Analysis of Sustainability in the Pig Production Chain:

Life Cycle Assessment of Contrasting Scenarios

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A thesis submitted for the degree of

Doctor of Philosophy

Newcastle University

School of Agriculture, Food and Rural Development

December 2009

Declaration

This thesis has been composed by myself and has not been submitted as part of any previous application for a degree. The work of which this is a record has been done by myself unless otherwise stated. All sources of information have been specifically acknowledged by means of referencing.

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Abstract

This research investigated the environmental impact of the pig production chain by modelling contrasting scenarios. Life Cycle Analysis (LCA) and scenario analysis methodologies were used to reveal the main opportunities to improve sustainability. Pig production systems were modelled in two countries (The UK and Mexico), each with a standard production system and on alternative system. This gave four scenarios which were different in the degree of integration that exist between pig and crop production and were then specified in detail to allow for comparison of environmental impact.

This study used two strategies to analyse the four scenarios: A pre-assessment facilitated the construction of the system boundary and clarified the processes and commodities which should be included in the Life Cycle Inventory (LCI). A hybrid-LCA method combined a detailed collection of environmental burdens (e-burdens) from the main sources (process-LCA) and a broad compilation of e-burdens from indirect sources (Economic Input Output-LCA).

The pre-assessment, conducted as a general LCA, explored novel techniques to construct the system boundary and explore the supply chains in detail. This step clarified the importance of the supply chains of different commodities that are used in the pig farm. The importance of previously reported commodities and processes that mainly contribute to the environmental impact, i.e. feed consumption and manure fermentation were confirmed. Novel findings included the importance of the environmental impacts of goods and services, i.e. machinery, equipment, disinfectants and medicines, that have negligible weight in the impact of environmental indicators that are traditionally analysed (global warming, acidification and eutrophication). The inclusion of novel indicators, such as ozone depression and ecotoxicity to water and soil, demonstrated the importance of including in the LCA those commodities and indicators that have been excluded in many previous studies on the sustainability of pig production.

Subsequently, the hybrid-LCA method allowed the expansion of the system boundary of the LCA in a detailed evaluation of each scenario. Results showed the UK scenarios to be superior in management of nutrient flow, by manure management and good agricultural practice. Opportunities to capture methane and recycle nutrients for crop production in the Mexican scenarios were highlighted. In contrast, reduction in machinery and equipment use and fuel consumption were the main opportunities which emerged for the UK scenarios. In addition, specific opportunities to reduce the environmental impact of different pig supply chain sectors were identified in each scenario.

In conclusion, the EIO-LCA method allowed for an extension of the traditional system boundary of the LCA, to encompass those e-impacts that have not been included in previous studies. The contrasting of different scenarios allowed emphasis to be placed on opportunities to reduce environmental impact of pig production by highlighting the main challenges in each case. This avoids the controversial issue of denoting a set of specific e-impacts that then favour one production system over another.

Key words:

Pig production, sustainability, Hybrid Life Cycle Analysis, UK, Mexico, LCA, supply chain.

Acknowledgements

The end of this challenge is the beginning of another one, this statement makes me very happy because of the support of friends that I have enjoyed over the course of this PhD.

Firstly, I would like to thank my supervisors. Particularly Sandra Edwards and Jonathan Guy have been supportive and committed during this time of my life, as this PhD would not have been completed without their support and patience. Special thanks to Elizabeth Stockdale, who provided guidance at key points in my research. Thanks to Francisco Trigo for believing that I could complete this PhD in the first place.

This project was very challenging and therefore I have plenty of people to thank for their support. Thanks to the three main researchers at the Research Centre Foulum, Denmark: John Hermansen, Thu Lan Thi Nguyen and Lisbeth Morgensen. John and Thu Lan gave on enormous amount of help throughout, especially in those difficult tasks with nutrient flow calculations and modelling.

Thanks to all staff at the CEIEPP-Jilotepec in Mexico for the friendship and support. Special thanks to Maria Elena Trujillo, German Borbolla and Francisco Galindo from FMVZ in Mexico for advice and support. German helped particularly with the formulation of pig diet. Thanks to entire AMVEC specialists for all their patience and assistance during the parameterisation of farms in Mexico. Special thanks to Jose Maria Wence and Luis Morales Santini for help in overcoming certain difficulties during the collection of farm information. Thanks to Magdalena Escamilla and Rodrigo Merino for helping with the administration aspects of my scholarship.

Thanks also to my family for understanding my absences over the last three years-either a long time away from my parents or countless afternoons from my wife and son. One note of special thanks goes to Alejandra for all her love and support, endless patience, as well as unwavering trust in my capacities. Special thanks to my son Rafael for his enthusiastic attitude and humorous jokes.

Finally important acknowledgements should be mentioned to the National Autonomous University of Mexico (UNAM) and DGAPA staff for maintaining a healthy flow of my scholarship.

Publications as a result of this research

Refereed papers:

Olea, P. R., Guy, J., Edge, H., Stockdale, E. A. and Edwards, S. A. 2009. Pigmeat supply chain: Life cycle Analysis of contrasting pig farming scenarios. *Aspects of Applied Biology.* **95:** 91-96.

Conference abstracts:

Olea, P. R., Guy, J., Edge, H. and Edwards, S. A. 2009. The pigmeat supply chain: pre-assessment for a Life Cycle Inventory. *Proceedings of the British Society of Animal Science 2009.* p.126.

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List of Abbreviations

AIAO	All-In All-Out
AP	Acidification Potential
Bo	Capacity of volatile solids to produce methane
b-sow	breeding sow
C	Carbon
CFC	Chlorofluorocarbon
CGG	General Coordination of livestock in Mexico
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2-eq	Carbon Dioxide equivalent
Con-Feed	Feed and Crop production
CP	Crude Protein
Defra	Department for Environment, Food and Rural Affairs
DS	Danske Slagterier
DTI	Department for Trade and Industry
e-burden	Environmental burden
EDIP	The Environmental Design Industrial Products
e-impact	environmental impact
EIO	Economic Input-Output
EIO-LCA	Economic Input-Output Life Cycle Analysis
EP	Eutrophication Potential
ESCM	Environmental Supply Chain Management
EU	European Union
FADN	Farm Accountancy Data Network
farm-MM	Manure Management at farm level
FE	Fossil Energy
feed-N	Total nitrogen content in feed
feed-P	Total phosphorous content in feed
fertiliser-N	Nitrogen used for plant fertilisation
FSC	Food Supply Chain
GHG	Greenhouse Gas
GWP100	Global warming potential (100 years)
Ind-Comm	Industrial commodities
IO tables	Input-Output tables
IPP	Integrated Product Policy
kgdw	kilogram dead weight
LCA	Life Cycle Assessment or Analysis
LCI	Life Cycle Inventory
locMEX	Local pig production system in Mexico

M	Manure
M&E	Machinery and Equipment
manure-N	Total nitrogen content in manure
manure-P	Total phosphorous content in manure
MCF	Methane Conversion Factors
mg	milligrams
MJ	Mega Joules
MM	Manure management
N	Nitrogen
N_2O	Nitrous oxide or dinitrogen oxide
NAICS	North American Industrial Classification System
NH_3	Ammonia
NO_3	Nitrate
NOx	Nitrous oxides
NRC	National Research Council
O_3D	Ozone Depletion
orgUK	Organic pig production system in the United Kingdom
P	Phosphorous
PhS	Photochemical Smog
pig-N	Total nitrogen content in pigmeat of live pigs
pig-P	Total Phosphorous content in pigmeat of live pigs
plant-N	plant available N
PM10	Particulate matter less than 10 micrometers
PPC	Pig Production Chain
pre-LCA	pre-assessment of the LCA
process-LCA	Process Life Cycle Assessment
PSC	Pigmeat Supply Chain
PSC-Process	Pigmeat Supply Chain- Process
SALSA	Systems Analysis of Sustainable Agriculture
SCM	Supply Chain Management
SO_2	Sulphur dioxide
stdMEX	Standard pig production system in Mexico
stdUK	Standard pig production system in the United Kingdom
tlw	A tonne of pig live weight at the farm gate
TxS	Chronic ecotoxicity to Soil
TxW	Chronic ecotoxicity to Water
UNEP	United Nations Environmental Programme
up-PPC	upstream sector of the Pig Production Chain
VCA	Value Chain Analysis
VOC	Volatile Organic Compounds
VS	Volatile Solid

Chapter 1 Introduction

The Food and Agriculture Organisation of the United Nations calculated that total meat consumption *per capita* will increase world wide twice times between now and 2050, and by 2.5 for 2100 in developing countries (Kanaly *et al.*, 2009). World meat demand is expected to change as the income in developing countries increase. In developed countries with current consumption levels, future per capita meat consumption may not change or even decrease (Kanaly *et al.*, 2009). However, the average meat consumption in developed countries has been three times higher than that in developing countries since the end of last century (Delgado *et al.*, 2000). At the present pigmeat is the major contributor to animal protein in all developing countries including China (Kanaly *et al.*, 2009). The production increment of total meat is expected to be mainly caused by an increase in pig and poultry meat. Even than in the past, trends in animal production for developing countries had considerable uncertainty, the general tendencies go toward intensification of production systems. Alternative systems have arisen as response to this pressure. In some cases relationship between sectors in the supply chain and in others the pig production system have changed. Thus different systems offer different options in the pigmeat supply chains and their possibilities of sustainability can vary as much as their links give them flexibility (Bourlakis and Weightman, 2004).

1.1 *Definition and structure of the pigmeat supply chain*

Being high in the natural food chain, humans possess the special characteristic of being omnivorous. Thus, as the last step (link) in the natural interchange process of matter and energy, the human has two functions. Firstly as a consumer, to eat vegetables and meat, and secondly as a business person to establish interpersonal, environmental and animal relationships to produce and provide the wide diversity of foods. So, from the first human settlements until the present time, the food supply chain has been developing in parallel to the growing complexity of human society.

A company related with the supply of food must have links to suppliers of raw materials and also links to other companies which will bring its product to the end-user. Sinclair (2002) defines the pigmeat supply chain (PSC) as the full range of activities from the earliest level of input, through processes along the chain, to delivery of the final product to the consumer. In this context, "the full range of activities" is undertakes by different enterprises which are integrated in the chain. These multiple enterprises are organized in a network of food-related business through which food products move from production through to consumption to deliver consumer value (de Castro *et al.*, 2005).

From the farm to the consumer, each different enterprise in the entire production process is viewed as a link in the chain. The food supply chain, therefore, represents all links which manage the entire set of production, manufacturing/transforming, distribution and marketing activities by which a consumer is supplied with a food (Opara, 2003).

Food enterprises are grouped as producers, processors/manufacturers or retailers (Sinclair, 2002; Agra CEAS, 1999). Furthermore, a meat supply chain can include the additional steps of feed production, animal breeding and subsequent rearing as part of the business enterprises in the producer sector. Abattoir and processing/manufacturing meat plants are classed as the processor sector. Finally, food distributors or marketers, supermarkets or retailers and butchers are considered in the retailer sector as shown below in Figure 1.1 So a pig farmer, for example, extends upstream to feed producers and downstream through abattoir and retailers. However, the PSC division is not always the same.

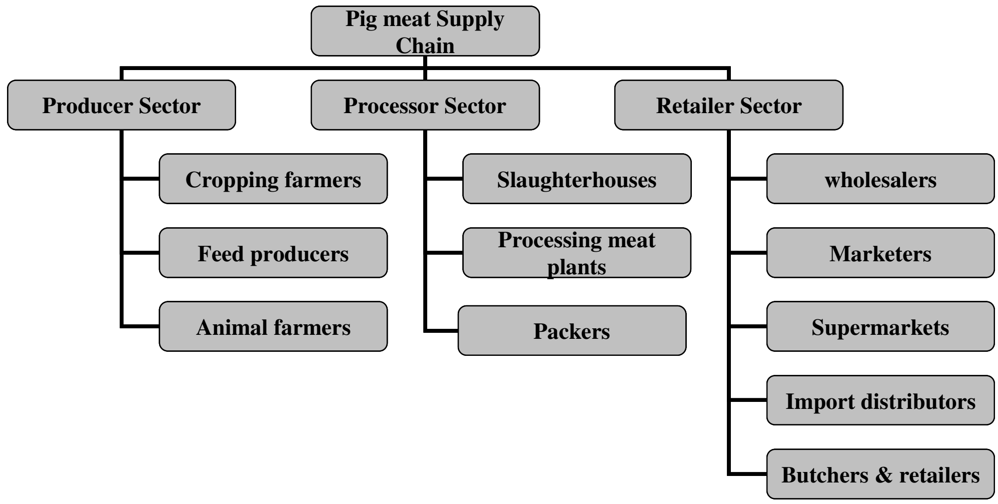

Figure 1.1 Sectors and subsectors in the PSC, adapted from Agra CEAS (1999), Hamm *et al.* (2002) and Sinclair, *et al.* (2002).

Every PSC has a specific arrangement, with a different number of enterprises by sector. For example in the UK, the sector that produces pigs has several stages and pig production units may be categorized in terms of output, depending on the stages in which they are involved. Some farmers have breeding and finishing herd in their units, whereas others only produce weaned piglets and pass them to other farmers (i.e. rear until an acceptable slaughter weight) (Thankappan and Flynn, 2006). In this case, the producer sector includes the relationship between two or three enterprises before delivering finished pigs to the next sector in the supply chain.

1.2 *Inter-relationships in the PSC*

The PSC involves different enterprises which share the same objective, namely adding value to pigmeat before passing their product to the next partner or eventually the consumer. Two kinds of relationships can be established following the same commercial aim: vertical and horizontal relationships. The flow of products upstream and downstream in the PSC determines the vertical relationships between partners in the PSC. For example, pig farmers establish upstream relationships to buy feed needed to rear their pigs and downstream to sell finished pigs to meat processors. Pig farmers that join between them to sell their pigs on more advantageous conditions establish horizontal relationships between their partners.

There are different forms of establishing relationships between partners along the chain. Fearne *et al.* (2001), in a review of concepts of collaboration in supply chain management, argue that the development of collaborative marketing ventures is a response to the economic pressures that are driving the evolution of the chain. These pressures encourage greater vertical and horizontal co-ordination (also named value-added chains), rather than the complete vertical integration experimented with at the end of the 20th century or the traditional open market trading. Thus, when companies decide to be involved in any supply chain, they have to make decisions about how they will control and manage the primary supply chain (i.e. the chain from where a company obtains its principal inputs). Companies face decisions about where they should position themselves in the chain and how partnerships are established. For Hobbs (1996), supply chain management can be viewed as a continuum of vertical integration. At one extreme lies the 'spot market', here goods are exchanged between multiple buyers and sellers in the current time period, with price and willingness to buy as the only determinants of the final transaction (e.g. auction market, stock market, purchases of food in a supermarket). In this market transaction, management of the supply chain is entirely absent. At the other end of this vertical co-ordination spectrum lies full vertical integration, where products move between various stages of the production-processing-distribution chain as a result of within-firm managerial orders rather than at the direction of prices. Hobbs (1996) added that in between these two extremes lie a myriad of alternative ways of co-ordinating economic activity, from strategic alliances and formal written contracts, to vertical integration (when one firm carries out two or more consecutive stages of the production-distribution chain).

In strategic management horizontal integration describes a type of control where the corporation seeks to sell its products in numerous different markets. To get this market coverage, several small subsidiary companies are created. Cooper and Ellram (1993) view supply chain management (SCM) as lying between fully vertically integrated systems and those in which each member in the chain operates completely independently of each other. They added that a partnership refers to a relationship that attempts to build interdependence, enhance coordination, improve market position focus, or to achieve other share goals, and that it entails sharing benefits and burdens over some agreed time horizon see (Figure 1.2).

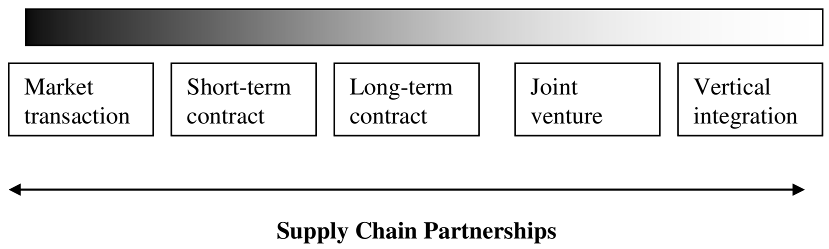

Figure 1.2 Typology of supply chain partnership (Cooper and Ellram, 1993)

Cooper *et al*. (1997) later defined the chain co-operation as "the integration of business processes from consumer to the original supplier leading to product-service information that has added value to customers". This means that a network of several organizations uses processes and transactions to deliver merchandise to their consumers and to achieve better results, develop controls and co-ordination through different degrees of vertical organization. Hagellaar and van der Vorst (2002) add that because each relationship has its own set of motivating factors driving its development as well as a unique operating environment, the duration, breadth, strength and closeness of the partnership will vary from case-to-case and over time. Hagellaar and van der Vorst (2002) analysed the critical success factors for partnership and concluded that there is variation in the motivations (i.e. profit stability/growth), facilitators (i.e. symmetry in power) and success characteristics (i.e. sharing of benefits/burdens) needed to develop and maintain supply chains.

Thus, many enterprises in different sectors of the food supply chain (FSC) (e.g. from independent farmers to high street butchers) face the challenge of constructing a more efficient FSC, which permits them to persist in the open economy and keep consumer trust. Vertical integration businesses could earmark funds to address consumer and society concerns about their social and environmental impact (Fearne *et al.*, 2001).

1.3 *Conditions of the PSC*

1.3.1 Worldwide changes in Agriculture and Agro-business

In the last fifteen years, the greater return on capital of economy of scale and the sustained rise in demand for food of animal origin has encouraged intensive livestock producers and the animal FSC to integrate their business in both vertical and horizontal directions. This organization between distribution, processing and production sectors is characterised by the prominence of large retailers, industrialization of the production process, a tendency towards vertical integration and coordination along the food chain (Costales *et al.*, 2006).

The pig and poultry industries have been the pioneers of meat production which has a high level of intensity and management control. According to Sørensen *et al*. (2006), intensive pig production has developed worldwide in regions of high grain production, such as the American Corn Belt states and Canadian Prairie Provinces or in the major arable areas of Europe. Sørensen *et al*. (2006) further emphasised that significant concentrations of pigs can also be located either around areas where cheap industrial by-products from human food processing are available for feeding, as seen in the Netherlands, or in regions where the activities of large integrator companies have stimulated growth.

1.3.2 Issues in the structure of the PSC

In many countries where intensive pig production has increased and become concentrated in integrated firms, the views of consumers and society have changed. These firms have frequently been associated with social concern due to job losses and high environmental impact from pollution (Costales, 2006; Hodges, 2005; Honeyman, 1996). Thus, in most of the countries, economies of scale in production have resulted in a consistent decrease in the number of pig farms and related increase in the number of animals per unit (Costales, 2006; Hartog, 2005). These large concentrations of pigs in certain geographic areas have raised major concerns about waste management, and the risk of adverse environmental impact from groundwater pollution, gaseous emissions and odour (Sørensen *et al.*, 2006).

1.3.3 Trends in the PSC

Less intensive systems, as an alternative method of pig production, retain the perception of producing wholesome products and being an environmentally-friendly production system (Edwards, 2005). These alternative systems, such as indoor deep litter housing or outdoor production, have become widespread in many European countries (Hermansen, 2001). Notably the UK leads welfare and environment regulations, and in this country a significant numbers of breeding sows are kept outdoors (Sørensen *et al.*, 2006). Sheppard *et al.* (1996) estimated that at the end of the last century 30% of the UK sow herd were housed outdoors.

Despite the increased European Union (EU) legislation on pig welfare (e.g. European Commission (2001) and pollution prevention and control (e.g. European Commission, 1996), and growing public pressure, it cannot be forgotten that pig production is part of a world open market. Without government support, less intensive systems have limited hope of success in the new worldwide economy if they do not integrate in market systems where they can add value to their enterprises (Thomas, 2007). Accordingly to Thomas (2007), the integration of sectors will be the core step for all pig producers, who therefore have to look for innovative and more sustainable enterprise relationships. They added that it is important that traditional as well as new players in the FSC consider the different options for association with their partners and fulfil the growing international environmental regulations and society demands of their enterprises.

1.4 *Issues with the PSC structure*

Many European countries have been affected by world agreements and other local problems. Taylor (2006) stated that the UK red meat industry was in crisis. He maintained that reform of the EU on Common Agricultural Policy, animal diseases (Foot and Mouth and BSE) and concentration of power in the hands of retailers have contributed to unprecedented structural change in the red meat industry, adding "Many producers and processors struggle to survive, since the current "trading mentality" between retailers, processors and farmers has a strong tendency to try to maximise their short term profits, either in relation to fluctuations in commodity prices or their ability to bargain with their supply chain partners".

However, the increasing concentration of the industry at retailer, processor and farmer levels presents a dichotomy. On the one hand, larger companies may choose to use their increased power to improve their profits by squeezing weaker supply chain partners. On the other hand an increasingly concentrated industry has much greater potential to organise itself into cooperative, focused supply chains (Ilbery and Maye, 2005). For many companies however, these new challenges will require the abandonment of many long held business norms (i.e. inter-organizational mistrust) and a significant change in attitude to overcome the traditional lack of trust and hostility towards other chain members, since the pork markets are becoming increasingly global, with increasing competition from lower cost economies (Taylor, 2006).

1.5 *Supply chain management in the food and PSC.*

In a more advanced definition of the FSC, van der Vorst *et al.* (2004) said that the supply chain is not a chain of businesses with one-to-one, business-to-business relationships, but a network of multiple businesses and relationships where co-operation rather than competition is the way forward. Fearne *et al.* (2001) argue that business success will be derived from companies managing enhancing the total performance of the supply chain so that it can deliver improved value to customers. Companies are therefore instructed to construct ever more efficient and responsive supply chain. The development of collaborative marketing ventures in the global agri-food chain encourages grant vertical co-ordination, namely vertical collaborative ventures, alliances or value-added chains (Fearne *et al.*, 2001). To investigate factors influencing the success and failure of organic marketing and impact on rural development, Stevenson (2006), used the term "value chain" to embrace both the characteristics of the business relationships within a FSC and a product differentiation instead of characterizing only the nature of business relationships between enterprises. Stevenson (2006) also classified value chains into three different organization forms of the FSC: the traditional, the value food chain and the mid-tier value food chain, which have evolved in relation to the form they share responsibilities and incomes. These three chains will now be discussed in more detail.

1.5.1 The traditional food chain

According to Stevenson (2006), the traditional food chain is the most variable and weak structure because most of the sectors in this chain are often framed in win-lose terms (i.e. they compete for the profit), with resulting levels of inter-organizational mistrust. Their relationships are constructed as competitors or adversaries, whereby each company seeks to buy as cheaply and to sell as expensively as possible. For the production sector, the crop or animal farmers are treated as interchangeable and exploitable input suppliers often operate in restricted markets or under short-term contracts where risks are usually born by producers. The benefits or profits from the sale of final food products are unevenly distributed across the supply chain, with food processors and retailers/marketers usually receiving a disproportionately higher share. Frequently, commercial relationships are established between primary producers and processors purely for short-term economic gains. Taylor *et al*. (2006) added that before the free-market agreements were in place, this was the main commercial relationship between stakeholders in the FSC around the world.

1.5.2 The value food chain

The value food chain differs from the traditional chain in the combination of their operational relationships, where the business relations are managed by "strategic partnerships" and their products can be focused on food quality and safety. Stevenson (2006) said that in this chain there are more opportunities to consider the environmental and the social attributes. He defines the value food chain as a whole vertical and sometimes horizontal integration business, with the same economic values shared. The business relationships between strategic partners within *value food chains* are framed in win-win terms (i.e. both sides of the relationship benefit), and constructed on collaborative principles that feature high levels of inter-organizational trust. The "strategic partners" are those businesses that significantly add value to food products and/or to supply chain performance such as producers, processors and retailers. According to Stevenson (2006), in this chain, the strategic partners are as important as investors in an international enterprise, with the same rights and responsibilities related to information, risk-taking, governance and decision-making. Commitments are made to the welfare of all strategic partners in a value chain, including fair profit margins, fair wages and business agreements of appropriate duration. Therefore, the *value food chain* can be characterised by a number of features: i) Organizations typically have high levels of performance and high levels of inter-organizational trust. ii) High levels of performance are essential to consistently deliver high quality products and services. iii) These organisations have developed appropriate standards and conduct performance evaluations across the entire value food chain, employing quality assurance systems. iv) Inter-organizational trust among strategic business partners is pivotal to the success of the chain. v) *Value food chains* emphasize shared values and vision, shared information to give transparency, and shared decision-making among the strategic partners.

The *value chain* described by Stevenson (2006) looks like the Danish PSC which, according to Hobbs (1998), has successful put the Danish PSC as one of the first worldly exporters. Exploring the reasons for this success, Hobbs (1998) found that the organization of the Danish PSC had a good distribution of responsibilities and final benefits between all partners in the chain. This success comes despite the Danish pork industry having seemingly more disadvantages than its principal competitors (e.g. the US and Canada), such as on surface, environmental regulations, labour cost and capital equipment cost which rises unit cost. Danish industry sends 91% of its total export sales to Japan, the highest value and highest quality market in the world (Hobbs, 1998). The principal strength found by Hobbs (1998) was the co-operative structure. In this structure one key feature is the education and training at all levels of the chain. Commercial farmers must complete a training course at an agricultural college. And all slaughterhouse workers receive training from the Danish Meat Trade College. Nevertheless, membership for farmers of any co-operative is voluntary and open, having joined a co-operative, farmers are bound to supply it for two to three years. The four farmer-owner co-operatives account for most of pig slaughtering and processing in Denmark using the most advanced technology available. However, co-operatives compete with one another for members based on the size of the end-of-year profit which are distributed to members in proportion to the size of the farmer’s sales to the co-operative. Danske Slagterier (DS) is an umbrella organization encompassing all Danish pork co-operatives including farmers, processors and exporters. DS is the logistic partner in coordinating advances in production and processing technology, market research and training for the pork sector. These strengths allow Danish PSC to provide high quality products tailored to the needs of international and individual buyers. Hobbs (1998) conclude that the adversary relationships between buyer and seller appear to be absent from the Danish pigmeat industry within the PSC.

1.5.3 The mid-tier food value chain

The last kind of supply chain described by Stevenson (2006) is the *Mid-tier food value chain.* This chain consists of midsize, independent (often co-operative) business enterprises that produce, process, distribute and market differentiated food products at regional scales. *"Mid-tier food value chain* has been successful in situations in which regionally-oriented markets have been developing differentiated food products such as in regional market or organic FSC in the US. In this kind of supply chain, the scale is lower than the previous organization chains and frequently certification of the standards is required by third-parties which provide reassurances about food safety to the consumers. Another advantage of this association is that stakeholders become comfortable with alternative business models based on trust and organizational interdependence (Stevenson, 2006).

The De Hoeve PSC described by Brandsma *et al*. (2005) is a regional pigmeat small supply chain initiative in Denmark and could be an example of the mid-tier food value chain. In 2004 De Hoeve set up a regional supply chain for certificated fresh pigmeat that meets specific requirements of "Kaurslager" butchers. The "Kaurslager" hallmark symbolized a PSC with environmental certified meat and additional quality criteria. The De Hoeve PSC was composed of the chain director, 16 pig producers, a slaughterhouse, a meat cutter/wholesaler and 26 high quality butchers, operating under the same hallmark. Farmers produced 900 pigs weekly for this PSC, pigs were produced according to the criteria of the Environmental certification label. Producers sold all their pigs to De Hoeve at the weight and leaning percentage negotiated. After passed by slaughterhouse and meat cutter, pigmeat was distributed to regional Kauslager butchers who commercialised this distinctive product. De Hoeve director was responsible for the overall management of the supply chain such as commercial transactions between partners and agreements with regard to pricing, logistic and production. The extra added value in this PSC was generated by cost reduction, whereas the consumer prices were similar to pigmeat in the regional market. Any profit was redistributed amongst all chain members. All chain members benefited from their new PSC. Brandsma *et al*. (2005) concluded that this PSC was not only a more transparent PSC but also a more efficient one. They added that distinctive products and the use of its own brand will be strategic cornerstones to future develop and scale up De Hoeve initiative.

Other examples of the mid-tier food value chain referred by Stevenson (2006) can be seen in organic or regional FSCs in the USA (e.g. www.bamco.com;www.sysco.com.), or regional supermarket and restaurant chains (e.g. www.newseasonsmarket.com; www.burgerville.com; www.oregoncountrybeef.com) also in the USA. Except in few cases, the stakeholders of the mid-tier value chain have found too difficult to construct more efficient and responsive supply chains, where vertical co-ordination play the principal roll. In most cases in this kind of PSC relationship the evolution of enterprise relationships has focused either on develop complete vertical integration dominated by one firm or continue in the traditional structure of the food chain (described in Section 1.5.1). There are different possible sources of the prevalence of inter-organizational mistrust but the principal one stems from the alleged uneven distribution of the benefits obtained by adding value to pigmeat along the PSC. Consequently, most of the societal concerns and environmental burdens continue to be passed between sectors in the PSC, who blame one another for the failures (Taylor, 2006).

Supply chain management methodology has opened some option to increase the co-operation between sectors in PSC such as offering different forms of association with transparent rules and innovative business relationships. However, this has not been sufficient to remove mistrust between PSC sectors, because stakeholders do not find sufficient justification to share benefits and responsibilities when the associations look unbalance between the actors (Taylor, 2006). Thus, an assessment of benefits and responsibilities, to show how the real picture and role of these stakeholders is should be analysed in integrated way rather than isolated assessments of burdens or profits. In conclusion, this will be especially useful if provide different alternatives with a sustainable form of relationships. Specially if the impact either economic or environmental is seeing with whole perspective of the pigmeat life cycle

1.6 *Main sectors in the PSC*

Pigmeat, like other meat products and foods, comes in a variety of forms such as fresh, frozen, perishable, processed and unprocessed, and can be purchased from a range of sources including grocery stores, farmers' markets, restaurants, the internet and countless other outlets that sell food or meat products (Bourlakis and Weightman, 2004). The channels used to distribute pigmeat, as well as other kinds of meat, have remained almost static, although the uses of technology and advanced management methods have brought about significant efficiencies in some parts of the supply chain (Bourlakis and Weightman, 2004). For the vast majority of food products, including pigmeat and pigmeat products, truck distribution is used as main transportation system (Bourlakis and Weightman, 2004).

1.6.1 The PSC

As shown in Figure 1.3, the product movement within a PSC can take one or more different paths. In some instances, pigmeat can go directly to the final consumer, as is the case with produce being sold at farmers' markets or produce stands. In other instances, pigmeat does not go directly to final consumers, but rather goes from the processing source to retailers and food service organizations such as fast-food and full-service restaurants.

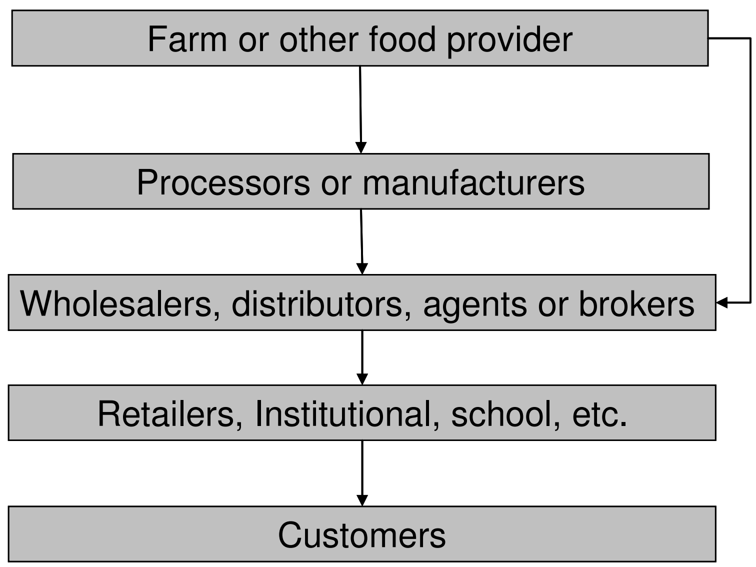

Figure 1.3 Generic overview of the food supply chain adapted from (Bourlakis and Weightman, 2004)

The major PSC from a commercial perspective are, briefly, pig farms/pigmeat providers, manufacturers/processors, wholesalers/distributors and institutions/retailers/schools/military (Bourlakis and Weightman, 2004). Pig farms are the pigmeat providers in the PSC. In many economies the largest segment of this group includes the very smallest of firms. Although there has been a concentration occurring, with many smaller farms and enterprises going out of business, merging or being acquired by larger firms. However, the basic production process remains with insignificant changes (Bourlakis and Weightman, 2004). Manufacturers/processors deliver pigmeat and food products to wholesalers, grocery stores, restaurants, convenience stores and innumerable outlets that sell or distribute food items to customers. Manufacturers are typically the largest firms within the FSC. These manufacturers are often companies very well known to consumers because of branding of food items (Bourlakis and Weightman, 2004). Finally wholesalers, distributors, agents and brokers are firms engaged in purchasing groceries and related products from food processors or manufacturers and selling them through several channels until they become available to the final consumer where pigmeat is part of the merchandises purchased (Bourlakis and Weightman, 2004).

1.6.2 Summary

There is a great diversity of pigmeat production chains which have developed according to economic and market forces. On the one hand, traditional local production units have grown and intensified into larger corporations to take advantage of economies of scale. On the other hand, farms have diversified into specialist production methods, such as organic production, to take advantage of premium in diversified niche markets. These supply chains increasingly need to demonstrate in a more transparent way their conformity with wider societal goals relating to key sustainability issues such as animal welfare and environmental care. Defining objective ways to express such information across the different partners in supply chains of different complexity is a major challenge for the industry.

Chapter 2 Literature review

2.1 *Sustainability in the PSC*

2.1.1 Definition

The concept of sustainability in relation to food production and consumption has been developed traditionally around agriculture. Sustainable agriculture has been linked to concepts of alternative agriculture, such as ecological food production, organic agriculture or low input sustainable agriculture (Yakovleva and Flynn, 2004). Farmers were seen as the natural custodians of the countryside and it was assumed that a prosperous agriculture industry would automatically ensure conservation of the countryside, but this has not happened (Ilbery and Maye, 2005). Instead, Ilbery and Maye (2005) added that the agro-food system has undergone significant modernisation and mechanisation, a process promoted by the rise and increasing power of large-scale food processors and retailers. According to Poole (2002) these processors and retailers seek to control most parts of increasing and globalising FSCs. A major consequence of such development has been the increasing disconnection between farming and food, and thus between farmers, the traditional producers of foodstuffs, and final consumers (Ilbery and Maye, 2005). Nowadays, the issue of sustainability is linked to sustainable consumption too, and sustainability of production and consumption are increasingly viewed together (Yakovleva and Flynn, 2004). Departments for Environment, Food and Rural Affairs (DEFRA) and for Trade and Industry (DTI) (2003) gave a general definition for sustainable consumption and production as “continuous economic and social progress that respects the limits of the Earth’s ecosystems, and meets and aspirations of everyone for a better quality of life, now and for future generations to come”. Also taking a broad view were Robins and Roberts (1997, cited by Yakovleva and Flynn (2004), who specified the principal sectors and needs for sustainable production and consumption as follows: “The emphasis of sustainable production is on the supply side of the equation, focusing on improving environmental performance in key economic sectors, such as agriculture, energy, industry, tourism and transport. Sustainable consumption addresses the demand side, looking at how the goods and services required for meeting basic needs and improving quality of life -such as food and health, shelter, clothing, leisure and mobility- can be delivered in ways that reduce the burden on the Earth's carrying capacity". In an integrated viewpoint, Yakovleva and Flynn (2004) suggested that the route to sustainable consumption lies in the more efficient production of more sustainable products. This means that sustainable production is when all economic sectors minimize material use and reduce pollution and waste to levels at least within local and global carrying capacity. For sustainable consumption this means that goods and services used respond to basic needs and improve the quality of life, whilst minimizing environmental damage throughout their life cycle.

2.1.2 Sustainability and the PSC

Using Value Chain Analysis (VCA), Taylor (2006) studied and mapped in detail a number of complete pork chains from farm to retail with a view to identification of cost saving and performance improvement opportunities, either for fresh pork product (pork chops) or value added product (pork sausages). He concluded that there is a significant opportunity to improve the efficiency of pork chains both operationally and strategically. However, as other authors have also said (van der Vorst *et al.*, 2004; Yakovleva and Flynn, 2004), Taylor (2006) concluded that a really efficient value chain cannot be created without the full cooperation of all partners. Thus, the value chain management requires a different business model, in which improved profits arise from cooperation rather than an ability to play the market or exercise power over supply chain partners (Taylor, 2006).

Van der Vrost *et al*. (2004) highlighted a direct link between two important dimensions of corporate environmental improvement-environmental management concepts and environmental performance. This linkage is considered to be a critical success factor for the establishment of truly higher environmental performance (van der Vorst *et al.*, 2004). The leading principle is that of environmental care strategies, in which environmental targets and organisational activities to reach those targets are linked. The linkage means that when a company or chain of companies wants to improve on its environmental performance and changes its environmental care strategy, fundamental organisational changes are required (van der Vorst *et al.*, 2004).

Joining these characteristics, for sustainable consumption and sustainable production, and for improvement in the opportunity to be competitive in the open market, a company has to seek increased partnership as well as decrease environmental impact and social concerns in its supply chain. In these circumstances, the analysis of the whole PSC, with different supply chain associations, will be a more appropriate form for consideration of production of pork and pork products than simply considering the primary producer.

According to Pretty *et al*. (2005), there are many perspectives on what constitutes sustainability and how it can be applied to agricultural contexts. Amongst the analytical approaches are: energy accounting (Carlsson-Kanyama *et al.*, 2003), economic valuation of non-marketed goods and services (Pretty *et al.*, 2000), ecological footprint (Rees, 2003), carbon accounting (Lal *et al.*, 2004) and finally the use of indicators for sustainability (MAFF, 2000). Pretty *et al*. (2005) assessed the full cost of the UK weekly food basket by analysing the environmental cost to the farm gate, and the additional environmental cost of transporting foods to retail outlets and then to consumers' homes, and the cost of disposal of wastes. They developed various production and transport scenarios to assess the best cost-avoidance options. Pretty *et al*. (2005) assessed the external costs (those that are not produced directly in the product supply chain) of different scenarios rather than different production systems. However the goal of this thesis is focussed on pig production systems.

2.1.3 Indicators of sustainability in the pig production supply chain

There is considerable diversity in thinking about how to assess sustainability in the meat supply system, especially in agricultural production sectors. It is crucial to use well-defined environmental indicators and valid data to describe resource use and emissions from different farm types in order to identify the most polluting sources of agricultural production (Dalgaard *et al.*, 2006).

2.2 *Indicators in the agricultural sector of the PSC*

Agriculture production, the first sector of the FSC, has an impact on the environment on a local scale (e.g. nitrate leaching to ground water) and on a global scale (e.g. greenhouse gas emissions to the atmosphere). Halberg *et al.* (2005) differentiate between area-based indicators (e.g. nitrate leaching per ha) and product-based indicators (e.g. greenhouse gas emissions per kg product). Although, both types of indicators are useful to characterize the environmental impact from food production, they are used for different purposes.

Area-based indicators are useful for evaluating farm emissions of nutrients, such as nitrate, ammonia and phosphate, that all have an effect on the local environment. Area-based indicators have been used to compare nutrient surpluses from different farm types (Nielsen and Kristensen, 2005; Haas *et al.*, 2001). On the other hand, production-based indicators are useful to evaluate the impact of food production on the global environment (e.g. climate change) and have the advantage that, in addition to emissions from the farm, emissions related to the production of inputs (e.g. soybean, artificial fertilizer) and outputs (e.g. manure exported to other farms) are also included (Dalgaard *et al.*, 2006). In order to produce representative environmental indicators, Halberg *et al.* (2004) suggested basing environmental assessment on representative farm accounts. Thus Dalgaard *et al*. (2006) used the annual sample of The Farm Accountancy Data Network (FADN) in Denmark and selected 31 different farms types as the data source for performing area-based and product-based environmental assessments. They analysed the main environmental burdens from agricultural products on a pollutants basis. For example, they included nitrate (NO_3), ammonia (NH_3), nitrous oxide (NO_x), methane (CH_4) and fossil carbon dioxide (CO_2).

Pretty *et al*. (2005) estimated the scenario cost of the principal negative externalities of UK agriculture in 2000, for current agriculture and as if the whole of UK production was organic. They used standard organic protocols to model possible scenarios and to estimate the contribution that would be made to total cost by ten principal negative externalities of UK agriculture. They estimated the economic impact as cost-avoidance (i.e. benefit compared with current agricultural systems). For this work the unit costs per kg from conventional agriculture and from an organic production scenario arising from rearing pigs are shown in Table 2.1.

Table 2.1 External cost to the farm gate for pig raised in the UK (p kg^{-1}) (Pretty *et al*, 2005)

	Production system		
	Conventional	Organic	Change, %
Pig	12.81	3.79	-29.6

Using the major objectives for sustainable development stated in Agenda 21 (The program run for the United Nations for sustainable development) as a framework, Yakovleva and Flynn (2004) outlined a set of sustainability indicators for assessing financial, social and environmental sustainability of the FSC. These indicators were based on criteria to assess the interrelationship of the PSC sectors. They considered that the difficulties of the stakeholders in the PSC to construct more efficient and responsive supply chains arose because, in their view, mistrust dominates the partner relationships. Thus, isolated analyses are not sufficient to show the real picture of the balance between benefits and burdens for each sector and whether the profitability of firms in each sector allows them to carry out their societal and environmental responsibilities. An integrated analysis with environmental, societal and economic indicators of sustainability would help to clarify the alleged uneven distribution of the benefits obtained by each sector and the environmental burdens that every sector has to minimise. Profitability, employment and certain aspects of environmental burdens, which are susceptible of transformation to monetary value, were used for Yakovleva and Flynn (2004) to construct an integrated indicator as shown in Figure 2.2. The advantage of a monetary basis for these indicators is the easy method to add or discount value when its impact is favourable or unfavourable in the general picture. Additionally, this is a common concept and an easy form in which to show stakeholders how is every sector participation and the relation with other sectors. However, these approaches mainly highlight opportunities for improvement of equity between stakeholders in the PSC, rather than showing sustainability hotspots for each sector.

Table 2.2 Key sustainable indicators for food supply chain (Yakovleva and Flynn, 2004)

Food supply chain	The stakeholders	Indicators		
		Economic	Social	Environmental
Agriculture Seed production and Animal breeding Agricultural growing And production	Breeders, Seed companies, Farmers, Agricultural Companies, Material Providers, Equipment providers.	Contribution to GDP Labour productivity Firm profitability Diversity and structure of market Importer products vs. domestic products Distribution of imports by countries	Employment Average wages Animal welfare Exposure to hazardous substances Number of health and safety incidents Number of fair trade initiatives Environmental reporting	Energy use Fresh water use Absolute waste generated Varieties of breeds and varieties, over-fishing of other species Packaging per tonne of product Harvest loss
Food industry Primary food processing Further food processing Final food processing	Packers, Food processors, Packing providers, Transport providers, Equipment providers	Output growth Labour productivity Profitability Diversity and structure of market Importer products vs. domestic products Distribution of imports by countries	Employment Average wages Exposure to hazardous substances Number of health and safety incidents Number of fair trade initiatives Environmental reporting.	Energy use Fresh water use Waste generated Packaging per tonne of product Food loss
Food distribution Wholesale Retail Food service	Wholesale companies, Retail outlets, Food service, State food procurement	Output growth Labour productivity Diversity and structure of market Importer products vs. domestic products Distribution of imports by countries Profitability	Employment Average wages Exposure to hazardous substances Number of health and safety incidents Number of fair trade initiatives Environmental reporting.	Energy use Absolute waste generated Packaging per tonne of product Food loss
Domestic consumption	Household	Expenditure on different food by different social group	Ratio between fresh vs. highly processed foods and its distribution by social groups Consumption of fair trade products	Energy use Food waste

2.3 *Assessment of environmental sustainability in the PSC*

Yakovleva and Flynn (2004) included five elements that should be taken into account when analysing the sustainability of FSC: (1) including all states of the chain (from raw materials to last consumer); (2) capturing at least three aspects of sustainability: economic, social and environmental; (3) using indicators that correspond to stages of the supply chain (i.e. for agriculture, for industrial processing, for pig production, for transportation); (4) using several environmental impact indicators within each stage of the FSC that have significant implications for sustainability including, for example, waste, transport, energy consumption; (5) comparing effects of different strategies of the FSC. Some examples could be to assess the impacts of competing strategies such as organic versus conventional supply chain, or local supply chain versus global supply chain.

For Hagelaar and van der Vorst (2002), LCA can be seen as the main technique for gathering data on environmental care issues which can be used to restructure the supply chain in order to improve its environmental performance. Additionally, the LCA method is used in environmental supply chain management (ESCM), which is a technique with an umbrella concept for attention to environmental care within the supply chain. ESCM is defined as "the set of supply chain management policies held, actions taken, and relationships formed in response to concerns related to the natural environment with regard to the design, acquisition, production, distribution, use, reuse, and disposal of the firm's goods and services" (Zsidisin and Siferd, 2001). This technique takes into consideration the linkage between chain management concepts and environmental performance. Van der Vorst *et al*. (2004) stated that the successful coordination, integration and management of key business processes across members of the supply chain will determine the ultimate success of the single enterprise if environmental performance is taken into consideration. Furthermore, he maintained that the linkage between chain management concepts and environmental performance is of the utmost importance.

However, not all information in the LCA is suitable in all situations. Certain parts of the LCA are more suitable when certain environmental objectives are pursued than other parts. Hagelaar and van der Vorst (2002) said that results depend on the perspective and goals followed when one develops a LCA, since LCA is a context-dependent tool. They emphasised that the fulfilment of environmental objectives by applying LCA requires specific ways of working and forms of co-operation in the supply chain. Thus, when a supply chain strives to realize specific environmental care, one specific supply chain structure is more suitable than another.

2.3.1 Evaluation of food production with LCA

Product-based indicators are useful for evaluating the impact of food production on the global environment (e.g. climate change) and have the advantage that, in addition to emissions from the enterprise *per se* (e.g. the farm), emissions related to the production of inputs (e.g. soybean, artificial fertilizer) and outputs (e.g. manure exported to other farms) are also included. Life-cycle thinking is the basic idea behind the product-based indicators (Dalgaard *et al.*, 2006).

Life cycle thinking is one of five key principles in the European Union's Integrated Product Policy (IPP) (European Commission, 2003 referred to by Dalgaard *et al.*, 2006) and is also supported by the United Nations Environmental Program (UNEP, 2004). In life-cycle thinking, the cradle-to-grave approach for a product is adopted to reduce its cumulative environmental impacts. The most developed tool for life-cycle thinking is LCA, which is a method of evaluating a product's resource use and environmental impact throughout its life-cycle (UNEP, 2004). LCA has been used for environmental assessment of pork (Basset-Mens and van der Werf, 2005; Eriksson *et al.*, 2005; Cederberg and Flysjo, 2004) and for other agricultural products (Cederberg, 1998). The investigation of different chain structures and their environmental impact has been useful to consider the environmental impact, but targeting environmental and economic performance according to the company's chain organisation is a more applicable approach.

2.3.2 Strengthens and weaknesses to assess the PSC with LCA

In many cases, area-based indicators (indicators of the effect on the local environment) have limited application and are more useful for specific farm conditions. Therefore, area-based indicators used to assess the performance of one productive sector are limited to specific areas or enterprises. Their boundary depends on the number of farms (or companies) used to represent the sector. There is also considerable variation in resource use and emissions between farms, making it difficult to classify farms in a specific set of categories or requiring many categories (Thomassen and Boer, 2005; Halberg, 1999). For example Dalgaard *et al.* (2006) split the Danish farm sector into 31 categories reducing representative data per sector. Under these conditions, the lack of representative data for environmental indicators misleads the assessment, because results such as comparison between farm (or company) types may be influenced by individual performances (Dalgaard *et al.*, 2006). Thus, product-based indicators are more useful for assessing production systems. Hagelaar and van der Vorst (2002) established additional considerations for the successful application of LCA, in the assessment of supply chains on a production basis. Since LCA is a context-dependent tool, the perspective and goals established at the beginning, the environmental care strategies and the specific ways of working and forms of co-operations in the supply chain should be defined to assess a supply chain, because the results depend on these. Additionally, the environmental care strategy is operationalized into a number of environmental performance indicators and, when different strategies are pursued, different performance indicators emerge and /or a different weighting is given to each indicator along the supply chain (Hagelaar and van der Vorst, 2002). Therefore, product-based indicators are useful for PSC assessment but are also limited for the system boundary and system specifications (Hagelaar and van der Vorst, 2002). Then alternative or contrasting systems are useful for the impact assessment on the LCA phase (Basset-Mens and van der Werf, 2005). Basset-Mens and van der werf (Basset-Mens and van der Werf, 2005) argue that alternative scenarios give an additional strength for interpretation of impact assessment. In short, developing a LCA produce inevitability uncertainty, which is inherent to assessment procedures (Halberg *et al.*, 2005), but this can be reduced using product-based indicators and alternative or contrasting systems.

2.4 *LCA methods to assess environmental sustainability in the PSC*

According to Hagelaar and von der Vorst (2002), to environmentally assess a supply chain the following basic steps should be carried out: (1) establish or clarify the supply chain management and partnership, (2) focus on the LCA "code of practice" stated in the standardised procedure (ISO, 1997), and (3) define specific environmental care strategies, and type of LCA, according to the supply chain to assess.

2.4.1 Supply chain management

The partnership established between stakeholders in the FSC should be considered because each relationship has its own set of motivating factors driving its development, as well as a unique operating environment. The duration, breadth, strength and closeness of the partnership will vary from case-to-case and over time. Hagelaar and von der Vorst (2002) analysed the critical success factors for partnership and concluded that there is variation in the motivations (i.e. profit stability/growth), facilitators (i.e. symmetry in power) and success characteristics (i.e. sharing of benefits/burdens) needed to develop and maintain supply chains. Finally, they concluded that this differentiation in partnerships must be incorporated in the fine tuning between the LCA to be executed and the supply chain structure. In other words, it is necessary to define the chain co-operation and partnership in the supply chain to identify the most appropriate LCA to use.

2.4.2 Life cycle assessment

Life cycle assessment (LCA) is an instrument with which environmental effects of a product during its life cycle can be integrally assessed. Integral means that all processes in the supply chain that contribute to the overall environmental burden are incorporated in the assessment, from the use of raw material, to the use, re-use and disposal of the product (Hagelaar and van der Vorst, 2002). Accordingly, with the definition of LCA at the moment (ISO, 1997), the LCA is divided into the following four main steps: (1) Goal definition and determination of the scope, (2) Inventory analysis, (3) Impact assessment and (4) Interpretation. These four steps are explained in details in the methods chapter (Section 3.1)

2.4.3 Environmental care strategies, type of LCA and supply chains

The type of LCA is selected according to the goals that the organization strives to assess but, according to Hagelaar and van der Vorst (2002), it should consider environmental care strategies applicable to individual companies and supply chains. They divided these strategies according to the environmental goals of the company or supply chain, as follows:

- *Compliance-oriented strategy* (comply with rules and regulations with the help of end-of-pipe techniques) such as a water clearance installation to diminish a particular kind of emission.
- *Process-oriented strategy* (strive for control of environmental burdens caused by the production process by means of production integrated measures that achieve both regulations and a better return i.e. pollution prevention pays) such as new technologies to save water or other raw material or process redesign to accomplish less waste during the production process.
- *Market-oriented strategy* (achieve competitive advantage by the design of the product, which reduces the environmental burden) such as the use of different packaging or reduced food miles in specific food chains.

These environmental care strategies are linked in an ideal-typical way to specific characteristics of a company or supply chain. Table 2.3, developed by Von Koppen and Hagelaar (1998) in Hagelaar and van der Vorst (2002) present this linkage on an aggregate level, where different organizational capabilities are joined to different environmental care strategies. This implies that, in a supply chain, the goals serve as selection criteria for the LCA data needed, because whenever the goals vary, the information needed to take decisions will vary as well. Based on this assumption, Hagelaar and van der Vorst (2002) established the criteria shown in Table 2.4 to choose the type of LCA and data required. As this table shows, when the environmental care strategy becomes more ambitious, so the LCA has to generate much more detailed information.

Table 2.3 Environmental care strategies and organizational characteristics (van Koppen and Hagelaar, 1998, in Hagelaar and van der Vorst, 2002)

Characteristics	*Compliance*	*Process*	*Market*
Internal			
Knowledge	About some, prescriptive, aspects	About production process aspects	About the product supply chain
Information	Little horizontal and vertical information sharing	Information sharing on tactical and operational level	Information sharing on strategic level
Technology	End-of-pipe technology	Process-integrated technology	Product design technology
Structure	Few and isolated tasks	Explicit tasks on the tactical and operational level	Integrated tasks on different levels including staff level
Budget	Budget is small	Budget for investment with a long term pay-back period	Budget for strategic investments
External			
Risks	Risks are deduced from the rules and regulations	Risks are limited and/or changeable	Risks become challenges
Opportunities	No opportunities	Opportunities through cost	Market opportunities

Table 2.4 Type of LCA and data required (Hagelaar and van der Vorst, 2002)

Type of LCA	*Data required*
Compliance-oriented LCA	End-of-pipe data (emissions, etc.)
Process-oriented LCA	End-of-pipe, process steps, and transport data
Market-oriented LCA	End-of-pipe, process steps, transport, nature and quality of raw materials, and disposal data.

Independent of these considerations, Andersson *et al*. (2005) developed models from the farm gate through food industries and transport to simulate food chains when using LCA methodology. In these models, simulation is made of the whole food chain, enabling evaluation of different production systems with respect to resource requirements (energy, etc.) and environmental impacts. Andersson *et al*. (2005) then developed simulation models for the whole food chain for a number of case studies and with SALSA (Systems Analysis for Sustainable Agriculture) these models allow the evaluation of resource requirements and environmental impacts for different ways of producing a food product. They also developed a method of future scenarios for agricultural production and applied these in a number of case studies, where the scenarios were based on minimal resource requirement, minimum environmental impact, or best animal welfare.

Andersson *et al*. (2005) argued that, with a LCA approach, data taken from measurements, databases or the literature can be aggregated in such a way that resource consumption, environmental impact and production can be calculated for the system under study. Alternatively, data used in the LCA can be produced by means of simulation models instead of taking them from measurements. With these models, the different flows of energy and other input resources are modelled, together with products and other material flows, as well as the emissions that are caused by the production system. Andersson *et al.* (2005) concluded that the advantage with such models is basically that different scenarios for production can be simulated and evaluated fairly rapidly compared with LCA based on empirical data, which are normally much more time consuming.

Basset-Mens and van der Werf (2005) used a LCA to assess the current intensive pig production system and two alternative production systems in France. In this instance the inventory data were built with representative data of the systems obtained with a scenario-based approach. They argued that in the case of the alternative systems, there only existed a small number of farms and these were often at a more or less experimental stage. Consequently, the availability of representative data was problematic. Therefore, Basset-Mens and van der Werf (2005) concluded that it is useful to evaluate the environmental impact of the three pig production systems, identify hot spots and margins for improvement for each system with a scenario-based approach.

In summary, it seems possible to assess the PSC using a scenario-based approach to model different organizational chains, after the model has been defined to clarify the orientation of LCA to use.

2.4.4 Issues of evaluating the PSC using a LCA approach

Although there seems to be a clear-cut approach to gathering environmental data, Hagelaar and van der Vorst (2002) advised that, in the literature, they found quite a few problems and ambiguous moments of choice in the execution of LCAs. Including:

- *Representativeness and legitimacy;* when disturbing factors (i.e. missing data, calculation errors and disputable assumptions in the demarcation of the functional unit) can produce ambiguous results and the LCA does not provide absolute values.
- *Specific usefulness;* the lack of an environmental theme can be a problem in reaching a globally representative result. In the case of specific company or chain goals, the problem can lie in the fact that LCA databases are filled with average industry data. In the latter case, choice of a specific supplier for a specific company is difficult on the basis of a global data-set.
- R*eturn;* LCA is low in cost-efficiency. The gathering of data for specific chains is very expensive. On the other hand, databases filled with average industry data can easily lead to wrong management choices in specific companies and chains.
- *Comprehension and transparency;* the more complex the LCA, the less transparent and comprehensive it is for those who are not environmental specialists. Transparency depicts the level at which other parties have an inward view on the relation to the competitive position.

From a managerial point of view, Hagelaar and va der Vorst (2002) conclude that the application of the LCA instrument is not without problems. Choices have to be made about:

- the amount or resources one intends to invest in the execution of an LCA.
- the required information to make far-reaching decisions including implementation.
- the required information to satisfy stakeholders, and
- the ability to publish information.

2.4.5 LCA methods for contrasting production systems

The assessment of a product's life cycle has not been sufficient (Basset-Mens *et al.*, 2007). Contrasting substitute products' life cycles has been found to be useful in the design of new products (Bras, 1997), modelling future production systems (Cederberg and Flysjo, 2004) or simply contrasting available commodities in the market place (Hendrickson *et al.*, 2006). Results of such study could be disconcerting, since products which seemed to be close to nature were not obviously superior in terms of using less energy and materials, producing less waste, or even disposal at the end of life. Hendrickson *et al.* (2006) gave a good example, discussing how close is the option of choosing paper cups versus foam plastic cups when the environmental implications were analysed for both materials. Which cup is better depends on how bad one thinks water pollution is compared to air pollution, or compared to using a non-renewable resource. Hendrickson *et al.* (2006) added that, perhaps most revealing was the contrast between plants and processes to make paper versus plastic. The best plant-process for making paper cups was much better for the environment than the worst plant-process; the same was true for plastic cups. Similarly, the way in which the cups were disposed of made a great deal of difference (incinerating or land filling). Hendrickson *et al.* (2006) conclude that perhaps the most important lesson for consumers was not whether to choose one material over another, but rather to insist that the material chosen be made in an environmentally-friendly plant.

The same concepts could apply to meat consumption. Comparing production processes and forms in which to supply meat to consumers can be more revealing than looking for which is worse. In this sense, contrasting different scenarios for processes involved in the PSC could be helpful to improve the process, reduce energy use and avoid environmental burdens. Thus, analysing different processes for pig production and how these link in the whole PSC gives a complete perspective. Contrasting different scenarios could help consumers, companies, and policy makers to take best decisions and know the implications of their choices for environmental quality and sustainability. There are different analysis perspectives to assess the complete life of a product and the processes involved. In the following Sections the general approach and relevant advantages and disadvantages will be explained.

2.5 *Life cycle assessment*

LCA "studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle to grave) from raw materials acquisition through production, use and disposal" (ISO, 1997). The LCA "process analysis" has been developed by engineering to create energy and materials balances for each relevant process: mining ore or extracting natural resources, making materials and subcomponents, making the product, and the end of product life. These processes have been used to trace environmental burdens of different products and services. LCA requires careful energy and material balances for all stages of the life cycle. For example, the production of one kilogram of meat should consider:

1. facilities for extracting the phosphoric rock, petroleum, and other energy sources;
2. vehicles, ships and pipelines and other infrastructure that transport the raw materials, processed materials and subcomponents along the supply chain to produce the consumer product, and transport the product to the consumer: phosphoric rock ships, trucks carrying fertilizers, grain going to an animal farm, trucks carrying the animals to slaughterhouse, trucks transporting carcasses and meat products to supermarkets;
3. factories and farms that make each of the ingredients for fertilizing plants and for animal feed compounds; production or processing of meat, including pharmaceuticals and the animal itself;

4. refineries and electricity generation facilities that provide energy for making and processing meat; and
5. farms and factories that handle manure and by-products such as bones, entrails and fat; manure recycling, shredding, landfill for waste produced in all parts of the supply chain.

Each of these tasks requires energy and materials. Reducing requirements saves energy, as well as reducing the environmental discharges, along the entire supply chain. Often a new material or procedure in one sector, or different interlink relationship, requires more energy to produce, but promises energy saving or easier recycling later. Evaluating whether a new material or new process in the supply chain helps to improve environmental quality and sustainability requires an examination of the entire life cycle of every alternative (Hendrickson *et al.*, 2006). This kind of LCA, where the inventory of input and output is made up with a detailed inventory of commodities used in product production is named a process-LCA.

2.5.1 The process-LCA

The International Organisation for Standardisation (ISO) formalizes the process model for the LCA in the series ISO 14040 (ISO, 1997). In these standards, a variety of process steps are required. Modelling the process shows a series of boxes and transportation links, of which every one represents a separate process model, with resource requirements and environmental impacts. Figure 2.1 summarizes the general components of a life cycle. The LCA consists of three complementary components inventory, impact, and analysis.

The process-LCA model assessment typically consists of a detailed inventory of resource inputs and environmental outputs for the analysis period and processes considered. These outputs can then be evaluated for environmental harm or possible design changes. This process should be developed to create energy and materials balances for each relevant process for each sector in the supply chain: extracting natural resources, making materials such as fertilizers and subcomponents, making or processing the product for each sector, and the end life of different by-products. Each material and energy balance tabulates the energy and material inputs, the desired outputs, and the undesired outputs that become environmental discharges. These analyses can be as long as the supply chain is disaggregated.

