification potential (AP) and energy use (EU) (ISO, 2006:5).

There are a large number of impact categories in terms of which the environmental performance of a system can be evaluated or expressed. Reckman et al. (2012:103) mention the main impact categories for environmentally assessing pork production. Table 1 in Section 2.3.3 illustrates a summary of the main impact categories proposed for an LCA of pork production.

3.4 Conclusion

The goal of this chapter was to inform the reader, how to use the LCA method, and to explain how LCA was applied in the study. A brief discussion of the three case studies and the relevant data was provided. The data for the three case studies were provided to illustrate the life cycle inventory that is used to model the three case studies in the LCA software. Data for the most reasonable situations and practices was collected to avoid outlier data that could potentially influence the results. The environmental impact categories (GWP, EP, AP and EU) of the three case studies were summarised and explained. Also, the different life cycle impact assessment methods were explained. The next chapter provides the impact category results, as obtained for the models created in the LCA software.

4 Life cycle impact assessment and interpretation

4.1 Introduction

In the previous chapter, all the production chain inputs for the three case studies are summarised and presented. These are included to provide the reader with an understanding of the inputs used to model the life cycles of the three case studies. The data also serves as the life cycle inventory in the software; it is converted into the life cycle impact category results. This chapter mainly reflects on the life cycle inventory results. It also includes the goal and scope definition, life cycle impact assessment and life cycle interpretation. Brief comparisons and discussions of the results are made in Section 4.2, the life cycle impact analysis. A comparison among the environmental and financial performance of inputs like diesel and electricity is made.

4.2 Life cycle impact analysis

This section presents the factors that contribute to the impact category results (GWP, EP, AP and EU) for each case study's LCA. The production chain was divided into the feed acquisition, farming, and slurry management activities. Due to inadequate record keeping, not all the data were available for the specific activities within each case study. Only where the data were available could comparisons be made among activities in the case studies. In general comparisons made among the case studies are for the whole supply chain. Comparisons among specific activities are made where data were available, and this is indicated accordingly. Tables 24a, 24b, 24c, 25a, 25b, and 25c provide the results of the flows for each case study. These results were calculated by the Gabi program for the specific inputs and outputs that are modelled. The models for the three case studies can be viewed in Annexures 1 to 3. The figures in these models were scaled to the FU of a one kg live-weight pig.

The environmental impacts of the slurry management technique used in the three case studies were determined from the literature. The three case studies use the same slurry management technique. By using LCA, Lopez- Ridaura et al. (2009:1302) evaluated the environmental impacts of various slurry management techniques. One of the slurry management systems evaluated was similar to the slurry management technique used in Case studies 1, 2 and 3. The Lopez-Ridaura et al. (2009:1302) slurry management system included the following activities in managing the slurry: slurry storage (anaerobic dam), intermediate storage (aerobic dam), application on the land, and the fertiliser usage avoided. The FU of their study was 1 000 kg of raw slurry. The results, therefore, were divided by 1 000 to reflect the environmental impacts expressed in the impact categories for one kg of raw slurry. The results were expressed in global warming potential (GWP), eutrophication potential (EP), and acidification potential (AP). It was found that managing one kg of raw slurry with this slurry management technique yielded a GWP of 0.132 kg of CO_2-eq, an EP of 0.000502 kg of PO_4-eq, and an AP of 0.0023 kg of SO_2-eq (Lopez-Ridaura et al., 2009:1302).

In this study, Case studies 1, 2 and 3 yielded 13.2, 12.3 and 11.2 kg of slurry per FU (one kg of live-weight pig). In order to obtain results per FU of live weight, the results for managing slurry in each case study were multiplied by the amount of slurry produced per FU (one kg of live-weight pig per year). The slurry management activity for Case study 1 was 13.2 kg of slurry x 0.132 kg CO_2-eq for GWP, 13.2 kg x 0.000502 kg PO_4-eq for EP and 13.2 kg x 0.0023 kg of SO_2-eq for AP. The impact category results for Case study 1 per FU are 1.745 kg CO_2-eq for GWP, 0.0067 kg PO_4-eq for EP, and 0.0303 kg SO_2-eq for AP. Case study 2 generated 12.3 kg of slurry per FU. The environmental impact result for managing slurry in this case study was 1.626 kg of CO_2-eq/FU for GWP, 0.0062 kg of PO_4-eq/FU for EP and 0.0282 kg of SO_2-eq/FU for AP. In Case study 3, 11.2 kg slurry was produced per FU. This result for GWP is 1.481 kg of CO_2-eq/FU; EP is 0.0056 kg of PO_4-eq/FU; and AP is 0.0257 kg of SO_2-eq/FU.

These results were added to the life cycle impact results shown in Tables 24-27 in the next section. In Section 4.2.1, the life cycle impact results of each Case study are shown according to the inputs used throughout the life cycle.

4.2.1 Global warming potential impact

As discussed in Section 2.3.3 'life cycle impact assessment', GHGs cause high radiation absorption levels, which can lead to higher temperatures in the atmosphere. GWP measures take into account all the emissions of GHGs, like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). For the purpose of comparison, the GWP results are illustrated in kg of CO_2-eq. The life cycle impact results are shown in Tables 24, 25, 26 and 27. The results are summarised from the figures generated by the Gabi software for the each of the three case studies. The inputs used to generate the results for each case study are presented in the life cycle inventory, in Chapter 3. In Table 24a, 24b and 24c the resultant GWP of the three case studies is illustrated.

The absolute and relative contributions of emissions to GWP are illustrated in kg of CO_2-eq/FU. The inputs contributing to GWP is shown under the Flows column. The contribution of the specific input is shown under the Absolute and Relative columns; for example, in Table 24a, the first input contributing to GWP is 'Diesel: Salt'. This input refers to the environmental impact (GWP) of the diesel used to acquire salt for the feed ration. The three inputs that contribute the most to the impact category for each case study are indicated in bold. Note that slurry management, tap water and the truck for maize transportation were the three impacts identified and indicated in bold that contributed the most to GWP for Case study 1. Slurry management contributed almost 90 % of the GWP in Case study 1.

Table 24a: Inputs and processes contributing to global warming potential (GWP) for Case study 1

	Absolute values	Relative contribution
	(kg CO_2-eq.)	(%)
Flows		
Diesel: Salt	9.36E-06	0.0005
Diesel: Fish meal	1.13E-05	0.0006
Diesel: Maize	9.22E-04	0.0489
Diesel: Soybean	9.52E-05	0.0051
Diesel: Wheat	5.79E-05	0.0031
Diesel: Feed lime	1.36E-05	0.0007
Diesel: Farm	0.005908	0.3133
Electricity from hard coal	**1.17E-01**	**6.2042**
Slurry Management	**1.68E+00**	**89.1852**
Tap water PE	9.84E-03	0.5217
Truck-trailer: Maize	1.11E-02	0.5888
Truck-trailer: Soybean	1.15E-03	0.0608
Truck-trailer: Wheat	6.98E-04	0.0370
Truck-trailer: Fish meal	1.36E-04	0.0072
Truck-trailer: Salt	1.13E-04	0.0060
Truck-trailer: Feed lime	1.63E-04	0.0087
Truck-trailer: Farm	**0.056721**	**3.0081**
Total	1.82E+00	100.0000

Table 24b: Inputs and processes contributing to global warming potential (GWP) for Case study 2

	Absolute values	Relative contribution
	(kg CO_2-eq.)	(%)
Flows		
Diesel: Farm	0.003069	0.1563
Diesel: Maize	7.08E-05	0.0036
Diesel: Soybean	5.21E-04	0.0266
Diesel: Wheat	2.12E-04	0.0108
Diesel: Molasses	4.33E-05	0.0022
Diesel: Fish meal	1.74E-04	0.0089
Diesel: Feed lime	8.18E-05	0.0042
Electricity from hard coal	**3.35E-01**	**17.0512**
Slurry Management	**1.57E+00**	**79.7951**
Tap water PE	7.37E-03	0.3753
Truck-trailer: Farm	**0.037106**	**1.8895**
Truck-trailer: Soybean	6.28E-03	0.3198
Truck-trailer: Maize	8.53E-04	0.0434
Truck-trailer: Wheat	2.55E-03	0.1298
Truck-trailer: Feed lime	9.85E-04	0.0502
Truck-trailer: Molasses	5.22E-04	0.0266
Truck-trailer: Fish meal	2.10E-03	0.1067
Total	1.92E+00	100.0000

Table 24c: Inputs and processes contributing to global warming potential (GWP) for Case study 3

Flows	Absolute values	Relative contribution
	(kg CO_2-eq.)	(%)
Diesel mix: Farm	0.002056	0.0999
Diesel mix: Maize	3.22E-03	0.1565
Diesel mix: Lupines	3.11E-05	0.0015
Diesel mix: Wheat	5.27E-05	0.0026
Diesel mix: Soybean	1.85E-05	0.0009
Diesel mix: Canola	2.66E-05	0.0013
Diesel mix: Fish meal	2.16E-05	0.0010
Diesel mix: Molasses	2.97E-04	0.0144
Diesel mix: Sunflower	7.59E-06	0.0004
Diesel mix: Lucerne	7.86E-05	0.0038
Diesel mix: Oat bran	2.37E-06	0.0001
Diesel mix: Salt	3.41E-05	0.0017
Diesel mix: Feed lime	1.99E-05	0.0010
Electricity from hard coal	**0.494705**	**24.0305**
Heavy fuel: Sunflower	2.20E-04	0.0107
Heavy fuel: soybean	1.74E-03	0.0846
Slurry management	**1.43E+00**	**69.3111**
Tap water	6.17E-03	0.2998
Container ship: Soybean	1.38E-02	0.6690
Container ship: Sunflower	1.74E-03	0.0845
Truck PE: Farm	0.024752	1.2023
Truck-trailer: Wheat	6.34E-04	0.0308
Truck-trailer: Soybean	2.23E-04	0.0108
Truck-trailer: Canola	3.20E-04	0.0155
Truck-trailer: Sunflower	9.14E-05	0.0044
Truck-trailer: Lupine	3.75E-04	0.0182
Truck-trailer: Fish meal	2.60E-04	0.0126
Truck-trailer: Molasses	3.57E-03	0.1735
Truck-trailer: Feed lime	2.39E-04	0.0116
Truck-trailer: Maize	**3.88E-02**	**1.8847**
Truck-trailer: Lucerne	9.47E-04	0.0460
Truck-trailer: Oat bran	2.86E-05	0.0014
Truck-trailer: Salt	4.11E-04	0.0200
Coal	3.69E-02	1.7928
Total	2.058662	100.0000

4.2.2 Eutrophication potential

As discussed in Section 2.3.3, eutrophication refers to the high levels of nitrogen (N) and phosphorus (P) that result mainly from the run-off of agricultural water and the disposal of urban waste. The aquatic environment absorbs the run-off elements, which causes environmental change. Emissions of these elements into the air are also taken into account in EP. The results for EP are shown in kg of PO_4-eq. Table 25a, 25b and 25c provides the EPs caused by the life cycles of the three case studies. The three inputs that contribute the most to each case study's EP are illustrated in bold.

Table 25a: Eutrophication potential results for Case study 1

	Absolute values	Relative contributions
Flows:	(kg PO_4-eq.)	(%)
Diesel mix: Salt	1.85E-08	0.001
Diesel mix: Fish meal	2.24E-08	0.001
Diesel mix: Maize	1.82E-06	0.053
Diesel mix: Soybean	1.88E-07	0.005
Diesel mix: Wheat	1.15E-07	0.003
Diesel mix: Feed lime	2.68E-08	0.001
Electricity from hard coal	**2.38E-05**	**0.688**
Slurry management	**3.29E-03**	**95.147**
Diesel mix: Farm	7.65E-06	0.221
Tap water PE	4.83E-06	0.139
Truck-trailer: Maize	1.12E-05	0.323
Truck-trailer: Soybean	1.16E-06	0.033
Truck-trailer: Wheat	7.03E-07	0.020
Truck-trailer: Fish meal	1.37E-07	0.004
Truck-trailer: Salt	1.14E-07	0.003
Truck-trailer: Feed lime	1.65E-07	0.005
Truck-trailer: Farm	**0.000116**	**3.353**
Total	3.34E-03	100.000

Table 25b: Eutrophication potential results for Case study 2

	Absolute values	Relative contribution
	(kg PO_4-eq.)	(%)
Flows		
Diesel mix: Farm	6.07E-06	0.1874
Diesel mix: Maize	1.40E-07	0.0043
Diesel mix: Soybean	1.03E-06	0.0318
Diesel mix: Wheat	4.19E-07	0.0129
Diesel mix: Molasses	8.57E-08	0.0026
Diesel mix: Fishmeal	3.44E-07	0.0106
Diesel mix: Feed lime	1.62E-07	0.0050
Electricity from hard coal	**6.81E-05**	**2.1038**
Slurry management	**3.07E-03**	**94.7251**
Tap water	3.62E-06	0.1116
Truck: Farm	**7.38E-05**	**2.2789**
Truck: Soybean	6.33E-06	0.1953
Truck: Maize	8.59E-07	0.0265
Truck: Wheat	4.08E-06	0.1260
Truck: Feed lime	1.58E-06	0.0487
Truck: Molasses	8.35E-07	0.0258
Truck: Fish meal	3.35E-06	0.1036
Total	3.16E-03	100.0000

Table 25c: Eutrophication potential results for Case study 3

	Absolute values	Relative contribution
Flows	(kg PO_4-eq.)	(%)
Diesel mix: Farm	4.07E-06	0.132
Diesel mix: Maize	6.37E-06	0.207
Diesel mix: Lupine	6.16E-08	0.002
Diesel mix: Wheat	1.04E-07	0.003
Diesel mix: Soybean	3.66E-08	0.001
Diesel mix: Canola	5.25E-08	0.002
Diesel mix: Fish meal	4.27E-08	0.001
Diesel mix: Molasses	5.87E-07	0.019
Diesel mix: Sunflower	1.50E-08	0.000
Diesel mix: Lucerne	1.55E-07	0.005
Diesel mix: Oat bran	4.69E-09	0.000
Diesel mix: Salt	6.75E-08	0.002
Diesel mix: Feed mixing	3.93E-08	0.001
Electricity from hard coal	**8.06E-05**	**3.269**
Heavy fuel: Sunflower	5.63E-08	0.002
Heavy fuel: Soybean	4.46E-07	0.014
Slurry management	**2.79E-03**	**90.721**
Tap water	2.80E-05	0.909
Container ship: Soybean	**4.72E-05**	**1.534**
Container ship: Sunflower	5.97E-06	0.194
Truck: Farm	2.52E-05	0.818
Truck-trailer: Wheat	6.39E-07	0.021
Truck-trailer: Soybean	2.24E-07	0.007
Truck-trailer: Canola	3.22E-07	0.010
Truck-trailer: Sunflower	9.21E-08	0.003
Truck-trailer: Lupines	3.78E-07	0.012
Truck-trailer: Fish meal	2.62E-07	0.009
Truck-trailer: Molasses	3.60E-06	0.117
Truck-trailer: Feed lime	2.41E-07	0.008
Truck-trailer: Maize	3.91E-05	1.269
Truck-trailer: Lucerne	9.53E-07	0.031
Truck-trailer: Oat bran	2.88E-08	0.001
Truck-trailer: Salt	4.14E-07	0.013
Coal burning	2.03E-05	0.660
Total	3.08E-03	100

4.2.3 Acidification potential

As described in Section 2.3.3, acidic gasses like SO_2, NO_x and NH_3 react with water in the atmosphere, and have the potential to form acids like H_2SO_4 and HNO_3. Pollutants like SO_2, NO_x, HCL and NH_3 are the main pollutants that cause AP. All these pollutants have a common characteristic, which is that they form acidifying H+ ions. The AP results are shown in kg of SO_2-eq/ FU. In Table 26a, 26b and 26c the AP of the three case studies is shown. The three inputs that contributed the most to AP in each case study are illustrated in bold.

