The University Of Southern Queensland
Faculty of Engineering and Surveying

Life Cycle Assessment of the Production of Raw Milk

A dissertation submitted by

Simon Thomas Charles ORPHANT

In fulfilment of the requirements of

Courses ENG4111 and ENG4112 Research Project

Towards the degree of

Bachelor of Engineering (Agricultural)

Submitted: October, 2004

Abstract

The environmental impacts and the sustainable development of agricultural activities have been identified as a significant national issue. This has led to many techniques in quantifying the impact of agricultural activities on the surrounding environment. One such technique used is Life Cycle Assessment (LCA). This project presents an initial assessment of the life cycle environmental impacts of a simple dairy farm in Southeast Queensland, Australia, using the most appropriate software (SimaPro5.1).

Recently, the perception of environmental management has shifted away from the prescriptive approach of fixing a problem after it has occurred. This change in attitude has led to the development of the preventative approach. This involves stoping the system before it causes impact. LCA has been created for the specific application of testing and comparing systems to find the best outcome for the environment. The methodology involves four steps: Defining the Goal and Scope of the Assessment, Life Cycle Inventory Analysis, Life Cycle Impact Assessment and Life Cycle Interpretation.

PRé Consultants based in the Netherlands produced the Life Cycle Assessment software SimaPro5.1. The assessment program was originally used for assessing and comparing industrial systems. In the late 90's SimaPro was adapted for the use on agricultural systems. This has led to much research into the agricultural industries in Australia. Most research has found the need for updated Australian databases in the program so that results are quantified with respect to Australia.

The scope of this project was only looking at the effects of the agricultural system. Thus, the model was setup to show the effects of producing one litre of milk at the farm gate. Results have indicated that the major impacts to the environment occur during the pasture production phase. The impact during the pasture production phase is largely due to the usage of fertilizers and the irrigation pump being driven by electricity. Other substantial impacts in the system were the environmental impact to climate change produced by methane outputs from the cow.

University of Southern Queensland

Faculty of Engineering and Surveying

ENG4111 & ENG4112 *Research Project*

Limitations of Use

Prof G Baker
Dean
Faculty of Engineering and Surveying

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Simon Thomas Charles ORPHANT

Student Number: q11215630

____

Signature

____

Date

Acknowledgements

I would like to thank Dr. Guangnan Chen for his assistance, guidance, encouragement and especially his enthusiasm in the topic through to completion of this project.

I would also like to acknowledge the support and assistance in gathering data of the Department of Primary Industries & Fisheries Mutdapily Research Station that has been tremendous throughout this project. The particular assistance from Sarah Kenman and Robert Chataway has been greatly appreciated.

I would also like to acknowledge the Faculty of Engineering and Surveying of the University of Southern Queensland. The faculties help with acquiring an extended licence for the Life Cycle Assessment software has been greatly appreciated.

Table of Contents

List of Appendices

List of Figures

List of Tables

List of Plates

CHAPTER 1
Introduction

1 Introduction

Dairy farming has been an integral part of many small communities since Australia was settled. This has led to many years of successful dairy farming with increased cow production levels and growing cow numbers. Many farms in the early days of Australia started off as dairy farms or part of their income came from dairy farming. However, as new ventures came along the smaller dairies disappeared and average dairy heard numbers have increased.

The dairying industry has enjoyed the benefits of a regulated market. This means that farmers knew for certain the returns that they would receive for a given quota of milk. Since deregulation occurred in 1999 the dairy industry has found increased pressure under the constraints of a more competitive market, as has occurred in many other agricultural industries. The deregulation has led to a change in the industry to larger farms and improvements in the overall operations of farms using more intensive farming methods. This change to more intensive operations has brought forth increased criticism from the public sector. Unfortunately, this criticism is supported and amplified by the close proximity of many dairy farms to areas were there are high population densities.

The criticism has led to the development of many assessment techniques to quantify environmental impacts. One such technique is Life Cycle Assessment (LCA). This LCA is an environmental management tool, which evaluates the product and its processes throughout the whole life cycle. This tool has been around for many years, being used in the assessment of industrial situations. After seeing the benefits of the assessment technique it has been modified to accommodate complex agricultural systems and thus can now be applied to the agricultural sector.

The Life Cycle Assessment methodology gives the dairy industry the ability to assess the environmental damage incurred from their raw milk production systems. This ability to assess and quantify environmental impacts of agricultural systems will lead to the ability of eco-labelling. Eco-labelling of products in the agricultural industry will open up specialised markets for goods, thus allowing consumers to choose which good they purchase based on those foods with smallest environmental impacts.

This project aims to produce an outline of the Life Cycle Assessment (LCA) methodology and also to set up an initial working model to confirm the feasibility of the applications of LCA method in Australia's dairy industry.

The objectives undertaken to complete this project were:

1. Research previous Life Cycle Assessment studies done on Milk production Activities.
2. Research the Life Cycle Assessment methodology and the software package used in its undertaking.
3. Define the goal and scope of the Life Cycle Assessment of a Limited Irrigation pasture based dairy herd.
4. Collect data needed for the Life Cycle Assessment (from DPI&F Mutdapily Research Station and other sources). Check data for uncertainties and data gaps that need to be filled.
5. Set up a basic model to confirm the "feasibility" of the method, and to characterize the environmental impact of a typical representative farm. The model should produce sensible results in comparison with other studies.
6. Add other processes into the analysis model.
7. Carry out model sensitivity analyses.
8. Identify and evaluate opportunities for farm improvements.

A copy of the project specification is presented in Appendix A.

This project is being undertaken with the guidance of supervisor Dr Guangnan Chen and with the help of the Mutdapily Research Station. The project has been undertaken to create a basis for continuing research to be completed in this area at the University of Southern Queensland.

CHAPTER 2
Background

2 Background

Dairy farming plays a major role in rural Australia. When the dairy farming industry first began in Australia, it was the sustaining force of many communities and was the main income of most farming enterprises. For example, many farms in the Gympie area started as dairies and then shifted focus to other enterprises as opportunities came forth. The agricultural industry has gone through many changes throughout Australia's history and there is now a tendency towards environmental accountability. This has led to the need for a tool to quantify environmental impact of the agricultural sector. The following section provides a background of the dairy industry, a brief history of Life Cycle Assessment (LCA) and an in depth literature review of previous studies into LCA of dairy farms.

2.1 Milk Industry

Plate 2.1: From 'Grass to Milk' (www.dairyaustralia.com.au)

The milk industry is known simply to many people as the production of milk into bottles. However, we can expand on the basic knowledge of milk production, with respect to the agricultural production phase of milk. The essential factor in the 'grass to milk' phase is the cow. The following diagram shows the digestive system of the cow and the udder that produces the milk.

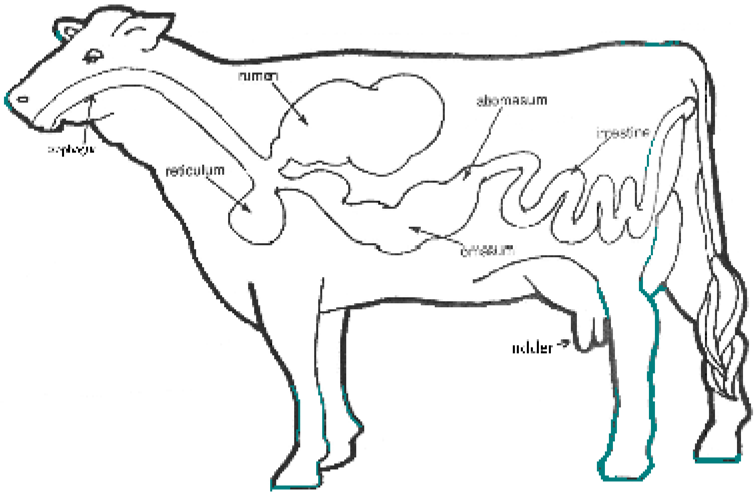


Figure 2.1: The Digestive System of a Dairy Cow (www.umass.edu)

The cow consumes pasture, water and other supplements. This food then passes through to the rumen of the cow. The rumen of the cow can hold up to 100 litres of food, and its function is to mix the food and only partial digestion occurs here. The mixture then passes through to the reticulum where the food is broken into smaller pieces. The smaller pieces pass through to the next chamber while larger clumps are regurgitated back to the mouth for re-chewing. Once pieces are small enough to pass through the reticulum the food then gets passed onto the omasum where water is absorbed into the blood stream. The mixture then passes into the final chamber, the abomasum, from which the food can enter the intestines. The intestines then remove all the nutrients available into the blood stream. The udder is supplied with these nutrients through the blood system and milk is produced. It usually takes around 50-70 hours to produce milk after the ingestion of green grass. Methane is produced as a by-product of the digestive process. Solid waste and urine are also waste products of this process.

The dominant breed in Australian dairy farms is the Holstein-Friesian cow. It accounts for approximately 70 per cent of all dairy cattle in Australia (seen in Plate 2.1). The milk that the cow produces can be milked by a number of different types of mechanised milking systems that are available. One such machine is illustrated in Plate 2.2 below. This milk is then piped to holding tanks where it is refrigerated until it is transported to factories for further processing and bottling. In this study however, the agricultural system is being investigated. Therefore, only the system up to and including the refrigeration of the milk on farm is being studied.

Plate 2.2: Milking Shed in action (www.ruralskills.com.au)

Mutdapily Research Station have currently characterised Australian dairy systems into five broad categories. They are currently researching these systems to optimise the performance and now desire to observe if Life Cycle Assessment can possibly be integrated into their trial dairy systems to improve the environmental aspects in parallel with increasing profitability. The five types of milk production systems as characterised by the DPI&F are as follows:

1. Dry land rain grown tropical pastures
2. Limited irrigation pastures (rain grown tropical pastures and a small component of annual ryegrass)
3. Limited irrigation crops (forage crops plus a small component of annual ryegrass)
4. High irrigation (predominately irrigated annual/perennial temperature pastures and summer forage crops)
5. Intensively grown feedlot (based on home-grown irrigated silage, Lucerne hay and purchased concentrates)

As previously stated, dairy farming is important to Australia. This industry employs many people and supplies plenty of high quality milk. The industry has had great profitability over many years; particularly when it enjoyed regulated prices and farmers knew the returns they would be receiving. Since deregulation (1999) has been implemented, the dairy industry has followed other agricultural industries, and has experienced increasing pressures in a competitive market. This has led to a change in the industry resulting in larger herd numbers and improvements in the overall operations of farms using more intensive farming methods. The effects of deregulation can be seen through the decline in Australian dairy farm numbers over the past two decades. In 1980 there were 22,000 farms. However, by 2003 fewer than 11,000 remain. The following table shows changes in the total stock numbers and the improvements in cow production that occurred from 1980 until 2003.

Table 2.1: Figures on the Dairy Industry (www.dairyaustralia.com.au)

	1980	**2003**
Milk Produced per Cow	2,850 litres/year	4,800 litres/year
Number of Cows	1.88 million	2.095 million
Milk Production per Year	5.358 billion litres	10.056 billion litres

The dairy industry is confined to a reasonably small area situated relatively close to urban areas. This close proximity to high population areas (shown in Figure 2.2) has led to close scrutiny from the urban community because of their environmental concerns regarding dairy systems.

Figure 2.2: Concentrations of Dairy Farms in Australia (www.agriculture.gov.au)

The major concerns of the public with the dairy industry include the large water usage (Table 2.2), cow methane output and the relatively intensive nature of dairy farming. These two conflicts of interest, that is, the interests of the public and the dairy industry, have brought forward the idea of sustainable agricultural activities. From this idea a large quantity of various management systems have been developed to control environmental impacts, whilst still producing sufficient amounts of saleable milk.

Table 2.2: Annual returns to water and intensity of water use (www.agriculture.gov.au)

Table 1: Annual returns to water and intensity of water use (PFE 1997/97)*

Land use	Water returns$/m	Total water use Gl	% of total water use	Water use ML/ha
Vegateables	1295	392	2.6	3
Fruit	1276	665	4.4	7
Tobacco	985	13	0.1	4
Grapes	600	781	5.2	8
Tree nuts	507	140	0.9	6
Cotton	452	2314	15.5	7
Coarse grains	116	518	3.5	3
Dairy	94	5902	39.5	7
Peanuts	90	25	0.2	3
Hay	54	20	0.1	4
Rice	31	1696	11.3	11
Legumes	24	33	0.2	3
Sheep	23	13	0.1	4
Sugar cane	21	1195	8.0	7
Beef	14	1080	7.2	4
Oilseeds	10	85	0.6	3
Cereals	-9	87	0.6	3
All irrigated land uses	**193**	**14,959**	**100.0**	**7**

* Derived from estimates of mean water use per land use type in each region

2.2 Life Cycle Assessment

Life Cycle Assessment (LCA) is an evaluation tool available to aid in the decision making process. It is an internationally recognized method for compiling and assessing environmental information for particular products. This tool, when coupled with good management strategies, has been found to increase profits and lessen environmental impacts. This project is essentially a pilot study into the ability of LCA methodology to be adapted to assessing agricultural systems.

The concept of Life Cycle Assessment was first produced to quantify impacts of industrial situations. The largely software based assessment came about from the need to continuously improve industrial systems both economically and environmentally. After the benefits became evident in the industrial industries the methodology branched into other areas such as the agricultural industry. The process of changing this software to assess agricultural systems has been difficult and this difficulty has arisen from the complex nature of agricultural systems. It is also compounded by the fact that there is limited data available to create substantial assessment libraries

LCA as defined by the Society of Environmental Toxicology and Chemistry (SETAC) as:

> "A process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment, to assess the impact of those energy and material uses and releases to the environment; and to identify and evaluate opportunities to effect environmental improvements. The assessment includes the entire life-cycle of the product, process, activity, encompassing extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance; recycling and final disposal."

This new assessment methodology was set out by SETAC and four international standards of ISO14040, ISO14041, ISO14042 and ISO14043. Designing a methodology around international standards produces an internationally accepted assessment tool. The inclusion of international criteria also creates an international standard on which to base future Life Cycle Assessments.

LCA is achieved by identifying and profiling all the resources (energy, land, water and other materials) used and all wastes released to the environment during the whole life cycle. The Life Cycle Assessment Methodology follows a four-step system. The simple diagram below best shows these steps.

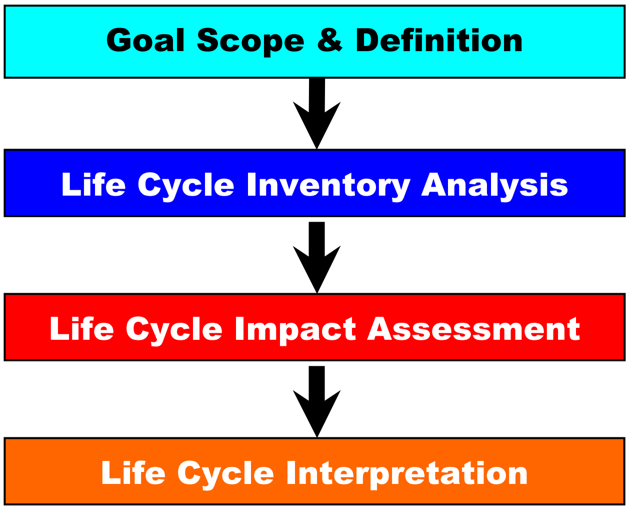


Figure 2.3: Life Cycle Assessment Methodology

Briefly the steps include: Step 1- Definition of what will be assessed; Step 2- Analysis of all materials used and waste products produced; Step 3- Assessment of all impacts using impact indicators; and finally Step 4- Determination of what is shown by the assessment and what needs to be improved? (For further information regards methodology, refer to Section 3.2 page 19 "Life Cycle Assessment Methodology".)

Step 3 and 4 of this assessment methodology is software based. SimaPro5.1 is the software used in this project. It is a widely used and respected LCA software program from the Netherlands. There are twenty or more different software packages available. These software packages vary in price and quality. The range includes free versions, with little calculation capacity, extending to full versions, worth a substantial amount.

Current research typically focuses only on one or two single aspects of environmental impacts, for example greenhouse gas emissions. However, LCA has the advantage of providing a rigorous, comprehensive and multi-dimensional analysis of all relevant factors. These include the influences of:

- Energy usage
- Greenhouse gas emissions
- Land salinisation
- Acid rain
- Waste and toxic releases
- Natural resource depletion
- Human health

LCA is therefore a very useful and powerful tool for the evaluation of environmental impacts of complex systems. This includes systems such as agricultural activities like dairy farming. A comprehensive LCA gives the advantage of being able to determine the magnitude of potential decreases of environmental impacts in each environmental category if changes were made to the system. It also avoids the difficulties of researching the impact of only one environmental category at a time, as currently occurs in many research projects.

2.3 Literature Review

This review entails the comprehensive examination of previous studies relevant to the Life Cycle Assessment of Raw Milk Production. It outlines the reasons for doing this project, show what has been done by previous studies and what needs to be done in the future. The following paragraphs discuss the essential points of "Benefits of LCA", "Current Research" and "Current Research Gaps".

2.3.1 Benefits of LCA

The primary objective of the dairy industry is to generate the largest quantities of milk to an accepted standard. This milk is produced from the feed, the cows and the obtainable resources. In order to achieve their objective, the dairy industry has made advancements in per-cow production levels and production methods. There has been little recognition of the impact on the environment that this resource usage in the production system has had. However, quantification of this impact is necessary in order to maintain industry standards and help promote a clean image.

As stated by Hamilton *et al*: 'Modern society now demands a "preventative" approach to environmental management rather than a "prescriptive" approach'. This has lead to two main concepts in sustainable farming methods. The first is stated by Hamilton *et al*: 'The national strategy for Ecological Sustainable Development defines ESD as development, which aims to meet the needs of Australians today while conserving our ecosystems for the benefit of future generations'. The other main concept, as stated by van Berkel, is the theory of improving the Eco-Efficiency of supply chains. ANZECC (1999) defines Eco-Efficiency which entails "The delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's estimated carrying capacity".

Essentially, today's farmers have the expectation that they have to look after their land for the future while still producing an acceptable product for today's consumers. This incorporates that the landholder must manage their operation in a manner that is sustainable to the soil and water resources. They must also avoid damaging the downstream environment. With respect to the main concepts of sustainable development, both Hamilton *et al* (2000) and van Berkel (2002) have come to the conclusion, that Life Cycle Assessment is an emerging technology for supporting the implementation of ESD and Eco-Efficiency.

The benefit of using Life Cycle Assessment is best stated by Hamilton *et al* (2000). She states: 'LCA is designed to prevent rather than control or treat environmental damage by providing useful information on production processes while, at the same time, offering cost saving through improved resource management.' Thus, the reason for implementing the Life Cycle Assessment Methodology is because of the significant environmental impact the industry produces and the potential benefits that LCA can have on this impact.

To further complicate the situation of dairy farms, the industry is confined to a small part of Australia that is frequently visited by the urban community. This means that the environmental impacts of the milk production phase at farm level will be under close scrutiny from the greater population. Hamilton *et al* (2000) states: 'It is therefore imperative that South Queensland dairy farmers implement better environmental management and using a tool such as life cycle assessment may ensure that these impacts are minimised or kept to a sustainable level.' There have been substantial benefits gained from using LCA in other industries. The benefits gained by the usage of LCA in the dairy industry can be, for example, ongoing environmental improvements, which would potentially improve their image. Thus, it is of great benefit to adapt this technology to the struggling agricultural enterprise of dairy farming.

2.3.2 Current Research

Numerous studies into milk production have been done using the LCA methodology in many countries overseas. These include studies into areas comparing and assessing organic and conventional milk production and also assessment of Galician milk production. Cederberg *et al* (2000), when comparing organic to conventional milk production in Sweden, concluded, "This study shows that a low-input agricultural system such as organic milk production, has obvious environmental benefits." They found the biggest benefit came from the reduction of pesticide and fertilizer use. Their functional unit was 1000kg of energy corrected milk leaving the farm gate.

Imke J.M. de boer (2003) assessed the impact of conventional and organic milk production. The functional unit of 1000kg of milk leaving the farm gate was also used. This study concluded global warming was largely caused by methane emissions. The usage of large amounts of fertilizer was also found to produce large impact in the assessment of the conventional dairy system compared to that found in the organic system.

Hospido *et al* (2002) assessed a simplified Galician milk production system. The functional unit of this assessment was one litre of packaged milk ready to be delivered to the customer. Due to poor information, this assessment did not include any pesticides use in the system. However, there was inclusion of an allocation to meat production of 13% whilst 87% remained with milk production and the cream co-product was disregarded. Hospido *et al* (2002) concluded that the raw milk production phase was a crucial impact in the assessment as well packaging manufacture contributed significant impact. Major impacts from the raw milk production came from the production of animal foods.

Whilst there are many LCA's of dairy systems overseas, limited assessments have been completed on Australian milk production. Hamilton *et al* (2000) conducted a study titled "The LCA of a Dairy Farming System in South Queensland". However, at this time there was little data on Australian conditions. The assessment was done on milk production from cradle to milk powder and was completed on SimaPro4.0. The following figure is an output from this study.

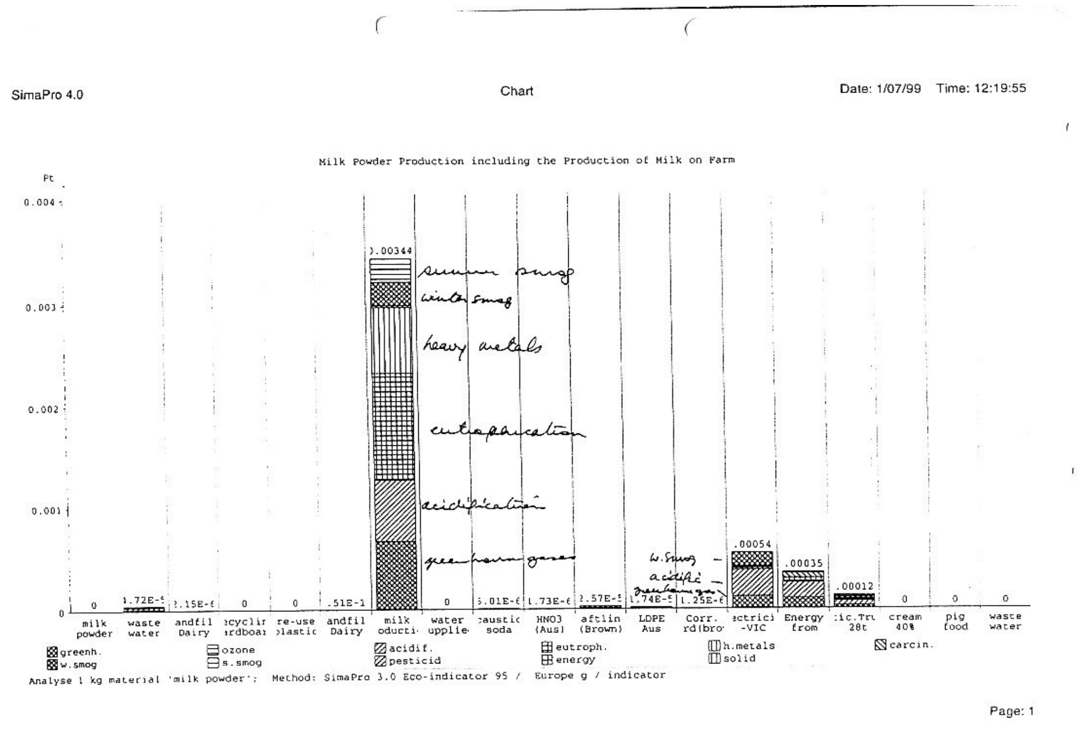


Figure 2.4: Assessment of Milk Powder Production (Amanda Hamilton et al, 2000)

The results illustrated that milk production (the tallest bar on graph) was a large cause of greenhouse gases, acidification, eutrophication, heavy metals, winter smog and summer smog. The milk production section included the pasture production phase that first produced the milk. This study concluded the pasture production phase is the foremost contributor to increased levels of greenhouse gases, acidification, eutrophication, heavy metals, energy usage and solid waste production. It also found that the transportation of farm inputs and milk were the most important contributor to winter smog.

2.3.3 Current Research Gaps

There is little Australian LCA data on dairy farms and current research only involves LCA of cradle to milk powder production. Therefore there is a need for a Life Cycle Assessment on the production of raw milk. If an assessment was done on this area of raw milk production to farm gate, evidence of potential improvements could be easily found. This would illustrate the major impacts associated with raw milk production and help raise awareness of problems with current techniques.

The main problem that has occurred in past research of this methodology is the fact that with any software based assessment good data is needed to produce good results. With the previous lack of data in Australia there has been trouble trying to produce meaningful results using data that was not suited to our conditions. Because of the databases that are being created for this software for Australian conditions, this project will produce results relating more to the Australian situation. There is also an opportunity to continue this development of databases in Australian conditions and also to investigate how international data might be applied to Australian systems.

Hamilton *et al* (2000) reported there were suspected problems with the SimaPro4.0 software version, as stated: 'The software was unable to model the hay, silage and feed grain components of the production system and it is unclear whether Sima Pro 4.0 was able to model an effluent pond waste management and recycling system.' The new program that is available (SimaPro5.1) has a greater ability than the old version. This fact, coupled with the updated Australian databases this should produce a concise result for Australian conditions.