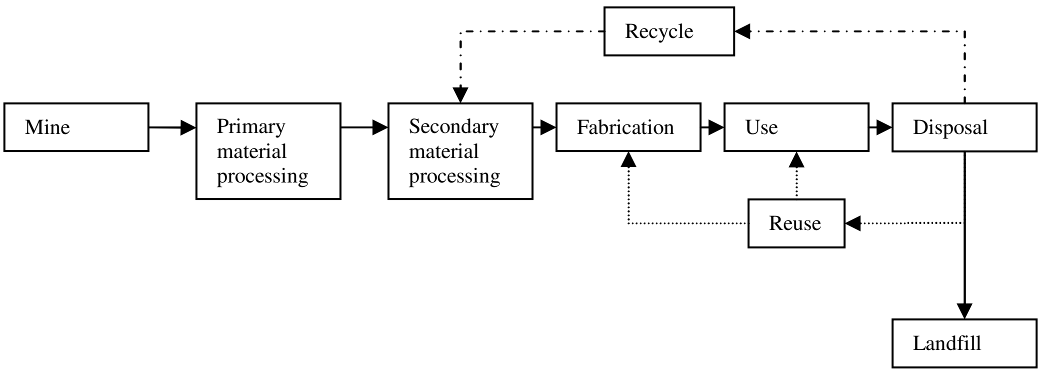

Figure 2.1 A generic supply chain life cycle model (adapted from Hendrickson *et al.* 2006)

2.5.2 Disadvantages of developing a process-LCA

The process-LCA approach draws a tight boundary around the process to be investigated. However, the procedure to produce a material or product has myriad processes, and so these have to specify the materials and processes in great detail. For example, a major LCA of a product looks carefully at the processes for extracting raw materials from natural resources and making steel, plastic, fuels, etc. It also looks carefully at making the major components of immediate feedstuffs and their process. This leads to another difficulty: in a dynamic economy, materials and processes are continually changing in response to factor prices, innovation, regulations, and consumer preferences. Since these data are difficult to assemble, studies are forced to compromise by selecting a few steel mills and plastic plants as "representative" of all plants. Similarly, only a few component plants are analyzed. A criticism of these studies is that many aspects of the process were not studied, such as much of the transportation of materials and fuels and the "minor" components (Hendrickson *et al.*, 2006). A further issue is the end of life of a product or by-products (Lave *et al.*, 1999). Which should be traced to reveal whether, the product/by-product is reused, recycled, put into a landfill, burned to generate electricity or discarded into the environment. However this information is not always available or consistent. In consequence, the scope of the analysis has to be appropriately broad and frequently many facets of life cycle impacts are simply ignored or accounted as zero emissions (Suh *et al.*, 2004). However, from a life cycle perspective, there is no zero emissions process, since all processes use energy and materials and involve some disposal at the end of their lives. Such a perspective encourages an analyst to consider the difference between products in terms of the full life cycle, not just the use of a production sector (Hendrickson *et al.*, 2006). Thus, performing a careful material and energy balance for a process is time-consuming and expensive, which limits the number of processes that it is practical to analyse. Indeed, the rapid change in materials and processes, together with the expense of analyzing each one, means that it is impractical and inadvisable to attempt to characterize a product in great detail (Hendrickson *et al.*, 2006).

Considering the disadvantage of process-LCA, undertaking a complete process LCA of a complicated product or different sectors in the supply chain of a product is not worthwhile in either time or money terms. A process LCA requires materials and energy balances for each of the processes upstream and downstream in the supply chain. Compiling and updating all the materials and energy balances is then almost impossible. Furthermore, each of the processes directly involved in producing the components requires inputs from the other processes. For example, agricultural machinery requires steel directly, but also electricity, natural gas exploration, production and pipelines, technical services, and lawyers. Directly or indirectly, making agricultural machinery involves the entire economy, and getting detailed mass and energy balances for the entire economy is impossible. Whilst conducting a complete process-LCA is time limited, focusing on the product itself while ignoring all other parts of the life cycle would lead to inaccurate results and an unreal picture of the production process. This has encouraged economists to do an economic approach for LCA of products and services which will now be considered.

2.6 *The Input-Output Approach to LCA*

2.6.1 Economic Input-Output approach

An Economic Input-Output (EIO) LCA approach, takes the sectors that produce all of the goods and services in the country's economy, but uses two major simplifications compared to a process-LCA. First if 10% more output from a particular factory is needed, each of the inputs will have to increase 10%. Second, all production facilities that make products and provide services can be aggregated into approximately all national economic sectors. The EIO models are based on the economic interchange between sectors in the whole economy. Thus input-output matrix tables summarise the value of interchanges between all sectors in the country's economy. Each sector of the economy is represented by one row and one column. Tables represent total sales from one sector to others and purchases from different sector to produce its outputs. The EIO method has proven to be useful to know the sectors´ participation when a quantity of output of a specific sector is required (Hendrickson *et al.*, 1998).

2.6.2 Application of the EIO approach to LCA

Since its early development, Leontief (1970) suggested that EIO models are useful for assessing environmental impacts. Hendrickson *et al*. (2006) set up EIO models to be able to exploit modern information technology. Their model had a set of large tables (or matrices), each with 481 rows and 481 columns where economic sectors were disaggregated. Also, their associated energy requirements and environmental burdens for each economic sector were computed. A website provides free access to this software (http://www.eiolca.net/use.html). Economic sectors and the associated burdens can trace when an increase in production in one specific sector is required.

2.6.3 Use and advantages of the EIO-LCA software

The basic steps of EIO-LCA are shown in Figure 2.2. Firstly, a purchase associated with a product or process is identified. This purchase is used as the desired output of one sector for the EIO model. Once this purchase is specified, all the supply chain requirements are estimated, from extracting the raw materials to producing high-grade materials to components. The software simultaneously computes the environmental discharge resulting from the initial purchase and the entire supply chain. The process of identifying purchases continues until all the initial manufacture, use and disposal stages of the products are represented (Hendrickson *et al.*, 2006).

The advantage of the EIO-LCA approach is firstly that it does not need to draw any boundary and so covers the entire economy, including all the material and energy inputs (Hendrickson *et al.*, 2006). Secondly, the EIO-LCA approach is relatively quick and inexpensive to undertake.

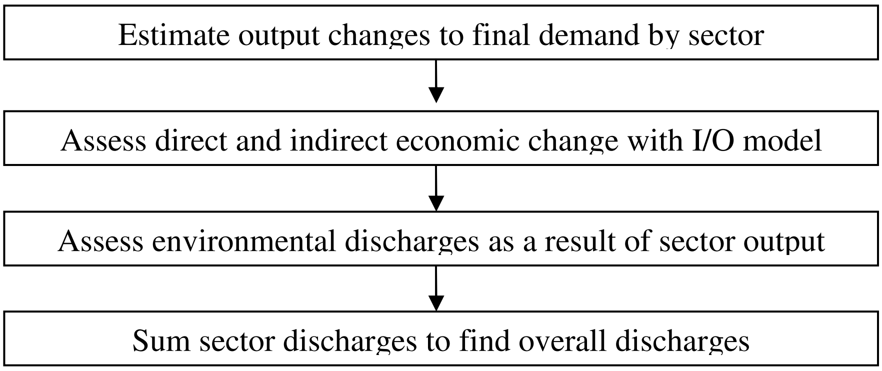

Figure 2.2 Steps in the EIO-LCA process (Hendrickson *et al.*, 2006)

2.6.4 Disadvantages of the EIO-LCA

The main disadvantage is that EIO-LCA is only a general approach to performing LCA, because it operates at an aggregate level and does not give the detailed information required for product analyses (Hendrickson *et al.*, 2006). EIO-LCA gives information for the whole sector rather than the particular factory that goes into making a good or service. Doing an approach for a particular good or service should not only disaggregate the sector where the commodity is included, but should also disaggregate participation of other sectors that supply products to the specific process. Another disadvantage is that most of the nations that develop such input-output tables do not publish such as detailed tables as the 481-sector one in the Hendrickson model. For example, the IO table for the UK economy for 2000 published in 2003 was aggregated in only 41 sectors (Yamano and Ahmad, 2006).

2.7 *Hybrid models*

A hybrid model combines the scope of the economy-wide EIO-LCA model with the detail of process-LCA (Hendrickson *et al.*, 2006). Combining both models give extra advantages that is explained in next section.

2.7.1 Advantages of hybrid models

The advantage of the EIO-LCA model is its comprehensiveness; its disadvantage is its aggregate nature (explained in Sections 2.6.3 and 4). The advantage of the process-LCA model is its disaggregated nature, while its disadvantage is the need to draw a tight boundary so that there is a wide variation in the number of process models that are used (for explanation refers to Section 2.5.1). Trying to fill this gap, a hybrid model combines the EIO-LCA and the process-LCA model (Hendrickson *et al.*, 2006). The process-LCA improves and extends the possibilities for analysis. The EIO-LCA simplifies the modeling effort and avoids errors arising from the necessary truncation or boundary definition for the network of process-models.

A hybrid system uses the two models together to get the best of each. The process-LCA analysis can give the detailed input, output, and discharges for manufacturing a commodity. This then approximates each of these detailed inputs by one of the input-output sectors in order to give a comprehensive LCA of the commodity. The hybrid analysis uses the detail of the process analysis to define precisely the commodity to be considered, then uses EIO-LCA to trace out the economic-wide implications by buying the desired quantity of each material (Suh and Nakamura, 2007; Hendrickson *et al.*, 2006).

2.7.2 Application of hybrid model analyses

Suh (2004) used the name 'tiered hybrid approach' when data exchange is done by the interaction of EIO-LCA with process-LCA models. Using tiered hybrid analyses has extra advantages. Input-output matrices or coefficients need not be altered at all, and thus can use a standard model such as EIO-LCA. Analysis can be performed rapidly, allowing disaggregation of sectors and consideration of a wide range of alternatives. The use of

EIO-LCA for standard inputs can avert truncation errors. Process-LCA models can be introduced whenever greater detail is needed or the EIO-LCA is inadequate.

2.7.3 Use of hybrid models

Several approaches to hybrid LCA modeling have been suggested. The common thread is combining LCA models to yield improved results. The approaches vary in their theoretical basis, the ways in which the sub models are combined, and how they have been used and tested. Suh *et al*. (2004) examined boundary problems and integrated input-output models. Florin and Horvath (2004) defines potential data interactions. Joshi (1999) developed disaggregation schemes for input-output models. Whilst, Cano-Ruiz (2000) provided an input-output process model framework, Lin and Polenske (1998) developed enterprise input-output models. However, even considering these aspects, a suitable method to draw a clear and transparent boundary around the process is needed.

2.8 *Methods to define a system boundary in the LCA*

The LCA is divided into four main steps, as described previously (see Section 2.4.2 and 3.1). Firstly, the goal should be defined and the scope should be determined. Both of these are allocated by practitioners on the basis of stakeholders' requirements, or to meet specific research objectives. After the goal is defined, the scope of study is stated to cover the proposed goal. The functional unit will be the central measure to compare all process in the supply chain. Usually the functional unit is defined to characterize the final product in the supply chain (Rebitzer *et al.*, 2004). For example, analyzing the pig production chain (PPC), one kilogram of pig at the farm gate is the functional unit. The PPC is the main part of the PSC, which extends the framework from crop production to pig farming. Consumers are all downstream of the PPC, whilst every upstream process in the PPC can use a customized functional unit to model its production process. However, the functional unit should directly be related between processes in order that, finally, only one functional unit is obtained at the end of the chain (Rebitzer *et al.*, 2004), in this study the PPC.

Inventory analysis is the second main step in the LCA. This is the part of the LCA where all inputs and their environmental burdens are registered and a more detailed system boundary should be established. The first approach in the Life Cycle Inventory (LCI) is to determinate which inputs, outputs and processes should be included in the analysis. The processes included should be those that are expected to be affected in the short and/or long term by the decisions to be supported by the study. However, different approaches carried out for the same product go into different levels of depth in its supply chain. General recommendations have been set down for modelling supply chains with process-LCA (Dalgaard *et al.*, 2004; Yakovleva and Flynn, 2004) and also for EIO-LCA (Hendrickson *et al.*, 2006). However, methods for including or discarding commodities or sectors (the system boundary) often depend on subjective criteria. The following sections analyse existing methodologies to place a system boundary around a LCA.

2.8.1 The cut off criteria

In the past, the criteria for cut offs for specific processes in the LCI has often been done on a subjective basis, giving rise to problems such as those referred to by Hagellar and van der Vorst (2002) and discussed previously (Section 2.5.2). Hunt *et al.* (1998) reviewed techniques that reduce the effort for the LCI by applying different subjective cut-offs (i.e. deliberately excluding processes of the system from the inventory analysis). They found that these cut off criteria were arbitrary assigned when the LCA system boundary was drawn, which brings poor success rate when the LCA is undertaken (Table 2.5).

Table 2.5 Analysis of LCA simplification method (Hunt *et al.*, 1998)

Cut-off method	Description (applied to packing, industrial chemical, household cleaners, etc)	Success rate (same ranking as detailed LCA)
Removal of upstream components	all processes prior to primary material production)	58%
Removal of partial upstream components	as above, but the one preceding step is included (e.g., monomer production)	70%
Removal of downstream components	all processes after primary material production are excluded (manufacturing, use, end of life)	67%
Removal of up- and downstream components	only primary materials production is included (e.g., only polymerisation)	35%

Hunt *et al.* (1998) based their analysis on a flow chart, where flows start with resource extraction at the top and end with the final disposal at the bottom. They concluded that a vertical cut of flow components instead of a horizontal cut, whereby data are collected for all relevant stages and stressors but in less detail, is generally preferable to eliminating processes at any given stage. This implies that recognizing relevant input and outputs can not be done in the first stages of the LCI without running the risk of omitting important environmental burdens. Rebitzer *et al.* (2004) said that the area of simplifying is still in its infancy, and no general methods are recommended at present for building a clear system boundary around the LCI. They also added that there are a variety of specific simplifying methods for specific applications based on experience and detailed LCAs. Other authors have recommended doing a screening, or pre-assessment, of the LCA prior to commencing a simplified inventory (De Beaufort-Langeveld A *et al.*, 1997). The most frequently used approaches to pre-assess a LCA have been the matrix approaches (Rebitzer *et al.*, 2004) and the input-output approaches (Hendrickson *et al.*, 2006; Rebitzer *et al.*, 2004). Both these approaches have requirements or impose restrictions to screening components for the LCI which will now be considered.

2.8.2 Matrix approaches

Quantitative matrix approaches and the use of energy demand as a screening indicator are the most widely applied screening approaches to find important processes in the LCI (Rebitzer *et al.*, 2004). However, matrix methods need detailed LCAs of similar product systems before commencing the screening (i.e. for the case supply chains). Nevertheless, matrix approaches are useful to identify differences between well-known systems (Rebitzer *et al.*, 2004).

2.8.3 Input-Output LCA approaches

Another quantitative group of approaches can be done using the EIO-LCA model described previously (see Section 2.6). With EIO-LCA modeling, the product system, which consists of supply chains, is modeled using economic flow databases (matrix tables). These databases are collected and supplied by statistical agencies of national governments. They describe in financial terms the amount that each industrial sector spends on the goods and services produced by other sectors (discussed in section, Section 2.6.3). Emissions and associated impacts are then assigned to different commodity sectors. Process modeling relies directly on inventory databases that quantify requirements to produce one unit of output needed. The approach includes requirements for manufacturing, transportation, energy generation processes, etc.

The EIO methodology could be useful to screen the relevant sectors for modeled processes (Hendrickson *et al.*, 2006). However, a specific methodology has not been developed with EIO model to set down a system boundary around the processes in a hybrid LCA. This pre-assessment can save time in tracking only relevant processes.

Thus, for the current thesis, a systematic method will be proposed to find important sectors that contribute to environmental burdens when a process is modeled (see Chapter 4). These sectors then should be included in transparency way when a system boundary is drawn around the LCI.

2.9 *Summary*

A LCA analysis provides the most complete means of assessing the environmental impact of a production chain. In order to obtain the best compromise between analytical detail and workload, hybrid LCA models offer the best option. These allow important stages to be modelled in detail using specific data in a process LCA model, while using EIO models to account for less important upstream processes which contribute goods or services. This hybrid approach will therefore be adopted in this thesis. Definition of the system boundary for the analysis is a critical first step, and a systematic and transparent method for defining the LCI, which will be adopted as the first stage of the analysis.

Chapter 3 General Methodology

Introduction

This study presents a detailed environmental evaluation of contrasting pig production scenarios that includes industrial commodities that are frequently avoided in studies of this nature. Also, the study analyses the environmental consequences of lack of agricultural integration in the PPC, through comparison of different types of scenario in different countries. The method selected for the environmental evaluation was LCA (Alcamo, 2001) and for the modelled systems was scenario methodology (Stern *et al.*, 2005). The analysis was mainly conducted to assess the environmental impact of contrasting conditions of pig production. Additionally, opportunities for improvement in profitability and labour shared incomes were investigated (Section 8.7).

3.1 *Pre-assessment of the LCA for pig production*

Before developing the LCA of specific scenarios it is important to know which commodities should be included in the LCI. Thus, the system boundary drawn around the LCA should avoid both omitting important contributors and including negligible contributors. Developing a pre-assessment step is highly recommended amongst the different systems reviewed previously to define the system boundary in the LCA (Section 2.8). Since there is no specific methodology to develop the pre-assessment, a systematic procedure was developed in Section 4.1. The pre-assessment brings to light the major commodities that produce, or are responsible for, the main environmental impacts (e-impacts) in the PPC.

3.2 *LCA*

As described previously in Section 2.4.2 LCA is a tool for assessing the environmental impact caused by a product or a service (ISO, 1997). The basic principle for LCA is to follow the product through its entire life cycle. The product system is delimited by a system boundary. The energy and material flows crossing the boundaries are accounted for as input-related (e.g. feed, petrol, transport) and output-related (e.g. emissions to air) flows. The LCA methodology has been developed and harmonised within an international standardisation process (ISO, 1997). Four phases make up the procedure; the first two phases were discussed in Section 2.8 and Figure 3.1 shows the four phases interaction. In the first phase, the goal and scope, the aim and the range of the study are defined. A functional unit is defined and an allocation method. The system boundary is also established. In the second phase, the LCI, information about the system is gathered and inputs and outputs are identified and quantified. The third phase is the impact assessment where data and information from the LCI are linked with specific environmental parameters, so that the significance of these potential burdens can be assessed. In the final interpretation phase, the findings of the inventory analysis and the impact assessment are combined and interpreted to meet the previously defined goal of the study.

3.2.1 The goal and purpose for the LCA

The purpose of this phase of the study was to gain an understanding of the environmental impacts of contrasting scenarios in the PPC. The study will also help to illustrate possible opportunities to improve the sustainability of specific PPCs. The contrasting scenarios analysed focus on pig production as cornerstones of the PPC of standard and alternative systems under specific country conditions as described in Table 3.1.

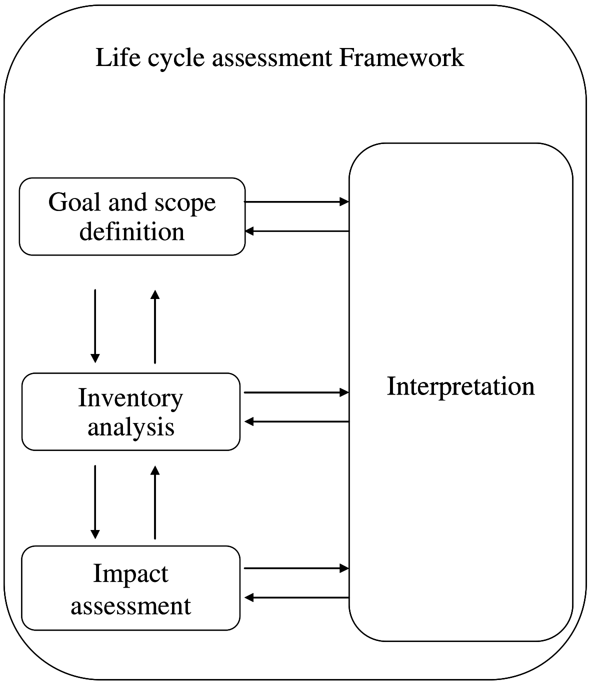

Figure 3.1 Normalised methodology for the LCA, boxes represents the phases of the LCA (ISO, 1997)

3.2.2 Definition of scenarios

The scenarios were chosen to contrast four different PPC conditions, trying to be extreme in perspective. Standard pig production systems under specific country conditions are contrasted with their alternative systems for two countries: Mexico and the UK. Alternative systems are in the case of the UK the system that was developed as a niche market option and the case of Mexico the system of more traditional production which has been displaced by intensive production. Mexico is part of the developing world where intensive pig production (stdMEX) has displaced traditional pig production (locMEX), as was reviewed by Tejera and Santos (2007). The UK, on the other hand, is in the developed world where intensive pig production (stdUK) is increasingly criticised and organic pig production (orgUK) has increased in recent years as an alternative option (Pollock, 2006). Table 3.1 shows the modelled contrasting scenarios.

Table 3.1 Contrasting scenarios

Scenarios	Country: Mexico	Country: UK
Standard	stdMEX	stdUK
Alternative	locMEX	orgUK

3.2.3 Scope of study

The analysis involves all phases of the life cycle of pig production as shown in Figure 3.2, including production of materials, transport and energy used.

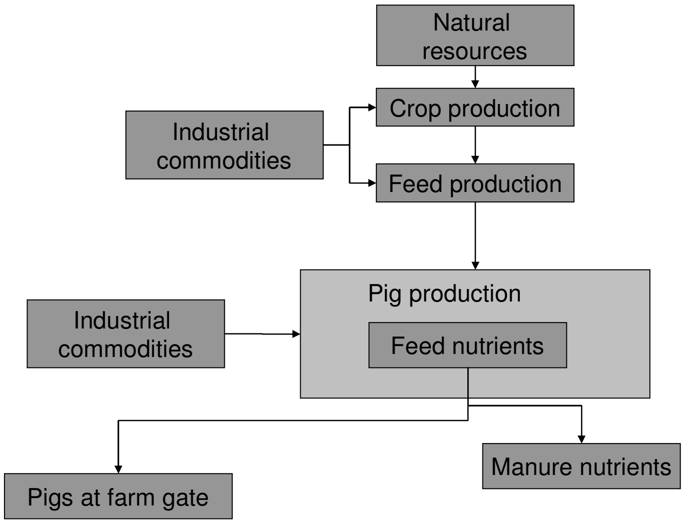

Figure 3.2 Scope of the LCA

3.2.4 Description of the scenarios

The stdMEX scenario is based on pig production on intensive farms which focus on increased productivity with no integration to crop production. The pig herd is kept indoors. Finished pigs are marketed to the principal meat consumption places in the country, often travelling long distances. Feed is compounded using imported crops. Pig manure is stored in open earthen tanks and discharged to riparian zones.

The locMEX scenario is similar to stdMEX in the pig production system, but contrasts in scale of operation and approach to manure disposal. The pig production is more integrated to crop production. Surrounding land receives pig manure that is used for crop fertilisation on an empirical basis. Feed is compounded using imported crops, since locally grown crops are sold to the human food market. Since the pig farmers represented in this scenario have been displaced from the more intensive market chains, finished pigs are marketed principally in local and regional markets.

The stdUK scenario is based on intensive pig production whose focus on increased productivity. The system is integrated to crop production through manure disposal. Where the surrounding land receives pig manure that is used for crop fertilisation on the basis of the nutrient requirements for the following crop. The pig herd is kept indoors (even though a significant proportion of standard UK production now comes from outdoor breeding herds, to give a more interesting range of scenario contrasts). Feed is principally compounded with home country crops, but soya bean meal is imported. Finished pigs go to national meat markets.

The orgUK scenario is based on outdoor pig production, where the herd is kept outdoors at all stages. Pig production is integrated with crop rotation and pig manure is directly deposited on paddocks. So that pig production is part of the rotation system and crop fertilisation. This system is 75% self-sufficient in feedstuffs and only 25% of nutrients are imported because of limitations in availability of suitable home grown protein crops. Finished pigs are marketed on the organic meat market.

3.2.5 Delimitations and methods framework

Since the system assessment was built to assess all possible sources of environmental impact, the LCI was carried out using a hybrid LCA methodology. This methodology allowed splitting of the environmental impacts associated with nutrient flows from those arising from the industrial production process for other commodities, such as buildings and equipment, transport or services. Two methods, the process-LCA and the EIO-LCA, made up the hybrid LCA methodology (described in hybrid models, Section 2.7). The process-LCA model calculated losses and outputs arising from nutrient transformations from crops to finished pigs. The EIO-LCA model calculated the e-burdens produced by supply chains of those commodities consumed by the pig farm (with the exception of feed). The SimaPro database manager (PRe Consultants, 2008) gathered data and summarised total e-burdens. Figure 3.3 shows the methods framework.

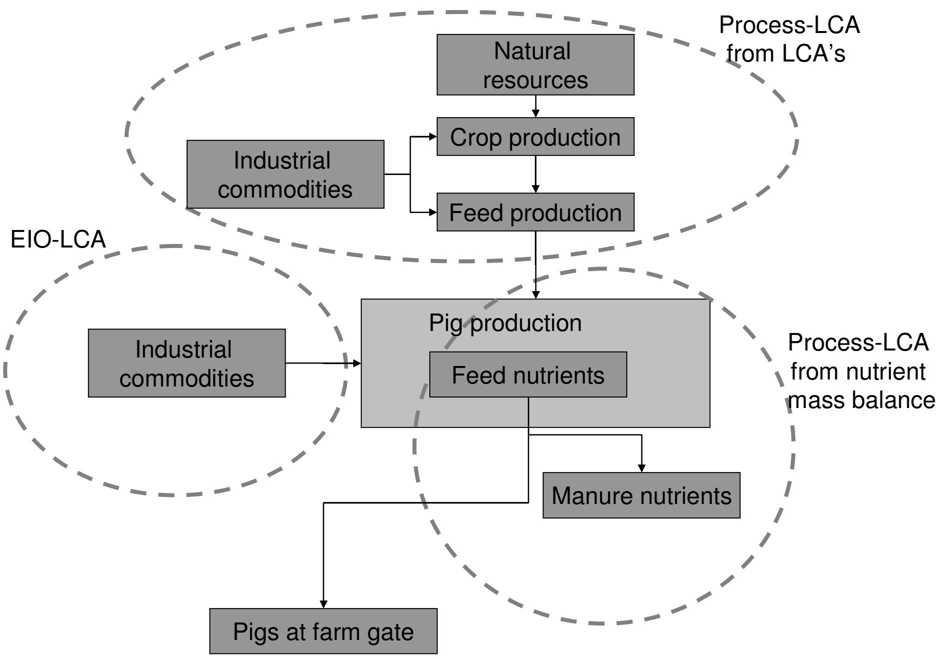

Figure 3.3 Methods framework used to gather the LCI of the PPC

Pig production was the starting point to develop the LCI of the PPC scenarios. Pig farm performance and farm financial budgets gave starting parameters for pig production. Next, methods that track energy flow and resource use are described in order of data complexity.

- The nutrients mass balance was the main approach to develop a detailed calculation of nutrient losses and outputs for each scenario during pig farming. Feed consumption provided the nutrient inputs. The nutrient mass balance was carried out under the IPCC framework (2006). This method followed nutrient flows from feed input to manure disposal.

- LCA processes reported in the literature or in the Ecoinvent database (Swiss Centre for LCI, 2007) were used to model feed production and crop production. The energy and commodities used for compounding feed were calculated from the consumption of different diets. Crop production was from home or imported origin according to demand of feed production mills in each scenario.

- Finally, the EIO-LCA model was used for those goods and services needed to operate the pig farm, except for feed. These are more diverse and come from multiple processes in a net of industrial sectors. These commodities were modelled according to the financial budget of representative pig farms by scenario and their e-burdens were traced through an EIO-LCA model that includes e-burdens arising from the net of economic sectors that participate in the commodity supply chain (use of the EIO-LCA software, Section 2.63). This method is further described later in the industrial commodities section (Section 6.1.1)

Since the process-LCA approach did not include the e-burdens arising from commodities used in the pig farm except for the feed, the EIO approach assessed the burdens from production of buildings and machinery, medicines and other commodities. The emissions arising from drug use were not accounted for due to lack of knowledge of the environmental impact from medicine residues in the environment after being metabolised by the animal and released to the environment. Disinfectants, washing detergents and minor farm equipment were also accounted. The production and use of pesticides and fertilisers in crop production were assessed with the process-LCA approach. Production of synthetic amino acids, enzymes, vitamins, salt, and minerals were included as general compounds coming from the organic and inorganic chemical industry in the ecoinvent database (Swiss Centre for LCI, 2007). Since the objective of this study was to compare different scenarios, and not all scenarios have pig production integrated with crop production, the soil nutrient changes (N, P, C) and their economy in soil was not modelled because this was outside the study framework. Only the supplied N and P through pig manure were modelled.

3.2.6 Functional unit

A tonne of pig liveweight at the farm gate (tlw) was the basis for building the inventory and this was the functional unit. Data involve the inputs and outputs required by both the breeding herd and the growing herd to produce a tonne of live pig. This functional unit was selected to facilitate clear contrasting assessment between scenarios, since the pig farm is the main comparison point. When data on a PPC sector are presented, it is mostly as amounts of inputs needed or outputs produced per tlw. For example, for the feed production sector the amount of feed required to produce a tlw was the functional unit.

3.2.7 Allocations

Since pig production was the cornerstone for the LCA, a system expansion approach (ISO, 1997) was used in order to calculate the e-burdens from inputs and outputs. In the crop production sector, in order to estimate the e-burden from sub-products, the following methods were used:

1. A system expansion approach was used to allocate the stover maize part for maize production in the Mexican scenarios. The system e-burdens associated with maize

grain were subtracted from total burdens of both corn grain and corn stover (Kim *et al.*, 2009).

2. Soya bean processing for the Mexican scenarios was allocated on a mass basis, using the yield of soya meal and soya oil (Landis *et al.*, 2007; Miller *et al.*, 2007).
3. System expansion approaches characterised the LCI for crops used in the UK scenarios. The LCI was handled separately for each crop and overall measures in the crop rotation were divided between all crops.
4. The energy used and burdens produced for rapeseed and soya bean oil extraction processes were allocated on a mass basis for meal and oil.
5. Burdens and credit for manure disposal: Emissions (ammonia, methane and nitrous oxide) were debited against the animals whilst credits were given for fertiliser value for manure disposal.

3.2.8 Chosen impact categories

Since the feed is the main commodity demanded to produce pig, it was assumed that the main adverse effects from the PPC are focussed on nutrient chain flow and the more important agricultural effects on the environment were included. The environmental impact categories considered for the nutrients mass balance were:

- Resources – energy
- Ecological effects
    - Climate change
    - Acidification
    - Eutrophication

However industrial commodities required for pig production do not substantially contribute to these impact categories, though industrial processes closely related to the petrochemical process release other kinds of toxic substances. Pig production, as a final consumer of these industrial commodities, is responsible for these emissions. Thus the environmental impact categories for industrial commodities, highlighted in the LCA pre-assessment were:

- Air pollutants,
- Greenhouse Gases,
- Energy use and
- Toxic releases

The 100-year time horizon global warming potential (IPPC, 2001) was used for the climate change calculation. Climate change is measured in CO_2 equivalents of greenhouse gas emission (CO_2-eq) and this is referred to as Global Warming Potential (GWP) through this study. The Environmental Design of Industrial Products method (EDIP) developed in 1996 and adapted for SimaPro 7.1 (LCAfood, 2002) was used to sum up the burdens and generate an appropriate weighting for environmental impact (e-impact). The important EDIP e-impacts included were:

- Global Warming Potential (GWP)
- Acidification Potential (AP)
- Eutrophication Potential (EP)
- Photochimical smock (PhS)
- Ozone depletion (O_3D)
- Chronic eco-toxicity to water (TxW)
- Chronic eco-toxicity to soil (TxS)
- Fossil Energy use (FE)

3.2.9 Data quality

The scenarios are projections of representative PPCs existing in Mexico and the UK, based on system reports or modelled for this study (scenarios construction). The data on crops are based on LCAs developed for representative crop production in the country and for each system of crop origin. The feed nutrient composition and feed formulation data were based on representative commercial conditions for the UK scenarios and standard reference sources for the Mexican scenarios (diet nutrients and diet ingredients). The pig production data were based on descriptions in the literature and national sector statistics. Pig production data reported for the Mexican industry are too general and often did not match the details of the modelled Mexican scenarios. Hence this gap was filled with an expert panel opinion, with national and regional specialists interviewed to parameterise Mexican pig production.

3.3 *Inventory analysis*

Since the scenarios were deliberately constructed to be extreme in perspective, scenarios methodology described by Stern *et al.* (2005) was used to parameterise every system. Parameters were firstly taken from published sources. When conflicts, on data certainty or unavailability were found, the data were parameterised with an expert panel opinion (as was the case for Mexican scenarios).

3.3.1 Scenarios construction

The different scenarios for contrasting PPC were constructed according to representative pig production systems. The scenarios were optimised according to two strategies:

- That the standard scenario be representative of main pig production system in the specific country

- That the alternative scenario be a contrasting scenario to the country standard scenario

Mexico and the UK were chosen as contrasting countries to compare the agricultural integration of the pig production in the PPC. In all scenarios, pig production includes breeding and growing herds as a unit. The standard scenarios for PPCs focus upon profitability and productivity whereas the alternative scenarios focus on more integrated agricultural systems to reduce dependency of external commodities and environmental impact.

Standard systems

The *stdMEX scenario:* In this scenario breeding and growing herds are kept indoors. The breeding herd is kept on partially slatted floors (50/50 solid-slatted floor), in individual crates during maturing and the first third of gestation and in pen groups for the remainder gestation. During lactation sows are kept in crates on slatted floors with their litter. The growing herd is on 50% slatted floors, in pens established according to body weight at weaning, in all-in all-out (AIAO) systems by room. The space allowed per pig is 1.2 m^2. Natural ventilation is the dominant ventilation system, although in farrowing and nursery buildings a mechanical forced air system extracts stale air. AIAO is the sanitary population practice in the growing herd and farrowing rooms. The feed is provided as a concentrate. The feeding strategy is on a production stage basis for the breeding herd, and on a weight change basis for the growing herd. Slaughter is based on age, thus the whole batch is slaughtered at the same time. The feed consists of imported cereals and soya meal from the US Corn Belt. Feed is supplemented with synthetic amino acids, phytase enzyme and growth promoters. Manure is collected in under-floor pits and pumped when rooms are emptied out or on a monthly basis. Open lagoons store manure for more than a year.

After evaporation and manure fermentation, the remaining sewage is sent to riparian zones (zones that receive drainage or runoff water such as ditches, streams, rivers and estuaries). Federal slaughter houses process finished pigs and deliver carcasses to butchers in high street markets, supermarkets or pigmeat processors in the main national population centres.

The stdUK scenario: The main differences from the stdMEX scenario are that the breeding herd is accommodated individually only during the lactation period and for the entire gestation period they are kept in group pens. Mechanical ventilation system is the dominant ventilation system. Feed consists of cereals produced nationally and imported soya beans. Synthetic amino acids and phytase enzyme are included, but no anabolic additives are used. Collected manure is pumped from buildings almost weekly and stored outside the pig buildings in covered tanks for a year. Tanks are emptied in the crop cultivation season on the basis of the following crop requirements to reflect the best manure application practices.

Alternative systems

The locMEX scenario: The main differences from the stdMEX scenario are that the breeding herd is accommodated similarly to the stdUK scenario, with more time spent in pen groups. A natural ventilation system is employed in practically all buildings. Continuous flow of animals rather than AIAO is the common population management in the growing herd. Feed, feeding practice and slaughtering frequency is similar to the stdMEX scenario. Manure collected from pens is pumped twice a week and gathered outside in a small tank, sending manure frequently to cultivation land. Municipal slaughter houses process finished pigs and deliver carcasses on regional butchers and pigmeat processors.

The orgUK scenario: The main differences from the stdUK scenario are that both the breeding and growing herd are kept outdoors. Pigs are accommodated in group arcs with straw bedding. The paddocks are integrated with the crop rotation system that allows the pig herd to be kept for one year on the same land, often in a two or more year crop rotation (Hermansen *et al.*, 2004). Lactation length is longer than the stdUK scenario (Table 3.4). Piglets are grouped together at weaning. The farm is self-sufficient in cereals, but imports soya bean. Feed does not contain synthetic substances and the only raw minerals added are to balance calcium and phosphorus. Manure is deposited directly to the soil and the herd is moved annually.

3.4 *Pig production*

3.4.1 Pig farming performance

For the physical performance of the pig farming scenarios, data come from different sources. For the stdUK scenario, Fowler (2008; 2006) and the Pig YearBook 2006 (BPEX, 2006) were the primary sources. For the orgUK scenario, Lampkin (2006) and Martins *et al.* (2002) were the principal sources. For both Mexican scenarios (stdMEX and locMEX), the expert panel's opinion and National Statistics (SIAP, 2006) were the sources. When some parameters were not found, where possible, these were calculated from more general data. For example, feed consumption per sow, including the lactation and gestation period, for the orgUK and the stdUK scenarios were provided in the literature as annual total feed consumption. So this was disaggregated according to time spent in each productive stage and reproductive cycles per year (litters per year). Table 3.2 displays the parameters used to model the physical performance of pig farming. Among the calculated parameters are the following key values.

For the stdUK scenario, annual feed consumption per breeding sow (b-sow) was calculated in this study as 1337 kg per sow (adding lactation and gestation consumption) which was similar to the level of 1339 kg reported by Fowler (2006).

For the orgUK scenario, Martins *et al.* (2002) reported 1700 kg of feed consumption per sow when weaners' feed consumption is included. In this study, adding calculated weaners' consumption (to 8 weeks of age) to sow consumption resulted in 1680 kg. In all scenarios, boar and gilt daily feed consumption was assumed to be similar to dry sows. The period of time of feeding gilts before service was assumed to be two oestrous cycles (21 days per cycle) and 18 days pre-puberty days for all scenarios. The weaning weight for the orgUK scenario was calculated from the daily gain for organic weaners and the 32 kglw of transfer or sale weight at 12 weeks reported by Lampkin *et al*. (2006). Finished pigs per b-sow were calculated using annual sow productivity (litters per year and weaners per litter) and consecutive mortality per productive stage (rearing and finishing mortality).

The physical performance of pig production by scenario allowed calculation of most of the inputs and outputs from the pig farming. Since a tlw (the functional unit) is affected by both the breeding herd and the growing herd performance, some calculations were first done on a b-sow basis and then put into a twl basis. For example, feed needed to produce a tlw included the proportional part of feed for sows, boars and gilts added to feed consumption of growing pigs per b-sow before being scaled to feed used to produce a tlw.

3.4.2 Farming financial budget

Since the farm financial budget was an important part to assess e-burdens from use of industrial commodities, this was modelled in detail in the farm budget section (Section 6.2).

Table 3.2 Physical performance of pig farming scenarios

Scenario	locMEX		stdMEX		orgUK		stdUK	
General								
Litters per year	2.05	a	2.30	a	2.00	b	2.25	f
Boar-sow ratio	0.05	a	0.05	a	0.10	c	0.05	d
Breeding								
Annual replacement,%	31	a	36	a	37	b	47	f
Feed per dry sow or boar, kg/day	2.38	a	2.20	a	2.50	c	2.50	f
Feed per gilt, kg/day	2.38	a	2.20	a	2.50	c	3.10	f
Gilt enter-first service, days	60	d	60	d	60	c	60	d
Cull weight, kg	250	a	220	a	200	d	220	d
Mortality, %	3.25	a	5.0	a	5.0	b	4.7	e
Lactation								
Feed per sow, kg/day	5.25	a	5.5	a	5.4	c	6.1	f
Weaners/litter, heads	8.65	a	8.90	a	9.00	b	9.81	f
Weaning age, days	22.7	a	21.4	a	56.0	c	27.0	f
Weaning weight, kg	5.9	a	5.8	a	20.6	b	7.2	f
Rearing								
End age, weeks	11.7	a	10.6	a	12.0	c	12.1	e
Feed conversion, kg/kg	1.72	a	1.65	a	1.60	c	1.70	e
Daily Gain, kg	0.41	a	0.43	a	0.43	c	0.51	e
Mortality, %	4.5	a	3.5	a	2.8	b	3.4	e
Finishing								
End age, weeks	24.5	a	23.6	a	26.0	c	26.0	e
Feed conversion, kg/kg	2.98	a	2.75	a	3.00	c	2.74	e
Daily Gain, kg	0.75	a	0.78	a	0.70	c	0.64	e
Mortality, %	3.5	a	5.0	a	2.0	b	6.5	e
End weight, kglw	98.25	a	101.0	a	100.0	b	97.0	e
PIGMEAT								
Finished pigs per b-sow, heads	16.34		18.77		17.15		19.94	
Pigmeat per b-sow per year, kglw[1]	1675.0		1963.5		1778.6		2027.1	

Reference: a) Expert panel; b) Lampkin *et al*., 2006; c) Martins *et al.* 2002; d) Estimated; e) Fowler 2006, 2008; f) BPEX 2006.

[1]Pigmeat per b-sow includes pigmeat from finished pigs and culls from breeding herd.

3.4.3 Meat production

The meat production was based on pig farming performance. Meat from finishers includes finished pigs at slaughter weight produced by the sow on an annual basis. Meat from the culled breeding herd was calculated from the replacement rate, less breeding mortality, and cull weight. The replacement rate was used since this is similar to cull rate on a steady-state farm. Finishers and cull yield of meat was allocated on tlw basis. Table 3.3 shows both yields on a sow production and tlw basis.

Table 3.3 Pigmeat production at the farm gate, kglw

Scenarios		locMEX	stdMEX	orgUK	std UK
Per sow	Cull	69.4	68.2	64.0	93.3
	Finishers	1,605.6	1,895.4	1,714.6	1,933.8
	Total	1,675.0	1,963.6	1,778.6	2,027.1
Per tonne (tlw)	Cull	41.4	34.7	36.0	46.0
	Finishers	958.6	965.3	964.0	954.0
	Total	1,000.0	1,000.0	1,000.0	1,000.0

3.4.4 Feed consumption

Feed consumption was calculated from the physical performance of pig production on an annual basis (Table 3.2). Since the physical movement of pigs in the farm does not always match the feed changes, the b-sow feed consumption was calculated for reproductive stage and for the growing herd it was done on a weight basis, according to national feed recommendations (BSAS, 2003; Edwards *et al.*, 2002; NRC, 1998). For the growing herd, two feed changes were modelled, at 25 and 50 kglw. Weekly consumption was estimated from physical performance parameters (weaning weight, daily gain and feed conversion), thus feed consumption was matched to corresponding weight ranges. Finished pigs per b-sow were then used to calculate annual consumption and scaled to tlw (Table 3.4).

Table 3.4 Feed consumption for each productive stage (kg sow^{-1}year^{-1})

Scenario	weight, kg	locMEX	stdMEX	orgUK	stdUK
Breeding herd, include (boar and gilts)		840	777	762	886
Lactating sow		245	271	600	371
Weaners	<25	645	652	579	726
Growers, 1st phase	25-50	1,359	1,502	1,248	1,218
Finisher, 2nd phase	50-110	2,301	2,536	2,499	2,692
Annual feed, kg/b-sow		5,390	5,738	5,687	5,893
Annual feed, kg/tlw		3,218	2,922	3,198	2,907

The orgUK scenario shows higher feed consumption for lactating sows because lactation length is longer than for other scenarios (see Table 3.2). Most other differences are due to efficiency of production, especially in finishers per sow per year. Thus the most intensive scenarios (stdMEX & stdUK) have lower feed consumption per tlw, which contrasts with locMEX and orgUK scenarios where feed consumption on this basis is higher. These calculations to define the characteristics of the basic scenarios were carried forward into the calculation models for nutrient flows (Chapter 4).

Chapter 4 Pre-assessment of LCA:

Introduction

This chapter includes the pre-assessment for the pig production LCA. The aim of the pre-assessment is to highlight all commodities that are responsible for the main e-impacts from the PPC. In consequence, e-burdens of these commodities or their supply chain should be included in the LCI. Since there is no specific methodology to develop the pre-assessment (see Section 2.8 on method to define a system boundary), a systematic procedure is developed in this chapter. The main challenge in developing the pre-assessment of pig production is to give the most complete figure of the network of sectors that supply the pig farm, either directly or indirectly and the way in which they are connected. This requires the identification of which commodities consumed in the farm come from these suppliers. Additionally it is necessary to know the e-impact delivered by every industry in the network. Then, with this background, the farm consumption of commodities can be used to track the respective suppliers' e-burdens. However, the pre-assessment is only a general feature of the LCA, so this should be simpler than the detailed LCA to be time and resource efficient. Thus, in this study, the EIO-LCA model was used to develop the pre-assessment.

4.1 *Main sectors in the PPC*

4.1.1 Methods

The EIO-LCA model works through matrix tables that can track the participation of all economic sectors when there is an increment on demand from one of those sectors. Thus, an increment in demand of the animal production sector (except cattle and poultry and eggs) which is the economic sector where the pig industry is, can show the network of industrial suppliers.

4.1.2 Model and software

The software 'eiolca.net' designed for Green Design Institute (2006) was used to track the e-burdens produced for the pig production net of suppliers. The eiolca.net software works with matrix tables for 491 economic sectors. Matrix tables in the eio-lca.net software come from the economic activity of all sectors in the United States for 1997. Working with these matrix tables enables eiolca.net to track the complete interactions of one sector with all other sectors that share the economic activity. Thus, when one dollar of a specific product is demanded by the sector of interest, the software shows how much economic activity from the other 490 sectors is necessary (Hendrickson *et al.*, 2006). In addition, eiolca.net shows the environmental burdens that arise for this economic activity in every sector. Environmental burdens included are air pollutants, greenhouse gases and toxic releases. Energy use is also shown. Indicators for environmental burdens are detailed in Table 4.1.

Table 4.1 Environmental indicators by burden group and measure unit.

Indicators	Burdens	Measure units
Air pollutants	SO_2 (Sulphur dioxide) CO (Carbon monoxide) NOx (Nitrous oxides) VOC (Volatile Organic Compounds) Lead (Pb) PM10 (Particles matter <10µm)	g (grams)
Global Warming Potential	CO_2 (Carbon dioxide) CH_4 (Methane) N_2O (Nitrous dioxide) CFCs (Chlorofluorocarbons)	gCO_2eq((grams of CO_2 equivalent)
Energy use	All sources	MJ (Mega-joule)
Toxic releases	Air Water Land Ungrounded	mg (milligrams)

The eiolca.net model has the advantage that it tracks environmental data for all economic sectors without needing more information than a quantity of economic activity in one specific sector (Hendrickson *et al.*, 2006). This is a great advantage when making the pre-assessment of the PPC, because this does not need previous experience, or similar detailed analyses to choose the principal processes responsible of these burdens. Any monetary quantity can be used to do this assessment, because the increase in economic activity in one sector is linearly related with that for the other sectors and for their environmental releases (Hendrickson *et al.*, 2006).

4.1.3 Modeling PPC processes

The principal enterprises that contribute economically in the PPC were allocated in one of the eiolca.net sectors to track environmental indicators that appear in Table 4.1. Sectors from the eiolca.net software used to allocate enterprises in the PPC are shown in Table 4.2.

Table 4.2 Sectors of the eiolca.net software used to allocate enterprises in the PPC.

Enterprises in the PPC	eiolca.net sectors
Crop farming	Grain farming
	Oilseed farming
Feed producers	Soya bean processing
	Other Animal Food Manufacturing
Animal farmers	Animal production, except cattle and poultry and eggs

4.1.4 Results from the eiolca software

Results of tracked burdens were arranged on matrix tables with the 15 indicators and the 491 economic sectors by running eiolca.net. Next, criteria were used to discard negligible participations and obtain the principal suppliers:

- Sectors that contributed ≥ 5% by indicator were included
- Suppliers that accounted through an upstream PPC process were discarded as direct suppliers and their burdens were tracked through the supply chain. For example, burdens from fertilizer manufacturing were linked through grain farming. Considering that sectors that are in the supply chain of feed are the upstream sectors for the main supply chain of pig farming (see Figure 3.2)
- The upstream supply chain was divided by levels: Pig production was the cornerstone in the supply chain.

Participation of direct and indirect suppliers is shown as percentage weight for each indicator in Table A2.I in Appendix 2. Data in this table were not clear enough to trace commodities used in the PPC. These economic sectors were arranged by levels in the commodity supply chain in the following section.

4.1.5 Level in the commodities supply chain for the PPC

Primary suppliers, such as those in the feed production chain, were highlighted as the main contributors of e-burdens. Electricity was another important supplier. Services and industrial commodities did not produce a great impact by themselves, but their supply chains gave rise to important burdens. For example, the mineral mining sector contributes most of the toxic releases but does not directly deliver products to the pig farming process. From the initial analysis, the net of industries that participate in the supply chain of commodities used in the pig farm was developed. Six levels were set down for the distribution of industries in the complete supply chain:

1. Natural resource extraction was in turn divided into mineral mining, fossil fuels extraction (that includes oil and gas extraction and coal mining) and other natural resources. Which includes fishing, forestry, agriculture and water use.
2. Industrial transformation was in turn divided into ore mining transformation, fossil fuels distribution and transformation, and transformation or distribution of other natural resources. Industrial transformation can include one or two levels of industries that pass products between them before their products are delivered downstream or upstream.
3. Services were all those sectors that give general services, such as transportation, warehousing and storage and, in some cases, agricultural activities. Agricultural activities include soil preparation or crop production, such as ploughing, fertilizing, seed bed preparation, planting, cultivating, and crop protection. Agricultural activities for agricultural processes, such as grain farming and oilseed farming, were included as services because it is an activity than can be developed in the process or for other enterprises. Other agricultural activities were allocated to the section on transformation or distribution of other natural resources.

4. Previous processes were those industries that were modelled in the food supply chain of pig farming and are located upstream. For example, grain farming is an upstream sector of food manufacturing that delivers feed to pig farms.
5. Pig farming is the process to which sectors supply commodities.
6. Disposal services are sectors in which materials are reused, recycled, put into landfill, burned to generate electricity or discarded into the environment waste produced by the process.

Table 4.3 summaries these levels of division, subdivisions and abbreviations used. Burdens from individual sectors were summed for each level and are shown in Figure 4.1.

Table 4.3 Supply chain levels for the PPC

Level	Sub-level	Abbreviation
Natural resources extraction	Mineral mining	Mineral-ext
	Fossil fuels extraction	Fuels-ext
	Other natural resources	Other R-ext
Industrial transformation or distribution of natural resources	Ore mining industrial transformation	Mineral-IT
	Fossile fuels distribution and transformation	Fuels-IT
	Transformation or distribution of other natural resources	Other-IT
Services		Services
Previous process		Previous-P
Pig farm		Pig farm
Disposal service		Disposal

Figure 4.1 shows the burdens distribution across the whole supply chain. Specific commodities consumed in the PPC then need to be traced if burdens delivered for the commodities supply chain need to be included.

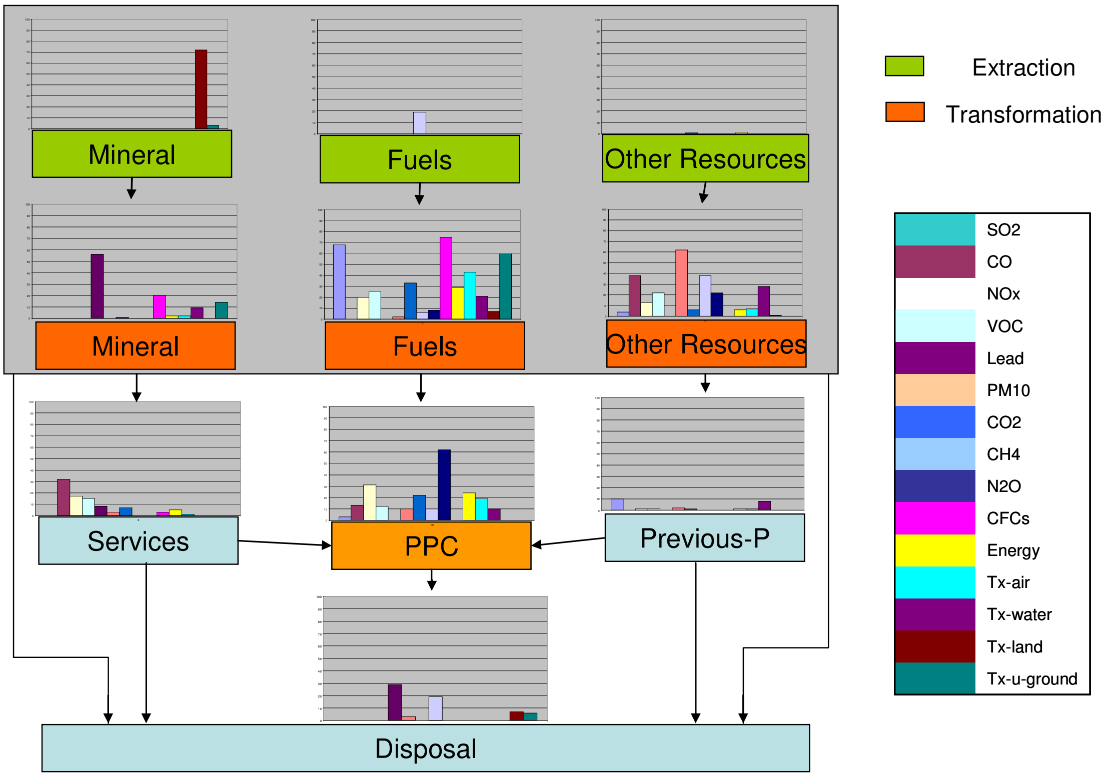

Figure 4.1 Burdens distribution for industrial levels in the commodities supply chain of the PPC

4.2 *Representative items by industry*

Industries that were highlighted with the eiolca software were assigned to one of the six levels described previously (Section 4.1.5). Descriptions of industrial sectors in the North American Industrial Classification System (NAICS, 2002) were used to assign a specific level. The NAICS and the aggregated burdens in Figure 4.1 were used to assign the main products delivered downstream in the commodities supply chain used for the PPC.

4.2.1 Extraction of natural resources

Extraction of natural resources was the upper level in the supply chain of raw materials. Natural resources extraction was divided into three groups, namely mineral resources extraction, fuel resources extraction and other natural resources extraction.

Mineral resources extraction

According to the eoilca results (Section 4.1.4) and the NAICS classification, two economic sectors for mineral resources extraction were the principal suppliers of raw materials for upstream sectors of the PPC (up-PPC): Gold, silver and other metal ore mining sector and Copper, nickel, lead and zinc ore mining sector. The economic sectors supply raw materials for metal industries or by-product components of the next downstream level. These two industries share similar industrial processes.

Iron, copper and nickel are the principal minerals in metal ore mining (BLS, 2007). Some 25% of ore mining revenue comes from iron ore and 20 % from metal concentrate (source of other metals). Iron ore is used to make steel for many industries, whilst copper is commonly used in construction. Other metals are used for jewellery, electronics and equipment (BLS, 2007). Environmental burdens of these sectors will be tracked through machinery and equipment used in the PPC. Gravel, sand and other by-products of the mineral ore industries are used in building construction (BLS, 2007). The building construction industry uses steel, gravel, sand and cement from the mineral ore sector to build facilities for up-PPC and PPC processes. Therefore, buildings and facilities in PPC processes are also suited to tracking the burden for mineral ore. Rent or depreciation will be used to track this effect. The principal environmental burdens of these industries are toxic releases to land and under water by extraction and purification processes which involve removing unwanted parts to improve the quality and purity of the metal.

Fuel resources extraction

For fuel resources extraction, two economic sectors were highlighted: the coal mining sector and the oil and gas extraction sector. The oil and gas extraction sector produces the petroleum and natural gas that heats homes, fuels cars and power factories (BLS, 2007). Petroleum products are also the raw materials for plastics, chemicals, medicines, fertilizers and synthetic fibres (BLS, 2007). The coal mining industry segment produces coal, a fossil fuel that is used primarily for electric power generation and in the production of steel (BLS, 2007). In the case of PPC processes, environmental burdens of these sectors will be tracked principally through consumption of electricity, gas and combustibles. Secondary consumption will be tracked through consumption of many other products delivered by other industries that use petroleum as a raw material and these will be described below.

The principal environmental burden of the fuel resources extraction industries is methane (CH_4) emissions to air by extraction and oil transportation, which involves pumping and transportation to refineries by pipeline, ship, barge, truck or railroad. Whilst oil refineries may be many thousands of miles away from the producing fields, gas processing plants typically are near the gas supply fields. Natural gas is usually transported to processing plants by pipeline (Energy Information Administration, 2008).The oil refining industry is considered as a separate industry in the fuel industrial transformation level. The PPC processes consume electricity, gas and combustibles as raw materials and so these commodities will be modelled.

Other natural resources extraction

The fishing sector is an important sector that will be tracked for the feed production sector. The feed industry manufactures diets for animals with fishing products and by-products.

4.2.2 Mineral transformation industries

Mineral transformation industries use ore raw materials and transform these into commodities which are used by PPC processes and also by other industrial sectors. Almost all of the economy in a country uses some products which have component parts produced in these sectors.

General mineral process

The principal environmental burdens of the mineral transformation industries for the PPC are: lead as air pollutant, CO_2 as a product of fuel combustion and CFCs from chemicals used in acid and electrolytic separation of metals. Toxic releases to air, water and underground water arise from extraction and purification processes of metals, such as crushing, washing, filtering, sorting, sizing, separating and acid leaching (BLS, 2007). Mineral separation is undertaken in one or more steps. Finally, metals such as iron, aluminium, copper, zinc, other metal and by-products (i.e. phosphoric rock) in different forms pass to downstream industries. Mineral transformation industries frequently are not the final suppliers for the PPC processes. However, in the commodity supply chain, the transformation of minerals gives the principal burdens. Iron and steel mills, primary and secondary processing of other non-ferrous metals and primary aluminium production sectors will be tracked through machinery, equipment and building depreciation or rent, as stated previously in the section on mineral resources extraction.

Basic inorganic chemical manufacturing

Inorganic chemicals are those derived from inanimate earth materials, such as minerals, and the atmosphere. They are differentiated from organic chemicals, which are derived from plant and animal sources. Organic chemicals are based on carbon whereas inorganic chemicals are based on all other naturally occurring and synthetically produced elements (NAICS, 2003). Manufacturers typically produce inorganic chemicals from ores or brines, or as co-products or by-products of other processes. In turn these manufacturers serve industrial users who put them to work in the creation of other products and as chemical catalysts. Inorganic chemicals are also used as ingredients in non-chemical products. The primary markets for chemical products are paper, housing, automobiles, water treatment, fertilizer, petroleum refining, steel production, soap and detergent production (NAICS, 2003).

The U.S. census of 2007 shows the following report substances as principal inorganic chemicals (U.S. Census, 2007)

- Chlorine gas
- Sodium hydroxide
- Hydrochloric acid
- Fertilizers and related chemicals
- Pharmaceutical preparations
- Plastic and rubber products

This is a general classification, because there are huge quantities of products that need inorganic chemicals or use them as intermediates in the production process.

Next there is a more detailed description of inorganic chemicals related with groups of commodities linked to PPC processes (U.S. Census, 2007).