Table 26a: Acidification potential results for Case study 1

	Absolute values	Relative contribution
	(kg SO_2-eq.)	(%)
Flows		
Diesel mix: Salt	1.20E-07	0.0008
Diesel mix: Fish	1.45E-07	0.0009
Diesel mix: Maize	1.18E-05	0.0756
Diesel mix: Soybean	1.22E-06	0.0078
Diesel mix: Wheat	7.40E-07	0.0048
Diesel mix: Feed lime	1.73E-07	0.0011
Diesel mix: Farm	6.63E-05	0.4254
Electricity from hard coal	**1.85E-04**	**1.1901**
Slurry management	1.48E-02	**95.0321**
Tap water	1.22E-05	0.0783
Truck-trailer: Maize	4.67E-05	0.2996
Truck-trailer: Soybean	4.82E-06	0.0309
Truck-trailer: Wheat	2.93E-06	0.0188
Truck-trailer: Fish meal	5.23E-07	0.0034
Truck-trailer: Salt	4.32E-07	0.0028
Truck-trailer: Feed lime	6.87E-07	0.0044
Truck-trailer: Farm	**0.000440**	**2.8233**
Total	1.51E-02	100.0000

Table 26b: Acidification potential results for Case study 2

	Absolute values	Relative contribution
	(kg SO_2-eq.)	(%)
Flows		
Diesel mix: Farm	3.92E-05	0.2659
Diesel mix: Maize	9.05E-07	0.0061
Diesel mix: Soybean	6.66E-06	0.0452
Diesel mix: Wheat	2.71E-06	0.0183
Diesel mix: Molasses	5.54E-07	0.0038
Diesel mix: Fish meal	2.22E-06	0.0151
Diesel mix: Feed lime	1.05E-06	0.0071
Electricity from hard coal	**5.31E-04**	**3.6006**
Slurry management	**1.38E-02**	**93.6040**
Tap water	9.15E-06	0.0620
Truck: Farm	**0.000280**	**1.8991**
Truck: Soybean	2.64E-05	0.1791
Truck: Maize	3.58E-06	0.0243
Truck: Wheat	1.65E-05	0.1116
Truck: Feed lime	6.36E-06	0.0431
Truck: Molasses	3.37E-06	0.0228
Truck: Fish meal	1.35E-05	0.0918
Total	1.44E-02	100.0000

Table 26c: Acidification potential results for Case study 3

	Absolute values	Relative contribution
	(kg SO_2-eq.)	(%)
Flows		
Diesel mix: Farm	2.63E-05	0.179
Diesel mix : Maize	4.12E-05	0.279
Diesel mix : Lupine	3.98E-07	0.003
Diesel mix : Wheat	6.73E-07	0.005
Diesel mix : Soybean	2.36E-07	0.002
Diesel mix : Canola	3.40E-07	0.002
Diesel mix : Fish meal	2.76E-07	0.002
Diesel mix : Molasses	3.79E-06	0.026
Diesel mix : Sunflower	9.70E-08	0.001
Diesel mix : Lucerne	1.00E-06	0.007
Diesel mix : Oat bran	3.03E-08	0.000
Diesel mix : Salt	4.36E-07	0.003
Diesel mix : Feed mix	2.54E-07	0.002
Electricity from hard coal	**7.84E-04**	**5.324**
Heavy fuel: Sunflower	1.21E-06	0.008
Heavy fuel: Soybean	9.58E-06	0.065
Slurry management	**1.26E-02**	**85.301**
Tap water	1.70E-04	1.157
Container ship : Soybean	**4.61E-04**	**3.129**
Container ship : Sunflower	5.82E-05	0.395
Truck: Farm	9.61E-05	0.652
Truck-trailer: Wheat	2.67E-06	0.018
Truck-trailer: Soybean	9.37E-07	0.006
Truck-trailer: Canola	1.35E-06	0.009
Truck-trailer: Sunflower	3.51E-07	0.002
Truck-trailer: Lupines	1.58E-06	0.011
Truck-trailer: Fish	9.97E-07	0.007
Truck-trailer: Molasses	1.37E-05	0.093
Truck-trailer: Feed lime	9.18E-07	0.006
Truck-trailer: Maize	1.63E-04	1.107
Truck-trailer: Oat bran	3.63E-06	0.025
Truck-trailer: Lucerne	1.10E-07	0.001
Truck-trailer: Salt	1.58E-06	0.011
Coal	3.19E-04	2.163
Total	1.47E-02	100.000

4.2.4 Energy use in the three case studies

In this study only the energy inputs were taken into account when the EU of each case study was modelled. The EU indicator reflects the primary energy by LCA methods i.e.1 kWh translates to 3.6 MJ of primary energy. In Table 27a, b and c the EU results of case study 1, 2 and 3 are shown in MJ equivalents per FU and the relative contribution of each activity.

Table 27a: Energy use for Case study 1

	Absolute values	Relative contribution
Flows	(MJ/FU)	(%)
Diesel mix: Salt	0.002	0.032
Diesel mix: Fish meal	0.002	0.039
Diesel mix: Maize	0.178	3.194
Diesel mix: Soybean	0.018	0.330
Diesel mix: Wheat	0.011	0.201
Diesel mix: Feed lime	0.003	0.047
Electricity from hard coal	**1.830**	**32.894**
Slurry management	**2.490**	**44.769**
Diesel mix: Farm	**0.915**	**16.449**
Tap water	0.114	2.044
Total	5.563	100.000

Table 27b: Energy use for Case study 2

	Absolute values	Relative contribution
	(MJ/FU)	(%)
Flows		
Diesel mix: Farm	**0.591**	**7.0009**
Diesel mix: Maize	0.014	0.1615
Diesel mix: Soybean	0.100	1.1893
Diesel mix: Wheat	0.041	0.4828
Diesel mix: Molasses	0.008	0.0988
Diesel mix: Fish meal	0.034	0.3971
Diesel mix: Feed lime	0.016	0.1866
Electricity from hard coal	5.238	**62.0027**
Slurry management	2.321	**27.4716**
Tap water	0.085	1.0086
Total	8.447	100.0000

Table 27c: Energy use for Case study 3

	Absolute values	Relative contribution
Flows	(MJ/FU)	(%)
Diesel mix: Farm	0.396200	3.3997
Diesel mix: Maize	**0.620794**	**5.3269**
Diesel mix: Lupines	0.006000	0.0515
Diesel mix: Wheat	0.010152	0.0871
Diesel mix: Soybean	0.003565	0.0306
Diesel mix: Canola	0.005120	0.0439
Diesel mix: Fish meal	0.004161	0.0357
Diesel mix: Molasses	0.057151	0.4904
Diesel mix: Sunflower	0.001463	0.0126
Diesel mix: Lucerne	0.015145	0.1300
Diesel mix: Oat bran	0.000457	0.0039
Diesel mix: Feed lime	0.006572	0.0564
Diesel mix: Salt	0.003829	0.0329
Electricity from hard coal	**7.738017**	**66.3981**
Heavy fuel oil: Sunflower	0.024275	0.2083
Heavy fuel oil: Soybean	0.192160	1.6489
Slurry management	**2.113119**	**18.1322**
Tap water	0.071351	0.6122
Thermal energy from hard coal	0.384441	3.2988
Total	11.653972	100.0000

4.3 Comparison of impacts of the three value chains

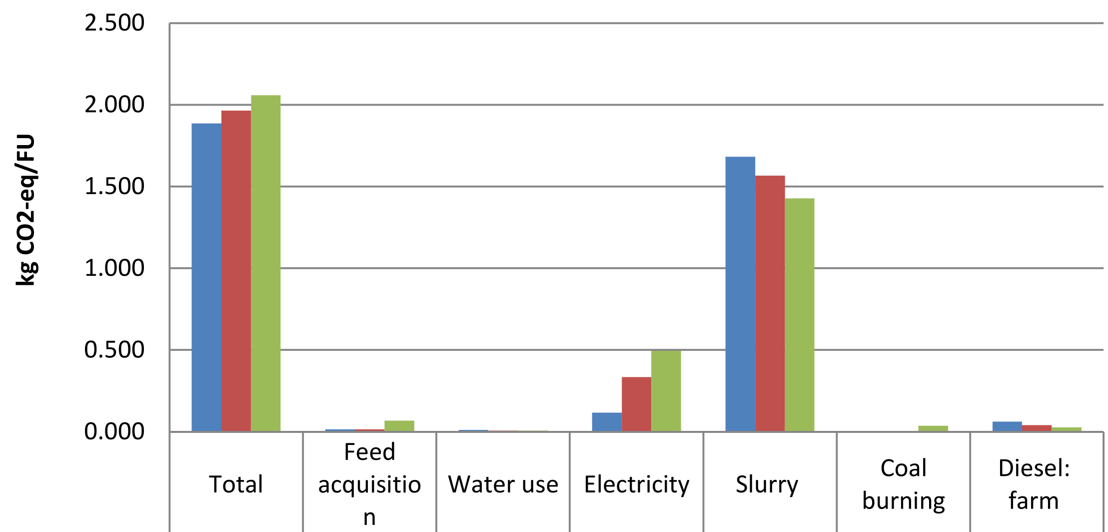
In this section the different case studies' impact categories are evaluated and compared with one another. Significant differences are identified, and a brief discussion follows. Discussions and comparisons are made in Chapter 5.

4.3.1 Global warming potential

The breakdown of the factors and processes that contribute to the GWP for the different case studies can be viewed in Table 26. In Figure 14 the GWP comparison among the three case studies is illustrated. The different activities into which environmental impacts are grouped include the feed acquisition, water usage, electricity usage, and slurry management activities. The gate-to-gate life cycle assessment for Case study 1 (KZN), shows a contribution of 1.886 kg of CO_2-eq /FU in one year. Case study 2 (NW) and Case study 3 (WC) contribute more than Case study 1, namely 1.964 and 2.059 kg of CO_2-eq /FU respectively. Case study 3 generated more GWP/FU than Case study 1 and Case study 2 in one year.

The acquisition of feed contributed 3.43 % of the total GWP for Case study 3. For this case study, maize is transported over a long distance, and feeds, in the form of sunflower and soybean, are imported from Argentina. The acquisition of maize contributed 1.88 % of the GWP for this case study. The feed acquisition activity of Case studies 1 and 2 contributed only 0.8 and 0.75 % respectively to GWP. The feed-mixing company that supplies feed in for Case study 3 uses coal in the mixing process. The use of coal contributed only 1.79 % to GWP for Case study 3.

The slurry management activity for Case study 1 had a share in its contribution to GWP of 10 % more than the same activity in Case study 2, and 20 % in Case study 3. The slurry management technique for the three case studies is similar. A higher feed conversion ratio (FCR) for Case studies 1 and 2 was the main factor that caused the higher emissions in the slurry management activity. Case studies 1, 2 and 3 used 23.5l, 17.6 and 14.8 litres of water per FU respectively. Electricity usage had an overall GWP impact of 14.59 %. The electricity usage for Case study 3 contributed almost four times more to GWP than for Case Study 1. The reason for the high electricity usage for Case study 3 was not disclosed.

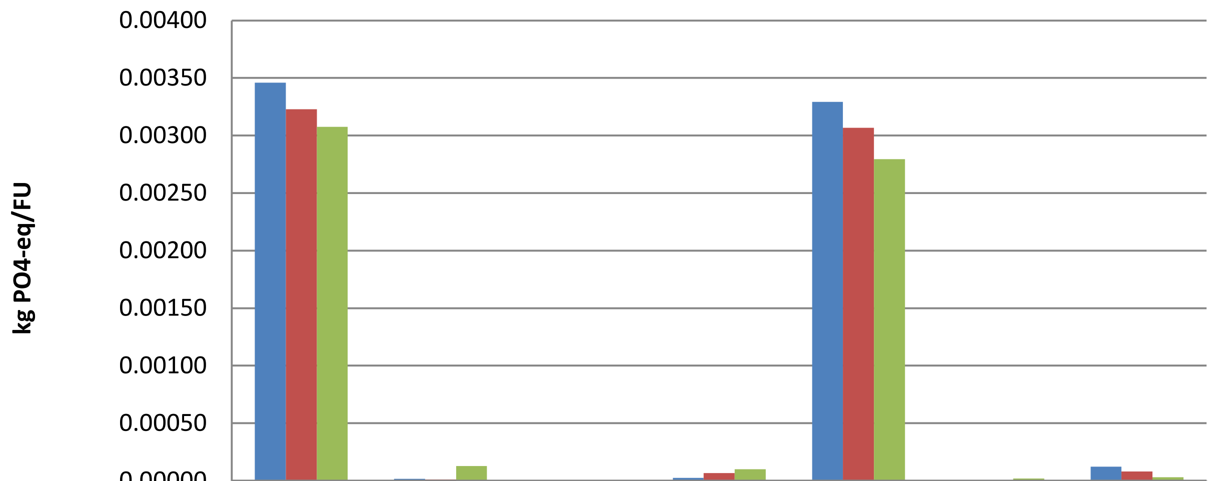


	Total	Feed acquisition	Water use	Electricity	Slurry	Coal burning	Diesel: farm
Case study 1(KZN)	1.886	0.015	0.010	0.117	1.682	0.000	0.063
Case study 2 (NW)	1.964	0.014	0.007	0.335	1.567	0.000	0.040
Case study 3 (WC)	2.059	0.067	0.006	0.495	1.427	0.037	0.027

Figure 14: GWP comparison for the three case studies

4.3.2 Eutrophication potential

Figure 15 illustrates the three case studies' activities and their contributions to EP. The total EP for Case studies 1, 2 and 3 are 0.00346, 0.00323 and 0.00307 kg of PO_4-eq/FU respectively in one year. Case study 1 had a 7.15 % higher EP than Case study 2, and 11.27 % higher EP than Case study 3. Devers et al. (2012:57) found that the leaching of nitrogen from the slurry was the main contributor to EP in a cradle-to-gate LCA. In this study slurry management contributed 95.1 %, 94.7 % and 90.7 % of the EP for Case studies 1, 2 and 3 respectively. The contribution of the feed acquisition activity for Case study 3 delivered an EP of 8 times more than the same activity for Case study 1, and 13 times more than the same activity for Case study 2. This was mainly due to the acquisition of maize over a large distance inland and the importation of sunflower and soybean.

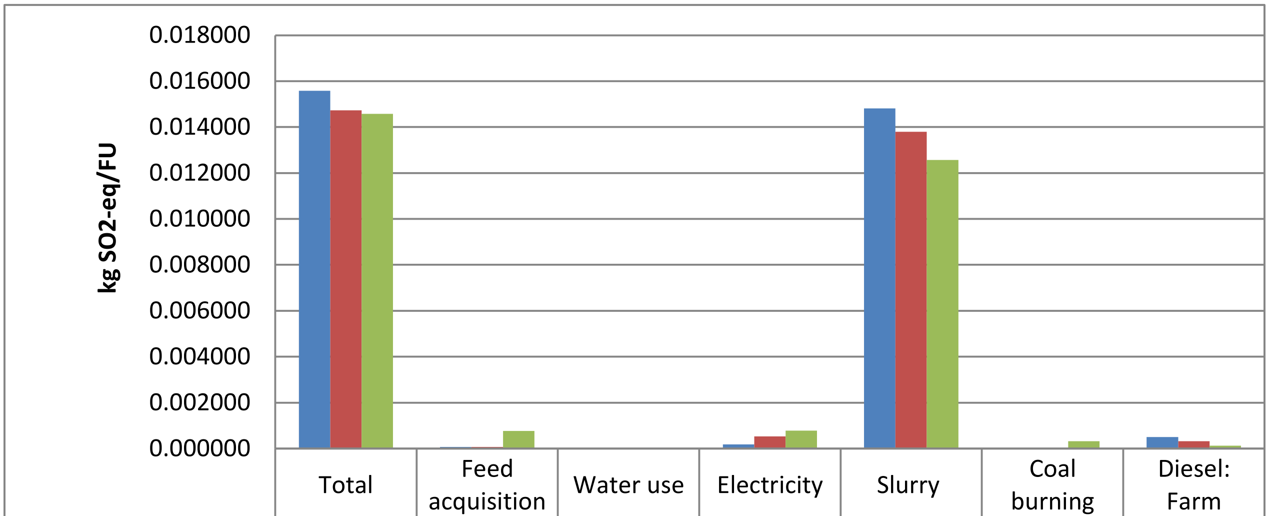


	Total	Feed acquisition	Water use	Electricity	Slurry	Coal burning	Diesel: Farm
Case study 1(KZN)	0.00346	0.00002	0.00000	0.00002	0.00329	0.00000	0.00012
Case study 2 (NW)	0.00323	0.00001	0.00000	0.00007	0.00307	0.00000	0.00008
Case study 3 (WC)	0.00307	0.00013	0.00000	0.00010	0.00279	0.00002	0.00003

Figure 155: EP comparison among the three case studies

4.3.3 Acidification potential

The AP for the three case studies in one year is 0.0156, 0.0147 and 0.0146 kg of SO_2-eq/FU respectively. In Figure 16 the contributions of the various activities to AP in the three case studies is illustrated. The slurry management activity contributed the most emissions to AP for all three case studies. The feed acquisition activity for Case study 3 generated about 10 times more AP than for Case studies 1 and 2. The importation of soybean and sunflower, as well as the acquisition of maize contributed 5.04 % of the AP for Case study 3. The transportation of maize contributed only 1.1 % of the AP for Case study 3. The importation of soybean for Case study 3 contributed 3.2 % of the AP. Case studies 2 and 3 had an AP of approximately 3 times that of Case study 1 for electricity use.



	Total	Feed acquisition	Water use	Electricity	Slurry	Coal burning	Diesel: Farm
Case study 1(KZN)	0.015585	0.000071	0.000012	0.000185	0.014810	0.000000	0.000506
Case study 2 (NW)	0.014726	0.000066	0.000009	0.000531	0.013801	0.000000	0.000319
Case study 3 (WC)	0.014569	0.000770	0.000008	0.000784	0.012566	0.000319	0.000122

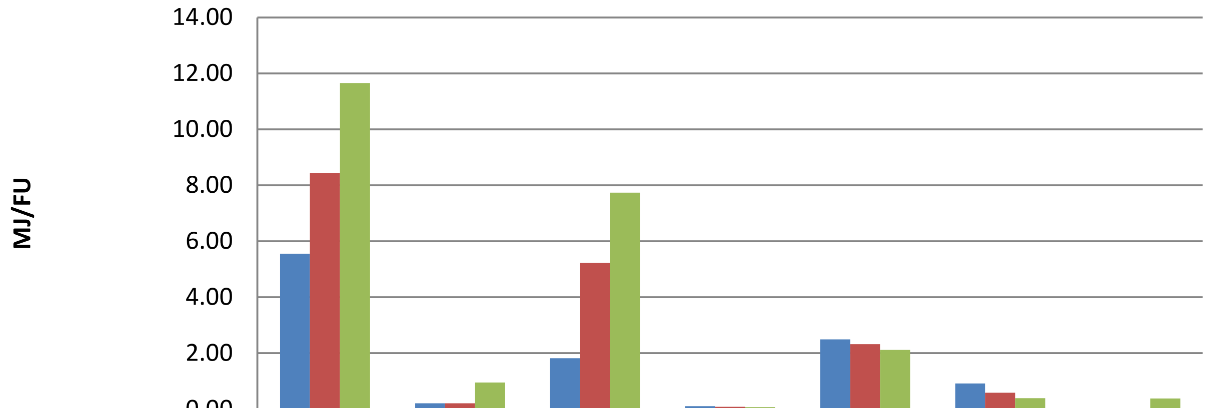
Figure 16: AP comparison among the three case studies

4.3.4 Energy use

The energy use (EU) for the various activities in the three Case studies can be seen in Figure 17. The EU for Case studies 1, 2 and 3 is 5.55, 8.44 and 11.66 MJ/FU respectively. Electricity use and slurry management were the major contributors to EU for the three case studies. For Case studies 2 and 3 more electricity per FU was used than for Case study 1. Case study 1 showed a higher EU for the slurry management activity.