This project has been created to see if the LCA methodology can be used by the mainstream dairy industry to assess the milk production phase to farm gate. This means that the research is centred on the agricultural system and producing the milk in a sustainable way while still maintaining profits. With this new software and Australian databases this project will be able to model the whole agricultural dairy system. The potential for improvement in any agricultural enterprise with the use of this assessment methodology is endless. These may include improving materials and resource usage. This potential is supported by the many industrial situations that have benefited already from its use.

CHAPTER 3

Research Methodology

3 Research Methodology

3.1 Objectives & Methodology

The aim of this project is to produce an outline of the Life Cycle Assessment (LCA) methodology and set up an initial working LCA model. The main research objective of this investigation is to study the potential of adopting the LCA method to the Australian diary industry. This will be undertaken by characterising the environmental impact of a representative farm using one particular farming method. The study will then identify the potential improvements of the farming operations in order to discover the optimum use of all resources required in the farming operation.

The methodology followed in this project entailed an extensive literature review of previous Life Cycle Assessment studies done on agricultural production systems. This review gave good background knowledge of starting points for this project and also highlighted previous failings of the methodology used on previous projects. Possible ways of simplifying the study were also found that decreased the complexity of the large agricultural system to a smaller model that produces similar results. The review also showed past results in a similar area of study. This helped in validating this study's outcomes when compared to previous study's findings.

A comprehensive study of the Life Cycle Assessment methodology and the SimaPro5.1 software package used was also undertaken. This increased the understanding of LCA methodology with respect to its applications in the SimaPro5.1 software. Thus, the chances of understanding how the software works was increased and improved results could be achieved. This understanding also helped in comprehending the results produced by the software and led to better diagnosis of the impacts of the system.

Once the methodology study had been completed the actual assessment was started. This included defining the goal and scope of the Life Cycle Assessment of a simple dairy farming enterprise. The scope of this particular project entailed only the agricultural system therefore, we focused on 'cradle to farm gate'. This process also sets up a functional unit, that is, simply a reference unit for the whole study and the criteria for data quality.

At this stage we had a large amount of interest from the Department of Primary Industries & Fisheries (DPI&F) Mutdapily Research Station. The interest shown from Mutdapily in addition to the availability of quality data led to the study of a dairy system based on the Mutdapily limited irrigation pasture research farm.

The creation of a running model using data from previous studies or reference material available was the next step. During this period, extra aspects of the dairy system were included, as time permitted. This was completed in order to produce a reasonable model of the limited irrigation production system. The additions involved the inclusion of the application systems for the fertilizer of a tractor and a transport truck. The reason that this model was produced without using new data (readily available from the DPI&F Research Station) was because the main objective was to produce a running model. After this running model was established, the correct data was simply substituted to produce a relevant result for Australian conditions. Once the model had been produced the results were compared with other studies to see if they were sensible.

Since time permitted a model sensitivity analyses was carried out to find if any small variations in inputs completely changed the trends shown by the model. The sensitivity analysis was carried out on the electricity generation types. The results shown by this analysis gave the ability to suggest opportunities for improvement in the studied agricultural system. Time was not available to include other complex aspects in the basic dairy model such as pesticides or waste treatment. The timeline for completion of each of these objectives is located in Appendix B of this report.

3.2 Life Cycle Assessment Methodology

The methodology used in assessing this agricultural system is Life Cycle Assessment (LCA). This methodology is a widely accepted multidimensional assessment strategy used for quantifying environmental impact in any production system. This section will provide an in depth understanding of the LCA methodology. The following subsections will follow through each of the four steps of the LCA methodology. The following figure is another representation of the LCA methodology.

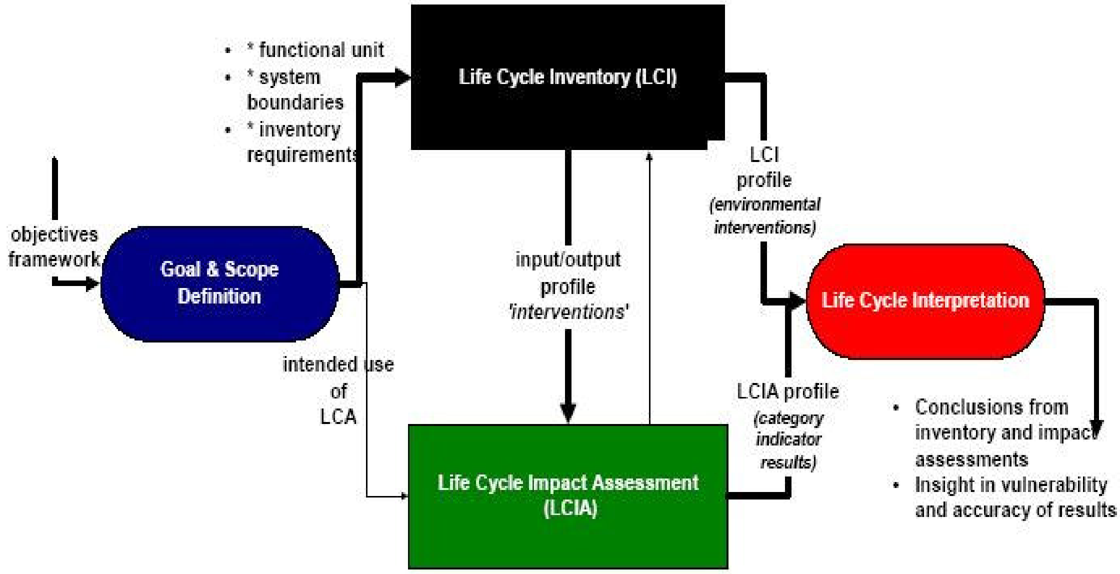


Figure 3.1: Modified LCA structure from ISO 1997a (Rene van Berkel, 2002)

3.2.1 Goal and Scope Definition

This first step is essentially for planning purposes so it can be clearly stated what the study entails. In this section the main statements that are made are that of defining the goal and the scope. The goal and scope also identifies the functional unit. This unit will become the reference unit for the whole study. This will be the denominator used to measure all environmental inputs and outputs for the entire assessment. The goal of the assessment should clearly define the reasons for carrying out the study. It should also define the intended application of the study and outline the target audience. The defining of the scope entails the descriptions of the boundaries of the study and the limitations, if any.

Once the goal and scope definition has been completed various parameters of the study will be defined. These include the life cycle stages, environmental impact categories, aims and context of the LCA to be performed. In summary this initial step produces a blueprint of the context in which the LCA will be completed. The following table gives the goal and scope definition for an LCA of Queensland Wheat Starch production as an example of the function of this step.

Table 3.1: Example of Goal and Scope Definition for LCA of Queensland Wheat Starch (Rene van Berkel, 2002)

Goal	▪ To identify key environmental impacts in the wheat starch life cycle ▪ To measure environmental performance ▪ To identify environmental performance improvement opportunities in starch production
Target group	Starch production company & policy makers
Questions answered	▪ What is the environmental profile of wheat starch? ▪ Whether LCA can be used to identify and improve company environmental performance?
Functional unit	One kilogram of starch as most starch application and end uses are on a mass basis.
Allocation rule	No allocation was considered, as it was not economically viable to make co-products without producing starch.
Life cycle stages studied	Crop cultivation, crop storage, flour milling, transportation, starch production, and starch end-use
Study boundaries	▪ All above stages plus intermittent transportation (road, rail and sea). ▪ Greater emphasis on starch production. ▪ Electricity from 100% black coal assumed
Items excluded from the study	▪ Buildings, equipment and machinery ▪ Life cycle of farm inputs ▪ Packaging of powdered starch
Impacts considered	▪ Global warming potential ▪ Acidification potential ▪ Eutrophication potential ▪ Aquatic oxygen depletion potential
Lifecycle evaluation	Quantitative wherever emissions data were available and qualitative wherever data were unavailable or time consuming to gather.

3.2.2 Life Cycle Inventory

The Life Cycle Inventory (LCI) section of the LCA methodology is essentially the collection of data. This includes data collection for inputs and outputs of the production system throughout its life cycle. During this stage all data is collected within the boundaries stated in the goal and scope definition. It is also collected with respect to the functional unit since this is the reference for the entire study. Data types collected during this stage range from the man made materials to natural resources used. They also include the environmental releases such as air and solid waste emissions. In the Life Cycle Inventory (LCI) the collected data is then manipulated into a form that can be entered into a software package such as SimaPro5.1. The data is then entered into the software package and the Life Cycle Impact Assessment can be undertaken. The following table gives an example of the LCI of the wheat crop cultivation stage for the production of the functional unit of 1kg of wheat starch.

Table 3.2: Example of LCI of Wheat Crop Cultivation as Part of LCA of Queensland Wheat Starch (Rene van Berkel, 2002)

Wheat crop cultivation	
Parameters	*Per 1 kg of starch*
Environmental Inputs	
Gasoline (litre)	0.03
Diesel (litre)	0.03
Electricity (Wh)	140
Energy used in Transportation (kJ)	163
Nitrogen (g)	50
Phosphorous (g)	20
Insecticides (g)	0.7
Herbicides (g)	5
Resource Energy (MJ_{heat})	4.25
Some Environmental Outputs	
Emissions from fossil fuel combustion	
Carbon dioxide - CO_2 (g)	260
Carbon monoxide - CO (g)	13
Nitrogen oxides - NO_X (g)	1.8
Sulphur dioxide - SO_2 (g)	0.061
Volatile Organic Chemicals - VOC (g)	3.7
Emissions due to electricity use	
CO_2 (g)	164
CO (g)	0.02
NO_X (g)	0.662
SO_2 (g)	0.402

3.2.3 Life Cycle Impact Assessment

The diagram following gives a graphical representation of the Life Cycle Impact Assessment (LCIA) stage. This figure shows the mandatory steps of the LCIA according to ISO 14042 and the optional elements depending on the specific requirements of the study.

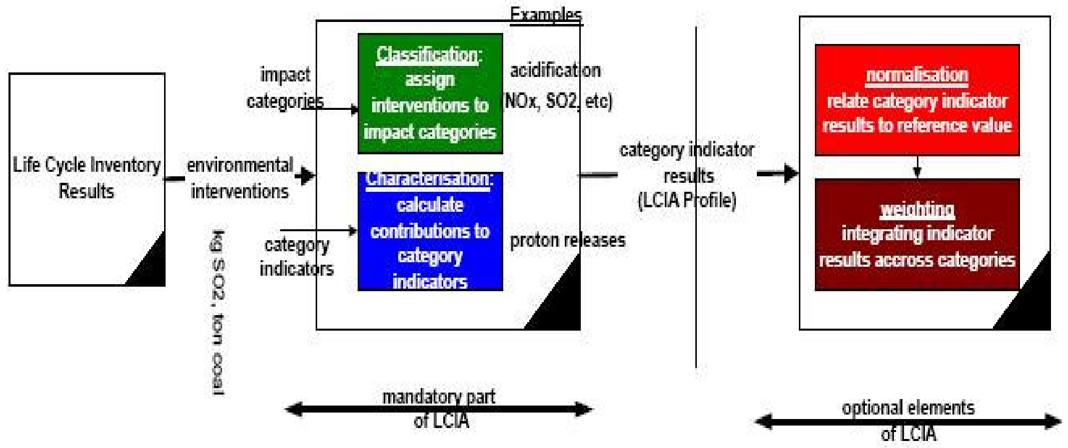


Figure 3.2: Structure of the Life Cycle Impact Assessment (ISO 14042)

The Life Cycle Impact Assessment is undertaken after the data from the Life Cycle Inventory has been entered in the software package. This step aims to examine the product system from an environmental perspective by using impact categories and category indicators. Essentially this step calculates the likely environmental effects of the material consumption and environmental releases identified during the inventory analysis.

In relation to SimaPro5.1, this stage can calculate the environmental impacts using one of a variety of eco-indicators. Eco-indicators are "damage oriented" impact assessment methods for LCA. This means that the environmental impacts are assessed by damages to ecosystem quality. In SimaPro5.1 the damages are expressed as the percentage of species disappearing in a certain area due to the environmental load.

The eco-indicator used depends on the impact categories wanting to be assessed. Therefore, the reasons for assessment and the system being assessed in this life cycle assessment determine the eco-indicator used since they also define the impact categories. The indicators can assess categories in the following areas:

- Human Health:
  - Radiation, Smog, Carcinogens, Climate Change, Ozone Layer, Noise
- Eco System:
  - Acidification, Eutrophication, Eco-toxicity, Land Use
- Resources:
  - Minerals, Fossil Fuels

There are several eco-indicators available for use however all have their failings. The following indicators are included in the LCA software. The CML 92 eco-indicator assesses all the above categories however, does not include land use, noise and models fine particles poorly. Similarly, the Eco-indicator 95 assesses most categories except land use, fossil fuels depletion and noise. The Eco-indicator 99 categorises all of the above except noise. Finally, EPS 2000 assesses all categories, however sometimes this is completed in a poor manner. From this wide range if different eco-indicators it is apparent that there is an indicator specialised for every situation depending upon the specific area of focus.

The software also has the ability to allocate damages produced from a co-product of the system. This allows the assessment of systems that create two products at once. For example, in the milking system to farm gate, a cow produces milk for 300days and then dries-off to produce a calf so it can produce milk again. This is a natural phenomenon encountered in the dairy industry to enable the cows to lactate for 300 days of each year.

The software is very useful in this stage to produce graphs and network trees showing the unique environmental impacts. SimaPro5.1 has many graphs available to illustrate the impacts of the life cycle. Depending on the information needed, the graph choice is crucial to produce an understanding of the program outputs. The network trees available of the life cycle are also very helpful to show the impact flow to produce the item being assessed. There is also a section in Appendix C "Simon's Tips to Learn SimaPro5.1", which outlines useful ways of inputting data into the program.

The first step the software undertakes in the Life Cycle Impact Assessment phase is the classification of the life cycle inventory into relevant impact categories. The assessment graphs used in this report include single score, normalisation, characterisation and process contribution. These four assessment types produce a very comprehensive understanding of large impact areas and contribution analysis.

Single Score assessment is a similar version of the weighted assessment and it determines the impact of each single process in a particular production phase. This assessment technique is controversial due to the fact that each impact category effects the environment in a magnitude of different ways. Therefore, it is hard to quantify these impacts on one scale that is totalled for each process. In the past this caused a many problems. However, in eco-indicator 99 these problems have been reduced and/or solved. As a result, the eco-indicator 99 assessment technique produces a good illustration of the process that creates the highest total of environmental impact.

Normalisation is the technique by which the impacts from each process are grouped into each impact category. This procedure illustrates to what extent an impact category has contributed to the overall environmental problem. It serves two processes. Firstly, it allows identification and elimination of the impact categories that contribute a very little to the overall environmental problem and secondly, it illustrates the order of magnitude of the environmental impacts generated in the system.

Characterisation assessment classifies the processes into impact categories and shows the relative share each process has on each impact category. This gives the ability to see the process that creates the most impact within each category. This is especially beneficial since the impact from one particular process can be hard to determine from other assessment graphs, due to the fact that the graphs have small sized bars and can be difficult to interpret the relative impact share.

Process Contribution is an important tool in understanding the contribution of each process to the overall impact. With this assessment technique it can easily be determined which process contributes the most to the environmental impact. This contribution analysis can be done using the single score assessment or by using many impact categories. If the many impact categories option is used, parameters such as climate change and fossil fuels depletion can be assessed separately. Most LCAs contain several hundreds of different processes. However, often there are only about ten major processes that contribute to 95-99% of the total impact for the system. Thus, Process Contribution is indeed a useful tool.

3.2.4 Life Cycle Interpretation

The final step of the Life Cycle Assessment Methodology deals with understanding the structure of the results produced by the software as a result of the completion of the LCIA stage. It also includes interpretation of these results. This process allows determination of the areas of environmental concern. Interpretation is carried out with reference to the assessment areas developed in the goal and scope definition phase.

This interaction with the first step allows determination of the impacts can be linked to the assumptions made and methods used in the previous phases. This might have an effect on the overall assessment outcome. Finally, the effects of interactions from cut-off decisions, allocation rules, selected impact categories, impact indicators and characterisation models can be assessed.

A commonly used method for identifying significant environmental issues is the division of the results into several relevant categories. These categories include the inventory data category (energy or waste), impact category (greenhouse gas emissions or eco-toxicity) or life cycle stages (process contribution to total life cycle environmental impacts). However, depending on the eco-indicator used, these impact categories vary.

When starting this stage, the important interpretation is whether the LCIA results from direct or indirect effects. Direct effects result from foreground processes, examples of which include processing, energy and waste management. Indirect effects occur from background processes, such as, materials and resources used, which create a flow on effect. Therefore, indirect effects can be decreased by lowering the required usage of materials and resources, while direct effects can only be reduced by innovation or increased efficiencies within the process.

CHAPTER 4
Life Cycle Analysis

4 Life Cycle Analysis

The following chapter is the Life Cycle Analysis. It includes the Goal and Scope Definition phase and the Life cycle Inventory phase of the Life Cycle Methodology in particular reference to the specific steps undertaken in this project. The final steps, Life Cycle Impact Assessment and Life Cycle Interpretation, follow in subsequent chapters. This Life Cycle Analysis entails the explanation of the first two stages of the LCA methodology that were completed in this assessment. It includes all definitions, data sources, limitations, and problems found. The undertaking of these steps will provide essential background to understand where the results of the assessment have arisen.

4.1 Goal & Scope Definition

The Goal of this project is to set up an initial working model to confirm the feasibility of the applications of the LCA method in the Australian Dairy Industry, and therefore, allow the environmental loads of dairy farms to be shown. This has led to the scope of this assessment being limited to the agricultural system. Thus, production of milk is only followed to the farm gate. The initial model will be basic and will only contain the essentials for a basic farming enterprise. The model can then be increased in complexity as time permits.

The functional unit for this Life Cycle Assessment will be the production of ONE litre of raw milk at the farm gate. The milk bottling companies will then buy this off the farmer. The particular functional unit chosen was the best option because most people can easily quantify one litre of milk. This functional unit is much better compared to other studies that use one tonne of saleable milk, which is a large figure not quantified easily.

After completion of the literature review on this topic, it was evident that there would be limitations to getting results in the time available. This led to the construction of a hypothetical dairy farm situated at Gympie, QLD. This construction was completed with help from the Department of Primary Industries & Fisheries (DPI&F) Mutdapily Research Station. The system was based off the limited irrigation pasture dairy herd they are currently researching. A farm in this high rainfall environment is reasonably simple and consists of a pasture-based diet for the cows. This hypothetical dairy was a small farm consisting of 50 hectares with 100 cows. Other limitations imposed by time restrictions included:

- No use of pesticides or medicines
- No use of supplements such as grain
- No allocation for co-product of a calf per cow each year
- No waste treatment or recycling

As can be seen from the above limitations, the hypothetical farm was simplified to create an initial working model. With updating of the agricultural libraries in the SimaPro5.1 program, some of these limitations may be easily entered. However, in the absence of these inputs in the data libraries in the current program, making an entry that takes these into account would be a project in itself.

The next step was to select libraries for the assessment. There are various different libraries available in the program, however, only some are relevant to this project. In this case only the Australian data set was chosen. This led to the selection of the 'Australian Data Inventories' and the 'Methods' libraries. The selection of the 'Methods' library, in addition to those relevant for Australian data, was undertaken to allow the option of choosing any available eco-indicator.

The final step undertaken was to select the data quality requirements. This grades the data available to give an indication of how relevant the data is to the specific project requirements. The data quality requirements allow selection of options such as geography, type, allocation and system boundaries. Options selected included:

- Geography:
    - Australia, 2004
- Type:
    - Technology: Average & Modern
    - Representativeness: Average of specific processes or similar processes
- Allocation:
    - At this stage was not applicable- no co-product or waste treatment
- System Boundaries:
    - Cut-off rules: < 5% of physical, socio economic and environmental

- System Boundary: First, Second and Third order
- Boundary With Nature: Agriculture is part of the production system

Geography requirement is the selection of the area and time the study is being done. The Type requirement includes the technology used in the system and the representativeness of this technology. It allows the use of the data that is most representative for the assessment. Allocation requirement takes into account the instances where co-product and waste treatment calculations may be used; however, they were not required in this project due to the limitations imposed.

The first of the System Boundaries is Cut-off rules for tracking of impacts. This was a simple study therefore, < 5% cut-off was sufficient. The system boundaries also comprise the first, second and third order System Boundary. These indicate the calculation depth. In this study only first order (materials) and second order (processing and transport) are required, while third order (capital goods) have not been included. Boundary With Nature is the final section of System boundary. The dairy farm system will be modelled as a production system. This allows us to model the factor of land use. This implies that that the impact of land-use will be taken into account. This particular modelling method is also useful in including impacts from the fertilizer substances leaching deeper into soil and water, or those that evaporate.

Another important choice in this step is selection the eco-indicator to be used when calculating the environmental impact. It is important to choose the correct indicator for the specific application. This is because there can be differences in assessment results depending on the eco-indicator used. After an examination of the types of eco-indicators available, an indicator was chosen that was widely used and accepted, which would also assess the milk production system successfully. This led to the selection of 'eco-indicator 99 E/A'. This indicator calculates and characterizes the environmental damages and resource. It does this from the egalitarian perspective (long term impacts) and is adjusted by average weighting method.

The environmental impact categories considered by eco-indicator 99 E/A include:

1. Resources: fossil fuels, land and mineral use
2. Ecological Quality: climate change, acidification/eutrophication, radiation, eco-toxicity
3. Human Health: carcinogens, and respiratory organics and in-organics

The following table gives a tabulated summary of the above goal and scope definition stage.

Table 4.1: Goal and Scope Definition for LCA of Gympie Dairy Farm

Goal	• Identify the potential to use this software for environmental impact assessment of dairy farming • Identify the environmental impact of the milk production system to farm gate • Identify the potential improvements to the system • Conduct a sensitivity analysis to validate assumptions of results made
Target Group	• Department of Primary Industries and Fisheries • Other interested Dairy Industry parties
Questions Answered	• Can the LCA methodology be readily used in the assessment of Dairy farming? • What is the environmental profile of the agricultural dairy system? • What are the major potential improvements?
Functional Unit	• One litre of Raw Milk at the Farm Gate
Allocation Rule	• No allocation to by product of one calf per year from cow at this stage
Life Cycle Stages Studied	• Irrigation, fertilizer, fertilizer transport and application, pasture production, cow (pasture to milk phase), milking and refrigeration of milk for company pick up
Study Boundaries	• All Life Cycle Stages Studied listed above • Main emphasis put on the production of pasture
Items Excluded From The Study	• Buildings, equipment and machinery • Pesticides and vaccinations • Grain or supplements due to time constraints • Waste treatment
Impacts Considered	• Single Score Assessment • Process Contribution Assessment • Climate Change Assessment • Fossil Fuels Assessment
Life Cycle Evaluation	• Quantitative where data is available easily • Qualitative where data unavailable or collection was limited by time

4.2 Life Cycle Inventory

The Life Cycle Inventory essentially involves the collection of all data required for the life cycle of the item. For this hypothetical farm we sourced data from the DPI&F

Mutdapily Research Station. This involved consultation with them to create a dairy farm that had a pasture based diet. The result was the development of a hypothetical farm situated in the high rainfall district of Gympie, Queensland. It supported 100 head of cows on 50 hectares of improved pasture.

Pasture feed available to the stock during summer was perennial Kikuyu grass with a yield of 15 tonne to the hectare over the whole farm with no irrigation. During winter, 20 hectares of the paddock would be over sown with ryegrass. This gave a yield of 10 tonnes to the hectare with irrigation. Therefore, the total yield of pasture grown equates to 750 tonnes during summer and 200 tonnes during winter. It was assumed the total of 950 tonnes for the year was completely consumed by the cattle.

For the pasture to yield this amount in these circumstances it required fertilizer. The fertilizers needed include nitrogen, phosphorus and potassium based fertilizers. The nitrogen based fertilizer used was urea that had a 46% nitrogen content. This resulted in a requirement of 41 tonnes of urea being applied for the year. The requirement of phosphorous for bulk feed production was much less than the amount of nitrogen needed. The phosphorous use equated to 1.5 tonnes being adequate to cover the plants needs. The addition of potassium to the pasture was largely for the health of the cows, because the stock required additional potassium in their diet. This potassium requirement led to the application of 3 tonnes of fertiliser for uptake into the pasture. The cow then consumed the potassium supplement through the feed.

The tractor and truck usage for the application of this fertilizer was also modelled. The tractor was used for the application of fertilizer and ryegrass seed. There was a small tractor in the data libraries available for use in this model, however it required the distance travelled in order to be able to determine impact. The known usage of diesel was 2 litres per hectare for each spreader application and the amount of hectares covered for the whole year was known (as defined above). Therefore, the kilometres could be calculated using the diesel usage of the tractor in the data inventory. This distance was found to be 3100 kilometres travelled for the season. The truck usage was easily found using the distance from the fertilizer processor to Gympie and the number of trips required to carry all the required fertilizer including empty return trips. This resulted in a total distance of 2800 kilometres.