- Chlorine Gas (Euro Chlor, 2005)
    - Making plastics and polymers (as intermediates)
    - Agrochemicals
    - Pharmaceuticals
    - Insecticides
    - Dyestuffs
    - Water purification
    - Disinfectants
- Sodium hydroxide
    - Soap and cleaners
    - Metal production
    - Food processing
    - Pollution control
    - Pulp and paper
- Hydrochloric acid
    - Refining ore
    - Fertilizers and dyes
    - Hydrolizing starch and protein in food products.
    - Textile and rubber industries.
- Fertilizers & related chemicals
    - Sulphuric acid (the most common manufactured chemical in the world)
    - Phosphoric acid
    - Ammonia, synthetic anhydrous

- Pharmaceutical preparations
    - For veterinary drugs
    - For human use
    - Vitamins, nutrient and haematinic preparations.
- Plastic and rubber products (including resins)
    - Thermosets
    - Thermoplastics
- Paints, coating & adhesives

This list illustrate that there is a high use of inorganic chemicals in most of the common objects and commodities used in all parts of common life and industries. However, the tracking of inorganic chemicals for PPC processes should be through commodities used in the production process of all PPC processes. Thus, a list of commodities used by PPC processes and linked to principal inorganic chemicals is detailed:

Grain and oilseed farming processes (American Chemistry Council, 2007):

- Pesticides and herbicides (Nitrochlorobenzenes, Chlorophenols)
- Rodenticides
- Fertilizers

Soya bean processing process

- Solvents for soya bean protein separation (chlorines and hydrochloric acids)
- Vegetable oil clarification (caustic soda)

Feed compounding

- Flavourings

- Sweeteners
- Equipment and surface disinfectants
- Soap and detergents
- Bags and plastic containers

Pig farm process

- Water purification
- Equipment and surface disinfectants
- Soap and detergents
- Veterinary drugs
- Rodenticides
- Pesticides

For the commodities previously stated, the environmental burdens of the major inorganic chemical sectors linked to PPC processes obtained in the PPC pre-assessment will be tracked, such as:

- Industrial gasses
- Inorganic dyes and pigments
- Nitrogenous and phosphoric fertilizer manufacturing
- Pesticides and other agrochemical manufacturing

Industrial gas manufacturing

The principal environmental burden of industrial gas manufacturing linked to PPC processes is the release of chlorofluorocarbons (CFCs), one of the most dangerous greenhouse gases. CFCs are nontoxic, nonflammable chemicals containing atoms of carbon, chlorine and fluorine. CFCs have been used in the manufacture of aerosol sprays, blowing agents for foams and packing materials, as solvents and as refrigerants (Elkins, 1999). Refrigeration gases are used in air conditioners, freezers and refrigerators. CFCs as refrigerants are being phased out and replaced with fluorocarbons following their control and prohibition by the Montreal and Kyoto protocols (Vorderstrasse, 2005). Industrial nations stopped using CFCs in large amounts in 1996 and developing nations such as Mexico are supposed to stop their use by 2010 (Smith and Vincent, 1997). The idea is that if there is no chlorine in the molecule, then it will not be able to destroy any ozone. However, the drawback is that the C-F bond absorbs far more infrared radiation than even CO_2 (Gumprecht, 2005)**,** thus these new fluorocarbons generally have a high greenhouse warming potential (Vorderstrasse, 2005)**.** Fluorocarbon refrigerants (HCFCs & HFCs) are now in the market (BOC industrial, 2008).

Refrigeration gases are used in all refrigeration systems along the PPC for chilling, freezing, storage, transporting and displaying meat. Refrigeration equipment used by the PPC process will be tracked as stated previously.

Synthetic dye and pigment manufacturing

This industry comprises establishments primarily engaged in manufacturing synthetic organic and inorganic dyes and pigments, such as lacquers and toners. In other words, the manufacture of various pigments and dyes including lead, chrome, metallic and zinc based pigments as well as disperse, vat and direct dyes. A chemical intermediate product, these various pigment and dyes are used to impart colour to numerous products. Synthetic dye and pigment manufacturing release lead to the air as the principal pollutant, which will be tracked through maintenance of machinery, equipment and buildings, except for soya bean farming and pig farming, where metal used in machinery and equipment production weight more for lead releases than products used for maintenance.

Phosphate fertilizer manufacturing

Commercial phosphate fertilizers are manufactured with rock phosphate (Rehm *et al.*, 1998). Due to the low availability of phosphorous in this native material, high transportation cost and small crop responses, very little rock phosphate is currently used in agriculture (Rehm *et al.*, 1998). Instead, the production process is based on phosphoric acid obtained either by the electric furnace heating of rock phosphate (more pure and expensive) or adding acid to rock phosphate (then heating the phosphoric acid is heated, driving off water and producing super-phosphoric acid). Ammonia can be added to create a material containing both nitrogen (N) and phosphorous (P). The liquid, 10-34-0 (10% Nitrogen, 34% phosphate and 0% Potassium, respectively), is the most common product. This can be mixed with finely ground potash and urea to form 7-21-7 (7% Nitrogen, 21% phosphate and 7% Potassium, respectively) and related grades. Phosphate fertilizers are available as ammonium phosphates, superphosphates and other mixes of phosphates (Rehm *et al.*, 1998).

Phosphate fertilizers will be tracked for their use in grain farming and in turn through grain used in feed compounding. Due to the heating process, phosphate fertilizers also create a burden due to greenhouse gases (CO_2 emissions), energy use and toxic releases to the air in the grain farming process.

Nitrogenous fertilizer manufacturing

Ammonia is the basic component of nitrogenous fertilizers. Ammonia is synthesized from an inexpensive raw material, namely air. However the industrial process has a high demand for energy and needs to burn fuels (Stocchi, 1990). Chemical reactions also contribute to environmental burdens. The effect of nitrogenous fertilizer manufacturing on PPC processes will be tracked as follows:

Grain and oilseed farming

- as a commodity supplied directly to these processes

Soya bean processing

- oilseed supplied

Feed compounding and Pig farming

- grain
- soya bean meals or protein meals

Pig farming

- compounded feed
- grains supplied directly
- protein meals supplied directly

Nitrogenous fertilizers contribute air pollutants (SO_2 and NOx) and greenhouse gases (CO_2) for grain farming. Additionally, N fertilizers account for energy use and toxic releases to air, water and underground for grain and oilseed farming.

Pesticides and other agricultural chemical manufacturing

Raw materials used in the manufacture of pesticides are basic organic and inorganic chemicals. Specific pesticide manufacturing operations are usually unique and are characteristic only of a given facility. There are more than 500 individual pesticides of commercial importance (Wang, 2005). Active ingredients are produced by diverse manufacturing processes, including synthesis, separation, recovery, purification and product finishing (i.e. drying). Chemical synthesis can include chlorination, alkylation, nitration and many other substitution reactions (Wang, 2005). The principal environmental burdens come from leaks and spills of active substances and solvents (Cleaner Production

International, 2005). Pesticides account for air pollutants (SO_2, NOx and VOC) and toxic releases to water and underground water in grain farming. VOC and underground toxics releases are the principal burdens from soya bean farming to pig farming. The effect of pesticide manufacturing on PPC processes will be tracked by the direct use of pesticides in every PPC process.

4.2.3 Fuel transformation industries

Fuel transformation industries use oil or gas as raw materials to produce a wide variety of basic products for other sectors. Here there are sectors which were highlighted for the PPC pre-assessment. Transportation and petroleum refining are the upstream levels of many PPC commodities. After crude oil passes through oil refineries, it is either delivered as fuel or used in petrochemical transformation.

Fuel consumption

Fuels are used to produce electricity or used as combustibles in all PPC processes. Petrochemicals are more difficult to follow as a specific commodity because they are the basic product for many industries. Among the important sectors for combustible sales and electricity generation in the PPC processes are natural gas distribution, pipeline transportation, petroleum refineries and power generation. Power generation can also include other sources of raw materials such as coal. Therefore the ratio of petroleum and other sources of energy will be established. Electricity consumption is also an important commodity for all PPC processes. Fuel transportation (natural gas distribution and pipeline transportation) accounts mainly for CO_2 emissions. Petroleum refineries are principally responsible for toxic releases to water. Power generation and supply contribute air pollutants (SO_2 and NOx), green house gases (CO_2 and CFCs), toxic releases to air and land and with energy used by all PPC sectors. Environmental burdens of power generation can vary as different technologies are used to produce electricity.

Petrochemicals

Among the different kinds of petrochemicals that are produced, a core sector for all PPC processes is the basic organic chemical manufacturing sector. Packaging materials (foam products and non-cellulosic organic fibres) figure as important contributors in the up-PPC sectors.

Petrochemical manufacturing

Petrochemicals are made from petroleum refinery products or other hydrocarbon origins such as coal or natural gas, although petroleum is the major source (Noria Corporation, 2007). The petrochemical manufacturing sector is engaged in manufacturing acyclic hydrocarbons and cyclic aromatic hydrocarbons (a hydrocarbon is an organic chemical compound that is comprised only of carbon and hydrogen atoms) (Green Design Institute, 2007; ILPI, 2005). Acyclic hydrocarbons are used to produce oils, fats, waxes, solvents, paraffin and detergents or their precursors (ILPI, 2005). Examples of oils and fats are motor oils and greases. Wax (paraffin) is used in the packaging of frozen food, sulphuric acid for fertilizer and detergent production (Kiefer, 2001). Cyclic aromatic hydrocarbons (carbon atoms in the form of a ring) such as benzene, toluene, styrene, xylene, ethyl benzene and cumene are used to produce polymers and plastics (benzene), resins and adhesives (cumene, toluene, xylene), nylon (cyclohexane), paints, paint thinners, silicone sealants, disinfectants, polyurethane foam (toluene, xilene), pesticides (xylene) and in small quantities for rubbers, lubricants, dyes, detergents and drugs (Rana, 2005).

Petrochemicals are also used to produce polymers. Polymer materials can be used as plastic, elastomers (rubber) or fibres (Harry *et al.*, 2003). The environmental burdens from petrochemicals and related sectors will be tracked through packaging materials, paintings and building maintenance, fertilizers, pesticides, cleaners and disinfectants for PPC processes. In addition, the use of solvents in soya bean processing and drugs for food manufacturing and pig production will be tracked.

4.2.4 Other transformation industries

In this section, those industries that use other natural resources not included in the previous sections will be considered. In this case, most of the resources come from agriculture or forestry. Water and sewage systems will also be included. Agriculture industries were divided into crop production and animal production sectors.

4.2.5 Crop production sectors

These are sectors related to crop production for the PPC processes**.**

Agricultural and forestry support activities sectors

These economic sectors refer to agricultural activities that will be undertaken to plant, grow and harvest plants, such as ploughing, fertilizing, seed bed preparation, planting, cultivating and crop protection services that are carried out on a contract basis (Green Design Institute, 2006). These activities affect all PPC processes. Agricultural activities will be accounted for as an extra commodity for crop processes (grain and oilseed farming) when these have not been previously accounted for. For example, agricultural activities can be done by third parties on a contract basis. From soya bean processing to pig farming, the effects of agricultural activities will be tracked through crop products used for each sector or through products passed by upstream PPC processes, such as compounded feed. Effects of sectors that were modelled directly upstream from the PPC, such as grain farming, oilseed farming and soya bean processing will also be tracked through products passed by upstream PPC processes. Crop products coming from other crop farming, including cotton farming, other oilseed processing and rice milling, will be tracked through grains, seeds and vegetable oil consumed in food processing.

The principal effects of agricultural support activities are air pollutants emissions (CO, VOC and PM10). Milling of grains (rice milling) also contributes air pollutants (SO_2, NOx AND VOC). Crop farming sectors, not modelled in the PPC, contributed to air pollutant emissions (NOx) and GHG (N_2O).

4.2.6 Animal production sectors

This is the main sector that will be included and directly assessed. Their environmental burdens will be modelled as the main factor in this study.

Forestry sectors

Pull mills are engaged in manufacturing pulp (separation of cellulose fibres from other impurities) from wood or other materials, such as used or recycled rags, linters, scrap paper and straw (Green Design Institute, 2006). These pulps are used to manufacture paper, cardboard, or basic products for packaging that include different kinds of paper (paper and paperboard mills). The environmental effects of these sectors will be tracked through packaging products used in the PPC processes. The principal effects of paper-related sectors are toxic releases to air and water.

4.2.7 Water and sewage systems

This sector includes water and sewage systems engaged in the treatment and supply of water for drinking, irrigation and other uses. It sector includes pumping, conduct and distribution structures and their burdens, and will be tracked through water consumption. The principal effects of water and sewage are in GHG emissions (CH_4 and N_2O).

4.2.8 Services

In this section, those industries that give services to PPC processes or commodities that are not included within the output, such as computer equipment used to control processes, are gathered together. The most important service was transportation. Other services which will be tracked are the specific sectors of: maintenance of transport equipment (support activities for transportation). The principal environmental effects of transportation are air pollutant emissions (CO, NOx and Lead).

4.2.9 Waste management

Waste management and remediation services include collection, treatment and disposal of waste materials such as plastic, paper, cardboard, organic residues, etc. (Green Design Institute, 2006). All PPC processes leave different materials and these waste materials will be tracked in all PPC processes as solid wastes or sewages. The environmental effects of waste collection, treatment and disposal vary among PPC processes, but common effects are the release of air pollutants (Lead), GHG emissions (CH_4), and toxic releases to land and underground water.

4.3 *PPC commodities*

In this section are commodities needed to track the principal environmental burdens of sectors that participate in the raw material supply chain of the PPC processes. The raw material supply chain includes sectors from natural resources extraction through industrial transformation and PPC processes to disposal of waste, sewage or scrap materials (cradle to grave flow). Some commodities appear in more than one table. For example, machinery and equipment appears as an important commodity for all PPC processes, namely extraction of natural resources, transformation of metals and transformation of fossil fuels. This means that accounting for environmental burdens for the use of machinery and equipment in the PPC processes alone is not enough. Burdens coming from metal and fossil fuels transformation to produce metal and plastic components in the machinery and equipment supply chain should also be tracked. In contrast, vitamins are a commodity that is only accounted for in the food manufacturing PPC process and its effects are limited to the mineral industrial transformation where vitamin producers obtain raw materials**.**

The pre-assessment PPC allowed the gathering of important commodities in a clear and transparent way. These commodities allow the formation of a LCI with more confidence and less uncertainty. Commodities gathered from these lists will be used to build the LCI for the PPC processes.

4.3.1 Natural resources extraction

- Capital goods
    - Machinery and equipment
    - Buildings and facilities
- Commodities
    - Electricity
    - Gas
    - Petrol
    - Diesel

4.3.2 Mineral industrial transformation

- Capital goods
    - Machinery and equipment
    - Buildings and facilities
    - Maintenance of building, machinery and equipment
- Commodities
    - Raw materials
    - Pharmaceuticals (vet. drugs, preservatives, buffers)
    - Fertilizers
    - Solvents (i.e. for extraction of seed oil)

- Vitamins
- Synthetic amino acids
- Chemicals
    - Agrochemicals, such as pesticides, rodenticides and herbicides
    - Insecticides
    - Disinfectants (surface disinfection)
    - Soap, cleaners and detergents

- Consumables
    - Bags and plastic containers
    - Bags and paper containers or cardboard boxes
    - Plastic wrap

4.3.3 Fuel industrial transformation

- Capital goods
    - Machinery and equipment [a]
    - Maintenance of machinery and equipment
    - Maintenance of building, machinery and equipment
- Raw materials
    - Fertilizers
    - Solvents (i.e. for extraction of seed oil)
    - Pharmaceuticals (veterinary products, preservatives, buffers)
    - Detergents
    - Disinfectants (surface disinfection)
- Consumables
    - Bags and plastic containers
    - Plastic wrap
    - Vacuum seal packs and plastic containers
- Combustibles
    - Electricity
    - Gas
    - Petrol
    - Diesel

4.3.4 Other industrial transformation

- Crop products
  - Extra-agricultural activities on a contract basis
  - Grains
  - Seeds
  - Straw
- Vegetable oil
- Soya or seed meals
- Compound feed
- Animal products
- Pigs
- Blood meal, blood hydrolyzed protein
- Animal fat, animal oil, lard, etc.
- Bone meal
- Fish meal, fish hydrolyzed protein
- Bags and paper containers or cardboard boxes
- Water and sewage systems
- Water (potable, irrigation)

4.3.5 Services and waste disposal

- General services
  - Truck transportation
  - Rail transportation
  - Ship transportation
  - General maintenance of transport media
  - Storage and warehousing (external service)
  - Electronic equipment [a]
- Waste management
  - Solid waste
  - Sewage

4.4 *Conclusion of pre-assessment*

Depending on the indicators used to evaluate the PPC, it is important to include or exclude different levels in the supply chain of processes. To assess air pollutants released for processes in the PPC, it is important to track the supply chain up to industrial transformation and distribution of natural resources. Extraction of natural resources in any case accounted for more than 5% of air pollutants. This is also the case for energy use. However, if greenhouse gases are being evaluated, the supply chain needs to be followed up to fossil fuel extraction (Figure 4.1). In the case of toxic releases, these are distributed along the complete supply chain of processes, from extraction of natural resources to disposal. Using the eiolca.net software, it was possible to develop the pre-assessment of LCA for PPC and identify the important commodities for the LCI.

Chapter 5 Feed and Pig production LCI

Introduction

Chapter 3 described the general methodologies used to carry out the scenarios LCIs. Additionally, the PPC pre-assessment developed in Chapter 4 established commodities that are important to include in the LCI. Feed, as a commodity, and pig farming, as a process, gives rise to most of the e-burdens relating to nutrient flows (Table A4.1). Thus, a detailed LCI was developed using the process-LCA model to assess feed and pig production e-burdens (see methods framework, Section 3.2.5). Burdens from feed production depend on the demand for diets of the pig farms in the scenarios, so initially the pig farm production was modelled.

5.1 *Method for the LCI of pig production*

This inventory was built up using the physical pig farm performance (shown in Table 3.2) as the cornerstone to model inputs and outputs needed to produce a tonne of pig live weight at the farm gate (tlw). Nutrient mass balances were developed for input-outputs of Carbon (C), Nitrogen (N) and Phosphorous (P) compounds. Figure 5.1 shows the nutrient flows from dietary nutrient inputs until nutrients in manure-disposal (M-disposal), including intermediate nutrient losses.

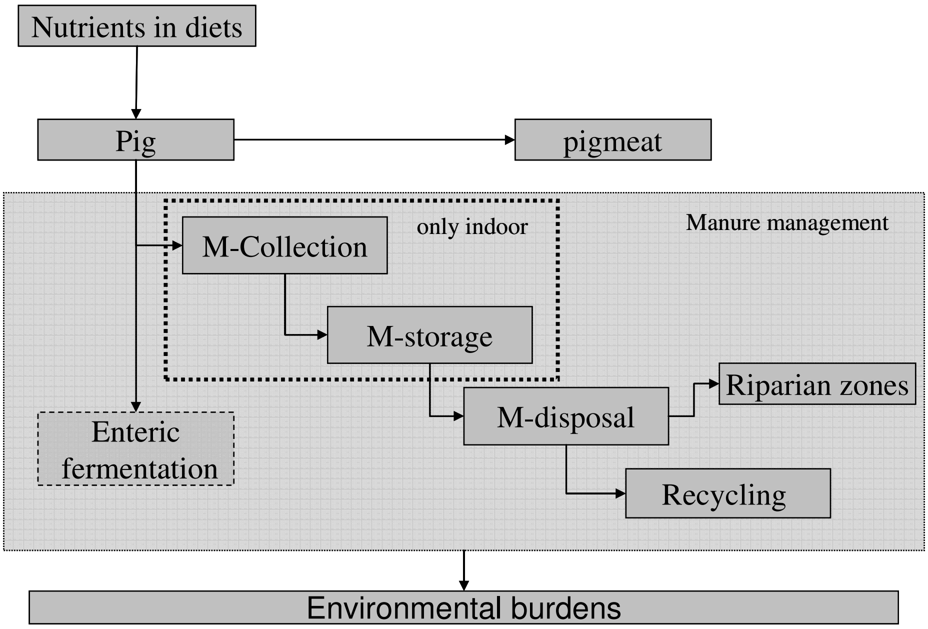

Figure 5.1 Environmental burdens from nutrient flows in a pig farm

Nutrients in diets

Total nutrients that go into the system are determined by the diet formulation. Different ingredients can be included in the feed, but the specified nutrient content fixes their inclusion levels in the diet. Table 5.1 and Table 5.2 show the modelled diet nutrient contents and Appendix 3 discusses the different approaches used to gather these values. The main sources of diet nutrient specifications for the Mexican scenarios were the NRC (1998) and van der Peet-Schwering *et al. (1999)*; for the stdUK scenario Edwards *et al*. (2002) and Hazzledine (2009, Personal communication); for the orgUK scenario Martins *et al.*(2002).

Table 5.1 Percentage of crude protein content of pig diets for each scenario

Scenarios	stdMEX	locMEX	std UK	orgUK
Dry sow	12.4	12.4	12.5	13.0
Lactating sow	17.2	17.2	17.0	17.0
Weaners <25 kg	20.9	20.9	21.5	20.0
Grower 25-50 kg	18.0	18.0	17.4	20.0
Finisher 50-110kg	14.4	14.4	15.1	16.0

Table 5.2 Percentage total phosphorus content of pig diets by scenario

Scenarios	stdMEX	locMEX	stdUK	orgUK
Dry sow	0.50	0.50	0.50	0.60
Lactating sow	0.48	0.48	0.57	0.70
Weaners <25 kg	0.54	0.54	0.49	0.60
Grower 25-50 kg	0.48	0.48	0.50	0.60
Finisher 50-110kg	0.43	0.43	0.60	0.50

The main differences in dietary formulation between scenarios are in the P content for the orgUK diets, since phytase enzyme added to non-organic diets gives greater availability of P from raw materials and so less supplementary P is need to balance the diet. Another advantage for Mexican scenarios is that finishers' diets contain Ractopamine, is a beta agonist compound that promotes leanness in pigs and this reduce P losses in manure and the level of extra dietary P needed (Hankins *et al.*, 2001). These two diet additives permit the nutrient content of commercial diets in the Mexican scenarios to be close to NRC recommendations (NRC, 1998).

5.1.1 Pigmeat nutrient composition

From the mass nutrient balance perspective, N and P content of pigs are the principal elements to account for in finished pig production.

The N content: For pigmeat was estimated through the lean pigmeat content of pigs on a live weight basis. This was estimated as 170g of protein $kglw^{-1}$, which is the average protein content for intermediate and lean pigs (BSAS, 2003). Similar leanness for finishers was assumed between scenarios. Pigs in the UK are not castrated, which increases leanness, however castrated pigs in Mexico are fed with Ractopamine that compensates for this possible difference in leanness. For cull sows, 156g protein /kglw was used which is the average protein content between intermediate and fat pigs (BSAS, 2003). These values are similar to those used by Poulsen *et al*. (2001) and Dalgaard *et al*. (2007a). It is expected that pigs in the breeding herd would have lower proportionate protein yield since bone and fat content reduce the total protein proportion. The standard conversion factor of 6.25 for protein N content (Mosse, 1990) was used to calculate the final pigmeat N output at the pig farm level.

P content: In pigmeat this has been reported on both dead weight (kgdw) and live weight (klw) basis, depending whether it refers to carcase weight or live pigs. BSAS (2003) stated 5g $kgdw^{-1}$ as the standard P content in pigmeat. Van der Peet-Schwering *et al*. (1999) used different P content in live pigs to characterise P utilisation by different pig categories. They specified a P content of 5.4 g $kglw^{-1}$ for finished pigs (at 110 kg) and 5 g $kglw^{-1}$ for sows. Since pig farming yield was calculated on a live weight basis, the P-pig content values stated by Van der Peet-Schwering *et al*. (1999) were used.

5.1.2Manure management and nutrient losses

Manure is the other main nutrient output for pig production. Thus manure nutrient transformation and losses were modelled. Pig manure usually includes both dung and urine (i.e. the solids and the liquids) produced by pigs (IPCC, 2006). Manure management (MM) starts with manure collection, followed by manure storage and finally manure disposal/deposition (Figure 5.1). Table 5.3 gathers the principal elements of the MM in the scenarios described previously (scenarios construction, Section 3.3.1). Appendix 4 provides a detailed explanation of weather conditions modelled in each scenario.

Table 5.3 Manure management characteristics by scenario

Scenario	stdMEX	locMEX	stdUK	orgUK
M. Collection	Pit under pens	Pit under pens	Pit under pens	NA
Retention time	>1 month	1 day	< 1 week	NA
M. storage system	Earthen pond	Open tank	Covered tank	NA
IPCC system eq.	Slurry	Slurry	Slurry	
Retention times	> 1 year	1 week	1 year	NA
Temp. exposed, ^{o}C	24	18	10	10
M. disposal	Riparian zones	Land spreading	Land spreading	Direct to pasture
Application rate decision	NA	Empirically	Nutrient balance	Direct

The stdMEX scenario: Large farms modelled in the stdMEX scenario typically have slatted flooring over a pit with storage capacity for more than a month, or until completion of the all-in all-out animal period. Subsequently, the system is characterised by an earthen pond outside the animal housing and long periods of storage, for more than one year. This system facilitates high rates of evaporation and reduces the disposal volume. Stabilised sewage is sent to water streams, finishing in riparian zones that receive drainage or runoff water such as ditches, streams, rivers and estuaries (Perez, 2006).

The locMEX scenario: Farms in this scenario typically have a pit below the animal pens that is designed only to collect and conduct manure. Slurry is immediately conducted outside the building. In typical cases, farms in this scenario have outside manure storage containers that allow for only a short retention time, no more than one week. Manure is then sent to land, by drainage or irrigation channels, without real soil incorporation or correct matching to crop fertilising requirements. The slurry fertilisation value is decided on an empirical basis based on previous experience (Jurado, 2003). Since most of these farms are more involved in crop farming than those in the stdMEX scenario, the locMEX scenario has been modelled as slurry with a short retention time for outside manure storage and agricultural use of manure at the end. Pig slurry is conducted through irrigation channels or pumped directly to surrounding land and applied before water is applied onto the land (rainy season or irrigation).

The stdUK scenario: For this scenario, it was assumed that optimal manure handling techniques were used to ensure ammonia emission control. Manure collection is through a slatted floor into a manure pit which is emptied out to a storage tank. After storage the manure is spread onto field crops at an optimal application rate for high crop N retention and minimal N leaching. The stdUK scenario conditions are similar to those modelled for Greenhouse Gas Emissions in the UK (Baggott *et al.*, 2007).

The orgUK scenario: In this scenario, MM at farm level (farm-MM) was not taken into account, since animals outdoors apply manure directly to the paddocks. Paddocks are integrated into the crop rotation system whereby pigs stay no longer than one year in the same paddocks and crop rotations of two or more years are used (Hermansen *et al.*, 2004).

Nutrient losses: The nutrients in manure can be in organic or inorganic form and the main nutrient losses are through inorganic forms. Thus, when more nutrients are present in inorganic forms in the manure, the nutrient losses increase and the type of manure handing processes determines the organic: inorganic nutrient ratio. The interaction between the MM system and the organic compounds content in slurry determines the amount of inorganic compounds and, in consequence, the nutrient losses. Most of the organic forms in manure are associated with the volatile solids content (Dubrovskis *et al.*, 2008), and their levels are not appreciably altered by MM until are transformed to inorganic forms (Stein, 1997). In contrast, the water-soluble inorganic forms of nutrients will decrease dramatically in concentration during MM, especially when the manure is stabilised (Stein, 1997). The MM of liquid pig manure, called slurry, is virtually a stabilization process. Stabilisation reduces the volume of the slurry because many of the solids are degraded to inorganic forms emitting carbon dioxide, methane, ammonia or other products. This decomposition of the organic matter in the slurry and the subsequent release of volatile compounds results in lower levels of organic C, N, S (sulphur) in the stabilised slurry than were present in the raw collected manure or previous manure stages (Stein, 1997). The under-pen pit that characterises most of the collection systems in non-organic scenarios, or the earthen ponds and tanks during manure storage, works as stabiliser manure-containers. These stabilisation processes for liquid manure include aerobic and anaerobic digestion of VS content at different rates. The digestion or stabilisation rate produced in the container depends on operational parameters (e.g. temperature, retention time, mixing frequency) and VS concentration. Therefore, consecutive MM processes result in further decreases in organic constituents. In general, the organic N and C content of manure decreases as MM increases.

Since every nutrient follows different fermentation routes, the nutrient balance was modelled separately for each element.

The IPCC (2006) guidelines were used to calculate the nutrient losses from pig manure. The IPCC methodologies were developed according to country and species specifications. Thus, these methods are useful for pig production and the conditions modelled in this study. These methodologies are divided into three degrees of complexity. The simplest (Tier 1) is suitable for animal populations where the environmental impact has low relevance in one specific burden, such as enteric methane fermentation for pigs (see enteric fermentation in Section 5.1.4). Tier 2 and Tier 3 require specific population data regarding more specific conditions and they are used for those processes where the population produces the most relevant environmental impacts. For tier 2 methodology, the IPCC guidelines provide standard conversion factors suitable for different species, temperatures and world region specific conditions. For tier 3 methodology, all factors that affect pollutant values should be specific for the animal populations in the study. Tier 2 methodology is recommended for animal populations where not all information is available or to compare animal populations where the available data do not have the same accuracy, such as the scenarios used in the current study. Thus, the main conversion factors stated in chapters 10 and 11 of the IPCC guidelines (2006) were used and are summarised in the following section.

5.1.3C mass balance

Methane is the principal environmental pollutant (e-burden) arising from C compounds from nutrients used in pig farming. Fermentation of non-absorbed carbohydrates is the principal source for methane. Methane is produced either in the digestive tract (enteric fermentation) or when manure is exposed to anaerobic conditions (manure fermentation).

Enteric fermentation

Pigs produce only moderate amounts of methane in the digestive tract, because enteric fermentation in monogastrics is negligible compared with the rate of methane produced by manure (IPCC, 2006). Since enteric fermentation does not substantially affect total methane production, the IPCC guidelines suggest a general conversion factor for pigs fed with compounded feeds which are made up principally of grains, or for pigs that have rare grain supplementation (shown in IPCC 2006 as developed and developing countries). Since feeds in all scenarios are compounded principally from grain (see diet formulation, Section 5.2.5) the enteric methane production was allocated as it is in the IPCC guidelines. The value of 1.5 kg methane head^{-1} year^{-1} for developed countries was used. Pigs under grazing conditions or in outdoor conditions, such as those in the orgUK scenario, eat more fibre and can produce more methane from enteric fermentation than those fed exclusively on concentrate. Verbic (2006) used an enteric methane production of 2.33 kg $head^{-1}$ $year^{-1}$ for small scale farm production where grass was the main raw material used, but this production looks more similar to rare grain supplementation conditions in the IPCC guidelines. There are no available methane conversion factors (MCF) for outdoor pigs (New Zealand Climate Project, 2002), nor are the alternative enteric MCF used for small ruminants suitable, since goat and sheep rumen fermentation is principally methanogenic. Since enteric fermentation of fibre in outdoor pigs receiving concentrate-based feed is expected to produce a negligible methane difference compared with no extra fibre for indoor pigs (New Zealand Climate Project, 2002; EPA, 1997), the same MCF as used for intensive systems was also used for the orgUK scenario.

Manure fermentation

Methane from manure fermentation is influenced by weather conditions. The time that manure is stored, or retention time anywhere in the MM process also strongly influences the methane yield since manure storage under anaerobic conditions (absence of oxygen) increases methane fermentation. Such conditions occur most rapidly in intensive pig production, where animals are confined in small areas and when manure is disposed of in liquid-based systems. The main factors affecting methane emissions are the amount of C compound susceptible to methane fermentation in the manure and the storage system, especially if it provides anaerobic conditions. When manure is stored or treated as liquid (e.g. in lagoons, ponds, tanks or pits), such as in the non-organic scenarios is anaerobically decomposed and can produce a significant quantity of methane (IPCC, 2006). The temperature and retention time in the storage units along the MM flow greatly affect the amount of methane produced. Since temperature affects methane production, geographic temperature variations between scenarios, together with the modelled retention time (Table 5.3), were used to select the most appropriate MCF for each scenario from those provided by IPCC (2006). However, for the orgUK scenario, the farm-MM does not give rise to methane production because the manure is deposited directly onto pasture and this tends to decompose more under aerobic conditions (IPCC, 2006).

The C compounds susceptible to methane fermentation in the manure are the volatile solids compounds (VS) and the capacity of these VS to produce methane (Bo) is influenced mainly by diet digestibility (IPCC, 2006). These two manure characteristics bring about the methane yield during the farm manure flow. According to IPCC (2006), it is better to use country-specific values for the daily excretion of VS and their maximum methane production capacity (Bo) for different pig categories. As no such data were found in the literature available for Mexico, the Tier 2 type methodology was followed. Koelsch (2007) provided values for the standard VS in excreted pig manure from different productive stages (Table 5.4). These values were considered to more accurately reflectreferred VS changes per productive stage than standard values in IPCC (IPCC, 2006).

Table 5.4 Standard VS by productive stage (Koelsch, 2007)

Productive stages	kg/day
Nursery pig	0.110
Grow-finish	0.374
Gestating sow	0.449
Lactating sow including litter	1.043
Boar	0.340

There were no country-specific Bo values available for Mexico. Thus Bo default values valid for North America (the closest geographic zone to Mexico) and Western Europe were taken from IPCC (2006). Finally, characteristic methane conversion factors (MCF) were selected from the IPCC guidelines (2006) to match with the country, climate and

MM system in the manure flow of every scenario detailed in Table 5.3. Table 5.5 details the Bo and MFC for each scenario.

Table 5.5 Bo and MCF values used for farm-MM

Value	farm-MM	locMEX	stdMEX	orgUK	stdUK
Bo, $m^3CH_4\ kg^{-1}VS$		0.48	0.48	0.48	0.45
MCF, %	Collection	0.5%	60.0%	NA	3.0%
	Storage	35.0%	60.0%	NA	17.0%

Manure disposal

Methane production arising from manure application was allocated at minimum values to avoid duplication, considering that crop production calculations account for pollutants produced during soil management. The MCF for a daily manure spreading system and that for 'other systems' were used in scenarios that use manure as fertiliser and in the stdMEX scenario, respectively. Table 5.6 shows the MCF used for manure disposal for each scenario.

Table 5.6 MCF for manure disposal by scenario

Value	Manure Management	locMEX	stdMEX	orgUK	stdUK
MCF, %	Disposal	0.5%	1.0%	0.1%	0.1%

5.1.4Nitrogen mass balance

Nitrogen input

The dietary protein content (Table 5.1), feed consumption (Table 3.4) and standard conversion factor of 6.25 for protein N content (Mosse, 1990) were used to generate the N input (named as feed-N)**.**

Utilisation and losses of N in pig farming

The feed-N is the total N directly used to produce pigmeat, but not all N goes to the meat; most of the N goes to manure and consequently can leave the pig unit as a pollutant or as a fertiliser. The feed-N can be used for pig tissues (pig-N), or be released by urination or defecation to N-compounds in manure (manure-N). As soon as manure is deposited, N losses start and continue through manure collection, storage and disposal. N-manure losses arise from dynamic nitrification and denitrification processes, facilitated by consequential aerobic and anaerobic storage conditions of organic compounds in the manure solids (Stein, 1997). N may be present in manure in an inorganic form, such as ammonium (NH_4) or nitrate (NO_3) or in organic form such as proteins (Stein, 1997). The form in which N is present in manure, principally in liquid forms such as slurry, is a key factor in determining how much N remains available in manure, as well as the potential for N losses into the environment. Generally, inorganic N forms either remain in manure, such as NO_3 (the most water-soluble N-compound), or volatilise, such as NH_4 conversion into ammonia (NH_3). Nitrous oxide (N_2O) is a secondary product of ammonia or nitrate transformation, which is released directly or secondarily from ammonia volatilisation or nitrate leaching (IPCC, 2006; Stein, 1997). N_2O is produced at a lower rate than its predecessors but it has a higher environmental impact than ammonia or nitrate. Finally, the remaining N can be used for plant nutrition (fertiliser-N).

N losses as N_2O emissions

The N loss through nitrous oxide was accounted for as the direct and indirect emissions. Direct N_2O emission depends on manure N and C content and the system of MM. Indirect emissions result from volatile N losses that occur primarily in the form of ammonia and nitrous oxides (NO_x) which arise from urea excreted by pigs (Asman *et al.*, 1998) and N degradation of organic matter in manure. Thus ammonia formation depends primarily on storage time and, to a lesser extent, temperature during the manure flow. Another indirect source of N_2O is the nitrate leaching and runoff after manure deposition on land. Manure soil application produces N_2O emissions through two indirect pathways (IPCC, 2006). The first of these is through the volatilisation of N as ammonia and oxides of N (NO_x), and the second one through deposition of these phases and their products, NH_4^+ and NO_3^- , onto soil and the surface of lakes and other waters.

Thus N_2O indirect emission from soil sewage deposition comes from ammonia and nitrate releases. Urine and faeces deposition from grazing animals in the orgUK scenario produces N_2O emissions in an exactly analogous way to the application of sewage from storage manure, but at a higher rate (IPCC, 2006). The emission factors considered for direct and indirect N_2O emissions are shown in Table 5.7.

Table 5.7 Emission factors for N_2O direct and indirect emissions from MM

MM process		stdMEX	locMEX	std UK	orgUK
collection-M	Direct	0.2	0.2	0.2	NA
	Indirect	1	1	1	NA
storage-M	Direct	0.5	0.5	0.5	NA
	Indirect	1	1	1	NA
disposal-M	Direct	1	1	1	2
	Indirect-NH_3	1	1	1	1
	Indirect-NO_3	0.75	0.75	0.75	0.75

NA- not applicable

The direct and indirect N_2O emission factors vary according to the MM system shown in Table 5.3. The direct N_2O emission factors were taken from Tables 10.21 (p10.62) and 11.1 (p11.11) in the IPCC guidelines (2006). The direct deposition of manure onto paddocks for grazing pigs increases the N_2O emissions compared with slurry application (Table 5.7). In most soils, an increase in available N enhances nitrification and denitrification rates. Thus N deposited on soil from urine and dung by grazing pigs increases the direct production of N_2O.

N losses as ammonia and nitrate

Ammonia (NH_3): This is the main form of N-losses during farm-MM. Most of the organic N in slurry is associated with the slurry solids. Solid degradation increases ammonia production principally during manure stabilisation, especially if the system supplies alternate aerobic and anaerobic conditions during MM (Stein, 1997). Thus, MM conditions also alter the rate of NH_3 production as was the case for methane. Table 5.8 shows the values used for N loss due to volatilisation of NH_3 and NOx according to MM type in every scenario. These values follow the criteria stated in the IPCC guidelines (Table 10.22 p10.65} and MM conditions stated in Table 5.3.

Nitrate (NO_3^-): This can be lost by leaching and runoff from land. Some of the inorganic N in or on the soil, mainly in the NO_3^- form, may bypass biological retention mechanisms in the soil/vegetation system by being transported in overland water flow (runoff) and/or flow through soil macropores or pipe drains (leaching) (IPCC, 2006). Where NO_3^- is present in the soil in excess of biological demand, such as under sow urine patches (orgUK scenario) or continuous sewage supply (locMEX and stdMEX scenarios), the excess leaches through the soil profile. This may take place in the groundwater below the land to which the sewage was applied, in riparian zones receiving drain or runoff water, or in other superficial water bodies into which the land drainage water eventually flows (IPCC, 2006).

Table 5.8 Percentage of N loss due to volatilisation of NH_3 and NOx according to MM type by scenario

Category	IPCC (2006)	stdMEX	locMEX	std UK	orgUK
Collection-M	25% (15-30)	25	15	15	NA
Storage-M	48% (15-60)	40	25	15	NA
Disposal-M					
Ammonia	20% (5-50)	5	20	5	24
Nitrate	30% (10-80)	100	50	10	30

The assigned rate of ammonia volatilisation, either for manure collection or manure storage, followed the VS degradation rate considered in the methane section, within the range provided by the IPCC (2006).

The stdMEX scenario: This has a long retention time and higher temperatures that suit manure stabilisation either during collection or storage. Thus a high ammonia volatilisation rate was modelled, similar to the VS degradation rate stated for methane since the ammonia output is directly related to VS degradation. The ammonia conversion rate under these conditions was 70% of the higher value, and was similar to the rate modelled for VS losses. During disposal, a low rate of ammonia production was expected for the stdMEX scenario, since sewage is sent to natural water streams where aerobic conditions reduce the possibility of ammonia losses. In contrast, nitrate was modelled with the maximum loss rate, since sewage was not used for agricultural proposes.

The locMEX scenario: This also has warm conditions but the time for manure stabilisation is shorter than in the stdMEX scenario. Manure in this scenario is only stored for short periods, thus it is not expected that high ammonia losses occur during farm-MM. Higher losses were expected during land application, since N application is not calibrated and N leaching or runoff rate will be greater than the average expected (IPCC, 2006).

The stdUK scenario: This has weather and storage conditions which allow lower than expected ammonia losses for farm-MM. Since the stdUK scenario was modelled for the best manure application practice, the lower loss rate was also modelled in manure disposal. For this scenario, it was assumed that N supplied through spread pig manure is included in the N fertilization balance. Thus manure after storage is spread on field crops at the optimal balance for high crop N retention and minimising N leaching, as discussed in the MM section. Hence N leaching for the stdUK scenario was modelled to be the lowest range value supplied in the IPCC (2006) guidelines (Table 5.8).

The orgUK scenario: This did not have farm-MM, but a higher rate of ammonia and nitrate losses were expected during manure deposition, because direct urine and dung deposition by grazing pigs is not N efficient. It is difficult to obtain a specific nitrate leaching figure under organic pig farming conditions for the orgUK scenario. Modelling N leaching has many uncertainties, principally due to difficulties in predicting the N leaching from different types of grass fields and rotation systems (Hansen *et al.*, 2000). N leaching from pig manure depends on plant N uptake and N supplied through other sources (i.e. deposition, fixation, etc.). Thus N supplied through pig grazing frequently acts as a surplus, since this is deposited on paddocks in specific zones (e.g. near feeders). Considering that rainfall can occur all year and vegetation from paddocks is easily and quickly removed by pigs (Eriksen and Hermansen, 2005; Williams *et al.*, 2000), levels of N leaching could be expected to be more than for storage manure application. Thus for N leaching in the orgUK scenario, the average value (30%) supplied by the IPCC (2006) guidelines was used. This value is similar to measured N leaching for pig organic farms in Denmark (Eriksen *et al.*, 2002; Hansen *et al.*, 2000). This value can be considered also as a conservative value for outdoor pig farming in the UK. Williams *et al.* (2000) found that after grass cover is removed from pig paddocks (in the second year of grazing), N losses increase, particularly on urine patches and around feeders. They reported losses for ammonia volatilisation for outdoor dry sows on the region of 11 g NH_3-N $sow^{-1}day^{-1}$ and three times more nitrate leaching than in arable paddock. Other factors that increase nitrate leaching under outdoor pig conditions are if paddocks used for grazing pigs are incorporated into crop production every two years, rather than annually, and if wetter weather conditions suiting leaching and runoff N-losses pertain.

Potential N available for plant nutrition

This was defined as the N available from pig manure in the soil after discounting possible N losses. The soil-N changes were not included because this is outside the pig farming framework. Only the N supplied through pig manure was modelled.

Nitrous oxide, ammonia and nitrate

N_2O, NH_3, and NO_3^- losses were accounted with the respective N losses and specific conversion factors (1.57 for N_2O; 1.2 for NH_3 and 4.4 for NO_3^-) according to their molecular composition. Finally, N losses were expressed as kg of N_2O, NH_3 or NO_3 per 1000 kglw, respectively.

5.1.5 Phosphorous mass balance

Phosphorous input

The product of P content of pig diets (shown in Table 5.2) and feed consumption (shown in Table 3.4) gave the total P input (named feed-P).

Uses and losses of Phosphorus in pig farming

The P economy in the pig farm has a similar distribution to that for the N input-output mass balance. Feed-P leaves from the pig farm through pigmeat (pig-P) or manure (manure-P) represented graphically in Figure 5.1. After subtracting the relatively similar pig-P value, the feed-P content gives the main variation in the amount of manure-P between scenarios. The total inclusion of P in pig diets is related to the availability of P in feedstuffs and pig feeding regimen (Van der Peet-Schwering *et al.*, 1999). Parameters of pig physical performance consider both factors. The diets were formulated for all production stages and two feed phases in the finishing stage, adjusting diets more precisely to pig growth needs (Table 5.2). For the non-organic scenarios, the P content of pig diets also considered the inclusion of phytase enzyme. Phytase increases the availability of plant-P content and reduces the total P content in diets. This was different for the orgUK scenario, because organic standards dictate that feed-P can not be reduced by enzyme addition or use of more available sources. Thus, the total P diet content considered the best available techniques to characterise pig farming scenarios. The largest difference from manure-N is that manure-P is not lost through volatilisation and is mostly retained until manure disposal. Pig-P output was explained in the meat nutrient composition section (Section 5.1.1) and manure-P output is explained below.

P losses by P leaching

Unlike N losses, P losses during MM are only by leaching/runoff, because there are no P emissions during manure housing and storage. Most of the manure-P is in organic form, which is highly available for plants. Thus P losses allocated from manure-P have been assumed to be minimal. Eghball *et al.* (2005) stated that 100% of manure-P can be used as substitute fertiliser-P, since most of manure-P is available for crops and only in P-deficient land does this remain in soil. Also, Basset-Mens *et al*. (2007) allocated only 0.5% of manure P to water P runoff losses, independent of the pig MM system (liquid, solid or composted solid manure). They allocated 50% of total excreted P to paddocks and 50% to the following crop (maize or hay), assuming that manure fertilisation was calculated according to anticipated plant needs. Hence Basset-Mens *et al*. (2007) only consider a negligible amount of P losses as phosphate; even when they used a phosphate conversion factor of 1%, this was applied only to manure P allocated in paddocks. In addition, The Fertiliser Recommendations for Agricultural and Horticultural Crops in the UK (Defra, 2000) consider that 100% of pig manure P must be considered over the whole rotation fertilisation account, as manufactured fertiliser must be. Finally Nguyen *et al.* (Nguyen *et al.*), when modelling three different European pig farming scenarios with contrasting production systems, considered that a conservative criterion of soil-P losses in all scenarios was 4%. Considering that in the British scenarios pig manure was applied on a N basis, P surpluses are inevitable because the N: P ratio in pig manure over-supplements P plant needs (Williams *et al.*, 2002). This imbalance between the N: P ratio in manure and that in crop uptakes leads to excessive P in soil and can increase P losses. In the current study practically all pig farming systems modelled for the scenarios incur an excessive P deposition, either when manure is applied in controlled volumes or under free deposition, because N losses during MM reduce the N: P ratio. Manure-P applied directly on paddocks, modelled for the orgUK scenario, has unavoidable site-specific manure deposition, since pigs defecate near to the most visited areas such as feeders and mud sites (Eriksen *et al.*, 2002; Williams *et al.*, 2000). This animal behaviour avoids homogenous P deposition and increases surpluses of P deposition. The locMEX scenario has more uncertainty in the surplus rate, since manure nutrient content is not considered in fertilisation calculations and high variation in surpluses is expected. This uncertainty in soil P application is assumed to be more in the surplus direction than in deficiencies, because a continuous flow of manure results more in site specific deposition than homogeneous nutrient distribution. The stdUK scenario that uses the best agricultural practice applies manure on an N basis instead of P content. Thus N losses during MM in all scenarios result in excessive P deposition. Therefore, a maximum value of 4% was adopted as the general P loss rate for manure-P losses except in the stdMEX scenario. The stdMEX scenario involves nil agricultural manure use, since all manure-P is sent to riparian zones where P can be leached to underwater streams or used for plankton in superficial water. In both cases, manure-P was considered with nil soil integration, so 100% of manure-P was accounted to P losses. Table 5.9 summarises the manure-P loss rates.

P soil distribution

Whilst only a small proportion of manure-P was allocated as runoff losses (except in the stdMEX scenario), not all manure-P applied to soil is available for plant nutrition. The proportion of P available to the following crop depends on a number of factors, such as time of application, soil type, rainfall, soil incorporation technique and how long after application this incorporation takes place (Basset-Mens *et al.*, 2007; Williams *et al.*, 2002). Thus, in calculating the amount of fertiliser replaced by P from the pig manure, it is recommended to use the same criteria as for artificial fertilisers (Defra, 2000), but only a proportion of this can be considered to be used for the next crop. According to Defra (2000), the rate of P available from pig manure for the next crop varies according to manure presentation. A rate of 50% has been allocated for the next crop when plant P demand is calculated in advance (Basset-Mens *et al.*, 2007; Defra, 2000). In the current study, soil applied P was available for plant fixation at a rate of 50% and 60% for the stdUK and orgUK scenarios respectively (Table 5.9). The rate for the orgUK scenario was higher because direct manure deposition by grazing animals was assumed to be equivalent to FYM manure type, which has a higher P content available for plant nutrition than slurry that is applied in liquid form (Basset-Mens *et al.*, 2007; Defra, 2000). In the Mexican scenarios, the plant P fixation rate was set down as 40% and 0% for locMEX and stdMEX scenarios respectively (Table 5.9). In the locMEX scenario, slurry application is on an empirical basis and traditional forms of crop production reduce the crop yields and nutrient use (Jurado, 2003). Thus, for the locMEX scenario a lower plant-P use was expected than occurs under good agricultural practice. Agricultural practices modelled for the locMEX scenario included P amount miscalculation and continued slurry application. This technique poorly incorporates P when it is required by plants, thus available P for plant nutrition is decreased. Therefore, an extra 10% reduction in P used for plants was modelled for the locMEX scenario. Finally, the stdMEX scenario included nil fertilisation manure use, thus no fertiliser replacement P rate was allocated here. Table 5.9 gives details for soil P losses and credits for the four different scenarios.

Table 5.9 Rates of P manure losses and credit allocations (%)

Category		stdMEX	locMEX	std UK	orgUK
Method of cal[1]		no agricultural use	random	pre-crop	pre-crop
P-losses	PO4-P	100	4	4	4
P-credit[2]	Soil-structure	0	60	50	40
	P-plant	0	40	50	60

[1]Method of manure soil application or disposal
[2]P-credit is P that can be credited to pig farming, either for soil structuring (soil-st) or plant nutrition availability (P-plant)

5.2 *Methods for the LCI of feed production*

As described in the methods framework section (Section 3.2.5) and Figure 3.3, the process-LCA method was used to gather the LCI of feed production and crop production. Since feed production depends more on industrial activities than biological nutrient transformation, the LCI was gathered from specific published LCAs. The LCAs reported in the Ecoinvent database were used to obtain the e-burdens for milling and mixing feedstuffs, production of industrial ingredients and transportation of feedstuffs or products. Figure 5.2 shows the feed production processes and the system boundary. For oilseed processing, such as soya bean and rapeseed, specific LCAs reported in the literature were used (Landis *et al.*, 2007; Williams *et al.*, 2006). The feed demand to produce a tlw given in Table 3.4 was the functional unit in this sector.

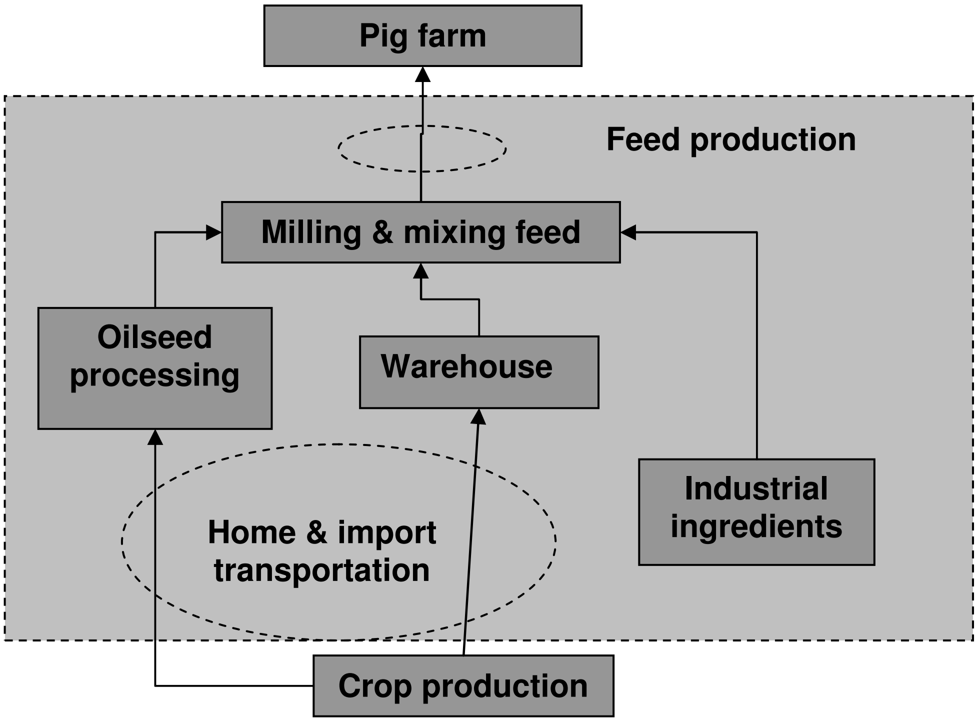

Figure 5.2 Processes included in feed production

5.2.1 Milling and mixing feed process

The e-burdens for the milling and mixing feedstuffs process were modelled by Nemecek (2005) in the Ecoinvent database. These burdens were accounted by kilogram of feed processed. The LCI included:

- Transformation and use of land for industrial purposes and storing of the feed mixes
- Electricity at low voltage from the urban grid for crushing or milling
- Natural gas for heating and steaming during mixing, squeezing and pelleting
- Tap water
- Transportation from the warehouse (this was discarded for imported feedstuffs where it was already included)
- Heat waste as emission to air
- Wastewater treatment

5.2.2Transportation of home and imported raw materials

Transport was accounted by tonne-kilometre (tkm) of commodity transported by road, train or sea. Transportation in the different systems was modelled by Spielmann (2003) in the Ecoinvent database. The LCI included:

- Production, maintenance and disposal of the vehicle, train or ship.
- Construction and maintenance and disposal of road and rail in Europe

Transportation of compounded feed included distance from the feed mill to the pig farm on a km and tonne (tkm) basis. A value of 100 km and 150 km was the distance modelled for the stdMEX and locMEX scenarios, respectively. The calculation considers that more feed mills have been built near to bigger farms than those near to independent small farms, because commonly organised farmers, similar to those in the stdMEX scenario, are stockholders of feed mills whilst independent farmers, which are only clients of union mills, are not in the priorities when the mill is built (Santiago, 2008, Personal communication 2008). For the UK scenarios, 100 km was the average distance modelled as stated by Williams *et al.* (2006, p60). Table 5-10 shows transportation distance of pig feed each scenario.

Table 5-10 Transportation distance of feed mill to pig farm (tkm)

Scenario	stdMEX	locMEX	stdUK	orgUK
Transportation distance	100	150	100	100

Imported feedstuffs transportation included the distance from overseas crop farms to feed mills in the home country. For the Mexican scenarios, Iowa was the U.S.A. state considered as the origin of imported feedstuffs. Iowa is one of the main states in the U.S.A. Corn Belt (Kim *et al.*, 2009; Landis *et al.*, 2007). Rail was the main system of transport that delivers crops from origin to the mill factory in the Mexican scenarios. Feed mills in Mexican cities of Guadalajara and Mazatlan were the fate for the locMEX and stdMEX scenarios respectively. Rail distances were obtained from the www.timeanddate.com web page. In the UK scenarios, information on imported feedstuffs transportation was obtained from Williams *et al.* (2006, p36). The Williams model included rail, ship and road distances. Transport distances for feedstuffs produced at home were distances by road from crop farms to the warehouse. Williams *et al.* (2006) provided road distances for the UK scenarios. For the Mexican scenarios, raw materials were delivered directly to feed mills through railways (Table 5-11).

Table 5-11 Transport distance for principal imported feedstuffs (tkm)

Method of transport	locMEX	stdMEX	orgUK	stdUK
Rail	2,495	2,361	1,080	1,080
Ship	0	0	7,478	7,478
Road	0	0	300	300

5.2.3Industrial ingredients

Minerals, vitamins, synthetic amino acids, enzymes and trace elements added to diets come from a net of industries that use and interchange products and co-products produced in the organic and inorganic chemical industries. The chemical industry, in particular the organic chemical industry, supplies different raw materials to the pharmaceutical industry where many minor feed ingredients are produced. Minerals added to feed are produced as co-products in the mineral supply chain and processed in the inorganic chemical industry (see Mineral transformation industries in Section 4.2.2). Thus mineral origin ingredients, such as limestone and dicalcium phosphate were considered as generic inorganic products. Organic origin products such as enzymes, vitamins and synthetic drugs were modelled as generic organic chemicals, since organic fermentation or chemical reactions are the principal production process for these feed ingredients. LCA of limestone (Kellenberger, 2003) and generic organic chemicals (ETH-ESU, 1996) modelled for the Ecoinvent database was used to account e-burdens of feedstuffs listed in Table 5-12. The LCI of organic chemicals and limestone included:

- For organic chemicals
    - Energy consumed to produce organic materials
    - Emissions of chemicals that are used
- For Limestone
    - Milling and packing of limestone
    - Heating energy for production of $CaCO_3$

Table 5-12 Processes used to account for minor ingredients

Inorganic process	Organic process
Limestone	Lysine HCL
Salt	DL Methionine
Dicalcium Phosphate	Threonine
Calcium carbonate	Tryptophan
	Phytase
	Vitamins

5.2.4 Oilseed beans processing

Amongst the oilseed beans, soya bean is the principal source of vegetable oil and protein meal. The process is also similar for other oilseeds, such as rapeseed. The industrial sector is called either the "soya bean crushing industry" or the "soya bean processing industry." This industry processes soya beans producing the two major commodities locked in them, soy oil and soya bean meal. There are basically two ways of removing the oil from soya beans: pressing it out mechanically, or crushing the beans into thin flakes, then percolating these with a solvent to extract or dissolve it out. The mechanical press is the oldest process (used for organic oilseeds), whereas solvent extraction is the most efficient and common process. By 1970 over 90% of the world's soy oil was solvent extracted (Shuurtleff and Aoyagi, 2007). Modern solvent extraction includes:

- Cleaning beans, cracking, dehulling, heating, crushing and rolling them into flakes.

- Hexane based oil extraction, including heating and vacuum for hexane reclaimation. Hexane is a liquid petroleum-based solvent, which extracts the oil by dissolving it out of the flakes.
- Oil degumming and refining processes

Since oil and meal are products of soya bean processing, both are obtained at the same time, but in different proportions. They have been allocated in multiple ways in LCA models (Dalgaard *et al.*, in press; Miller *et al.*, 2007). For this study, the best way to allocate them was on a mass basis. Thus, soya bean oil and soy meal are responsible for 18% and 82% respectively of the inventory flows associated with soya bean production, respectively (Miller *et al.*, 2007). Landis *et al.* (2007) developed the LCA of soya bean cropping and processing in the U.S. Corn Belt, whilst Miller *et al.* (2007) stated the principal e-burdens from the cropping and milling processes of soya bean. These sources were used to model the imported soya meal for Mexican scenarios. For the orgUK and stdUK scenarios, Williams *et al.* (2006) provide suitable oilseed process data for soya meal and rapeseed in the UK.

5.2.5 Diet formulation

Diet formulation provided the inventory of feedstuffs. The set of pig diets included feed for gestating or dry sows, lactating sows, weaners, growers and finishers. Dry sow feed and lactating sow feed were for the breeding herd and the other diets for rearing pigs. Piglet feed or pre-weaning feed, offered before 9-12 kg of live weight was not modelled with a particular composition because it accounted for less than 3.8% of feed consumption and ingredients will not fulfil limits of inclusion for this study (being not more than 5%). Thus pre-weaning feed was accounted as weaning feed. Weaning feed was calculated as pig feed consumption until 25 kglw, growing feed until 50 kglw and finishing feed from

50 kglw until pigs leave the farm (near 100 kglw). Specific diet composition was modelled for each scenario as described in the following sections.

The Mexican scenarios

As stated in Appendix 3, there were no studies characterising diet nutrient compositions or diet ingredients used in Mexican pig farms. Accessed public reports from the animal feed industry, government agencies or pig farmer associations do not include reports that characterise feedstuffs content of pig diets in the detail required for this study. Three strategies were followed to characterise suitable diet formulations for the Mexican scenarios: (1) An expert panel was asked about typical ingredients for diets in each scenario; (2) Expert panel opinion was contrasted with national statistics; (3) Specific diets were formulated with the principal raw materials consumed by the milling industry in Mexico. A consultant nutritionist included in the expert panel (German Borbolla) formulated the diets.

Expert panel opinion of diet composition: The expert panel (Section A1.4) stated that there were no differences in composition of diets used for the two different Mexican scenarios because, on the whole, farms in both scenarios have access to similar compounded feed, or feed premixes for feed mixed on-farm. The expert panel could not establish a mill-mixed and farm-mixed ratio, neither was this reported in the available literature. The expert panel agreed that the principal difference between scenarios in feed efficiency arises from genetic quality of the pigs, equipment updating and building facilities modernisation developed by farmers more than from feed composition. The expert panel stated that farmers acquire feed through one of the following schemes:

- Buying feed from specialised commercial mills

- Buying commercial supplements named “feeding nucleus” which are added to specific quantities of grain and soya meal
- Buying raw materials and having constant support of an animal nutritionist, or
- Being associated with a mill plant.

The last option is the most frequent situation for farms modelled in both Mexican scenarios. Even when farmers use the other options, they receive constant support from pig nutritionists. Since feed mills appear as the principal scheme, feed was modelled as mill plant production and only one set of diets was used for both Mexican scenarios.

Regarding the typical ingredients for pig diets, the expert panel agreed that maize, sorghum and wheat are interchanged energetic feedstuffs and soy meal is the essential protein ingredient of pig diets. Borbolla (2007, Personal communication) stated that the main difference in pig diets between the two Mexican scenarios could be that smaller farms use maize, sorghum and wheat as substitute feedstuffs more frequently than the large farms. Borbolla agreed with the other experts that there are no differences in access to similar diet compositions between farms. The expert panel agreed that maize is the principal source of energy used in pig diets. However, wheat is more frequently used for piglet and weaner diets (expert panel’s opinion). Also, Borbolla said that polished rice, sorghum and dry whey are alternative feedstuffs that can be found in some seasons. Feed mills integrated with pig farms used maize and seasonally available wheat and sorghum. These diets are frequently adjusted to fit nutrient composition, but typical diets have not been characterised.