Relevant information specific to the EU of the slurry management activity was gathered from the literature. Devers et al. (2012:19) found that the pig-farming activity contributed 4.7 of MJ/FU to the environmental burden of pork production in South Africa. The on-farm EU for inputs other than slurry management contributed 0.9 of MJ/FU. The carcass-to-live-weight ratio was 0.71. The reference farm used in this study generated 14.3 kg slurry per FU. This impact did not include the possible positive environmental impacts that the slurry can deliver to the environment. An example of a positive environmental impact would be a reduction in use of industrial fertiliser for application to agricultural land: the nutrient qualities that the slurry provides to the soil replace the industrial fertiliser applied to the soil.

For the purpose of this study, the EU for managing one kilogram of slurry is 0.188671 of MJ/FU when taking the difference of the FUs into consideration. The amount of slurry generated for Case studies 1, 2 and 3 to produce one FU is 13.2, 12.3 and 11.2 kg respectively. The EU for slurry management for Case studies 1, 2 and 3 is 2.49, 2.32 and 2.11 MJ/FU respectively.



	Total	Feed acquisition	Electricity	Water use	Slurry	Diesel: Farm	Coal
Case Study 1 (KZN)	5.55	0.21	1.82	0.11	2.49	0.915	0.00
Case study 2 (NW)	8.44	0.21	5.23	0.09	2.32	0.591	0.00
Case study 3 (WC)	11.66	0.96	7.74	0.07	2.11	0.396	0.38

Figure 17: Energy use impact for the three case studies

4.4 Life cycle interpretation

4.4.1 Identification of significant issues

Tables 24-27 provide the life cycle inventory results. These are detailed lists of all the resultant impacts of the various factors and processes that contribute to the impact categories for each case study. Three of the major factors that contribute to the impact categories for each case study are shown in bold. Table 28 gives a summary of the impact category results for each case study.

Table 28: Summary of the impact categories for the three case studies

Impact category	**Case studies**		
	Case study 1 (KZN)	Case study 2 (NW)	Case study 3 (WC)
GWP (kg CO_2-eq per FU)	1.886	1.964	2.059
EP (kg PO_4-eq per FU)	0.00346	0.00323	0.00308
AP (kg SO_2-eq per FU)	0.0156	0.0147	0.0147
Energy use (MJ per FU)	5.55	8.44	11.66

For all three case studies, the factor that contributes the most to GWP is slurry management. It contributes 89 %, 79 % and 69 % to GWP for Case studies 1, 2 and 3 respectively.

The main factor contributing to the EP for all three case studies is slurry management. Slurry management accounts for 95 %, 94 % and 91 % of the contributions to EP for Case studies 1, 2 and 3 respectively. Devers, et al. (2012) found that slurry management contributed 85 % of the total EP in a cradle-to-gate LCA in South Africa, and in Flanders 58 %. These two figures are lower because the production of raw materials was included in the study by Devers et al. The results are similar, but the way in which the two studies accounted for the impacts of the slurry differ.

In this study, AP was also caused mainly by the slurry management, and accounted for 95 %, 93 % and 85 % of the AP for the three case studies respectively. Case study 1 produced the highest amount of slurry per FU, and had the highest AP per FU.

The EU for Case studies 1 to 3 is 5.5, 8.4 and 11.7 of MJ/FU respectively. Electricity use and slurry management were the major contributors to the EU for the three case studies. The piggery in Case study 3 generated less slurry per FU but used far more electricity than those of the other two Case studies.

4.4.2 Completeness check

After completing the results, the LCI data and the results achieved for the different impact categories were compared with other similar LCA studies. In Chapter 5 the comparisons are summarised and substantial differences are questioned and reviewed.

4.4.3 Consistency check

After reviewing the results, it becomes clear that significant differences among the three case studies were achieved, mainly in electricity used. This and other differences are discussed in the next chapter. Other relevant results from previous studies are reported on in the recommendation section of the next chapter.

4.5 Conclusion

In this Chapter the LCA results achieved by the three case studies for the various impact categories are illustrated. The results for each impact category are grouped into the following activities: feed acquisition, electricity use, water use, and slurry management. Slurry management and electricity use are the activities that contribute most to the selected impact categories for the three case studies. Chapter 5 elaborates on the results found and provides a discussion on the relevant differences among the case studies.

5 Discussion of the LCA results for the three case studies

5.1 Introduction

In this chapter a discussion of the life cycle assessment results of the three case studies is provided. The results are compared with previous intensive pork production LCA studies in the literature. Variations among the results found for this study and those of previous studies are discussed. The results for the environmental impact categories are compared among the three case studies. A financial and environmental comparison is made in Section 5.4. Deviations between the relative proportions of financial and environmental impact for each case study are pointed out. Final discussions, conclusions and recommendations are made.

5.2 Goal and scope definition

In all LCA studies, the FU is important for comparison and discussion purposes. In this study all the inputs and emissions are converted to a FU of one kg of live-weight pig. When one compares the results of this study with a study that uses a FU of one kg of slaughter-weight, the absolute values of the environmental impacts are lower roughly by the difference between the live and slaughter weight conversion ratios, and by the difference between the environmental impacts of the slaughtering process. This will hold true only if the studies have the same system boundaries and include the same inputs in their LCIs. Some studies use an FU of one kg of bone and fat-free meat. The latter approach achieves higher results for the impact categories per FU, because the production chain and system boundary include more processes that contribute to environmental impacts. In Table 29 a summary of previous LCA impact category results is provided. The country and the year in which the study were completed are included. Not shown in this table are the LCA software that was used, the environmental accounting methods and the LCIA methods (CML 2001-2013, Eco indicator 95, EDIP 2003, Impact 2002+ and TRACI) used. Also excluded were the exact system boundaries used and which inputs and outputs were taken into consideration. In this study the CML 2001-2013 method was used.

Table 29: Comparison among relevant pork LCA impact category results

Authors	Origin	Year	GWP (kg CO_2 eq)	EP (kg PO_4 eq)	AP (kg SO_2 eq)	EU (MJ)	FU	System boundary
Cederberg & Flysjo	Sweden	2004	2.06	0.0183	0.0304	9.3	1 kg bone and fat free	Cradle to gate
Devers et al.	R.S.A	2012	4.5	0.034	0.063	30.7	1 kg carcass weight at distribution centre (Antwerp)	Cradle to gate
Devers et al.	Flanders	2012	2.55	0.022	0.039	18.3		
Olea,	UK	2009	3.167	0.021	0.045	-	1 kg, live-weight	Cradle to farm gate
Basset-Mens & Van Der Werf	France	2005	2.3	0.0208	0.0435	15.9	1 kg live weight at slaughterhouse	Cradle to gate
Reckman et al.	EU	2013	3.2	0.0233	0.057	-	1 kg pork at slaughter weight (Slaughterhouse)	Cradle to gate
Dolman et al.	Netherlands	2012	546 (5.46)	-	5.3 (0.053)		100 kg slaughter weight (1 kg slaughter weight)	Cradle to gate
Stone et al.	USA	2012	398.2 (3.37)	5.03 (0.042)	3.01 (0.025)	-	one head of swine at 118 kg (1 kg live weight)	Cradle-to-farm gate
Pelletier et al.	USA	2010	344 (2.91)	2.08 (0.017)	-	11.45	one head of swine at 118 kg (1 kg live weight)	Cradle-to-farm gate
This study: Case study 1	R.S.A	2014	1.886	0.00346	0.0156	5.55	1 kg live weight at farm gate	Gate to farm gate
This study: Case study 2	R.S.A	2014	1.964	0.00s323	0.0147	8.44	1 kg live weight at farm gate	Gate to farm gate
This study: Case study 3	R.S. A	2014	2.059	0.00308	0.0147	11.66	1 kg live weight at farm gate	Gate to farm gate

5.3 Life cycle inventory analysis

The life cycle inventory (LCI) phase of this study includes data capturing and processing. All the data required was collected by the author and modelled according to the LCI for each case study. The confidential data is not included here but was taken into account in the software. For all three case studies, similar inputs were used, for example, the diesel, source of electricity, tap water and trucks for transporting the feed. The dataset used in GABI did not contain specific South African inputs and processes. The results therefore cannot be taken as being specific to the South African LCA of pork production, but instead, serve as a proxy for comparing the three case studies selected.

5.4 Life cycle impact assessment

In this section the results of the three case studies are discussed under each impact category. The environmental impacts of the various activities in the three case studies are compared with one another and are illustrated in graphs. Discussions and recommendations are addressed accordingly.

5.4.1 Global warming potential (GWP)

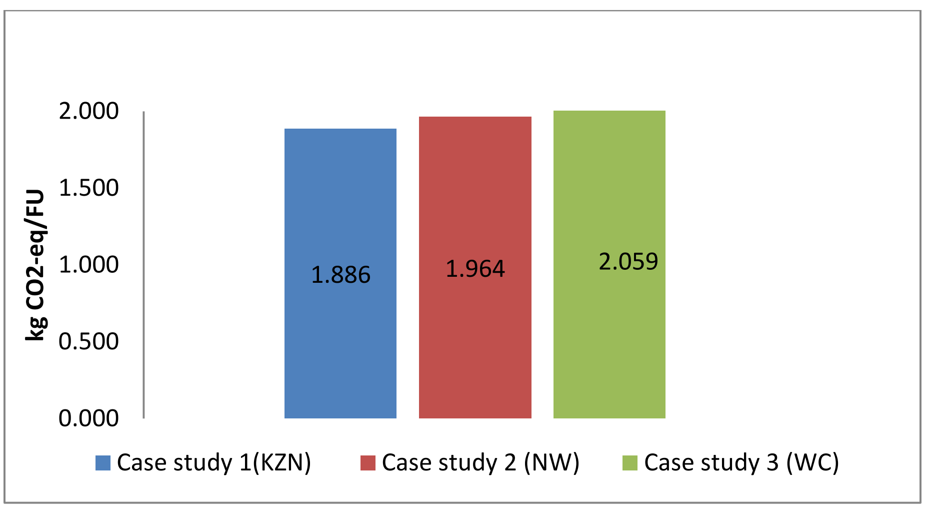


Figure 18: Global warming potential results for Case studies 1, 2 and 3

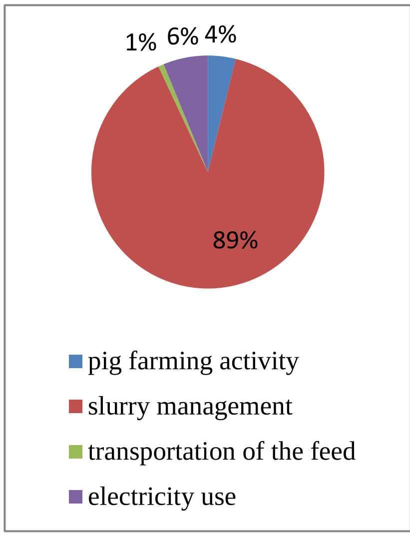


Figure 19: GWP results for the LCA activities in Case study 1

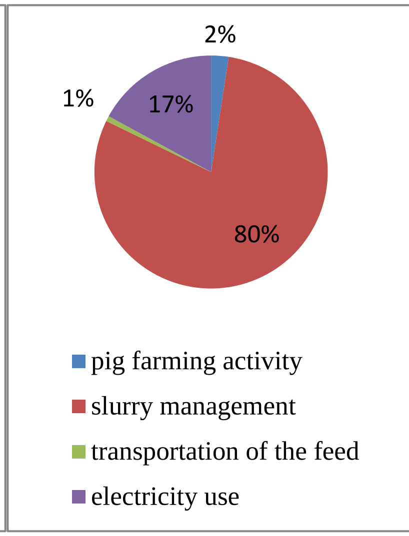


Figure 20: GWP results for the LCA activities in Case study 2

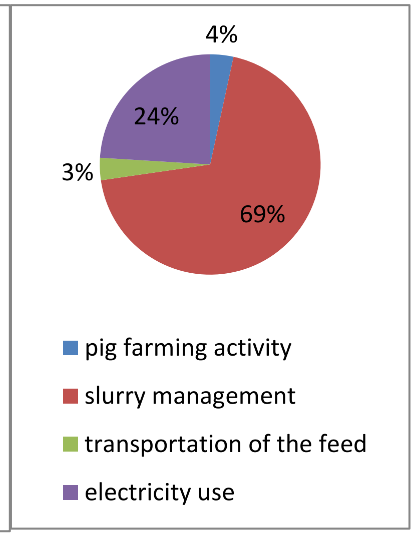


Figure 21:GWP results for the LCA activities in Case study 3

As described in Section 2.3.2, greenhouse gasses (GHG) are known for their ability to enhance the radioactive forcing in the atmosphere. These GHGs absorb and emit radiation and can lead to higher temperatures in the atmosphere. GWP measures take into account all the emissions of GHGs, like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), which cause an increase in temperature. As described in Section 3.3, various life cycle impact assessment (LCIA) methods exist to account for impact categories. In this study the CML 2001-2013 method was used.

In Figure 18, the GWP results for Case studies 1, 2 and 3 are 1.886, 1.964 and 2.059 kg of CO_2-eq /FU respectively. This study had a gate-to-gate system boundary. The system boundary did not include the environmental impacts pertaining to the production of the feed and fertiliser, the distribution of the final product and its recycling. The slaughterhouse activity and its inputs, as well as the distribution of the final product were also excluded. Therefore, if comparisons of results are to be made with previous studies, one must compare the segments in their production chain that included similar inputs and processes studied. Figures 19, 20 and 21 illustrate the GWP results for the pig-farming activity, slurry management, transporting of the feed, and electricity use for the three case studies. It is clear that in all three of the case studies, the slurry management activity contributed the most to the GWP/FU.

A previous LCA study about pork production in South Africa yielded a GWP of 0.411 kg CO_2-eq per FU for the pig-farming activity, 1.612 kg CO_2-eq per FU for the slurry management, 0.0156 kg CO_2-eq per FU for the transportation of feed and 0.475 CO_2-eq per FU for the electricity use. The FU used in this study was one kg of carcass weight (Devers et al., 2012:54). Similar results were found for the transportation of feed (0.015 kg CO_2-eq per FU), slurry management (1.682 kg CO_2-eq per FU) and electricity use (0.117 kg CO_2-eq per FU) for Case study 1. For Case study 2, the GWP results for the transportation of feed (0.014 kg CO_2-eq per FU), slurry management (1.567 kg CO_2-eq per FU) and electricity use (0.335 kg CO_2-eq per FU) were similar. The GWP results for Case study 3 were as follows: transportation of feed 0.067 kg CO_2-eq per FU, slurry management 1.427 kg CO_2-eq per FU, and electricity use 0.495 kg CO_2-eq per FU.

Electricity use for Case study 2 per FU was more than double that of Case study 1. In Case study 2 an added heating source is provided in the pig's pen during the winter season when the piglets are born. In Case study 1 an added heating source was not provided during winter, due to the higher average winter temperatures in this region.

In a comparative LCA between UK and Mexican pork production, it was found that the mixing and milling of feed, as well as its transportation to the farm accounted for only 5 % of the total GWP in a cradle-to-farm gate LCA (FU of one kg of live-weight pig to the farm gate in one year). The feed acquisition alone constituted only 1 % of the total GWP (Olea, 2009:148).

The feed acquisition activity's relative contribution to GWP for Case studies 1, 2 and 3 was 0.80 %, 0.75 % and 3.43 % respectively. This contribution of the feed acquisition activity was smaller than initially envisaged. Case study 3 had a higher GWP for feed acquisition. The higher GWP for the feed acquisition activity was mainly due to maize being transported approximately 1 250 km by road to the farm. In Case study 3, 11 % less maize was used than in Case study 1, and 14 % less than in Case study 2, when their feed rations were compared. A higher percentage of wheat, sunflower, oats, lucerne, canola and lupines were used in Case study 3, because these feed components were produced closer to the piggery than the maize component. This was done to offset some of the transportation distance of the maize component. In Case study 3, therefore, the farm adapted to some extent to the unavailability of resources in its region.