The irrigation during winter was based on applying 50 mm (equivalent too 0.5 megalitre/hectare) to the ryegrass pasture every 14 days. Thus, the 5 ML/ha allocation will be used up over 5 months. A travelling gun irrigator was used, which costs around $42/ML to run. Based on the fact that $1 buys 10 kilowatt hours of electricity, it was calculated that the energy requirements of 420kWhr were needed to pump 1 megalitre of water. Other water requirements needed include that of stock water. Cows require 65 litres per day. This water was consumed from dams in the paddock filled by runoff from rainfall.

On this predominantly pasture based diet, the average milk production per cow was 3750 litres per year. This is lower than the national average and is largely due to the lower nutrients levels in the pasture. To produce this amount of milk the cow consumed an average of 9.5 tonnes of pasture and 23.7 kilolitres of water each year. In consuming this diet, previous research of Dr Richard Eckard shows that the cow would produce an emission of 140 kilograms of methane per year. Solid waste emissions were exempted from this life cycle and assumed to be of no effect to the natural environment.

The final necessary data was the electricity required for the milking of cows and the refrigerated storage of the raw milk until pick up. Previous DPI&F research found Queensland farmers spend 0.4 cents/litre on milking and refrigeration. The price of electricity is typically known to cost $1 for 10 kilowatt hours of power. A total of 15000 kilowatt hours of power are required for the year. This calculated to be a requirement of 0.04 kilowatt hours per litre of milk stored. A raw data sheet can be found in Appendix D showing the data given and any manipulations done for input into the program.

The following table is a list of figures put into the program to produce the life cycle impact assessment. These results are listed exactly in the form in which they appear in the SimaPro5.1 program.

Table 4.2: Life Cycle Inventory of the Production of one litre of Raw Milk at Farm Gate

Milk Production to Farm Gate	
Milking and Storage	**Per one Litre of Milk**
Queensland Low Voltage – Electricity	0.04 kWh
Cow	**Per one Litre of Milk**
Water (ground)	6.33 kg
Pasture	2.53 kg
Methane (rural) – Emission	0.0373 kg
Pasture	**Per Year**
Pasture Yield	950 tonnes
Water (Rain)	625 tonnes
Land Use	50 ha
Fertilizer Phosphorus	1500 kg
Fertilizer Potassium	3000 kg
Fertilizer Urea	44.13 tonne
Water Pumped (Irrigation)	100 kton
Tractor Travelled	3100 km
Truck Travelled	2800 km
Pumped Water (Irrigation Pump)	**Per kton**
Water (ground)	1 kton
Queensland Low Voltage – Electricity	420 kWh

This data was then entered into SimaPro5.1 life cycle inventories. The following screen shot shows the inventory screen for the pasture process. It shows the resources used and the categories they are put under in the production of pasture. This is an example of a typical lifecycle inventory sheet. Similar inventory sheets exist for all other processes including milk storage, cow and pumped water.

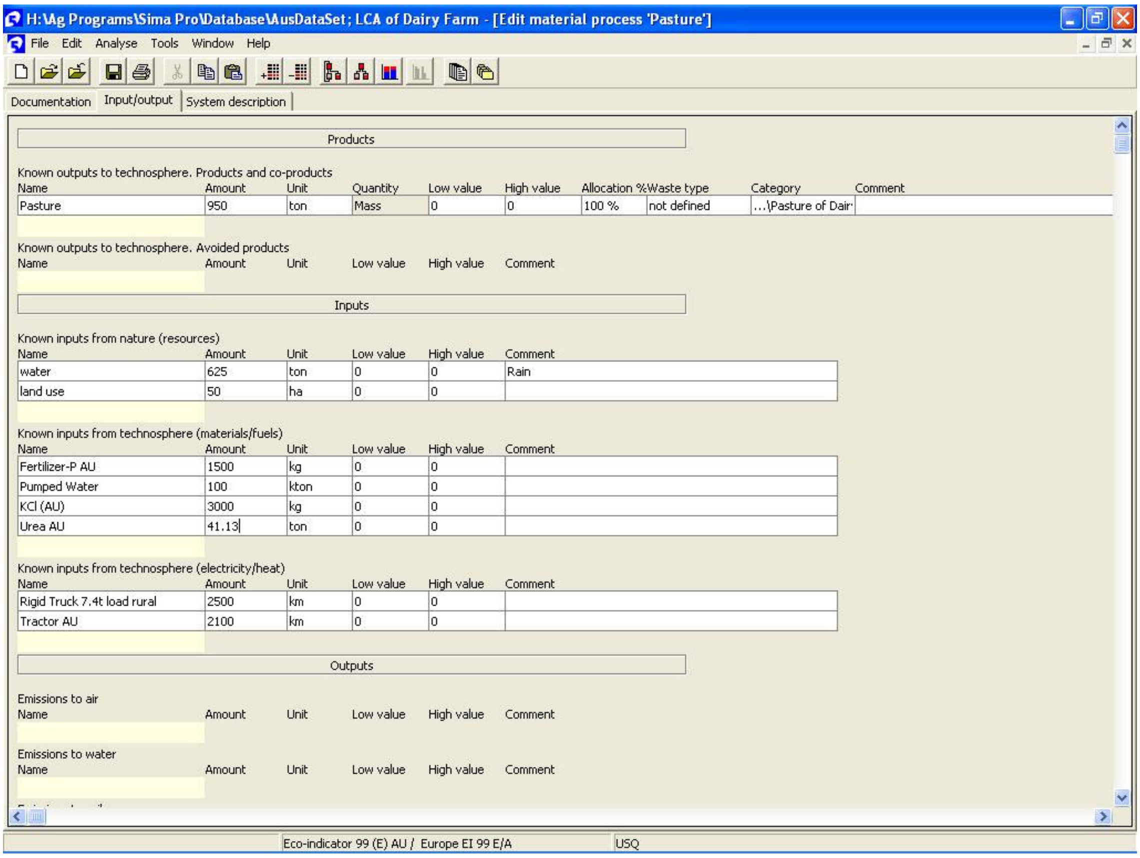


Plate 4.1: SimaPro5.1 Life Cycle Inventory of the Pasture Process

CHAPTER 5
Life Cycle Impact Assessment

5 Life Cycle Impact Assessment

This section is the third step of the life cycle assessment methodology. The results of the impact assessment have been shown after all data has been input into the program. When entering data into the software package, great care was taken to create the exact parameters of the life cycle being studied. This allowed the impacts to be followed easily.

The types of assessments used in this section are the single score, normalisation and characterisation assessments. Single score represents the total impact of each process being analysed compared to all the environmental impact categories of the eco-indicator. Normalisation calculates the total impact on each impact category from each process showing the impact on one scale. Characterisation calculates the percentage share each process has out of the total impact shown by each impact category of the eco-indicator used.

The following flowchart (Figure 5.1) is an output of SimaPro5.1. It shows the inputs that were entered into the program.

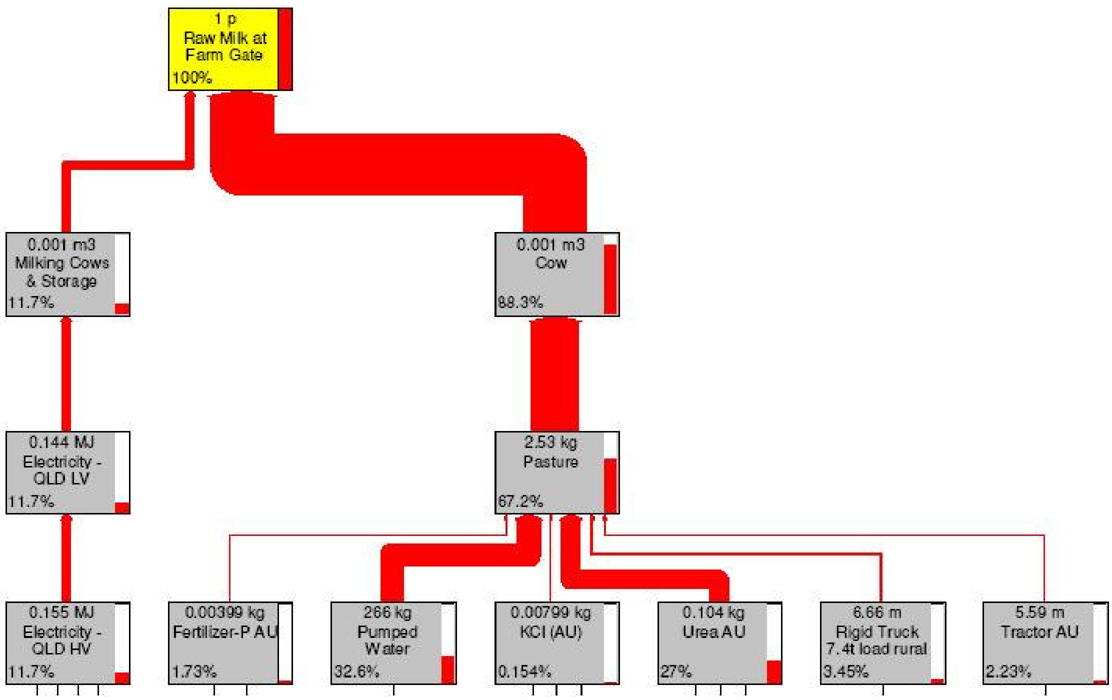


Figure 5.1: Flowchart of LCA of Raw Milk Production

5.1 Life Cycle Impact Assessment of Pasture Production

The Following results show the impact of pasture production on the environment with reference to eco-indicator 99. The following flowchart shows the flow of impact through the system and illustrates the processes involved in pasture production. The thicker the red line in this flowchart the greater the impact flow. The impact is progressively totalled as it flows through each step of the pasture production system. Thus, the difference in size between inflows of a particular process and the outflows of that same process will give a representation of the process contribution to the total impact of the phase. This enables the ability to rapidly distinguish where the large impact areas are.

In the following system flowchart (Figure 5.2), the production of pasture requires the application of phosphorus, nitrogen and potassium based fertilizers. Since this was a limited irrigation farm, water application was assessed. Finally, usage of a transport truck and tractor for fertilizer application was included. From the single score assessment used in this flowchart, it is illustrated that for the production of 1kg of pasture, pasture water application (Pumped Water 48.6% impact) and nitrogen based fertilizer (Urea 40.2% impact) are the main causes of impact in the pasture production phase. In Appendix E "LCIA of Pasture Production" all these figures are reproduced in full size to allow the figures on the graphs to be easily read.

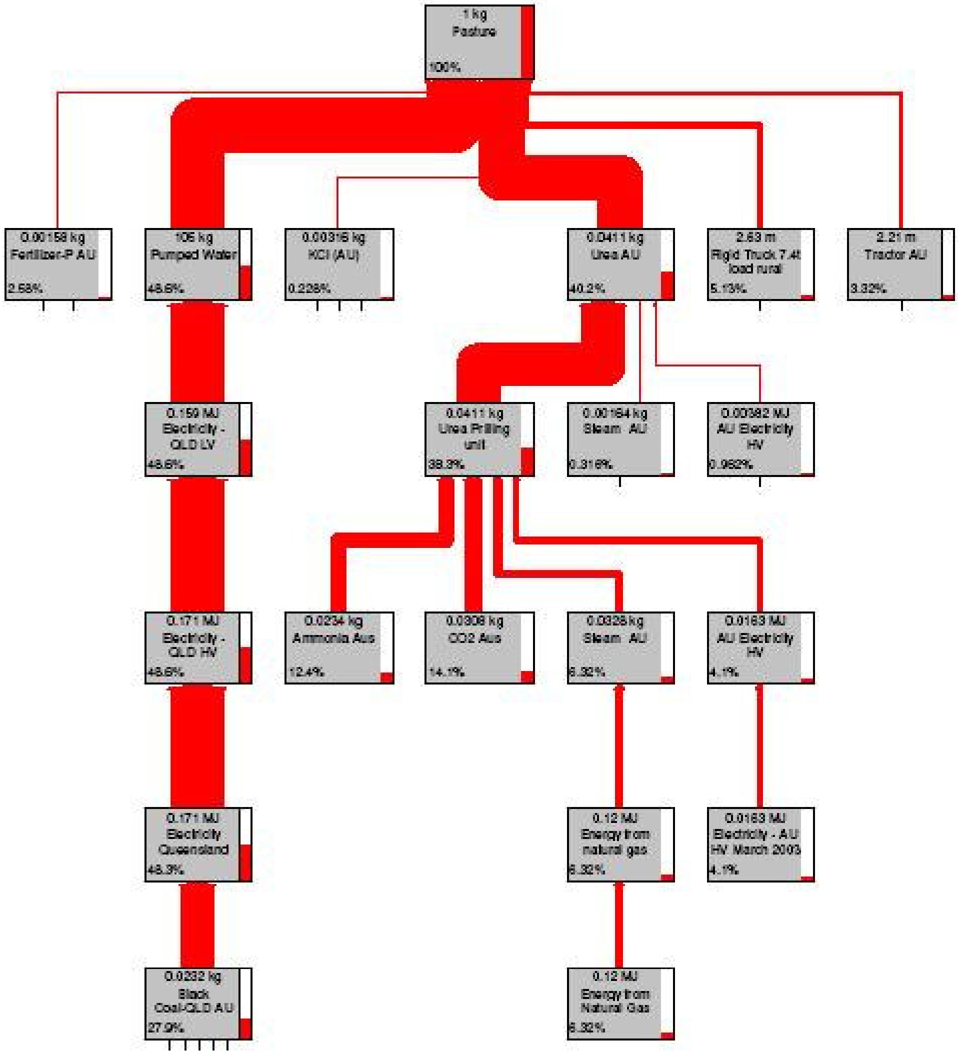


Figure 5.2: Flowchart of Pasture Production

The following graph (Figure 5.3) illustrates the impact of the processes in the system with the aim of producing a single score assessment. The Graph shows the impact of the application of water and fertilizers with commonly used modern technology. Its inclusion enables a quick assessment of each input into the pasture production system. This illustrates how each part of the system affects the environment through the assessment according to each of the eleven indicators used by eco-indicator 99. It shows the same outcome as the previous flowchart with pumped water and urea application giving the highest total impact. However, it gives the additional information that the major cause of this impact comes from the fossil fuels indicator.

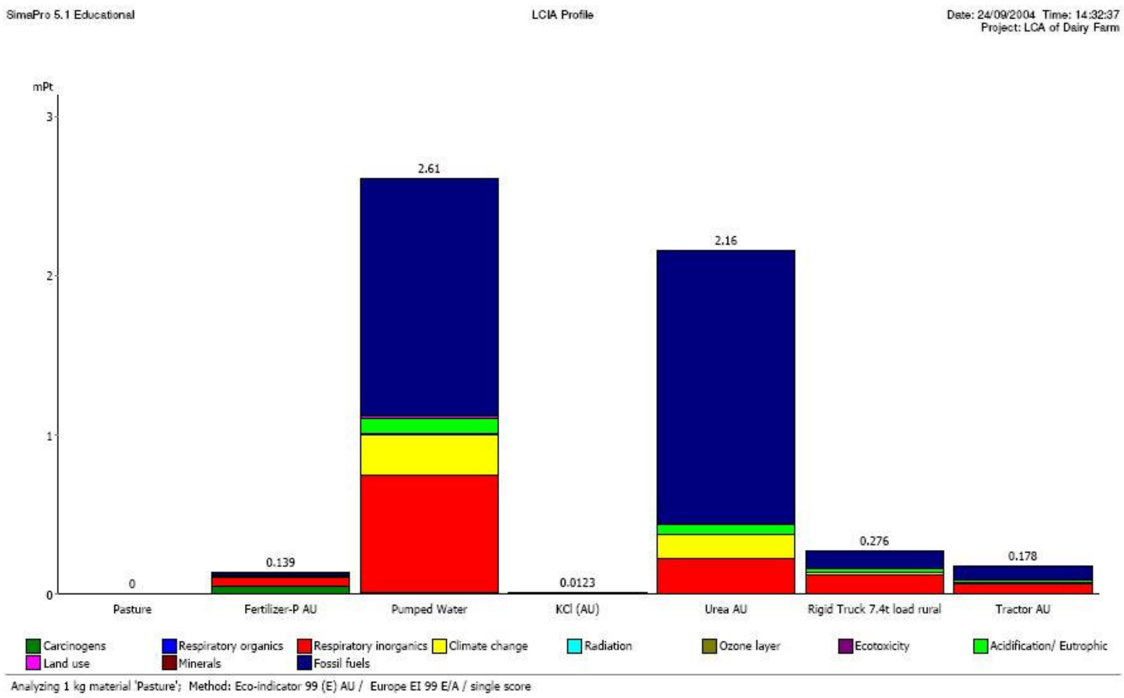


Figure 5.3: Single Score of Pasture Production

The next graph (Figure 5.4) shows the major impact to the environment using a normalisation assessment. This graph shows the major impact category that should be attended to when reducing the environmental degradation. The results show that fossil fuels impact indicator has contributed an extreme amount to the total environmental impact.

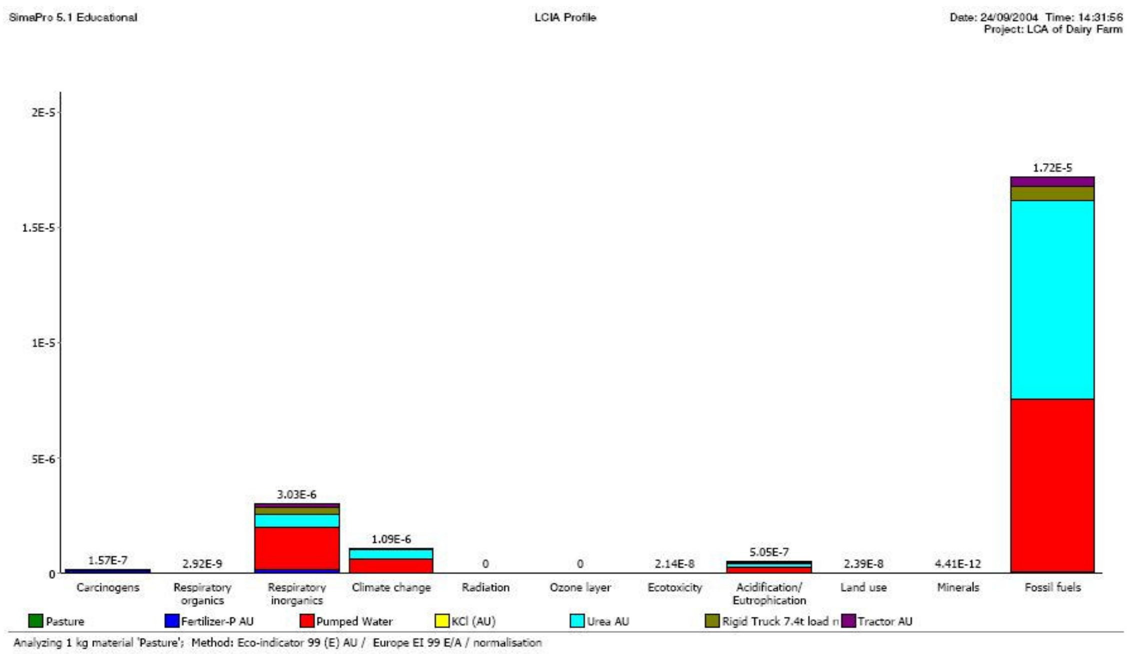


Figure 5.4: Normalisation of Pasture Production

The above graph shows clearly the major environmental impact, however, it does not clearly show how each impact indicator is influenced by a particular processes. This is remedied in Figure 5.5, which illustrates visibly how each process in production affects each individual indicator. From this characterisation assessment graph, processes can be highlighted that contribute to a majority of the impact indicators. Therefore, those processes expressing universal concern can be identified.

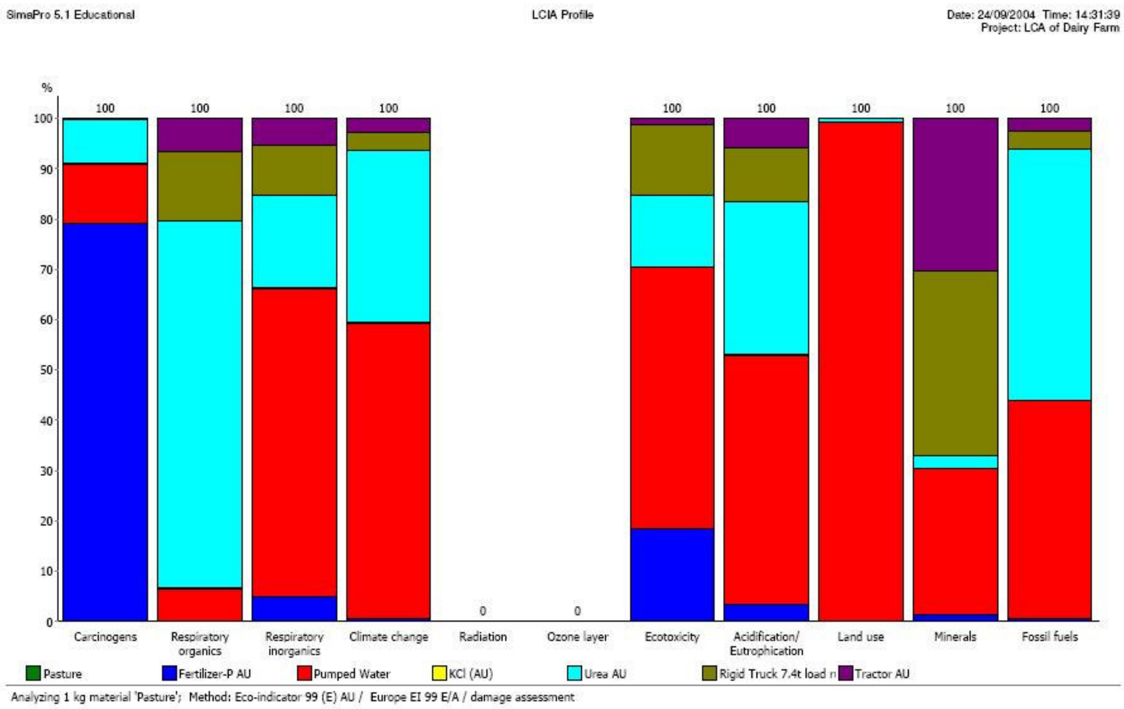


Figure 5.5: Characterisation of Pasture Production

5.2 Life Cycle Impact Assessment of Cow

The impact of the cow comes form two main categories. First, is the fact that the cow consumes pasture, and the pasture must be grown and fertilised. Second, is the specific impact relating to the biological processes of the cow, which are methane emissions. In this case an individual flowchart of the cow is not essential to show the flow of impact. The flow of impact can easily be seen by assessing the pasture production phase flowchart. However this is only possible because the diet of the cow is only based on pasture and no other supplements are provided. The following graphs produced are the same assessment types as included in the previous section. These three bar graphs give an adequate representation of the cow system and clearly show the result of methane emission from the cow.

As previously stated the only emission from the cow being modelled is the methane output from the digestion system. The next figure (Figure 5.6) shows the single score impact assessment of the cow producing 1 litre of milk at the teat. For this assessment stage the pasture category includes all impacts made by the pasture production processes (shown in the previous section). As can be seen, pasture production impact is quite substantial compared to the cow impact. However, the impact on climate change from the cow is very substantial relative to that shown by the pasture production. In Appendix F all these figures are reproduced in full size to allow the small lettering to be easily read.

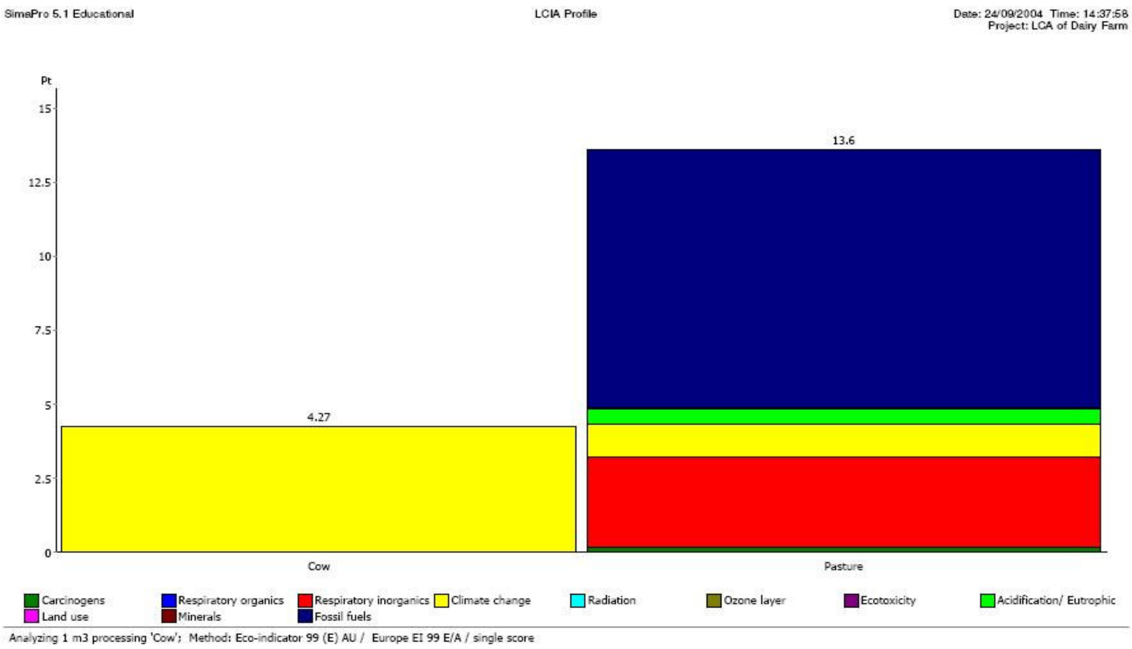


Figure 5.6: Single Score of Cow Phase

The normalisation graph below shows the major impact to the environment of the cow producing one litre of milk with respect to the eleven impact indicators of eco-indicator 99. This figure shows the major impact category that should be attended to, in order to reduce the environmental degradation produced from the cow phase. Figure 5.7 shows that fossil fuels impact indicator has contributed an extreme amount to the total environmental impact of the cow phase, but this is entirely due to the pasture production process. However, there is evidence that there is significant impact in the climate change indicator from the cow methane emissions.