Contrasting expert’s opinion with national statistics, maize was the main crop harvested (71%) followed by sorghum (18%). Wheat had a lower harvesting figure (10%) and the soya bean output was negligible (0.35%) in 2007 (Table 5-13).

Table 5-13 Data on crops harvested in Mexico in 2007 from SIAP (2007)

Crops	Surface (million has)		Yield (tonnes/ha)	Ratio (%)
	Sowed	Harvested		
Maize	8.067	7.839	3.02	71.27
Wheat	0.702	0.693	5.02	10.46
Sorghum	1.669	1.637	3.64	17.92
Soya bean	0.069	0.059	1.96	0.35

Ancestral traditions and food habits of Mexicans include maize in the human diet. Maize is the principal grain used to make tortillas and the main source of carbohydrates in Mexican cuisine. All kinds of maize are suitable for human consumption, but Mexico is not self sufficient in maize production. Nearly 40% of maize demand is imported as is shown in the supply-demand balance for 2005 (Table 5-14).

Table 5-14 Supply-demand balance of cereal grains in Mexico in 2005, thousands of tonnes (SIAP, 2006)

Concept	National	Imports	Total
Initial stock			4,471
Maize	12,564	8,454	
Sorghum	4,645	3,021	
Wheat	317		
Barley	154		
Supply	17,681	11,474	29,155
Proportion of supply, %			
Maize exportation			-48
Forage grain available			33,674
Human consumption			11,703
Animal feed consumption			19,003
Seeds to sowing			237
Total consumption			30,942

National maize production is mainly assigned to human consumption (SIAP, 2007; CANACINTRA, 2004). Less than 10% of national production of maize is assigned to animal consumption, so that almost 90% of animal grain demand is filled with imported maize (Table 5-15).

Table 5-15 Feedstuffs assigned to animal consumption in 2005 (with data of Table 5-14)

Concept	Million of tonnes	*Percentage*
National maize	12.564	
Human consumption	11.703	
Maize to animal feed	0.862	9.3
Maize import	8.454	90.7
National sorghum	4.645	60.6
Imported sorghum	3.021	39.4
Wheat	0.317	100

The General coordination of livestock (CGG) in Mexico (CGG-SAGARPA, 2006) used data from mill associations to calculate that 19 million tonnes of grain was assigned to animal consumption (Table 5-16). This amount is similar to that calculated by ISAP statistics (Table 5-14). CGG (2006) reported that the pig farms' share was 22.5% and 19.7% of grains and seed meals respectively allocated to animal consumption for the five years up to 2005 (Table 5-16).

Table 5-16 Annual feedstuffs consumption in Mexico, million tonnes (CGG-SAGARPA, 2006)

Year	Total livestock		Pig production	
	Grains	Seed meals	Grains	Seed meals
2001	17.871	3.847	4.486	0.852
2002	18.036	3.925	4.198	0.798
2003	18.127	3.937	4.007	0.761
2004	18.616	4.043	4.131	0.785
2005	19.007	4.137	4.280	0.813

Maize was expected to be the main grain for pig diets since sorghum is mainly assigned to cattle diets, because the composition of sorghum (high level of tannins) reduces feed consumption in pigs (Cheeke, 1999). Only in the cropping season, when regional sorghum supply increases, could sorghum be included in breeding herd diets. Wheat is principally included in light quality piglet diets (Ochoa and Ortega, 2005). Whilst sorghum and wheat are supplied regionally and on an irregular basis, maize is supplied nationally and during the whole year. Therefore maize was the main grain used for pig diets in the modelled scenarios. Soy bean national production was negligible and practically 100% was imported (SIAP, 2007). Finally the ratio of feedstuffs used by mills for pig diets (CGG-SAGARPA, 2006) and the expert panel opinions on feedstuff composition for pig diets were compared (Table 5-17). Results showed that expert panel opinions and national statistics assigned a similar grain: soy meal ratio and maize was the main grain included in pig diets. Thus maize and soy meal were considered as the main feedstuffs for pig diets in the Mexican scenarios.

Table 5-17 Proportion of grains and soy meal used in Mexico for pig diets (%)

Ingredients	Mills consume[1]	Expert panel			average	std deviation
		Carvajal	Garcia	Wence		
Soya meal	16	17	17	16	16.5	0.57
Maize/sorghum/ wheat	79	78	76	76	77.25	1.5
Other ingredients	5	5	7	8	6.25	1.5

1 CGG-SAGARPA (2006)

Specific diet formulations considered grain availability for pig diets and the most frequent feedstuffs inclusion level in pig diets. A national consultant nutritionist (integrated in the expert panel, Section A1.4) and a pig farming assessor were asked for suitable diets for farms in the Mexican scenarios. Dr. German Borbolla, the expert pig nutritionist, and Jose Maria Wence, the pig assessor, provided a set of diets. Wence provided typical diets for the northwest region. Dr. Borbolla formulated a set of typical diets suitable for pig farms considered in both Mexican scenarios.

Table 5-18 Set of diets for Mexican scenarios (Borbolla, 2007, Personal communication)

Diet	Dry sow	Lactating	Weaner	Grower	Finisher
Weight, kg			< 30	30-60	>60
Maize	82.50	68.64	71.68[a]	67.40	77.67
Soya meal 44 (Imported)	14.01	27.60	22.90	26.40	17.01
Soy oil mixed			2.54	4.04	3.30
Calcium carbonate	1.60	1.45	1.21	0.93	0.93
Dicalcium Phosphate	1.20	1.46	0.83	0.31	0.20
Salt	0.44	0.55	0.23	0.40	0.38
Lysine HCL	0.03	0.08	0.38	0.29	0.30
Phytase	0.02	0.02	0.02	0.02	0.02
Complement mix[b]	0.20	0.21	0.22	0.21	0.20
Total	100.00	100.00	100.00	100.00	100.00

Almost a third must be wheat; (b) vitamins & trace element supplement

On average, diets in Table 5-18 have slightly more soy meal and a little less maize than the expert panel suggested previously. However, taking into account that finishers have the higher consumption, these diets generally agree with expert panel opinion. On the whole, the expert panel opinion agreed with national statistics for grains consumption and Borbolla's diets. Thus, Borbolla's diets were used to characterise Mexican scenarios.

The orgUK scenario

Diets described by Martins *et al. (2002, p22)* and reproduced in Table 5-19, were used to characterise feedstuffs for diets in the orgUK scenario.

Table 5-19 Diets for the orgUK scenario (Martins *et al.*, 2002)

Diet	Dry sow	Lactating	Weaner	Grower	finisher
Weight, kg			< 30	30-60	>60
Wheat		47.2	54.7	47.5	
Barley	55.6				45.6
Wheatfeed	25	20	10	10	25
Peas	15	15	10	15	15
Expellar Soy meal	0	0	0	25	12.5
Full fat soya (imported)	2	15	15		
Fishmeal			9		
Calcium carbonate	1.5	1.1	1	1.1	1.4
Salt	0.3	0.3	0.1	0.3	0.3
Dicalcium Phosphate	0.4	1.2	0	0.9	0
Complement mix [a]	0.2	0.2	0.2	0.2	0.2
Total	100	100	100	100	100

(a) vitamins & trace element supplement

The stdUK scenario

Diets described by Edwards *et al. (2002)* were used to characterise the stdUK scenario. These authors used different target protein crude contents to formulate alternative pig diets. The reference commercial diets, for which nutrient contents were provided by mill factories, were used to model the stdUK scenario (Table 5-20). Since the amount of molasses used was negligible, this ingredient was substituted by rape seed oil on an energy basis.

Table 5-20 Diets for the stdUK scenario (Edwards *et al.*, 2002)

Ingredient	Dry sow	Lactating	Weaner	Grower	Finisher
Wheat	55.0	55.0	50.0	50.0	50.0
Barley	12.5	0.1	23.7	20.5	15.0
Wheatfeed	23.8	10.3		2.4	8.7
Field beans		12.5			7.6
Rape meal	3.5	5.0		7.5	7.5
Soya meal		10.0	15.6	16.4	8.2
Rapeseed oil	1.2	0.6			
Fishmeal			6.0		
Soya oil		2.0	2.2	0.4	0.3
Limestone	1.2	1.2	0.3	1.17	1.21
Salt	0.42	0.49	0.31	0.37	0.36
Dicalcium Phosphate	0.77	1.31	0.9	0.69	0.68
Synthetic amino acids	0.15	0.11	0.52	0.61	0.53
Complement mix[a]	0.2	0.2	0.2	0.2	0.2
Total	98.8	98.8	99.7	100.2	100.2

(a) vitamins & trace element supplement

5.3 *Methods for the LCI of crop production*

As described in methods framework section (Section 3.2.5), the LCI of crop production was assessed using a process-LCA. The LCI was gathered in the same way as for feed production, using specific published LCAs for those crops which were included as ingredients in the diets for the four scenarios. The LCI for these crops included inputs such as fertilisers, pesticides, lime, seeds, irrigation, crop farming, yields and transportation (Figure 5.3). The LCAs which were used provided the e-burdens for grain and oilseed crops. LCAs from Landis *et al.* (2007) and Miller *et al. (2007)* were used to model maize and soya bean production for imported crops in the Mexican scenarios. Williams *et al. (2006)* provided suitable LCAs for imported and home produced crops in the UK scenarios. The inputs and burdens for these crops were accounted for on a feedstuffs demand basis. Inputs for crop production in all LCAs were traced back to energy and natural resources use. The production process of crops was accounted by tonne of crop output and allocated according to the feed production demand.

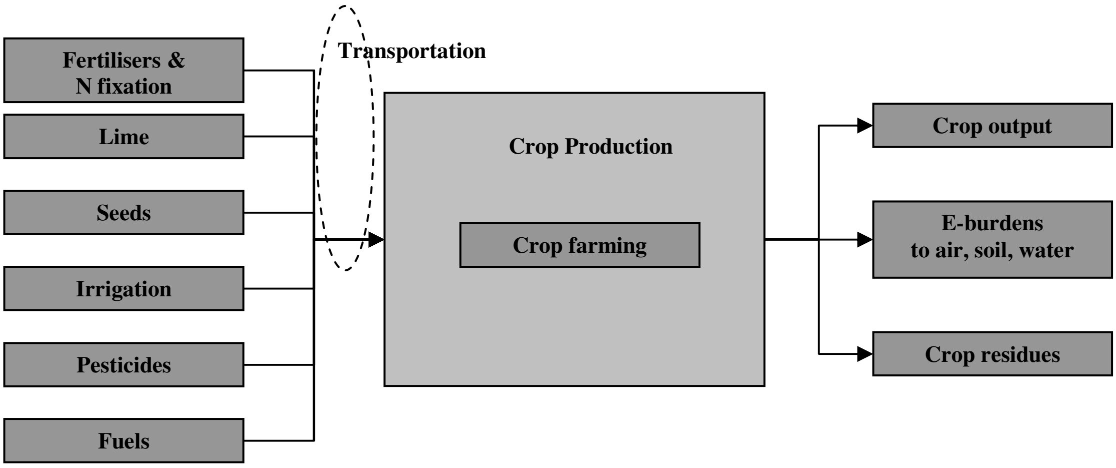

Figure 5.3 Processes included in crop production

5.3.1 LCI for crop production

Crop LCIs, either for crops produced in the US and imported to Mexico in the Mexican scenarios or for crops imported or home produced in the UK for the UK scenarios, included:

- Nutrient inputs that produce direct soil-crop emissions of N and P nutrients to either air or water and emissions of nitrate, nitrous oxide and ammonia
- Crop yield and crop residues
- Seed production
- Fuel for transportation and agricultural activities such as cultivation, chemical and manure application, irrigation and harvesting
- Production of fertilisers and pesticides
- Direct soil-crop emissions to air and water (nitrate, nitrous oxide and ammonia)
- One difference in the soya bean products used in the UK scenarios is that soya bean was modelled "as closely as possible using local techniques" in the UK for substitute crops (Williams *et al.*, 2006, p35).

Some differences were found between LCIs to calculate N emissions. Nitrate emissions to water were established using a simulation program in all scenarios. For US soya bean production the GREET 1.6 model included a Monte Carlo Analysis for N that simulated a probable range of outcomes given a set of variable conditions in terms of geography, annual variation and agricultural practice in the crop rotation. For maize production in the US Corn Belt (for Mexican scenarios) simulation was by the DAYCENT model for C dynamics, nitrate losses due to leaching and nitrogen oxide and nitrous oxide emissions. This model also included climate information, soil properties and crop management. Simulations were run with crop history for Iowa; native grasses for 1,860 years, corn-soya bean rotation for 10 years and continuous corn culture under no-tillage for 10 years. These simulations established a spin-up process that aligns the model for changes to continuous maize culture. After that, maize cultivation was simulated for 100 years with climate data for 42 years before 2003(Kim *et al.*, 2009). In the UK scenarios, the SUDIAL simulation program ran enough simulations until the rotations were in a steady state where the soil organic N fraction was the same at the start and end of a rotation. Simulation in SUDIAL included all possible N inputs such as atmosphere, previous crops, fertilisers and geography (nine combinations of soil type).

5.3.2P dynamics

Williams *et al.* (2006, p23 Section 2.2.5), consider N as the only readily mobile nutrient input. Thus P was considered to be applied principally to maintain soil fertility levels which, according to Williams *et al.* (2006), are checked and corrected over several years in response to soil tests. The input required, maintaining a constant level of P and its associated burdens, was calculated by mass balance.

5.3.3Other differences between scenarios

LCAs of crops grown in the US for the Mexicans scenarios:

- Included a LCI assessment for a maize-soya bean rotation system exclusively, because this is the most popular rotation system in the US Corn Belt (Miller *et al.*, 2007; Stewart, 2005).
- Excluded manure applied as fertiliser since in the US Corn Belt, on average, only 18% of maize and 6% of soya bean crops receive manure as a fertiliser supplement to synthetic fertiliser (Landis *et al.*, 2007)
- Did not include energy needed for grain drying during storage because this is not used (Kim *et al.*, 2009)
- Did not include machinery manufacture
- Did not include construction of buildings (warehouse)
- Did not include land use for seeds in soya bean LCI
- Did not include C sequestration for maize and soya bean e-burdens calculations.

LCAs of crops in the UK for the UK scenarios:

- Did not include some air emissions for fuels and equipment manufacture (VOC, PM10).
- Modelled conventional and organic crop production; both had similar inputs. The principal differences between production of conventional and organic crops was in the use of fertilisers. Whilst in conventional crops N was supplied by synthetic fertiliser, for organic crops N came from grass-clover leys and legumes and composting. Leys and cover crops necessary for fertility building increased the requirement for ploughing and land use for organic crops. Factors of 1.25 and 1.525 times increase were wasused for ploughing and land use respectively, but there was an adjustment for yields of grass-clover leys (Williams *et al.*, 2006). In the case of composting, this accounted for the energy spent on collection and turning of the composting material and for gases emitted during composting. In

organic cropping, additional light cultivations were used for weed control, but there were no pesticide applications. For organic soya and maize production, no extra land was used for leys, but two winter legumes were planted for grain crops with a land inflation factor of 3.4% (extra land used and allocated by crops).

- Imported soya bean was modelled as local pea production, considering both crop production processes as similar processes with negligible variation (Williams *et al.*, 2006, p27). Additionally, burdens for importation were added to soya bean importations. UK pea production was modelled in similar way to other crops and its rotation system that included 2 soya bean crops and 3 maize crops.

- Williams *et al.* (2006) did not include soil C sequestration for crops. They assumed that the potential quantities of CO_2 credited to crops during cultivation are released to the atmosphere when the crops are consumed and so they ignored them.

5.4 *Results of the LCI of Pig production*

The nutrient mass balance for pig production

The nutrient mass balance includes inputs and outputs of nutrients in the pig farming framework. All results were allocated according to the functional unit of one tonne of pig liveweight at the farm gate (tlw). A specific mass balance for C, N and P was carried out to calculate total e-burdens and credits from pig production. Environmental emissions included: Methane, NH_3 , NO_3^- , N_2O and P.

Firstly, general calculations useful for most of the mass balances were developed. These included: Firstly, the proportion of pigmeat produced from the growing herd or culled breeding herd by functional unit and secondly, the daily pig farm inventory necessary to produce one functional unit (one tonne of liveweight of pigmeat: tlw). Meat production and feed consumption are described in two sections of the pig production description (Sections 3.4.3 and 3.4.4, respectively). The principal calculations are explained or have reference to specific equations. All equations referred to are given in Appendix 5.

5.4.1 Meat production

As reported in Section 3.4.3, pigmeat includes culled breeding herd animals and finishers delivered at the farm gate. The cull rate was assumed to be equal to the replacement rate less breeding mortality. Thus the selling live weight, stated in the farm physical performance, and numbers of animals needed to deliver a tlw were used to calculate the mix of pigmeat types for a tlw. Equation 10 details these calculations and the results are shown in Table 5.21. Although each scenario has a different meat productivity and cull rate, differences between scenarios are small.

Table 5.21 Meat production by scenario (kg tlw^{-1})

Category of meat production	locMEX	stdMEX	orgUK	std UK
Meat from cull	41.4	34.7	36.0	46.0
Meat from finishers	958.6	965.3	964.0	954.0
Total	1,000.0	1,000.0	1,000.0	1,000.0

5.4.2 Daily farm inventory per tlw

The daily inventory at the farm for each tlw was calculated on an annual basis. This includes animals, cycles and proportion of the animals from each productive stages, both for the breeding herd and growing herd, to fit the inventory to produce the functional unit in one year. Equations 1 to 5 (Appendix 5) details the calculations and the results are given in Table 5.22. Although productivity was better for the standard scenarios, pigs for the UK scenario took more time to achieve market weight than pigs in the Mexican scenarios, increasing the total inventory need per tlw produced annually.

Table 5.22 Daily inventories at the farm tlw^{-1} (numbers of animals)

Category of animals	locMEX	stdMEX	orgUK	std UK
Dry sow	0.51	0.44	0.37	0.41
Lactating sow	0.08	0.07	0.19	0.08
Gilts	0.03	0.03	0.03	0.04
Boar	0.03	0.03	0.06	0.02
Weaners	2.28	2.05	2.27	2.46
Finishers	2.44	2.41	2.60	2.62
Total	5.38	5.03	5.52	5.63

5.4.3 Methane

Enteric fermentation

Since the methane produced from enteric fermentation was accounted on a head $year^{-1}$ basis, the inventory tlw^{-1} was multiplied by the conversion factor of 1.5 kg methane $head^{-1}$ $year^{-1}$ as given in the methods for manure fermentation (Section 5.14). Table 5.23 shows the results. Since enteric methane emission is proportional to the farm inventory, those inventories with a higher head tlw^{-1} had a higher enteric methane contribution. However, enteric fermentation did not produce large differences between scenarios because grain-based diets were utilised in all four scenarios (Section 5.1.4).

Manure methane production

Since methane production depends on manure VS content, the total output of VS in manure before MM started was calculated. The standard VS for each productive stage shown in Table 5.5 and the herd inventory tlw^{-1} given in Table 5.22 were used to calculate the total VS manure content (Equation 6). Manure-methane production during collection, storage and disposal was calculated according to the principal factors that modify methane production. Methane emissions were accounted separately for every MM-system in the consecutive steps occurring in MM. The specific VS content at each step in the MM-system was calculated before the specific MM took place. Calculation considered the VS degradation in previous MM-systems (Equation 8). The specific Bo of VS and the MCF by MM-system stated in Table 5.4 and Table 5.5 were also included (Equation 7). Methane emissions were accounted as kg CH_4 per tlw on an annual basis. Since methane was calculated in m^3, the conversion factor of 0.67 was used to transform from m^3 to kilograms (IPCC, 2006).

Table 5.23 shows methane production by MM-system in the four scenarios. The stdMEX scenario gave the greatest methane emissions during manure collection, because the retention time and temperature provide good conditions for methanogenic manure fermentation. Another difference arises from the weather conditions during manure outside storage. The Mexican scenarios store manure in similar systems to the stdUK scenario, but higher storage temperatures in Mexico lead to higher methane production. Manure disposal did not significantly increase methane emissions in any scenario.

Table 5.23 Volatile solid (Dubrovskis *et al. 2008*) and methane production by enteric fermentation and MM-storage (kg tlw^{-1})

Categories	locMEX	stdMEX	orgUK	std UK
Total VS	1.50	1.42	1.62	1.54
Methane production:				
Enteric fermentation	8.07	7.54	8.28	8.45
Manure collection	0.88	99.78	0	5.10
Manure storage	61.51	39.91	0	28.02
Manure disposal	0.57	0.27	0.18	0.14
Total	71.04	147.50	8.46	41.71

5.4.4 Nitrogen

Input N

Firstly total N input was calculated. The feed-N was the result of equation 9 in Appendix 5. Feed consumption and crude protein level in diets for each pig productive stage were taken into account. Table 5.24 summarises the feed-N inputs for each scenario. The time period in each productive stage influenced the feed-N variation more than the dietary CP content when comparing productive stages within scenarios. In contrast, the CP of diets and farm productivity affected total feed-N consumed in each scenario. There were no differences in feed-N consumed between the two standard scenarios. Alternative scenarios were less productive (less pigmeat/sow) than standard scenarios and consumed more feed per unit of pigmeat produced. The orgUK scenario has the highest feed-N consumption since dietary CP content is higher than in other scenarios and less pigmeat is produced per unit of dietary input.

Table 5.24 Feed-N consumed by pig productive stage (kg N tlw^{-1})

Productive stage	stdMEX	locMEX	std UK	orgUK
Dry sow	7.9	9.8	8.9	8.9
Lactating sow	3.8	4.0	5.1	9.1
Weaner	11.2	12.7	12.3	10.4
Grower	22.1	23.1	16.6	22.3
Finisher	29.8	31.2	32.0	35.8
Total	74.7	80.8	74.9	86.4

Output N

The N output was split into pig-N and manure-N. The pig-N was calculated using equation 13 (Appendix 5). The protein content of finishers and cull breeding animals was established as 170g kglw^{-1} and 156g kglw^{-1} respectively (see Section 5.1.2). Table 5.21 provides the proportional contribution of pigmeat from each source by functional unit (tlw). Since the functional unit is a tlw, pigmeat from culled breeding animals has hardly any influence on the N content of pigmeat. Since, a similar pigmeat composition was assumed in all scenarios (Section 5.1.2), the principal differences between scenarios were in manure-N, which was the difference between feed-N and pig-N. Table 5.25 shows these results. In this sense, differences between scenarios for feed-N are directly reflected in the manure-N and possible variations for lean meat between scenarios were modified only by the cull meat proportion. In consequence, there was more remaining N for MM in the alternative scenarios than for the standard scenarios, principally in the orgUK scenario.

Table 5.25 N input and output distribution (kg tlw^{-1})

N distribution	stdMEX	locMEX	std UK	orgUK
Feed-N	74.7	80.8	74.9	86.4
Cull-N	1.0	1.1	1.2	1.0
Finisher-N	25.9	25.8	25.7	25.9
Total Meat-N	26.9	26.9	26.9	26.9
Manure-N	47.8	53.9	48.0	59.5

Ammonia, nitrous oxide and nitrate N losses

As stated previously in the description of uses and losses of N in the LCI methodology (Section 5.1.5), manure-N is volatile, even during short retention time, which facilitates a dynamic nitrification-denitrification process and N losses. These losses are influenced by retention conditions and N concentration. Even though this is a dynamic process, modelling collection, outside storage and disposal as independent manure systems and summing up at the end allows calculation of total N losses during MM. Thus plant available N (plant- N) is the remaining N after MM losses. In accordance with IPCC (2006) guidelines, N losses were calculated in the following order. Shortly after manure arrives at the manure storage system there are direct N_2O-N losses, followed by slow ammonia-N volatilisation. Then a secondary N_2O-N loss is produced from volatilised ammonia-N. In all manure systems, nitrate is produced as a further pollutant, but only during manure disposal. When nitrate goes to soil, further secondary N_2O-N losses occur. The N losses were calculated using Equation 14 (in Appendix 5) considering that:

- N previously available for the manure collection system was the excreted-N (manure-N) and
- Nitrate and indirect N_2O-N losses from nitrate were calculated only during manure disposal.

Emission factors for N_2O-N, ammonia-N and nitrate-N losses used in Equation 14 (in Appendix 5) are shown in Table 5.7 and Table 5.8. Figure 5.4 and Figure 5.5 show details of N losses and Figure 5.6 summarizes the percentage contribution of nitrous oxide, ammonia and nitrate to N losses during MM. Table 5.26 shows the N mass balance, summarising results for input and output of N in the pig farming sector. Figure 5.7 shows the principal fates of N outputs.

Manure disposal gives rise to major differences in N_2O emissions between scenarios (Figure 5.4). Since outdoor pigs in the orgUK scenario apply manure directly to land, the orgUK scenario has higher direct N_2O emissions from urine and dung ammonia transformation (Figure 5.4). For this scenario, the N_2O factor for direct emission is twice as high as for other MM-systems for manure disposal (Table 5.7) and manure-N also has not been transformed in previous MM-stages (Figure 5.4). Thus higher N_2O emissions occurred in the orgUK scenario than in other scenarios. For non-organic scenarios, direct N_2O emissions predominated in total N_2O emissions. Differences between scenarios for direct N_2O emissions were influenced by N-manure, since the emission factors were similar (Table 5.7), resulting in only small differences between the non-organic scenarios (Table 5.26).

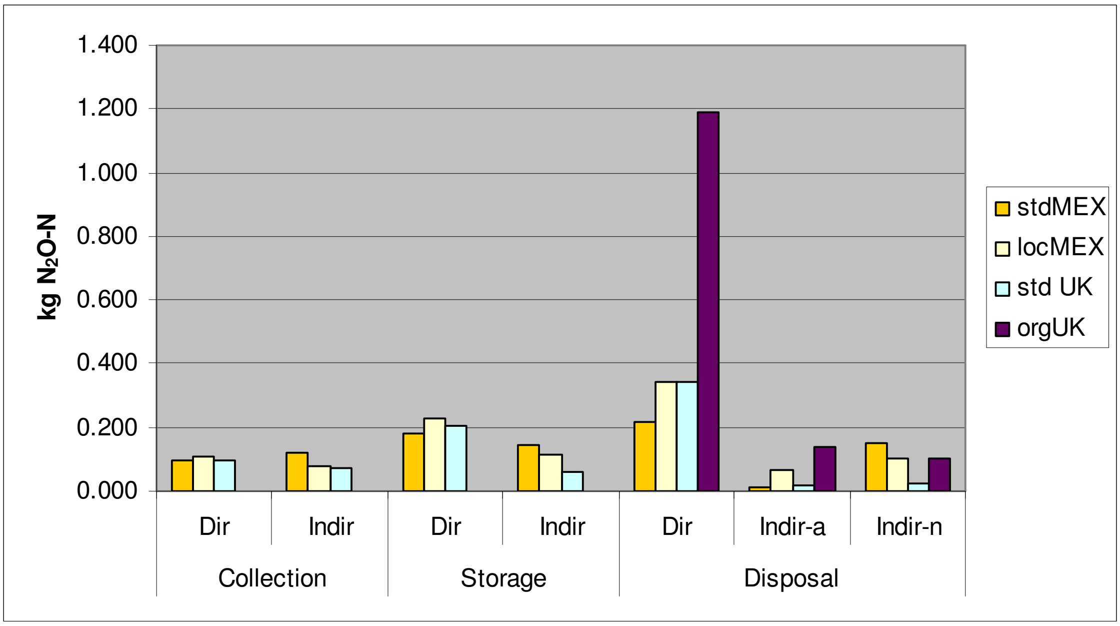

Figure 5.4 N2O-N losses during collection within buildings, outside storage and disposal of pig manure for each scenario (kg N2O-N tlw-1), indirect N2O-N losses during disposal were from ammonia (Indir-a) or nitrate (Indir-n) origin.

The MM-system and weather conditions strongly influenced ammonia volatilisation. Hence, during manure collection and storage, the stdMEX scenario had highest ammonia losses whilst during manure disposal the orgUK scenario was highest. The Mexican scenarios are exposed to higher environmental temperatures and therefore higher manure fermentation rates are expected. Additionally, the retention time in the MM-systems for the stdMEX scenario facilitates more active ammonia volatilisation than for the UK scenarios (Figure 5.9 and Table 5.26*)*. Usually, N losses during previous MM-systems and the system used for manure land application determine the nitrate losses. Whilst this is the case for most of the scenarios, it is not so for the stdMEX scenario. Since manure in this scenario was disposed of to riparian zones, Nitrate-N included all the remaining manure-N after ammonia and nitrous oxide N discounts (Table 5.7). Thus N available for plant nutrition (plant-N) cannot be credited to the stdMEX scenario. For the other scenarios, the

UK scenarios credited more N to crop production than the locMEX scenario because of lower previous volatilisation losses.

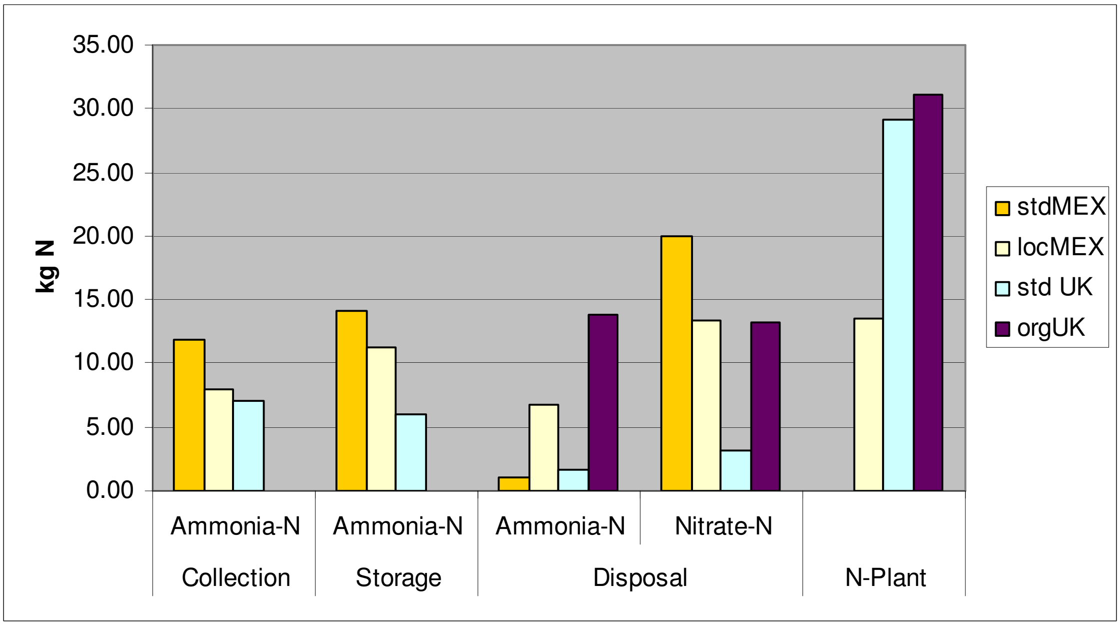

Figure 5.5 Ammonia-N and nitrate-N losses during collection within buildings, outside storage and disposal of pig manure for each scenario (kg tlw-1)

Summarising the N losses during the MM-systems, the stdMEX scenario has the highest ammonia and nitrate losses (Figure 5.6). The locMEX scenario also had high ammonia volatilisation, but nitrate losses were similar to the orgUK scenario (Figure 5.6; Table 5.26). The orgUK scenario had the highest N_2O emissions but a similar N credit to crop production compared to the stdUK scenario (Figure 5.5 and Table 5.26). The stdUK scenario showed the lowest overall rate of N losses and the stdMEX scenario the highest (Figure 5.7). The stdUK scenario lost 25% of input N and the stdMEX scenario lost 64%.

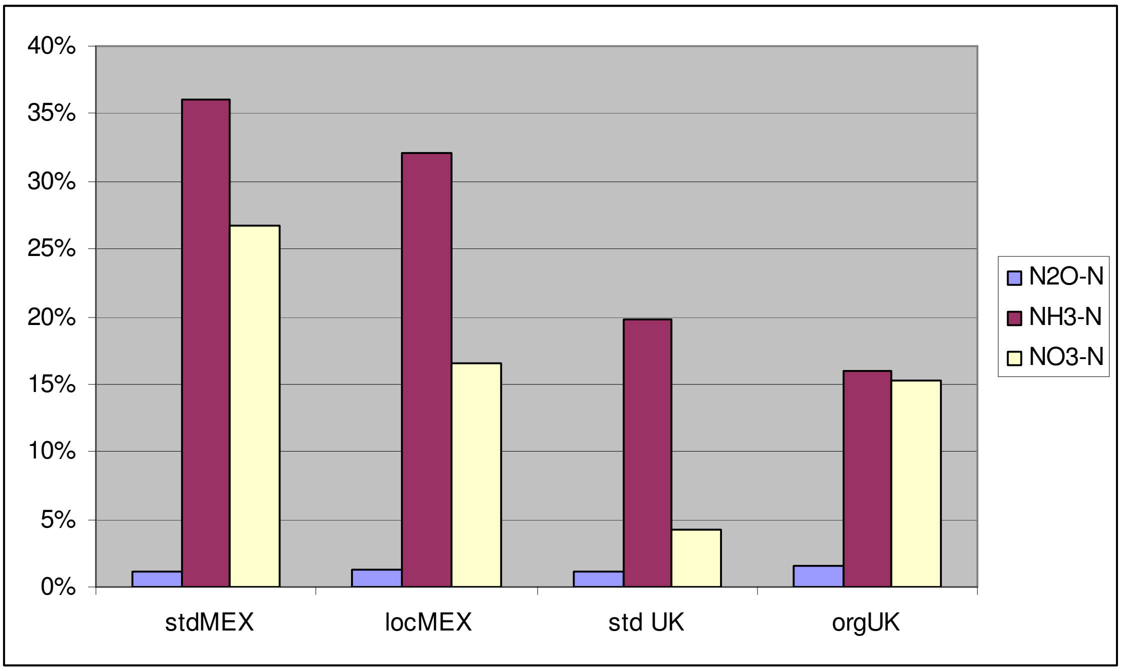

Figure 5.6 Percentage of manure-N lost in different forms for each scenario

Table 5.26 N mass balance for pig production (kg N tlw^{-1})

N distribution	stdMEX	locMEX	std UK	orgUK
Input-N	74.7	80.8	75.6	86.4
Output-N:				
Meat-N	26.9	26.9	26.9	26.9
N_2O-N	0.7	1.0	0.8	1.4
NH_3-N	27.0	25.9	15.0	13.9
NO_3-N	20.0	13.4	3.3	13.2
Plant-N	0.0	13.5	29.6	31.0

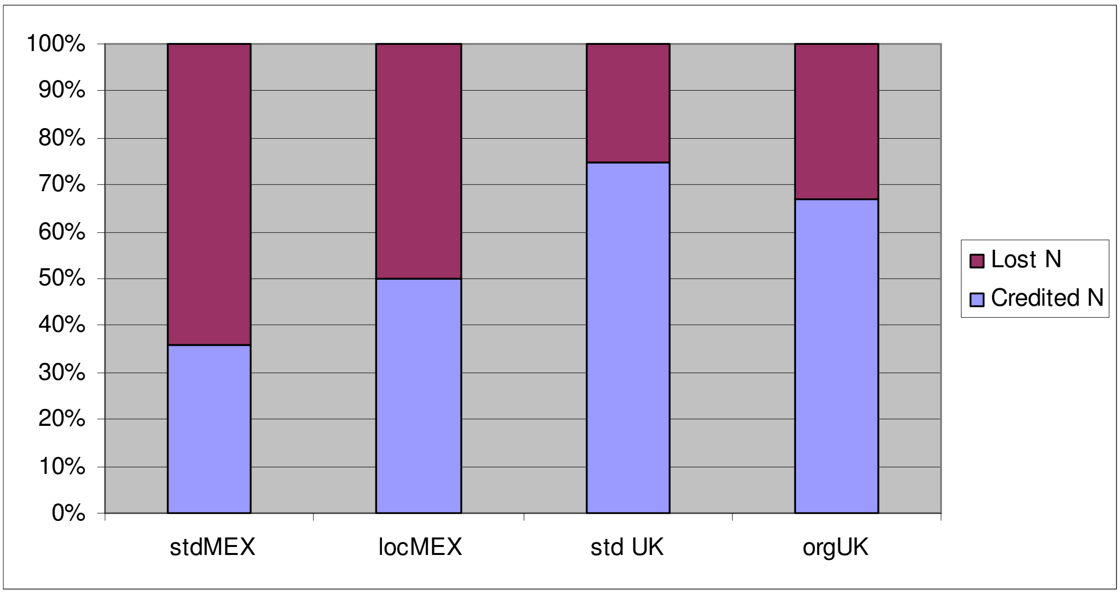

Figure 5.7 Percentage distribution of N output between environmental burdens (N_2O, NH_3 and NO_3) and credits (meat-N and plant-N) for each scenario

5.4.5 Phosphorus

Input P

Total input P was the feed-P. Feed-P resulted from multiplying feed consumption in each pig productive stage (Table 3.4) by the dietary P content stated in Table 5.2 (Equation 15). Table 5.27 summarises the feed-P inputs for each scenario. The Mexican scenarios had lower feed-P than UK scenarios, unlike feed-N which was lower for standard scenarios in both countries. Mexican scenarios had lower dietary P content because commercial diet formulation is closer to nutrient recommendations than in UK scenarios.

Table 5.27 Feed-P by pig productive stage (kg P tlw^{-1})

Productive stage	locMEX	stdMEX	orgUK	std UK
Dry sow	2.5	2.0	2.6	2.2
Lactating	0.7	0.7	2.4	1.0
Weaner	2.1	1.8	2.0	1.8
Grower	3.9	3.7	4.2	3.0
Finisher	5.9	5.6	7.0	8.0
Total	15.1	13.7	18.1	16.0

Output P

The P output was split in the same way as for N outputs, into pig-P and manure-P. Pig-P was calculated using Equation 16 (in Appendix 5). The P content of finishers and cull breeding animals was set at 5.4g $kglw^{-1}$ and 5g $kglw^{-1}$ respectively as established in the methods section. Table 5.21 shows the proportional distribution of pigmeat by functional unit (tlw). Manure-P was the difference between feed-P and pig-P. Table 5.28 shows that as was the case for N output, variations in excreted P between scenarios were strongly influenced by feed-P.

Table 5.28 P input and output (kg tlw^{-1})

P distribution	locMEX	stdMEX	orgUK	std UK
Feed-P	15.1	13.7	18.1	16.0
Cull-P	0.2	0.2	0.2	0.2
Finisher-P	5.2	5.2	5.2	5.0
Total Meat-P	5.4	5.4	5.4	5.3
Manure-P	9.7	8.3	12.7	10.7

Phosphate and soil credit P losses

As previously stated in the uses and losses of P section (Section 5.1.5), manure-P losses take place following manure disposal. These losses are dependent on available P in soil and the extent of any surpluses. Even though there is considerable variation in soil composition, all scenarios were modelled with P surpluses. Thus, 4% of applied P was modelled as P-runoff for scenarios with agricultural manure application and 100% for the stdMEX scenario which deposits manure directly into watercourses. The P credit as fertiliser for P applied to soil was also split into P credit for soil-structure and P available for plant nutrition in the next crop following soil manure application. Equation 17 (in Appendix 5) presents losses and credit calculations for P, using data from Table 5.9. Table 5.29 shows the manure-P economy for each scenario. P losses are dominated by that for the stdMEX scenario. Since soil-P is credited to crop production, the orgUK scenario showed the highest value for credit P.

Table 5.29 Manure-P losses and credit distribution (kgP tlw^{-1})

P distribution	locMEX	stdMEX	orgUK	std UK
P lost:				
$P\text{-}PO_4$	0.4	8.3	0.5	0.4
P credited:				
Soil-P	5.6	0.0	4.9	5.1
Plant-P	3.7	0.0	7.3	5.1

5.4.6 Principal environmental burdens and credits from the pig production mass balance

The N, C and P disposed to the environment, or credited to other PSC sectors from the pig-production nutrient mass balance, were transformed to principal substances that account for e-burdens in the scenarios. The conversion factors are based on molecular compound compositions (Table 5.30). Total nitrous oxide, ammonia, nitrate and phosphate were obtained by multiplying the total linked N and P by the specific conversion factor. This transformation was not necessary for methane production. Table 5.31 shows total burdens of different compounds to the environment and Table 5.32 the nutrient credits for plant nutrition on a commercial basis. Every compound has a different e-burden weight, feeding into the main assessment of the e-burden for each scenario.

Table 5.30 Conversion factors used to transform the N_2O-N, NH_3-N, NO_3-N and PO_4-P to nitrous oxide, ammonia, nitrate and phosphate, respectively (by molecular composition, see Section 5.1.5).

	N_2O	Ammonia	Nitrate	Phosphate	Urea
Conversion factors	1.57	1.20	4.43	3.06	2.14

Table 5.31 Pig farming e-burdens from the nutrient mass balance (kg tlw^{-1})

E-burdens	stdMEX	locMEX	std UK	orgUK
Methane	147.50	71.04	41.71	8.46
N2O	1.42	1.66	1.28	2.26
Ammonia	32.14	31.67	17.74	16.76
Nitrate	87.19	60.04	14.11	58.53
Phosphate	25.51	1.19	1.31	1.56

Table 5.32 Fertiliser credit from the nutrient mass balance to other sectors (kg tlw^{-1})

Commercial fertiliser	stdMEX	locMEX	std UK	orgUK
Urea	0	29.5	62.3	67.0
P_2O_5[1]	0	21.3	23.5	28.0

1) Phosphorous pentoxide (commercial P)

5.5 Results of the LCI of feed production and crop production

The LCI of feed production included the mixing and milling process of feed ingredients and the transportation of both ingredients and compounded feed. Feed ingredients included organic and inorganic industrial ingredients, energy ingredients and protein ingredients. Since the milling and mixing process and transportation from mill to farm was applied to total feed, their burdens were calculated from total feed demand per tlw pigmeat. Burdens for ingredient transportation and processing of industrial and raw crop ingredients were calculated on an ingredient inclusion basis. Total ingredients used were obtained by multiplying the feed consumption by the level of each dietary ingredient for each productive stage and scenario (Equation 18). Feed consumption is stated in Table 3.4 and diet ingredients in Tables 3.23, 3.24 and 3.25 in the methods chapter, feed ingredients were classified as energy, protein or industrial ingredients. Energy and protein ingredients were allocated according to their principal nutrient content. In some cases, industrial ingredients were allocated according to the industrial ingredient classification stated in Table 3.17 of the Methods chapter. Table 5.33 shows the proportion and total amount of energy ingredients included in the feed, whist Table 5.34 and Table 5.35 show this for protein and industrial ingredients, respectively. The main variation in ingredient inclusion between the different scenarios was in the orgUK scenario, since diets for the orgUK scenario were balanced without chemically processed or synthetic ingredients, more protein ingredients and fewer industrial organic ingredients were necessary (Table 5.34 and Table 5.35).

Table 5.33 Demand for energy crop ingredients (kg tlw^{-1})

Ingredient	stdMEX	locMEX	stdUK	orgUK
Maize (imported)	2186.5	2375.1		
Wheat			1490.2	666.6
Barley			462.3	874.1
Wheatfeed			255.5	625.0
Soy oil (imported)	82.3	86.9	18.1	
Rapeseed oil			6.7	
Total	2268.9	2462.0	2232.7	2165.7

Table 5.34 Demand for protein crop ingredients (kg tlw^{-1})

Ingredient	stdMEX	locMEX	stdUK	orgUK
Soya meal (imported)	593.6	639.0	280.5	349.0
Field beans			123.7	460.8
Full fat soya (imported)				107.4
Fishmeal			21.5	29.1
Rape meal			169.3	
Total	593.6	639.0	594.9	946.3

Table 5.35 Demand for industrial ingredients (kg tlw^{-1})

Ingredient	stdMEX	locMEX	stdUK	orgUK
Inorganic	57.4	63.3	64.9	61.5
Organic	14.0	15.0	19.2	6.4

5.5.1 Mixing and milling process

Diets for each scenario were compounded with almost the same proportion of ingredients (Figure 5.8), except for the orgUK scenario as stated previously. This difference was mainly due to ingredient restrictions for the orgUK scenario. Since ingredients cannot be chemically processed, most of the protein ingredients were included as whole seeds or crushed beans avoiding hexane oil separation from soya flakes (Figure 5.10).

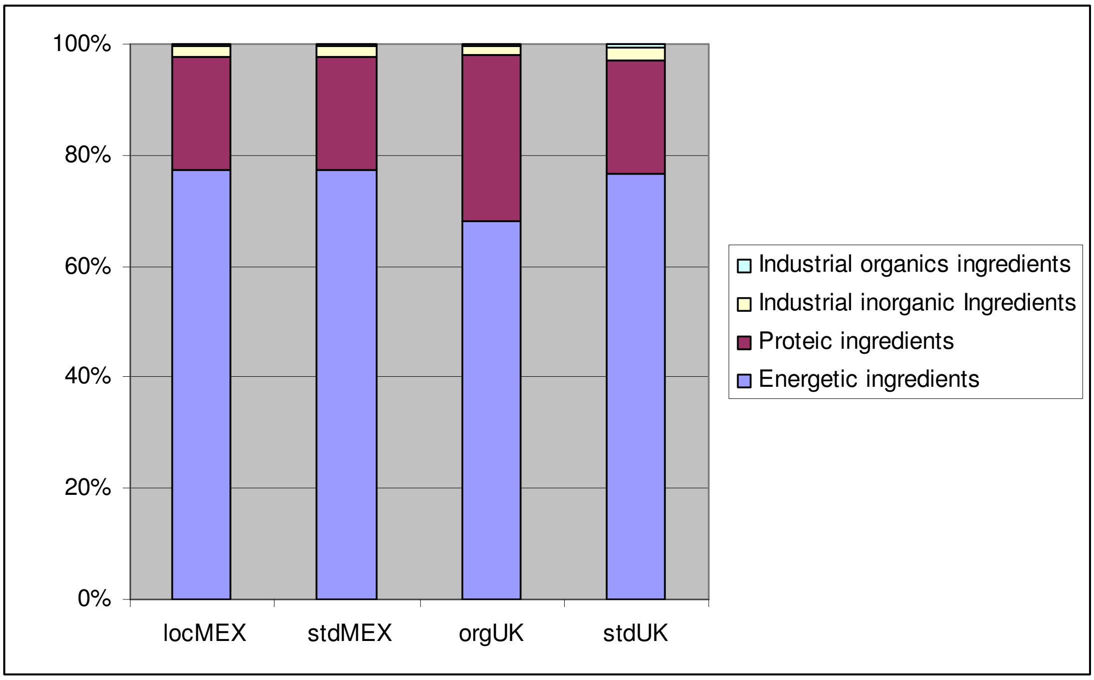

Figure 5.8 Percentage of different types of feed ingredients for each scenario

The UK scenarios fulfil dietary needs with grain produced at home (Figure 5.9) and less than 50 % of imported crops for protein needs (Figure 5.10). Mexican scenarios were totally dependant on imported crops.

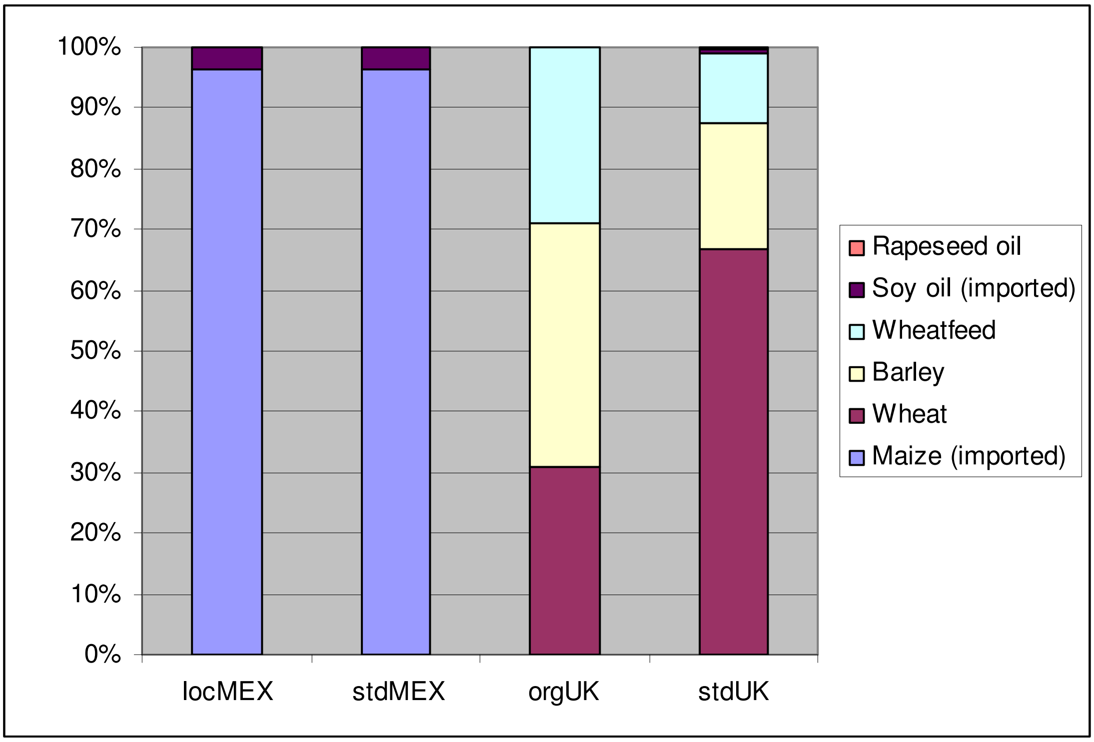

Figure 5.9 Percentage of different energetic ingredients in the scenarios' diets

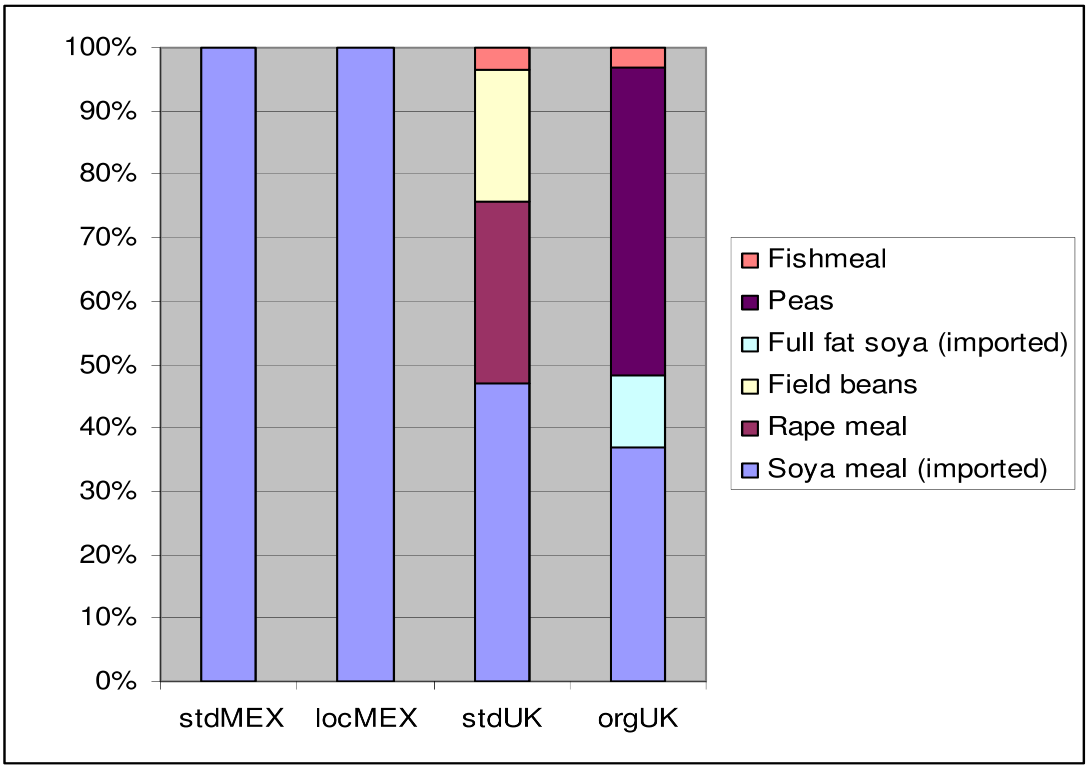

Figure 5.10 Percentage of different protein ingredients in the scenario's diets

Transportation

Transportation of feed and feed ingredients was assessed for each scenario according to the specific transport distance given in Tables 3.15 and 3.16. Equation 19 (in Appendix 5) describes these calculations.

5.5.2 Crop production and processing

Oilseed crops such as soya and rapeseed were processed before inclusion took place. In some cases only one co-product was included in the diets, such as rapeseed meal, or in other cases both co-products were used, such as soya oil and soya meal. The allocation of these co-products was done on a mass basis as stated in oilseed beans processing section (Sections 3.2.7 and 5.2.4)**.** Crop production burdens were assessed through specific LCA for each crop, as described previously in the methodology (Section 5.3.1)**.** Crops were accounted for according to the amounts stated in Tables 5.33 to 35 using the LCA described in the methods section (Section 5.3.1).

Impact assessment

The LCI of feed production and crop production, including the mixing and milling process, transportation and feed ingredients production were assessed though the database manager SimaPro software. E-burdens were calculated for each scenario. Appendix 6 shows the network of e-burdens distribution for each scenario. Total impact assessments for GWP, AP and EP for the major sectors in the PSC are presented in Tables 5.36, 5.39 and 5.42**,** respectively.

Global Warming Potential

Energy and protein ingredients accounted for nearly 95% of GWP impact in all scenarios (Figure 5.11). The highest GWP values were for the UK scenarios (Table 5.36). Higher values were calculated for the use of local crops that are in rotation systems and depend on synthetic fertilisers, than for scenarios using ingredients from intensive crop production, since intensive crop systems use less field labour and fuel, reducing tractor activities and fertilisers. Thus, even though the stdUK scenario had similar consumption to the stdMEX scenario, local crop production in the stdUK scenario increased the GWP. Similarly, the orgUK scenario that is less dependent on industrial processing and ingredients for crop and feed production showed higher GWP impact than other scenarios. This result is because field preparation and weed control for organic crops require more mechanical labour (Shepherd *et al.*, 2003). Thus the inclusion of more raw ingredients than processed co-products increased the GWP impact.

Table 5.36 Global warming potential for feed and crop production (gCO_2 eq tlw^{-1})

Categories	stdMEX	locMEX	stdUK	orgUK
Energy ingredients	1,138,512	1,248,689	1,471,183	1,159,479
Protein ingredients	295,605	321,437	513,136	975,484
Inorganic ingredients	1,336	1,473	1,510	1,431
Organic ingredients	26,665	28,569	36,569	12,190
Milling & mixing	48,534	52,587	48,170	52,603
Feed-transportation	16,789	25,184	16,789	16,789
Total	1,527,440	1,677,938	2,087,357	2,217,975

Maize, soya meal and soya oil included burdens for importation transport. Specific energy and protein ingredient burdens produced the main differences in GWP. Feed consumption per tlw was lower for the standard scenarios in both countries, but GWP impact was higher in the UK scenarios. Thus diet composition and crop production burdens were more important than burdens from transportation. Table 5.37 shows that those feed ingredients classified as energy crops have relatively similar burdens between the different scenarios, but inclusion of different protein crops increases the GWP impact of UK diets (Table 5.38).

Table 5.37 GWP of energy ingredients demanded for tlw (gCO_2eq)

Ingredient	stdMEX	locMEX	stdUK	orgUK
Grain maize	1,123,853	1,232,719	0	0
Soy oil	14,710	15,970	0	0
Wheat	0	0	1,089,483	476,143
Barley	0	0	333,456	615,987
Wheatfeed	0	0	32,708	67,509
Rape seed oil	0	0	10,702	0
Soy oil	0	0	5,032	0
Total	1,138,563	1,248,689	1,471,381	1,159,639

Consumption of protein ingredients was higher in the orgUK scenario than in the intensive scenarios because more protein ingredients were necessary to fulfil the demand for essential amino acids such as lysine. Additionally extra land activities were necessary for weed control. These differences are discussed further in Chapter 7 (Table 7.5 and Section 7.3.3).

Table 5.38 GWP of protein ingredients demanded for tlw (gCO_2eq)

Ingredient	stdMEX	locMEX	stdUK	orgUK
Soy meal	295,804	321,437	264,837	329,456
Field beans	0	0	124,958	465,408
Soy beans	0	0	0	139,620
Rape meal	0	0	93,131	0
Fishmeal	0	0	30,297	41,000
Total	295,804	321,437	513,222	975,484

Summing up the industrial ingredients, the milling and mixing process and the transportation from mill to farm accounted for around 5% of GWP (Figure 5.11). Transportation of feed from mill to farm was higher for the locMEX scenario (Table 5.36), although this did not make a major difference to total GWP burdens between scenarios.

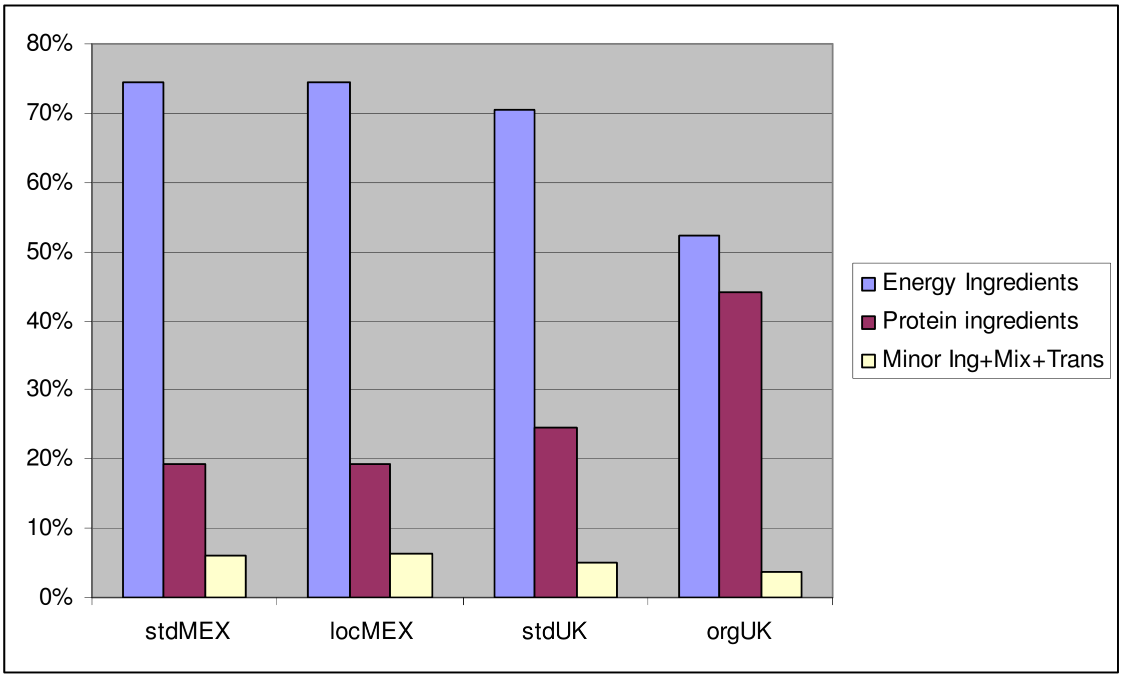

Figure 5.11 Contribution of diet ingredients to total feed GWP (%)

Acidification Potential

Energy and protein ingredients accounted for between 95% and 97% of AP impact in all scenarios (Figure 5.12). The higher AP values were for the Mexican scenarios (Table 5.39). The AP of scenarios showed the opposite impact to that seen for GWP. Those scenarios that were more integrated with crop rotation systems had lower AP impact. Differences between the UK scenarios again show a higher impact for the orgUK scenario, where nutrient application is less efficient than the stdUK scenario.