5.4.2 Eutrophication potential

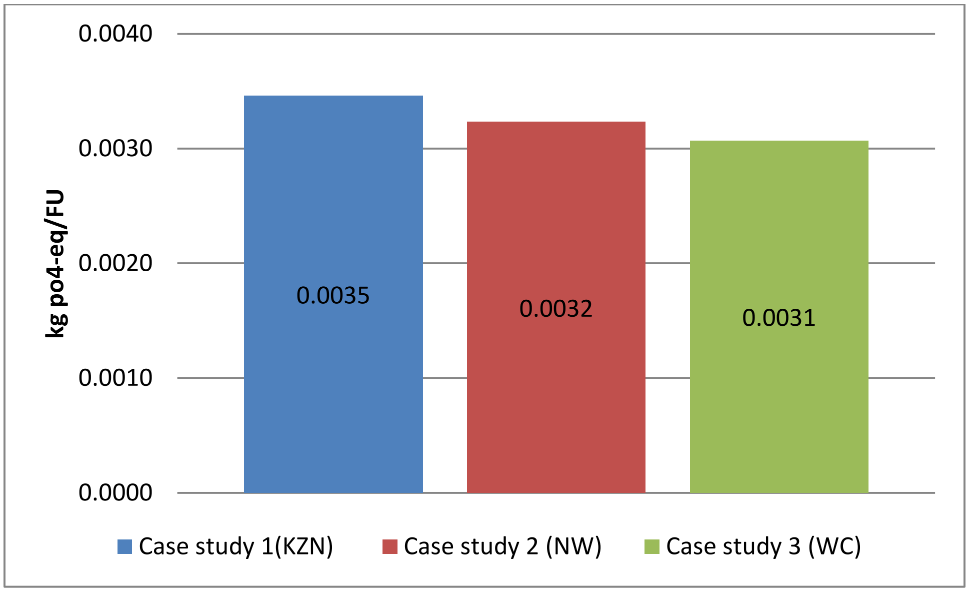
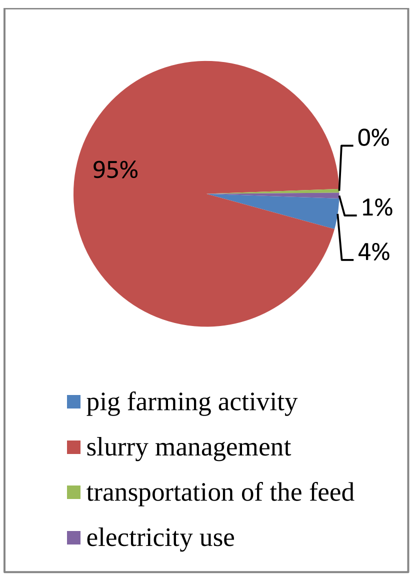
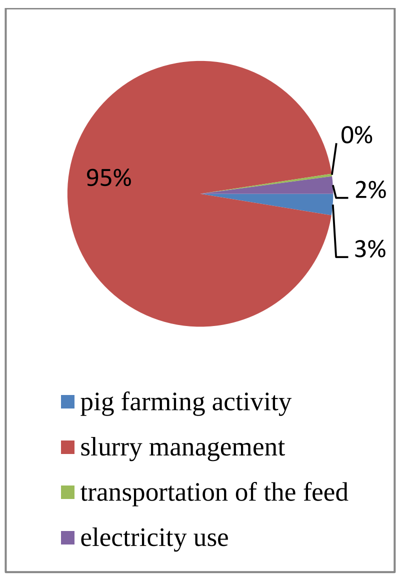


Figure 22: Eutrophication potential results for Case studies 1, 2 and 3





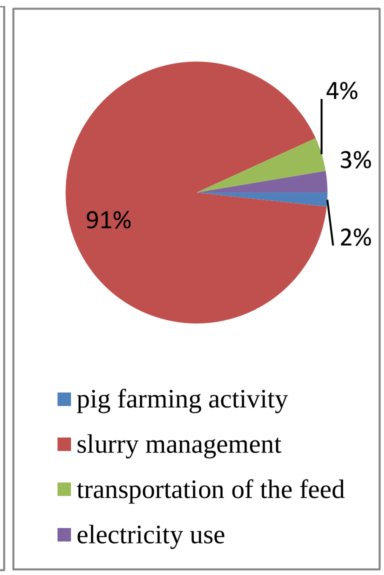


Figure 23: EP results for the LCA activities in Case study 1

Figure 24: EP results for the LCA activities in Case study 2

Figure 25: EP results for the LCA activities in Case study 3

As discussed in Section 2.3.2, EP is known for its high quantity of nitrogen (N) and phosphorus (P) levels, which result mainly from the run-off of agricultural water and urban waste disposal.

The aquatic environment subsequently absorbs the run-off elements, which causes environmental change.

The results for the total EP in Case studies 1, 2 and 3 are 0.00343, 0.00323 and 0.00308 kg of PO_4-eq/FU respectively, in one year. These results are shown in Figure 22. The EP for Case study 1 was 6% higher than for Case study 2, and 10 % higher EP than for Case study 3.

A previous LCA study of pork production in South Africa found that the leaching of nitrogen from the slurry and the production of feed were the major contributors to EP: slurry management was responsible for 90 % of the EP (Devers et al., 2012:55).

In Figures 23, 24 and 25, the EP results for the pig-farming activity, slurry management, transportation of the feed and the electricity usage for the three case studies is shown. It is clear that in all three case studies, the slurry management activity contributed the most to EP/FU. In this study the slurry management activity made a relative contribution of 95 %, 95 % and 91 % to the EPs for Case studies 1, 2 and 3 respectively. The contribution of the slurry management activity to EP in this gate-to-gate LCA was high because another large contributor to EP, namely the production of feed, was outside the system boundaries.

A slurry management technique that included the application of slurry to agricultural land contributed 53 % to the EP in a cradle-to-farm gate LCA. This accounted for 0.031 kg of PO_4-eq per FU. The FU used in that study was one kg of live-weight pig. The other major contributor of EP was the cultivation of feed. This accounted for 33 % of the total EP per FU in the aforementioned LCA. It was suggested that the key factor in managing EP is to avoid excess slurry production and reduce the leaching of nitrate from agriculture fields (Fry & Kingston, 2009:12).

The pig-farming activity and the feed-mixing and transportation activities were minor contributors to the EP for a South African Case study. These two activities accounted for only 0.2 and 0.7 % respectively. The pig farming activity included neither the enteric emissions nor emissions from managing the slurry. The slurry management was done separately and accounted for 0.0289 kg of PO_4eq/FU (Devers et al., 2012:55). The transportation of feed did not contribute significantly to the EP in that cradle-to-grave LCA.

If the slurry management activity is deducted from the total EP, then the EPs for Case studies 1, 2 and 3 are 0.000168, 0.000171 and 0.000281 kg of PO_4-eq/FU. Only the result for Case study

3's EP is similar to the findings by Devers et al. (2012), which is 0.000305 kg of $P0_4$-eq/FU. Note that the EP for the feed production activity in Devers et al. (2012) was also deducted from the results. Both studies included transporting maize by truck inland for 1 200 km and imported soybean from countries like Brazil and Argentina. Maize accounts for 31 %, and soybean 37.4 % of the EP in the feed acquisition activity for Case study 3.

The reason for the lower impacts in EP for this study can be explained by the following: 1) different methods of accounting for environmental impacts, 2) smaller system boundaries, and 3) a different FU. When looking at the results, it is clear that the case study that produces the least slurry per FU will have the lowest EP. The FU is also heavily affected by the FCR. The production chain in Case study 3 needed less feed than those of the other two case studies to convert it to the FU. In Case study 2, more piglets were weaned in a year than for the other two case studies (refer to Table 30). Case study 1 produced the most slurry per FU, and needed more feed and water to produce one FU. In Case study 1, also fewer piglets per sow per year were weaned. Case study 1 had a high percentage of pre-weaning (9.9 %) and post-weaning mortality (3 %) compared with to the other two case studies. Case study 1 housed more sows per year per FU. This implies that the farm of Case study 1 would have a higher feed usage per FU, produce more slurry per FU and have a higher EP than for those of the other two case studies. The EP results of the three case studies did not provide useful information regarding an optimal environmentally friendly region for the production of pork. The higher EP for Case study 1 could also be the result of different structuring in the pig's pen. Weaker genetics could also result in a higher pre- and post-weaning mortality. The EP results show that the management of the pork production chain holds major environmental impact mitigation opportunities.

Table 30: Livestock numbers for the three case studies

	Case study 1 (KZN)	Case study 2 (NW)	Case study 3 (WC)
Weaners/sow/year	23.1	26.7	24.3
Cycles/sow/year	2.31	2.51	2.45
Pre-weaning mortality (%)	9.9	2.6	4.7
Post-weaning mortality (%)	3	2	0.35
Piglets born per litter	11.6	11.1	9.9

5.4.3 Acidification potential

As discussed in Section 2.3.2, AP calculates the loss of the nutrient base (calcium, magnesium, potassium) in an ecosystem, and its replacement by acidic elements caused by atmospheric pollution. Pollutants like SO_2, NO_x, HCL and NH_3 are the main pollutants that cause AP. All of these pollutants have a common characteristic, which is that they form acidifying H+ ions. Acidic gasses like SO_2, NO_x and NH_3 react with water in the atmosphere, and have the potential to form acids like H_2SO_4 and HNO_3.

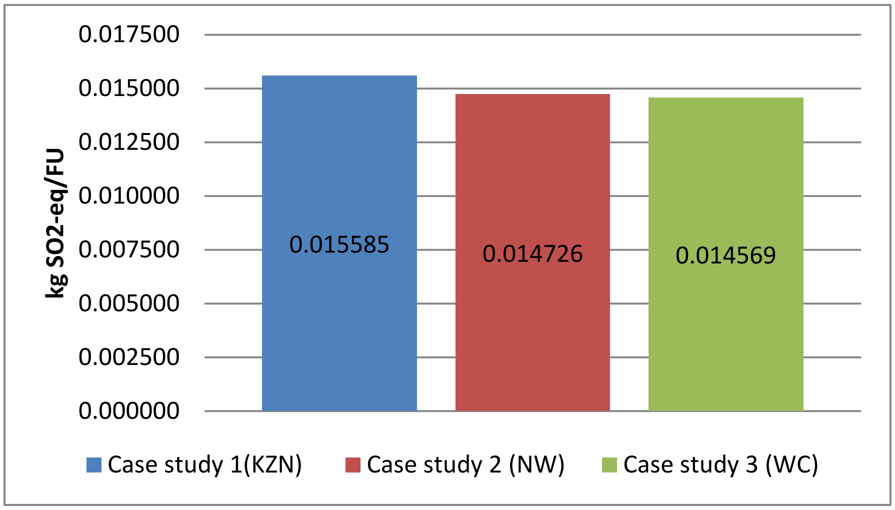


Figure 26: Acidification potential results for Case studies 1, 2 and 3

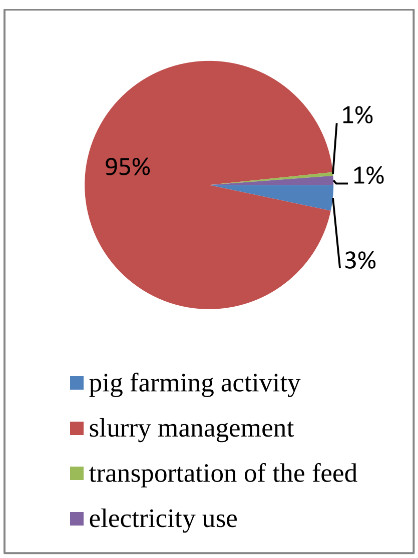


Figure 27: AP results for the LCA activities in Case study 1

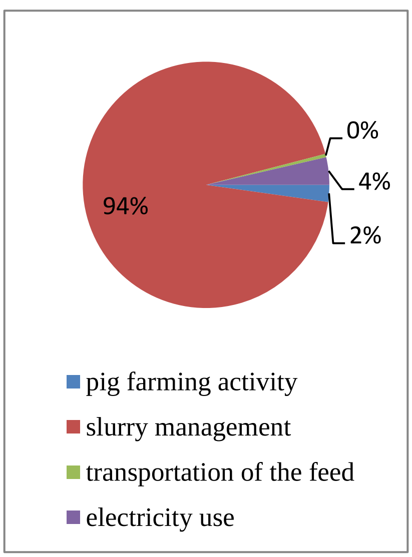


Figure 28: AP results for the LCA activities in Case study 2

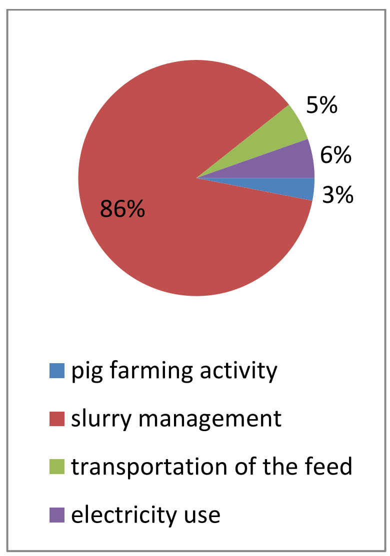


Figure 29: AP results for the LCA activities in Case study 3

The results for AP in Case studies 1, 2 and 3 are 0.0155, 0.0147 and 0.0146 kg of SO_2-eq/FU respectively. These results are shown in Figure 26. For Case study 1 a 6 % higher AP was generated than for Case study 2, and a 7 % higher AP than for Case study 3. In Figures 27, 28 and 29, the AP results for the pig farming activity, slurry management, transportation of the feed, and electricity use for the three case studies are shown. The major activity that contributed to AP in all three case studies was the slurry management activity. This activity accounted for 95 %, 94 % and 86 % of the total AP for Case studies 1, 2 and 3 respectively.

The main contributor to AP in this study is the ammonia emitted from the slurry applied to agricultural land. This process contributed 67 % of the total AP in a cradle-to-gate LCA. The feed production activity also contributed heavily to the AP (Fry & Kinston, 2009:14). A cradle-to-farm gate LCA in the USA found an AP of 0.025 kg of SO_2-eq per kg of live weight. This LCA study covered the slurry management activity, the feed production activity and the enteric emissions of the pig itself. The production of the feeds accounted for 45 %, and slurry management accounted for 43 % of the total AP. The AP for slurry management was 0.011 kg of SO_2-eq per kg of live-weight. The enteric emissions of the pig contributed 0.0027 kg of SO_2-eq to the total AP per kg of live weight. The enteric emissions contributed only 10 % of the total AP of the LCA (Stone et al., 2012:7). These results are similar to the findings in this study. The contribution to AP of the slurry management for Case studies 1, 2 and 3 was 0.0148, 0.0138 and 0.0125 kg of SO_2-eq/FU.

The results for AP in comparative European pork LCA yielded 0.0571 kg of SO_2-eq/FU. All results were expressed in an FU of one kilogram of pork meat at slaughter weight (Reckman et al., 2013:593). These results are higher than for Case studies 1, 2 and 3, because the production of feed and the slaughterhouse process were included, and a smaller FU was used. Managing the slurry in pork production in South Africa contributed more than 50 % to AP, and for Belgium, it contributed more than 80 %. The results per FU were 0.063 kg of SO_2-eq for South Africa, and 0.039 kg of SO_2-eq for Belgium (Devers et al., 2012:56). An LCA Case study on Mexican pork production found an AP of 0.0075 kg of SO_2-eq/FU. This result was higher than for other studies, due to the slurry management technique in that specific case study. The slurry was delivered to open areas, and no anaerobic fermentation was considered (Olea, 2009:194).

The AP in Case studies 1, 2 and 3 was highly affected by the slurry management activity. Slurry management and the production of feed are the highest contributors to this impact category, but only the slurry management was accounted for in this LCA. Feed production was outside of the system boundaries.

The farm in Case study 1 generated the most to AP per FU, followed by those of Case studies 2 and 3. The reason for this finding is that the subject of Case study 1 produced more slurry per FU than those of the other two case studies. This could have been related to the lower number of weaners that one sow produced per year in Case study 1 (refer to Table 30). The subject of Case study 1 produced more piglets per sow per birth, but the pre- and post-weaning mortality rate resulted in fewer pigs being weaned per sow in one year. Therefore, the AP results could be related to the different infrastructure and management techniques in the production chain, and not to the specific region were the production of pork is located.

5.4.4 Energy use

The energy use (EU) indicator was included as an impact category in this study to compare the efficiency of energy use among the three case studies. The total EU of the pork production chain is a way of measuring its efficiency in using renewable and non-renewable energy. The results are expressed in MJ equivalents. The EU results for Case studies 1, 2 and 3 are 5.6, 8.4 and 11.7 of MJ/FU respectively. Case study 3 had an EU of 52 % more than Case study 1, and 28 % more than Case study 2. These results are illustrated in Figure 30. In Figures 31, 32 and 33, the EU results for the pig farming activity, slurry management, transportation of feed, and electricity use for the three case studies are shown. The electricity use and slurry management activity contributed the most to EU/FU. Electricity use contributed more than 60 % to the EU/FU in Case studies 2 and 3, but only 33 % in Case study 1.

An LCA of pork production in the Western Cape of South Africa found that the production chain from cradle to grave generated an EU of 30.5 MJ/FU (Devers et al, 2012:115). The FU used was one kg of slaughter-weight pork. The activities included in this study were the production of raw materials, the transportation of raw materials, the mixing of feed, the pig farming activity (which includes slurry treatment), the slaughterhouse activity and the distribution of the product (meat).