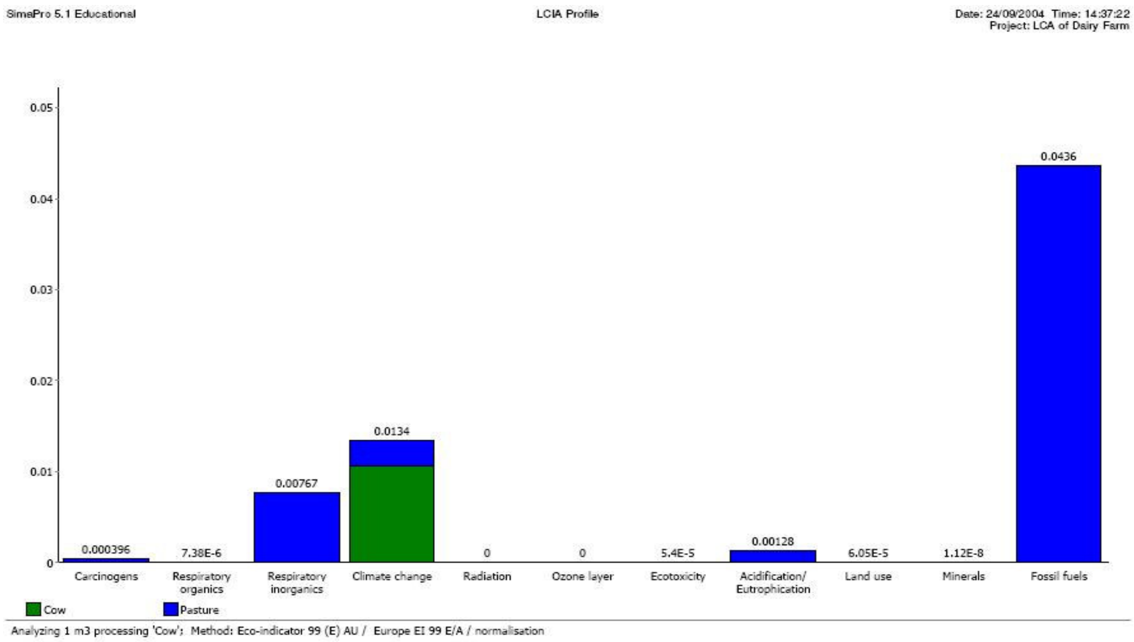


Figure 5.7: Normalisation of Cow Phase

The following graph (figure 5.8) indicates the processes that contribute most significantly to the impact indicators and therefore highlights a process of universal concern. This figure is here to show the effect that the cow emission has on the climate change indicator. It equates roughly 80% of the total impact relevant to that impact indicator

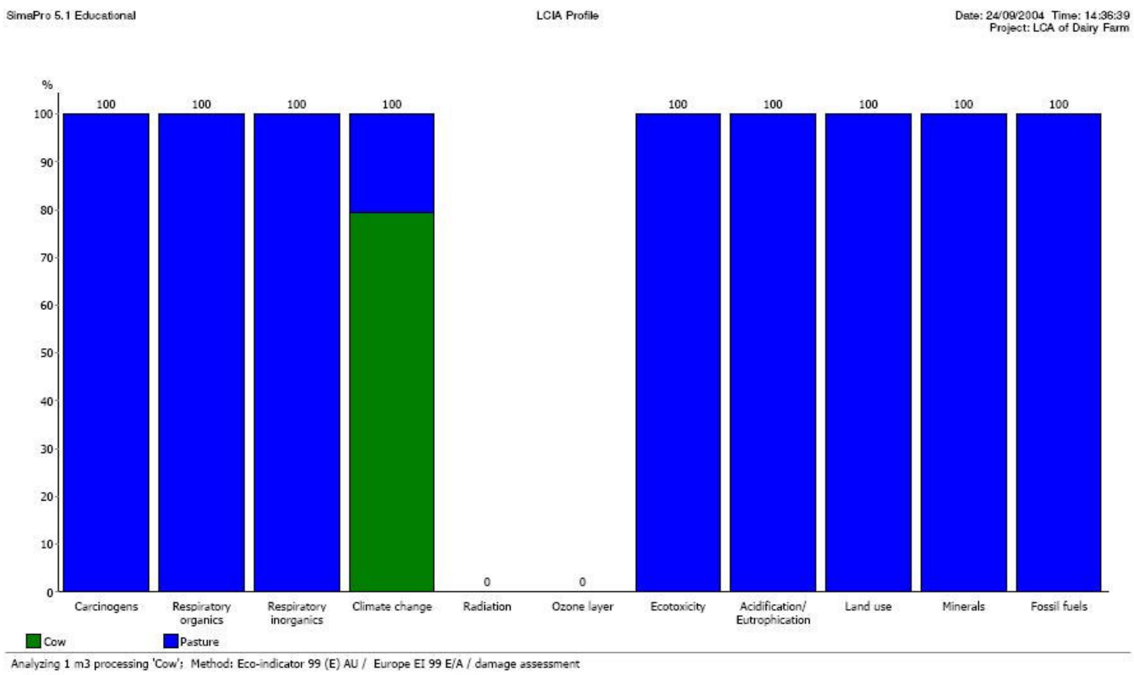


Figure 5.8: Characterisation of Cow Phase

5.3 Life Cycle Impact Assessment of Raw Milk

This section is the Impact assessment of the whole system and illustrates the impact incurred by the cow (including the food it eats) and the refrigerated milking system. This section assesses the major environmental impacts of all phases in the production of raw milk. This final assessment, when coupled with the assessment of previous stages, produces an extensive representation of impact flows and highlights areas for potential improvements.

The flowchart for the whole LCA system can be seen on page 37 Figure 5.1 this chart gives a single score assessment of the total impact flows of the system. As can be seen, major impact flows originate from the pasture phase. These include: pumped water (32.6%) and urea (27%). Another significant impact originates form the Cow which contributes 21.1% of total impact (found from the difference from pasture of 67.2% and cow 88.3%). The three same assessment graphs are utilized to give a good representation of the impacts made in the production of one litre of raw milk at the farm gate. In Appendix G all these figures are reproduced in full size.

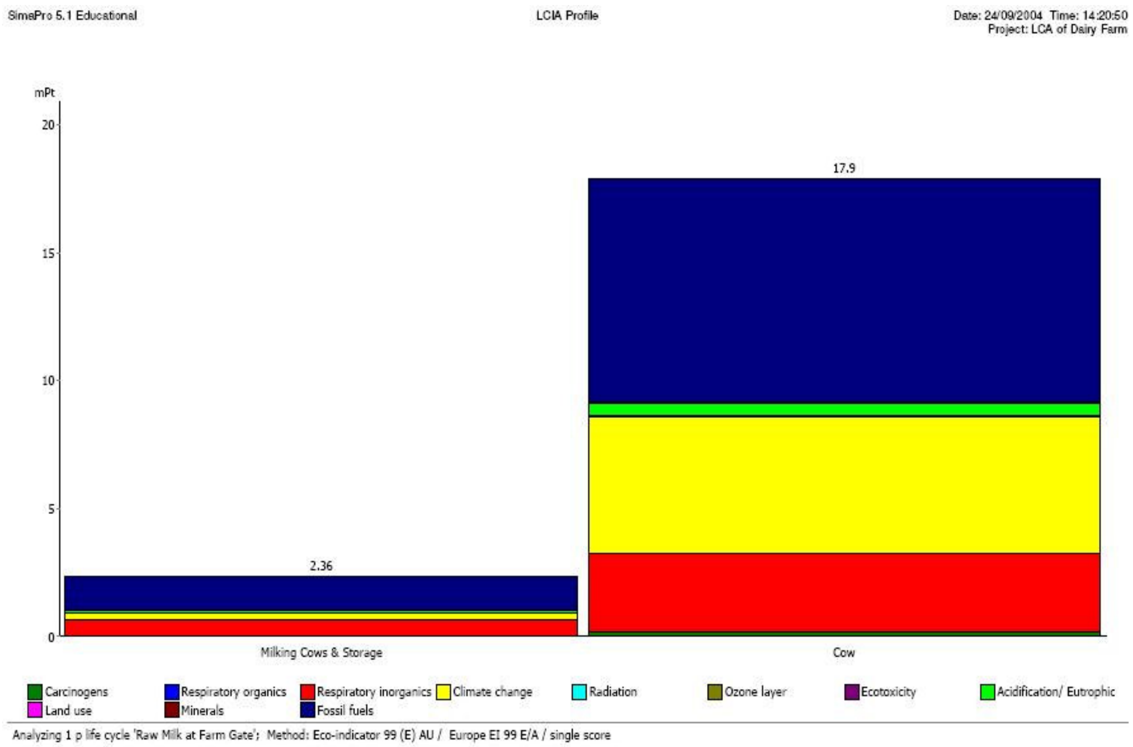


Figure 5.9: Single Score of Raw Milk Production

This single score assessment shown previously (Figure 5.9) illistrate there is considerably greater environmental impact incurred for a cow to produce one litre of milk at the teat, compared to the damage incurred due to milking and refrigeration of the milk. It can be seen that the fossil fuel impact indicator is the major impact category in both processes. While the climate change indicator is also rather large in the assessment of the cow process.

The following normalisation graph (Figure 5.10) illustrates large environmental impact in the fossil fuel indicator due to a substantial contribution from both processes. However, the greatest contribution is still derived from the cow. The climate change indicator also shows substantial impact from the cow producing milk phase. This diagram gives a helpful representation of possible target impact categories to improve the system.

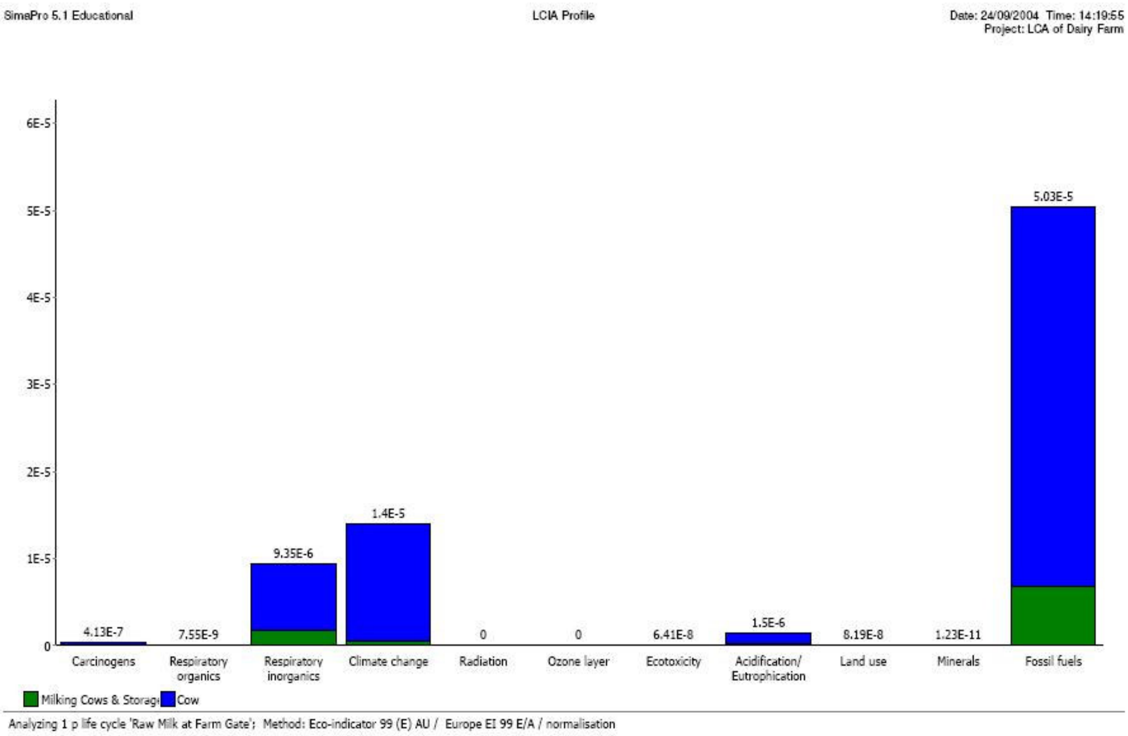


Figure 5.10: Normalisation of Raw Milk Production

Figure 5.11 indicates the processes which contribute substantially to a majority of the impact indicators. This figure is here to show the substantial impact, in all impact categories, which a cow makes in the production of one litre of milk. This illustrates there is a need to improve the milk production system at the milk produced to the teat phase in order to lower these environmental impacts shown.

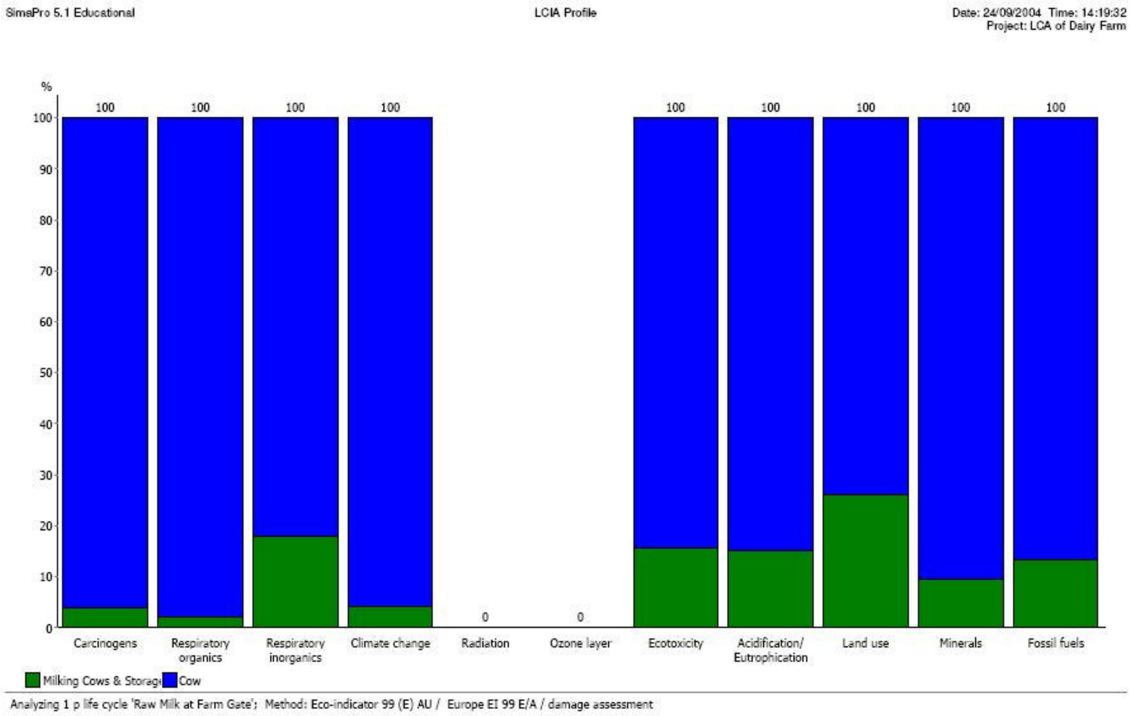


Figure 5.11: Characterisation of Raw Milk Production

From all the previous graphs it is evident that the flow of impact from pasture production has the major influence on the high impact on the overall process that the cow has contributed compared to the impact of the refrigerated milking system. While the previous figures produced a good understanding of the available opportunity for improvement in the system, it does not suggest the major contributor to the overall environmental impact. However, the next three graphs below illustrate the process contribution for the whole system and show the highest contributors.

The graph following (Figure 5.12) illustrates, on a single score assessment basis, which process is the major contributor to the overall environmental impact. It is evident from this graph that the usage of black coal (25.2%) in the production of electricity is the main impact contributor. However, an interesting second is the contribution from the cow process (21.1%).

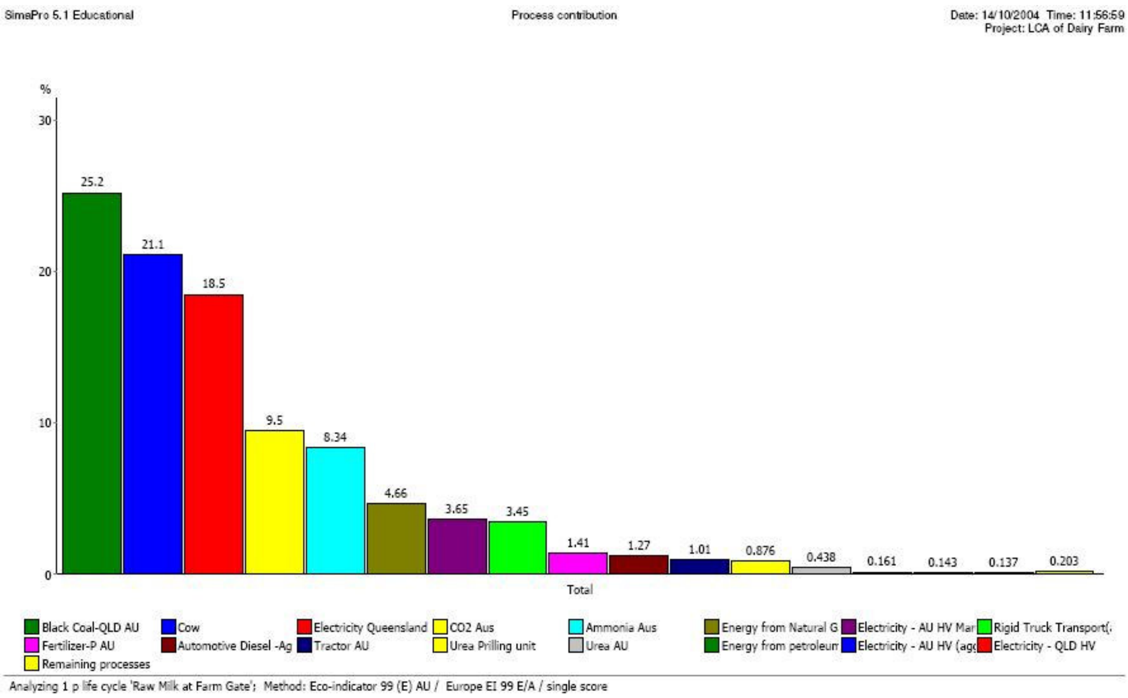


Figure 5.12: Raw Milk Production Single Score Process Contribution

The following graph assesses the process contribution using the fossil fuels impact category. It is evident from this graph that the usage of black coal (50.4%) in the production of electricity is the main impact contributor to the fossil fuels category.

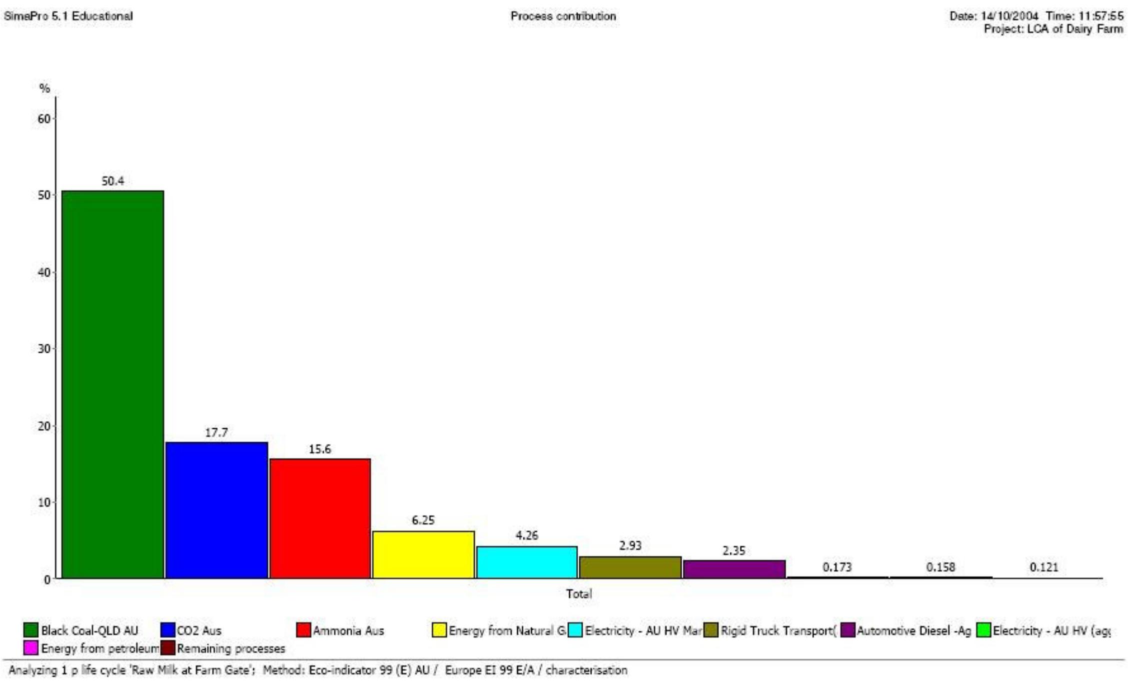


Figure 5.13: Raw Milk Production Fossil Fuels Process Contribution

This graph (Figure 5.14) is assessed using total process contribution and the climate change impact category. It shows that the main contributor to the climate change category indicator was the cow process (76.2%).

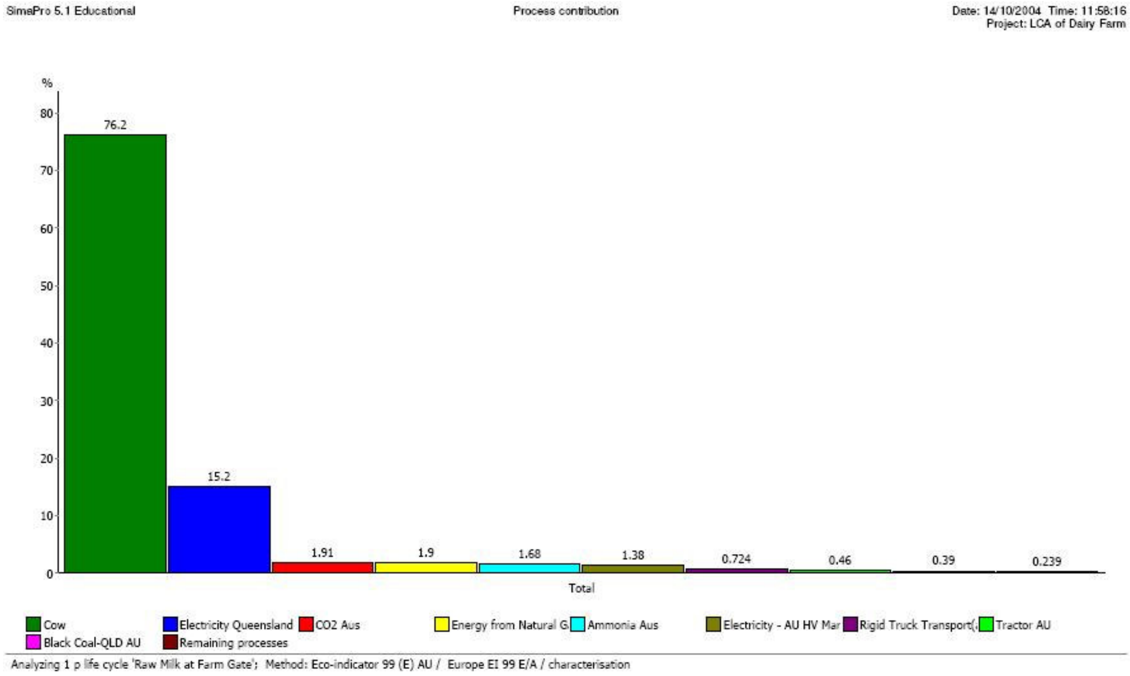


Figure 5.14: Raw Milk Production Climate Change Process Contribution

The two impact indicator categories used above are important because of the growing public concern regarding fossil fuel usage and climate change. Therefore, these graphs illustrate the major processes that contribute to the two main impact indicators that cause concern in the public sector.

CHAPTER 6

Life Cycle Interpretation & Recommendations

6 Life Cycle Interpretation & Recommendations

The final step of the Life Cycle Assessment is the Life Cycle Interpretation. This is essentially the discussion of the interpretations of the results shown in the previous chapter. The interpretation involves the declaration of "hot spots" and potential improvements. These are essentially the same. However, hotspots are areas of very high environmental impact and while potential improvements also involve high environmental impacts there needs to be the potential for improvement. These improvements are only made available where there is an opportunity to do so. Practically, this means that in some instances the environmental impact may be at the lowest level possible but there is no technology available to improve the situation.