Table 5.39Acidification potential for feed and crop production (gSO_2-eq tlw^{-1})

Categories	stdMEX	locMEX	stdUK	orgUK
Energy ingredients	13,028	14,229	5,770	4,966
Protein ingredients	722	797	3,986	6,176
Inorganic ingredients	7	7	7	7
Organic ingredients	190	203	260	87
Milling & mixing	100	108	99	108
Feed-transportation	119	179	119	119
Total	14,165	15,525	10,243	11,464

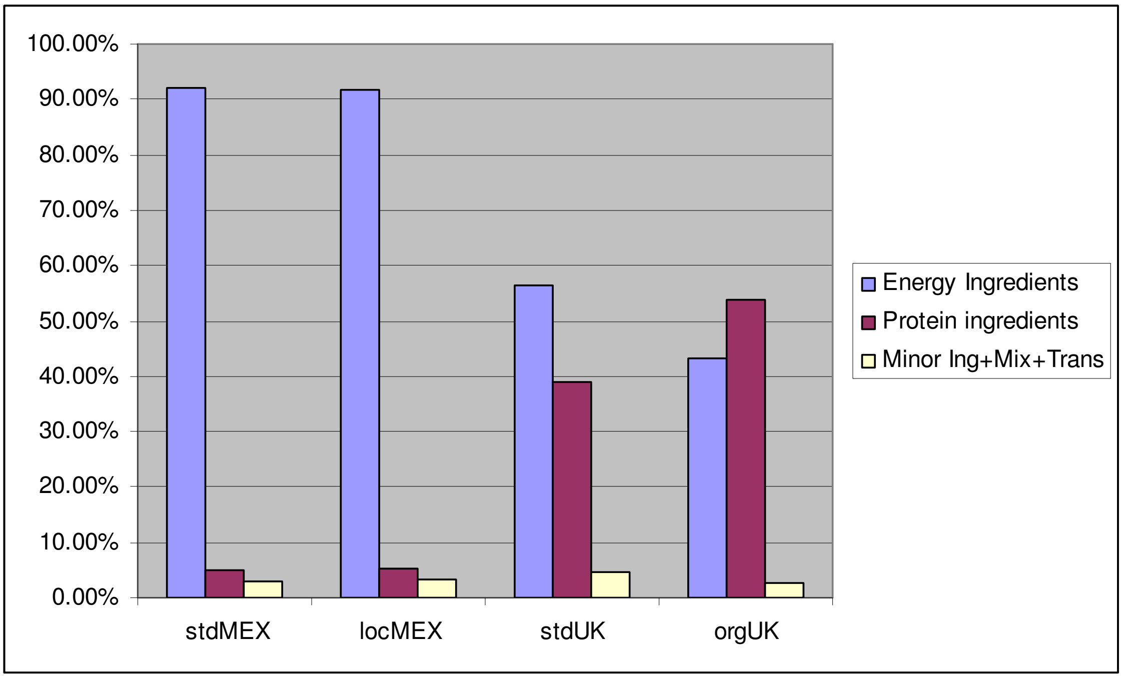

Figure 5.12 Contribution of diet ingredients to total feed AP (%)

Eutrophication Potential

Energy and protein ingredients accounted for nearly 99.5% of EP impact in all scenarios (Figure 5.13). The highest EP value was for the orgUK scenario and the lowest for the stdUK scenario (Table 5.42). The Mexican scenarios had between 16 and 25 % higher EP impact than the stdUK scenario. As for GWP, differences between the non-organic scenarios arise from the inclusion of monoculture crops or diverse crop inclusion (Table 5.40 and Table 5.21). In contrast to GWP, the stdUK scenario had a lower EP impact than the Mexican scenarios. This was not true for the orgUK scenario that had the highest EP impact. Table 5.40 and Table 5.41 show higher values for inclusion of organic crops than from conventional crops.

Table 5.40 EP of energy ingredients demanded for tlw (gNO_3eq)

Ingredient	stdMEX	locMEX	stdUK	orgUK
Grain maize	100,429	109,176	0	0
Soy oil	450	478	0	0
Wheat	0	0	46,724	62,702
Barley	0	0	11,789	66,873
Wheatfeed	0	0	2,403	12,411
Rape seed oil	0	0	944	0
Soy oil	0	0	133	0
Total	100,878	109,654	61,994	141,986

Table 5.41 EP of protein ingredients demanded for tlw (gNO_3eq)

Ingredient	stdMEX	locMEX	stdUK	orgUK
Soy meal	13,403	14,443	21,988	27,353
Field beans	0	0	7,628	28,411
Soy beans	0	0	0	8,193
Rape meal	0	0	6,901	0
Fishmeal	0	0	418	565
Total	13,403	14,443	36,934	64,522

Table 5.42 EP for feed and crop production ($gNO_3eq\ tlw^{-1}$)

Categories	stdMEX	locMEX	stdUK	orgUK
Energy ingredients	100,874	109,654	61,985	141,967
Protein ingredients	13,394	14,443	36,928	64,522
Inorganic ingredients	10	11	12	11
Organic ingredients	70	76	97	32
Milling & mixing	104	113	104	113
Feed-transportation	184	277	184	184
Total	114,637	124,573	99,310	206,829

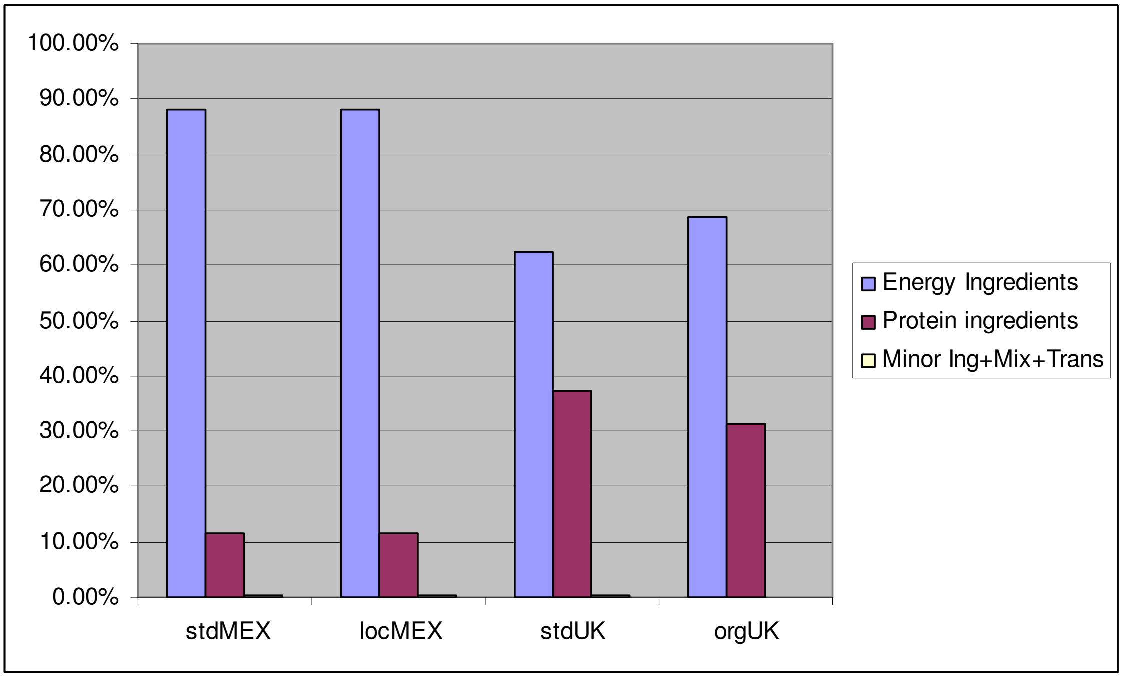

Figure 5.13 Contribution of diet ingredients to total feed EP (%)

5.6 *Conclusions*

Feed production and MM gave rise to large environmental burdens in all scenarios. Differences between scenarios resulted from effects of dietary ingredient formulations, efficiency of feed use, climate and MM systems. The results from these calculations were carried forward to the whole scenario assessments discussed in Chapter 7.

Chapter 6 Industrial commodities

Introduction

The e-burdens associated with feed consumption, which is the main commodity demanded by pig production, were split off from other expenses in the pig farm. Feed e-burdens were accounted through the process-LCA described in Chapter 5. The remaining commodities used to produce pigs belong to a very diverse group of goods and services. Most of these commodities are linked to large groups of sectors that use various processes. These were classified as Industrial Commodities (Ind-Comm) in the current study. Modelling detailed processes for all Ind-Comm involves an impractical amount of work in the scope of this study, since the main aim is to focus on pig production and the Ind-Comm network of production is out with the system boundary. Nevertheless, it is important to account for e-burdens arising from production and consumption of Ind-Comm. Thus a pre-assessment of the PPC was carried out, highlighting the main commodities and their supply chains that account for the LCA of the PPC (see Section 4.2). This chapter explores the contribution of the Ind-Comms to the e-burdens from pig production. Since some data needed more detailed disaggregation, this was carried out as described in Appendix 7. Sections and tables in the Appendices are referred to by adding an "A" before the section number; additionally, table numbers are given in roman style, e.g. Table A7-IV.

6.1 *Methods*

Since the Ind-Comm are used to give services to pig production, their e-burdens are proportional to the farm Ind-Comm consumption, which can be based either on the amount of goods and services, or on their monetary value. Since the effort involved in developing detailed processes for each minor commodity is not worthwhile, as discussed previously (Section 2.5.2) the Ind-Comms' e-burdens were tracked through their monetary value. In this context, the EIO-LCA model offered great advantages (discussed in the literature review, Section 2.6.3). Using the EIO-LCA model requires the matching of specific monetary consumption of commodities to specific economic sectors. This requirement was fulfilled using the list of commodities highlighted in the pre-assessment (pre-LCA) and combining these with specific financial categories in the pig farm budgets developed for each scenario. Finally the e-burdens produced by the industrial processes in the Ind-Comms' supply chain were tracked with the EIO-LCA model. ***Figure*** 6.1 illustrates these procedures and provides the details of every step followed.

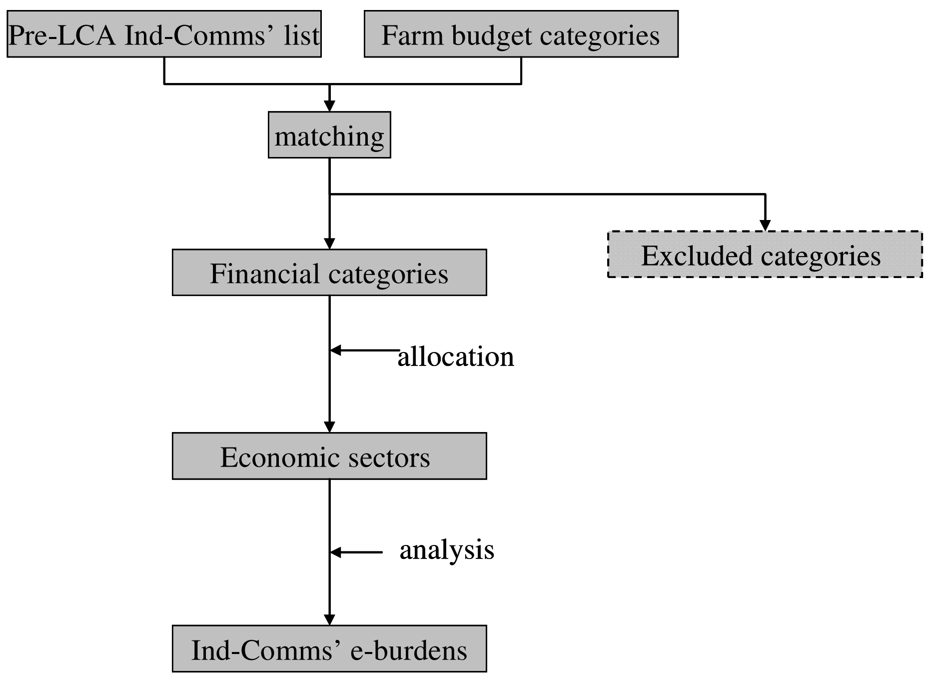

Figure 6.1 Methods used to obtain the Ind-Comms' e-burdens

6.1.1 Pre-LCA commodity list

Figure 6.2 shows the main commodities and their supply chains highlighted in the pre-assessment. The supply chains of these commodities are the main contributors to indirect pig farm e-burdens. Feed and manure disposal were modelled and analysed in the nutrient mass balance section (Chapter 5), so they were excluded from the list analysed in this chapter. The other commodities in Figure 6.2 consumed directly by the pig farm were used to characterise the Ind-Comm that produce the main indirect e-burden load to pig production.

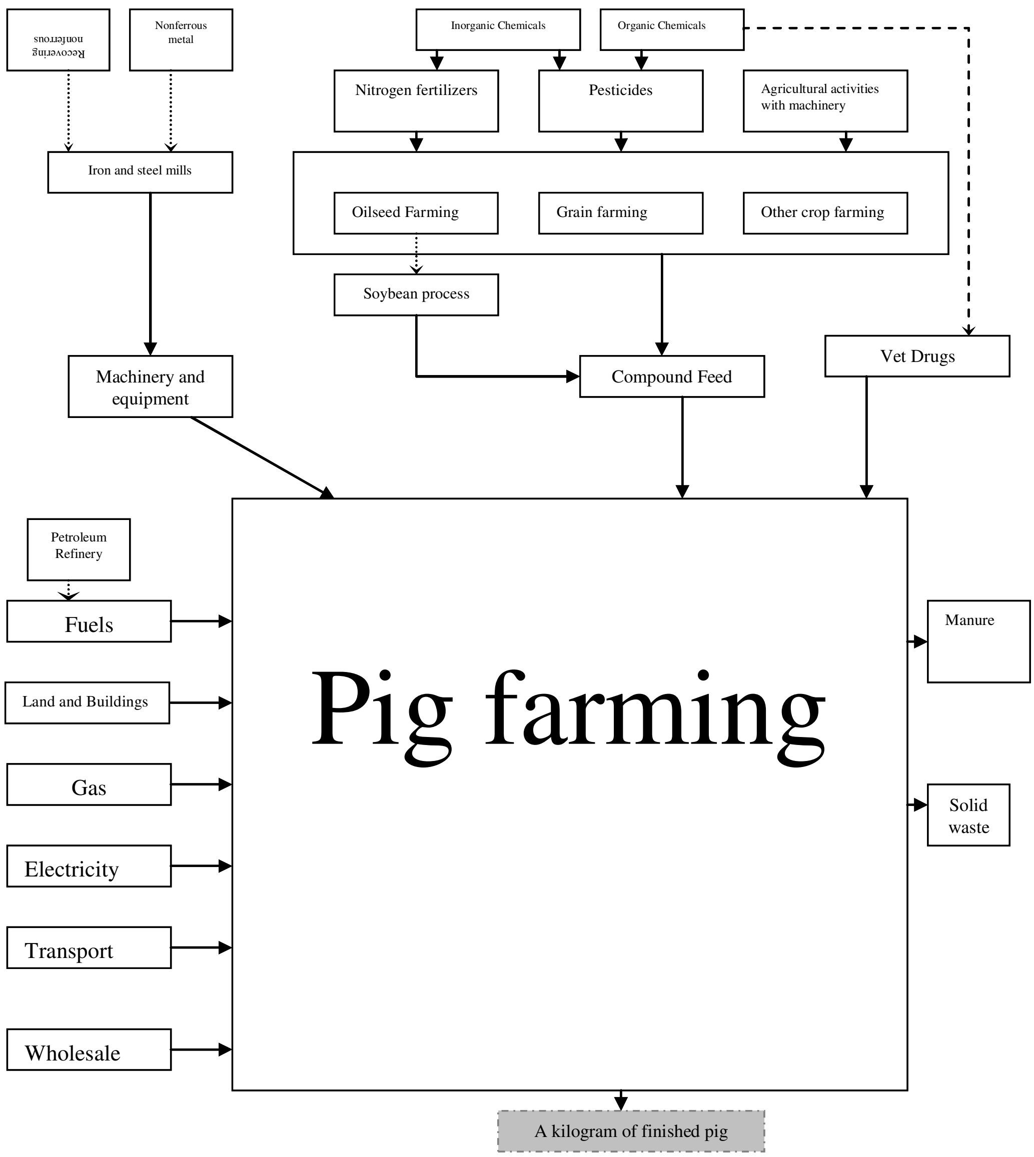

Figure 6.2 Ind-Comms' supply chain tracked in the pre-LCA (Section 4.2)

6.1.2 Financial budget

The financial categories detailed in the financial farm budget can be matched with the categories of the pre-LCA list. Thus specific farm financial budgets were modelled using information from appropriate farm financial activities, existing budgets and published economic information. Since the size of the businesses that provided data varied considerably, a common-size comparison methodology was used to make the inter-scenarios comparison more valid (Warren, 1997, p30). Thus, all factors in the farm budget were related to a specific factor, the sale revenue or turnover, which was the product of the amount of sales for one tonne of pig at the farm gate (tlw), during a specific period and sale price. The accounts were therefore calculated to show costs and profit as a percentage of sales revenue. Whenever possible, general cost categories were disaggregated using secondary sources to fulfil the pre-assessment requirements. Data from secondary sources were also expressed as a percentage of the pigmeat value. Thus, aggregated commodities combined under general purchases in the financial budget were split out into more specific goods and services. When more complex calculations were needed, specific equations were defined. In this way, the final demand for different commodities was expressed as a percentage of the pig sale price tlw^{-1}, using the sale price of a kglw as the reference for calculations and necessary transformations in the eiolca.com model (see Section 6.2.5).

Data sources

The Mexican scenarios: Data for the financial performance of the Mexican scenarios come from different sources. Detailed reports of purchases and sales were not found in published literature, neither were they available from the pig specialists gathered in the expert panel. Published financial assessments in the most representative pig production regions were too aggregated to provide the information directly, but were used to characterize the main categories of financial performance of farms suitable for the locMEX and stdMEX scenarios (Nava *et al.*, 2009; Gallardo *et al.*, 2006; Magana-Magana *et al.*, 2002). These sources were used to validate disaggregated financial performance data from a specific farm used for the locMEX scenario and detailed in Appendix 7.

The locMEX scenario: The financial performance of a well organised pig farm in Jalisco was used to characterise the locMEX scenario (further details given in Section A7.1.1). The benchmark included purchases for the operation of a farm with 305-sows and their progeny kept until market weight. The farm identity is not provided to maintain the confidentiality. The financial report included detailed monthly worksheets of sales, commodities consumed, commodity costs and changes in herd inventories. Data were well detailed and most categories were allocated for the pig production business. The annual financial performance was obtained from the monthly reports of 2008, obtaining the input cost of all commodities used to produce a tlw.

The stdMEX scenario: There was no detailed budget available in the accessed publications to model the stdMEX scenario. Gallardo *et al.* (2006) supplied the most disaggregated budget for farms suitable for the stdMEX scenario (Table A7-II). However data were not adequate to fulfil the pre-assessment requirements. This scenario was then modelled with the most suitable data available (see details in Section 6.2.2 and A7.1.2 in Appendix 7).

The stdUK scenario. Data for the financial performance of the stdUK scenario came mainly from three different sources of data. Defra (2007) supplied the main categories for the financial performance of the stdUK scenario. The other two sources, BPEX (2006) and Fowler (2006), were used to validate the data and disaggregate some categories (details in Section A7.2.1). The main data for the stdUK scenario come from the Specialist Pig Farm survey in England (Defra, 2007). This is the result of a survey on the financial performance of pig enterprises. Data come from a sample of farms that was weighted to represent all farms with a Standard Labour Requirement greater than 0.5 in England on their 2004/05 and 2005/06 accounts. On average, the accounting year ends in February (Defra, 2007), thus information for 2005/06 was used to model the stdUK financial behaviour. From this financial report, it was necessary to split the input costs that were shared between pig production and other farm activities. The main agricultural output was finished pigs, but there were also outputs from crop production, other animal production and diverse agri-environmental activities during the farm operation. Pig production was split out from the other activities by allocating the shared input costs between different activities based on their outputs. Some commodities and services of interest to the LCA were aggregated in this dataset under the concept of 'other livestock costs'. Specific calculations were carried out to disaggregate this category and match the categories to the pre-assessment requirements. The annual average price of pigs at the farm gate was used to allocate the input costs in relation to the functional unit of a tlw.

The orgUK scenario: In this scenario the financial budget for organic pig farms was obtained from Martins *et al*. (2002). Data come from a survey of established organic herds during 2001/2002 in the UK and were considered representative to obtain the expenses used to produce organic finished pigs under the orgUK scenario. The expenses and output were again used to produce the financial budget of a tlw.

6.1.3 Allocation of financial categories by economic sector

With the procedures stated in the previous section, the Ind-Comm consumption data were standardised to represent similar categories. After the financial data were obtained and standardised under same set of categories, they were assigned to one of the 490 economic sectors in the EIO-LCA model developed for the Carnegie Mellon University (Green Design Institute, 2006), referred to subsequently as the "eiolca.com model". Internal factors of production such as labour and capital management (bank charges, interest and profit) included in the farm budget were not highlighted as important e-burden contributors in the pre-assessment, so they were also excluded from this assessment. Table 6.1 shows the economic sectors used to develop the next step.

Table 6.1 The scenarios' commodities and their respective economic sectors for the eiolca.net software

Scenarios budget	eiolca.net sectors
Medicines	Pharmaceutical and medicine manufacturing
Transport	Truck transportation
Electricity & Gas	Power generation and supply
Water	Water, sewage and other systems
Straw & bedding	Grain Farming
Marketing	Wholesale trade
General farm overheads & sundries	Soap and other detergent manufacturing
Repairs and maintenance of machinery & equipment (M&E maintenance)	Automotive repair and maintenance, except car wash
Fuel	Petroleum refineries
Depreciation of M&E	Farm machinery and equipment manufacturing
Repairs and maintenance of buildings (Building maintenance)	Maintenance and repair of farm and no farm residential structures
Rental or depreciation charges of Buildings (Building depreciation)	New farm housing units and additions and alterations

6.1.4 The eiolca.net software

The eiolca.net was developed for economic sectors in the US (Weber and Matthews, 2007). The eiolca.net is made up of matrix tables that link commodities demand to their e-burdens arising from the commodity supply chain. This software uses input-output tables gathering the economic sectors of the US in 491 sectors. This includes 491 × 491 benchmark input-output matrix tables that are linked to similar tables for their e-burdens. Thus the demand of production in one sector can track the e-burdens produced by its supply chain, as was done in the pre-assessment (Section 4.1.4). This EIO-LCA model for the US is the most disaggregated version, since others models gathered all economic activities in less than 70 sectors (Suh and Nakamura, 2007), increasing aggregation error (Weber and Matthews, 2007). The eiolca.net was based on United States data, data were originally taken from U.S. governmental sources (Hendrickson *et al.*, 2006). Thus Ind-Comm demanded by all scenarios were assumed to be produced in similar conditions to those for the US. The environmental emissions were modelled as for the United States for data availability reasons and because the U.S. represents the most diverse economy in the data set. This decision is, of course, debatable and is associated with some uncertainty. However, this assumption allows expansion of the system boundary of the LCA that is the best method to allocate e-burdens (ISO, 1997 104). Additionally, the Ind-Comm are not the main inputs for pig production. Differences between scenarios are expected to be linked more to differences in commodity demand than in commodity production methods, so the uncertainty in commodity production can be reduced. Therefore, in analysing the environmental impact of Ind-Comm, the main emphasis was put on pig farm consumption, which was assessed through specific farm budgets explained in Section 6.1.2

6.1.5 Tracking Ind-Comms' e-burdens

The monetary demand specified in the farm budget was used to track the Ind-Comms' e-burdens in the eiolca.com model. Commodities demand in the eiolca.com model should be expressed in American Dollars (US$) in 1997. The specific currency values from farm budgets were therefore transformed to US$ in 1997. Mexican pesos and British pounds in the scenarios were transformed to US$ in 1997 using the Consumer Price Index for Mexico and the UK (SAT, 2009; National Statistics, 2008, respectively) and the historic exchange rates from Mexican pesos and British pounds (Tiago Stock Consulting, 2009). The specific amounts of demanded items and services were then calculated for each economic sector and each scenario. Specific calculations and values are detailed in the following sections.

6.2 *Modelling the farm budgets*

6.2.1 The locMEX scenario

The financial performance of a well organised pig farm in Jalisco was used to model the locMEX scenario (see detailed review for Mexican scenarios in Section A7.1 and methods Section 6.1.2). Monthly financial reports were used to obtain the annual financial performance of the farm. The average pigmeat price per kglw was weighted according to the proportion of finished pigs and cull stock sold monthly. The percentage contribution of different cost categories was calculated relative to the average pigmeat price. Table 6.2 shows these contributions. Additional data disaggregation was undertaken by the business accountant because the financial report had aggregated some categories. For example, machinery running cost included both repairs and maintenance cost and running cost (consumption of fuel). The accountant divided the machinery running cost on a 50:50 basis because she considered that, in the annual balance, the business spent similar amounts on both repairs and fuel. Since the business has other commercial activities, the accountant assigned 16% of business depreciation cost to the pig farm. From this percentage she estimated that 10% should be for equipment and 90% for buildings. The land rent was calculated for the surface area assigned to pig farm facilities plus 10 % of common areas of the farm. The rental charges were assigned the average rate for agricultural land in the region. Interest charges were calculated on CETES 28 days from the Mexican Bank (Certificados de la Tesoreria de la Federacion a 28 dias del Banco de Mexico) which is the alternative capital investment.

Table 6.2 Percentage cost distribution between different categories in the financial performance of the locMEX scenario (data expressed as percentage of the pig sale price)

Category	%
Feed	62.06
Replacement cost	2.14
Vet & Medicine	3.38
Transportation	3.03
Electricity & Gas	2.23
Water	0.40
Straw & bedding	0.00
Marketing	0.24
Miscellaneous	0.35
Labour	7.28
Machinery & Equipment	
-Repairs, maintenance and running cost	
-repairs & maintenance	0.05
-running cost	0.05
-Depreciation	0.10
Buildings	
-Repairs & maintenance	0.09
-Rental or depreciation charges	0.88
Land	
-Rental charge	0.48
Bank charges, professional fees and insurance	2.36
General farm overheads & sundries	0.22
Interest charges	2.91
Profit	11.76
Total	100.00

6.2.2 The stdMEX scenario

As discussed in the data source section (Section 6.1.2), there were no available published sources of data which were sufficiently disaggregated to model the stdMEX scenario. In consequence, this budget was modelled with alternative sources of data, as undertaken for pig diets (Section A3.1.1). Firstly, published, but aggregated data were examined and compared against the locMEX scenario, using the latter as an alternative source of data (Section A7.1). This comparison was made in published data, distinguishing farm results suitable for both Mexican scenarios (details given in Section A7.1). The locMEX budget, aggregated in the same way as published data, was in the range of consulted sources

(Table A7-VII). Thus the stdMEX scenario was modelled assuming the locMEX as the main source of data and adjusting this according to any differences found in the literature in data suitable for the stdMEX budget. In this context, since the financial performance data provided by Gallardo *et al*. (2006) showed little variation when compared with the data modeled for the locMEX scenario (Table A7-VIII), the differences between scenarios in the Gallardo data (Table A7-II) were used to model the financial performance of the stdMEX scenario. These differences were derived from the locMEX data aggregated as by Gallardo (Table 6.3). Therefore, a reduction of the locMEX values by 14.5 and 3.8 percentage points was used to model the stdMEX values for feed and labour respectively. At the same time, the stdMEX scenario was given increased weighting for financial cost, other cost, medicines, and profit by 7.2, 2.2, 5.1 and 3.7 percentage points, respectively (Table 6.3).

Table 6.3 Modelling the distribution of main cost categories in the stdMEX budget (data expressed as percentage of pig sale price)

Category	locMEX	Differences[1]	stdMEX
Feed cost	62.06	-14.5	47.61
Financial cost	6.72	7.2	13.94
Other cost such as electricity, fuels, sundries, transport, fees, machinery and buildings maintenance, miscellaneous	8.80	2.2	10.97
Medicines	3.38	5.1	8.49
Labour	7.28	-3.8	3.51
Profit	11.67	3.7	15.39

[1] Differences between farms suitable for the locMEX and the stdMEX scenario in Gallardo *et al*. (2006)

The proportion of commodity values within aggregated data in the locMEX scenario was assumed to be similar to the aggregated data for the stdMEX scenario. Thus modelled aggregated values for the stdMEX scenario stated in Table 6.3 were disaggregated in the same way as those for the locMEX scenario (Table 6.4). Equation 20 in Appendix 5 was used for calculations and Table A7-IX shows individual procedures.

Table 6.4 Distribution of cost categories in the budget for the stdMEX scenario (data expressed as percentage of the pig sale price)

Category	%
Feed	47.61
Replacement cost	2.67
Vet & Medicine	8.49
Transportation	3.78
Electricity & Gas	2.78
Water	0.5
Straw & bedding	0
Marketing	0.29
Miscellaneous	0.44
Labour	3.51
Machinery & Equipment	
-Repairs, maintenance and running cost	
-repairs & maintenance	0.06
-running cost	0.06
-Depreciation	0.2
Buildings	
-Repairs & maintenance	0.11
-Rental or depreciation charges	1.82
Land	
-Rental charge	0.99
Bank charges, professional fees and insurance	4.9
General farm overheads & sundries	0.28
Interest charges	6.03
Profit	15.48
Total	100.00

6.2.3 The stdUK scenario

The main source of financial assessments accessed to characterize pig production for the stdUK scenario was the Specialist Pig Farm survey (Defra, 2007). These data were compared to other sources and validated (detailed in Section A7.2.1). Pig production activities and inputs and outputs were disaggregated from crop activities and other farm activities as discussed in the data sources section (Section 6.1.2), with detailed calculations are shown in Appendix 7 (Section A7.2.1). Table 6.5 shows the main categories for the financial performance of pig production in the stdUK scenario.

Table 6.5 Distribution of cost categories for the stdUK scenario adapted from Defra (2007) (as a percentage of pig sale price)

Category	%
Variable costs:	
Replacement cost	1.53
Feed	46.98
Veterinary fees & medicines	3.32
Other livestock costs	7.54
Fixed costs:	
Labour	11.32
Machinery cost	
-Machinery running cost	3.77
-Machinery depreciation	3.5
Bank charges & professional fees	0.99
Water, electricity and other general costs	4.41
Share of net interest payments	2.51
Land and property costs	
-Rent paid	3.26
-Maintenance, repairs and insurance	0.25
-Depreciation of buildings	3.22
Profit	7.61
Total	100.0

Whilst most commodities were disaggregated, other categories grouped several commodities. Alternative data sources were used to disaggregate the grouped categories in Table 6.5. Appendix 7 (Section7.2.1) shows the details for specific calculations for disaggregating the cost categories of other livestock costs, water, electricity and gas cost and machinery running cost. Table 6.6 shows the final data used to model the stdUK scenario.

Table 6.6 Financial budget for the stdUK scenario (data expressed as percentage of pig sale price)

Category	%
Variable costs:	
Replacement cost	1.53
Feed	46.98
Veterinary fees & medicines	3.32
Transportation	2.17
Marketing	2.80
Straw and bedding	0.79
Daily sundries	1.66
Fixed costs:	
Labour	11.32
Machinery cost	
-Fuels	1.86
-Repairs	1.86
-Machinery depreciation	3.50
Bank charges & professional fees	0.99
Water	1.19
Electricity and gas	3.15
Share of net interest payments	2.51
Land and property costs	
-Rent paid	3.26
-Maintenance, repairs and insurance	0.25
-Depreciation of buildings	3.22
Profit	7.61
Total	100.0

6.2.4 The orgUK scenario

Data for the orgUK scenario came from a budget for a 100-sow herd under organic conditions selling pigs at finished weight (Martins *et al.*, 2002). They calculated variable costs per sow and fixed cost per herd, but both sections were then allocated on a per herd basis (Table 6.7) as in the stdUK scenario. The monetary costs of commodities demanded for the pig farm were transformed to a percentage of farm income (Table 6.7).

Table 6.7 Financial budget for the orgUK scenario, adapted from Martins *et al.* (2002)

Category	£	%
Variable costs:		
Replacement cost	7,950	3.33
Feed	130,150	54.56
Vet & Medicines	2,500	1.05
Transportation	3,500	1.47
Electricity and gas	0	0.00
Water	1,000	0.42
Straw & bedding	5,300	2.22
Marketing	1,800	0.75
Miscellaneous	700	0.29
Fixed costs:		
Labour	25,500	10.69
Machinery & equipment		
-Repairs, maintenance & running cost	4,500	1.89
-Depreciation	15,200	6.37
Building		
Repairs and maintenance	500	0.21
-Rental charge	2,600	1.09
Land		
Rental charge	6,500	2.72
Insurance	1,000	0.42
General farm overheads & sundries	5,200	2.18
Profit	24,652	10.33
Total		100.0

Only repairs, maintenance and running cost of machinery and equipment cost categories were grouped. These were disaggregated in a 50:50 proportion, using the same criteria as that for the other three scenarios (see budget for the locMEX scenario in Section 6.2.1 and disaggregation of grouped cost for the stdUK in Appendix 7, Section A7.2.1). Interest charges were not accounted for in the original budget, because Martins *et al*. (2002) assumed that the herd was kept on rented land (not borrowed money for fixed cost). However, considering that the investment has an opportunity cost, capital tied up in the enterprise was charged with 6% of interest (assumed for Martins *et al*., 2002) and split out from the profit. Table 6.8 shows the final budget for the orgUK scenario. Under the category of general farm overheads & sundries, different sub-categories were included since detergents and disinfectants are not significant requirements for outdoor accommodation. Hand tools substituted detergents and disinfectants in the organic budget.

Table 6.8 Modelled budget for the orgUK scenario (data expressed as percentage of pig sale price)

Category	%
Variable cost	
Replacement cost	3.33
Feed	54.56
Vet & Medicines	1.05
Transportation	1.47
electricity & gas	0.00
Water	0.42
Straw & bedding	2.22
Marketing	0.75
Miscellaneous	0.29
Fixed cost	
Labour	10.69
Machinery & equipment	0.00
-Repairs & maintenance	0.94
Fuels	0.94
-Depreciation	6.37
Building	0.00
Repairs and maintenance	0.21
-Rental charge	1.09
Land	0.00
Rental charge	2.72
Insurance	0.42
General farm overheads & sundries	2.18
Opportunity cost (shared interest)	3.35
Net farm income	6.98
Total	100.0

6.2.5 Matching budgets for e-burdens calculation

The scenarios budgets were modelled as percentage of the pig sale price, so this was used to calculate the commodity demand of Ind-Comm tlw^{-1} for each scenario. Firstly, a pig sale price for each scenario was obtained. The farm benchmark detailed in the financial budget section (Section 6.1.2) provided the locMEX pig sale price. Gallardo *et al*. (2006)

provided this for the stdMEX scenario, and for the stdUK and orgUK scenarios the Pig Year Book 2006 (BPEX, 2006) and Martins *et al*. (2002) respectively provided suitable values. When the sale price was for carcase value (dw), the farm gate weight and killing out percentage was used to calculate the pig sale price per tlw. The pig sale prices were year specific, so these were transformed as described in the pig farm demand and industrial suppliers method section (Section 6.1.2). Table 6.9 summarises these calculations.

Table 6.9 Pig sale price calculations

Scenarios	stdMEX	locMEX	stdUK	orgUK
Year of data source	2005	2008	2005	2002
Currency, Mexican pesos (M$) or pounds (UK£)	M$	M$	UK£	UK£
Price per kg lwt	15.38	18.73	0.81	1.52
CPI year origin	114.07	129.20	757.30	695.10
CPI in 1997	60.62	60.62	621.30	621.30
Prices in 1997	8.17	8.79	0.66	1.36
Change rate to US$ in 1997	0.13	0.13	1.63	1.63
Price per Kg lwt (US$ in 1997)	1.03	1.11	1.08	2.22

6.2.6 Summary of scenario budgets

Budgets for the four scenarios were calculated to produce a tlw, in US$ in 1997. The Ind-Comm given in Table 6.1 accounted for between 18.1% and 35.4% of total output value (Table 6.10). Table 6.11 shows the four scenarios budgets used to track the Ind-Comm e-burdens.

Table 6.10 Distribution of total output value (data expressed as percentage of pig sale price)

Scenarios	stdMEX	locMEX	stdUK	orgUK
Commodities not included	62.5	70.2	56.9	66.6
Ind-Comm	22.0	18.1	35.4	26.5
Added value	15.5	11.8	7.6	7.0

Table 6.11 Final budgets used to track the e-burdens of the Ind-Comms (different of feed) of a tlw (US$ in 1997)

Scenarios	stdMEX	locMEX	stdUK	orgUK
Income for tlw	1033.9	1111.7	1081.4	2218.6
Feed	492.2	689.9	508.1	1210.4
Breeding cost	27.6	23.8	16.5	73.9
Medicine	87.8	37.6	35.9	23.3
Transport	39.0	33.7	23.5	32.6
Electricity & Gas	28.7	24.8	34.0	0.0
Water	5.2	4.5	12.9	9.3
Straw & bedding	0.0	0.0	8.6	49.3
Marketing	3.0	2.6	30.3	16.7
Miscellaneous	4.5	3.9	0.0	6.5
Labour	36.3	81.0	122.4	237.2
M&E[1] maintenance	0.6	0.5	20.1	20.9
Fuels	0.6	0.5	20.1	20.9
M&E[1] manufacturing	2.1	1.1	37.8	141.4
Buildings maintenance	1.1	1.0	2.8	4.7
Building construction	18.8	9.7	34.8	24.2
Overheads & sundries	2.9	2.5	17.9	48.4
Rental and land charge	10.2	5.3	35.2	60.5
Bank charges & insurance,	50.7	26.3	10.7	9.3
Interest charges	62.3	32.3	27.2	74.4
Profit	160.1	130.8	82.3	154.9

1) Machinery and Equipment

The orgUK scenario was not charged with electricity and gas cost, since this scenario uses no heating or ventilations systems. Similarly, straw or other material for bedding was not supplied in the Mexican systems, because they are not provided in this scenario. Other differences between scenarios are linked to specific conditions of pig production. These differences are difficult to explain only with the financial assessment, but the assessment of specific technical conditions is out of the system boundary of this study.

Differences in demand

Differences in commodities demand between scenarios are shown in Figure 6.3. Medicine, transport and electricity and gas were the main commodities demanded for the scenarios, apart from the orgUK scenario where electricity and gas were not included. The orgUK budget has some differences in demand and shows higher demand for straw, machinery and equipment (M&E), overheads and sundries. Straw is a common raw material for bedding in outdoor systems and higher demand than in intensive scenarios is expected. However, higher M&E, overheads and sundries consumption for outdoor and organic activities is more difficult to explain. Their differences may be more linked to the financial allocation of these commodities, but the financial data used to model this budget did not permit more detailed category disaggregation. Since the M&E running cost for the orgUK scenario is similar to that in the stdUK scenarios, is suggests that M&E which consume fuel was similar. The arcs, which are the outdoor accommodation, are normally depreciated as M&E. Since their actual length of use can be longer than budgetary assumptions, the depreciation cost is overrated. Additionally, the budget (Martins *et al.*, 2002) used to model the orgUK scenario was based on new M&E cost which is an unusual situation in the Specialist Pig Farm Survey (Defra, 2007) used for its alternative scenario (the std UK scenario). Cost of overheads and sundries includes miscellaneous products such as cleaning products. These products are more frequently used under intensive conditions for cleaning and disinfecting pig buildings but not for outdoor pig farms. Thus additional small equipment such as hand tools may be included under this category in the orgUK scenario. However, there were no further data that allowed disaggregation of these costs.

Further differences were seen between the UK and Mexican scenarios. The UK scenarios had higher marketing, machinery and equipment, building construction and maintenance costs than Mexican scenarios. Lower cost in the Mexican scenarios occurs because Mexican farmers have cheaper labour and more uncertainties in the pig market. These factors discourage pig farmers from investing in new equipment and facilities (Perez, 2006), extending the useful life of assets and reducing amortisation costs. Thus mechanisation of farm activities looks to be the difference between countries for Ind-Comm consumption.

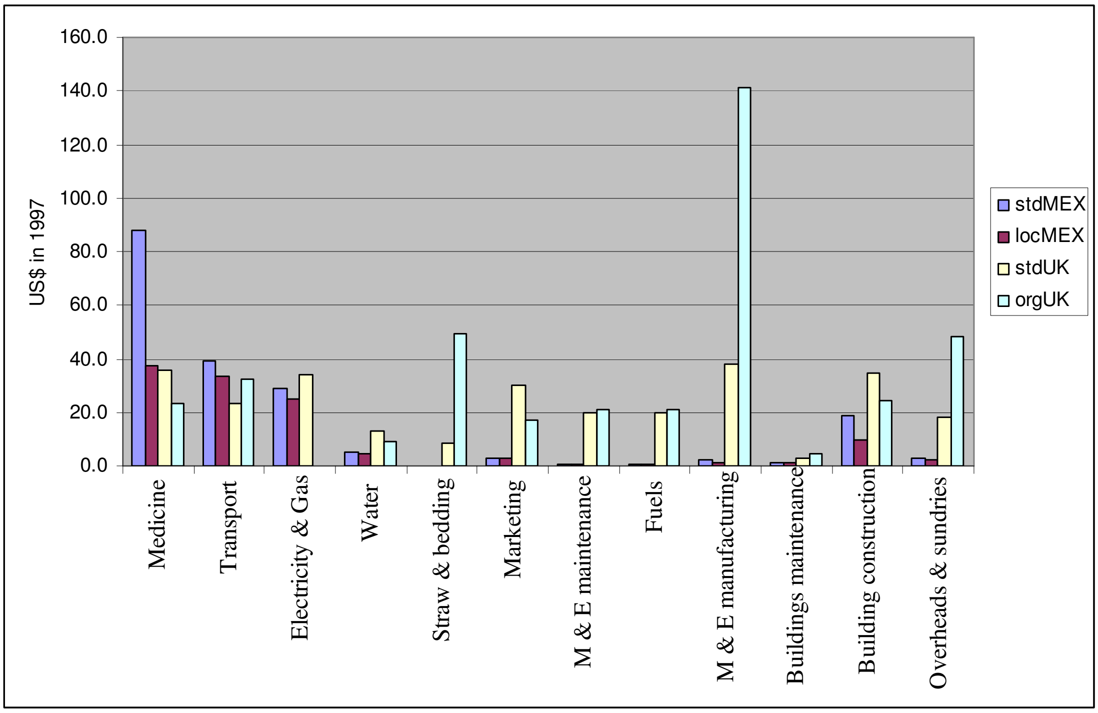

Figure 6.3 Ind-Comms' monetary demand, transformed to US$ in 1997

6.3 *Results*

Air pollutants, GWP, energy use and toxic releases were the e-burdens tracked for the Ind-Comm needed to produce a tonne of pig meat live weight. Chapter 3 (Section 3.2.8) gives the general characteristics of these e-burdens**.** Total e-burdens for the Ind-Comm in the four scenarios are displayed in Figure 6.4 and Figure 6.5. The greatest e-burdens for most of the air pollutants such as CO, VOC, lead and PM10 and toxic releases were for the orgUK scenario. The orgUK scenario only had the lowest value for SO_2 and values similar to intensive scenarios for NOx, CO_2 and energy use. Differences between intensive scenarios were less evident. However, the stdUK scenario values were higher than the Mexican scenarios in most of cases (Figure 6.4 and Figure 6.5). These differences were traced to the origin of the commodities in the following sections.

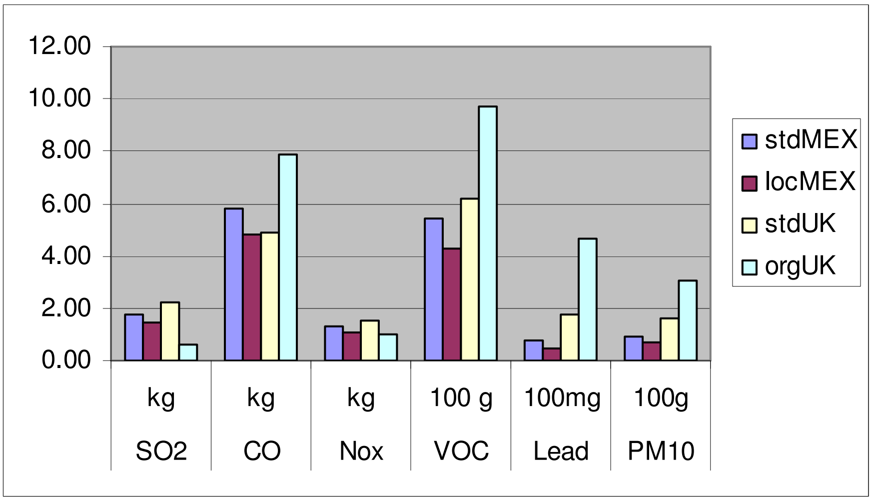

Figure 6.4 Total air pollutants from Ind-Comm

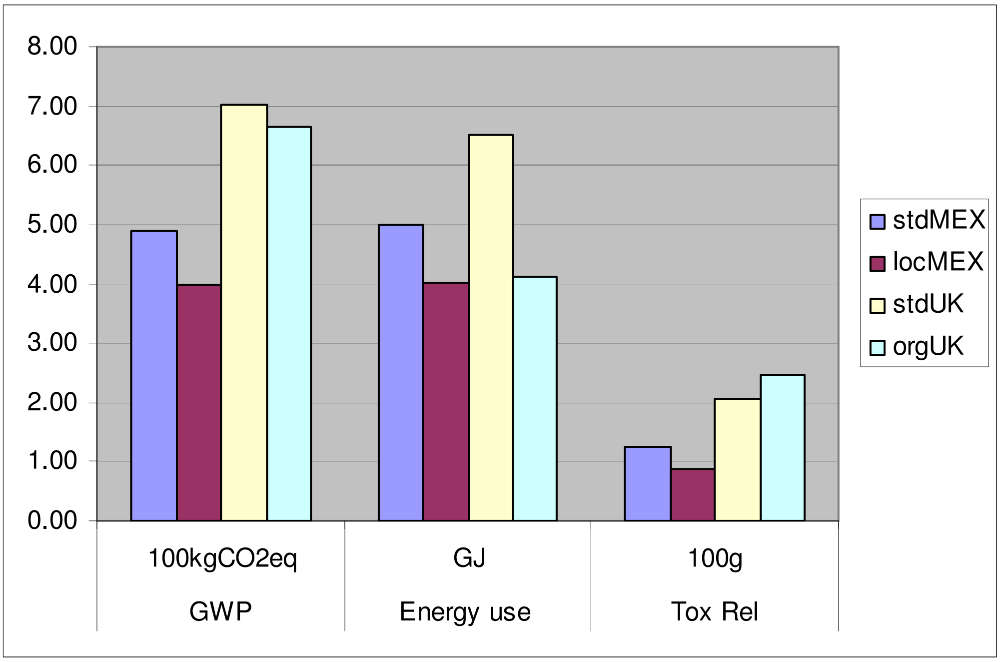

Figure 6.5 Totals of GWP, energy use and toxic releases (Tox Rel) from Ind-Comm

6.3.1 Scenario burdens for different commodities

The scenarios' e-burdens for each Ind-Comm were traced to highlight their impact on the overall scenario e-burdens. Air pollutants, GWP, energy use and toxic releases are shown in Figures 6.5 to 6.13. The main demand of intensive scenarios was for medicine, transport, electricity and gas (Figure 6.3). Transport, electricity and gas were the main commodities responsible for e-burdens arising from the industrial supply chains that provide services to intensive pig farming. Electricity and gas produced the major e-burdens of SO_2, NOx, PM10, GWP, energy use and toxic releases; transport was primarily responsible for CO and VOC, whilst medicine showed similar burdens to those from transport, electricity and gas for lead emissions. Since the orgUK scenario had a similar demand to intensive scenarios for transport and higher demand for straw and M&E manufacturing (Figure 6.3), its main e-burdens were quite different from that of the other scenarios. The orgUK scenario had the highest CO, VOC, lead, PM10 emissions and toxic releases: Straw was the main source of PM10 and GWP; M&E manufacturing was most important for lead and toxic releases; transport for CO and VOC emission, although straw and M&E manufacturing increased the final amount of these emissions (Figure 6.6 and Figure 6.8). Straw was the unique industrial commodity analysed in this section with agricultural origin, since the process-LCA assessment (chapter 5) only included feed materials, but not bedding materials. Grain and seed e-burdens accounted for in the process-LCA were split from those arising from their co-products, such as straw and oil. Primary activities such as sowing for crops or mining for inorganic raw materials produce high PM10 releases, as was stated in the pre assessment (natural resources extraction, Section 4.3.1). Thus, since most of these primary activities are directly linked to the production process of an industrial commodity, this shows higher PM10, such as for straw in the orgUK scenario' budget.