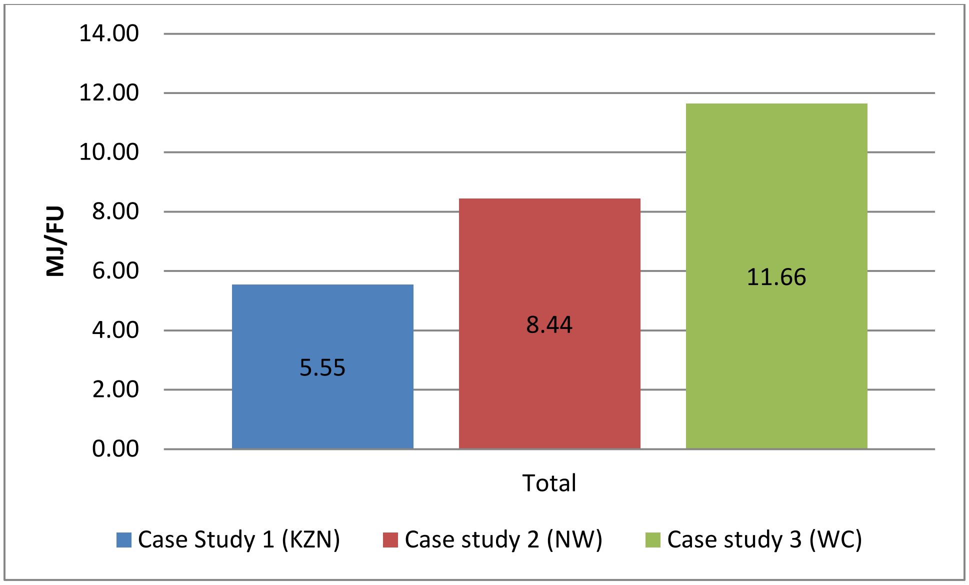


Figure 30: Energy use results for Case studies 1, 2 and 3

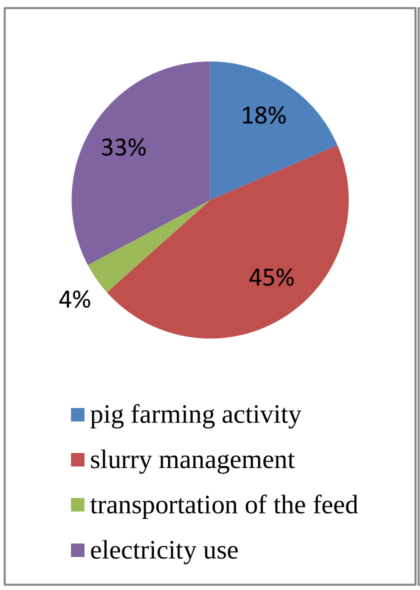


Figure 31: Energy use of the LCA activities in Case study 1

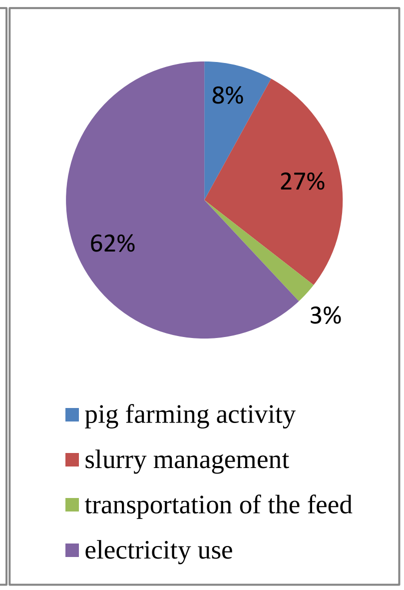


Figure 32: Energy use of the LCA activities in Case study 2

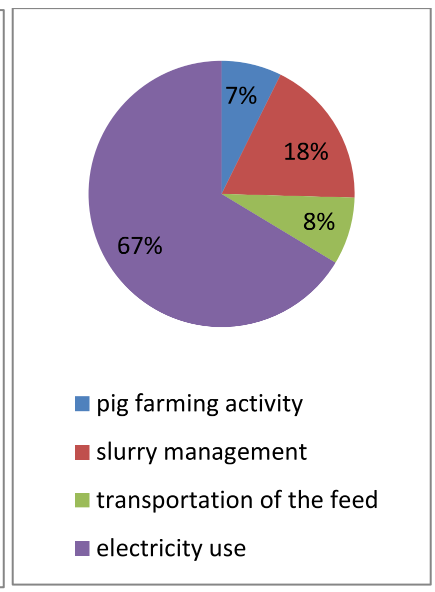


Figure 33: Energy use of the LCA activities in Case study 3

The pig farming activity included diesel, water, and electricity use, and the slurry management on the farm. The pig farming activity contributed 4.7 MJ per FU (Devers et al., 2012:58). The conversion from live weight to slaughter weight in that study was 71 %. When taking the live weight to slaughter weight into consideration, the EU was 6.62 MJ per KG of live weight.

The feed acquisition activity accounts for only 6 % of the total EU for all three case studies. The feed acquisition activity in Case study 3 made a contribution to EU of 4.4 times more than those in Case studies 1 and 2. For the purpose of this comparison, no potential energy outputs were taken into account. In creating the model for the electricity, generating 100 % coal-combusted electricity was taken as the reference. This is not the exact energy mix for South Africa, because other resources in addition to coal are also used to create electricity. In all three of the case studies, the electricity mix was the same (100 % coal combustion) and, therefore, did not affect the relativity of the comparison among the three case studies. The South African electricity mix is generated mainly from coal combustion, gas turbines, hydroelectric schemes, and nuclear power stations. The exact energy mix depends on the availability of the resources and varies during climatic seasons. Case study 3 is located close to the nuclear energy plant, which could suggest that in this case study, the environmental impact for electricity use is not the same as it is for the other two case studies, because of the higher proportion of nuclear electricity used in the production process. However, Eskom, the major electricity provider and redistributor in South-Africa, argues that the Western Cape does not receive electricity generated exclusively by the nuclear plant in the Western Cape province. Therefore, in this study the electricity from nuclear energy cannot be considered to be localised to the Western Cape province.

After completion of the gate-to-gate LCA for the three case studies, it became clear that transporting the main feed inputs over large distances did not have a significant environmental impact in the four impact categories reviewed. Strategically, it would place less strain on the environment if the piggery were located close to the production area of the main feed inputs. But transporting the feed accounts for only a minor portion of the environmental impacts in this gate-to-gate LCA. If the piggery is located close to other enterprises that can benefit from the fertilisation properties of the slurry, it will offset the environmental burden of acquiring the feed over a large distance.

From a tactical point of view, a piggery that is already located in an area where the environmental impact of acquiring the feed is high therefore could compensate by improving the herd performance with better genetics and by incorporating better technologies in its slurry management technique. From a financial perspective, it is better to locate the piggery closest to the market of the main input sources and closer to the offset point of the final product. In this way the transport costs are minimised.

5.5 Financial and environmental performance comparison

The comparison of the three selected piggeries in terms of environmental, financial and economic performance should provide useful information with regard to the impact of the location of the piggery relative to input sources, pork markets and the impact of location relative to other infrastructure

When evaluating environmental impacts and financial performance in order to make meaningful and relevant comparisons, it must be borne in mind that the nature of this study was limited by the availability of data.

Evaluating the three case studies only on their environmental performance would not indicate whether deviations among the relative monetary and environmental performance had occurred. Sustainable production requires that the product's life cycle be economically viable, ecologically sound and socially acceptable for the present generation as well for as for future generations. Dolman et al. (2012:143) found that a high variation existed in the economic, environmental and societal performance of Dutch pork production. Net farm income (NFI) was used to calculate the economic performance, and LCA was used to quantify the environmental impacts. The criteria used for the societal performance included using antibiotics and the pig mortality rate. The farms that outperformed other farms on economic, environmental and societal performance criteria produced pigs on larger areas and used higher percentages of by-products in the pig's ration. The farms that outperformed the others on the environmental criteria used less feed per FU and a higher percentage of wet by-products. The result was that the profitability of pork production was inversely proportional to the feed-related environmental impacts, and that many important deviations among the relative monetary and environmental impacts occurred. The environmental impacts that were generally not accounted for were mainly greenhouse gasses and eutrophication emissions, and the ecosystem's ability to provide energy inputs while being able to absorb the wastes. Dolman et al. (2012:143) suggest that policy intervention may be required to compensate for market failures.

The major concerns with environmental impacts are that there is uncertainty regarding the monetisation of environmental impacts. Not all of the environmental impacts can be monetised sufficiently (Ngugyen et al., 2012:168). Pelletier et al., 2010:607) also noticed that there exists an imperfect relationship between the economic and environmental performance measures of pork production. They further found that profitability tracks well with resource throughput, but only indirectly with emission intensity.

Therefore, it is necessary to evaluate the piggeries on their environmental as well as on their financial performance. LCA results are used to evaluate the piggeries on their environmental performance. Prices in the market place are often administrated prices, regulated by government and large market participants. Administrated prices cannot be used for comparative purposes because these prices are not a true reflection of the market price of the inputs. Diesel and electricity are supplies that are controlled by government and large market participants. Therefore, financial and economic performance measurements can be misleading. It is recommended that financial as well as environmental performance measurements need to be taken to ensure a more realistic view of the function of a market.

5.5.1 Financial and environmental comparisons of diesel use in the three case studies

In this section, the environmental impacts of the diesel used to acquire the main feed components (maize, soybean and wheat) and the diesel used in the pork production chain are compared with the financial expense of the same input for each case study. The relative contribution of the environmental performance and the financial performance are compared among the three case studies. Significant deviations in the relative ratio between the financial and environmental performance will depend on how the production chain differs among the three case studies. The price of the diesel input was standardised among the three case studies. All three case studies were modelled individually in the Gabi LCA software. These production chains are shown in Annexures 1, 2 and 3. Case study 3 has an additional process included for when the main feed components are acquired. The process of importing feed with a container ship will not cause an environmental impact of the same proportion as transporting it by truck.

The difference among the case studies' proportion of relative financial or environmental impacts will depend on how efficiently the Case study farm, used the inputs in the production process, where it is located relative to the input, the infrastructure at its disposal, the sow herd's productivity, and the managerial abilities of its manager.

5.5.1.1 Financial and global warming potential comparisons of the diesel input for the three case studies

Table 31 provides a summary of the GWP and financial impact of the diesel input used to transport the main feed components for the three case studies. Figure 34 illustrates the diesel expense for acquiring the same feed components per FU. It is clear that Case study 2 has a lower diesel expense per FU. Case study 2 is located closer to the production area of the main feed inputs compared with the other two case studies. Case study 3 imports some of the feed by container ship. Case study 2 has a location advantage compared with the other two case studies. This result is also shown in Figure 35. The farm in case study 2 generated less GWP/FU compared with the other two case studies. When comparing the financial and GWP performance, it is clear that deviations occur. In Figure 34, Case study 1 had a 33 % relative share for the total diesel expense per FU, and as is illustrated in Figure 35, Case study 1 had a 36 % share of the relative GWP per FU for diesel use. This comparison indicates that a deviation exists in the GWP and financial performance of Case study 1. The share of relative diesel expense per FU for Case study 2 is 24 %, and the share of relative GWP/FU is also 24 %. Case study 3, however, has a higher share of the financial expense than of the relative GWP/FU. This deviation occurs because Case study 3 imports some of the feed by container ship. Fuel burned by the container ship was accounted for by the LCA software and was also converted to GWP.

5.5.1.2 Financial and EP comparisons of the diesel input for the main feed components

Figures 36, illustrates the relative EP/FU of the diesel input for the three case studies. It is clear that the farm in Case study 2 generated less EP/FU than did those for the other two Case studies. Figure 34 illustrates the relative financial performance of the three case studies for diesel input. When comparing the financial and environmental performance, the largest deviation occurs for Case study 3. Case study 1 had a share of 33 % of the relative financial contribution per FU and a share of 39 % for EP/FU. The piggery in Case study 2 made a relative financial contribution per FU of 24 % and a relative EP per FU of 26 %. Case study 3, made a relative financial contribution per FU of 43 % and a relative EP per FU of 35 %. The EP impact category shows a deviation for all three case studies, and the largest one occurs for Case study 3.

5.5.1.3 Financial and AP comparisons of diesel input for the main feed components

In Figure 37 the relative AP/FU contribution of the diesel input for each case study is illustrated. Case study 2 generated less AP/FU compared with the other two case studies. Case study 1 delivered a relative financial contribution per FU of 33 % and a relative AP/FU contribution of 33 %. Case study 2 made a relative financial contribution per FU of 24 % and a relative AP per FU of 21 %. Case study 3 delivered a relative financial contribution per FU of 43 % and a relative AP per FU of 46 %. For the environmental impact category AP, a deviation exists for the financial and environmental performance of Case studies 1 and 3.

5.5.1.4 Financial and EU comparisons of diesel input for the main feed components

The financial and EU environmental impacts are shown in Table 31. In Figure 38 the relative EU/FU of the diesel input for each case study is illustrated. The piggery of Case study 1 delivered a relative financial contribution per FU of 33 % and a relative EU/FU of 38 %. For Case study 2, the piggery made a relative financial contribution per FU of 24 % and a relative EU/FU contribution of 26 %. For Case study 3, the piggery made a 45 % relative financial contribution per FU and a relative EU per FU of 36 %. This comparison shows that the largest deviation between the environmental impact and financial expense of the diesel input occurs for Case study 3. It can be said that the location for this case study causes a higher deviation among the relative financial and environmental impacts than for the other case studies. The environmental and financial comparison of the diesel input gave valuable results, but this comparison cannot be applied for the entire life cycle of pork production. The relative environmental impact for GWP, EP, AP and EU for the diesel input deviates from the overall environmental impact for each case study. More inputs need to be taken into consideration when comparing the financial and environmental impacts among the production units of various regions. In the next section, the same comparisons are made between the financial and environmental impacts, with specific reference to the electricity used in the production process.

Table 31: Financial and environmental comparison of the diesel input for the three case studies

	Case study 1 (KZN)	Case study 2 (NW)	Case study 3 (WC)
Diesel expense of main feed components/FU	0.1922	0.1359	0.2451
Relative share (%)	33	24	43
GWP of the main feed components' diesel input/FU	0.077	0.051	0.085
Relative share (%)	36	24	40
EP of the main feed components' diesel input/FU	0.000139	0.000093	0.000120
Relative share (%)	39	26	35
AP of diesel for the main feed components/FU	0.000575	0.000376	0.0008017
Relative share (%)	33	21	46
EU of the main feed components diesel input/FU	0.1885	0.1086	0.2403
Relative share (%)	38	26	36

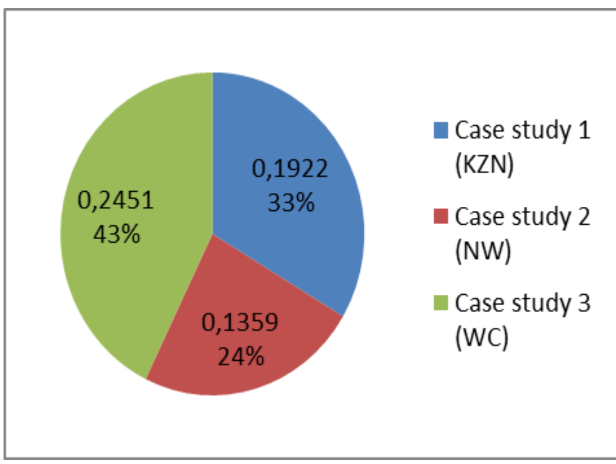


Figure 34: Relative diesel expense in acquiring the main feed inputs per FU for the three case studies

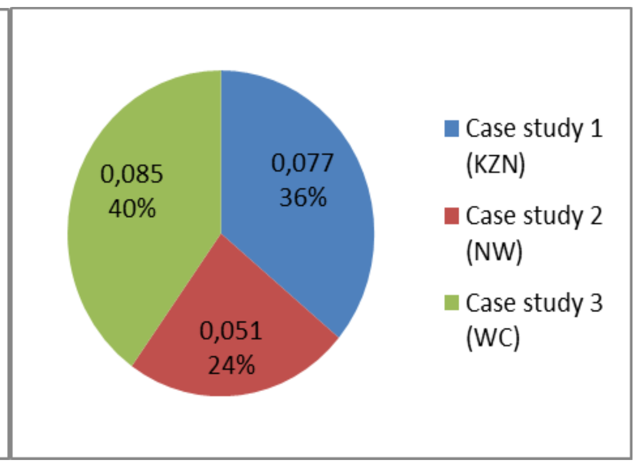


Figure 35: Relative GWP/FU of diesel use in the feed acquisition activity of the main feed components for three case studies

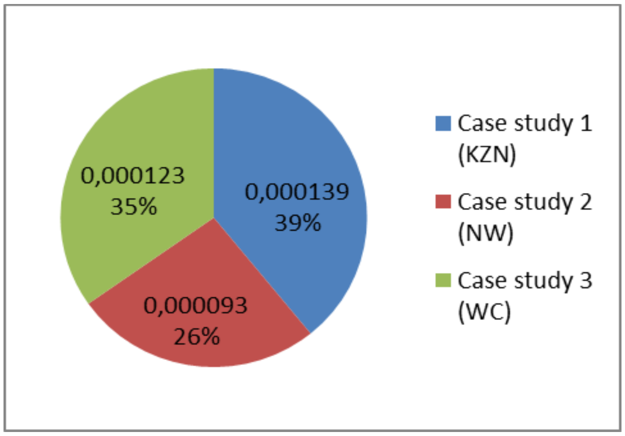


Figure 36: Relative EP per FU of diesel used in the feed acquisition activity of the main feed components for the three case studies

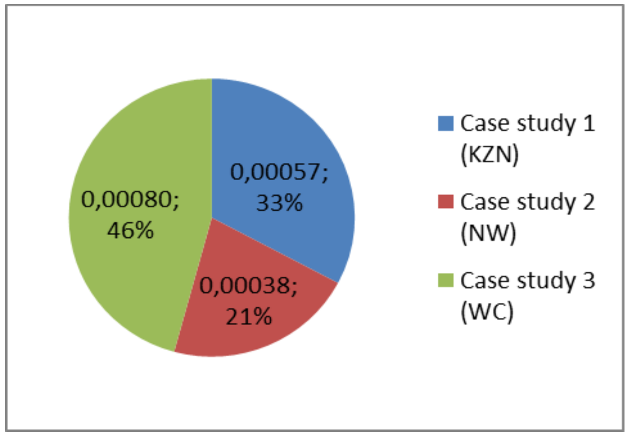


Figure 37: Relative AP per FU of diesel used in the main feed components for the three case studies

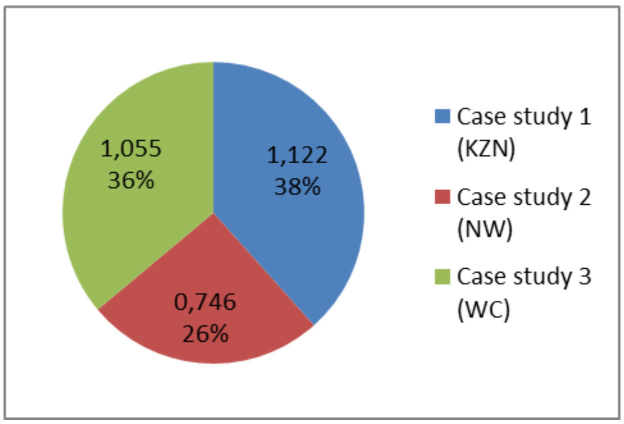


Figure 38: Relative EU per FU of diesel used in the feed acquisition activity of the main feed components for the three case studies

5.5.2 Financial and environmental comparison of the electricity input for the three case studies.

The previous section included the financial and environmental comparisons for the diesel input used for the acquisition of feed. This comparison was made for all three case studies. It included the GWP, EP, AP and EU impact categories. In this section, the financial and environmental performance comparison for the three case studies are made. In Table 32, the financial and environmental performance of the electricity input is detailed.