This chapter also includes a sensitivity analysis of the assumption made of the large impact incurred by Queensland's power generation scheme. Recommendations are also made at the conclusion of this chapter offering suggestions of potential improvements to the system.

6.1 Life Cycle Interpretation of Pasture Production

In previous research it has been noted that pasture production is a major cause of impact in the production of raw milk. The inclusion of the assessment of this phase was essential to identify the factors creating environmental impact. This will give an opportunity to further refine the pasture development stage to produce a better overall system.

The results shown in section 5.1 give an extensive representation of the effects of pasture production. These results have been cross-examined with previous studies and similar outputs have been found. This shows that the data used to create the hypothetical farm was very similar to the real situation portrayed in previous literature.

The assessment graphs from SimaPro5.1 illustrated the hotspot determined by eco-indicator 99 was the fossil fuels impact indicator. This environmental impact is largely due to the usage of fossil fuels, most of which was the high usage of black coal for electricity generation. The process with the largest single score environmental impact was that of the pumped water and this impact was closely followed by that of urea. The impacts form both these processes stems from the power generation scheme and the emissions associated with this electricity generation. This high impact from electricity usage shows the benefit that the environment would have if electricity generation was from a renewable resource as opposed to the current electricity generation from fossil fuels.

Since the major impact category affected has come from the usage of electricity, potential improvements must be available in areas containing high usage of this resource. Therefore, in this system it would be imperative to find potential improvements in the pumped water system and the urea production system. For example, the pumped water system may not be running at the most efficient level. This is a common situation in many agricultural pump systems. It is usually because of a mismatch of pump and motor. This problem largely occurs because property owners are after the cheapest means to pump water, which may be the use of any pump and motor in there possession, and it will more than likely be mismatched.

The potential improvements available in the urea production system are not as easily solved within the agricultural system. This is because the agricultural enterprise has no means of improving the urea production system. However, the property owner does have control over the amount applied. The quantity used in many systems is usually based on trial and error, the farmer usually believes the more nitrogen the better. This assumption is flawed however. The response of production to a small amount of urea is quite dramatic, but increasing urea levels above a threshold value has only limited response to increasing crop production. As such the cost to yield efficiency is dramatically decreased when higher urea amounts are applied. Therefore, the need to produce the best cost to yield efficiency would be the better aim compared to trying for the overall best pasture yield. In order to create this situation, soil testing would be needed to find the deficiencies in the soil for pasture production and then only to apply urea as needed.

Pasture production phase incurs the most environmental impact in the system. This highlights the need for this phase to be the most efficient with respect to environmental damage indicators. With the pasture process impact indicators decreased to the lowest possible impact, the damage from the whole system would decrease substantially because of the flow on effects.

6.2 Life Cycle Interpretation of the Cow

As previously stated the only emission modelled for the cow is methane output from the consumption of the pasture-based diet. This emission from the cow was included largely due to the growing concern of the quantity of methane output from cattle. However, the inclusion of this variable had little effect on the impacts shown by many impact indicators except that of climate change.

The two graphs showing the single score pasture assessment and the single score cow assessment show that the methane emission causes an increase of four times the amount of damage in the climate change indicator. This increase illustrates the importance of the growing concern of the effects from methane production in cattle. At this stage further inclusion of additional emissions from cattle in now warranted to discover any more unknown impacts.

There is a need to lower this methane output of cattle from their digestive system. At the moment research is being undertaken to assess possible ways of lowering emissions from cattle. This leads to the potential improvement to the climate change indicator of the whole system. Ways that have been found are through changing the diet of the cows to increase the amount of supplements that produce less emission of methane from the digestive track.

6.3 Life Cycle Interpretation of Raw Milk Production at Farm Gate

Through the flow on effects used in the assessment strategy of SimaPro5.1, the impact shown by the milk to teat phase of the cow equates to all the processes involved that make up that single process. This includes the methane impact and pasture production. These individual impacts have already been assessed in previous sections. The software then assesses the milking and refrigeration systems impact compared to the impact created by the entire milk to teat production phase. This fact makes it hard to individually assess the refrigerated milking system in the best possible way.

The inclusions of the last three graphs were needed to show the single process contribution that produces the greatest impact. These graphs assess all the single processes on the basis of a single score assessment, fossil fuels indicator and climate change indicator. These assessments helped pinpoint the exact causes of environmental impact in a holistic way (single score) and also highlighted the major indicators of concern in the public sector today (fossil fuels and climate change).

These graphs illustrated that the black coal usage was the cause of the overall largest environmental impact. The major impact from black coal is its large usage to generate electricity in Queensland. This is illustrated by the fact that the third highest impact was shown to be electricity generation. From knowing this, it can be stated that any rise in efficiency in the usage of electricity in the whole system would help lessen the environmental impact indicated. This includes all processes from the irrigation pump to the refrigerated milking machine. The possibility of using renewable energy resources is the next step to producing less environmental damage.

The second highest single score impact assessment is that of the cow. This impact is only produced by the methane emission. The impact from this emission is therefore important to consider since it ranks so highly in a single process contributions. It would therefore be interesting to investigate the change in the cow system impact if further impacts from manure and urine excretions were considered in the cow phase.

When comparing these results to figures produced by a leading researcher into the greenhouse gas emissions of dairy farms, Dr Richard Eckard of Melbourne University, this model has produced quality results. On the following website (http://www.innovateaustralia.com/newsletter/v1_3/greenhouse.htm) Dr Eckard states that cow methane emissions cause 60-80% of the total greenhouse gas emissions. Our model calculates that our cow methane emissions contribute to 76.2% of the total climate change indicator, which is a representation of the greenhouse gas emissions. This contribution is in the high end of the range stated and is more than likely due to the pasture based diet of these cows. It is of poorer quality compared to grain supplements.

The greenhouse contribution from diesel and electricity consumption on farm was stated by Dr Eckard as ranging between 5-10%. Our model has produced a total of 15.2% contribution from electricity usage for the irrigation pump and the refrigerated milking system. This value is 5% higher than that of Dr Eckard. This may be due to data being incorrect or the pump system may be inefficient in this system creating extra impact. Alternatively, the problem may be due to the higher usage of black coal in the production electricity in Queensland compared to Victoria. However, this small difference is reasonably insignificant in a basic model and therefore changing inputs to suit would not be needed at this stage.

6.4 Sensitivity Analysis

The statements made in the life cycle interpretation are all assumptions at the present time. This leads to the need for a sensitivity analysis to see the effect of changing certain variables and the corresponding change in impact. The following section contains a sensitivity analysis concentrating on investigating variations in the black coal usage for electricity generation. In this analysis the pasture phase was again assessed using a different electricity source that uses a gas-based electricity generation rather than black coal. This assessment is shown in Figure 6.1. All the following graphs are reproduced in full size in Appendix H.

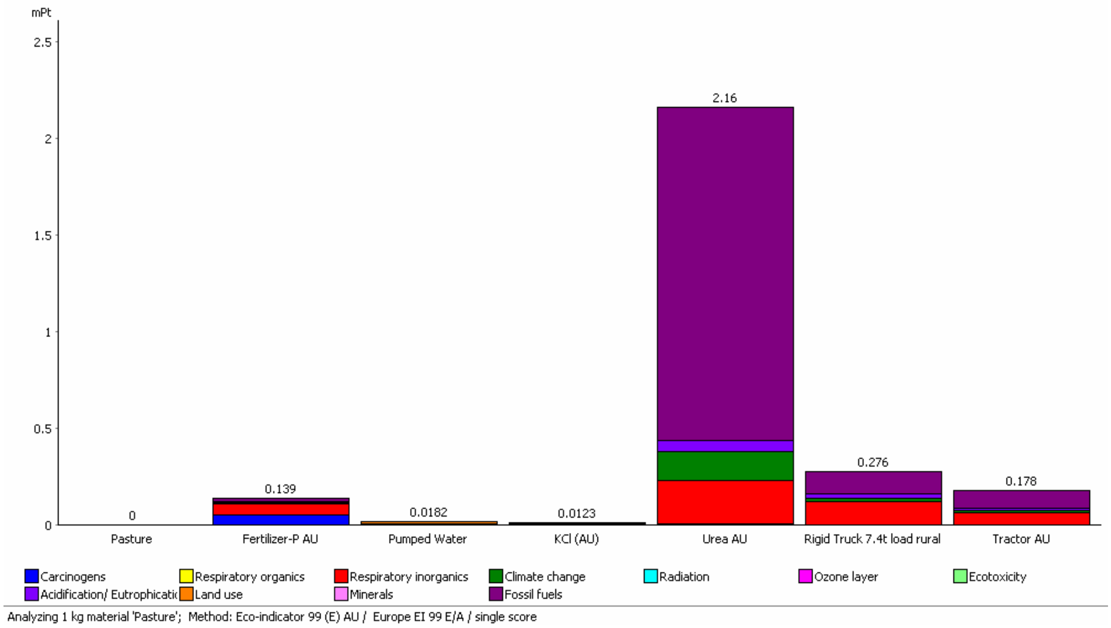


Figure 6.1: Single Score of Pasture Production using Different Electricity Source

The previous graph, when compared to Figure 5.3, shows that changing from the usage of non-renewable energy sources, such as coal based, to a renewable source has a substantial effect on the environmental impact. This can be seen through the change in environmental impact of the pump system when electricity generated from biogas produced from landfill is used. Note that urea impact is still high since black coal is still used for the urea production. The following characterisation graph has been produced to see the drastic change in the pumped water impact compared to the previous characterisation of Figure 5.5.

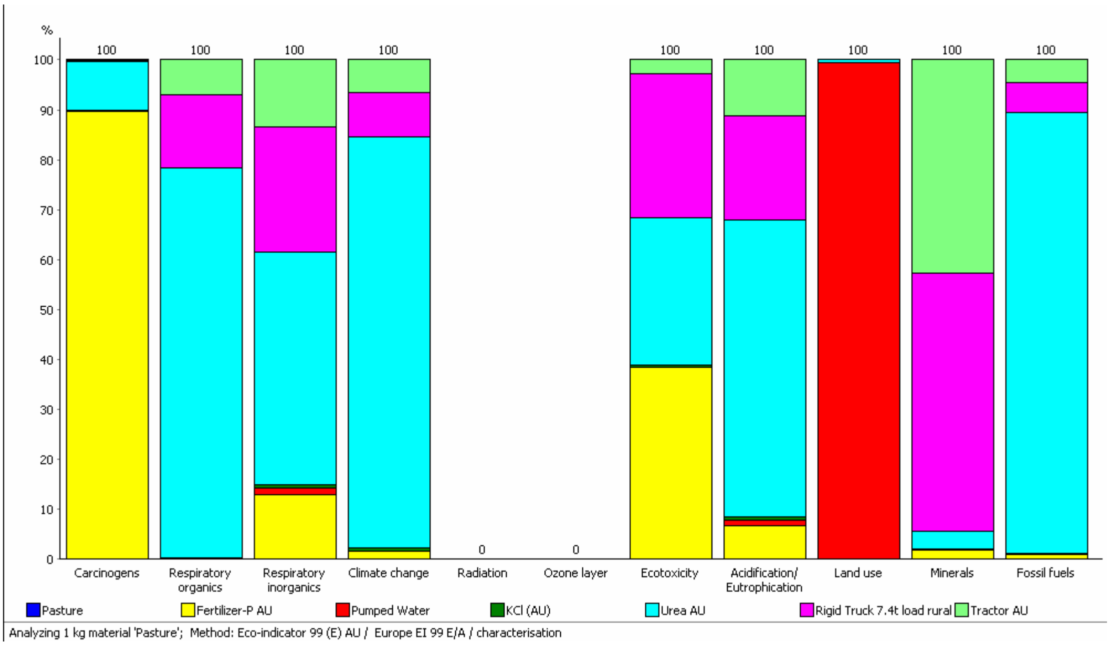


Figure 6.2: Characterisation of Pasture Production using Different Electricity Source

As illustrated above the range of impacts previously incurred by pumping water using electricity generated by black coal, substantially declines with the use of a better resource. However, the price of electricity is very cheap when the black coal method is used. Changing the method and bettering efficiencies might not prove to be cost effective.

6.5 Recommendations

From the Life Cycle Interpretation of the Life Cycle Impact Assessment discussed previously in this chapter, the following recommendations will be made to improve the environmental image of this production system. These suggestions will provide a basis for improving the system as a whole. They will also provide the potential for any dairy farm to improve their production system to lower impacts.

Starting with the pasture production system, it is evident that reduction in any of the inputs of the pasture system will lessen the total environmental system impact substantially. The most influential process causing large environmental impact is the pumping system applying water to the pasture. With the correct usage of this water through scheduled irrigation and the use of any moisture probes available, there may be substantial improvement in the water use efficiency. This will lower the amount of water required and therefore lower the impact because less pumping will be needed. Along with the correct coupling of electric motor to pump, the power usage of the irrigation system impact could be lowered substantially. This would be the most successful route to lower impact because of the small chance that power generation methods would be changed.

Another available technique to lower impact of the pasture production system would be through the fertilizer processes. There is poor ability to change the way in which these fertilizers are made. However, the amount of fertilizer applied is in control of the farmer. This results in the need to determine what fertilizer is required and how much is needed for the pasture. Any reduction in the amounts of these fertilizers used will greatly diminish the environmental impact incurred by the production of pasture.

The cow phase also has large impact in the climate change indicator (76.2%). However, the impact from methane emission comes from the natural process of digestion of the cow. There has been research done on reducing cow methane levels. It was found that methane output levels were increased if cows were fed on a poor diet. This means that if cows were fed on the correct diet required for milk production they would emit less methane.

The final area of possible improvements is the milking and refrigeration stage. This process only takes into account the usage of electricity. Therefore, the only reduction in environmental impact can come from greater efficiencies in the extraction and storage of milk. Again, this is because there being little chance of changing power generation methods. However, the usage of solar power may be integrated into the shed through lighting systems or other low voltage requirements. These increased efficiencies and the integration of solar electricity would lower the environmental impact of this process.

By using some of these recommendations the flow on impact to the system would be diminished substantially. The largest potential for improvement would come from the increased water use efficiency coupled with an efficient pump system. The second would be the effective use of fertilizer for pasture production. There is a large amount of potential improvement of cow methane emissions, but the ability to do so with current research is low. Finally, there is always a need to keep the refrigerated milking system at a high efficiency, but the inclusion of solar power would lower power resources for night milking substantially.

CHAPTER 7
Conclusions

7 Conclusions

This paper has presented a Life Cycle Assessment model based on a realistic hypothetical dairy farm in the high rainfall area of Gympie in southeast Queensland. It has been shown that the model is able to produce reasonable results in comparison with other researchers. This confirms that SimaPro5.1 software and the LCA methodology is a useful tool to indicate and aid the understanding of environmental impact of agricultural activities.

7.1 Conclusions

The limitations that have been placed on this model have simplified the model immensely. However, these limitations have not made the results insignificant in modelling the agricultural system. Present limitations include:

- The model is based on a simplified hypothetical farm with limited irrigation pasture.
- No feed supplements such as grain and silage
- It has been assumed cattle consume all feed on farm
- The model has not taken into account the allocation of the co-product such as the cow or calf meat.
- Other small items ignored include: environmental impact from refrigerant production, energy required for ryegrass seed production, pesticides and medicines.

These limitations were created to allow the complete modelling of major known environmental impacts such as pasture production and cow methane production. The basis of this hypothetical farm was to produce a basic dairy system model. Limitations were made on the basis of past studies and areas known as low impact. The pasture-based system was created due to pasture production being the major impact in previous studies. No pesticides and medicines were used owing to little information in the data sets on types used in the dairy system. Allocation of a co-product was not considered at this stage due to differing opinions in literature of how much impact can be attributed to each individual product. Other small impacts limited at the moment were not undertaken from aspect of time constraints.

Preliminary research for this particular dairy system indicates that major impacts to the environment are the flow on effects from the energy used by the irrigation pump, the large quantities of urea fertilizer used and the methane emissions from the cow. This means for future improvements to the system these large areas of impacted should be considered.

With the correct usage of this water through scheduled irrigation and the use of any moisture probes available, there may be substantial improvement in the water use efficiency. This will lower the amount of water required and therefore decrease the environmental impact because less pumping would be required. The correct coupling of electric motor to pump would also substantially lower power usage of the irrigation system.

There is a poor ability to change the way in which these fertilizers are made. However, the amount of fertilizer applied is controlled by the farmer. This leads to the benefits that can be gained by knowing what fertilizer is needed and the quantities of nutrients that are required for the pasture. Any reductions in the amounts of these fertilizers used will inturn diminish the environmental impact incurred by the production of pasture.

The impact from methane emission comes from the natural process of digestion of the cow. There has been research done on reducing cow methane levels, it was found that methane output levels were increased if cows were fed on a poor diet. This means that cows fed on the correct diets would emit less methane. Thus, alternatives for higher quality food stuffs should be investigated in order to decrease environmental impacts.

At the present stage, this research highlights the poor data available in the agricultural sector. Through the future improvement of the Australian Data Inventories the problems associated with poor data may diminish. LCA can be combined with Life Cycle Costing to produce a complete tool for assessing both economic and environment areas. The ability to use real farm data may also be desired in the future.

The objectives of this project as set out in section 1 of this report have been met as follows:

1. Research was carried out on previous Life Cycle Assessment studies done on Dairy Production Systems.

2. Life Cycle Assessment methodology and the software package used in its undertaking were extensively researched so that an assessment could be done.
3. The goal and scope of the Life Cycle Assessment of a Limited Irrigation Pasture dairy herd was defined to produce a representative farm.
4. Data was collected through liaisons with Mutdapily Research Station of a representative farm in the Gympie district. Checked data for uncertainties and data gaps that need to be filled with credible Australian literature and other sources.
5. A basic model to confirm the "feasibility" of the method was setup, which characterized the environment impact of a very basic representative farm modelling only pasture production. The model produced sensible results in comparison with the studies of other people.
6. Other processes were added to the model until it represented a basic limited irrigation farm with the cow diet based solely on pasture.
7. A sensitivity analysis was carried out to test assumptions made change in electricity generation methods and how they change environmental impact.
8. Recommendations were made on opportunities for farm improvements to lessen environmental impact.

7.2 Future Work

The opportunity for future work on this topic is endless. There is a substantial need to extend on this basic Life Cycle Assessment to include further processes so that an extensive model of the dairy system can be produced. The first avenue to follow would be the inclusion of a grain supplement in the system. This would greatly improve the basic model and allow assessment of all possible dairy system types.

The inclusion of the grain supplement would create the opportunity to model all five of the standard dairy systems at the Mutdapily Research Station. These results have the potential to improve the dairy industry's environmental credibility. It can be helped further through the awareness that the Research Station could create with farmers in the industry. This environmental credibility would continue to be improved through the inclusion of more of the smaller processes into the system as data becomes available.

With a model that represented all inputs and outputs (even co-products) of the system there would be increases in the overall confidence of the industry in the model's results. From this greater confidence in the model, recommendations could be made with better assurance that changes could be made to decrease the environmental impacts. Through the usage of sensitivity analysis of these suggested improvements, potential changes to lessen environmental impact could easily be undertaken.

List of References

NARAYANASWAMY, V et al, 2002. A Primer on Environmental Life Cycle Assessment (LCA) for Australian Grains. Curtain University of Technology, Australia.

NARAYANASWAMY, V et al, 2003. Methodological Framework for Application of Environmental Life Cycle Assessment (LCA) to Australian Grains. Curtain University of Technology, Australia.

BERKEL, RENE VAN, 2002. The Application of Life Cycle Assessment for Improving the Eco-Efficiency of Supply Chains. Curtain University of Technology, Australia.

CEDERBERG, C. AND MATTSSON, B., 1999. Life cycle assessment of milk production – a comparison of conventional and organic farming. Goteborg University, Sweden.

BOER , I.J.M., 2002. Review: Environmental impact assessment of conventional and organic milk production. Wageningen University, The Netherlands.

HAMILTON, A. et al, 2000. Life cycle assessment of milk production systems in south Queensland. University of Sydney.

HOSPIDO, A. et al, 2003. Simplified life cycle assessment of galician milk production. University of Santiago de Compostela, Spain.

Institution of Engineers Australia, [Online], http://www.ieaust.org.au/, Accessed: 15 May 2004.

Government Services of Australia- Environmental Portal, [Online], http://www.environment.gov.au/, Accessed: 16 May 2004

Australian Milk Marketing- Milk Information Portal, [Online], http://www.mteam.com/, Accessed: 2 April 2004

Directory Site for the Australian Dairy Industry, [Online], http://www.dairy.com.au/, Accessed: 28 March 2004

Department of Primary Industries – Mutdapily Newsletter Page, [Online], http://www.dpi.qld.gov.au/m5/, Accessed: 15 March 2004

PRé Consultants, [Online], http://www.pre.nl/default.htm, Accessed: 7 May 2004

Government Services of Australia- Agricultural Portal, [Online], http://www.agricultural.gov.au/, Accessed: 16 April 2004

Dairy Australia, [Online], http://www.dairyaustralia.com.au, Accessed: 1 September 2004

Innovate Australia, [Online],
http://www.innovateaustralia.com, Accessed: 29 September 2004

Rural Skills Australia, [Online],
www.ruralskills.com.au, Accessed: 5 October 2004

University of Massachusetts Amherst, [Online],
www.umass.edu, Accessed: 5 October 2004

Appendix A – Project Specification

This appendix contains a copy of the project specification that was drawn up as part of the requirements of the project work, for the University of Southern Queensland. It details the objectives of the project.

University of Southern Queensland
Faculty of Engineering and Surveying

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR: Simon ORPHANT

TOPIC: Life Cycle Assessment of the Production of Raw Milk

SUPERVISOR: Dr. Guangnan Chen

PROJECT AIM: The project aim is to produce an outline of the Life Cycle Assessment methodology and to set up an initial working model to confirm the feasibility of the applications of LCA method in Australia's dairy industry.

PROGRAMME: Issue B, 15th October 2004

1. Research previous Life Cycle Assessment studies done on Milk production Activities.
2. Research the Life Cycle Assessment methodology and the software package used in its undertaking.
3. Define the goal and scope of the Life Cycle Assessment of a Limited Irrigation pasture based dairy herd.
4. Collect data needed for the Life Cycle Assessment (from DPI Mutdapily Research Station and other sources). Check data for uncertainties and data gaps that need to be filled.
5. Set up a basic model to confirm the "feasibility" of the method, and to characterize the environmental impact of a typical representative farm. The model should produce sensible results in comparison with other studies.
6. Add other processes into the analysis model

As time permits:

7. Carry out model sensitivity analyses.
8. Identify and evaluate the opportunities for farm improvements.

AGREED:

_______________ (Student) _________________ (Supervisor)

___/___/___ ___/___/___

Appendix B – Timeline for Project Completion

This appendix contains a copy of the timeline of the project, which helped in goal setting for completion times of major sections of the project.

Project Timeline

Week	My tasks	Submission Dates
1		
2	**Project Literature Review and Note Taking**	10/3/2004 Project Proposal
3		
4		22/3/2004 Project Specification
5		
6		
7	Holidays	
8		
9		
10	**Complete Software Tutorial and be able to run program**	Practice
11		
12		17/5/2004 Project Appreciation
13		
14	**Gather Needed Data**	
15		Seminars
16	**Produce an initial Working Model**	
17		
18		
19	Holidays	
20		
21		
22		
23		
24		
25	**Correct the model**	
26		25/8/2004 Presentation Abstract
27		
28		
29		**Presentation at 2004 Agricultural Engineering Conference**
30	Holidays	Final Project Presentations-Res School
31		
32		
33		
34	**Write Dissertation**	
35		**28/10/2004- Project Dissertation**
36		
37		
38		
39	Last Week of year	

Appendix C – Simon's Tips to Learn SimaPro5.1

This appendix is an optional extra included for project students wishing to do future work on this particular topic. It gives a broad overview of the steps that I took to learn SimaPro5.1 so that I could complete this project.

Simon's tips to Learn SimaPro5.1

In learning this program the most essential knowledge needed before opening the software package is an extensive knowledge on the actual Life Cycle Assessment (LCA) Methodology. After acquiring a good understanding of how the methodology undertakes an assessment the next step would be to read through the accompanying manual and tutorial book provided. The SimaPro5.1 manual provides essential information on the ability of the program to conduct a LCA and certain terminologies. The tutorial is also useful to read through before opening the program to understand the planning stages and how a simple life cycle can be broken into its stages for input into the program.

Once the background reading has been completed the next step is two follow through the tutorial book and complete the simple life cycle assessment provided. Once you have completed this tutorial look at the many outputs of the program and with use of the resources available understand the outputs of the life cycle impact assessment. After completing the tutorial delete the whole tutorial and start again. However, this time have a sheet of paper beside you and draw the flowchart as you go. This gives a feel for how the processes link together to create the full life cycle. After you have completed the two above steps you should have a reasonable understanding of the program and how to undertake your own assessment. If still unsure on how the program undertakes the simple tutorial repeat the above steps till you feel confident.