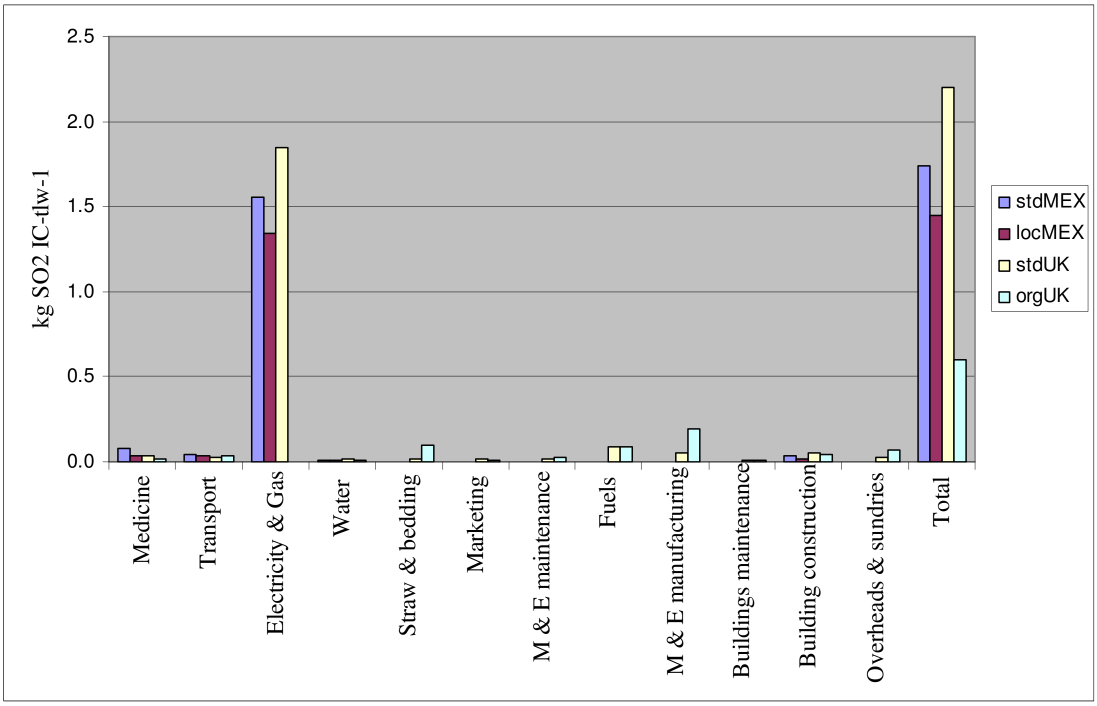

Figure 6.6 Distribution of SO_2 burdens for Ind-Comm

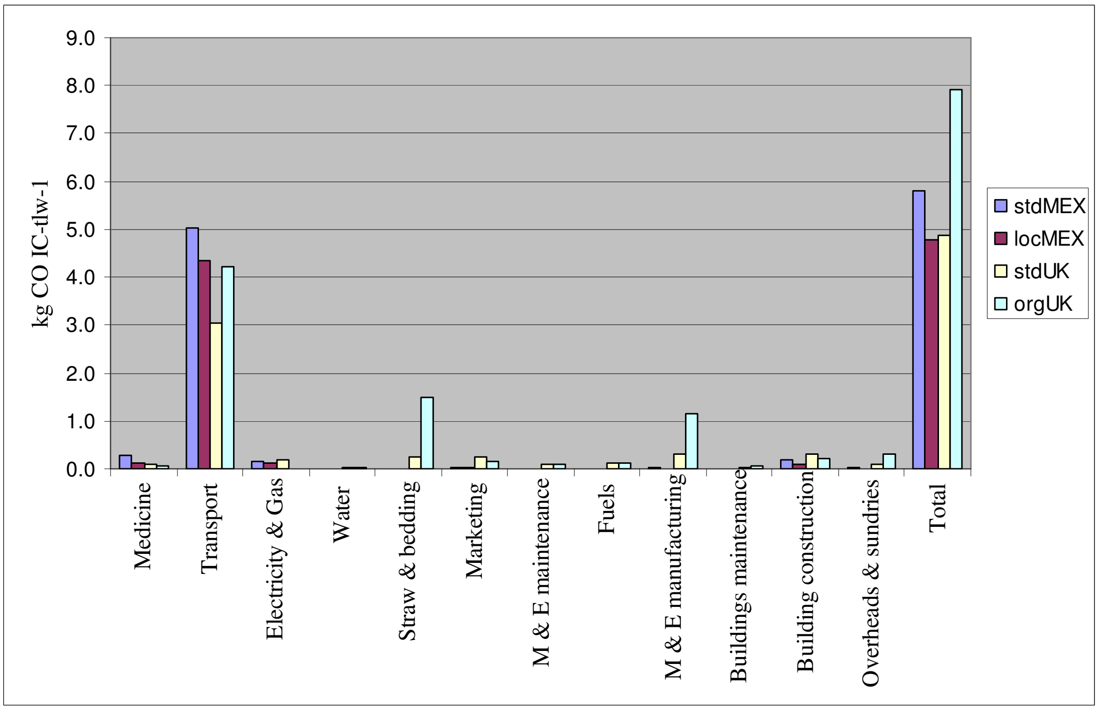

Figure 6.7 Distribution of CO burdens for Ind-Comm

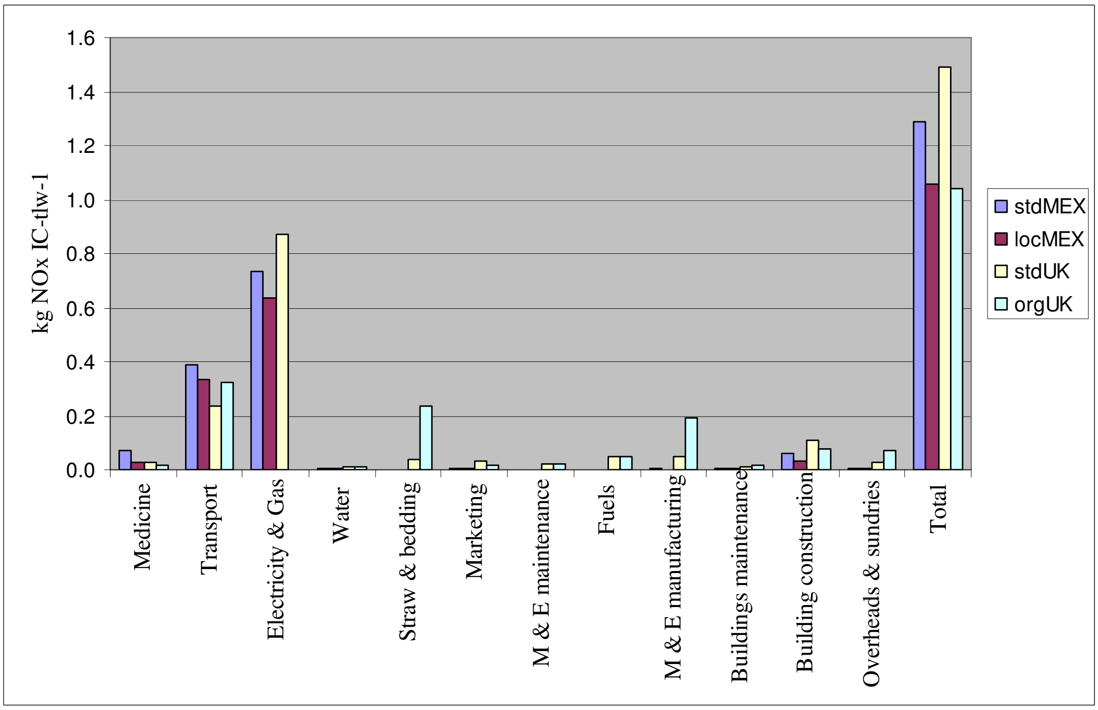

Figure 6.8 Distribution of NOx burdens for Ind-Comm

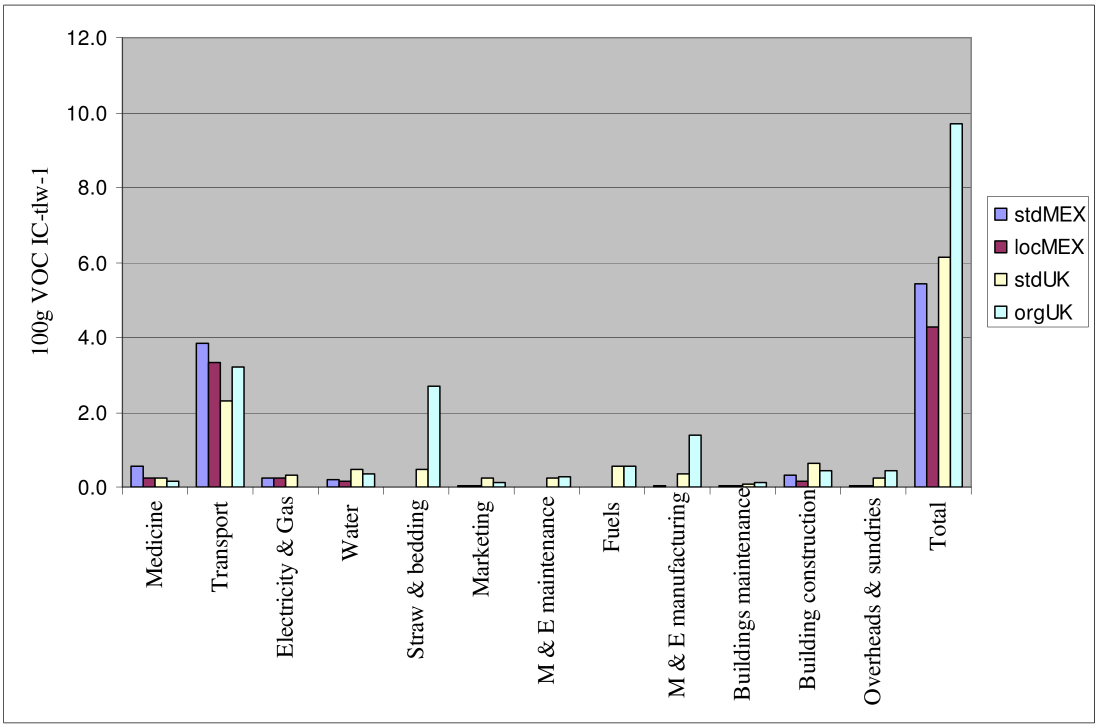

Figure 6.9 Distribution of VOC burdens for Ind-Comm

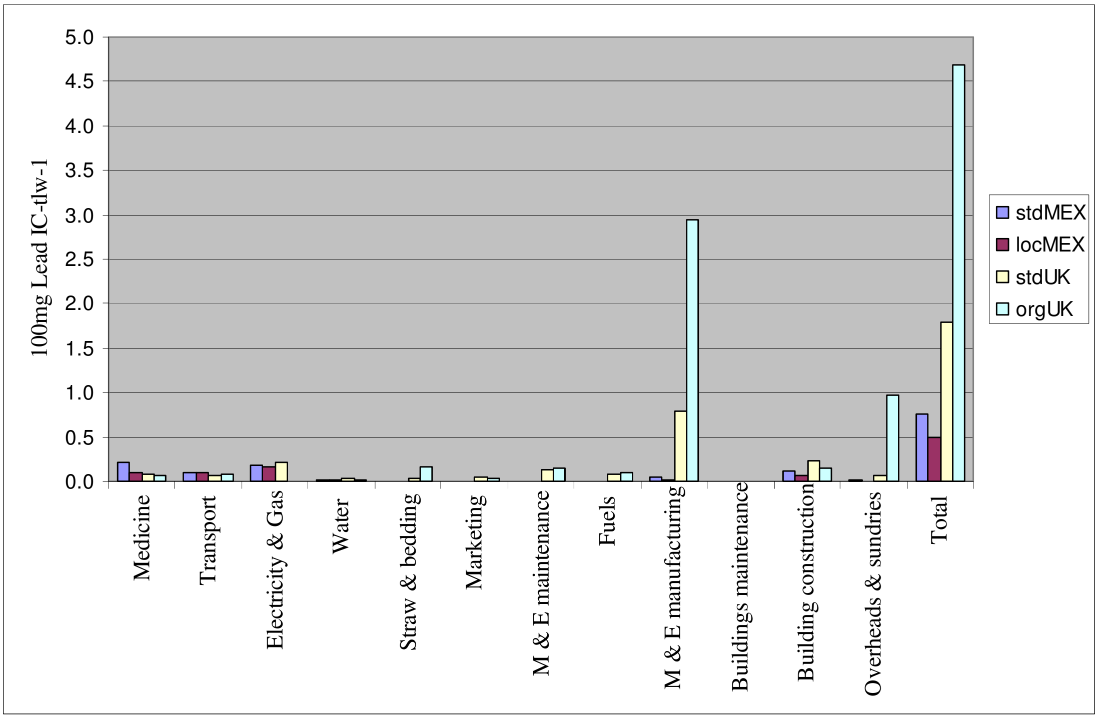

Figure 6.10 Distribution of lead burden for Ind-Comm

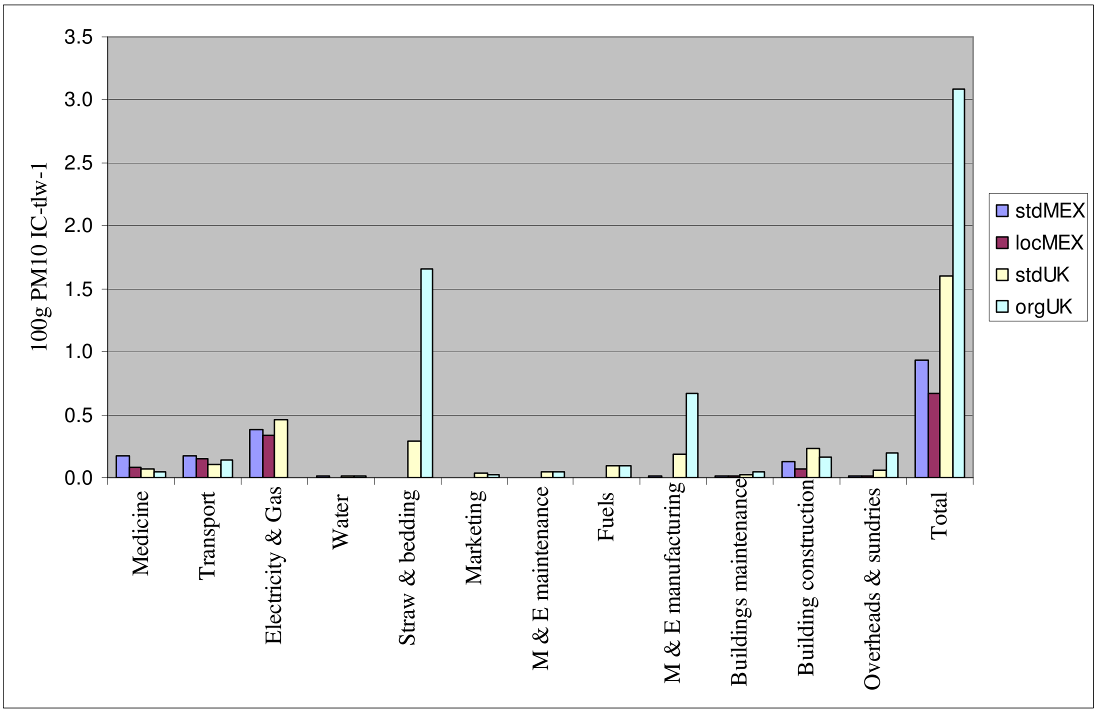

Figure 6.11 Distribution of PM10 burdens for Ind-Comm

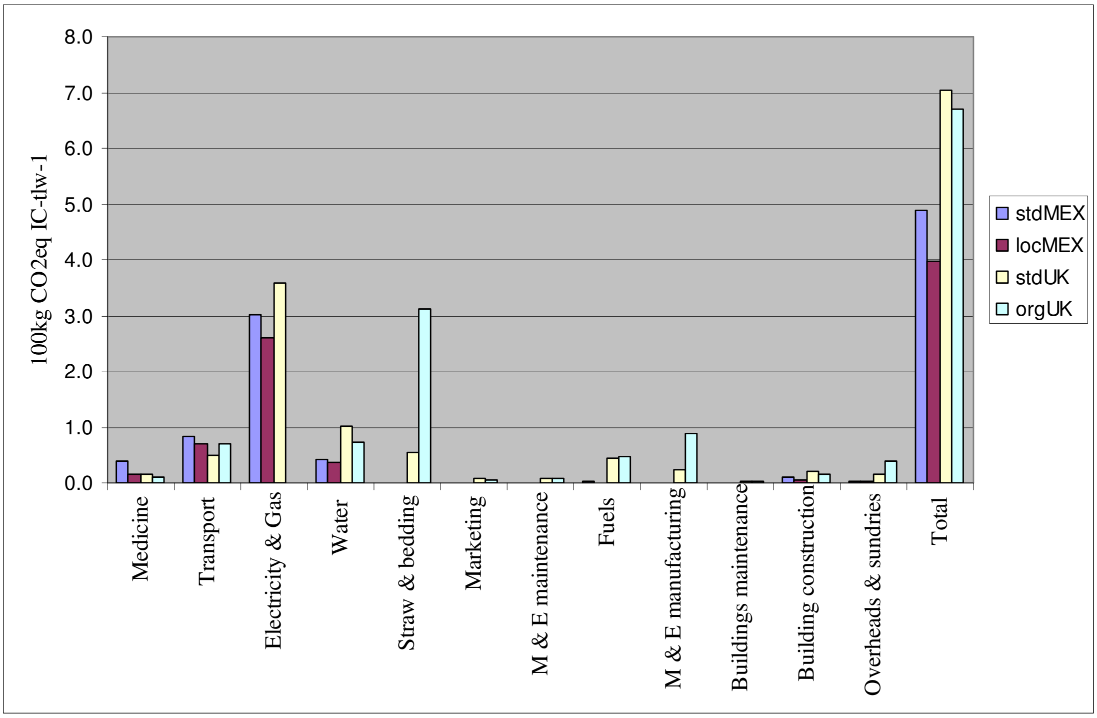

Figure 6.12 Distribution of GWP burdens for Ind-Comm

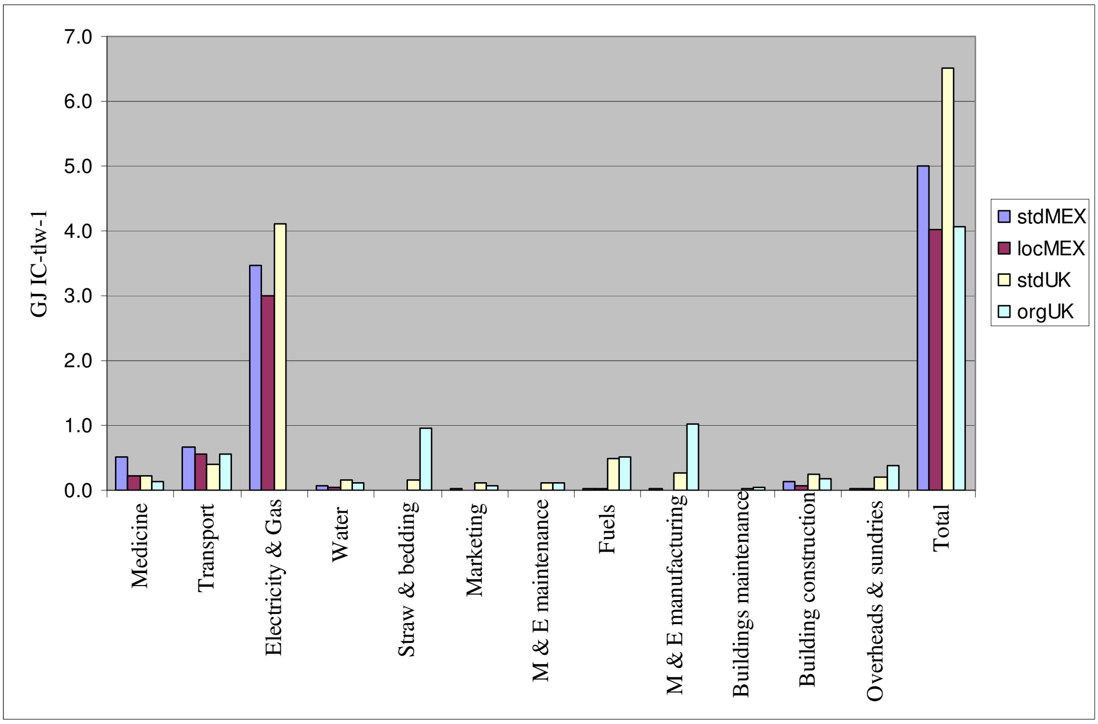

Figure 6.13 Distribution of energy use burdens for Ind-Comm

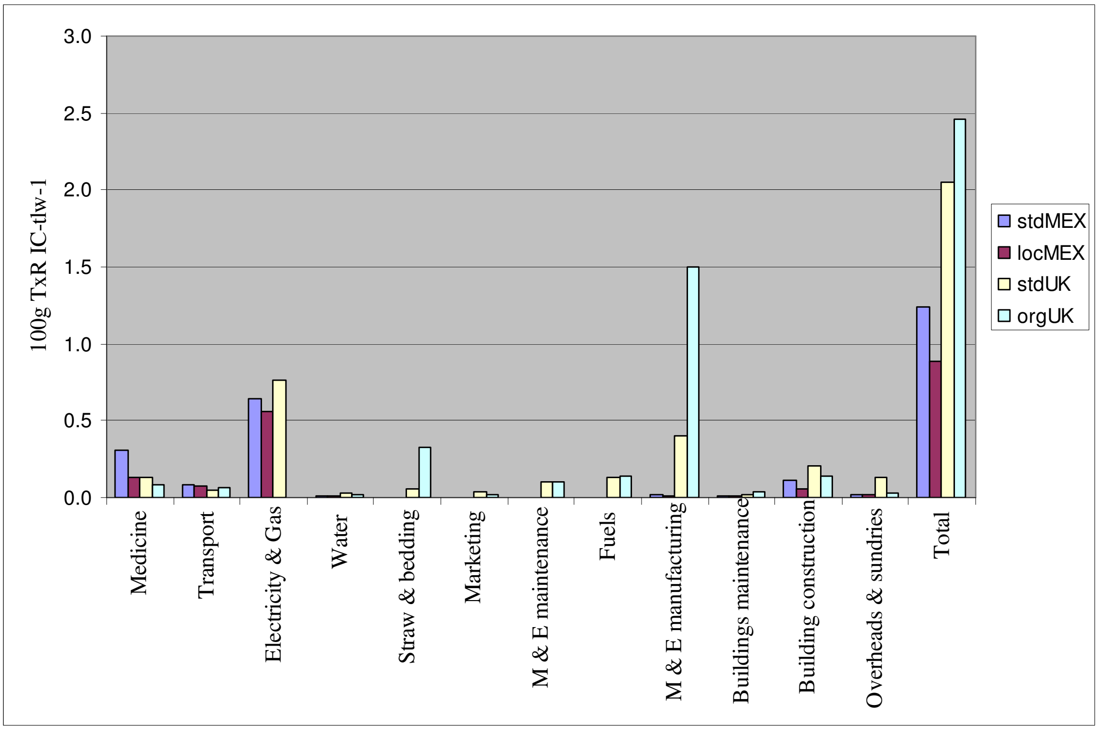

Figure 6.14 Distribution of TxR burdens for Ind-Comm

6.4 *Discussion*

Ind-Comm came from a net of industries that supply raw materials and services to pig farming and also interchange materials and services both up- and downstream. For example, producing electricity requires fuel from the petrochemical industry, which at the same time the electrical sector provides electricity for machinery and equipment used for transformation of fossil fuels to combustibles. Thus, tracing total e-burdens arising from one industrial sector that provides goods or services to the pig farm can be a task frequently out of the system boundary of any study. The EIO-LCA model used in this study is a good alternative method of tracing e-burdens arising from the supply chain industries (Hendrickson *et al.*, 2006). This method accounts for the e-burdens from the supply chain of any commodity, avoiding exclusion of the e-burdens from minor sectors (Hendrickson *et al.*, 2006). This method was time and resource efficient, considering that the consumption of Ind-Comms represented less than a third of commodities purchased for the farm operation (Table 6.10). On the other hand, the amount of Ind-Comms demanded was not directly linked to their e-burdens weight and tracing these helped to identify the main Ind-Comms that gave rise to significant e-burdens for the different pig farming scenarios.

The financial budget of the four scenarios showed a similar financial performance. The main differences between the scenarios arose from differences in the production systems and country conditions of pig production, as detailed in the demand section (Section 6.2.6). The exception was the M&E demanded by the orgUK scenario, which was three and a half times higher than for the stdUK, another scenario under the same country conditions. This difference could not be explained with data provided by Martins *et al.* (2002). However, the cost of fuel and M&E maintenance in the orgUK scenario were similar to those for the stdUK scenario (Table 6.11), which suggests that, with similar running cost, the amortisation cost was calculated differently. Two possibilities were feasible: that the amortisation cost was calculated exclusively with new M&E, or that the amortisation cost was not split equitably between crop production and pig production, since in this system pig paddock activities are closely linked to crop activities. Therefore, in reality the e-burdens of M&E manufacturing could be lower, when machinery and equipment is used for longer and depreciation cost is lower in practical conditions.

In spite of extreme differences in conditions between the four scenarios which were modelled, the infrastructure used to produce pigs did not give rise to large differences in e-burdens. Thus machinery, equipment and buildings and their management, frequently suggested to be environmental concerns for intensive pig systems, do not appear as the main challenge to improve sustainability. In contrast, M&E demand made an important contribution to air pollutants (Figure 6.5 to 6.10) and toxic releases in the orgUK scenario.

However, the amortisation cost used to model the M&E manufacturing cost could be unreal in practical conditions (see previous paragraph). Thus it is possible that e-burdens from M&E used in organic systems are similar to other intensive systems, if M&E demanded in organic systems is actually similar to intensive systems.

Transport, electricity and gas demand were the main source of e-burdens in the three intensive scenarios. The organic scenario (orgUK) did not include electricity and gas charges (for details see section of scenarios budget, Section 6.2.6). However, straw and bedding material raised the orgUK scenario e-burdens. Both these Ind-Comms are used to give comfort either providing suitable bedding (straw) or running ventilation and heating systems (electricity and gas). Then, both Ind-Comms are essential commodities for pig production under specific scenario conditions. The issue remains as to which e-burdens are preferable. Overall, the opportunity to improve sustainability of different pig production scenarios relates more to the challenge of increasing the efficiency with which Ind-Comms are used rather than avoiding their consumption.

6.5 *Conclusions*

Transport and Ind-Comms used to provide comfortable housing were the main sources of e-burden from Ind-Comms. Bedding material in the orgUK scenario and electricity and gas supply in the intensive scenarios (stdMEX, locMEX and stdUK) were the main sources of Ind-Comm e-burdens. The main opportunities to improve sustainability are then by making more efficient use of these commodities, more than the avoidance of their use. The EIO-LCA method facilitated a simple comparison of the e-impacts of Ind-Comms in different scenarios. These data were then carried forward into the overall assessment of scenario e-burdens described in Chapter 7.

Chapter 7 Impact assessment of the PPC

7.1 *Method for impact assessment*

The impact assessment of the e-burdens is the last step in the LCA (ISO, 1997). In this phase, data and information from inventories collected and analysed in Chapters 4, 5 and 6 were gathered and linked to specific indicators of environmental impact (e-impacts). The PPC components shown in Figure 3.2 were split into more specific processes following the main e-burden origins modelled in the LCIs. Figure 7.1 shows the main division of the PPC-processes. In this division, feed and crop production (Con-Feed) analysed in Chapter 5, was split according to the type of diet ingredients and where necessary, into specific crops. Nutrient flows and losses for pig production were split according to the main points where releases of e-burdens occurred. These were mainly during the manure-management phases (MM phases); specifically into manure collection, storage and disposal (M-collection, M-storage and M-disposal, respectively). The e-burdens of industrial commodities analysed in Chapter 6 (Ind-Comm) are shown together or individually as necessary to trace the origin of the main e-impacts.

There are specific categories to make up the e-impacts, so e-burdens collected in a LCI are allocated and summed in specific e-impacts. For example, the e-burdens CO_2 and NO_2 are suitable for allocation in the GWP impact. The CO_2 is scored as 1 for GWP, whereas NO_2 is given a score of 296 for GWP in the EDIP method (Wenzel, 1997, update 2003). Looking at the supply chain of a commodity, a great variety of substances are released to the environment, each one with its own potential impact. As the supply chain becomes more complex, the allocation of weighting on these substances also becomes more complex. Thus, database management software becomes more useful for data integration and analysis. In this study, SimaPro® software was used (Pré consultants group).

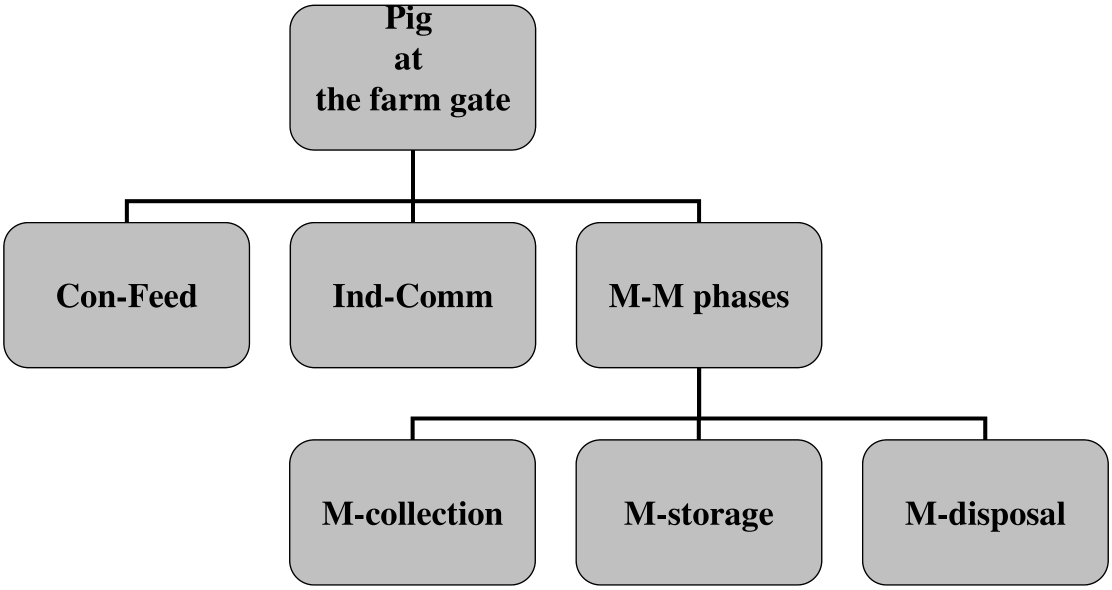

Figure 7.1 The main sources of e-impacts in the PPC (M= Manure, MM = Manure Management)

There are several methods available to allocate e-burdens. Even when most of them are based on the same international values, there are also specific methods conceived for specific purposes or industries. The Environmental Design of Industrial Products Method (EDIP) is suited to food commodities (Wenzel, 1997), and this method was adapted and updated for SimaPro software and used to assess the LCIs of the different scenarios. Table 7.1 shows the e-impacts and their characterisation factors used for the EDIP method.

Table 7.1 Environmental impacts and their characterisation factors in the EDIP method (Wenzel, 1997, update 2003)

e-impact	Characterisation factors
Global Warming Potential (GWP)	GWP is based on the IPCC 1994 Status report for 100 years impact. It includes methane, biogenic and fossil, CFC (such as HFC-123). No indirect impacts were included.
Ozone depletion (O_3D)	Stratospheric ozone depletion potentials are based on the status reports (1992/1995) of the Global Ozone Research Project (infinite time period is used).
Acidification potential (AP)	Acidification potential is based on the number of hydrogen ions (H+) that can be released from different sources, such as N compounds.
Eutrophication potential (EP)	EP is based on N and P compounds such as ammonium and dinitrogen monoxide compounds.
Photochemical smog (PS)	Photochemical ozone creation potentials (POCP) are taken from UNECE reports (1990/1992). POCP values depend on the background concentration of NOx, methane, benzene, 1,3,5-trimethyl- and propylene glycol methyl ether, among other chemical compounds with industrial origin or use. In SimaPro the POCPs are used for high background concentrations.
Ecotoxicity to water and soil (TxW, TxS)	Ecotoxicity is based on a chemical hazard screening method, which looks at toxicity, persistency and bio-concentration. Fate or the distribution of substances into various environmental compartments is also taken into account. Ecotoxicity potentials are calculated for chronic ecotoxicity to water and for soil. As fate is included, an emission to water may lead not only to water, but also to soil. Similarly, an emission to air gives ecotoxicity for water and soil. This is the reason to find emissions to water and soil compartments in the ecotoxicity category.
Fossil Energy use (FE)	FE is based on the ecoinvent version 1.01 (Frischknecht and Jungbluth, 2003) and expanded by Pré consultants group for the SimaPro 7.1® database.
Eiolca inventory	The e-burdens from eiolca.net were adapted for inventory data from the ecoinvent library in SimaPro.

7.2 *Results of the PPC e-impacts*

Results are presented as e-impacts arising from commodities or processes needed to produce a tlw of pig meat at the farm gate. Results of the main PPC-processes are shown in tables and figures in this chapter and in Appendix 8. Since some data required more detailed disaggregation, this was developed in appendices, mainly in Appendix 8. Figures in appendices will be referred to by adding an "A" before the appendix number; additionally figure numbers will be in roman style, i.e. Figure A8-IV.

7.2.1 Total PPC e-impacts

The e-impacts from a tlw of pigmeat are shown in Table 7.2 and Figure 7.2. Table 7.2 shows standard values for the eight e-impacts whereas Figure 7.2 shows the same values but scaled to units which bring together values for the different e-impacts in one figure. For example, GWP in Figure 7.2 was expressed as tCO_2-eq rather than gCO_2-eq stated in Table 7.2.

Table 7.2 The main e-impacts from a tlw of pigmeat at the farm gate

Impact category	Unit	locMEX	stdMEX	orgUK	stdUK
GWP 100 years	g CO_2	3,793,756	5,497,728	3,372,954	3,284,341
AP	g SO_2	74,990	75,284	43,905	43,776
EP	g NO_3	313,564	585,897	349,607	192,638
PhS	g ethylene	759	1,314	478	515
TxW	m^3	341,773	285,452	93,961	108,899
O_3D	g CFC11	0.461	0.641	1.501	0.925
TxS	m^3	46,133	60,134	81,867	53,740
FE	MJ	16,380	16,459	23,184	21,971

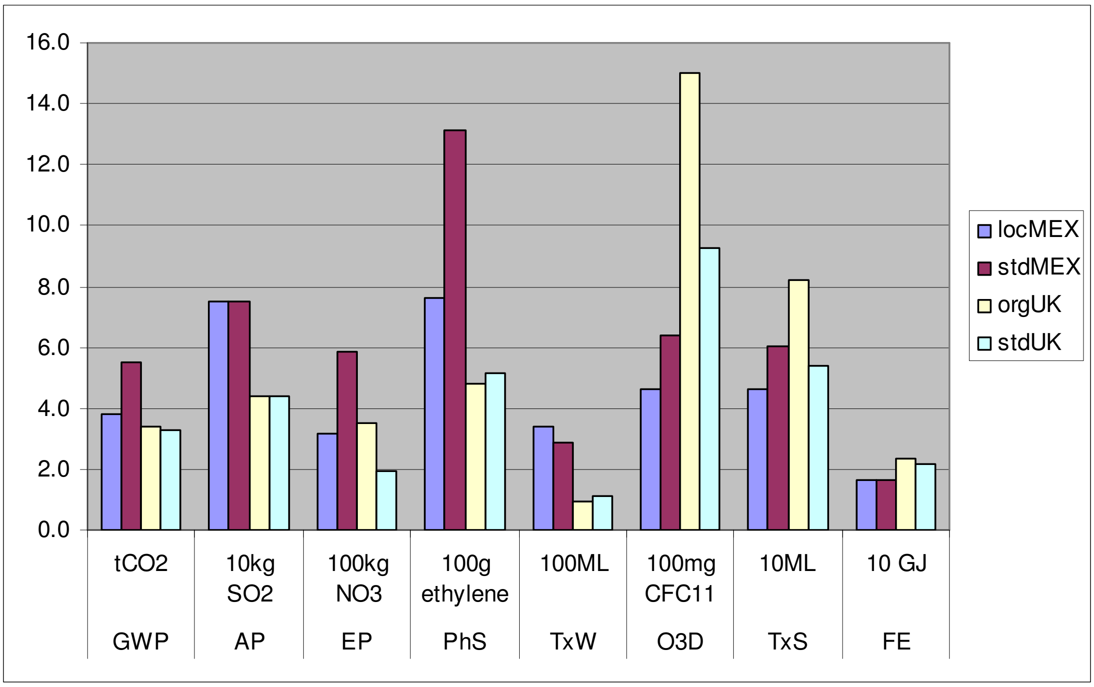

Figure 7.2 Distribution of the e-impacts of different scenarios from a tlw for Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), Photochemical Smog (PhS), Eco-toxicity water chronic (TxW), Ozone depletion (O_3D), Eco-toxicity soil chronic (TxS) and Fossil Energy use (FE). 1ML= 1000 m^3

Scenarios which led on individual e-impacts were identified as follows:

The locMEX scenario showed the highest values for TxW and shared higher values with the stdMEX scenario for AP and PhS. The stdMEX scenario had highest e-impacts linked to organic matter fermentation and nutrient losses, such as GWP, EP and PhS and shared higher values for AP and TxW with the stdMEX scenario. The orgUK scenario had the highest value for three e-impacts: O_3D, TxS and FE. The stdUK scenario on the other hand showed the lowest values for e-impacts linked to farm nutrient use such as GWP, AP, EP. However, along with orgUK, this scenario scored higher values for O_3D and FE.

The distributions of e-impacts for each PPC processes were traced and presented in relevant tables in the following sections. Values of scenarios that lead every e-impact were designated as 100% to produce appropriate charts that compare the e-impact weight of all scenarios and their sector distribution. Firstly, the e-impacts where the Mexican scenarios had the highest value are discussed, followed by those where the UK scenarios lead the impacts.

7.2.2 GWP

The GWP value of the stdMEX scenario was used to produce the percentage distribution of PPC processes, as shown in Figure 7.3. Detailed values for the PPC processes are shown in Table 7.3. M-collection and M-storage gave rise to the main differences between scenarios. The stdMEX scenario had the highest value for M-collection and the locMEX for M-storage. Mexican scenarios had higher total GWP than UK scenarios. A smaller GWP value from Con-Feed in the Mexican scenarios was not enough to compensate for the GWP impact of MM. The Mexican scenarios were modelled under warm climatic conditions, where higher temperatures increase the manure fermentation rate and consequently CO_2-eq emissions. Mexican scenarios had a different retention time of pig excreta during MM; the stdMEX scenario stored manure for a longer time during the M-collection (Table 5.3), so that M-collection in the stdMEX scenario was responsible for nearly 50 % of CO_2-eq releases. On the other hand, in the locMEX scenario manure was moved out of pig buildings daily, transferring the main manure fermentation to the M-storage phase (Figure 7.3).

Table 7.3 GWP100 of PPC-processes (gCO_2 eq tlw^{-1})

Scenarios	locMEX	stdMEX	orgUK	stdUK
Total	3,793,756	5,497,728	3,372,954	3,284,341
Con-Feed	1,698,090	1,521,428	2,230,400	2,085,225
Ind-Comm	116,222	162,645	598,191	343,409
M-collection	295,064	2,567,692	190,440	195,198
M-storage	1,576,772	1,066,463	0	767,146
M-disposal	107,608	179,500	353,923	-106,637

Longer retention time of manure in pits under the floor and warm weather conditions in the stdMEX scenario (Table 5.3) provided anaerobic conditions, increasing organic matter fermentation and reducing the VS content of manure. So, even though the stdMEX scenario had the highest retention time for M-storage, its GWP value from this phase of MM was lower than that for the locMEX scenario which had a shorter manure retention time. In contrast, the shorter retention time for M-collection in the locMEX scenario postponed the organic matter fermentation until the M-storage phase (Figure 7.3), increasing the possibility for methane collection.

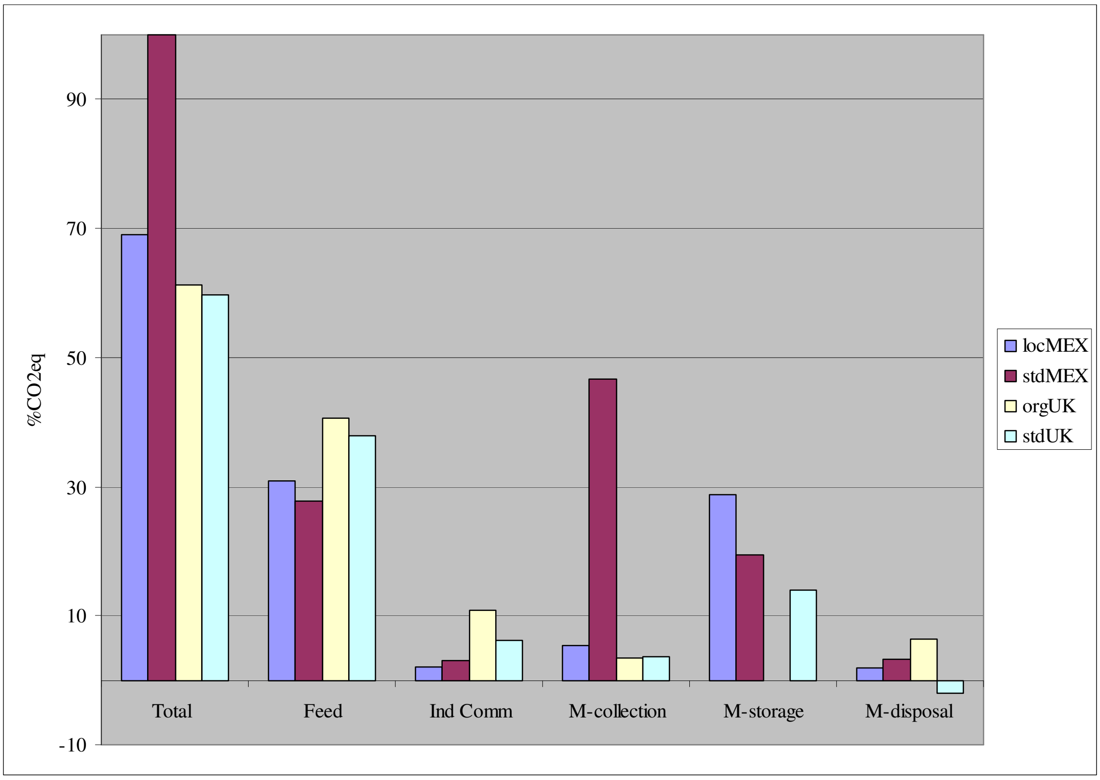

Figure 7.3 Distribution of GWP100 as a percentage of the highest total GWP100 value (the stdMEX scenario given in Table 7.3)

In contrast to the stdMEX scenario, the UK scenarios had lower CO_2-eq impacts from MM, either as a result of lower environmental temperature (the stdUK scenario) or direct manure to land application which avoids anaerobic conditions (the orgUK scenario). The GWP produced from feed production was higher for the UK scenarios than for the

Mexican scenarios (Figure 7.3). The GWP distribution flows (Figures A8-I to IV) show that it was the amount and type of feedstuff consumed which gave rise to the differences between scenarios. Grain consumption was the main source of GWP in the intensive scenarios (Figures A8-I, II and IV), whilst for the orgUK scenario this came from protein and energetic ingredients in similar proportions (Figure A8-III). The GWP from the UK scenarios was 5% higher than in the Mexican scenarios, even though the diet ingredients were imported in the Mexican scenarios (Con-Feed in Figure 7.3).

7.2.3 EP

Table 7.4 shows the EP values from the PPC processes. The value from the stdMEX scenario was used as the benchmark to produce Figure 7.4, since this was the highest value amongst the scenarios.

Table 7.4 EP of PPC processes (gNO_3-eq tlw^{-1})

Categories	locMEX	stdMEX	orgUK	stdUK
Total	313,564	585,897	349,607	192,638
Con-Feed	126,086	114,188	207,998	99,214
Ind-Comm	612	926	8,567	2,654
M-collection	35,506	51,258	0	31,002
M-storage	50,048	61,202	0	26,220
M-disposal	101,313	358,323	133,043	33,549

MM phases were the main sources of EP for intensive scenarios. EP from M-disposal in the stdMEX scenario gave the main difference between scenarios. Zero manure recycling in the stdMEX scenario caused substantial nutrient losses during M-disposal. Thus the stdMEX scenario made more than 60 % of its EP impact in M-disposal, mainly through lost NO_3 and phosphorous content in pig manure (Figure 7.4). The locMEX and orgUK scenario were less efficient than the stdUK scenario in using manure as fertiliser, since, in these scenarios manure was applied continuously to the land increasing nutrient losses from runoff and leaching. The highest EP values in M-collection and M-storage phases came from ammonia emission in the intensive scenarios (Figure 7.4). During the Con-Feed phase, the orgUK scenario had the highest EP value, which was 15% more than intensive scenarios. This was as a result of both higher consumption of feedstuffs and crop production characteristics (Table 7.5). In organic systems long rotation systems take advantage of natural N fixation but extra land is needed to build soil fertility, and yield is lower. Organic rotation systems share e-impacts between cropped outputs and, in this way, EP increased as much as there were N losses between cropping seasons (Williams *et al.*, 2006). Thus, crop production in the orgUK scenario showed high EP from both sources of nutrients (energy and protein) in pig diets. Additionally, organic restrictions on feed composition required great consumption of protein ingredients (Table 7.5). In contrast, the stdUK scenario had the lowest EP value for Con-Feed (Figure 7.4), due to lower average EP for energy ingredients and low protein consumption, even though the average EP from protein ingredients is high (Table 7.5). Finally the EP of Ind-Comm was negligible for all four scenarios. Summing up, the stdUK scenario shows the lowest EP values in all PPC processes.

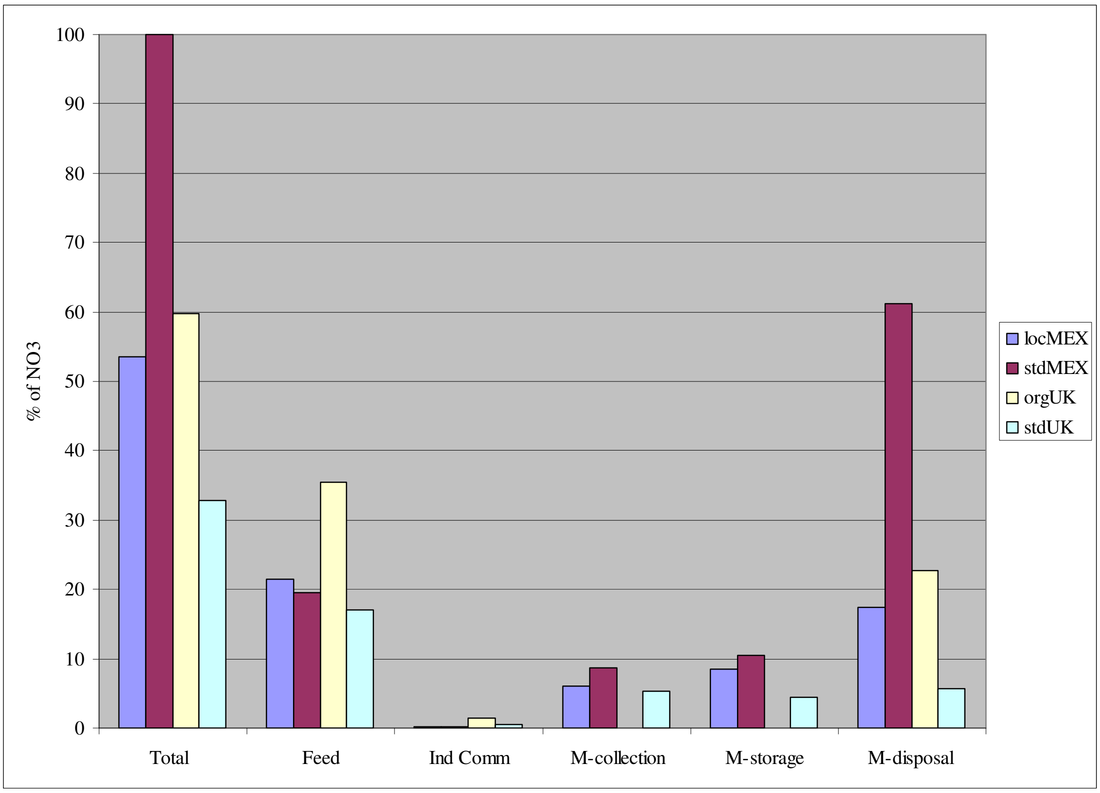

Figure 7.4 Distribution of EP impacts as a percentage of the highest EP value (the stdMEX scenario in Table 7.4)

Table 7.5 EP Average values for crop production (data from Figures A8-V to VIII)

Units	locMEX	stdMEX	orgUK	stdUK
Energy ingredients:				
Consumption, kg tlw-1	2,490	2,260	2,180	2,230
Total EP, gNO3-eq	111,000	100,000	143,000	61,800
Average EP, gNO3-eq/kg	45	44	66	28
Protein ingredients:				
Consumption, kg tlw-1	647	591	952	596
Total EP, gNO3-eq	14,600	13,300	64,900	37,000
Average EP, gNO3-eq/kg	23	23	68	62

7.2.4 PhS

The PhS is the potential to produce ozone from different compounds. In LCA, the PhS is referred to in ethylene-equivalents (C_2H_4-eq). Ozone is classified as a damaging trace gas at ground-level (De Keulenaer, 2006). Photochemical ozone production in the troposphere (where we live), also known as summer smog or photochemical smog, is suspected to damage vegetation and material. High concentrations of ozone are also toxic to humans (De Keulenaer, 2006). Ozone and other aggressive products, through complex chemical reactions, are formed from nitrogen oxides and hydrocarbons in the presence of sun radiation. Nitrogen oxides from MM, hydrocarbons emissions from incomplete fuel combustion and petrol losses (from storage, turnover, refueling), in conjunction with solvent losses occurring in industrial processes, are the main sources of PhS (De Keulenaer, 2006). Table 7.6 shows the PhS values for PPC processes. The stdMEX scenario value was used as the benchmark to produce Figure 7.5, since this scenario had the highest PhS value amongst the scenarios. M-disposal in scenarios that recycle manure show negative values (Table 7.6) because they have fertilisation credit for avoiding fuel combustion needed to produce synthetic fertilisers.

Table 7.6 PhS of PPC processes (gEthylene-eq tlw^{-1})

Category	locMEX	stdMEX	orgUK	stdUK
Total	759	1,314	478	515
Con-Feed	173	147	64	73
Ind-Comm	98	135	376	224
M-collection	63	751	58	36
M-storage	431	279	0	196
M-disposal	-5	2	-19	-14

Figure 7.5 shows that M-collection in the stdMEX scenario accounted for the main difference between scenarios. MM phases in the Mexican scenarios produced between 78% and 89% of PhS releases (locMEX and stdMEX scenarios, respectively). Weather conditions and the retention time in MM phases modelled in the Mexican scenarios facilitated NOx release alongside methane. As was the case for GWP, retention time facilitated higher manure fermentation during M-collection or M-storage for the stdMEX and locMEX scenarios, respectively. Transportation of imported feedstuffs produced twice the level of PhS released in the Mexican scenarios than in the UK scenarios.

Whilst the UK scenarios had lower PhS values for MM phases and Con-Feed, their main PhS impact came from Ind-Comm (Figure 7.5). This impact comes from diverse industries discussed in detail in the scenario discussion (which follows) and shown in Figures A8-IX to A8-XII.

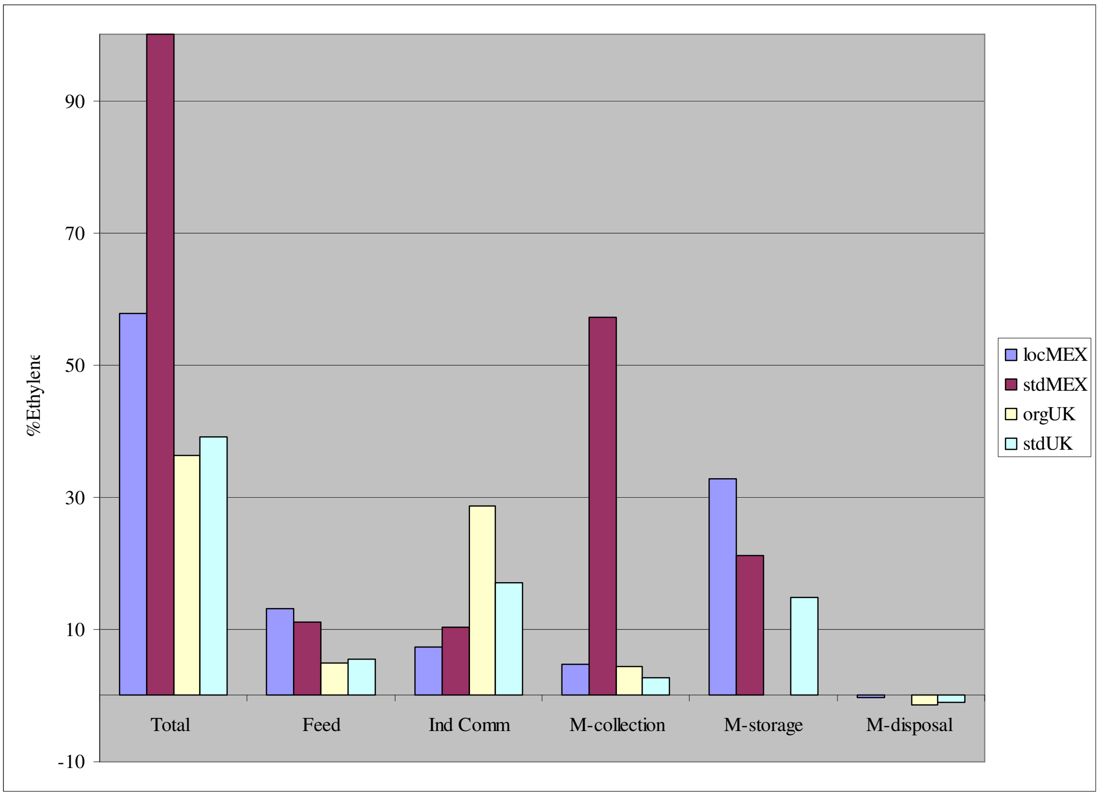

Figure 7.5 Distribution of PhS as a percentage of the highest PhS value (the stdMEX scenario in Table 7.5)

7.2.5 AP

Table 7.7 shows the AP values of the different PPC processes. Since the stdMEX scenario value had the highest AP value, this was used as the benchmark to produce Figure 7.6. M-collection and M-storage in the stdMEX scenario gave rise to the main difference between scenarios. Ammonia and NOx releases in the MM phases were responsible for the variations in the AP level between intensive scenarios. Different manure retention times and weather conditions between different scenarios were the reason for these variations.

Table 7.7 AP of PPC-processes (gS0$_2$-eq tlw^{-1})

Scenarios	locMEX	stdMEX	orgUK	stdUK
Total	74,990	75,284	43,905	43,776
Con-Feed	15,712	14,109	11,528	10,236
Ind-Comm	528	744	2,572	1,498
M-collection	18,338	26,474	0	16,012
M-storage	25,849	31,610	0	13,542
M-disposal	14,563	2,347	29,805	2,488

The stdMEX scenario had the most favourable conditions for AP releases during M-collection and M-storage. However, this was not the case for M-disposal, since sewage in the stdMEX scenario was sent to open areas and so no anaerobic fermentation was considered. In contrast, the locMEX scenario that continuously applied manure to land, and the orgUK scenario that had no MM, had a greater AP impact during M-disposal (Figure 7.6). The AP of the Con-Feed process was higher in the Mexican scenarios due to the transportation and production of imported feedstuffs (Figure 7.6). The stdUK scenario had the lowest AP values of all process in the PPC. Finally, the AP of Ind-Comm was negligible in all scenarios.

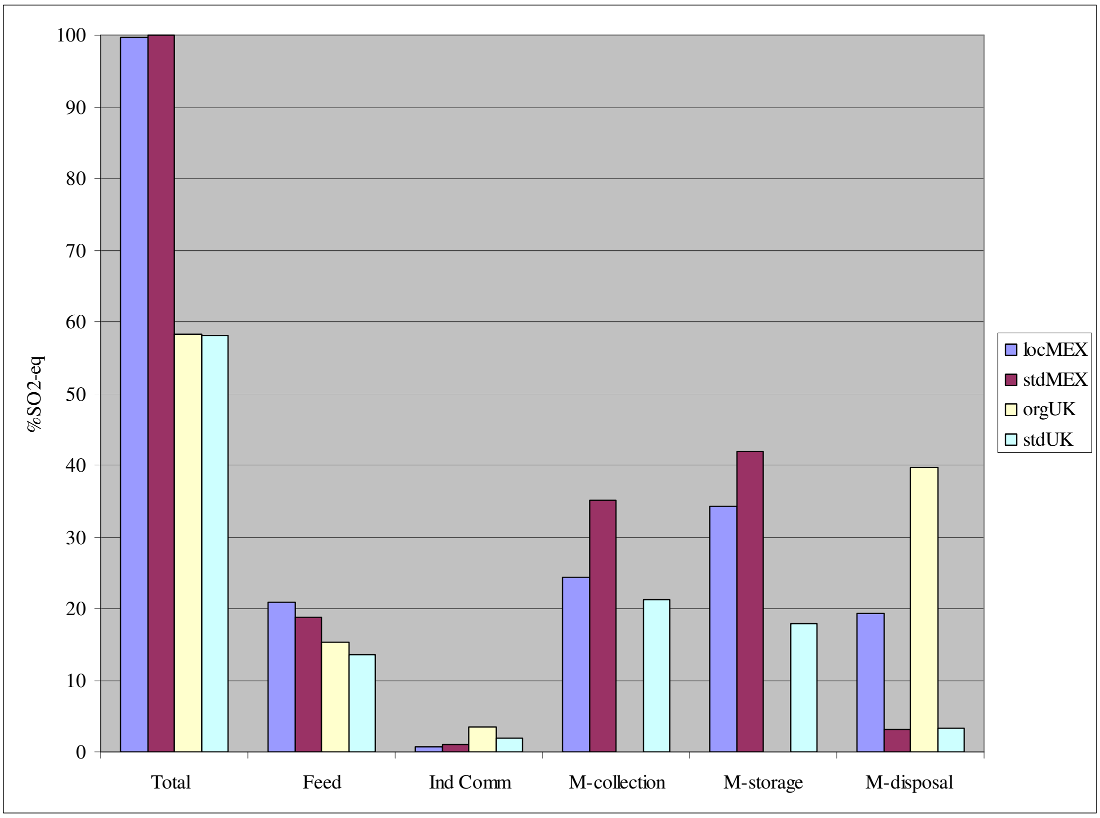

Figure 7.6 Distribution of AP impacts as a percentage of the highest AP value (the stdMEX scenario in Table 7.6)

7.2.6 TxW

Table 7.8 shows the TxW values for the different PPC processes. Since the locMEX scenario had the highest TxW value this scenario was used as the benchmark to produce Figure 7.7.

Table 7.8 TxW of PPC-processes (m^3 tlw^{-1})

Categories	locMEX	stdMEX	orgUK	stdUK
Total	341,773	285,452	93,961	108,899
Con-Feed	332,422	277,933	81,388	94,468
Ind-Comm	5,139	7,519	12,628	9,484
M-collection	0	0	0	0
M-storage	0	0	0	0
M-disposal	4,212	0	-55	4,947

By for the greatest contributor of TxW in the PPC processes was Con-Feed. As for the PhS and AP impacts, importation of feedstuffs produced the highest TxW impact (Figures A8-XVII and XVIII). Thus, the locMEX scenario which consumed more feed (Table 3.4) also had the highest TxW (Table 7.8). TxW differences between the UK scenarios were also linked to transport use; thus imported ingredients and local transport were responsible for their main TxW (Figures A8-XIX and XX). Ind-Comm accounted for less than 4% of total TxW impact. In the three different MM phases, TxW values were negligible (Figure 7.7).

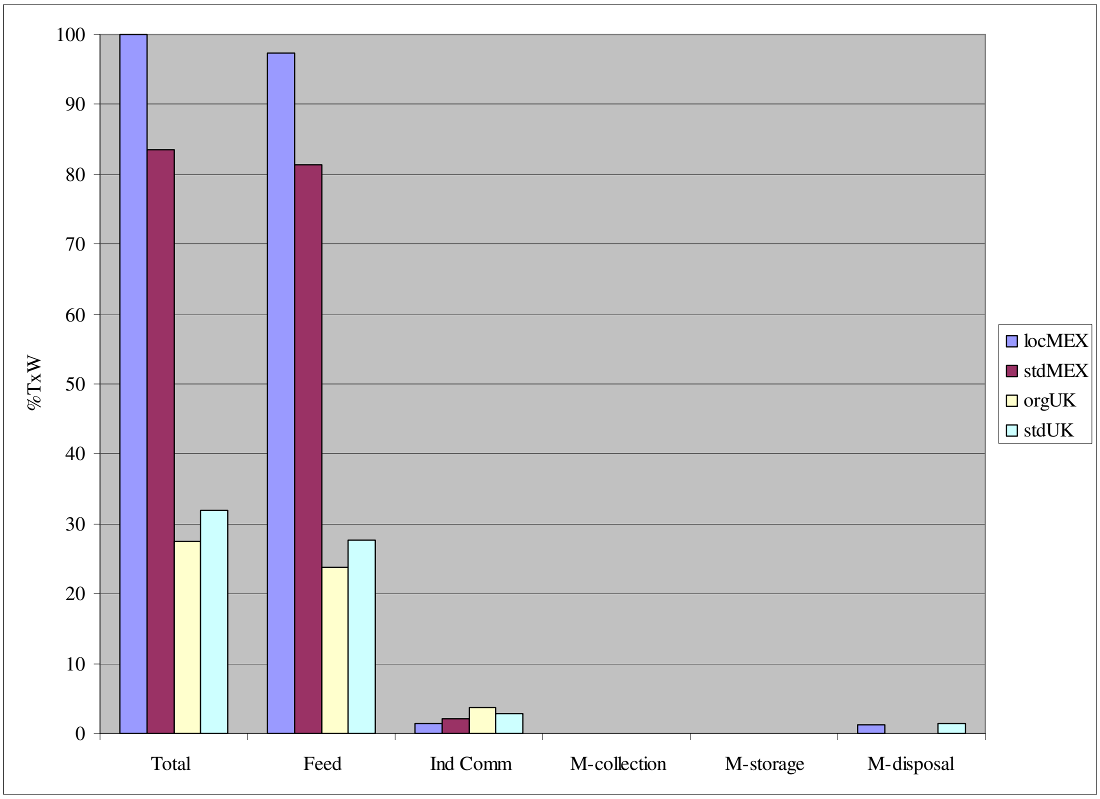

Figure 7.7 Distribution of TxW as a percentage of the highest TxW value (the stdMEX scenario in Table 7.7)

7.2.7 O_3D

There are two cases of ozone depletion: one in the troposphere that occurs near to the earth surface in polar regions during spring, and stratospheric ozone depletion which occurs for transport of ozone-depleting substances into the stratosphere after being emitted at the surface (Andino, 1999 373). The detailed mechanism differs between them, but in both cases the trend is catalytic destruction of ozone by atomic chlorine and bromine (Andino, 1999). The main source of these halogens is the stratospheric photo-dissociation of chlorofluorcarbon (CFC) compounds. The most abundant CFCs released into the troposphere are CFC 11 and CFC 12. These CFCs are not soluble in water, so deposition by rain does not remove them from the air (Andino, 1999). The major sources of CFCs are industrial substances used to produce aerosol propellants, cleaning solvents, refrigerants and plastic blowing agents amongst others. These commodities are used in intermediate industries that are in the supply chain of commodities required by the pig farm. The O_3D impact of these commodities was traced through the Ind-Comm consumption. Table 7.9 shows the O_3D values for each of the PPC processes. Figure 7.8 has the distribution of the main Ind-Comm that accounted for O_3D impacts according to individual O_3D figures for each scenario, as given in Appendix 8 (Figures A8-XXI to XXIV). Con-Feed accounted for less than 4.1% of all O_3D impact in all scenarios (Table 7.9). MM did not affect the O_3D impact (Table 7.9). Thus, only the Ind-Comm values were analysed in detail.

Table 7.9 O_3D of PPC processes (gFCF11-eq tlw^{-1})

Categories	locMEX	stdMEX	orgUK	stdUK
Total	0.461	0.641	1.037	0.925
Con-Feed	0.052	0.045	0.051	0.062
Ind-Comm	0.409	0.596	0.986	0.862
M-collection	0	0	0	0
M-storage	0	0	0	0
M-disposal	0	0	0	0

Following the PPC upstream, the main O_3D impact in the different scenarios came from different commodities. Transportation was an important contributor in all scenarios. Electricity, detergents, disinfectants and medicines were more important in O_3D impact for the intensive scenarios than in the orgUK scenario. M&E and fuel values were important for both the UK scenarios; building construction was important for the stdUK scenario, while straw and hand tools values were significant for the orgUK scenario (Figure 7.8). In short, interaction of the commodities demand and the industrial processes involved in each commodity's supply chain give the final O_3D. Thus, even though the orgUK scenario does not consume detergents, disinfectants or medicines, which have weighted chemical processes as their background, the orgUK scenario had higher O_3D impacts. The reason for this is that the UK scenarios consumed more M&E and fuel than Mexican scenarios. Additionally, the UK scenarios had higher consumption of overhead and sundries (detergents and disinfectants for the stdUK and hand tools for the orgUK), which suggests more mechanisation in these scenarios (see difference in demand, Section 6.2.6). Mechanisation of farm activities increases consumption of M&E and buildings. Maintenance and fuel consumption of machines become more significant farm activities, which in turn makes then responsible for greater e-impacts. Both UK scenarios showed higher O_3D, but the orgUK scenario has a lighter impact for straw bedding used in this outdoor system (Figure 7.8).

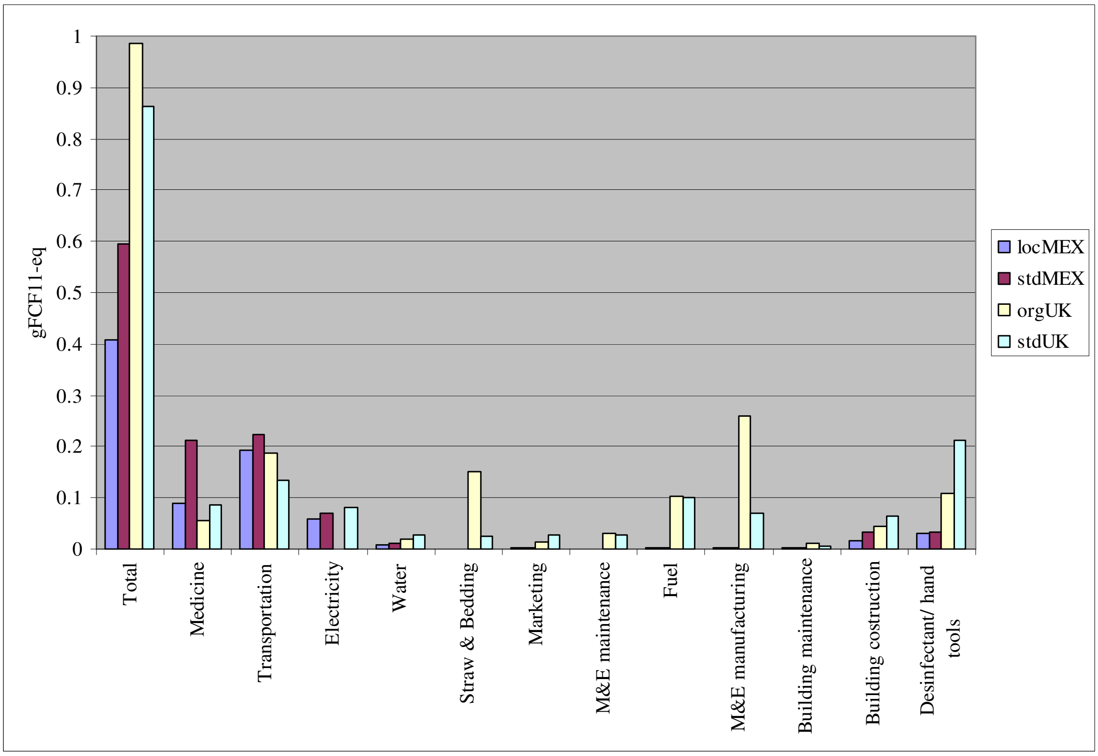

Figure 7.8 Distribution of the main O_3D values from Ind-Comm (gFCF11-eq tlw^{-1})

7.2.8 TxS

The TxS looks at toxicity, persistency and bio-concentration of substances in the soil (LCAfood, 2002). Table 7.10 shows the PPC-processes values for TxS.

Table 7.10 TxS of PPC-processes (m^3 tlw^{-1})

Categories	locMEX	stdMEX	orgUK	stdUK
Total	46,133	60,134	81,867	53,740
Con-Feed	15,210	13,055	1,508	1,795
Ind Comm	30,887	47,079	80,576	51,909
M-collection	0	0	0	0
M-storage	0	0	0	0
M-disposal	36	0	-216	36

There was no effect of MM phase on the TxS impacts. Con-Feed and Ind-Comm accounted for the main TxS impact. Since the main weights came from Ind-Comm, their values were split in Figure 7.9. Additionally, Appendix 8 shows four scenario diagrams

(Figure A8-XXV to XXVIII). Ind-Comm impacts of TxS are produced for same commodities as described for O_3D, whilst the Con-Feed impacts of TxS are produced mainly for transport of imported feedstuffs as was the case for TxW impacts.

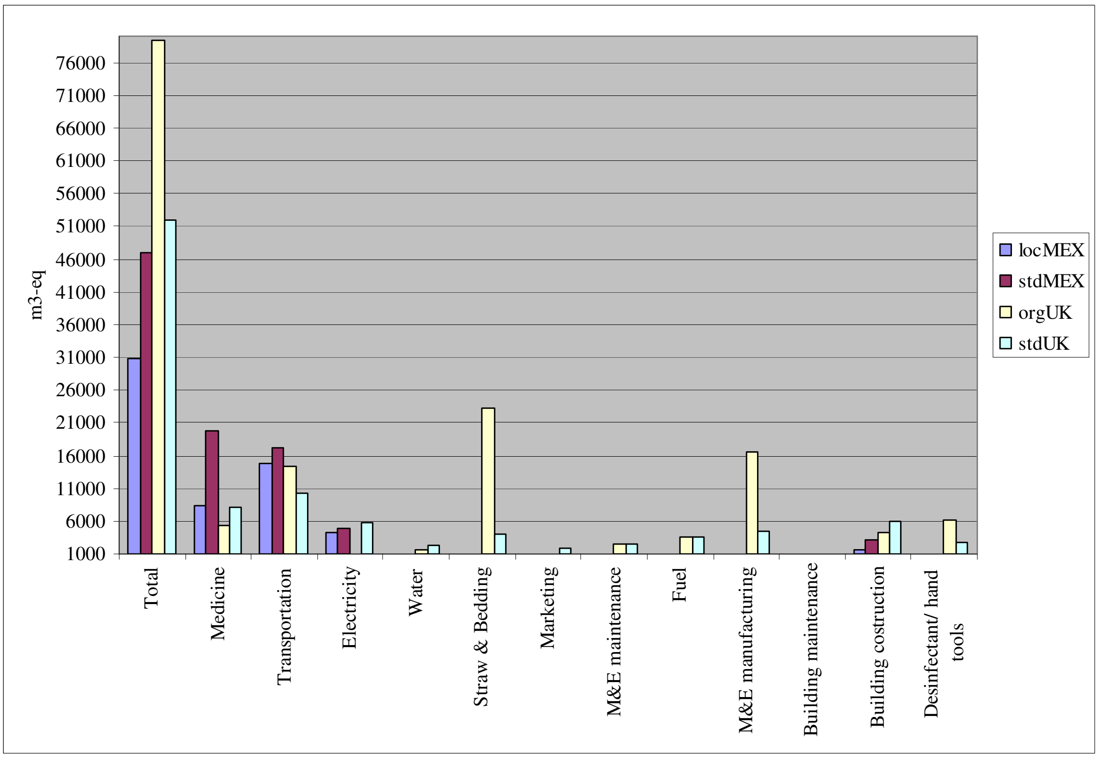

Figure 7.9 Distribution of the main TxS weights from Ind-Comm (m^3-eq tlw^{-1})

Tracking upstream, the origin of TxS in the supply chain of Con-Feed and Ind-Comm, the main TxS burdens were produced from the supply chain of services in the form, used either directly or indirectly. For example Con-Feed accounted for the main impact through transportation of feed ingredients (Figure A8-XXV to XXVIII). Utilisation of transportation was for importation of feedstuffs in the Mexican scenarios, which rely on importation of raw materials from the US Corn Belt. On the other hand, commodities that facilitate mechanisation in the UK scenarios (see differences in demand in Section 6.2.6 and O_3D impacts in Section 7.2.7) also increase the TxS. As with O_3D, higher use of straw and M&E in the orgUK scenario increased the final TxS value. So that, the TxS impact of orgUK was the highest of all four scenarios. Finally, TxS results show that the use of resources from the metal transformation industry, which is the upstream sector for engine, chassis and hand tool manufacturing needed for mechanisation, increases e-impacts.

7.2.9 FE

Table 7.11 shows the FE values for each of the PPC processes. Since the orgUK scenario had the highest FE value, this was used to benchmark Figure 7.10. The main FE came from Ind-Comm, so their values were split out in Figure 7.11. Additionally Appendix 8 shows four scenarios diagrams (Figure A8-XXIX to XXXII).

Table 7.11 FE of PPC processes (MJ-eq tlw^{-1})

Scenarios	locMEX	stdMEX	orgUK	stdUK
Total	16,380	16,459	23,999	21,971
Con-Feed	15,590	13,895	8,144	8,954
Ind-Comm	1,818	2,564	17,089	14,836
M-collection	0	0	0	0
M-storage	0	0	0	0
M-disposal	-1,029	0	-2,049	-1,819

The main FE impact from the PPC-processes came from two different sources: Ind-Comm for the UK scenarios and Con-Feed for the Mexican scenarios. Mexican scenarios import 100% of feedstuffs and used nearly double the level of energy from fossil sources compared to the UK scenarios. In contrast, the UK scenarios that are more dependent on mechanisation are also more energy intensive than Mexican scenarios. Since all industrial sectors in the supply chain of industrial commodities demand some kind of power, either for operation, transformation or transportation, the energy burdens accumulate in the final consumer account. Thus, consumers of products that have high energy consumption in their background, such as M&E manufacturing, also account for more energy in their final balance. (Figure A8-XXIX to XXXII). In addition, the UK scenarios directly consumed more fuel necessary to operate M&E. Fuel consumption accounted for nearly 60% of FE impact in the UK scenarios (Figure 7.11).