The farms in Case studies 1, 2 and 3 experienced an average yearly temperature of 16.32, 17.38 and 17.10 °C respectively. In the months between June and October, the farm in Case study 1 had a lowest temperature of 2.9 °C; in the same months, the farm in Case study 2 had a lowest temperature of -8.6 °C, and that of Case study 3 had a lowest temperature of 0.06 °C. The farm in Case study 2 used central heating in the piglet pen during the winter season. This indicates that the farm in Case study 2 would have used more energy in the winter season, to avoid piglet mortality, compared with the other two case studies.

5.5.2.1 Financial and global warming potential comparisons of the electricity input for the three case studies

Figure 39, illustrates the relative electricity expense per FU for each case study. Case study 1 had the lowest proportion of relative electricity expense per FU. Case study 2 had the highest electricity usage per FU. The reason for the high electricity usage in Case study 2 could be attributed to the added heating source for the piglets during the winter season. Detailed electricity data could not be obtained due to its confidentiality. In Figures 39 and 40, the electricity expense per FU is compared with GWP/FU. The differences in these two graphs results indicate to what extent the market for electricity can account for the environmental impact of its usage. The farm in Case study 1 had a 16 % proportion of electricity cost per FU of, and a relative GWP/FU of 12 %. That of Case study 2 had an electricity cost per FU of 42 %, and a share of relative GWP/FU of 36 %, while that of Case study 3 had a proportion of electricity cost per FU of 42 % and a relative share of GWP/FU of 52 %. The highest deviation among these comparisons was found for Case study 3.

5.5.2.2 Financial and eutrophication potential comparisons of the electricity input for the three case studies

Figure 41 illustrates the EP/FU of electricity usage for each case study. The highest EP/FU was generated by Case study 3, followed by those of Case studies 2 and 1 respectively. For Case study 1, the proportion of relative electricity expense per FU was 16 %; for Case study 2, it was 36 %; while for Case study 3 it was 52 %. The largest absolute difference between the financial and environmental performance among the three case studies was for Case study 3.

5.5.2.3 Financial and acidification potential comparisons of the electricity input for the three case studies

Figure 42 shows the relative AP/FU of electricity used for each case study. The relative share of AP/FU for Case study 1 was 16 %; for Case study 2, it was 36 %; while for Case study 3, it was 52 %. In Figure 39, the relative electricity expense of the three case studies is shown. The relative electricity expense per FU for Case study 1 was 16 %; for Case study 2, it was 42 %; and for Case study 3, it was 42 %. When comparing the relative financial and environmental shares, the largest deviation occurred for Case study 3.

5.5.2.4 Financial and energy use comparisons of the electricity input for the three case studies

Figures 43, shows the relative EU/FU of electricity used for each case study. The relative share of EU/FU for Case study 1 was 16 %; for Case study 2, it was 36 %; while for Case study 3, it was 52 %. When comparing the relative financial and environmental shares, the largest deviation occurred for Case study 3.

Table 32: Financial and environmental contribution of electricity usage for each case study

	Case study 1 (KZN)	Case study 2 (NW)	Case study 3 (WC)
Electricity expense (R)/FU	0.162	0.423	0.419
Relative share (%)	16	42	42
Electricity expense per year (R)	219 166	1 753 370	1 299 840
Relative share (%)	6	53	41
GWP of the electricity input/ FU	0.117	0.335	0.495
Relative share (%)	12	36	52
EP of electricity/FU	0.0000238	0.0000681	0.0001006
Relative share (%)	14	39	47
AP of electricity/FU	0.000185	0.000531	0.000784
Relative share (%)	14	39	47
EU of electricity/FU	1.83	5.23	7.74
Relative share (%)	14	39	47

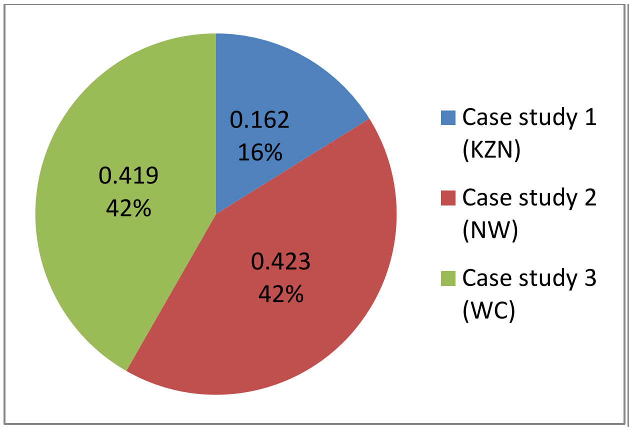


Figure 39: Relative electricity expense per FU for the three case studies

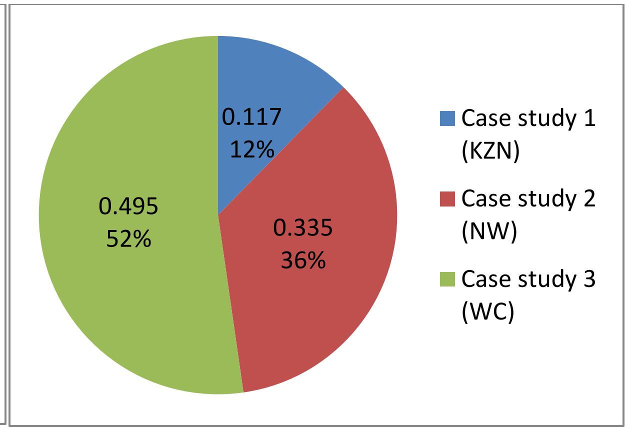


Figure 40: Relative GWP/FU of the electricity input for each case study

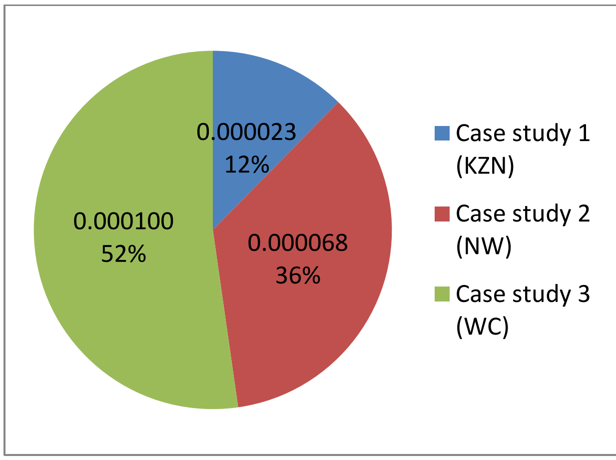


Figure 41: Relative EP of electricity input for each case study per FU

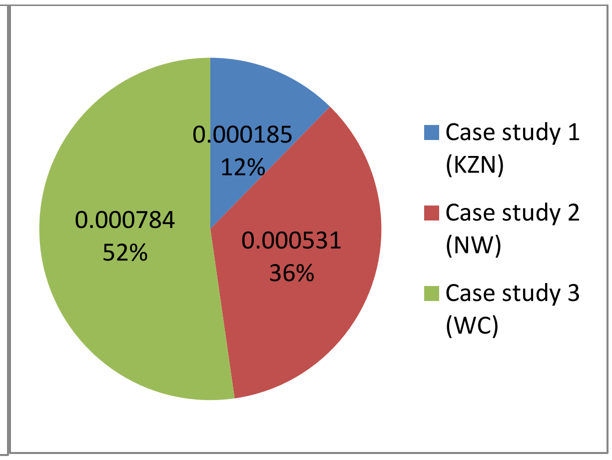


Figure 42: Relative AP per FU of the electricity input for each case study

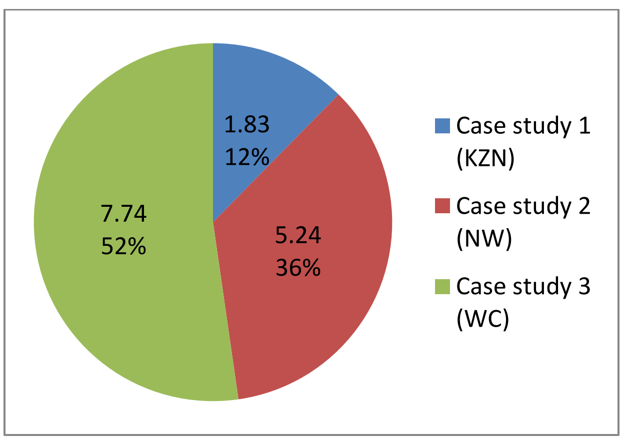


Figure 43: Relative EU/FU of the electricity input for each case study

5.6 Conclusion

The comparison of financial and environmental performance among the three case studies provides useful information with regard to the impact of the piggeries' location, and this relative to input sources. Only the diesel used to acquire the main feed components and the electricity used on the farm were used in the financial and environmental performance comparison. When all four of the impact categories were compared individually with the relative financial performance, the largest deviation occurred for Case study 3. When looking at the diesel input only, it could be said that Case study 3 had a location disadvantage for the environmental and financial impacts relative to the other case studies. The financial and environmental comparison of the electricity used on the farms also showed the largest deviation for Case study 3. The piggery in Case study 2 is located in a colder winter climate and used the most electricity, but the environmental impact categories did not indicate significant deviations. The financial and environmental performance for diesel and electricity gave useful information regarding the importance of the location of the piggery relative to the input sources, but these inputs contributed less than 10 % of the environmental impacts for all three case studies. The deviations between the environmental and financial impacts demonstrated that the financial figures alone could not be used as a proxy in accounting for the impacts of physical units. The LCA environmental accounting method, along with the financial performance, provides an accurate measure of impacts.

6 Conclusions

The aim of this study was to determine the energy balance and emissions of three pork farms, which serve as the case studies bases for the LCA. The three case studies were compared in terms of their energy balance and emission performance. The dominant factors and weak points in the various production chain segments were pointed out. In the LCA a model of the production chain was built, and the data for the case studies were modelled and converted into the FU of one kilogram of live-weight pig over a period of one year.

The GWP for Case study 3 is 8.4 % higher than for Case study 1; for Case study 3 it is 4.6 % higher than that for Case study 1. This was mainly because the piggery in Case study 1 used less electricity per FU than those of the other two case studies. The piggery in Case study 1 contributed 5.5 % and 9 % more EP than those in Case studies 2 and 3 respectively. This result was caused by the higher slurry production per FU of the piggery in Case study 1. The piggery in Case study 1 also delivered showed a 5.5 % and 6.1 % higher AP than did those in Case studies 2 and 3 respectively. This was also because the piggery in Case study 1 had produced more slurry per FU than those in the other two case studies. The results for the impact categories revealed the importance of the productivity of the sow herd and the slurry management activity.

This study found that acquiring and mixing the feed did not contribute the most to the environmental burden, as was initially considered to be the situation. The piggery in Case study 3 acquired its feed inputs from much further away than those in the other two case studies, but the feed acquisition activity accounted for only a minor environmental impact if the total life cycle is considered. It was found that slurry management and electricity usage contributed the most to the environmental impact categories selected for this study. From the inputs used on the farm, the electricity used was the most sensitive input for the impact categories selected for this study. The piggery in Case study 3 used considerably more electricity per FU than those in the other two case studies.

The slurry produced by the piggery is responsible for the highest environmental impacts per FU. Therefore, if the slurry management technique of the piggery could be managed to reduce the environmental impact, it would offset the impact of an environmentally unfavourable location. Slurry management appears to be the most important area where mitigation in South African pork production can be addressed. There are numerous technologies available to reduce the production of slurry and to capture the positive environmental contributions that it could make. In the three case studies, only some of the benefits to the environment were captured, namely, the application of slurry to the land and spraying runoff water onto animal pasture fields. In the European Union and United States of America, biogas from lagoons is captured to serve as fuel for generating electricity. A key environmental impact and financial mitigation strategy is to make use of better genetics. The results from this study thus confirmed that the feed conversion ratio is an important factor in intensive animal production practices. Differences are also reflected in the pre-weaning mortality among the three Case studies under study. For Case study 1, the pre-weaning mortality was 9.9 %; for Case study 2, it was 2.6 %; and for Case study 3, it was 4.7 %. If the farm in Case study 1 had achieved the same pre-weaning mortality as that of Case study 2, it would have produced the same amount of output (live-weight pigs) with 40 fewer sows (6.4 % of the herd size) per year. This would not only have saved on feed and transportation costs, but would also have reduced the slurry produced on the farm, as well the amount of water used, and the management input required.

The financial and environmental performance comparison for diesel and electricity used for the three case studies showed that the piggery in Case study 3 had a location disadvantage in terms of the amount of diesel used. This result was achieved because the piggery in Case study 3 is located further away from the main feed inputs compared with the locations for the other two case studies. With the impact categories evaluated in this study, it was found that the location of the pig farm does not have a significant impact on the environmental impacts. From the inputs used on the farm, the electricity used was the most sensitive for the selected impact categories. Further, it could be concluded that the production chain that produces the least slurry per FU will be the one with the best environmental performance, regardless of its location relative to production inputs in South Africa. All other variations in the environmental impacts among the three case studies could be inputs attributed to managerial differences, and not to the location of the piggery itself. From an environmental perspective, the choices relating to location and the acquisition of feed, therefore, are secondary to the slurry management, the slurry management infrastructure and the pig breeding programs. The efficiency of the slurry management technique holds the key to mitigating the environmental impacts for pork production. This study also found that the areas that have the highest potential to lower environmental impacts are usage of feed, slurry management and slurry utilisation.

Strategically, it would place less strain on the environment if the piggery were located close to the production area of the main feed inputs. However, the transportation of the feed accounts for only a minor portion of the environmental impacts in this gate-to-gate LCA. If the piggery is located close to other enterprises that can benefit from the fertilisation properties of the slurry, it will offset the environmental burden of acquiring the feed over large distances. The slurry management infrastructure is important for environmental mitigation. The slurry management infrastructure is the key to how efficiently the environmental benefits of the slurry can be captured. Investing in breeding technologies and feeding programs will also contribute to the efficiency of the pigs in gaining weight (FCR) and producing less slurry per FU. New technologies relating to electricity use and the heating of the piglets' pen can also have financial and environmental impact benefits. From a tactical point of view, therefore, a piggery that is already located in an area where the environmental impact of acquiring the feed is high can compensate by improving the herd performance with better genetics and by incorporating better technologies in its slurry management technique.

Not one of the piggeries in the three case studies selected for this study made use of biogas technologies. Numerous technologies exist for capturing the benefits from the biogas emitted from the slurry. In the EU the production of bioelectricity from biogas is a common practice in pork production. Using technology to lower the environmental impact of pig farming may be a financial burden at first, but if government enforces this, it can save the environment without any loss of production or disruption to the market. The amount of slurry produced per FU also can be lowered by using less water. This can be achieved by keeping the guttering system in good repair, using efficient water jets when cleaning the pig’s pen and avoiding spillage from drinkers. The ration of the pigs can also be manipulated for the pig to require less water; in this way less slurry is produced. Feed that contains more salt and crude protein will need more water for the pig. Separating clean water from slurry tanks will also decrease the amount of slurry that needs to be managed. In all three case studies, the nutrient-rich water that is separated from slurry is sprayed onto grazing pastures. The extent of the environmental impact will differ if the nutrient water is sprayed onto a concentrated area.