Once confident with completing the tutorial you will be able to start your own life cycle assessment. The best task to undertake before opening a new project is to complete the simplest life cycle flowchart of your system. This simple flowchart will entail the main aspects that are required for your system. An example of my first flowchart follows. This flowchart will aid to input into the program with help from the knowledge learn from making the flowchart as you completed the tutorial.

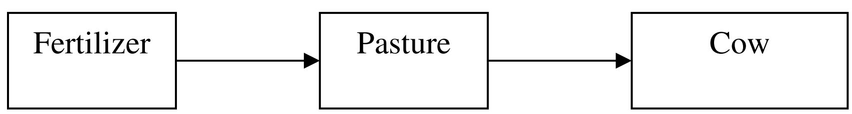


Figure C1: My First Flowchart Showing the Basics of Milk Production

Once the first basic flowchart has been entered in successfully more processes can be added each time until the whole system being studied has been entered. My second flowchart I made included the usage of irrigation, a tractor to apply fertilizer and a truck for transportation. This produced the following flowchart.

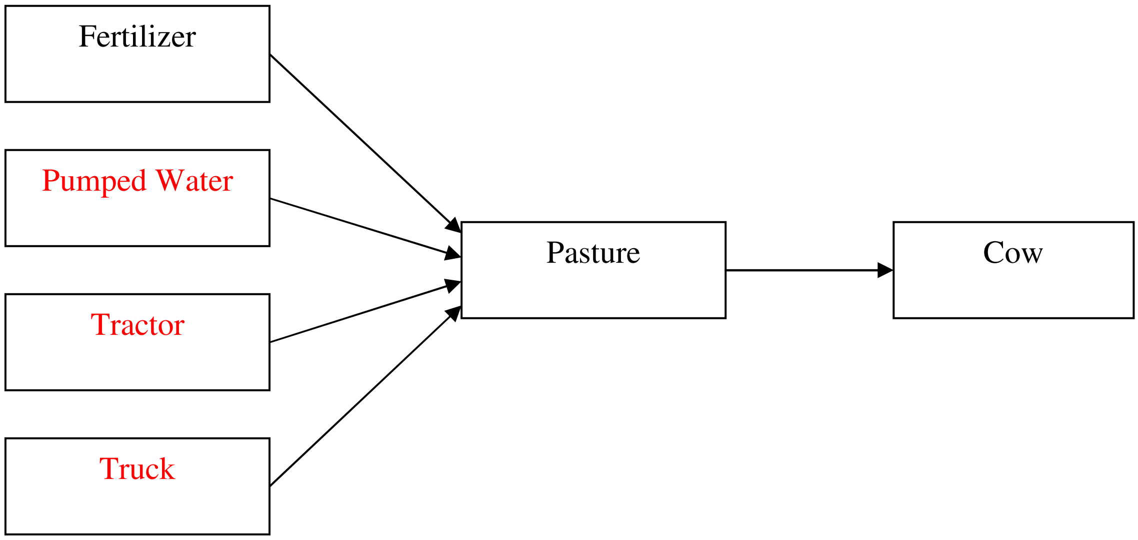


Figure C2: My Second Flowchart entitled 'Milk Production to Teat' (new entries in red)

After this flowchart was entered in successfully a third flowchart was created to include all the other processes required to produce raw milk at the farm gate. This included the usage of refrigerated milking system and the emission of methane from the cows to produce raw milk. The following flowchart shows the final processes included in my assessment.

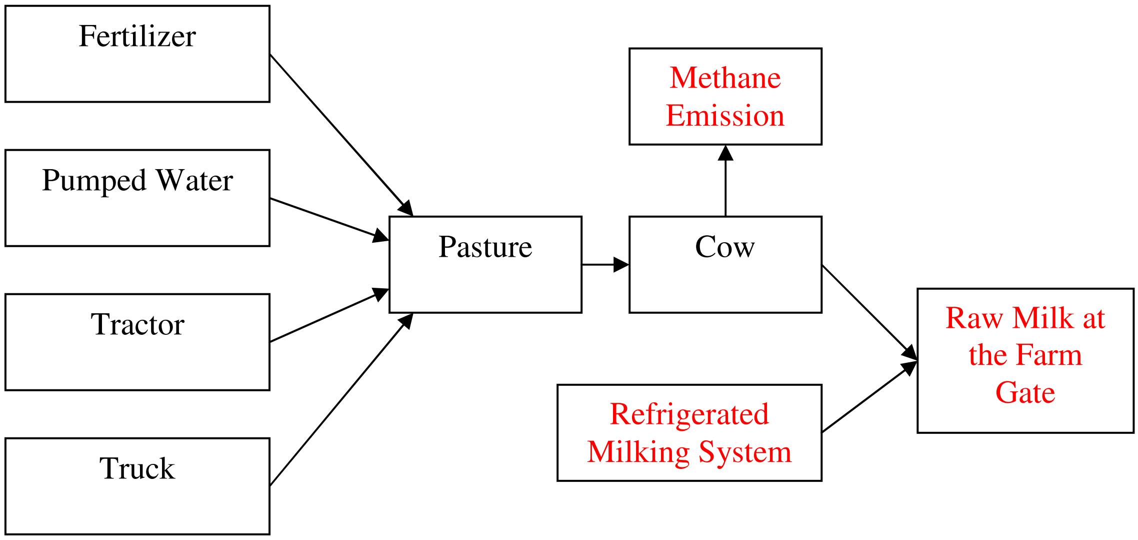


Figure C3: My Third Flowchart entitled 'Raw Milk Production' (new entries in red)

The number of flowcharts used may vary depending on how many processes need to be entered or how easily you can visualise the extra processes. These tips are only based on my experience with the program and are based on the easiest ways I found to input into the program. The help library in SimaPro5.1 is also very useful in interpretation of the life cycle impact assessments of the program in explaining the types of graphs and how they are shown. The libraries are also very helpful in the early stages of defining data quality requirements, which give an assessment of how relevant the data is to the life cycle you are modelling. Overall any questions on definitions are found in the SimaPro5.1 libraries very easily.

Appendix D – Data Given and Manipulations Required

This appendix contains the data given by the Department Primary Industries & Fisheries Mutdapily Research Station after a meeting showing progress with data gathered from previous studies. Manipulations are shown that were done to the given data to arrive at a compatible form for the software program.

Data Given and Manipulations Required

A simplified hypothetical farm modelled on tropical Queensland, with an annual rainfall of 1250 mm. The farm is assumed to have 100 cows and occupy 50 ha land area. The stocking density is 2 cows/ha. The milk production is assumed as 3750 litres per cow per annum. Feed input is purely from pasture production. Nothing else.

- Rain input = 1.25*50*10000=625000m^3 = 625tonnes
- Water requirement 65 L per cow per day or total 65*365/3750 = 6.33litres/liter of milk (from on farm storage no pumping required)

Summer season: Kikuyu grass with a yield 15t DM/ha. No irrigation involved.
Winter season: Ryegrass oversewn into Kikuyu pasture, with a yield of 10t/ha. Irrigation is required and only 20 ha used in winter.

- Therefore total annual winter yield is 10*20=200 t pasture, the total annual summer yield is 15*50=750 t pasture
- Total pasture production=750+200=950 tonne per annum
- The feed density is therefore 9.5t per cow per annum.
- And therefore 9500/3750=2.53 kg pasture consumed per litre of milk

Fertilizers:
Nitrogen: 250 kg/ha for summer (50 ha) and 350 kg/ha for winter (20 ha) so the total usage is 390 kg/ha per annum. Using Urea that contains 46% nitrogen.

- Summer: 250*50=12500kg
- Winter: 390*20=7800kg
- Total Nitrogen Required: 7800+12500=20300kg
- Total Urea Required: 20.3/0.46=44.13 tonnes

Phosphorus for pasture production: 30 kg/ha per annum.

- Total Phosphorus: 30*50=1500kg

Potassium for pasture production: 60 kg/ha/annum

- Total Potassium: 60*50=3000kg

Tractor used for spreading fertilizer and grass seeds. It may take 10 operations per annum. Previous calculations DPI&F have done worked on 2L diesel/ha for each spreading operation. No any form of artificial drying, silage and processing is involved in pasture and feed production.

- Fuel usage per annum: 2*10*50= 1000litres per annum
- In data library a small tractor available requiring a distance travelled of the tractor. Tractor in library used 0.28 kg of diesel to travel 1 km
- Distance travelled: 1000*0.86/0.28=3100km

A truck was also modelled to supply the farmer with fertilizer from the manufacture. The distance travelled was said to be 400km round trip and a 7.4 tonne truck required to carry all fertilizer (50 tonne roughly).

- Number of trips: 50/7.4=6.7 = 7 (rounded up due to cant do fractional trips)
- Distance travelled: 7*400= 2800 km

Each cow also produces some 100-150 kg. See Greenhouse Gas Emissions spreadsheet by Richard Eckard for methane emission per annum, depends on the assumed diet intake. The farm is also assumed to produce no solid waste, as all manure is to be used on-site as fertilizer.

- Found that cows on a good pasture based diet emit 140kg of methane/annum
- Emission per litre = 140/3750= 0.0373 kg/litre

Irrigation of the rye grass only:

- Total amount of irrigated water should be equivalent to 500 mm of rain fall or 0.5m*20ha*10000 m^2/ha = 100000 m^3 = 100 megalitre.

The pump should be able to pump this amount of water. Typical operating costs for irrigation systems - a travelling gun irrigator costs around $42/ML.

- Based on $1 per 10kWhr, this gives an energy requirement of 420kWhr to pump 1 megalitre (i.e. equals 1 kton).

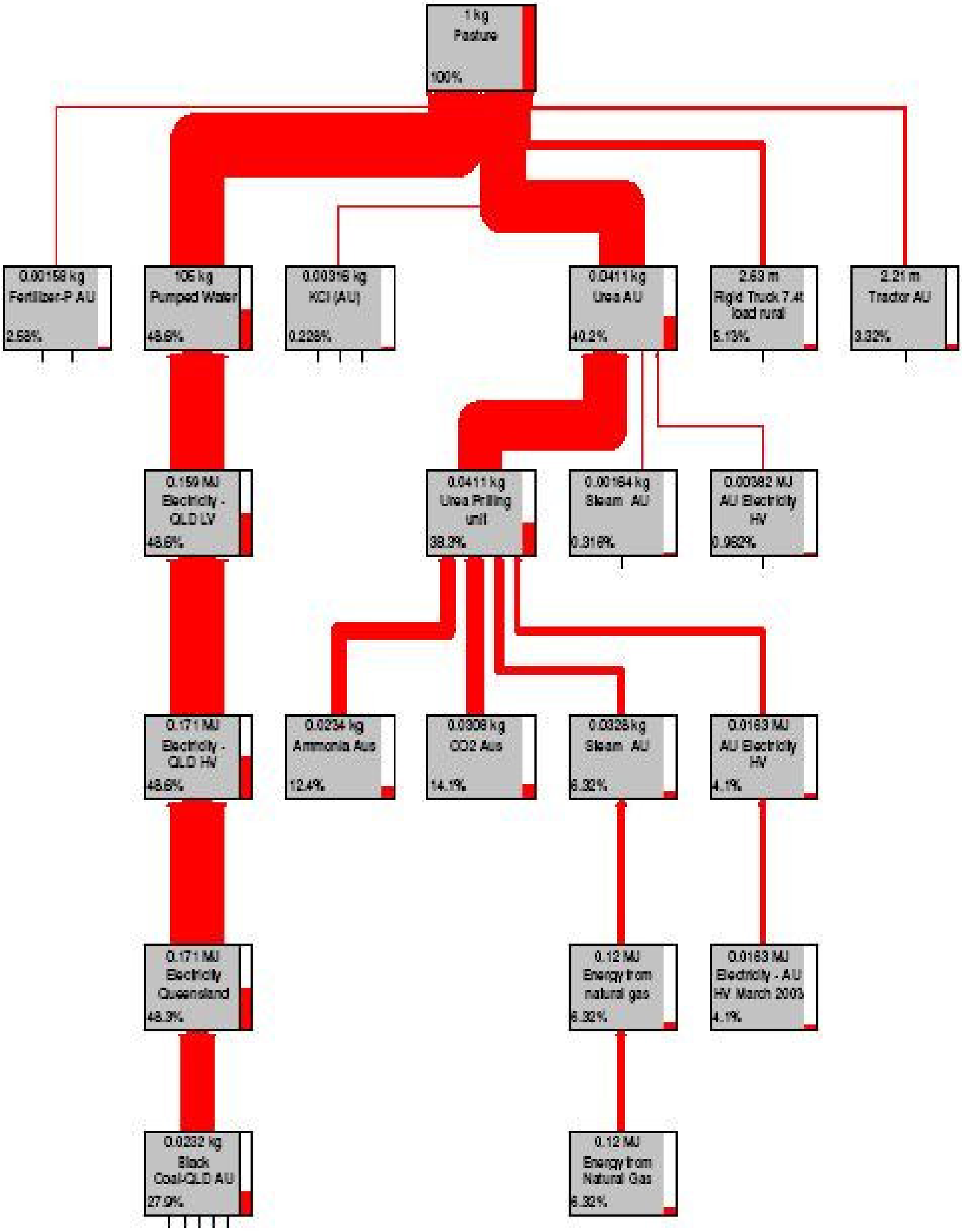
Furthermore, we also intend to take into account of the electricity used for temporary cool storage and milking machines. Queensland farmers spend about 0.4 c/L on milking and refrigeration. Based on some earlier work we did, our estimate was that $1 spent on electricity typically bought 10 kWhr of power.

- To Milk and refrigerate one litre of milk power used: 0.4{c/L}/100{c/$}*10{kWhr/$}= 0.04 kWhr/Litre of Milk

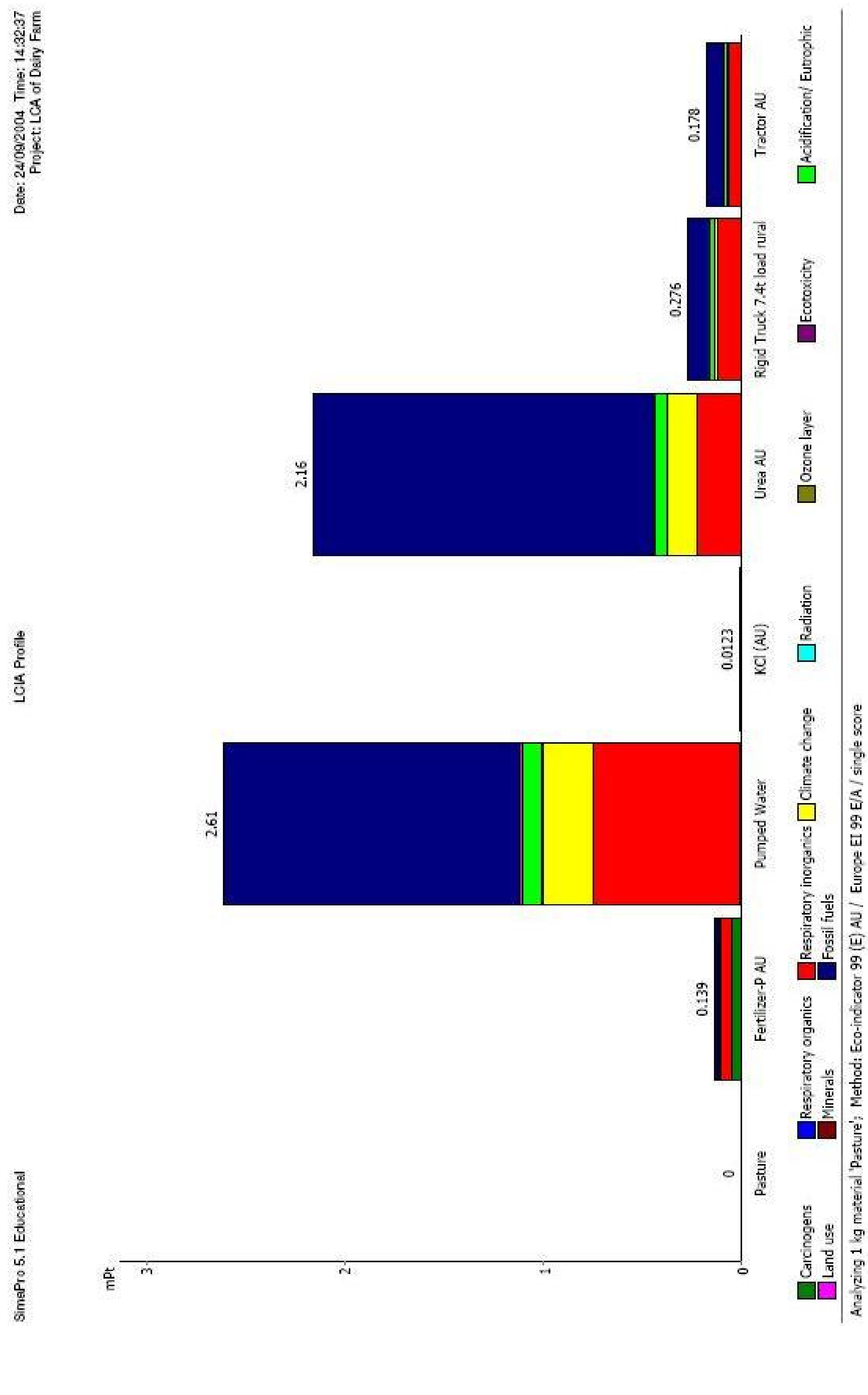
Appendix E – LCIA of Pasture Production

This appendix contains the full sized graphs and flowcharts that are shown in section 5.1.

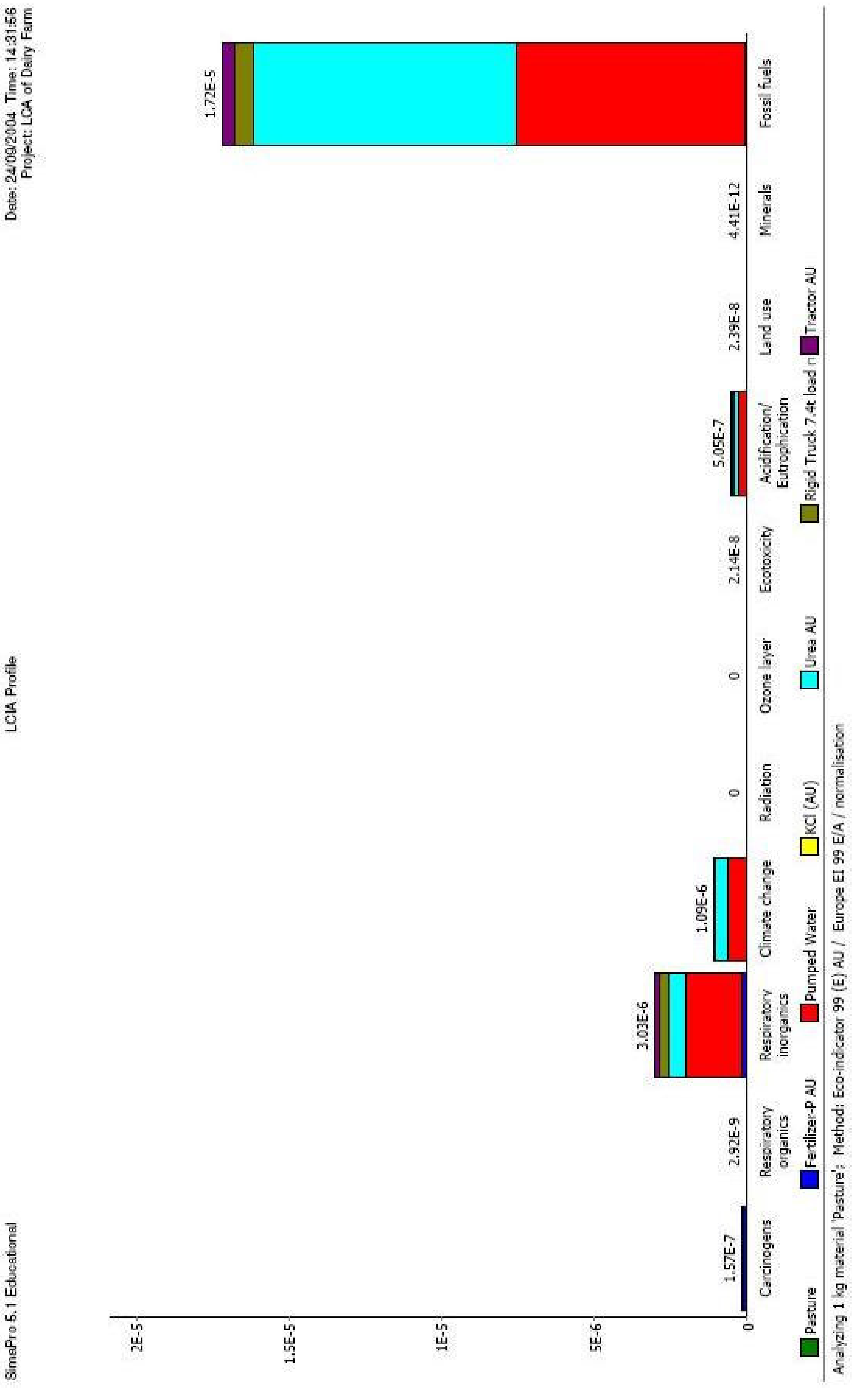
Pasture Tree – Using Single Score Assessment (Figure 5.2)



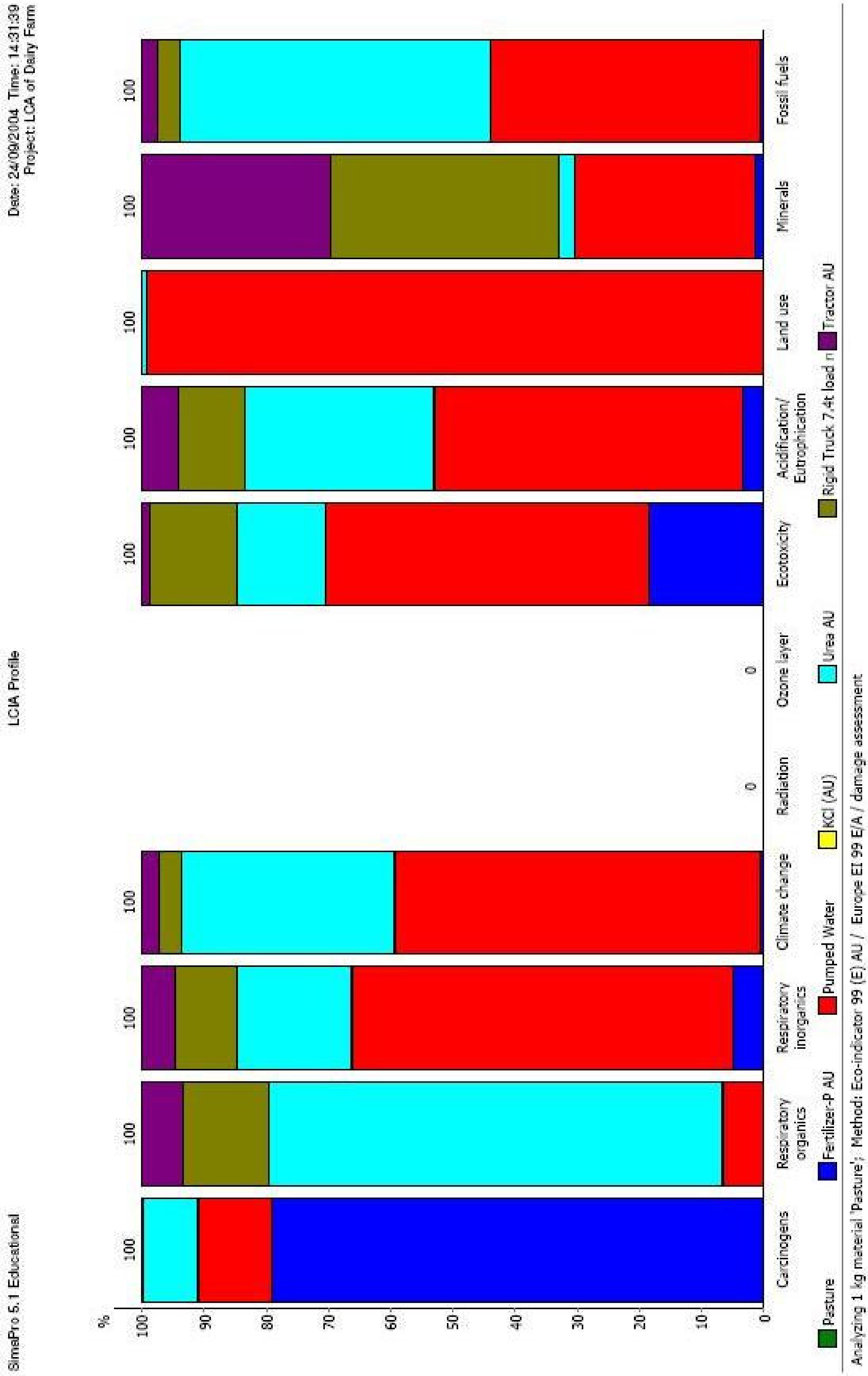
Pasture Single Score Assessment Graph (Figure 5.3)