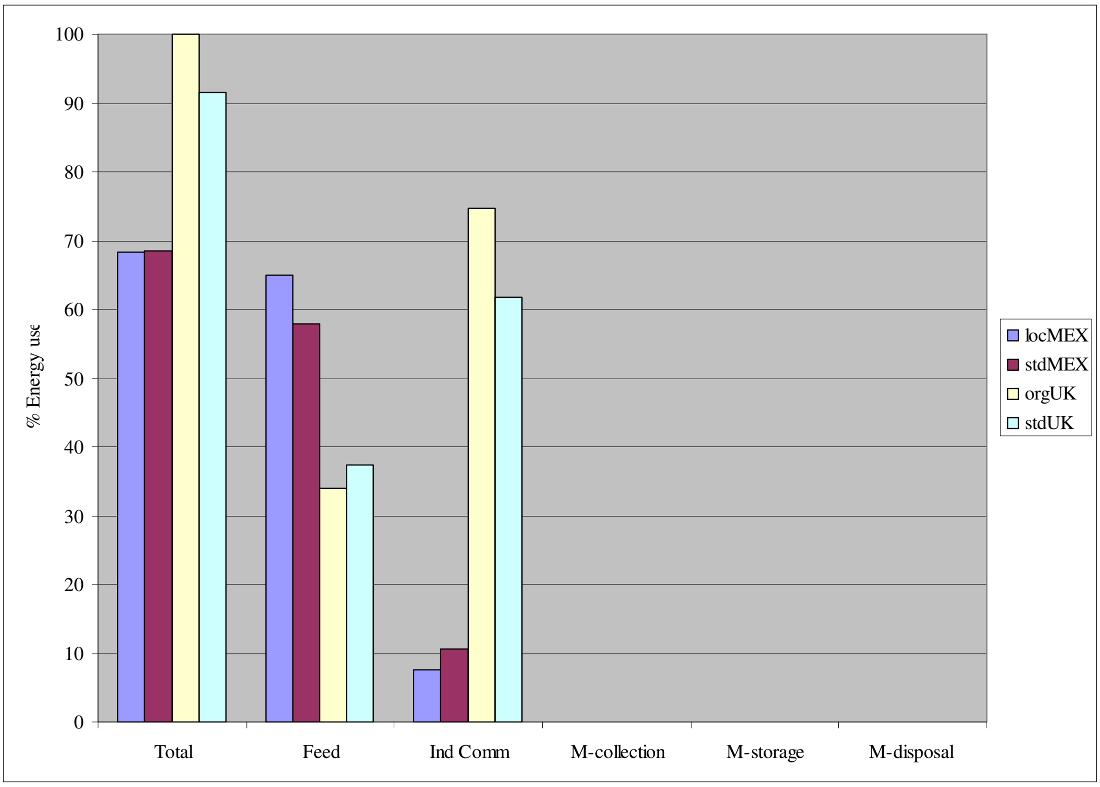

Figure 7.10 Distribution of Fossil energy use as a percentage of the highest FE value (namely the orgUK scenario in Table 7.10)

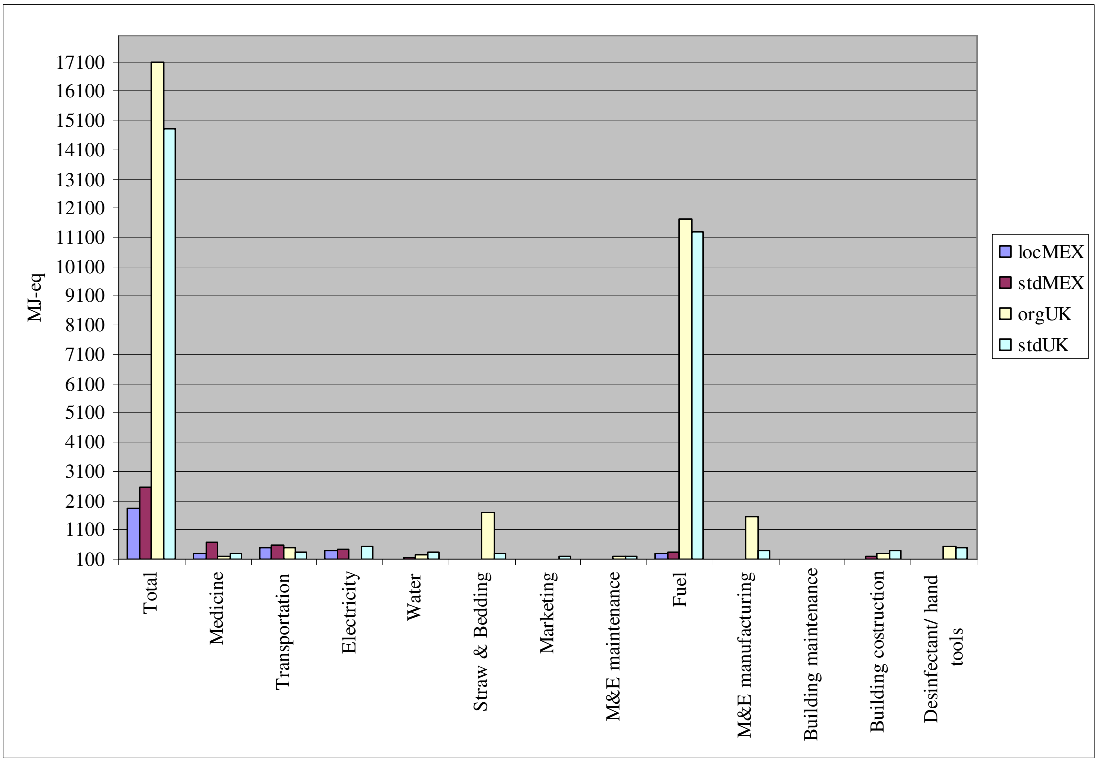

Figure 7.11 Distribution of the main weight of FE impact (MJ-eq tlw-1)

7.2.10 Uncertainty analysis

Since data using in generating models of general farm performance and management came from different sources, rather than from surveys or direct measurement, this will undoubtedly have produced some uncertainty about the validity of the results. Quantification of the uncertainty in this kind of model is measured through the LCA results, measuring intra-scenario and inter-scenario variability (Wenzel, 1997). These comparisons produce more robust outcomes, especially if they take into account the variability of technical performance of scenarios (Basset-Mens *et al.*, 2004). Since production systems were modelled from specific sources of data, and not from surveys or farm samples, parameters for physical farm performance and process conditions were specific values. In these circumstances, the variability produced for measurement or sampling does not exist. Contrasting alternative systems that include changes in values for the main sources of variation in the processes modelled is an alternative (Dalgaard *et al.*, 2007a; Stern *et al.*, 2005; Cederberg and Flysjo, 2004). For example, Dalgaard *et al*. (2007a) use different fates for pork sales to examine the effect on e-impacts. Similarly, Cederberg and Flisjo (2004) contrasted their scenarios using the same allocation method in the three scenarios they modelled by using alternative intra-scenario conditions to assess possible sources of variation.

On the other hand, Wenzel *et al*. (1997, p129) suggest that another option to assess the intra-scenario uncertainty is the use of 'hot spots' or outstanding process that emerge from the LCA results. Wenzel *et al*. (1997, p129) stated that in the results of the assessment phase, the potential contributors or key figures in the various environmental exchanges emerge. It is thus possible to decide which exchanges or hot spots are the most significant, and which are without significance in the total figure, and should thus be included in the sensitivity analysis. Therond *et al.* (2009) added that, by capturing key figures changes, 'alternative' systems can be produced and compared with the reference scenarios. The 'alternative' systems or 'alternative scenarios' account for system options and technological changes pin point key effects. Since the purpose of the sensitivity analysis is to clarify the sources of variation and to assess their relative significance, it is tempting to try to assess several 'alternative' options for each possible source of variation. Alcamo (2001) and Therond *et al.* (2009) recommended care in this approach, because developing a great number of 'alternative scenarios' can result in a confusing proliferation of scenarios. Thus, in the current study the uncertainty analysis was carried out by investigating three sources of variation, but restricting the analysis to one 'alternative scenario' for each kind of variation. These were: (1) an 'alternative' scenario that included the hot spots found in the LCA results; (2) an inter-scenario comparison of the LCA results; and (3) an 'alternative' scenario capturing technological changes. These three options will be described in detail.

Assessment of uncertainty and variability

The scenarios assessed in the LCA, both standard and alternative (stdMEX, locMEX, stdUK and orgUK) will be named in this section 'main scenarios' to avoid terms confusion between 'alternative' scenarios that model data variations and the alternative country scenarios (locMEX and orgUK) that contrast the standard country scenarios (stdMEX and stdUK).

(1) The intra-scenario uncertainty: The key factors highlighted in the LCA results for the PPC (Section 7.2.1 to 9) were used to produce 'alternative' scenarios of each PPC model. For each country the main scenarios and the 'alternative' scenarios were compared and their differences discussed. Table 7.12 summarises these key factors identified as the most important points in the assumptions, processes and environmental indicators used in the main scenarios.

(2) The inter-scenarios variability: This was investigated by contrasting the main scenario (i.e. the stdMEX) against the stdUK scenario, considering that the stdUK scenario represents the current practice in the UK and gives the possibility to compare outputs from other studies with one basic scenario in this study. Additionally, the variability produced for 'alternative' scenarios was discussed.

(3) The technical improvement variability: This was investigated assuming 10% improvement in feed efficiency. In this assumption, all other production factors remained the same. The assumption includes no changes in equipment and facilities, feed composition or feed production techniques.

The intra-scenario uncertainty

Physical and climatic variability were used to explore modifications in the scenarios e-impacts. The main sources of uncertainty within-scenario, as revealed by the major sources of burdens in the scenarios results (Sections 7.2.1 to 9), are summarised in Table 7.12.

Table 7.12 The main sources of uncertainty by scenario and by impact highlighted in the e-impact result sections (section 7.2.1 to 9)

Impact	locMEX	stdMEX	orgUK	stdUK
GWP	Retention time during M-storage	Retention time during M-collection	Enteric fermentation	Temperature during M-storage
EP	Frequency of M-disposal	No recycling during M-disposal	Method of grain production Feed consumption	---
PhS	Feedstuffs importation	Feedstuffs importation Retention time during M-collection	Fuel consumption	Fuel consumption
AP	Feedstuffs importation	Feedstuffs importation Retention time during M-collection	----	---
TxW	Feedstuffs importation	Feedstuffs importation	---	---
O_3D	Feedstuffs importation	Feedstuffs importation	M&E, fuel, straw	M&E, fuel
TxS	Feedstuffs importation	Feedstuffs importation	M&E, straw .	
FE use	Feedstuffs importation	Feedstuffs importation	Fuel	Fuel

Assumptions on data variation and uncertainty were taken into account to carry out the uncertainty analysis. The main conditions given in Table 5.3 and the summary of the main uncertainties affecting PPC processes (Table 7.12) were considered to provide the main sources of data uncertainty. These uncertainties are scenario-specific for different aspects of the PPC and so individual processes were then considered in each scenario. Table 7.13 summarises these variations in PPC processes for each scenario modelled, to assess the intra-scenario uncertainty.

Table 7.13 Changes in the 'alternative' scenarios to assess the data uncertainty in main scenarios.

PPC Processes	locMEX	stdMEX	orgUK	stdUK
Con-Feed	-30% feed importation, and local maize production	-10% feed importation, and local maize production	-5% feed consumption and grain production	
MM phases				
Enteric F			+30% Methane	
M-collection		Pit emptied twice a month		
M-storage	5% of annual earthen pond			+5 °C
M-disposal	5% increment in efficiency	+10% manure recycling		
Ind-Comm				
Fuel				-5%
M&E			-50%	-5%
Straw				

The locMEX scenario: The main data uncertainties in this scenario came from importation of feed ingredients, manure retention time during M-storage and the frequency of M-disposal (see Table 7.12). Since this scenario is linked to local markets, it is also possible to consider local production of feedstuffs. A reduction of 30% in maize importation was considered in the uncertainty analysis (see Table 7.13). Local crops were not modelled and LCAs for maize production in developing countries was not found in the accessed literature. Therefore, some assumptions were made about the e-impact of local maize production impact. Maize yields in Mexican, in the best case, are 50% lower than in USA, but are produced using similar crop production practices (Tejera and Santos, 2007). Thus, an increment of 50% of the e-burdens from USA maize was assumed for locally-produced maize. Although, the retention time of one week modelled for M-storage is the most common practice, it is possible that some farms have an earthen pond with the capacity to retain sufficient quantity manure to mean that annual emptying is possible. Therefore 5% of the manure during M-storage and M-disposal was accounted as being stored in earthen ponds emptied in the alternative scenario.

The stdMEX scenario: The main data uncertainties came from importation of feed ingredients, and manure retention time during M-collection and M-disposal (Table 7.12). Since the volume of ingredients demanded in this scenario is higher than for farms in the locMEX scenario, it is possible that only 10% of feed requirements could be met from local by-produced crops. Thus a reduction of 10% in maize importation was considered in the uncertainty analysis. The impact of cropping maize under local conditions was taken as that modelled in the locMEX scenario. Variation for M-collection was assessed, considering that all-in all-out is the normal practice in this scenario. Higher excreta volume is expected in the final phase of fattening, and thus a reduction of 50% in the retention time of M-collection was considered as a possible variation, since this is the percentage of contribution by finishers to total manure volume. The manure volume from finishers was calculated considering the daily farm inventory shown in Table 5.22 and manure volume produced for each productive stage (Koelsch, 2007). Originally, zero manure recycling was modelled, and 10% of manure recycling was considered as a possible variation in the alternative scenario, assuming that part of the land owned by the farm is irrigated with slurry.

The orgUK scenario: The main data uncertainties came from the amount of feed consumption, grain production, enteric fermentation, fuel, M&E and straw consumption (Table 7.12). Since sources of data on feed consumption and grain production did not show a large variation, 5% of variation was considered as possible. Pigs kept outdoors have access to grass, and so enteric fermentation can result in more methane production. However, there were no data available in the literature to give a more specific enteric fermentation rate (enteric fermentation in Section 5.1.3). Thus an increment of 30% in methane production from enteric fermentation was assumed. M&E was depreciated as new assets over a five year timescale. Considering that the functional time of new M&E could be substantially longer, a 50% reduction in M&E cost was assumed. Fuel and straw consumption were not changed.

The stdUK scenario: Since this scenario modelled the best agricultural and pig production practices, few uncertainties were found. The main data uncertainties came from climatic temperature during M-storage, fuel and M&E consumption (Table 7.12). In the alternative scenario, an increment of $5^{o}C$ in climatic temperature was considered during M-storage from the average of $10^{o}C$ modelled previously, considering that the majority of standard intensive pig production is in the warmer part of the country. M&E and fuels were considered with 5% variation of consumption, because data sources for the farm budget come from a representative sample of data, which might be expected to have low variation (Defra, 2007).

Results of intra-scenario uncertainty: Changes in data assumptions (Table 7.12) gave rise to substantial differences in the e-impacts of different scenarios, as shown in Figure 7.12. The e-impacts of the locMEX scenario changed by between 2.3% and -5.9% whereas those of the stdMEX scenario had only reductions (between -0.2% to -10.7%), as did the orgUK scenario (between -3.3% to -39.7%). The greatest increase in e-impacts was for the stdUK scenario which was as much as 21.9%. Reduction in feedstuffs importation in the locMEX scenario only brought about a slight reduction in its eco-toxicity (TxW and TxS). Since more of the changes made for the stdMEX scenario resulted in a positive impact, it can be concluded that this improvement was greater than assumed in the locMEX scenario. A slight reduction in feed consumption and extending M&E lifetime made major changes in the e-impact of the orgUK scenario (e.g.40% reduction in O_3D). In contrast, higher climatic temperature in the stdUK scenario increased its e-impacts, mainly for impacts linked to nutrient flow.

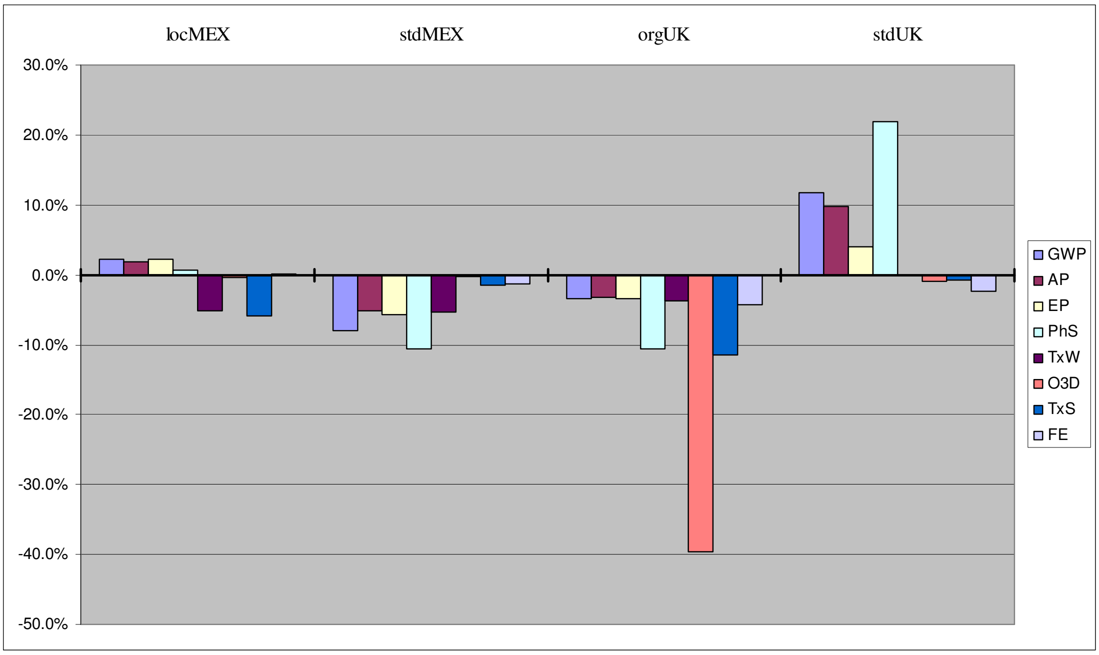

Figure 7.12 Changes in e-impacts for data uncertainties by scenario, expressed as percentage of the scenario values stated in Table 7.2. Negative values are reduction of main scenarios values.

The inter-scenario variability

The inter-scenario analysis shown in Figure 7.13 gives the distribution of the differences between scenarios and a reference value. Since the stdUK had the best performance, this was used as the reference. Difference between scenarios is shown as bars, changes in their alternative scenarios are shown as variation lines and the stdUK scenario values as the origin (zero). Scenarios had extreme differences in two kinds of impacts. The Mexican scenarios mainly accounted for impacts linked to nutrient flow through the PPC (GWP, AP, EP, PhS and TxW). The UK scenarios had impacts linked to mechanisation. Whilst, intra-scenario variations (within-bar lines in Figure 7.13) do not change the general picture for the Mexican scenarios variations, they reduce O_3D and FE values of the orgUK scenario to the level of the stdUK scenario. Consumption of M&E mainly accounted for O3D and FE impacts, and it is possible that the consumption of M&E between the UK scenarios is not different, as discussed previously (Section 6.4). However, the values remain higher than for the Mexican scenarios.

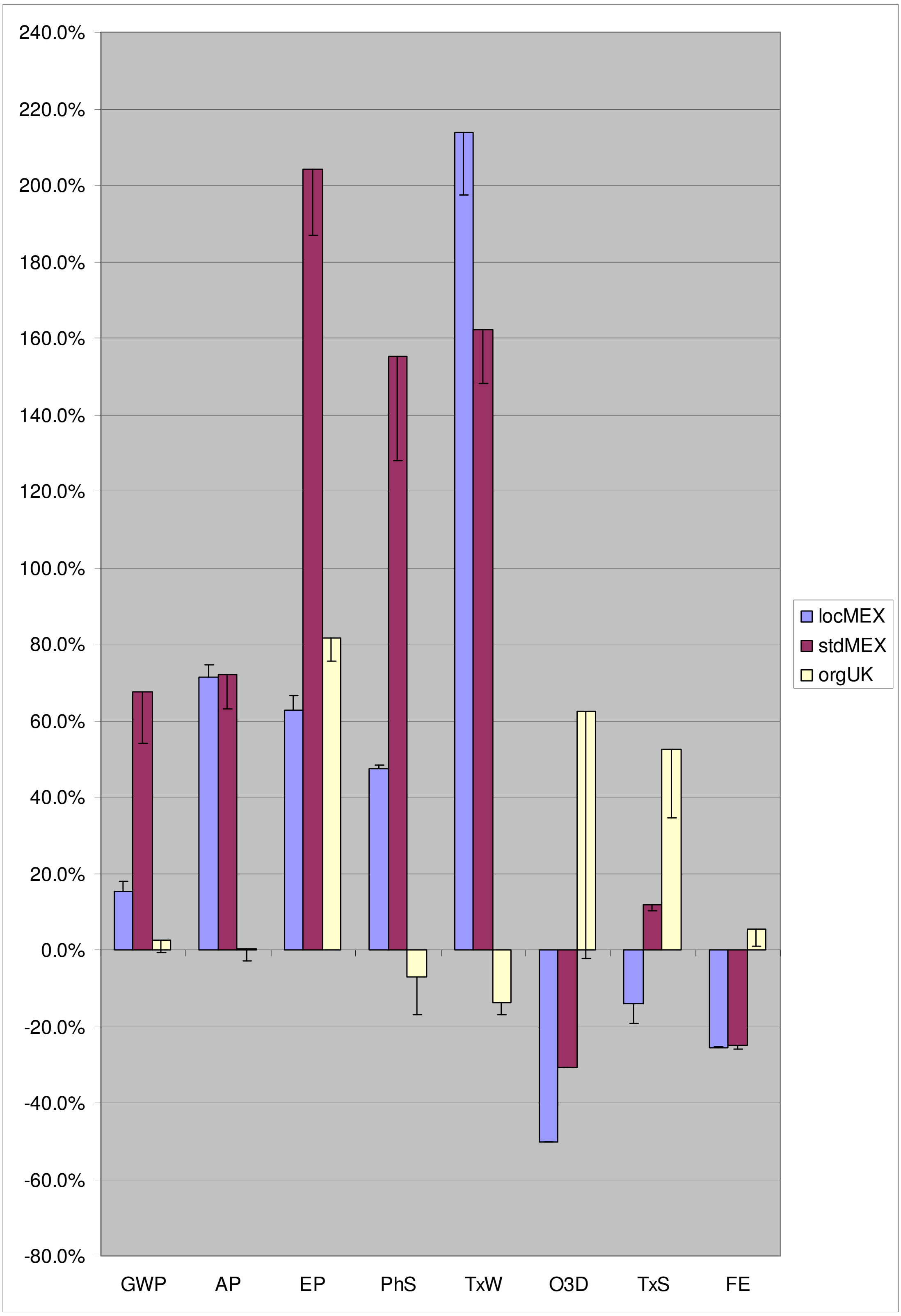

Figure 7.13 Inter-scenario (bars) and intra-scenario (lines) variations, expressed as a percentage of the stdUK scenario values (origin).

Variability following technical improvement

Reduction in feed consumption is the gross consequence of improvement in feed efficiency. Normally this involves other husbandry aspects such as genetic changes, accommodation conditions and feed quality and the final result is a reduction in nutrient losses, because more feed nutrients are converted into pig meat or because less feed is required to produce the same amount of pigmeat. Figure 7.14 shows that there was a reduction in most e-impacts following a 10% improvement in feed efficiency, values are shown as a percentage of the original value. However, this reduction in e-impacts was not proportional between all indicators of e-impact. E-impacts coming from N and P losses (AP and EP) were reduced almost by the same percentage as the improvement in feed efficiency, whilst those e-impacts from nutrient losses mainly influenced by the MM system (GWP and TxW) had a reduction of only about 5%. Finally, e-impacts linked to crop production (PhS, O3D, TxS and FE) decreased by only 2% or less. However, the e-impacts influenced by transportation burdens (TxS and FE) were reduced by 6% for the Mexican scenarios, which import 100% of feedstuffs. TxS and FE impact in UK scenarios were not reduced to the same extent by the improvement in feed efficiency, presumably because the UK makes considerable use of home grain feedstuffs.

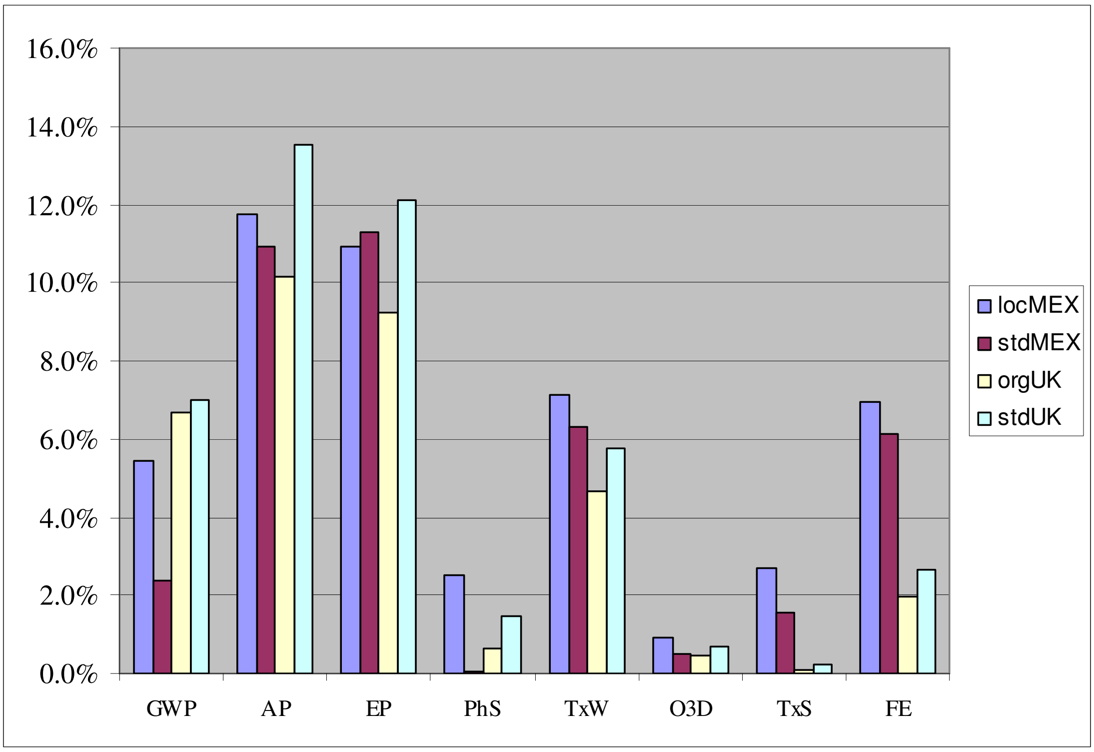

Figure 7.14 Reduction of e-impacts following a 10% improvement in feed efficiency

7.3 *Discussion*

Results of the overall assessment of the environmental impact of pig production show the main differences between scenarios and highlight the origin of these differences, allowing identification of the hotspots for every scenario. Thus, discussion of the impact assessment concentrates on the main opportunities to increase sustainability in each scenario.

7.3.1 Scenario contrasts

The objective of this study was not to determinate which was the best or the worst pig production system but, by comparing scenarios, to contribute to the assessment of their environmental impact. Thus, rather than criticising systems, the contrasting of scenarios highlights the main hot spots in the PPC processes. Considering that the stdUK scenario was the most efficient and balanced scenario in this study (it included the best agricultural and pig production practices), a comparison was made with other relevant European studies from the UK (Williams *et al.*, 2006), France (Basset-Mens and van der Werf, 2005), Sweden (Cederberg and Flysjo, 2004), and Denmark (Nguyen *et al.*, 2008; Dalgaard *et al.*, 2007a). Values for impacts analysed are shown in Table 7.14. In almost all the studies, two systems were modelled and the one which was considered to the most representative system of intensive pig production was used to compare with the stdUK scenario. Since some sources reported data on a dead weight basis and impacts per Kg of pigmeat, 75% killing out percentage and a tonne of live weight were used to transform data to the functional unit in this study. Nguyen *et al* (2008) and Dalgaard *et al.* (2007a), included values for pigmeat processing, which were removed using the percentage of processing provided by the authors.

Table 7.14 Comparison of e-impacts of the stdUK scenario with published data for intensive pig production in occidental European countries.

e-impact Units	GWP tCO2-eq tlw^{-1}	EP kgNO3-eq tlw^{-1}	AP kgSO2-eq tlw^{-1}	PhS kgEthylene-eq tlw^{-1}	FE GJ-eq
Current study	3.3	193	44	0.52	21.9
Cedenberg & Flysjo, 2004	2.0	128	28		
Basset Mens & van der Werf, 2005	2.3	206	43		
Williams *et al.*, 2006	4.8	784	296		
Dalgaard *et al.*, 2007	2.6	226	42	0.86	
Halberg *et al.*, 2007	2.7	230	43		
Nguyen *et al.*, 2008	3.0	201	35	0.84	22.4
Range	2.0-4.8	128-784	28-296	0.84-0.86	22.4

Results obtained in this study are within the range of values for previous reports for occidental European countries (Table 7.14). In the assessment of the LCI, these studies have generally accounted burdens associated with nutrient flows. Most of studies have also included the amount of commodities used for pig accommodation and farm operations, but their impacts have been negligible. The reason for this is because the main impacts of commodities for pig accommodation/farm operations are associated with industrial processes more than with nutrient flows, and the main discussion in these studies has been around impacts linked to nutrient flows. Table 7.15 shows the main distribution of e-impacts reported in two studies and results for the stdUK scenario from the current study. Predictably, there were some variations between studies, but e-impacts related with GWP, AP and EP have similar distribution, whilst commodities with industrial background have minimal participation in these impacts (Table 7.15). Thus inclusion of O_3D, TxW, TxS, and FE use in the current study was valuable.

Table 7.15 Comparison of e-impacts linked to nutrient flow in the stdUK scenario and alternative published data for occidental European countries (as a percentage of total impact).

Sector	Con-Feed	Ind-comm	MM
GWP			
Current study	63.5	10.5	20.2
Basset-Men & van der Werf, 2005	73.0	1.4	20.0
Dalgaard *et al*. 2007	63.0	0.0	17.0
AP			
Current study	23.4	0.0	67.5
Basset-Men & van der Werf, 2005	25.0	0.2	71.0
Dalgaard *et al*. 2007	29.0	0.0	70.0
EP			
Current study	51.5	0.0	47.1
Basset-Men & van der Werf, 2005	64.0	0.1	35.8
Dalgaard *et al*. 2007	72.0	0.0	28.0

7.3.2 The stdUK scenario

The stdUK scenario was used to contrast scenarios in the inter-scenario analysis and was considered to be the most balanced scenario (see Section 7.2.10). On the whole, the stdUK scenario had low values for most of the e-impacts analysed (Figure 7.2). Productivity, nutrient efficiency, good MM practice and low climatic temperature were the main favourable characteristics (Section 3.2.4 and Table 5.3) that conferred a low environmental impact. However, this scenario also has opportunities to improve its sustainability. During the e-impact analysis, contrasting values of different scenarios with the greatest value highlighted outstanding areas, which will now be discussed.

Feed and pig production: This scenario was modelled with good agricultural practice during crop production (Section 3.3.1). The MM phases had optimal conditions to reduce manure fermentation, and manure soil application was modelled according to the requirements of the following crop, thereby minimising N losses. These are normal practices for pig farms represented by the stdUK scenario, and no radical changes are expected to occur for crop or animal husbandry. However, the climatic temperature modelled was the annual average temperature, which can vary with region and season. Thus, in the uncertainty analysis, an increase of 5^{o}C in climatic temperature and 10% improvement in feed efficiency were assessed. Climate change was included to assess impacts on MM phases, since intensive pig farming has been developed in warmer regions. This change produced an increase in GWP and AP by around 10% and PhS by 22%. These increments were not enough to alter the position of this scenario compared to the Mexican scenarios. It also supports the statement that methane capture from natural releases during MM is not enough to make this activity profitable, unless extra heat is supplied (Mistry and Misselbrook, 2005). On the other hand, the main effect of improvement in feed efficiency was on AP and EP impacts. These impacts were reduced by a similar extent to which the feed efficiency was improved. These results contrast with those in a recent report by Fry and Kingston (2009) who undertook a pork LCA for the UK. Fry and Kingston (2009) compared values from the average figure with those ranked in the 'top third' for pig feed conversion and found that differences in feed conversion (17% for weaners and 9% for finishers) produced negligible differences in GWP, AP and EP. Higher differences in the current study were found because improvement of feed conversion in real conditions (top producers in the Fry and Kingston study) also includes other farm performance factors that were not considered for the technological change variability in the current study (Section 7.2.10). The findings of Fry and Kingston (2009) nevertheless support the importance of investigating hot spots highlighted in the scenario comparison.

Ind-Comm: This was responsible for the main O_3D, TxS and FE impacts in the stdUK scenario, which were higher than those for the Mexican scenarios but lower than for the orgUK scenario. The main difference however was with the orgUK scenario (Tables 7.9, 7.10 and 7.11**).** The stdUK impacts suggest that mechanisation of pig production can be responsible for O_3D, TxS and FE impacts, as was also the case for the orgUK scenario. However, impact values were spread amongst more commodities, such as fuels, cleaning substances and disinfectants, M&E, buildings and their maintenance (Figures 7.8, 7.9 and 7.11). Amongst these commodities, fuel was the outstanding consumption. Since the stdUK scenario represents an intensive system, it is clear that this system is energy dependent. However, even under these conditions, its fuel consumption produced lower e-impact than its alternative organic system (Figures 7.8, 7.9 and 7.11). Thus the main challenge that emerged for the stdUK scenario was to achieve a reduction in fuel use, either by using more efficient equipment or designing buildings which depend less on mechanical equipment or allowing for an extension of equipment lifetime. However, reducing fuel and M&E consumption by 5% reduced the Ind-Comm impacts by less than 3%. It is more difficult to reduce O_3D, TxS and FE impact with small changes in fuel and M&E efficiency. More global adjustment must be done also for transportation, electricity and medicines, which are other commodities that weight for these impacts. Nevertheless, this scenario had the lowest environmental impact amongst all the scenarios modelled.

7.3.3 The orgUK scenario

Overall, the orgUK scenario showed the highest e-impact values of all four scenarios for O_3D, TxS and FE impacts (F7.2). Consumption of Ind-Comm was responsible for these impacts. In contrast, the orgUK scenario had relatively low values for e-impacts arising from feed production and MM. Since organic restrictions result in less efficient nutrient flows, this elevates GWP, AP and EP impacts in some processes. Comparing the orgUK with its alternative scenario, the stdUK, shows that feed production and M-disposal were responsible for the main differences. This was especially so for EP, since GWP and AP did not show great differences in total values compared to the stdUK scenario.

Feed production: Values for GWP and EP in the Con-Feed process were greater in the orgUK scenario than in other scenarios. As stated in the EP section (Section 7.2.3), organic feed production demands more protein ingredients and the production of diet feedstuffs produces more EP than from intensively-produced crops. Similarly, an increment in GWP is attributable to organic specifications. Since pesticides are avoided in organic farming, more mechanical procedures are used in weed control. Thus more CO_2-eq was released from agricultural activities (Figure A8-III). The orgUK scenario produced more than double the level of EP for each kg of consumed grain and consumed more protein ingredients than the stdUK scenario (Table 7.5). Organic grain production requires rotation systems that include pre-fertilised soils from legumes, which has extra EP weight for leaching and runoff of nutrients, applied out of plant nutrition necessities (Williams *et al.*, 2006). Furthermore, more protein ingredients must be included to supply the right amount of essential amino acids for pig diets. Both points represent an important challenge for the orgUK scenario. On the other hand, whilst improving feed efficiency can reduce EP and AP by the same percentage that feed efficiency was improved, the substantial difference from the stdUK scenario remains, when the same criteria are applied (Figure 7.14).

Manure management: Adding up the EP impacts of MM phases for the UK scenarios, the orgUK scenario releases more gNO_3-eq than the stdUK scenario (Table 7.16). This is attributable to three reasons. Firstly, the N content of manure deposited by organic pigs is higher than for pigs under intensive conditions, outdoor organic pigs consume more protein ingredients and gain less weight, releasing more manure-N (Table 5.25) compared to pigs reared indoors. Secondly, manure applied to soil is more N concentrated, whilst slurry in the stdUK scenario is lower in N content because of storage N-losses that do not contribute to EP. Finally, N lost through runoff and leaching is higher in the orgUK scenario since outdoor pigs defecate in specific places, resulting in heterogeneous N distribution on paddocks and consequently more N losses between application and plant use (Halberg *et al.*, 2007; Hansen *et al.*, 2006). Reduction of excreted-N is directly linked to improvement in diet composition. Improvement of outdoor pig production for N fertilisation needs more research on animal husbandry and paddock management to reduce nutrient runoff and leaching.

Table 7.16 EP for kg of N losses during M-M phases

Categories	orgUK	stdUK
Kg N losses during MM phases, kg N tlw^{-1}	59.5	47.9
Total EP, gNO_3-eq	133,000	90,700
Average EP for kg N in manure, gNO_3-eq/kg	2,235.3	1,892.3

Ind-Comm: The orgUK scenario showed the highest values for O_3D, TxS and FE use (Figure 7.2). Values for these e-impacts were strongly influenced by Ind-Comm consumption (Section 6.2.6). Mechanisation was needed both for supplying machinery and arcs, and for transportation of mobile equipment and housing. Additionally, agricultural machinery used for straw production increased the contribution of straw for these e-impacts. Thus, higher consumption of straw, fuels, M&E and hand tools used on outdoor pig activities increased O_3D, TxS and FE use. However, it is possible that almost O_3D and FE impacts coming from M&E are similar to those for the stdUK scenario, as highlighted in the inter-scenario uncertainty analysis (Figure 7.13). A large straw consumption was expected, since additional bedding is essential under outdoor conditions. Fuel for running tractors to undertake daily feeding and arc movement is also an understandable consumption. However, the depreciation cost considered for M&E gives rise to more uncertainty (see Section 6.2.6), and thus doubling the lifetime of M&E was included in the uncertainty analysis (the orgUK scenario in Section 7.2.10). This change reduced O_3D by 40% (Figure 7.12), resulting in values similar to those for the stdUK scenario. The same was not true for TxS, with only a 10% reduction from doubling M&E lifetime, which was insufficient to achieve similar values to the other scenarios. TxS was also increased as a result of straw consumption (Figure 7.9). However, the M&E consumption causes higher O_3D impacts than in the Mexican scenarios; this could be a hot spot for the orgUK scenario.

On the whole, the main opportunities to improve sustainability in the orgUK scenario emanate from N-fixation and protein consumption for Con-Feed, paddock management for M-disposal and mechanisation for Ind-Comm consumption. The need for feed efficiency improvement and reduction in the risk of nutrient leaching in outdoor farming has been highlighted in other studies (Dalgaard *et al.*, 2007b; Williams *et al.*, 2006; Basset-Mens and van der Werf, 2005; Cederberg and Flysjo, 2004). However, the importance of consumption of other commodities on organic pig farms, and different e-impacts to those related with nutrients losses, was not found in the literature. The uncertainty analysis showed the importance of including those commodities of industrial origin and suitable indicators in the analysis of organic systems, not only processes and indicators for nutrient flows.

7.3.4 The stdMEX scenario

The stdMEX scenario showed the highest e-impact values for GWP, AP, EP and PhS (Figure 7.2). These e-impacts are strongly influenced by nutrient losses during MM phases and fuel combustion use of imported feedstuffs, long manure retention time under high climatic temperatures and zero recycling of manure nutrients were the main characteristics that meant this scenario had the greatest e-impact (Table 5.3). The stdMEX scenario had the highest values for four of the nine e-impacts considered in this study. GWP was almost 30%, and PhS nearly 45% greater than that of the locMEX scenario. Equally the EP was 40% higher than the orgUK scenario and its AP was almost the same as the locMEX scenario (Figures 7.3 to 6). Variations included in the uncertainty analysis only reduced the e-impact of the stdMEX scenario from 9% to 10% (Figure 7.12), a reduction which did not greatly alter its position compared to the stdUK impacts (Figure 7.13). Following the main origins of these differences in Appendix 8 (Figures A8-II, VI, X and XIV) maize inclusion and different MM phases were responsible for the major differences.

Feed production: Con-Feed impacts for PhS and AP from the stdMEX scenario were higher than the UK scenarios (Figures 7.5 and 6). The main PhS impact was for transportation of diet ingredients. Since imported maize and soya were the main feed-ingredients in Mexican scenarios, the extra PhS weight from importation was more than double that of home grain production in UK scenarios (Table 7.6 and Figure A8-X). Consequently, a reduction of 10% in imports reduced PhS impacts by 10%. Further reduction in PhS impact can be expected if extra transportation is avoided through improvements in feed efficiency, as shown Figure 7.14. Transportation had less effect on

AP, which was strongly linked to crop fertilisation. However Con-Feed PhS and AP weight were only 10% and 15% of total impacts respectively (Figures 7.5 and 7.6). Thus a negligible advantage could be expected over the locMEX scenario if feed efficiency is improved in both scenarios (Figure 7.14) and the main opportunities for improvement in the stdMEX scenario are in MM.

Manure management: This was the main cause for the high GWP, AP, EP and PhS values cited previously. Nutrient losses responsible for these e-impacts occurred in different phases. During M-collection the main nutrient losses that contribute to GWP and PhS impacts occurred, whereas M-storage was the main point for AP releases and M-disposal for EP impact (Figures 7.3 to 7.6). A long retention time during M-collection was the main management factor that provided greater anaerobic conditions. This factor, together with higher climatic temperatures, increased the CO_2-eq releases more than for the locMEX scenario, which had a relatively short retention time for M-collection in warm temperatures (Table 3.7). In the case of AP, it was mainly the M-storage and secondary M-collection that contributed to AP of the stdMEX scenario. During these two phases, high environmental temperature facilitated ammonia losses during a long period of anaerobic fermentation (Table 3.12). For EP, the M-disposal method gave extreme differences from the other scenarios. Zero manure recycling in the stdMEX scenario was responsible for the huge increment in EP impact. The stdMEX scenario has an EP value almost three times higher than its alternative scenario and more than ten times higher than the lowest scenario value, namely the stdUK (Table 7.4).

Taking account of e-impacts resulting from feed production and MM in the stdMEX scenario, the main opportunities to reduce e-impact are in the MM phases. Firstly, retention time for M-collection is a key management factor that can displace manure fermentation from individual pits to a general storage system such as lagoon or outdoor slurry tanks. Open M-storing containers do not reduce slurry emissions in themselves, but make it possible to implement methane collection systems that are impossible to install in pig buildings. Covering lagoons and tanks reduces methane and N losses simultaneously. This allows the possibility of using methane as an energy source and maintaining more N in the sewage in a soluble form (ONU, 2007). Secondly, reduction of nutrient losses in M-disposal, as much as methane collection, offers opportunities both for reduction of e-impacts and improvement in nutrient efficiency. Manure recycling reduces nitrate and phosphorus losses for runoff and leaching (Chambers *et al.*, 2000). For example, the locMEX scenario released only one third of the level of NO_3-eq released by the stdMEX scenario did under similar climatic conditions, even though the locMEX scenario did not use the most efficient manure recycling techniques (Table 5.3). Finally, consumption of local crops can reduce the need for importation. However, because of limited national crop availability and lower prices in the international market (SIAP, 2007), under conditions modelled for the stdMEX scenario, this possibility looks less promising because local crop production does not supply enough grain to cover the demands of the sector. Immediate implementation of manure recycling and utilisation of local crops could be more challenging than methane collection, since pig farmers in the stdMEX scenario are not integrated with crop production (Perez, 2006, p46; FAO, 2002). These two weaknesses in the pig production chain of the stdMEX scenario are simultaneously new opportunities in the short and long term. Extending links to crop farming partners is not only a matter of reducing e-impacts, but also offers great opportunities for reducing the uncertainty surrounding supply of feedstuffs. On the other hand, even though the integration of crop production to the PPC looks attractive, methane capture and recycling is more worthwhile, because MM results in more e-impacts than feed production in this scenario (Figures 7.3 to 7.6). However, implementation of both changes can contribute to the improvement of sustainability in the stdMEX scenario, reducing e-impacts and uncertainty in the availability of dietary ingredients.

7.3.5 The locMEX scenario

The locMEX scenario had the highest e-impact value only for TxW, but this had almost as high weight as the stdMEX scenario for AP (Figure 7.2). Lower climate temperature, shorter manure retention time in the MM phases and greater utilisation of manure recycling are the main advantages over its alternative scenario, the stdMEX scenario (Table 5.3). However, these differences not were enough to achieve the values obtained for the stdUK scenario for the Con-Feed and MM phases. The TxW in the locMEX scenario was 15% higher than the stdMEX scenario and more than 70% higher than the UK scenarios (Figure 7.7); its AP was almost similar to the stdMEX scenario and 40% higher than the UK scenarios (Figure 7.6). For GWP and PhS, the locMEX scenario has higher values than the UK scenarios and lower values than that the stdMEX scenario (Figure 7.2). TxW, the leading impact of this scenario, is strongly influenced by fuel combustion, mainly for transportation (Figure A8-XVII). AP, the second highest impact, comes from ammonia released during MM and fertiliser application in crop production (Figure A8-XIII). Tracking the origin of the locMEX impacts in Appendix 8 (Figures A8-I, V, IX, XIII, XVII) shows that feed ingredients, M-storage and M-disposal accounted for these differences.

Feed production: Since feed production was not different from the stdMEX scenario, its Con-Feed impacts looks similar, differing only in relation to feed consumption (the locMEX scenario consumed more). Thus the PhS and AP impacts from Con-Feed were the highest for all scenarios (Table 7.5 and 7.6). The main PhS impact in Con-Feed comes from transportation of diet ingredients, as was the case for the stdMEX scenario (Figure A8-IX). The AP impact from Con-Feed was mainly due to fertilisation in crop production (Figure A8-XIII). Thus reduction of PhS releases can be expected if extra transportation is avoided and utilisation of locally-produced crops is increased (Figure 7.12). In the uncertainty analysis, 30% of grain demand was met from local production, without crop improvement. The advantage gained from avoiding transport was then lost because of the lower locally-produced crops yields. However, PhS and AP impacts from feed production were less important than those coming from MM (Figure 7.5 and 6). This finding was supported for results of feed efficiency improvement (Section 7.2.10). In the locMEX scenario, as in other scenarios, e-impacts from nutrient losses are reduced as much as the feed efficiency is improved, except for the GWP and TxW, which are reduced by 5%. This emphasises the contribution of manure fermentation to GWP impact.

Manure management: During this PPC process, the main e-impacts of the locMEX scenario were produced. Nutrient losses responsible for the main impacts on GWP, PhS and AP occurred during M-storage (Figures 7.3, 5 and 6), and those for EP during M-disposal (Figure 7.4). A short retention time during M-collection did not allow manure fermentation in this phase, transferring the main losses to the following phases. Additionally, the 4^{o}C lower climatic temperatures than its alternative scenario (the stdMEX) reduced CO2-eq releases during manure fermentation (Figure 7.3). In the case of AP, the locMEX scenario had a similar distribution of ammonia releases to that of the stdMEX scenario, but lower ammonia losses occurred as a result of better climatic conditions and transfer of manure between MM phases (Figure 5.4 and 5.5). The EP of the locMEX scenario was three times lower than for stdMEX, but it was also three times higher than the stdUK scenario which disposed of manure more efficiently (Table 7.4). In the uncertainty analysis, 5% of M-storage in lagoons and a 5% increase in the efficiency of M-disposal gave relatively small changes in impacts related to nutrient losses, reducing TxW and TxS by nearly 5% (Figure 7.12).

Taking into account the origin of e-impacts and contrasting results of scenarios, in the locMEX scenario the main opportunities to reduce the e-impact are in the MM phases, just as for the stdMEX scenario. Firstly, a short retention time for M-collection gives the opportunity that fermentation will occur mainly during M-storage where it is easier to apply techniques for methane capture and use (Petersen *et al.*, 2007), even on farms with low manure volumes (Chara and Giraldo, 2001). Secondly, warm climatic temperatures promote more profitable methane capture yields than in temperate countries (Mistry and Misselbrook, 2005). Manure recycling according to plant requirement could reduce runoff and leaching losses by as much as 300% (compared with M-disposal impacts of the stdUK scenario in this study), strengthening strategies suggested for nutrient recycling (Chambers *et al.*, 2000). For example, the stdUK scenario, which had higher manure nutrient content during M-disposal, released one third of the level of NO_3-eq released by the locMEX scenario. Improvement in the integration of pig-crop production looks possible, since this link does occur from time to time in commercial farming practice. In addition, uncertainties regarding maize price and supply make farms in this scenario more susceptible to variations in the international market for crops (SIAP, 2007; Gallardo *et al.*, 2006). Thus, reducing the dependency on imported feedstuffs not only gives competitive advantages, but also improves manure recycling and, in consequence, its e-impact. Training or technical support on the appropriate rate of manure application can give immediate results in manure fertilisation and crop yield improvement. In addition, improvement of crop-pig farm integration in the intermediate and long term can reduce dependency on imported crops. On the other hand, the results for GWP show that there are two opportunities to improve the locMEX scenario e-impact. One is to capture and use methane produced by manure fermentation and the other is to adopt outdoor strategies of MM that avoid storing manure under anaerobic conditions, such as is done in intensive scenario (Figure 7.3). Thus, in summary, integration of pig-crop production as well as methane use offers opportunities to improve the sustainability of the locMEX scenario.

Chapter 8 General Discussion

8.1 *Structure of the pig production chain*

In the initial phase of this study, different options for inter-relationships in the PPC were reviewed, from the traditional food chain to the value food chain (Figure1.2). Integration of the PPC, increasing vertical and horizontal relationships, will be necessary to increase opportunities for sustainability. Thus those PPC that improve the links between different sectors of the chain will benefit not only economically, discussed in the structure of the PPC (Section 1.4), but also from environmental improvements. Chapter 7 highlighted the opportunities for environmental improvement in different parts of the PPC process for each scenario. Practically all sectors have challenges: crop production in fertilisation, feed production in nutrient availability, pig production in MM, and industrial sectors in M&E and cleaning substances. However, without communication and trust between partners in the PPC, consumer pressure is passed downstream from retailers through sectors to pig farmers, where attention is concentrated on the farm impact and performance (Hobbs, 1996). The challenges identified were scenario-specific and so emerged in different points of the PPC. Implementation of strategies includes actions in more than one sector, and thus increasing trust and collaboration between PPC sectors is another challenge arising in practical conditions.

8.2 *Methodology and LCI*

8.2.1 Scenarios methodology

In the case of animal production, scenario methodologies have been used before for dairy production (Demeter *et al.*, 2009; Chantreuil *et al.*, 2008), pig production (Basset-Mens and van der Werf, 2005; Stern *et al.*, 2005; Cederberg and Flysjo, 2004; Stern *et al.*, 2003) and poultry production (Pelletier, 2008; van Horne *et al.*, 1998). These studies modelled different scenarios for financial options (Demeter *et al.*, 2009), changes in regulations (Chantreuil *et al.*, 2008) and changes in farm management (Pelletier, 2008; Basset-Mens and van der Werf, 2005; Stern *et al.*, 2005; Cederberg and Flysjo, 2004; Stern *et al.*, 2003). Focusing on the environmental impact of pig production, scenario methodologies have been used to assess system changes in the future (Cederberg and Flysjo, 2004; Stern *et al.*, 2003) and possibilities for success in the present (Basset-Mens and van der Werf, 2005). In the current study, standard and alternative scenarios were defined for two country conditions. Thus the alternative scenarios encompassed internal country elements of variation and external variations or differences. In the scenario methodology, the impact of changes in a system is usually assessed by comparing outcomes of a scenario capturing the studied or proposed changes with the corresponding outcomes of a reference situation (Alcamo, 2001). In the present study this corresponded to the differences established for the standard and alternative scenarios. The comparison approach for integrated system assessment typically requires the definition of at least two main types of scenarios: the reference and the alternative scenario (Cederberg and Flysjo, 2004). The current study also contrasted two country conditions, giving extremes from the perspective of feed and pig production processes. Scenario methodology proved to be a suitable technique to analyse these differences. Scenarios have been used to estimate past and future tendencies or contrast current systems (Cederberg and Flysjo, 2004; Alcamo, 2001). The alternative scenarios account for system options and technological changes for which stakeholders require integrated assessments (Therond *et al.*, 2009)**.** Thus, in the current study, inter-scenario comparison allowed identification of hot spots in all scenarios. Scenarios can also be used to analyse the social, economic and environmental impacts of specific environmental and agricultural systems, or to contrast systems, highlighting the differences produced as a consequence of changes in the systems and/or technological changes due to external driving forces such as region or climate (Alcamo, 2001). Variations or combinations of reference scenarios were therefore developed to evaluate the uncertainty of external and internal driving forces as suggested by Alcamo *et al*. (2001) and Therond *et al*. (2009). Analysing uncertainties for each scenario involved integrating new scenarios in the uncertainty analysis. Capturing such uncertainty in single scenarios has advantages and disadvantages. On one hand, use of single scenarios reduces the risk of a confusing proliferation of scenarios, which is more useful for inter-scenarios comparison than comparisons for single variations (Therond *et al.*, 2009). On the other hand, a single change is useful for assessing specific strategy changes or assessing new technologies (Hendrickson *et al.*, 2006; Payraudeau and van der Werf, 2005). This is one of the suggestions arising from the current study. Defining scenarios with contrasting characteristics for MM, feed production and mechanical dependency produced good contrasting systems, but at the same time increased the variability and uncertainty, mainly for data availability. Although the process of modelling the Mexican scenarios was described carefully, several values were modelled using general statistics, expert opinions and personal previous experience, increasing the uncertainty. Available studies (Gallardo *et al.*, 2006; Perez, 2006; Ochoa and Ortega, 2005; Jurado, 2003; FAO, 2002) gave general guidelines for decisions on scenario performance and differences between Mexican scenarios, but experts' opinion gave more specificity in these scenarios. Modelling increases the uncertainty in the scenario results, therefore specific strategies to improve the opportunities highlighted in this study will be more valuable if they are assessed in real conditions.

8.1.2 Life Cycle Assessment

In this study, two strategies were used to analyse the four scenarios: a pre-assessment and a hybrid-LCA method. These methods facilitated the system boundary construction and clarified the burdens' inventory collection, two of main challenges in the LCA.

The pre-assessment: The methods to define a system boundary in the LCA can produce doubts on the LCI coverage, because some important processes or commodities may remain outside the analysis. However, it is very difficult to decide which process and commodities should be included, especially if previous experience is not present in the analyst's background, as was discussed in the definition of the system boundary (Section 2.8). Additionally, a wide and extensive LCI does not always allow for the analysis of all e-impacts that burden the analysed process. This is limited by the knowledge of the economic links, the main environmental impact for each industrial sectors and the network of connections among industries that exist in the supply chain (Hendrickson *et al.*, 2006, p21). Thus, the criterion used to draw a boundary around the studied process is a controversial issue (Suh *et al.*, 2004). The pre-assessment developed in the current study (Chapter 4) proved to be useful in giving the background needed on the environmental impacts of the supply chains providing commodities consumed in pig production. Predictably, the pre-assessment also increased clarity and transparency in the LCI construction. This was achieved by including in the LCI those commodities highlighted in the pre-assessment of the LCA (Section 4.3) and analysing e-impacts that are important not only for nutrient flow (Sections 7.2.7 to 9).

The hybrid-LCA: This methodology combined a detailed collection of e-burdens from the main sources (process-LCA), and a broad compilation of e-burdens from indirect sources (EIO-LCA), represented graphically in Figure 3.3. Hybrid-LCA methodology has been used widely in industrial sectors (Lagorse *et al.*, 2008; Suh and Nakamura, 2007; Weber and Matthews, 2007; Lenzen, 2002) and was recently used for agricultural products (Meisterling *et al.*, 2009). Meisterling *et al.* (2009) made a hybrid-LCA for wheat production in the USA. The advantage of a hybrid-LCA method is that it combines the main strengths of EIO-LCA and process-LCA (Hendrickson *et al.*, 2006). In the current study, the hybrid-LCA combined the easy and broad perspective of EIO-LCA to track e-burdens from commodities that were not in the main supply chain of pig production, with the specificity of information needed to track e-burdens from process involved in the nutrient flow of the process-LCA (Section 7.1). The hybrid-LCA made it possible to expand the system boundary and include the e-burdens of commodities that have not been included in previously studies or have been assessed with relevant indicators of the nutrient flow (Table 7.14 and 15), as reported in studies that used the hybrid-LCA in other industries (Suh and Nakamura, 2007).

In conclusion, common difficulties for construction of the system boundary in the LCI and for accounting e-burdens from indirect sources were solved through the methodology developed for the pre-assessment and implementation of a hybrid –LCA in order to analyse different pig production scenarios.

8.3 *The stdUK scenario*

The stdUK scenario had the highest values for physical performance and for interaction with other PPC-processes (discussed in Section 7.3.2). These characteristics conferred low nutrient-related e-impacts and resulted in the stdUK scenario impacts providing basic values for the inter-scenario analysis, which allowed for contrasts with other scenarios. On the other hand, the intra-scenario analysis showed the stdUK scenario had its own hot spots in M-storage and Ind-Comm processes (Section 7.3.2), highlighting opportunities to improve sustainability. Capturing and transforming methane into electricity is a technological change that can be assessed in specific conditions. For example, in the uncertainty analysis, a change of $5^{o}C$ in climate temperature increased the CO_2-eq emissions for GWP by almost 12% (Figure 7.12), of which nearly 60% came from methane production during M-storage (data not shown). In this context, in practical conditions increasing temperature during manure storing also increases methane yield in systems with similar conditions to the stdUK scenario. Thus, the statement of Mistry and Misselbrook (2005) that higher temperatures in slurry storage tanks are necessary to give profitable methane use in British farms is supported by the results of the current study. This is a good example of application of the results. However, polishing the LCI for individual cases produces more realistic results.

Another opportunity which emerged from the EIO-LCA analysis was the reduction of fuels and M&E consumption (Ind-Comm in Section 7.3.2). This challenge implies the development of more efficient and durable M&E for pig farming, although this challenge should be achieved in the intermediate and long term since it depends on other industrial sectors. Considering that mechanisation and modernisation of agriculture have been highlighted as being responsible for deterioration and damage of natural resources in the countryside (Ilbery and Maye, 2005; Yakovleva and Flynn, 2004), attention to this issue should be included in the scenario sustainability goals. This is especially important because globalisation of the food supply chain has increased disconnection between farming and food processors and the final consumer, passing pressure upstream (Poole *et al.*, 2002).

8.4 *The orgUK scenario*

Although guidelines for organic pig farming emphasise reduction in e-impacts and in consumption of natural resources, the version of organic farming analysed in the current study (the orgUK scenario) gave rise to some e-impacts that still offer substantial opportunities to increase sustainability. Von Borell and Sorensen (2004), in summarising basic rules for organic farming, stated that "production methods should be selected based on criteria that meet all health regulations, work in harmony with the environment, build biological diversity and foster healthy soil and growing conditions". Additionally, they say that "the organic farming should participate in the promotion of a balanced mix of crop and livestock production, leading to closed and sustainable nutrient cycle". Following these principles, reduction of EP is an important challenge for nutrient flows in the orgUK scenario. Previously, Hermansen *et al.*(2004), Eriksen and Hermansen (2005), Williams *et al*. (2006) and Halberg *et al*. (2008) concurred that the main differences in the EP impacts of conventional pig production systems came from higher nutrient losses in agricultural practices, ingredient consumption and nutrient losses from the grazing area. Thus, Hermansen *et al*. (2004), when summarised the challenges for organic pig production, maintained that attention should be focused on optimizing the value of the various animal capabilities and controlling the impact of animals in the environment, in order to balance environmental benefits and animal behaviour requirements. Hermansen *et al*. (2004) concluded that the challenge of this dilemma is to find the way for better integration of pigs into land use in general. Thus, the EP of the orgUK scenario can be reduced by avoiding nutrient losses for crop production and improving paddock management (Eriksen and Hermansen, 2005; Hermansen *et al.*, 2004). Since the orgUK system is dependant on N-fixation and manure deposition as the main sources of fertilisation, soil nutrient incorporation is dependent on crop rotation systems and variations in paddock management. This goal can be achieved in different ways. Strategies should change as changes in the pig accommodation system evolve. Thus, combinations of grazing and rearing in barns have different options to reduce the environmental impact and at the same time allow growing pigs to have plenty of space (Eriksen and Hermansen, 2005; Hermansen *et al.*, 2004). Individual farms take decisions on paddock layout; variation depends of soil type and farm size, but the paddocks are normally moved to a new field every spring (Hermansen *et al.*, 2004). The rotation system includes a year with barley or another grain crop with an under-sown grass-layer and a year with pigs on pasture. The stocking rate is practically adjusted to deposit 280 kg N/ ha every second year, to avoid exceeding an annual N supply of 160 kg/ha (Williams *et al.*, 2006; Hermansen *et al.*, 2004), but the rate of deposition is in surplus. This nutrient surplus represents an environmental risk, due to the gap in time between nutrient deposition and nutrient use by plants, both for maintenance of the grass-sward and for the time that mediates use of nutrients by the next crop (Eriksen *et al.*, 2002; Williams *et al.*, 2000). Investigating combinations of accommodation systems and crop rotations can give best soil nutrient management.