Recommendations

This study evaluated, in terms of the environmental impact categories selected, the impact of water usage in the production chain of each Case study. However, water usage did not contribute significantly as a factor among the impact categories. Therefore, the impact categories used in this study could not serve as a basis for comparing the environmental performance of water usage for the three case studies. It is recommended for future studies that a water footprint standard should be used to evaluate the environmental impact of water usage. In this regard, ISO 14046 (water footprint) was established only recently. ISO 14046 provides an opportunity for the water footprint to be assessed as a standalone study. This water footprint standard will aid in evaluating the impacts of water usage, make people aware of water usage, allow the sharing of knowledge and best practices with industries, and lead to more efficient water usage. Reckman et al. (2013:593) suggest that in order to provide a more holistic picture of the sustainability of the pork supply chain, more impact categories would be necessary. The additional impact categories include the following: land use, resource consumption, soil index and biodiversity. The bio diversity and land use indicators currently seem to be the most-discussed ones. Hence, it is recommended that more impact categories need to be used, namely land use, resource consumption, soil index and biodiversity. This will allow a true reflection of all the possible environmental impacts and will serve a basis for a more comprehensive comparison among production areas. A suggestion for avoiding the excess production of slurry is to lower the total usage of water by keeping the guttering in good repair.

It is also recommended that for future LCA studies on the environmental impact of pork production, a more in-depth focus will be needed on slurry management techniques, and a land-usage impact category will need to be added. The method used to calculate the amount of slurry produced per FU for each Case study in one year was based on assumptions. These assumptions include:

- 10 piglets per sow per birth
- The farm accommodates sows and raises piglets from birth up to 100 kg
- A slurry density of 1 029 kg/m^3

These assumptions did not accommodate for the differences among the three case studies. However, the slurry produced for each case study in a year was divided by that case study's amount of live-weight pig produced. Therefore, it is recommended that the quantity of slurry produced by a pork production facility needs to be established thoroughly and in depth.

While for Case Studies 1 and 2, the feed rations were similar, those for Case study 3 differed slightly. This LCA study accounted for the different feed rations for each Case study, up to the production of slurry. Where the environmental impacts of slurry management were quantified, the same composition of the slurry for all three case studies was used. However, since the feed rations differed slightly, it could be said that the composition of the slurry might differ as well; a different slurry composition could have a different impact on the environment.

Summary

1. Introduction

Intensive pork production systems traditionally have a poor image with the public because they are associated with environmental pollution. The public also tends to believe that organic farming practices are a ‘cleaner’ production method. The world demand for meat has led to the intensive production thereof. These production practices are placing heavy strain on the environment. No longer are animals grazing freely for food; we feed them in optimally controlled environments for profit maximising benefits, at the cost of the environment.

The aim of this study is to determine the energy balance and emissions (global warming potential, acidification potential, and eutrophication) for the three case studies. The case studies are of three typical South African pork production facilities. The life cycle under study included inputs from the acquisition of the feed up to the delivery of one kilogram of pig at the farm gate. The three farms are located in different areas in South Africa, namely the KwaZulu-Natal, North-West and Western Cape provinces. Life cycle assessment is an environmental accounting method used to quantify environmental impacts. This method was used in this study to quantify the environmental impacts of the three selected case studies. The relative contributions of the three case studies' financial and environmental performance will be compared. This comparison provides useful information on the importance of the location of the piggeries. The production of pigs entails a relatively efficient conversion of feed protein into meat products, but the efficiency of this conversion rate depends heavily on the type of feed used and the genetics of the pigs.

2. Life cycle assessment as an environmental impact assessment method

An increased awareness by the human race of the value of protecting the environment has led to developing various environmental impact-measuring methods. Life cycle assessment (LCA) is one of the methods that assist in quantifying environmental impacts and creating an awareness of

the resultant impacts caused by producing products and delivering services (ISO 14040, 2006:v). LCA has become a renowned methodology for considering environmental impacts. It is a biophysical accounting framework that can be used to characterise the material and energy flows of the different activities in a product's or service's life cycle. It also quantifies the contributions of the various activities to resource depletion and emission-related environmental impacts (Pelletier et al., 2010:600). LCA aims to express two types of environmental impacts during a product's life cycle, namely, the use of resources and the emissions emitted. The resources include (but are not limited to) land use, water use, energy use, and fossil fuels. The dominant polluted emissions include methane and ammonia, which contribute to climate change, eutrophication, and acidification, among other. (De Vries & de Boer, 2010:2). LCAs also induce more informed decision-making, which can be used for marketing advantages based on environmental performance.

The general framework of LCA includes the goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation of the results. The process of calculating the sum of all the costs related to the life cycle of a product is known as life cycle costing (LCC). The goal and scope definition is the first phase of LCA, where the definition of and reason for carrying out the study, the proposed audience, and whether or not the results of the study are to be used in comparative assertions need to be disclosed to the public (ISO 14044, 2006:7). ISO 14040 (2006:7) requires that the definition of the scope of a study include the product system, the functions of the product system, the functional unit (FU), the system boundaries, allocation procedures, data requirements, limitations and data quality specifications. The second phase of an LCA, the LCI, includes compiling and quantifying inputs and outputs for a given product system throughout its life cycle. These inputs and outputs may include the use of natural resources such as land, water and fossil fuels. The use of these resources may release emissions into the air, water and land associated with the system.

The third phase of an LCA is the LCIA. This phase aims to evaluate the importance of the potential environmental burdens. The LCIA also involves associating inventory data with specific environmental impact categories and category indicators, to clarify the impacts (ISO14040, 2006:14). The LCIA further entails limitations, for example, the limited characterisation models developed, setting the system boundaries, which may not encompass all possible unit processes for a product, and limitations on the collection of inventory data for each impact category (ISO 14040, 2006:15). The final phase of the LCA involves interpreting the results. In this phase of the LCA, the results from the inventory analysis and impact assessment are considered together, or in the case of LCI studies, the results of the inventory analysis only are considered. The interpretation phase must deliver results that are consistent with the goal and scope of the study.

For the purpose of this review, the life cycle is categorised in three stages, namely, the feed acquisition and mixing activity, the farming activity, and the post-production stage. An important part of the environmental impact of intensive pig production takes place outside the pig farm, and is related to the production, processing, transport, storage and mixing of the feed. Pork production depends heavily on concentrated feed ingredients. Due to climatic factors, not all the feed can be produced in the same area and must often be transported over great distances. Feed content for animal consumption generally includes cereals such as wheat, barley, soybean, maize and peas, which are not processed before being incorporated in the feed.

Within the farming activity, the pig housing, and manure and slurry management occur. According to the literature, key environmental mitigation possibilities occur in these segments of the production chain. The pig housing stage includes the way the pig's pen is designed, and how different technologies are incorporated to provide an optimal 'house' for the pig. This optimal house will differ from one production chain to another, due to climate, feed availability, water availability etc. Numerous heating and lighting technologies exist that can be incorporated to lower the energy demand in the farming process (Devers et al., 2012:126). For the pig farming activity, improvements can be made by limiting energy use with more efficient heating. Eutrophication is the main environmental impact resulting from the farming activity. The main contributor to eutrophication potential is the leaching of nitrogen from pig manure, ammonia emissions to the atmosphere, and phosphate leaching (Devers et al., 2012:118). Slurry is a mixture of the faeces, urine, strewing material, spilled feed and water, and water used for cleaning the pigpens (Hjorth et al., 2010:155). A concentration of animal production often comes with the excess production of manure on a small area. Slurry is produced in large amounts and has a high concentration of nutrients; hence the need to transport the nutrients from livestock farms with a nutrient surplus to arable farms with a nutrient deficit is high.

The postproduction activity includes processes like slaughtering, processing and packaging, cooling, transporting and distributing the product (pig meat). For this activity inputs like diesel for generating heat, electricity, fuel, water, packaging material etc. are used. The greatest relative differences among countries for the slaughterhouse and pig farming activities are due to differences in diesel composition and energy generation. The type and quality of the feed, as well as the genetics of the pigs also have a significant effect on the environmental performance of the pig production chain. Furthermore, better genetics will result in fewer inputs like feed, diesel, electricity, and water etc.

3. Materials and methods

For the purpose of this study, three typical pig-farming practices in South Africa were selected. Data from the three pig farming practices were collected in field trips for modelling purposes, in order to evaluate their environmental performance. All three case studies used typical production systems, except for Case study 2, which used an added heating source in the piglet's pen. This was required for the piggery of Case study 2 because of the low winter temperatures where the piggery in this case study is located. The farm in Case study 3 is located more than 1 000 kilometres from the production area of the main feed component of the pig's ration, namely maize. The unavailability of this input in the region of the subject of Case study 3 was substituted to some extent by other feed proteins in the region. Only 10 % of the maize was substituted with other feed inputs, and the rest of the maize was transported via truck over a distance of 1 200 kilometres. The slurry management technique for the three case studies was fairly similar, and typical of the slurry management systems used in South Africa. The technique used on the farms consists of a deep-pit slatted-floor system, with flush-channel management. The slurry is transported to a separating plant, where the liquid and solids are separated. It then flows into two storage dams. The first dam is an anaerobic dam, where the fermentation takes place. The second dam is an aerobic dam; the nitrogen rich water is stored in this dam. The liquids from the second dam are then used to irrigate grass fields for the grazing of sheep and cattle. The solids are transported to vegetable producers in the surrounding areas. In this section the LCI, or inventory of the LCA model, was collected and summarised. The following table provides a summary of the main production inputs and outputs for the three case studies.

These inputs were modelled in the Gabi LCA modelling software. This software translated the inputs into the selected environmental impact categories, global warming potential (GWP), eutrophication potential (EP), acidification potential (AP) and energy use (EU).

Inputs	Values			Unit of measure
	Case study 1	Case study 2	Case study 3	
Feed	3 741 000	11 494 000	8 160 000	Kg
Water	31 800 000	73 000 000	47 615 500	L
Electricity	113 000	1 412 000	1 624 800	Kwh
Fuel	24 000	48 000	45 300	L
Outputs				
Pigs (live-weight)	1 350 500	4 137 970	3 222 995	Kg
Slurry	17 764 000	50 703 000	36 236 000	Kg

4. Life cycle assessment results

The results for the total GWP of Case studies 1, 2 and 3 are 1.886, 1.964 and 2.059 kg of CO_2-eq /FU. This study found that the GWP for Case study 3 was 8.4 % and 4.6 % higher than that for Case studies 1 and 3 respectively. The electricity use for Case study 2 per FU was more than double that for Case study 1. For Case study 2, an added heating source was provided in the pig's pen when the piglets are born during the winter season. For Case study 3 maize was transported over large distances, which contributed to the greater GWP/FU. Slurry was the main contributor to EP in this study. Other studies that included producing feed found that feed production and slurry were the main contributors to EP and AP in the life cycle of pork production. The EP/FU for Case study 1 is 9 % and 6 % higher than that of Case studies 2 and 3 respectively. The most slurry per FU was produced for Case study 1. For Case studies 2 and 3, less slurry per FU was produced, and it achieved a lower EP/FU. The AP/FU for Case study 1 is 4 % and 5 % higher than for Case studies 2 and 3 respectively. More slurry per FU was produced for Case study 1 than for the other two Case studies, and therefore, it achieved the highest AP/FU. The EU/FU for Case study 3 was 52 % and 27 % higher than for Case studies 1 and 2 respectively. Electricity use was the main contributor to EU for this case study. For Case study 2, an added heating source was used in the piglet's pen, due to the colder winter temperatures. The reason for the higher electricity use per FU for Case study 3 was not disclosed.

A comparison between the relative environmental and financial performance of diesel and electricity was made. This was done to determine whether the market for these inputs functions correctly. Deviations occurred in the market for diesel usage in Case study 3, which indicates that the pig production facility in this case study had a location disadvantage compared with the other two case studies. The relative comparison of the financial and environmental performance for the electricity used in the three Case studies did not show significant results. The subject of Case study 2 clearly used more electricity per FU than those of the other two case studies, but the financial cost of the electricity was in line with the relative environmental impact. The comparison of relative financial and environmental performance did not yield significant results, because the inputs evaluated contribute only a small portion of the total environmental impact. The slurry management activity contributed by far the most to the environmental impacts. The production chain that produces the least slurry per FU will possibly be the production chain with the best environmental performance, regardless of its location relative to the South African production inputs.

5. Discussion of the life cycle assessment results

The relative contribution to GWP of the feed acquisition activities for Case studies 1, 2 and 3 was 0.80 %, 0.75 % and 3.43 % respectively. This contribution for the feed acquisition activity was smaller than was initially considered to be the situation. For Case study 3, there was a higher feed acquisition GWP. The higher GWP for the feed acquisition activity was mainly due to maize being transported approximately 1 200 km by road to the farm. The piggery in Case study 3 used 10 and 14 % less maize in its feed ration compared with Case studies 1 and 2. The results for the total EP for Case studies 1, 2 and 3 were 0.00343, 0.00323 and 0.00305 kg of PO_4-eq/FU respectively, in one year. The pig farming and feed-mixing and transportation activities were minor contributors to EP in a South African Case study. For Case studies 1, 2 and 3, the relative contributions to the EP of the slurry management activity were 95 %, 94 % and 91 % respectively. The results for AP for Case studies 1, 2 and 3 were 0.0155, 0.0147 and 0.0144 kg of SO_2-eq/FU respectively. A 6 % higher AP was generated for Case study 1 than for Case study 2, and a 10 % higher AP than for Case study 3. The major activity that contributed to AP in all three case studies was the slurry management activity. This activity accounted for 95 %, 94 % and 86 % of the total AP for Case studies 1, 2 and 3 respectively. The EU results for Case studies 1, 2 and 3 were 5.6, 8.4 and 11.7 MJ/FU. For Case study 3, EU was 52 % greater than that for Case study 1, and 27 % more than that for Case study 2. Electricity use contributed ± 60 %, and slurry management contributed ± 30 % to the total EU for all the three case studies. For the purpose of this comparison, no potential energy outputs were taken into account. In creating the model for the electricity, 100 % coal-combustion generation was taken as the reference. This is not the exact energy mix for South Africa, because other resources, apart from coal, are used to create electricity.

Evaluating the three selected case studies only on their environmental performance would not have indicated whether deviations among the relative monetary and environmental impacts had occurred. Sustainable production requires that the product's life cycle be economically viable, ecologically sound and socially acceptable for the present generation as well as for future generations. The differences among the case studies' contribution to relative financial and environmental impacts will depend on how efficiently the farms in the Case studies used inputs in the production process, where they are located relative to the input, the infrastructure at their disposal, the productivity of their sow herd, and the managerial properties of their managers.

All four of the impact categories were compared among the three case studies. The environmental and financial performance of the diesel and electricity inputs was used in this comparison. It was found that Case study 3 had a relative location disadvantage when looking only at the diesel input. The financial and environmental comparison of the electricity used on the farms showed the largest deviation for Case study 3. The farm in Case study 2 used the most electricity, which is located in a colder winter climate, but the environmental impact categories did not indicate significant deviations. While the financial and environmental performance for diesel and electricity gave useful information regarding the importance of the location of the piggery relative to the input sources, these inputs contributed less than 10 % of the LCA's environmental impacts in all three case studies.

6. Conclusions

This study found that the acquisition and mixing of feed did not represent the environmental burden that was initially thought to be the case. For Case study 3 the feed inputs were acquired over much greater distances than for the other two case studies, yet the feed acquisition activity accounted for only a minor environmental impact if the total life cycle is considered. It was found that slurry management and electricity usage contributed the most to the environmental impact categories selected for this study. Of the inputs used on the farm, electricity usage was the most sensitive for the impact categories selected for this study. Further, it can be concluded that the production chain that produces the least slurry per FU will be the production chain with the best environmental performance, regardless of the location of the production facility relative to the South African production inputs. All other variations in the environmental impacts among the three case studies is inputs that can be attributed to managerial differences, and not to the location of the piggery itself.

7. Recommendations

It is recommended for future that more impact categories be used, namely land use, resource consumption, soil index and biodiversity. This will allow a true reflection of all the possible environmental impacts and will serve as the basis for a more comprehensive comparison among production areas. Suggestions to avoid producing excess slurry are to lower the total usage of water by keeping the guttering in good repair. It is also recommended that for future studies a water footprint standard be used to evaluate the environmental impact of water usage. ISO 14046, water footprint, was only recently established. It provides an opportunity for the water footprint to be assessed as a standalone study. This standard will aid in evaluating the impacts of water usage, making people aware of water usage, sharing knowledge and best practices with industries, and will lead to more efficient water usage.

References

Baitz, M., Colodel, C.M., Kupfer, T., Florin, J., Schuller, O., Hassel, F., Kokborg, M., Kohler, A., Thylmann, D., Stoffregen, A., Scholl, S., Gorke, J & Rudolf, M. 2013. *Gabi Database & Modelling Principles*. Pe-International: Leinfelden.

Basset-Mens, C. & Van der Werf, H.M.G. 2005. Scenario-based environmental assessment of farming systems: the case of pig production in France. *Agriculture, Ecosystems and Environment* 105(1):127-144.

Bureau for Food and Agricultural Policy (BFAP). 2013. Evaluating the South African Pork Value Chain. A report by BFAP for the South African Pork Producers Organisation. Pretoria: University of Pretoria.

Baumann, H. & Tillman, A.M. 2004. The Hitch Hiker's Guide to LCA – An orientation in life cycle analysis assessment methodology and application. Lund: Sweden.

Beauchemin, K.A., Janzen H.H., Little S.M., McAllister, T.A. & McGinn, S.M. 2010. Life cycle assessment of greenhouse gas emissions from beef production in western Canada: A case study. *Agricultural Systems*, 103(1):371-379.

Beltran, H., Aparicio, N. & Belenguer, E. 2014. Renewable Electric Generation in a Pig's Farm. Energy from biomass. [Online]. Available: http://www.icrepq.com/icrepq07/214-%20Beltran.pdf [2014, July 16].