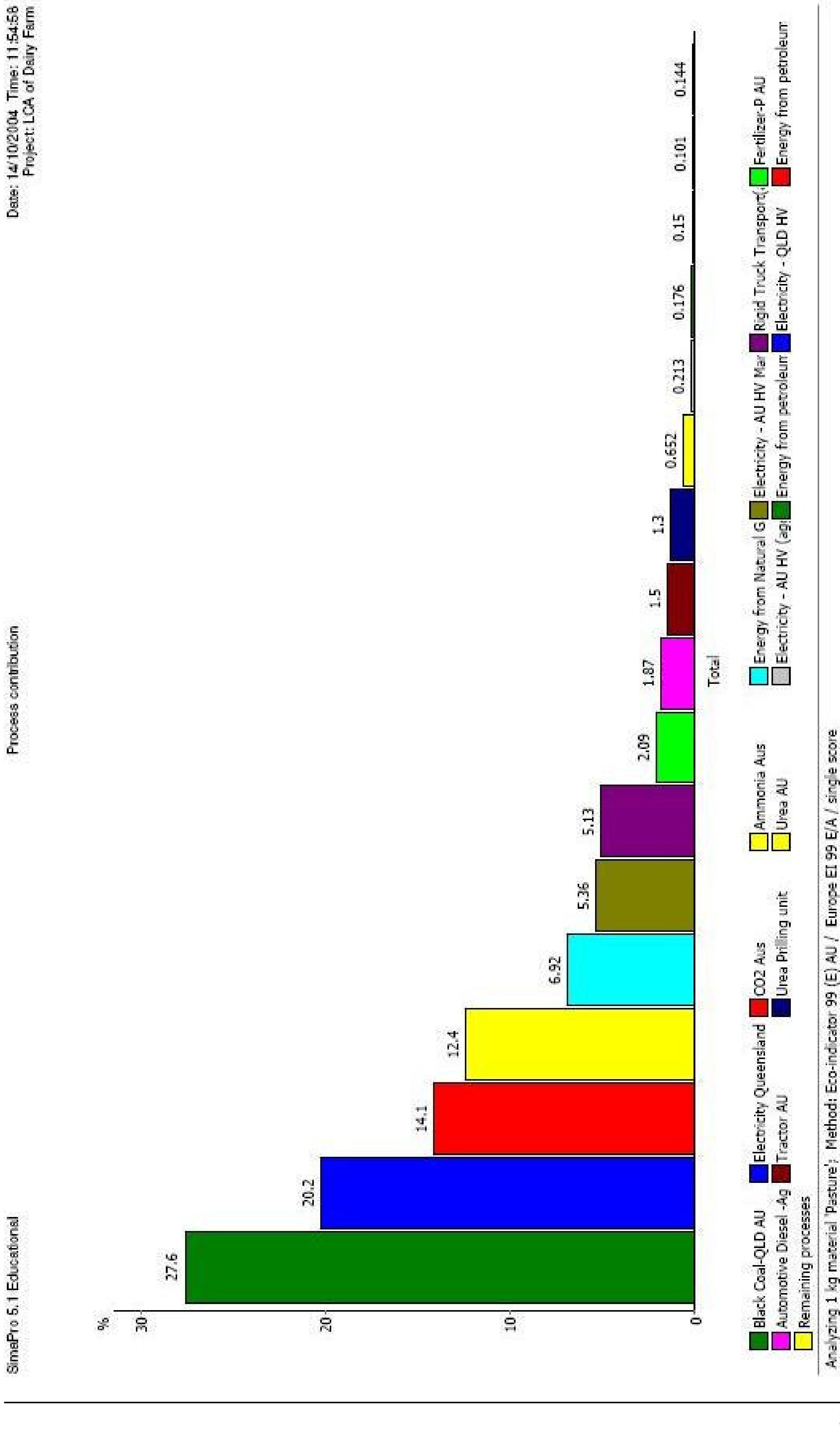
Pasture Normalisation **Assessment Graph** (Figure 5.4)



Pasture Characterisation Assessment Graph (Figure 5.5)



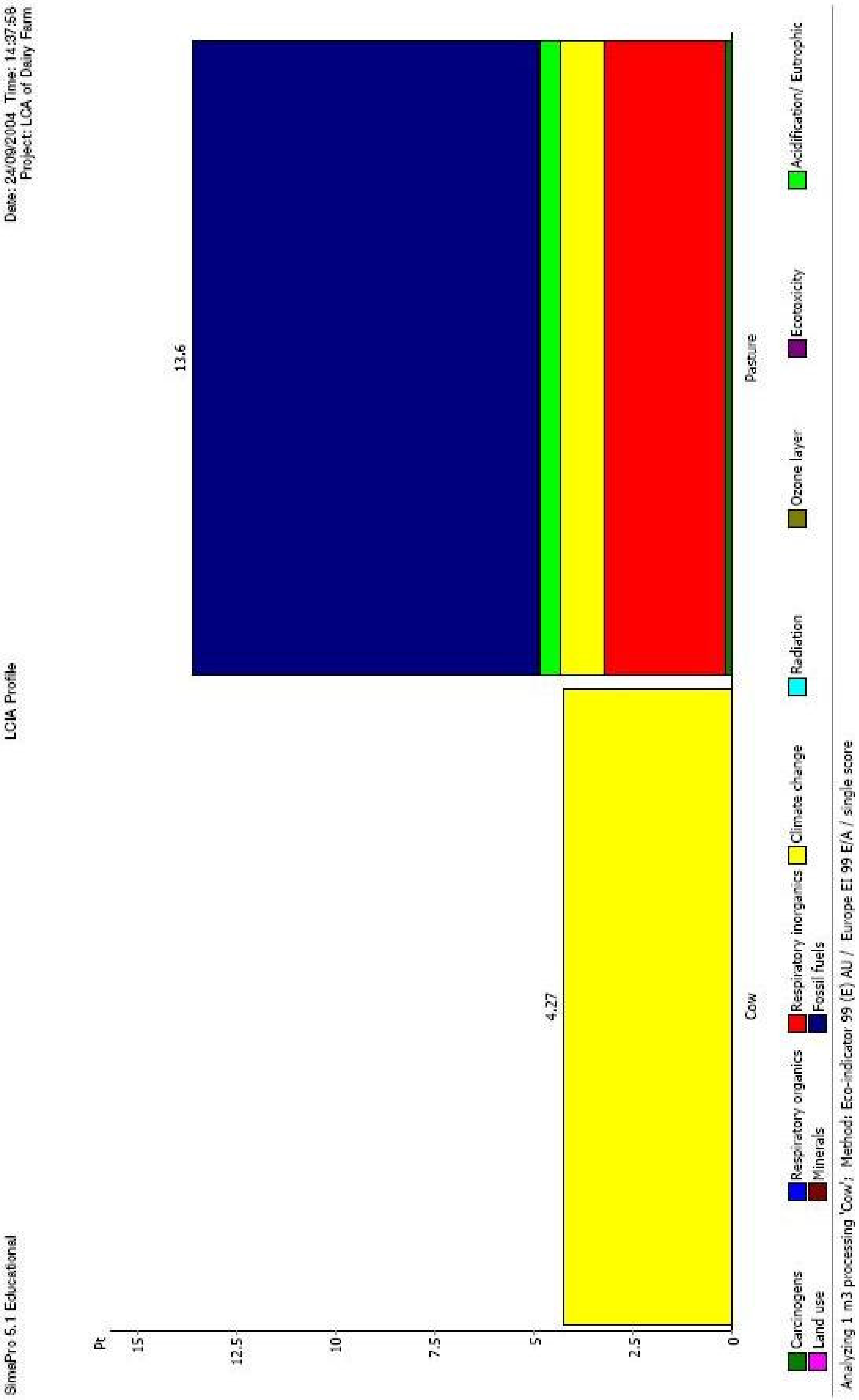
Pasture Single Score Process Contribution Assessment Graph (Extra)



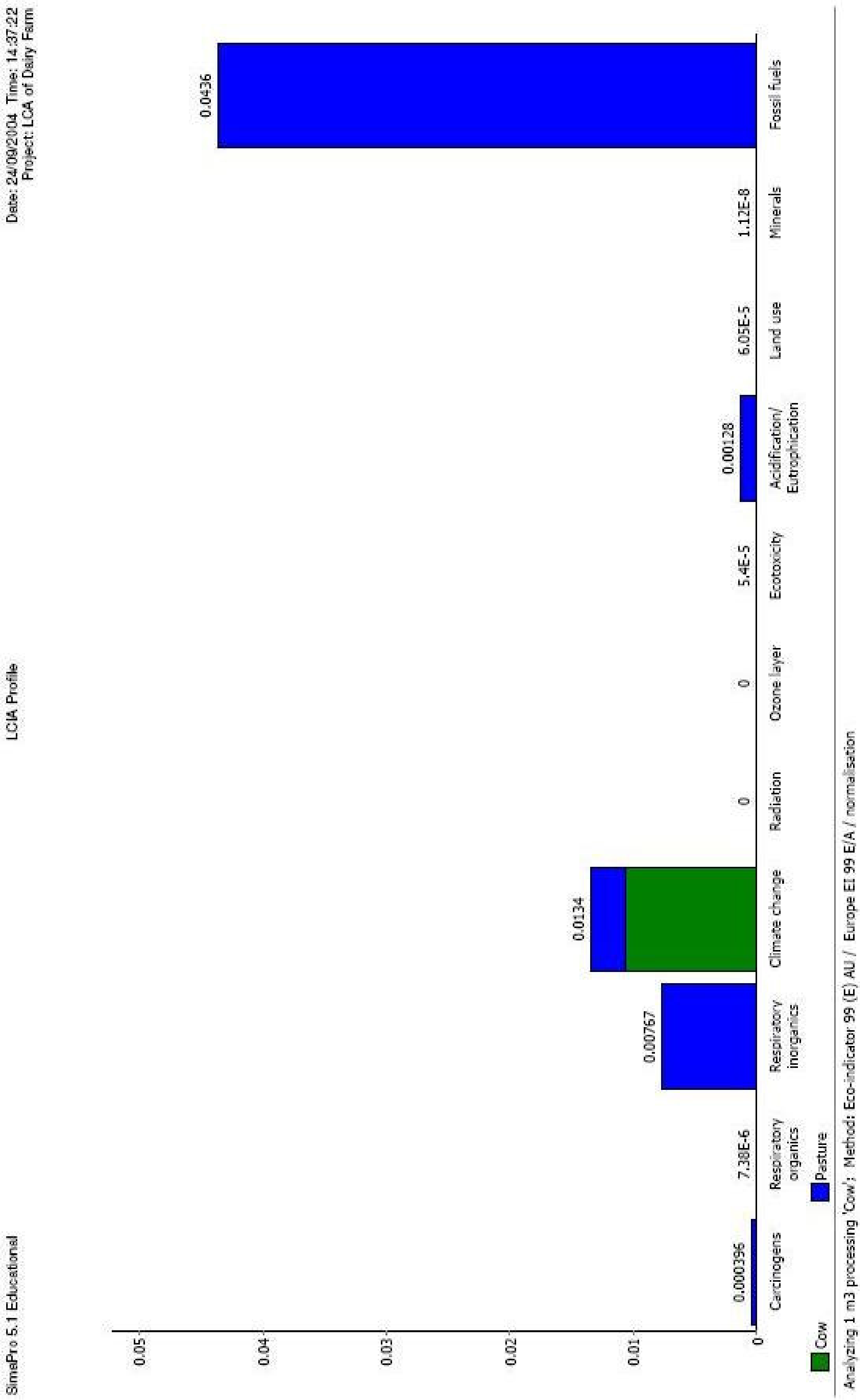
Appendix F – LCIA of the Cow “Pasture to Milk”

This appendix contains the full sized graphs that are shown in section 5.2.

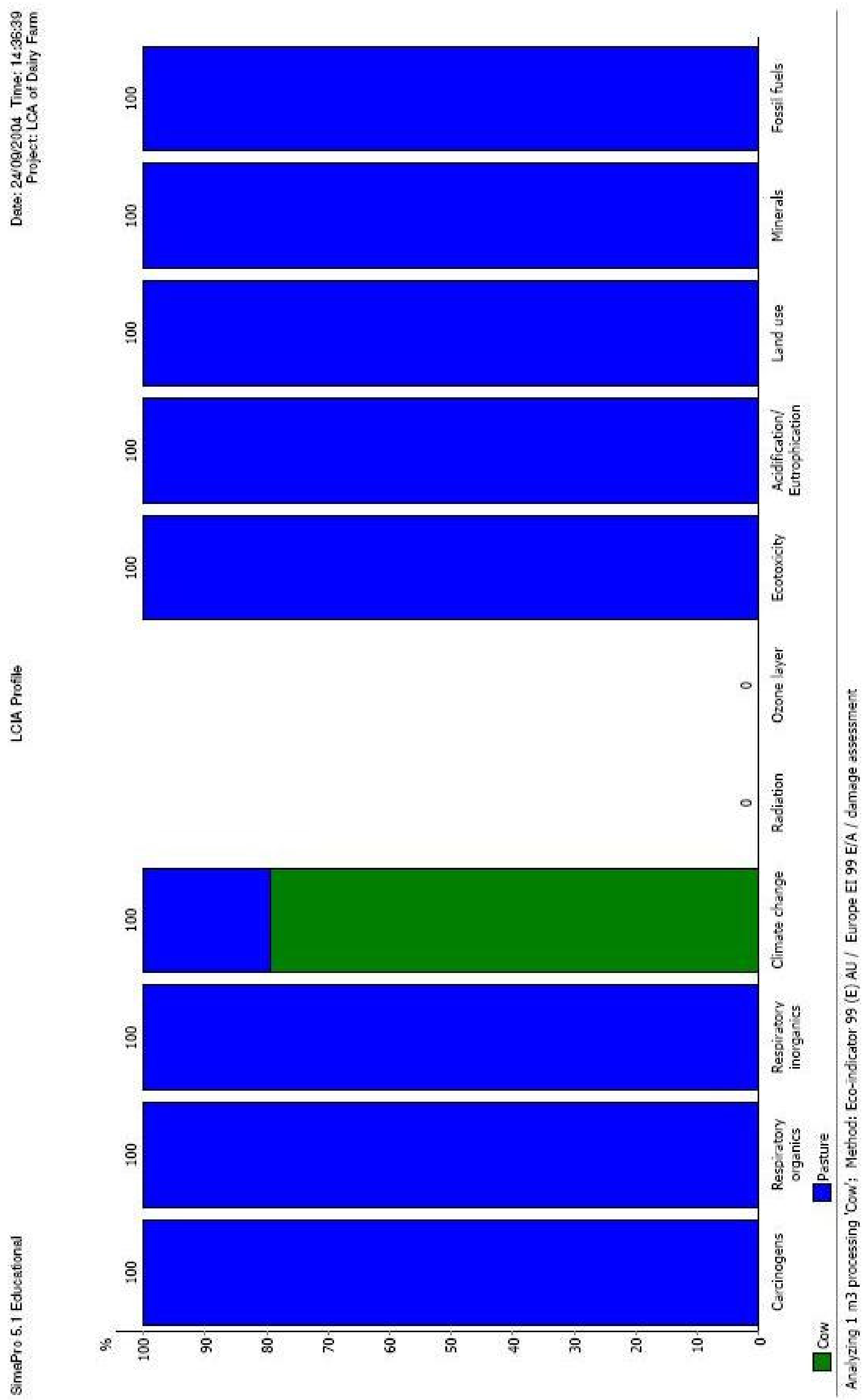
Cow Single Score Assessment Graph (Figure 5.6)



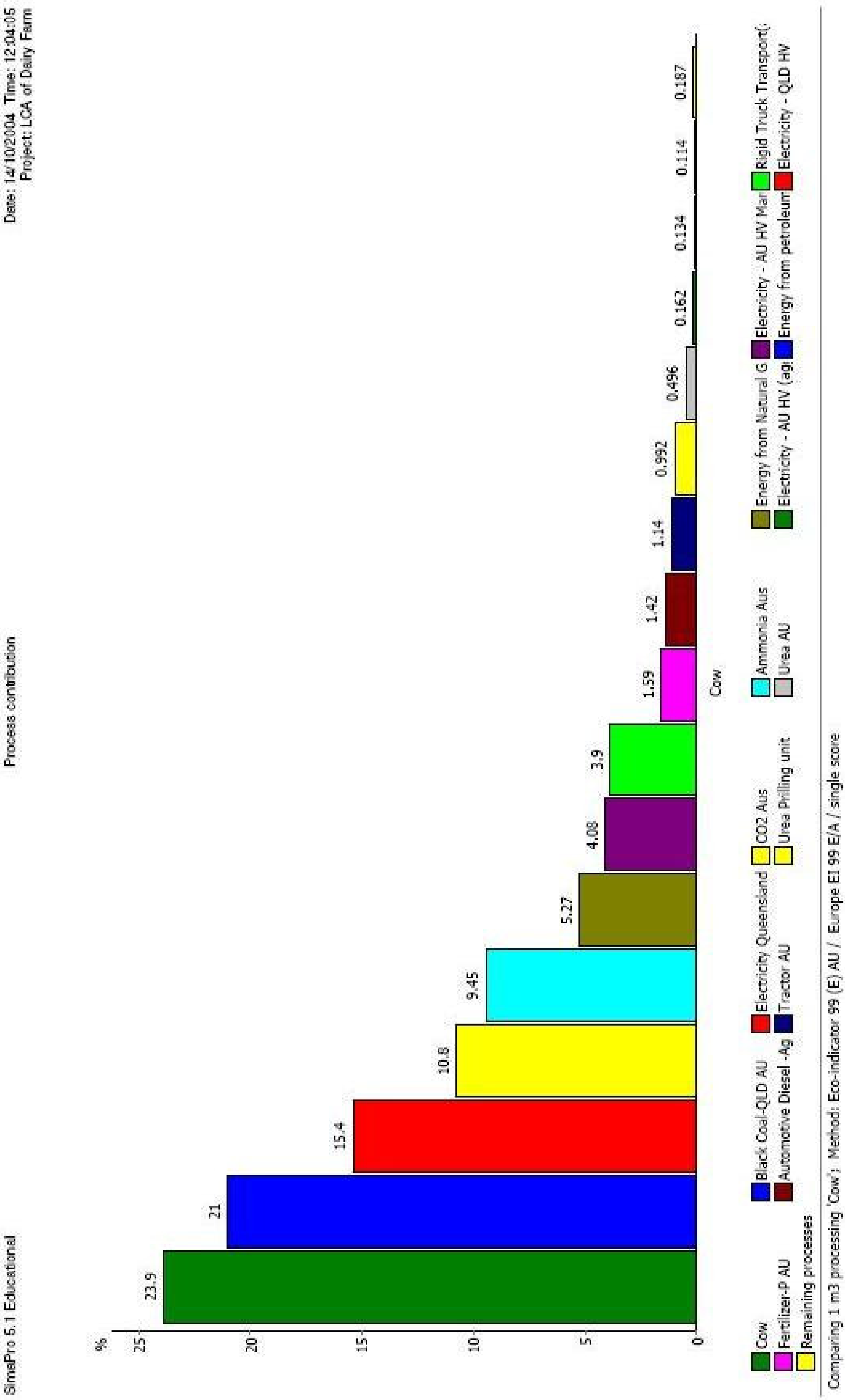
Cow Normalisation Assessment Graph (Figure 5.7)



Cow Characterisation Assessment Graph (Figure 5.8)



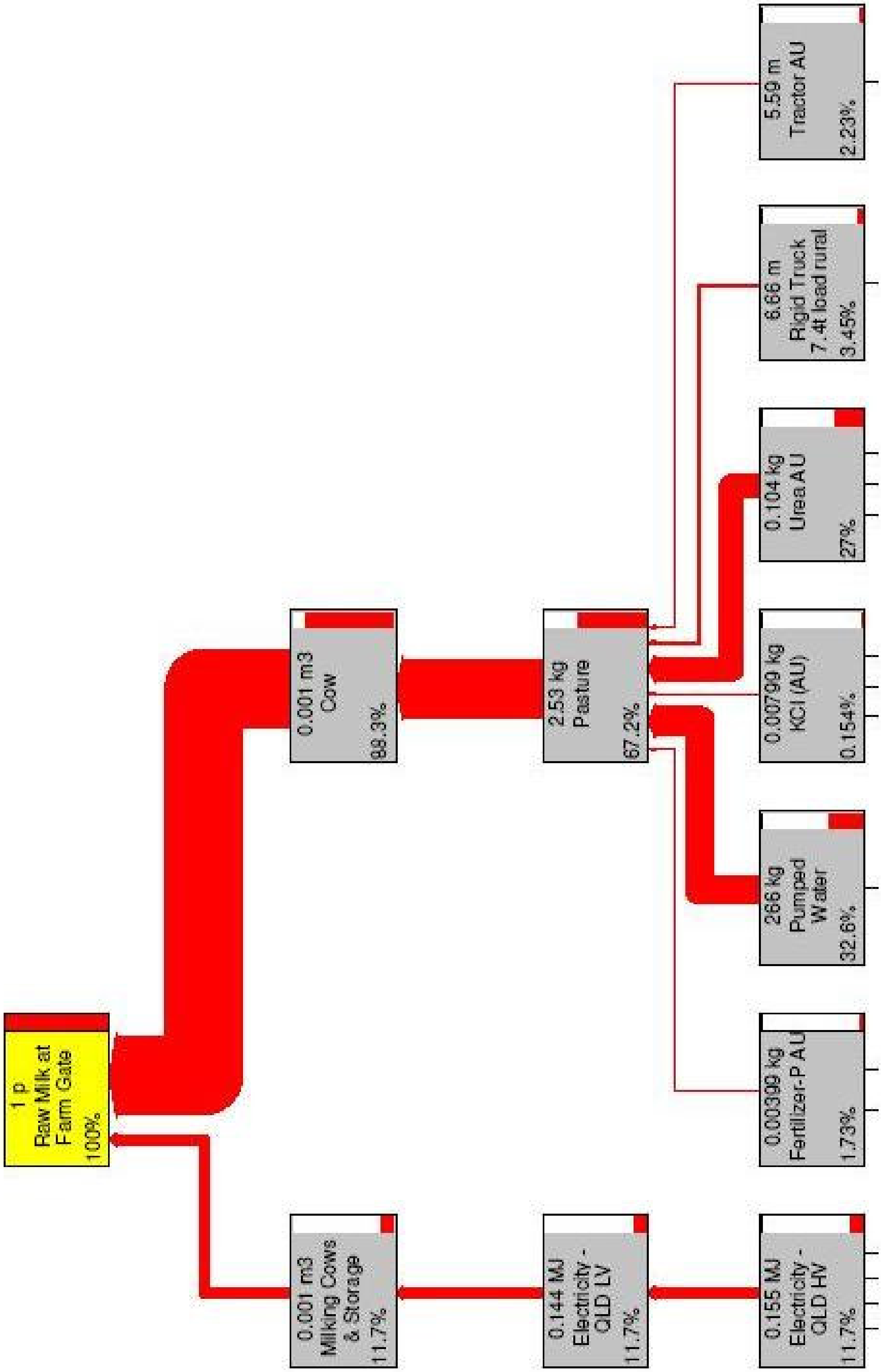
Cow Single Score Process Contribution **Assessment Graph** (Extra)



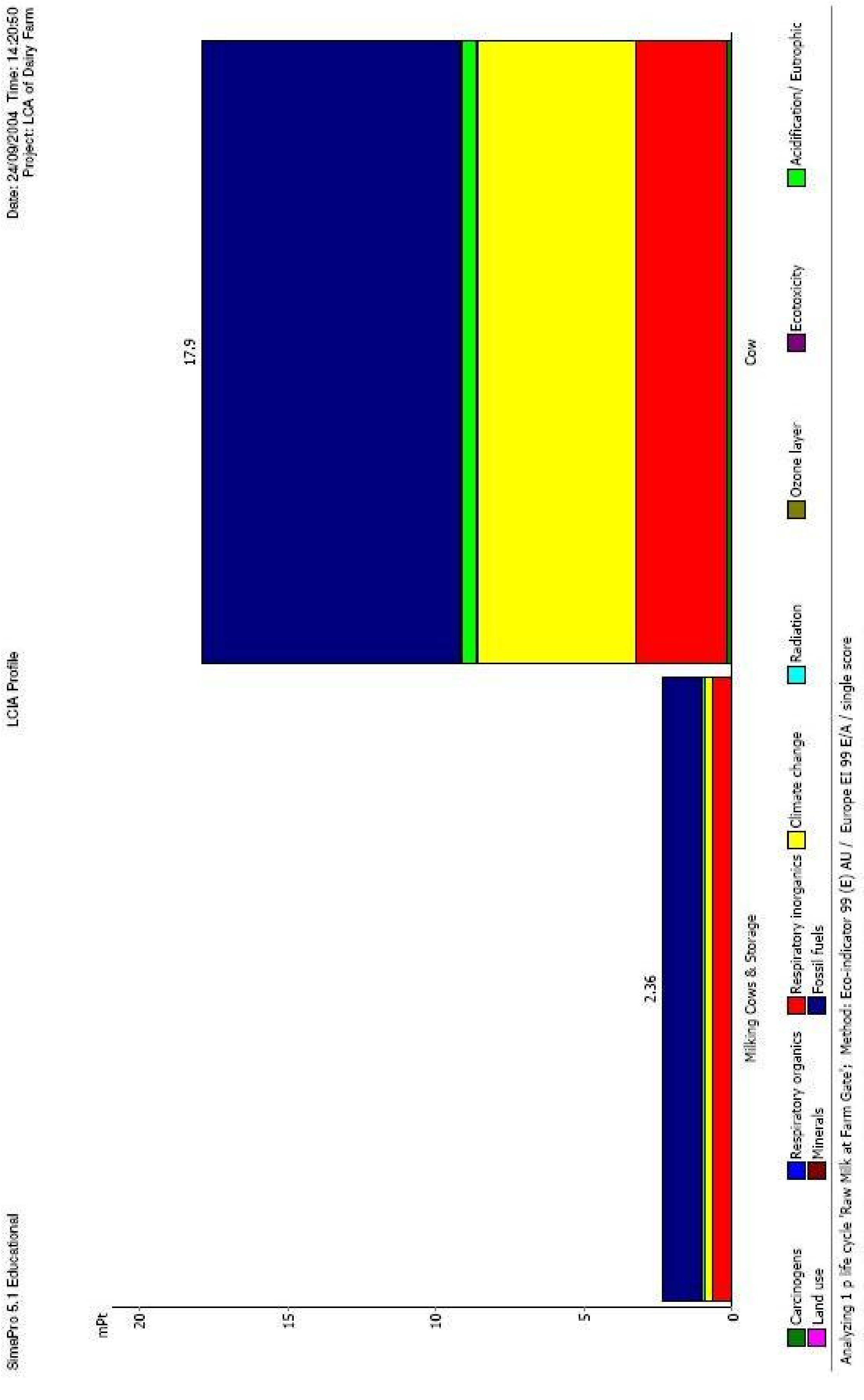
Appendix G – LCIA of Raw Milk Production

This appendix contains the full sized graphs and flowcharts that are shown in section 5.3.