Canh, T.T., Aarnink, A.J.A., Schutte, J.B., Sutton, A., Langhout, D.J. & Verstegen, M.W.A. 1998. Dietary protein affects nitrogen excretion and ammonia emission from slurry of growing–finishing pigs. *Livestock Production Science,* 56(1):181-191.

Cederberg, C. & Flysjö, A. 2004. Environmental assessment of future pig farming systems – quantifications of three scenarios. *The Swedish institute for food and biotechnology,* SKI Report nr. 723.

Chen, Y., Cheng, J.J. & Creamer K.S. 2008. Inhibition of anaerobic digestion process: A review. *Bioresource Technology,* 99(1):4044-4064.

Da Silva, V.P., Van der Werf, H.M.G., Soares, S.R. & Corson, M.S. 2014. Environmental impacts of French and Brazilian broiler chicken production scenarios: An LCA approach. *Journal of Environmental Management,* 133(1):222-231.

Davies, T. 2014. Evaluating the competitiveness of South African pork production within the global context - first annual progress report on the Agribenchmark project" Unpublished report by the Bureau for Food and Agricultural Policy for the South African Pork Producers Organisation (2014)"

Devers, L., Kleynhans, T.E. & Mathijs, E. 2012. Comparative Life Cycle Assessment of Flemish and Western Cape Pork Production. *Agrekon,* 51(4):105-128.

De Vries, M. & De Boer, I.J.M. 2010. Comparing environmental impacts for livestock products: A review of life cycle assessments. *Livestock Science,* 128(1):1-11.

Dolman, M.A., Vrolijk, H.C.J. & de Boer, I.J.M. 2012. Exploring variation in economic, environmental and societal performance among Dutch fattening pig farms. *Livestock Science*, 149 (1):143-154.

Fry, J. & Kingston, C. 2009. Life cycle assessment of pork. *Environmental research management.* August 2009.

Gabi, 2009. Handbook to Explain LCA Using the GaBi EDU Software Package. Pe International. [Online] Available: http://isites.harvard.edu/fs/docs/icb.topic636070.files/GaBi%20EDU%20handbook%20-%20v1.pdf/ [2014, June 6].

Gabi, 2014. Handbook for Life Cycle Assessment (LCA). Using GaBi Education software package. Pe International. [Online]. Available: http://www.gabi-software.com/South Africa/support/gabi-learning-center/gabi-6-learning-center/part-1-lca-and-introduction-to-gabi/ [2014, July 15].

Glucha, P. & Baumann, H. 2004. The life cycle costing (LCC) approach: a conceptual discussion of its usefulness for environmental decision-making. *Building and Environment*, 39(1):571-580.

Guerci, M., Bava, L., Zucali, M. Sandrucci, A., Penati, C. & Tamburini, A. 2013. Effect of farming strategies on environmental impact of intensive dairy farms in Italy. *Journal of Dairy Research.* 80(1):300-308.

Gyetvai, Z. 2012. Operational guidance for the life cycle assessment studies of the energy efficient buildings initiative. [Online]. Available: http://www.eebguide.eu/?p=1241 [2014, July 26].

Halberg, N., Van der Werf, H.M.G., Basset-Mens, C., Dalgaard, R. & De Boer, I.J.M. 2005. Environmental assessment tools for the evaluation and improvement of European livestock production systems. *Livestock Production Science*, 96(1):33-50.

Hjorth, M., Christensen, K.V., Christensen, M.L. & Sommer, S.G. 2010. Solid-liquid separation of animal slurry in theory and practice. A review. *Agronomy for Sustainable Development*, 30(1):153-180.

Holm-Nielsen, J.B., Seadi, T.A. & Oleskowicz-Popiel, P. 2009. The future of anaerobic digestion and biogas utilization. *Bio Resource Technology*, 100(1):5478-5484.

ISO 14040 (2006) ISO 14040 International Standard. *Environmental management-life cycle assessment-principles and framework.* Geneva/Switzerland, International Organisation for Standardisation (ISO).

ISO 14044 (2006) ISO 14044 International Standard. *environmental management-life cycle assessment-requirements and guidelines*. Geneva/Switzerland, International Organisation for Standardisation (ISO).

Koketsu, Y. & Dial, G.D. 1996. Factors influencing the post weaning reproductive performance of sows on commercial farms. *Minnesota Agricultural Experimental Station, REPO.*

Kupper, T., Bürge, D., Bachmann, H.J., Güsewell, S. & Mayer, J. 2014. Heavy metals in source-separated compost and digestates. *Waste Management*, 34(1):867-874.

Lammers, P.J. 2011. Life-cycle of farrow to finish pig production systems: A review. *CAB Reviews*, 6(26):1-8.

Lopez-Ridaura, S., Van Der Werf, H., Paillat, J.M. & Le Bris, B. 2009. Environmental evaluation of transfer and treatment of excess pig slurry by life cycle assessment. *Journal of Environmental Management*, 90(1):1296-1304.

Luo, L., Van der Voet, E. & Huppes, G. 2009. Life cycle assessment and life cycle costing of bioethanol from sugarcane in Brazil. *Renewable and Sustainable Energy Reviews*, 13(1):1613-1619.

Moller, H.B., Lund, I. & Sommer, S.G. 2000. Solid-liquid separation of livestock slurry: Efficiency and cost. *Bio resource Technology*, 74(1):223-229.

Nguyen, T.L.T., Hermansen, J.E. & Mogensen, L. 2012. Environmental costs of meat production: the case of typical EU pork production. *Journal of Cleaner Production*, 28(1):168-176.

O'Connell, M.S. 1997. *A study of the management factors affecting pig manure dry matter content, the implications for its efficiency of nitrogen utilisation for grass silage production and an approach to estimating its nutrient concentration*. Unpublished master's dissertation. Dublin: National University of Ireland.

Olea, P. 2009. Analysis of Sustainability in the Pig Production Chain: Life Cycle Assessment of Contrasting Scenarios. Unpublished doctoral dissertation. Newcastle: New Castle University.

Petersen, S.O., Sommer, S.G., Béline, F., Burton, C., Dach, J., Dourmad, J.Y., Leip, A., Misselbrook, T., Nicholson, F., Poulsen, H.D., Provolo, G., Sørensen, P., Vinnerås, B., Weiske, A., Bernal, M.P., Böhm, R., Juhász, C. & Mihelic, R. 2007. Recycling of livestock manure: A whole-farm perspective. *Livestock Science*, 112(1):180-191.

Pelletier, N., Pirog, R. & Rasmussen, R. 2010. Comparative life cycle environmental impacts of three beef production strategies in the Upper Midwestern United States. *Agricultural Systems*, 103(1):380-389.

Pelletier, N. 2008. Environmental performance in the US broiler poultry sector: Life cycle energy use and greenhouse gas, ozone depleting, acidifying and eutrophying emissions. *Agricultural Systems*, (1):67-73.

Pelletier, N., Lammers, P., Stender, D. & Pirog, R. 2010. Life cycle assessment of high- and low-profitability commodity and deep-bedded niche swine production systems in the Upper Midwestern United States. *Agriculture Systems*, 103(1):599-608.

Pindyck, R.S & Rubinfeld, D.L. 2009. *Microeconomics.* New Jersey: Pearson Prentice Hall.

Popovic, O., Hjorth, M. & Jensen, L.S. 2012. Phosphorus, copper and zinc in solid and liquid fractions from full-scale and laboratory-separated pig slurry. *Environmental Technology*, 33(18): 2119-2131.

Portrjoie, S., Dourmad, J., Martinez, J & Lebreton, Y. 2004. Effect of lowering dietary crude protein on nitrogen excretion, manure composition and ammonia emission from fattening pigs. *Livestock Production Science,* 91(1):45-55.

Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., Schmidt, W.P., Suh, S., Weideman, B.P. & Pennington, D.W. 2004. Life cycle assessment Part 1: Framework, goal and scope definition, inventory analysis, and applications. *Environment International*, 30(1):701-720.

Reckmann, K., Krieter, J. & Traulsen, I. 2012. Environmental Impact Assessment – Methodology with special emphasis on European pork production. *Journal of Environmental Management,* 107(1):102-109.

Reckmann, K., Krieter, J. & Traulsen, I. 2013. Life cycle assessment of pork production: A data inventory for the case of Germany. *Livestock Science,* 157(1):586-596.

Roy, P., Orikasa, T., Thammawong, M., Nakamura, N., Xu, Q. & Shiina, T. 2012. Life cycle of meats: An opportunity to abate the greenhouse gas emission from meat industry in Japan. *Journal of environmental Management*, 93(1):218-224.

Stone, J.J., Dollarhide, C.R., Benning J.L., Carlson, C.G. & Clay, D.E. 2012. The life cycle impacts of feed for modern grow-finish Northern Great Plains US swine production. *Agricultural Systems*, 106(1):1-10.

Suh, S. & Huppes, G. 2005. Methods for Life Cycle Inventory of a product. *Journal of Cleaner Production*, 13(1):687-697.

Teira-Esmatges, M.R., Babot, D., Boixadera, J. & Garcia-Ventosa, P. 2010. Generated amount and composition of pig slurry and poultry manure: a field study. [Online]. Available: http://www.ramiran.net/ramiran2010/docs/Ramiran2010_0238_final.pdf [2014, July 23].

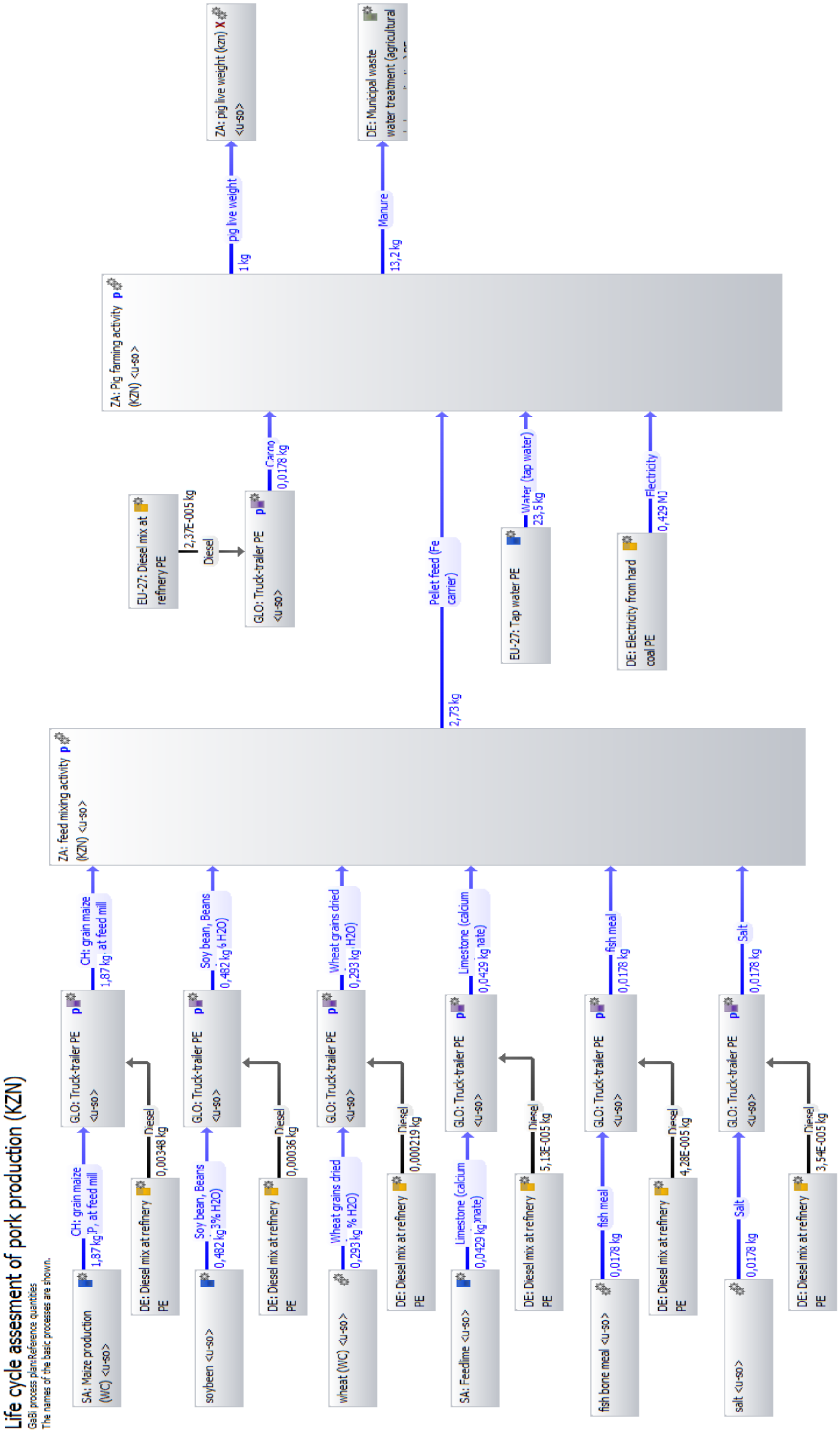
Von Doderer, C.C.C. 2012. Determining sustainable lignocellulosic bioenergy systems in the Cape Winelands District Municipality, South Africa. Published doctoral dissertation. Stellenbosch: University of Stellenbosch.

Wegener Sleeswijk, A., Kleijn R., Van Zeijts, H., Reus, J.A.W.A., Van Onna, M.J.G., Leneman, H. & Sengers, H.H.W.J.M. 1996. *Application of LCA to Agricultural products*. Leiden: Leiden, Centre of Environmental Science, Leiden University (CML).

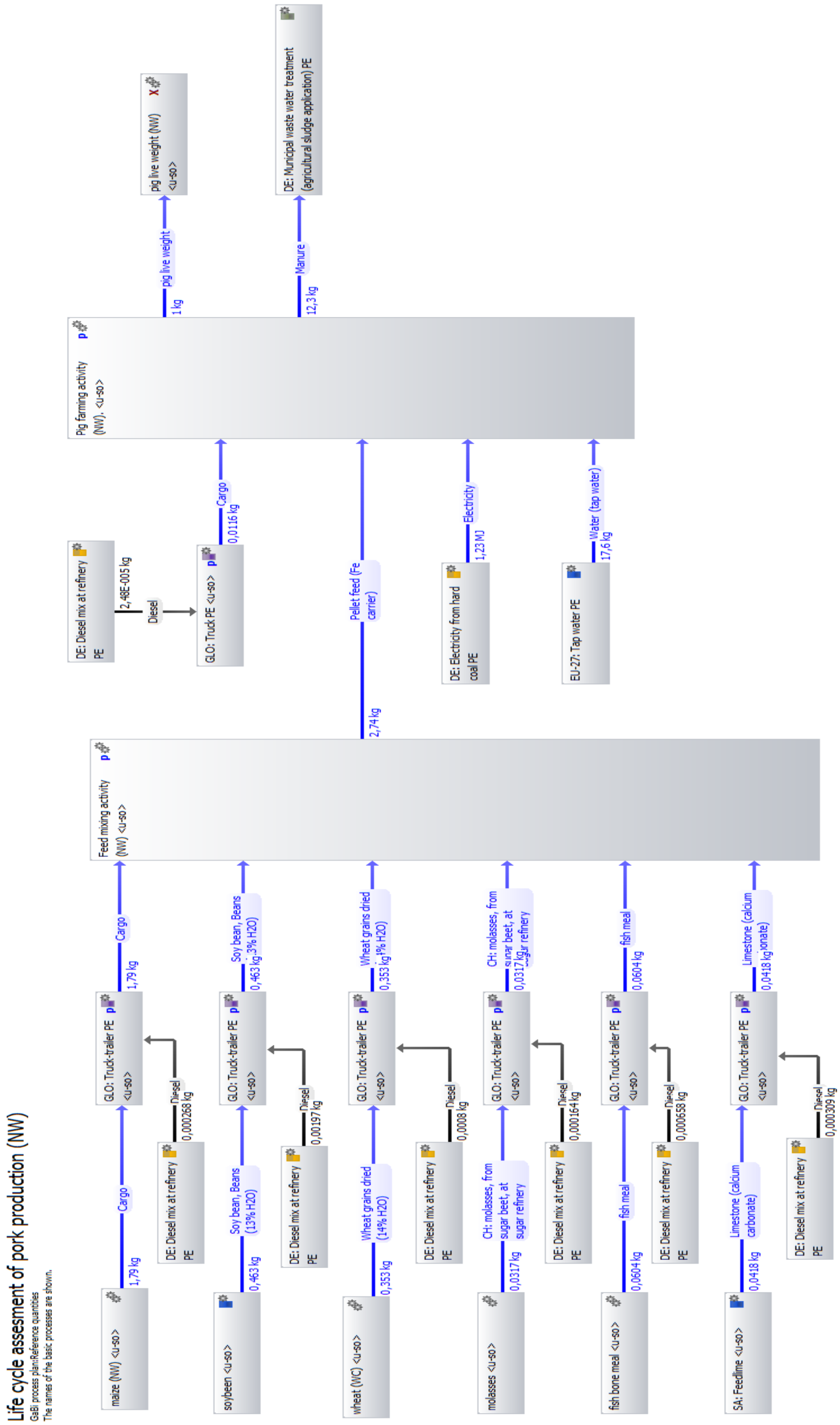
Woodward, D.G. 1997. Life cycle costing theory, information acquisition and application. *International Journal of Project Management*, 15(6):335-344.

Annexures:

Annexure 1 KwaZulu-Natal LCA model



Annexure 2: North-West LCA model



Annexure 3: Western Cape LCA model