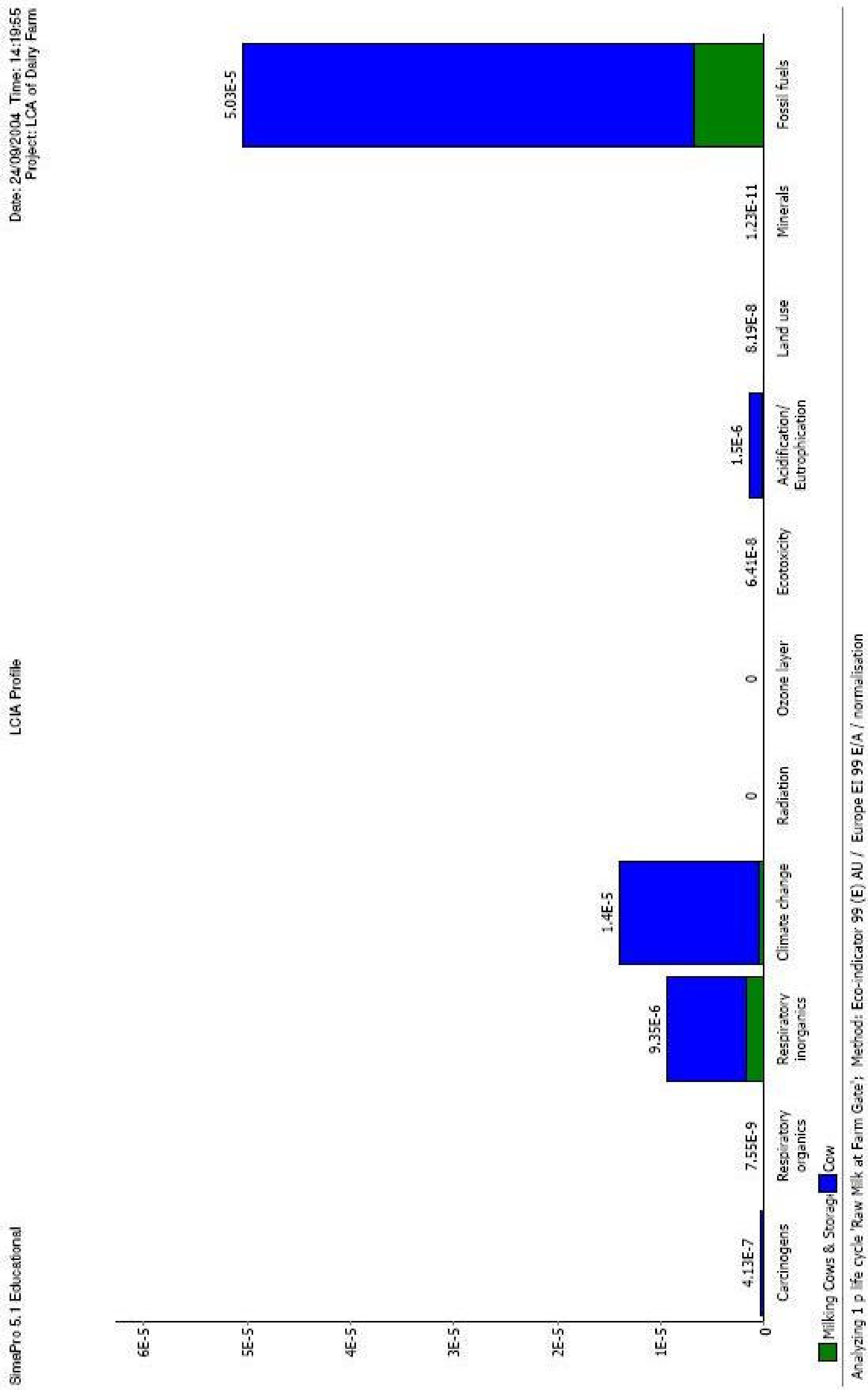
Raw Milk Tree - Using Single Score Assessment (Figure 5.1)



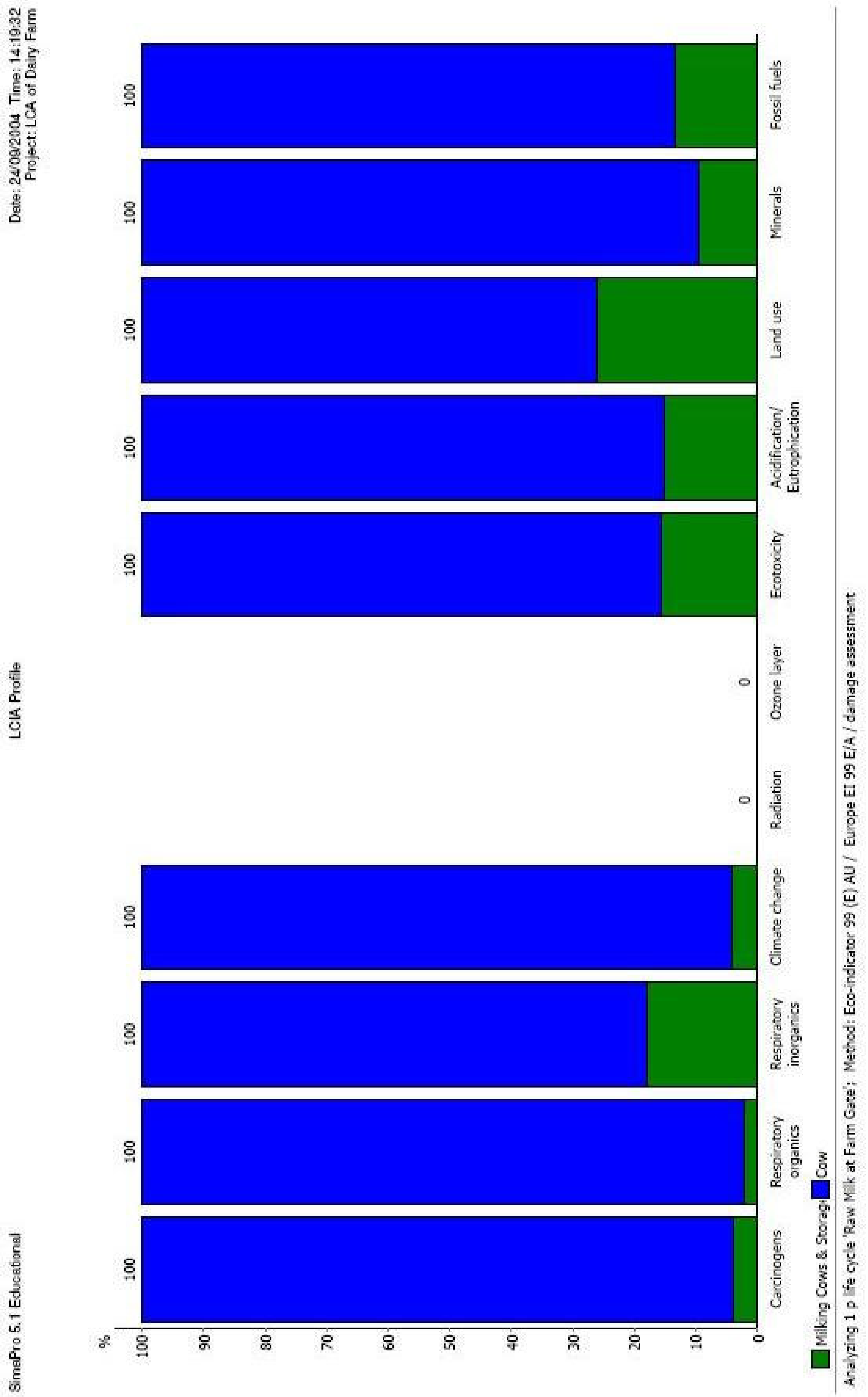
Raw Milk Single Score Assessment Graph (Figure 5.9)



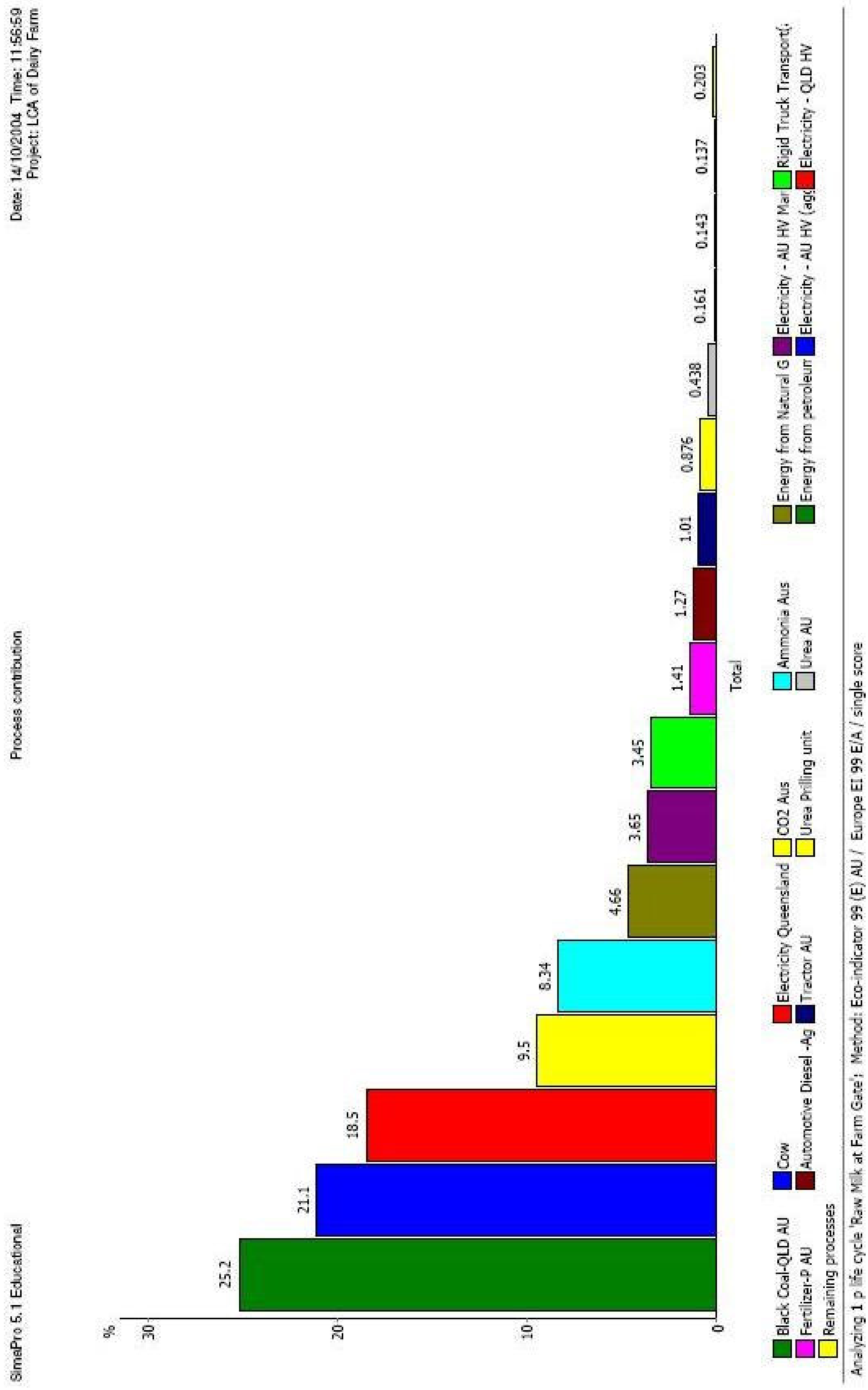
Raw Milk Normalisation Assessment Graph (Figure 5.10)



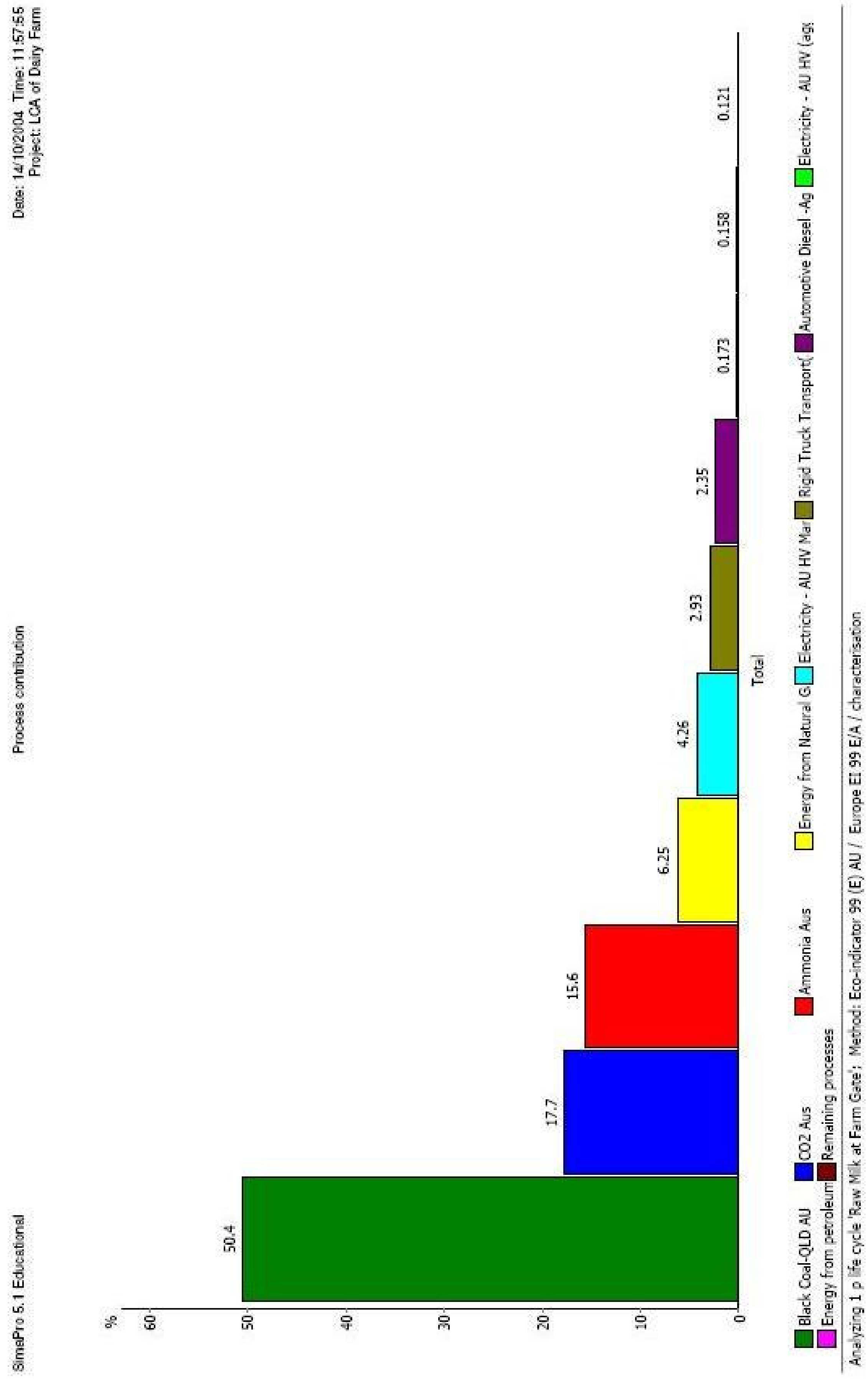
Raw Milk Characterisation Assessment Graph (Figure 5.11)



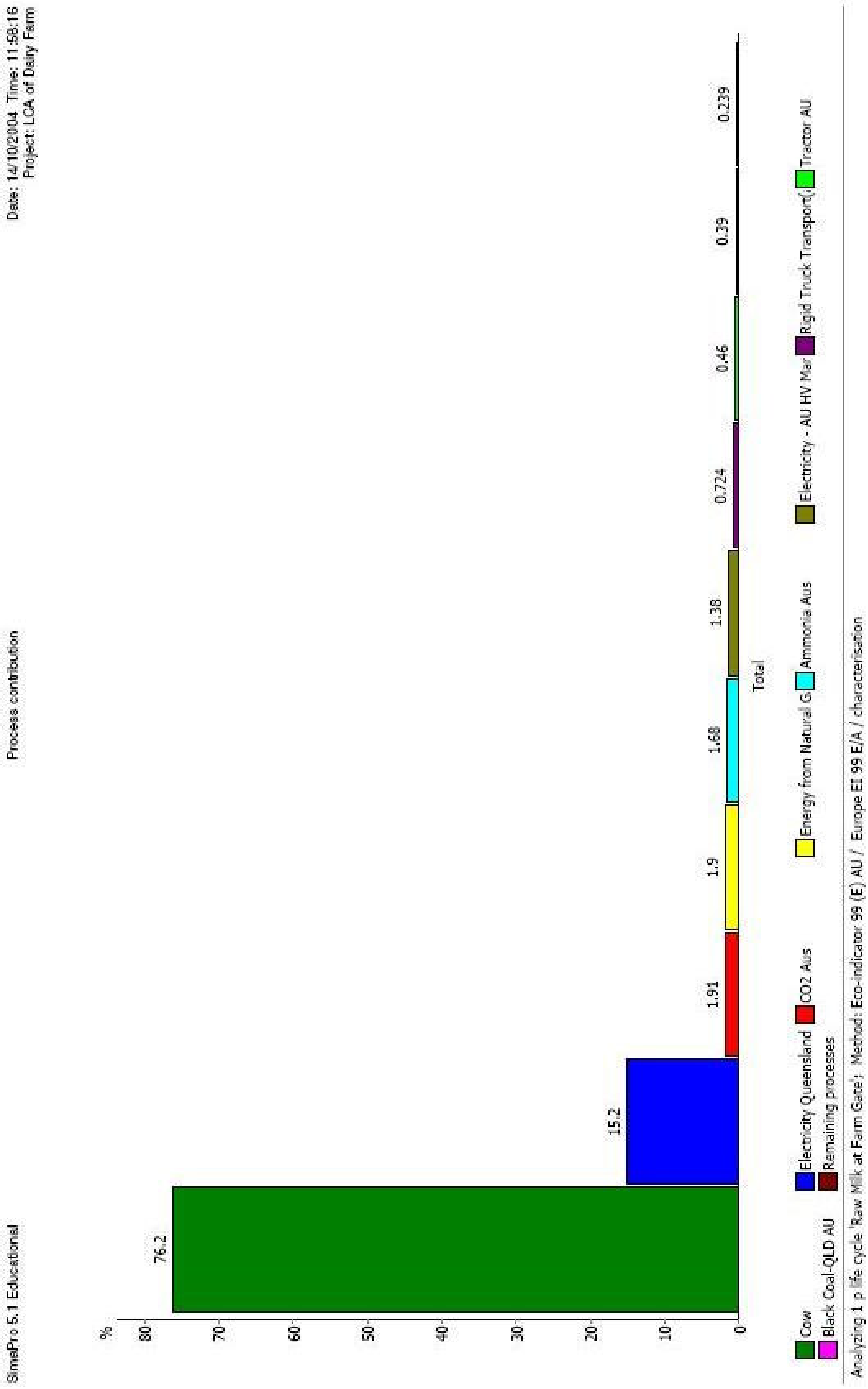
Raw Milk Single Score Process Contribution Assessment (Figure 5.12)



Raw Milk Fossil Fuels Process Contribution Assessment (Figure 5.13)



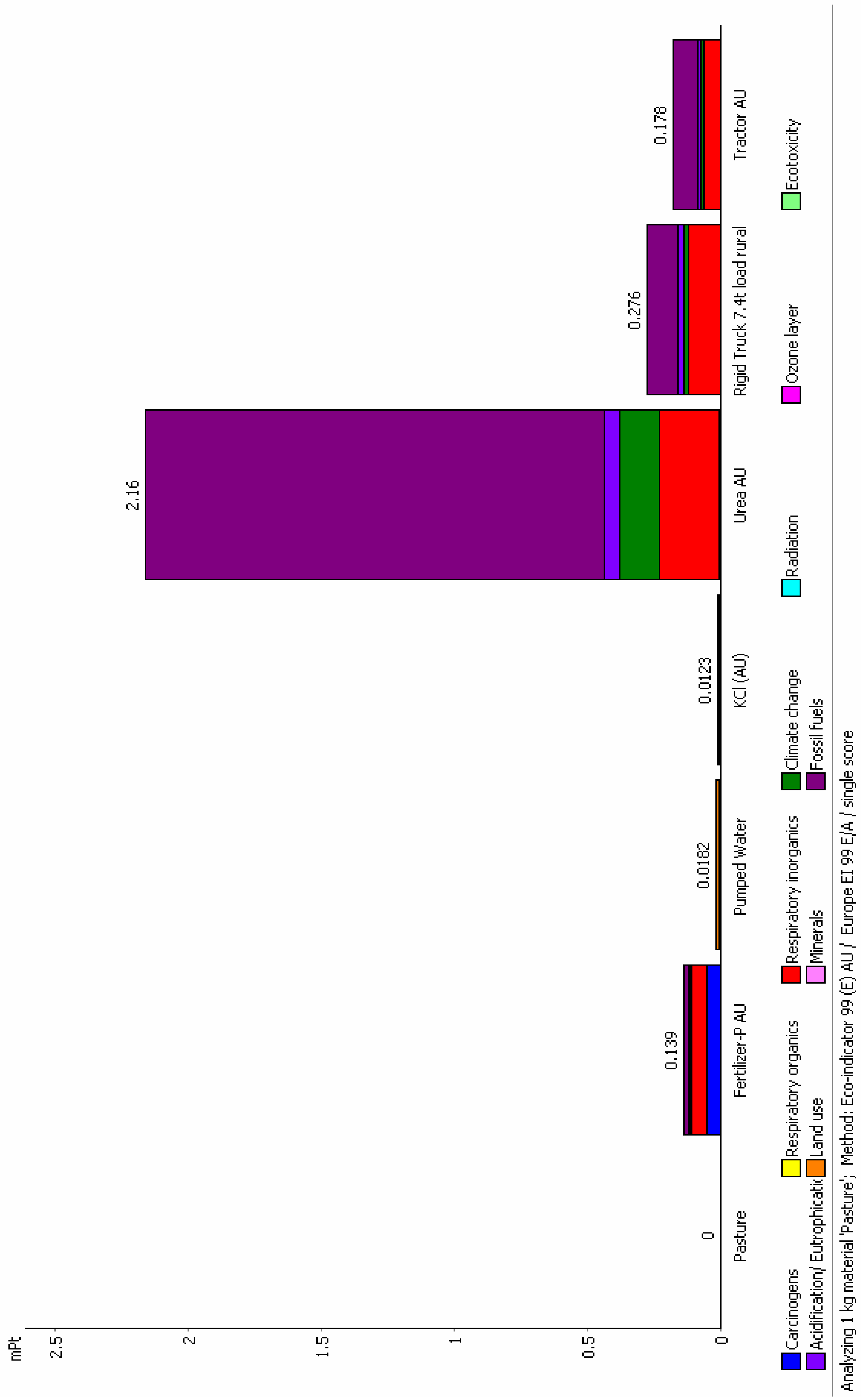
Raw Milk Climate Change Process Contribution Assessment (Figure 5.14)



Appendix H – Sensitivity Analysis

This appendix contains the full sized graphs that are shown in section 6.4 Sensitivity Analysis.

Single Score of Pasture – Biogas Power Generation (Figure 6.1)



Characterisation of Pasture – Biogas Power Generation (Figure 6.2)