Another opportunity highlighted to improve sustainability is in feed consumption. Comparing the orgUK with the intensive scenarios, the use of synthetic amino acids in the intensive scenarios allowed a 16% reduction in manure N excretion (Table 5.25), indicating a major challenge to reduce demand for protein crops during diet formulation.

Finally, mechanisation of pig farming activities was highlighted as an important source of e-impacts in the orgUK scenario. These findings were through M&E consumption and mechanical weed control that increase the environmental impacts of the system. Uncertainty analysis showed that equipment lifetime can be the cornerstone to reduce part of these impacts. Thus, instead of mechanisation, human participation in crop and animal husbandry and M&E use with a long lifetime should be in the list of opportunities for organic pig production, if the organic system is to be a real custodian of the countryside; mechanisation and modernisation have been highlighted by others as responsible for deterioration of the countryside (Ilbery and Maye, 2005, p 331)

8.5 *The stdMEX scenario*

The stdMEX scenario had the worst performance for most of the e-impacts related to nutrient flow. In contrast to the orgUK scenario, these impacts are not due to excessive nutrient consumption, but mainly came from transportation of feedstuffs and MM (Section 7.3.4). Considering the main findings in the Chapter 7, a 30% reduction of imported grain can reduce the PhS by 10%. However, more than half of this PhS reduction can be cancelled if best agricultural practices are not adopted in the production of local crops (Figure 7.12). Transferring collected manure from under-floor pits to the outdoor manure storage system more frequently (almost twice a month) increases by 50% the possibilities to collect methane from lagoons (in the uncertainty analysis, Section 7.2.10). Covering manure storage facilities can allow the Mexican farms in the main pig production regions of the country to capture methane in profitable way (AgCert, 2006). AgCert (2006) made a regional budget of the capacity for methane production and use in intensive farms in the central part of Mexico. The budget included 8100 sows and their respective progeny. By covering lagoons and burning methane, AgCert (2006) calculated a reduction of seven times the actual CO_2-eq releases. In the current study recycling manure yielded a reduction of 160 to 200% in the EP of stdMEX production, and can replace nearly 14 kgN of synthetic fertiliser on an N basis (almost 30 kg of urea) (Figures 7.13 and Table 5.32). Niles *et al*. (2002) suggested changes for agricultural practice in developing countries that favoured carbon mitigation, amongst which is manure recycling. They made calculations for the increment of net value in 2002 if a country was to adopt carbon mitigation changes in agricultural practice and implement carbon-friendly practices. Benefits included those of the host-country income for yield improvement, increment of biomass use, reduction in fossil-fuel use and reduction in agricultural emissions. Thus, methane collection and manure recycling are not only options to reduce e-impacts, but they are also profitable and sustainable opportunities for farms that share the stdMEX scenario conditions.

8.6 *The locMEX scenario*

The locMEX scenario had similar environmental impact compared to the stdMEX scenario. However, the e-impact burdens of the locMEX scenario are intermediate between its alternative scenario (the stdMEX) and the UK scenarios (Section 7.35). Lower productivity is the main weakness of the locMEX scenario and the recycling of manure its main advantage compared to the stdMEX scenario. The locMEX scenario has several opportunities to increase its sustainability. The main opportunities lie in improving productivity, reducing feedstuff dependency on imported, improving the crop-pig production relationship, increasing nutrient recycling efficiency and the capture and use of methane.

Improving productivity of the stdMEX scenario can reduce N-excretion by 11% (Table 5.25). Reducing importation of feedstuffs can diminish PhS impacts, but this reduction is conditional on improving crop fertilisation (Section 7.2.10). Integration of pig-crop production is a possibility that would allow improvement of pig manure recycling for crop fertilisation. Thus, the challenge is to improve manure incorporation techniques and implementation of tools to assess availability of nutrients in slurry used for fertilisation, fertilisation schedules and calculation plant requirements for the next crop. Farmers should be trained or given technical support to achieve this challenge. Farms in the same conditions as those in the locMEX scenario were highlighted as the second source of e-impacts that pig production delivers to the Mexican environment (Pérez, 1997). However, only methane capture and recycling of manure gross solids were pointed out as opportunities to increase income (Jurado, 2003). In contrast, changes in agricultural practices and manure fertilisation were not considered in these reports. Contrasting Mexican and UK scenarios shows the opportunity for a rethink of manure fertilisation as part of the PPC. For methane capture and increased nutrient preservation, manure storage capacity must be increased to one year, because fertilisation should be in specific crop seasons. Finally, farms similar to this scenario have a good connection between these opportunities and actual farm conditions, because the changes needed for implementation look possible in the short and intermediate term with worthwhile improvements.

8.7 *Other factors considered in this analysis*

The integration and applicability of opportunities relating to environmental issues are conditioned by financial and social issues. Thus, updating infrastructure, investment in alternative equipment, implementing technical changes and extending business links to other PPC sectors all require consideration of financial solvency and reliability. The financial budgets (Chapter 6) provide information on profitability and wage expenses. The farm-budgets of the different scenarios in Section 6.2 were used to facilitate the inter-scenario financial comparison. Profitability and labour ratios were used to determinate the financial and employment opportunities for each scenario. When inter-firm comparison is made, the ratio analysis becomes more useful to the business than the total financial information. The ratio analysis avoids potential confusion in accounts (Warren, 1997, p31).

Three profit margins and the wage expenses margin were calculated (Table 8.1), using the farm financial-budgets given in Section 6.2. The guidelines for inter-firm comparison on financial accounts provided by Warren *et al*. (1997) were used to calculate the profit and wage expenses margins.

Table 8.1 Inter-scenario comparison on profit margins (% of income from sales)

Category	stdMEX	locMEX	stdUK	orgUK
Sales	100.0	100.0	100.0	100.0
Gross profit margin	40.4	31.8	45.5	36.2
Operating profit margin	21.5	14.7	10.2	10.3
Net profit margin	15.5	11.8	7.6	7.0
Labour margin	3.5	7.3	11.3	10.7

The profit margins are ratios of sales to different stages of profitability. Net profit is the monetary income available after discounting all possible expenses from selling a tlw. The operating profit is the monetary income available after discounting the same categories as in net profit, except financial charges. Gross profit is the monetary income available after discounting only direct purchases. This means that categories classified as "other expenses" in the financial balance sheet, such as labour, machinery and power, rent and rates, services, administration and depreciation costs were not discounted in the gross profit. The percentage contribution by category is shown in Table 8.2.

Table 8.2 Category distribution in scenarios budget (as percentage of income from sales per tlw)

Scenarios	stdMEX	locMEX	stdUK	orgUK
Sales	100.0	100.0	100.0	100.0
Expense:				
Purchases	59.6	68.2	54.5	63.8
Other expenses :				
Labour	3.5	7.3	11.3	10.7
Machinery & Power	0.1	0.1	3.7	1.9
Rent and rates	1.0	0.5	3.3	2.7
Services	7.1	5.7	6.5	1.9
Administration	5.2	2.6	3.8	1.2
Depreciation	2.0	1.0	6.7	7.5
Finance charges	6.0	2.9	2.5	3.4
Net profit	15.5	11.8	7.6	7.0

The analysis of these financial margins gives additional information about the possibilities to improve sustainability for each scenario. Figure 8.1 shows variations in financial margins of each scenario in comparison with the stdUK scenario. Although profit margins allow inter-scenarios comparison, they are limited to interpretation of monetary income flow. It is risky to use these margins to assess productivity or enterprise activity. In Figure 8.1 it can be seen that the Mexican and the orgUK scenarios spend more money on common purchases than the stdUK scenario when considering gross profit margin, but this comparison is inverted when other expenses are included (i.e. looking at operating and net profit margin). Table 8.2 shows that, for the UK scenarios, the main increments for other expenses come from direct and indirect expenses for M&E and labour. Thus there was greater margin for operation in the Mexican scenarios than in the UK scenarios (the operating profit margins), even after considering financial charges (net profit margin). The opposite situation exists for the expenses used for wages. The labour margins show that less money from sales is used to share with farm workers in the Mexican scenarios than in the UK scenarios. The extra percentage on the net profit margin was similar to the percentage reduction in labour margin for Mexican scenarios. The stdMEX had the highest differences. Thus mechanisation and regional working regulations limit the profitability of the UK scenarios. Although from a different perspective, mechanisation does not necessarily limit sharing sale income with labour expenses.

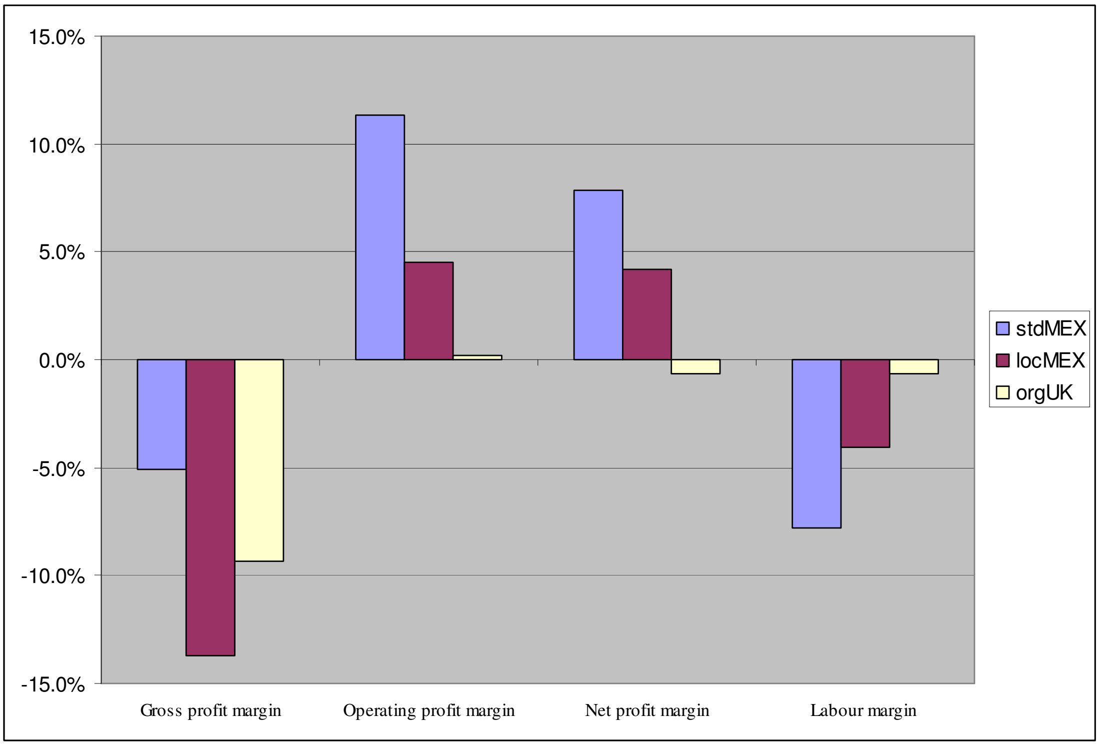

Figure 8.1 Comparison of variation in financial margins of different scenarios when compared with the stdUK scenario (percentage of margin)

Interpretation of results on profit margins should be considered carefully because annual variations in market and demand conditions across the enterprise activity can drastically change the margins (Warren, 1997, p37), especially for those scenarios where the supply chain has not been constructed on operational and strategic alliances (Taylor, 2006). Thus, under individual farm conditions, historical analysis of detailed financial annual worksheets and profit statements should be analysed (Warren, 1997, p33). However, major profitability does not always imply better business sustainability. Yakovleva and Flynn (2004), van der Vorst *et al*. (2004) and Taylor (2006) concluded that the individual business efficiency is more susceptible to economic turnovers in the long term than more efficient value chains, where full cooperation exists between all partners. Thus higher profitability gives the opportunity for more flexibility in investment in the short term, but historical analysis gives a better idea of financial sustainability. More steady and durable profit arises from cooperation, rather than an ability to play the market or exercise power over supply chain partners (Taylor, 2006). If the environmental performance is taken into consideration, the success of a single enterprise is conditional upon successful coordination, integration and management of key business processes across members of the supply chain (van der Vorst *et al.*, 2004), as concluded in Section 8.1.

The labour margin is also dependant on regional and labour conditions. This gives a good idea of expenses sharing in the local community, but does not allow discussion of the scope of this sharing, such as the amount of working hours or the number of employment places. However, expenses used locally contribute to local employment in rural areas, which is one important aspect of macro-economic measures, named equity within agriculture (FAO, 1986). Thus, a farm wage expense is an indicator of the farm's contribution to the local economy, because the cash income of small farmers, peasants and agricultural workers can have a sizeable multiplier effect on the whole rural economy. Thus, if the underemployment (together with unemployment) is widespread in rural areas, the expenses shared in the local community raise the cash income of the rural and surrounding areas. This effect can also improve off-farm employment opportunities for surplus agricultural population (FAO, 1986). On the other hand, urban-industrial non-farm sectors in cities and foreign agricultural jobs stimulate the agricultural landless worker migration, increasing rural poverty and reducing the agricultural business community connection. Thus the benefit of improved equity should not be overlooked in estimates of cost-effectiveness and farm sustainability (FAO, 1986, p164). In conclusion, the profit and labour margins of the Mexican scenarios give more flexibility in the immediate term than for the UK scenarios, when variations in prices and labour cost is facing. But, considering the long term impact, the low expenses on wages for the Mexican scenarios can have a negative impact on local employability, simultaneously reducing social participation of the pig farm.

8.8 *Uncertainty analysis*

Several types of uncertainty are inherent in the input-output assessments (Weber and Matthews, 2007), and several of these error types were present in the current study but are difficult to quantify. The list of error types includes temporal and spatial variability, allocation uncertainty and aggregation uncertainty. Allocation and aggregation uncertainty are especially important for industrial commodities because different producers or transformers in the scenarios may be more or less efficient than those in the US. However, as Weber and Matthews (2007) argued, with the World Trade Organisation accession, many industrial commodities are supplied by a mixture of both relatively new and highly efficient plants and older, highly inefficient plants, and it is likely that the newer plants produce more efficiently than the older ones. Thus, for some industrial sectors their supply chain includes a mixture of suppliers providing both high-value and low-value goods, and produce more and less environmentally intensive commodities. The cumulative effect of this uncertainty is unclear. In addition, data were assessed for possible variations in the main PPC processes, but not for data and factors variation, which can produce large variability in results (Basset-Mens *et al.*, 2004). However, the large range of uncertainty for factors calculation in previous publications has given rise to great variability, because there are contrasting backgrounds for parameterisation or measurement conditions (Basset-Mens *et al.*, 2004). A considerable variation in resource use and emissions between farms of the same enterprise has been reported (Thomassen and Boer, 2005; Halberg, 1999). Base evaluations and comparison of agricultural products in case studies commonly have also great uncertainty (Basset-Mens *et al.*, 2004). So, simulation of farm conditions through modelled scenarios is useful to highlight the importance of farmer practice more than production modes. Thus, the hot spots in this study reveal opportunities to improve crop and farm practice more than assessing the e-impact of specific farms by region, system or scale.

8.9 *Integrated conclusions*

The pre-assessment of the pig farm LCA and gathering the LCI in a database manager made it possible to follow upstream the origin of important e-impacts and clarify the supply chain of commodities used in the PPC. Using a hybrid methodology to collect the LCI made it possible to include e-impacts from commodities that have traditionally been avoided. This implied that e-burdens produced in different sectors of the PPC needed extra e-impact indicators to be included in the analysis. A wide range of e-impacts also expanded the possibilities of bringing to light opportunities for improving sustainability. Scenarios methodology allowed the modelling of contrasting situations of pig production, providing a good source of contrasting results that contribute to highlighting the main challenges for individual scenarios. However, great uncertainty remained in the modelled scenarios and their results were useful to highlight opportunities, but become very controversial in their use to characterise pig production systems.

A wide range of opportunities to improve sustainability were found for Mexican and the UK scenarios, and within country for standard and alternative scenarios. Facing the challenges and adopting suitable changes could make great advances in sustainability of pigmeat production in the Mexican scenarios in the sort term. In contrast, the challenges for the UK scenarios need more specific and careful changes in the long term. Alternative scenarios though, are behind the standard scenarios in environmental efficiency and profitability, but their scale of production allows more flexibility to adopt different strategies, including those implemented in the standard scenarios.

The financial and employment assessment of the different scenarios gave a complementary view of opportunities for sustainability. However, a greater depth of analysis is required to show the real influence on the whole sustainability of pig systems. As a general statement, those scenarios that have increased the efficiency of nutrient use for feeding pigs and manure disposal have also increased their level of technological investments, resulting in more mechanised processes. This mechanisation has changed the e-impacts from nutrient to industrially-related burdens. Financial assessment showed that mechanisation does not necessarily make the scenario more profitable. Employment opportunities can influence the regional and local economy, and its own sustainability. According to these findings, increasing the sustainability of pig production implies that not only should production be improved and made more efficient, but also efficiency should be seen as the best communication between stakeholders in the PPC to minimize material use and impact positively on the local community.

Reference List

AgCert. 2006. *GHG Mitigation* UNFCCC Clean Development Mechanism project Design Document. (project MX05-B-17). Jalisco, Mexico.

Agra CEAS. 1999. Justification for Government Intervention in The Pig Sector. Economic evaluation of the pig industry restructuring scheme. DEFRA http://statistics.defra.gov.uk/ esg/evaluation/pirs/section3.pdf. London.

Alcamo, J. 2001. *Scenarios as a tool for international environmental assessment* Experts corner report, prospects and scenarios, European Environment Agency (5). Copenhagen, Denmark.

American Chemistry Council, I. 2007. The chlorine tree. [Online]. http://www.americanchemistry.com/chlorine/ (Accessed: 16 June 2008).

Andersson, R., Algers, B., Bergstrom, L., Lundstrom, K., Nybrant, T. and P-O., S. 2005. Food 21: A research program looking for measures and tools to increase food chain sustainability. *Ambio.* **34:** 275-282.

Andino, J. M. 1999. Clorofluorocarbons (CFCs) are heavier than air, so how do Scientifics suppose that these chemicals reach the altitude of the ozone layer to adversely affect it? *Scientific American:* Octuber 21**:** [Online]. http://www.scientificamerican.com/ article.cfm?id=chlorofluorocarbons-cfcs (Accessed: 21 October 2009).

Asman, W. A. H., Sutton, M. A. and Schjoerring, J. K. 1998. Ammonia: emission, atmospheric transport and deposition. *New Phytology.* **139:** 27-48.

Baggott, S. L., Cardenas, L., Garnett, E., Jackson, J., Mobbs, D. C., Murrells, T., Passant, N., Thomson, A. and Watterson, J. D. 2007. *UK Greenhouse Gas Inventory, 1990 to 2005.* Framework Convention on Climate Change (Annual report). London.

Basset-Mens, C., van der Werf, H. and Durand, P. 2004. Implications of uncertainty and variability in the life cycle assessment of pig farming systems. *Proceedings of the International Environmental Modelling and Software Society.* Osnabruck, Germany., 14-17 June 2004

Basset-Mens, C., van der Werf, H., Robin, P., Morvan, T., Hassouna, M., Paillat, J.-M. and Vertes, F. 2007. Methods and data for the environmental inventory of contrasting pig production systems. *Journal of Cleaner Production.* **15:** 1395-1405.

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

BLS. 2007. Career Guide to Industries, 2008-09 Edition, Mining. *Bureau of Labour Statistics, U.S.:* [Online]. http://www.bls.gov/oco/cg/cgs004.htm (Accessed: July 01, 2008).

BOC industrial. 2008. Refrigerant gases. [Online]. http://www.bocindustrial.co.uk/bocindustrial/product_information/gas/refrigerants/index.asp (Accessed: 18 June 2008).

Borbolla, S. G. 2007, Personal communication. National pig farming nutritionist & consultant in Mexico, 10 March 2009.

Bourlakis, A. and Weightman, P. W. H. 2004. Food Supply Chain Management. Blackwell. Oxford, UK.

BPEX. 2006. Pig Yearbook 2006. Sloyan, M. Winterhill House, Snowdon Drive, Milton Keynes, UK: Meat and Livestock Commission.

Brandsma, P., Oostindie, H. and Roep, D. 2005. Marketing sustainable agriculture: An analysis of the potential role of new food supply chains in sustainable rural development. De Hoeve Case study report. The fifth framework programme 1998-2002. European Commission Copenhagen.

Bras, B. 1997. *Incorporating environmental issues in product design and realization.* United Nations Environment Programme Industry and Environment (UNEP/IE)

BSAS. 2003. Nutrient Requirement Standards for Pigs. British Society of Animal Science. Penicuik, The UK.

CANACINTRA. 2004. Food Animal Industry in Mexico 2004, in Spanish (La Industria Alimenticia Animal en Mexico 2004).*Annual Assembly of Mexican Association of Feed Industry.* Mazatlan, Mex., 26-28 February 2004.

Cano-Ruiz, A. J. 2000. Decision support tools for environmentally conscious chemical process design, in *Environmental life cycle assessment of good and services. An Input-Output Approach* Hendrickson, C. T., Lave, L. B. and Matthews, H. S.(eds). RFF Press, Washington, DC, USA. , ISNB, pp. 120.

Carlsson-Kanyama, A., Ekstrom, M. P. and Shanahan, H. 2003. Food and life cycle energy inputs: consequences of diet and ways to increase efficiency. *EcologicalEconomics.* **44:** 293-307.

Cederberg, C. 1998. Life cycle assessment of milk production - a comparison of conventional and organic farming. Swedish Food Institute (SIK) Goteborg, Sweden.

Cederberg, C. and Flysjo, A. 2004. Environmental assessment of future pig farming systems - quantifications of three scenarios from the FOOD 21 synthesis work, in *SIK Rapport* Swedish Institute for Food and Biotechnology (SIK), Goteborg, Sweden, ISNB, pp. 723, i-xi + 54 p.

CGG-SAGARPA. 2006. Agricultural Statistics. General Coordination of Livestock, Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food, in Spanish (CGG-SAGARPA) [Online]. www.sagarpa.gob.mx (Accessed: 12 May 2008).

Chambers, B. J., Smith, K. A. and Pain, B. F. 2000. Strategies to encourage better use of nitrogen in animal manures. *Soil Use and Management.* **16:** 157-166.

Chantreuil, F., Donnellan, T., van Leeuwen, M., Salamon, P., Tabeau, A. and Bartova, L. 2008. EU Dairy Quota Reform an AGMEMOD Scenario Analysis.*2008 International Congress of the European Association of Agricultural Economists.* Ghent, Belgium, August 26-29, 2008.

Chara, J. D. and Giraldo, S. 2001. Evaluation of polyethylene and pvc tubular bio-digesters in the treatment of swine wastewater. *Livestock Research for Rural Development.* **14:** 145-166.

Cheeke, P. R. 1999. Applied Animal Nutrition: Feeds and Feeding, Second Ed. Prentice Hall. New Jersey.

Cleaner Production International. 2005. The fertilizer and pesticides industry: Improvement of resource efficiency and environmental performance. [Online]. http://www.cleanerproduction.com/Directory/sectors/subsectors/Fertilizer.html (Accessed: 18 June 2008).

Cooper, M. C. and Ellram, L. M. 1993. Characteristics of SCM and the implications for purchasing and logistics strategy. *International Journal of Logistics Management.* **4:** 13-24.

Cooper, M. C., Lambert, D. M. and Pagh, J. D. 1997. Supply chain management: More than a new name for logistics. *Journal of Logistic Management.* **8:** 1-13.

Costales, A., Gerber, P. and Steinfeld, H. 2006. Underneath the Livestock Revolution, global perspective, FAO

Dalgaard, R., Dejgaard, J. J., Weidema, B., Halberg, N. and Sorensen, C. A. G. 2007a. Environmental assessment of Danish pork, in *Ph.D. Thesis "The environmental* *impact of pork production from a life cycle perspective"*. Vol. Paper 3 Dalgaard, R., University of Aarhus, Denmark, ISNB, pp. 87-110.

Dalgaard, R., Halberg, N. and Hermansen, J. E. 2007b. Danish pork production. An environmental assessment. *DJF Animal Science. Aarhus University.* November 2007.

Dalgaard, R., Halberg, N., Kristensen, I. S. and Larsen, I. 2004. *An LC inventory based on representative and coherent farm types.* Danish Institute of Agricultural Sciences Tjele, Denmark.

Dalgaard, R., Halberg, N., Kristensen, I. S. and Larsen, I. 2006. Modelling representative and coherent Danish farm types based on farm accountancy data for use in environmental assessments. *Agriculture, Ecosystems & Environment.* **117:** 223-237.

Dalgaard, R., Schmidt, J., Halberg, N., Christiansen, P., Thrane, M. and Pengue, W. A. In press. LCA of Soybean Meal. *International Journal of LCA.*

De Beaufort-Langeveld A, van den Berg N, Christiansen K, Haydock R, ten Houten M and S., K. 1997. *Simplifying LCA: just a cut?* . SETAC (Final report of the SETAC Europe Screening and Streamlining Working Group). Amsterdam, The Netherlands.

de Castro, R., Perez, C. and Simons, D. 2005. Pork supply chain: A Review.141-148 *10th International Symposium of Logistic.* Lisbon, 4-5 July 2005.

De Keulenaer, H. 2006. Photochimical Ozone Creation Potencial *The global community for sustainable energy professionals: Leonardo Energy, European Copper Institute* [Online]. http://www.leonardo-energy.org/photochemical-ozone-creation-potential-pocp (Accessed: 15 October 2009).

Defra. 2000. Fertiliser recommendations for agricultural and horticultural crops (RB209). **7th edition:** [Online]. http://www.defra.gov.uk/corporate/publications/pubcat/ag.htm#fertilisers (Accessed: 22July 2008).

Defra. 2007. Farm account in England 2006/07. Results of the farm business survey. *Department of environmental, Food & Rural Affairs:* [Online]. https://statistics.defra.gov.uk/esg/publications/fab/2007/ (Accessed: 22 July 2008).

Defra and DTI. 2003. Changing patterns: UK Government framework on sustainable consumption and production. *London: DEFRA Publications* [Online]. http://collections.europarchive.org/tna/20080530153425/http://www.sustainable-development.gov.uk/publications/report2003/foreword.htm (Accessed: 3 Sep 2008).

Defra, A. M. E. 2009. Farm business survey 2008/09: Instructions for collecting the data and completing the farm return. *Defra. UK.*

Delgado, C., Rosegrant, M. W., Seinfeld, H., Ehui, S. and Courbois, C. 2000. Livestock to 2020: The next food revolution. Background paper No.6 *Commission on Sustainable Development Eighth Session, FAO.* New York, 24 April - 5May 2000.FAO.

Demeter, R. M., Meuwissen, M. P. M., Oude Lansink, A. G. J. M. and Van Arendonk, J. A. M. 2009. Scenarios for a future dairy chain in the Netherlands. *NJAS - Wageningen Journal of Life Sciences.* **56:** 301-323.

Dubrovskis, V., Plume, I. and Straume, I. 2008. Anaerobic digestion of cow and broiler manure. *Engineering for rural development.* **29:** 57-60.

Edwards, S. A. 2005. Product quality attributes associated with outdoor pig production. *Livestock Production Science.* **94:** 5-14.

Edwards, S. A., Edge, H., Cain, P., Guy, J., Hazzledine, M. J. and Gill, P. 2002. A review and workshop to agree advice on reduced nutrient pig diets. *Defra report WA0321:* [Online]. http://randd.defra.gov.uk/Document.aspx?Document =WA0321_712_FRA.doc (Accessed: 17 February 2009).

Eghball, B., Wienhold, B. J., Woodbury, B. L. and Eigenberg, R. A. 2005. Plant availability of phosphorus in swine slurry and cattle feedlot manure. *Agronomy Journal.* **97:** 542-548.

Elkins, J. W. 1999. Chlorofluorocarbons (CFCs), in *The Chapman & hall encyclopaedia of environmental science* Alexander, D. E. and Fairbridge, R. W.(eds). Kluwer Academia, Boston, MA, ISNB, pp 78-80.

Energy Information Administration. 2008. Crude oil is made into different fuels, last review may 2008. *Energy Information Administration* [Online]. http://www.eia.doe.gov/basics/petroleum_basics.html (Accessed: 16 June 2008).

EPA. 1997. The U.S. methane emission from livestock enteric fermentation. Appendix VI.2 Emission Factors. accessed: 2 February 2009.

Eriksen, J. and Hermansen, J. E. 2005. Outdoor production of slaughter pigs requires an optimized management to mitigate N pollution. *Newsletter from Danish Research Centre for Organic Farming:* June2005: [Online]. http://orgprints.org/5482 (Accessed: 14 August 2009).

Eriksen, J., Petersen, S. O. and Sommer, S. G. 2002. The fate of nitrogen in outdoor pig production. *Agronomy Journal.* **22:** 863-867.

Eriksson, I. S., Elmquist, H., Stern, S. and Nybrant, T. 2005. Environmental systems analysis of pig production: the impact of feed choice. *International Journal of Life Cycle Assessment.* **10:** 143-154.

ETH-ESU. 1996. Chemical organic ETH. *Ecoinvent database.*

Euro Chlor. 2005. Uses of chlorine. [Online]. http://www.eurochlor.org/uses (Accessed: 16 June 2008).

European Commission. 1996. *Integrated pollution prevention and control.* Off. J. Eur. Communities (Council Directive 96/61/EC of 24 September 1996).

European Commission. 2001. *Laying down minimum standards for the protection of pigs.* Off. J. Eur. Communities (Commission Directive 2001/93/EC of 9 November 2001, amending Directive 91/630/EEC).

Expert panel. 2007. Expert panel of outstanding members of the Mexican Association for Veterinary Specialists in Pig Production (AMVEC from spanish abbreviation) *made up of Borbolla, S.G., Morales S. L.F., F., Chorne, R., Adelfa C., Wence, J.M.* interviewed to model scenarios

FAO. 1986. The dynamics of rural poverty. 240p. FAO.

FAO. 2002. Regional Integration of Agriculture and Livestock: Management options for pig farms sewage in the central region of Mexico. In Spanish (Intergracion por zonas de la Ganaderia y de la Agricultura Especializadas [AWI]: opciones para el manejo de efluentes de granjas porcicolas de la zona Centro de Mexico). Department of Agriculture and Consumer Protection, FAO. (LEAD, X6372/S). http://www.fao.org/WAIRDOCS/LEAD/X6372S/x6372s06.htm#bm06. Guadalajara, Mexico.

Fearne, A., Hughes, D. and Duffy, R. 2001. Concept of collaboration: supply chain management in a global food chain. In: *Food supply chain management: Issues for the hospitality and retail sector* Eastham, J., Sharples, L. and Ball, S.(ed), Reed Educational and Professional, Oxford, ISNB, pp. 134.

FIRA. 1993. Panorama general de la porcicultura nacional y participacion de FIRA en su desarrollo. *FIRA XXVI.* **54:** 48.

Florin, H. and Horvath, A. 2004. *Hybrid LCA.* PE Europe and University of California (Technical Report). Berkeley, Ca.

Fowler, T. 2006. *2005 Pig cost of production in selected EU countries* BPEX, Defra (Report for Meat and Livestock Commission). United Kingdom.

Fowler, T. 2008. Pig Meat Market Update. BPEX. United Kingdom

Frischknecht, R. and Jungbluth, N. 2003. *Implementation of Life Cycle Impact Assessment Methods.* Swiss centre for LCI (Final report ecoinvent 2000,). www.ecoinvent.ch. Duebendorf, CH.

Fry, J. and Kingston, C. 2009. *Life Cycle Assessment of Pork* Environmental Resources Management (August 2009). the UK.

Gallardo, N. J. L., Villalmar, A. L. and Barrera, W. M. 2006. Actual situation and Outlook of pigmeat production in Mexico 2006 in Spanish (Situación actual y perspectiva de la producción de carne de porcino en México 2006). *Report for CGG-SAGARPA, Mexico:* [Online]. http://www.sagarpa.gob.mx/Dgg (Accessed: 15 Feb 2008).

Garcia, G. 2009, Personal communication. Pig farming nutritionist for NASSA in Mexico.

Green Design Institute. 2006. Economic Input-Output Life Cycle Assessment (EIO-LCA), US 1997 Industry benchmark model. *Carnegie Mellon University, Green Design Institute:* [Online]. www.eiolca.net (Accessed: 5 May 2007).

Green Design Institute. 2007. *Economic Input-Output Life Cycle Assessment (eiolca.com).* Green Design Institute, Carnegie Mellon University; http://www.eiolca.net

Gumprecht, W. 2005. Refrigerants for the 21st Century. *Kennesaw State University* [Online]. http://chemcases.com/fluoro/index.htm (Accessed: 18 June 2008).

Haas, G., Wetterich, F. and Kopke, U. 2001. Comparing intensive, extensive field and organic grassland farming in southern Germany by process life cycle assessment. (Special issue: A tribute to Hamish Sturrock). *Agriculture, Ecosystems & Environment.* **83:** 43-53.

Hagelaar, J. L. F. G. and van der Vorst, G. A. J. 2002. Environmental supply chain management: using life cycle assessment to structure supply chains. *International Food and Agribusiness Management Review.* **4:** 399-412.

Halberg, N. 1999. Indicators of resource use and environmental impact for use in a decision aid for Danish livestock farmers. *Agriculture Ecosystems & Environment.* **76:** 17-30.

Halberg, N. 2008. Energy use and Green house gas emission in organic agriculture. *International Conference of Organic Agriculture and Climate Change.* Etnia of Clermont, France, April 17-18th 2008.EMCC Institute.

Halberg, N., Hermansen, J. E., Sillebak, K. I., J, E. and Tvedegaard, N. 2007. Comparative environmental assessment of three systems for organic production in Denmark. *Submitted.*

Halberg, N., Weidema, B., Larsen, I., Dalgaard, R., Nielsen, P. H. and Nielsen, A. M. 2004. Life cycle based environmental management and product declarations for food.555-565 *Quality assurance, risk management and environmental control in* *agriculture and food supply networks: 82nd Seminar of the European Association of Agricultural Economists (EAAE).* Bonn, Germany, 14-16 May 2003.Universitat Bonn-ILB.

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

Hamm, U. F. and Gronefeld, D. H. 2002. Analysis of the European market for organic food: organic marketing initiatives and rural development, Vol. One School of Management & Business. Wales, UK.

Hankins, S., DeCamp, S., Richert, B., Anderson, D. and Sutton, A. 2001. The effect of Paylean and dietary crude protein level on odor production and nutrient concentration in anaerobically stored pig manure. Purdue University 2001 (Swine Research Report of 16 June 2001, p 49-59). http://www.ansc.purdue.edu/swine/swineday/sday01/8.pdf. West Lafayette, Indiana, U.S.A.

Hansen, B., Kristensen, E. S., Grant, R., Høgh-Jensen, H., Simmelsgaard, S. E. and Olesen, J. E. 2000. Nitrogen leaching from conventional versus organic farming systems: a systems modeling approach. *European Journal of Agronomy.* **13:** 65-82.

Hansen, L. L., Claudi-Magnussen, C., Jensen, S. K. and Andersen, H. J. 2006. Effect of organic pig production systems on performance and meat quality. *Meat Science.* **74:** 605-615.

Harry, R. A., Frederick, W. L. and James, E. M. 2003. Contemporary Polymer Chemistry, 3rd Ed. Pearson Education. Oxford.

Hartog, L. d. 2005. Global Perspective on Integrated Pork Production. *London Swine Conference - Production at the Leading Edge, p 97-103.* London, Ontario, 6-7 April 2005.Ontario Pork Industry Council and University of Guelph.

Hazzledine, M. J. 2009, Personal communication. Phosphorous content in pig commercial diets. 2 March 2009.

Hendrickson, C., Horvath, A., Joshi, S. and Lave, L. B. 1998. Economic input-output models for environmental life cycle assessment. *Environmental Science & Technology.* **32:** 184A-191A.

Hendrickson, C. T., Lave, L. B. and Matthews, H. S. 2006. Environmental life cycle assessment of good and services. An Input-Output Approach. RFF Press. Washington, DC, USA.

Hermansen, J. E. (2001) Organic livestock production systems and appropriate development in relation to public expectations. *52nd EAAP meeting* Budapest, 26 August 2001. EAAP, pp.

Hermansen, J. E., Strudsholm, K. and Horsted, K. 2004. Integration of organic animal production into land use with special reference to swine and poultry. *Livestock Production Science.* **90:** 11-26.

Hernandez-Martinez, J., Rebollar-Rebollar, S., Rojo-Rubio, R., Garcia-Salazar, J. A., Guzman-Soria, E., Martinez-Tinajero, J. J. and Diaz-Carreno, M. A. 2008. Private profitability of swine farms in the south of the State of Mexico. *Universidad y Ciencia* **24:** 117-124.

Hernandez, M. M. C. 2001. Estrategias competitivas frente a la globalizacion: el caso de los porcicultores de Sonora (Mexico). *Report of Food and Development Research Centre (Centro de Investigacion, Alimentacion y Desarrollo)*

Hobbs, J. E. 1996. A transaction cost approach to supply chain management *Supply Chain Management: An International Journal.* **1:** 15 - 27.

Hobbs, J. E. K., W.A.; Klein, K.K. 1998. Creating international competitiveness through supply chain management: Danish pork. *Supply Chain Management: An International Journal.* **3:** 86-78.

Hodges, J. 2005. Cheap food and feeding the world sustainably. *Livestock Production Science.* **92:** 1-16.

Honeyman, M. S. 1996. Sustainability issues of U.S. swine production. *Journal Animal Science.* **74:** 1410-1417.

Hunt, R. G., Boguski, T. K., Weitz, K. and Sharma, A. 1998. Case studies examining LCA, streamlining techniques. *International Journal of Life Cycle Assessment* **3:** 36-42.

Ilbery, B. and Maye, D. 2005. Food supply chains and sustainability: evidence from specialist food producers in the Scottish/English borders. *Land Use Policy.* **22:** 331-344.

ILPI. 2005. Hydrocarbons. *The MSDS hyper glossary: Interactive Learning Paradigms Incorporated* [Online]. http://www.ilpi.com/msds/ref/hydrocarbon.html (Accessed: 19 June 2008).

INEGI. 2005. *Cartas de temperaturas medias anuales de Mexico* http://www.inegi.gob.mx/inegi/default.aspx?s=geo.(Accessed: 28 November 2008).

IPCC. 2006. Chapter 10, Emissions from livestock and manure management, in *Guidelines for National Greenhouse Gas Inventories: Agriculture, Forestry and Other land use.* IPCC(ed). Vol. 4 IPCC, ISNB, pp. 10.1-10.87.

IPPC. 2001. *Climate Change," The Scientific Basis".* IPCC (United Nations Environmental Programme/GRID-Arendale website. Section 4.2.1.1: "Non-CO2 Kyoto Gases, Methane).

IPPC. 2003. – Integrated Pollution Prevention and Control.2003. Reference document on best available techniques for intensive rearing of poultry and pigs. . *European Commission.*

ISO. 1997. ISO 14040: Environmental management- life cycle assessment-goal and scope definition and inventory analysis. International Organisation for Standardisation (ISO). Geneva.

Joshi, S. 1999. Product Environmental Life-Cycle Assessment Using Input-Output Techniques. *Journal of Industrial Ecology.* **3:** 95-120.

Jurado, G. P. 2003. Strategies for agricultural pig manure use in Mexico, in Spanish (Estrategias sobre el uso de excretas animales para la agricultura en Mexico). FAO report of Area Wide Integration: Integracion por zonas de la Ganaderia y de la Agricultura Especializada (Chapter 7 secction 7.3). http://www.fao.org/wairdocs/LEAD/X6372S/x6372s00.htm#Contents.

Kanaly, R. A., Manzanero, L. I. O., Macer, D. I. and Panneerselvam, S. 2009. *Energy flow, environment and ethical implications for meat production.* UNESCO (ACCAP Report, Working Group 13). Bangkok.

Kellenberger, D. 2003. Life cycle Inventories of building products. *Ecoinvent database.*

Kiefer, D. M. 2001. Sufuric Acid: Pombing up the volume. *American Chemical Society:* [Online]. http://pubs.acs.org/subscribe/journals/tcaw/10/i09/html/09chemch.html (Accessed: 19 June 2008).

Kim, S., Dale, B. E. and Jenkins, R. 2009. Life cycle assessment of corn grain and corn stover in the United States. *International Journal of Life Cycle Assessment.* **14:** 160-174.

Koelsch, R. 2007. *Estimating Manure Nutrient Excretion.* USDA (Feed Management Education Project report). http://www.puyallup.wsu.edu/dairy/nutrient-management/data/publications/EstimatingManureExcretion.pdf.

Lagorse, J., Simões, M. G., Miraoui, A. and Costerg, P. 2008. Energy cost analysis of a solar-hydrogen hybrid energy system for stand-alone applications. *International Journal of Hydrogen Energy.* **33:** 2871-2879.

Lal, R., Griffin, M., Apt, J., Lave, L. B. and Morgan, M. G. 2004. Managing soil carbon. *Science.* **304:** 393-410.

Lampkin, N., Measures, M. and Padel, S. 2006. 2007 Organic Farm Management Handbook, 7th Ed. Organic Research Group, Institute of Rural Sciences University of Wales, UK. Aberystwyth, The UK.

Landis, A. E., Miller, S. A. and Theis, T. L. 2007. Life Cycle of the Corn-Soybean Agroecosystem for Biobased Production. *Environmental Science & Technology.* **41:** 1457-1464.

Lave, L. B., Hendrickson, C. T., Conway-Schempf, N. and C., M. F. 1999. Municipal solid waste recycling issues. ASCE Journal of Environmental Engineering. **125:** 944-949.

LCAfood. 2002. Environmental design of Industrial Products, in Danish UMIP adapted for SimaPro. (2.3). PRe Consultants B.V. Amersfoort, the Netherlands.

Lenzen, M. 2002. A guide for compiling inventories in hybrid life-cycle assessments: some Australian results. *Journal of Cleaner Production.* **10:** 545-572.

Leontif, W. 1970. Environmental repercussion and the economic structure: An input-output approach. . *Review of Economics and Statistics.* **3:** 262-271.

Lin, X. and Polenske, K. R. 1998. Input-output modeling of production processes for business management. *Structural changes and economic dynamics.* **9:** 205-226.

MAFF. 2000. Towards sustainable agriculture: A pilot set of indicators. *MAFF, London.*

Magana-Magana, M. A., Matus-Gardea, J. A., Garcia-Mata, R., Santiago-Cruz, M. J., Martinez Damian, M. A. and Martinez-Garza, A. 2002. Profitability and effects of economic policy on pork meat production in Yucatan. *Agrociencia.* **36:** 737-747.

Maribo, H. and Fernanadez, J. A. 2002. Lupin prima as protein source for organic finishers. *Report No. 561 For Danish Pig Production, Copenhagen.*

Martins, A., Kelly, H., Day, J., Stopes, C., Browning, H. and Edwards, S. A. 2002. Optimising Organic Pig Production. A Guide to Good Practice. Defra. Warwickshire, UK.

Meisterling, K., Samaras, C. and Schweizer, V. 2009. Decisions to reduce greenhouse gases from agriculture and product transport: LCA case study of organic and conventional wheat. *Journal of Cleaner Production.* **17:** 222-230.

Miller, S. A., Landis, A. E., Theis, T. L. and Reich, R. A. 2007. A comparative Life Cycle Assessment of petroleum and soybean-based lubricants. *Environmental Science & Technology.* **41:** 4143-4149.

Millet, S., Ongenae, E., Hesta, M., Seynaeve, M., De Smet, S. and Janssens, G. P. 2006. The feeding of *ad libitum* dietary protein to organic growing-finishing pigs. *Veterinay Journal.* **171:** 483-90.

Mistry, P. and Misselbrook, T. 2005. Assessment of methane management and recovery options for livestock manures and slurries. Defra (AEA Technology plc, AEAT/ENV/R/2104). London.

Mosse, J. 1990. Nitrogen to protein conversion factor for ten cereals and six legumes or oilseeds. *Journal of Agricultural and Food Chemistry.* **38:** 18-24.

NAICS. 2002. Industry snapshot: "Statistics for Industry Groups and Industries: 2000." *U.S. Census Bureau:* [Online]. http://www.census.gov/epcd/naics02 (Accessed: 16 June 2008).

NAICS. 2003. North America Industrial Classification System, Definitions. *U.S. Census Bureau:* [Online]. http://www.census.gov/epcd/naics02/def/ND325120.HTM (Accessed: 16 June 2008).

National Statistics. 2008. Consumer Price Indices all items: 1996 to 2007. *CPI: Office for National Statistics* [Online]. www.statistics.gov.uk (Accessed: 2 August 2008).

Nava, N., Trueta, S. R., Finck, V. B., Barranco, V. B., Osorio, H. E. and Lecumberri, L. J. 2009. Impacts of technological level on production efficiency and economic variables in pork farms in the States of Guanajuato, Jalisco, Sonora and Yucatan , Mexico. *Tecnica Pecuaria Mexico.* **47:** 157-172.

Nemecek, T. 2005. Life Cycle Inventories of Agricultural Production Systems in The Ecoinvent database Ecoinvent database.

New Zealand Climate Project. 2002. New Zeland's Greenhouse Gases emissions and the Contribution from Agriculture. . *Chapter 4 from Abatement of agricultural greenhouse gas emissions.* accessed 2 February 2009.

Nguyen, T. L., Mogensen, L. and Hemansen, J. E. 2008. *Environmental profiles in different pork chains* EU Commission

Nielsen, A. H. and Kristensen, I. S. 2005. Nitrogen and phosphorus surpluses on Danish dairy and pig farms in relation to farm characteristics. *Livestock Production Science.* **96:** 97-107.

Niles, J. O., Brown, S., Pretty, J. N., Ball, A. S. and Fay, J. P. 2002. Potential carbon mitigation and income in developing countries from changes in use and management of agricultural and forest lands. *The Royal society:* **10:** pp. CarbonD/1-19. [Online]. http://www.hm-treasury.gov.uk/d/carbon-income.pdf (Accessed: 10 Nov 2009).

Noria Corporation. 2007. Lubrication and oil analysis dictionary [Online]. http://www.noria.com/dictionary (Accessed: 19 June 2008).

NRC. 1998. Nutrient Requirements of Swine, 10th ed. National Academy Press. Washington, D.C.

Ochoa, B. R. and Ortega, R. C. 2005. Dinamica de la produccion de carne de porcino en Mexico 2005. *Claridades Agropeccuarias:* Issue 143 pp. 3-29. . [Online]. http://www.infoaserca.gob.mx/claridades/revistas/143/ca143.pdf (Accessed: 20Aug 2008).

ONU. 2007. Guidance document on control techniques for preventing and abating emissions of ammonia. United Nations, Economic and Social Council, (ECE/EB.AIR/WG.5/2007/13). Geneva.

Opara, L. U. 2003. Traceability in agriculture and food supply chain: a review of basic concepts, technological implications, and future prospects. *Food Agriculture & Environment.* **1:** 101-106.

Payraudeau, S. and van der Werf, H. M. G. 2005. Environmental impact assessment for a farming region: a review of methods. *Agriculture, Ecosystems & Environment.* **107:** 1-19.

Pelletier, N. 2008. Environmental performance in the US broiler poultry sector: Life cycle energy use and greenhouse gas, ozone depleting, acidifying and eutrophying emissions. *Agricultural Systems.* **98:** 67-73.

Perez, E. R. 2006. Granjas porcinas y medio ambiente UNAM. Mexico.

Pérez, E. R. 1997. Porcicultura y medio ambiente. *.II Seminario de Manejo y Reciclaje de Residuales Porcinos.* Querétaro, México, 22-25 October 1997.CMP.

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

Pollock, C. J. 2006. Red meat and green farming: can we improve product quality, enhance farm income and deliver environmental goods on the same farm? p208 *The*

Annual Conference of the British Society of Animal Science 2006. Penicuik, York, UK, March, 2006.BSAS.

Poole, R., Clarke, G. P. and Clarke, D. B. 2002. Growth, concentration and regulation in European food retailing, in *European Urban and Regional Studies*. Vol. 9 Sage Publications Ltd, London, ISNB, pp. 167-186.

Poulsen, H. D., Borsting, D. F., Rom, H. B. and Sommer, S. G. 2001. Kvaelstof, fosfor og kalium i husdyrgodning - normtal 2000. . *DJF rapport nr. 36 Husdyrbrug (p.9).*

PRe Consultants. 2008. *SimaPro.* (7.1 LCA). PRe Consultants B.V. Amersfoort, the Netherlands.

Pretty, J., Brett, C., Gee, D., Hide, R., Mason, C. F., Morison, J. I. L., Raven, H., Rayment, M. and van der Bijl, G. 2000. An assessment of the total external costs of UK agriculture. . *Agriculture Systems.* **65:** 113-136.

Pretty, J. N., Ball, A. S., Lang, T. and Morison, J. I. L. 2005. Farm costs and food miles: An assessment of the full cost of the UK weekly food basket. *Food Policy.* **30:** 1-19.

Ramirez, H. G. 2005. Manejo de excretas porcinas. *Cuenca rural:* [Online]. http://www.engormix.com/manejo_excretas_porcinas_sistemas_s_articulos_375_POR.htm (Accessed: 14 June 2007).

Rana, S. V. 2005. Biochemical toxicity of benzene. *Journal of Environmental Biology.* **26:** 157-168.

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

Rees, W. 2003. Ecological footprints. *Nature.* **Issue 421:** 898.

Rehm, G., Schmitt, M., Lamb, J., Randall, G. and Busman, L. 1998. Understanding phosphorous fertilizers. *University of Minnesota, Extension Service: University of Minnesota* [Online]. http://www.extension.umn.edu/distribution/cropsystems/DC6288.html (Accessed: 16 June 2008).

Sagarnaga, M., Ochoa, R. F., Salas, J. M., Anderson, D. P., Richardson, J. W. and Knutson, R. D. 1999. Granjas porcinas representativas en Mexico, panorama economico 1995-2004. *AFPC Research Report 99-16.*

Santiago, G. E. 2008, Personal communication. Arrangement and use of premixes in Mexico (technical assesor for Nutrimix in Mexico), October, 2008.

SAT. 2009. Consumer Price Indices 2009, in Spanish (Indice Nacional de Precios al Consumidor 2009). *Taxes Administration Service in Mexico, in Spanish (Servicio de Administracion Tributaria): Sistema de Administracion Tributaria* [Online]. http://www.sat.gob.mx/sitio_internet/asistencia_contribuyente/informacion_frecuente/inpc/ (Accessed: 19 August 2009).

Shepherd, M., Pearce, B., Cormack, B., Philipps, L., Cuttle, S., Bhogal, A., Costigan, P. and Unwin, R. 2003. *Assessment of the environmental impact of organic farming.* Defra (Report project OF0405). Mansfield, UK.

Shuurtleff, W. and Aoyagi, A. 2007. History of soya bean crushing: Soy oil and soybean meal-part 1. *Soyinfo Center: Soyinfo Center Lafayette, California* [Online]. http://www.soyinfocenter.com/HSS/soybean_crushing1.php (Accessed: 16 September 2008).

SIAP. 2006. Animal production build up advance. Pigmeat as carcass in 2005, in Spanish (Avance acumulado de la producción pecuaria. Carne en canal de porcino. Año 2005). *The Service of Information and Statistics (SIAP) in the Council for Agriculture, Fisheries and Rural Development (SAGARPA) in Mexico:* [Online]. http://www.siap.gob.mx (Accessed: 2 May 2008).

SIAP. 2007. Sow and harvest advance of basic grains in basic indicators of Food-agricultural and fisheries sector, in Spanish (Avances de siembra y cosecha granos básicos en indicadores básicos del sector agroalimentario y pesquero) *The Service of Information and Statistics (SIAP) in The Council for Agriculture, Fisheries and Rural Development (SAGARPA) in Mexico:* [Online]. http://www.siap.gob.mx (Accessed: 2 May 2008).

Sinclair, S. 2002. Pork supply chains. *Department of Primary Industries and Fisheries Queensland Government* [Online]. http://www2.dpi.qld.gov.au/pigs/4519.html (Accessed: 12Sep 2008).

Smith, M. and Vincent, M. 1997. Tanking a killer coolant. *Canadian Geographic.* **117:** 40.

Sørensen, J. T., Edwards, S., Noordhuizen, J. and Gunnarsson, S. 2006. Animal production systems in the industrialised world. *Rev. sci. tech. Off. int. Epiz.* **25:** 493-503

Spielmann, M. 2003. *Life cycle Inventory of Transport Services for the Ecoinvent database.* Swiss Centre for Life Cycle Inventories (Report for the Ecoinvent database). Dubendorf, Swiss.

Stein, L. 1997. Land application of biosolids. CRC Press. Washington, D.C., The USA

Stern, S., Gunnarsson, S., Kumm, K.-I., Sonesson, U. and Öborn, I. (2003) 'Future scenarios for sustainable pig production - which way ahead?' *54th Annual meeting of the European Association for Animal Production.* Rome, Italy, Aug 31st –Sep 3rd, 2003. EAAP, pp.

Stern, S., Onesson, U., Gunnarsson, S., Kumm, K.-I., Oborn, I. and Nybrant, T. 2005. *Sustainable pig production in the future - development and evaluation of different scenarios.* FOOD 21 (5/2005). Uppsala Sweden.

Stevenson, S. 2006. Research and Education Support for the Renewal of an Agriculture of the Middle of the US. In the notes of Editor. *Agriculture and Human Values.* **23:** 137-141.

Stewart, G. 2005. Crop Production, wrestling with crop rotation decisions. *Ontario Corn Producer Magazine:* [Online]. http://www.ontariocorn.org/magazine/Issues/pre%20Nov%202005/ocpmag/as2000feat.html (Accessed: 4 Feb 2009.).

Stocchi, E. 1990. Industrial Chemistry. Ellis Horwood Ltd.

Suh, S., Lenzen, M., Treloar, G. J., Hondo, H., Horvath, A., Huppes, G., Jolliet, O., Klann, U., Krewitt, W., Moriguchi, Y., Munksgaard, J. and Norris, G. 2004. System Boundary Selection in Life-Cycle Inventories Using Hybrid Approaches. *Environmental Science & Technology.* **38:** 657-664.

Suh, S. and Nakamura, S. 2007. Five years in the area o Input-Output and hybrid LCA. *International Journal of Life Cycle Assessment.* **12:** 351-352.

Swiss Centre for LCI. 2007. *Ecoinvent data, The life cycle inventory data version.* (2.0). Swiss Centre for Life Cycle Inventories, ecoinvent report No. 2, Dubendorf, Swiss.

Taylor, D. H. 2006. Strategic considerations in the development of lean agri-food supply chains: a case study of the UK pork sector. *Supply Chain Management: An International Journal.* **11:** 271-280.

Tejera, H. B. and Santos, O. A. 2007. Mexico and his unfavorable insertion in the world agri-food system: Maize case study, In Spanish (México y su inserción desfavorable en el sistema agroalimentario mundial: el caso del maíz). *Revista de Geografía Agrícola.* **1:** 19-38

Thankappan, S. and Flynn, A. 2006. *Exploring the UK Red Meat Supply Chain.* The Centre for Business Relationships, Accountability, Sustainability & Society (BRASS) Cardiff University (Working paper series No. 32, pp 1-67). http://www.brass.cf.ac.uk. Cardiff, United Kingdom.

Therond, O., Belhouchette, H., Janssen, S., Louhichi, K., Ewert, F., Bergez, J.-E., Wery, J., Heckelei, T., Olsson, J. A., Leenhardt, D. and Van Ittersum, M. 2009. Methodology to translate policy assessment problems into scenarios: the example of the SEAMLESS integrated framework. *Environmental Science & Policy.* **12:** 619-630.

Thomas, P. C. (2007) 'Marketing and Consumer Impacts on Food Production- The Challenge of Choise'*, British Society of Animal Science Annual Conference.* Southport, UK, 2-4 April 2007. BSAS, pp.

Thomassen, M. A. and Boer, I. J. M. d. 2005. Evaluation of indicators to assess the environmental impact of dairy production systems. *Agriculture, Ecosystems & Environment.* **111:** 185-199.

Tiago Stock Consulting, L. 2009. Historic Exchange Rates. [Online]. http://www.x-rates.com/cgi-bin/hlookup.cgi (Accessed: 18 August 2008).

U.S. Census. 2007. Bureau Plunkelt's Chemicals. Coating & Plastic Industries, in *Almanac 2006* Washington, D.C.

UNEP. 2004. Life Cycle Initiative. *United Nations Environmental Programme:* [Online]. http://www.uneptie.org/pc/sustain/lcinitiative/home.htm (Accessed: 27 June 2007).

Van der Peet-Schwering, C. M. C., Jongbloed, A. W. and Aarnink, A. J. A. 1999. Nitrogen and phosphorus consumption, utilisation and losses in pig production: The Netherlands. *Livestock Production Science.* **58:** 213-224.

van der Vorst, G. A. J., Hagelaar, J. L. F. G. and Marcelis, W. J. 2004. Organising life-cycle in supply chains: linking environmental performance to managerial designs. (Environmental protection strategies for companies). *Greener Management International:* [Online]. http://goliath.ecnext.com/coms2/summary_0199-4665256_ITM (Accessed: 10 Sep 2008).

van Horne, P. L. M., Brake, J. and C.M., W. 1998. Economics of controlling ammonia emission from commercial layer farms. *Journal of Applied Poultry Research.* **7:** 61-68.

Verbic, J. 2006. *Inventory of greenhouse gas and ammonia emissions in Slovenia.* CEEC http://afoludata.jrc.it/events/2005-06.AgriProjections.CEEC/Presentations/Inv.SI.ppt#283, 2, Methodology. Ljubljana, Slovenia.

von Borell, E. and Sørensen, J. T. 2004. Organic livestock production in Europe: aims, rules and trends with special emphasis on animal health and welfare. *Livestock Production Science.* **90:** 3-9.

Vorderstrasse, A. 2005. Refrigeration (Dichlorodifluoronethane). [Online]. http://www.wou.edu/~avorder/Refrigeration.htm (Accessed: 18 June 2008).

Wang, L. K. 2005. Waste treatment in the process industries. CRC Press. Boca Raton, FL.

Warren, M. 1997. Financial management for farmers and rural managers. Blackwell Science. 4th Ed, Oxford.

Weber, C. L. and Matthews, H. S. 2007. Embodied environmental emissions in U.S. international trade, 1997-2004. *Environmental Science & Technology.* **41:** 4875-4881.

Wenzel, H., Hauschild M., Alting L.,. 1997. Environmental Assessment of Products. . Kluver Academic Publisher. Boston, USA.

Williams, A. G., Audsley, E. and Sandars, D. L. 2006. *Determining the environmental burdens and resource use in the production of agricultural commodities.* Cranfield University and Defra (Main Report. Defra Research Project IS0205.). www.silsoe.cranfield.ac.uk, and www.defra.gov.uk. Bedford, UK.

Williams, J. R., Chambers, B. J., Hartley, A. R., Ellis, S. and Guise, H. J. 2000. Nitrogen losses from outdoor pig farming systems. *Soil Use and Management.* **16:** 237-243.

Williams, J. R., Smith, K. A., Chambers, B. J. and Cross, R. B. 2002. Nitrogen an Phosphorous losses in drainage water following pig slurry applications to drained clay soil.109-113 *10th International Conference, RAMIRAN 2002.* High Tatras, Slovak Republic, 14-18 May 2002 RAMIRAN.

Yakovleva, N. and Flynn, A. 2004. Innovation and Sustainability in the Food System: A Case of Chicken and Consumption in the UK. *Journal of Environmental Policy & Planning.* **6:** 227-250.

Yamano, N. and Ahmad, N. 2006. *The OECD input-output Database: 2006 Edition.* Organisation for Economic Co-operation and Development. (Unclassified DSTI/DOC(2006)8). Paris.

Zsidisin, G. A. and Siferd, S. P. 2001. Environmental purchasing: A framework for theory development, European. *Journal of Purchasing and Supply Management.* **7:** 61-73.

Appendices

Appendix 1 Construction of Mexican Scenarios

A1.1 Farm classification

Farm classification in Mexico has been by technological level, but the classification criterion is subjective (FIRA, 1993). Subjective criteria produce discrepancies between studies and there is no a clear allocation of farm to differ at technological levels (Hernandez, 2001). Thus, Nava et al. (2009) used bio-security statements and pig farm productive parameters to allocate farms to technology levels, but ranges of each level were fixed arbitrarily and were not given in the report. Others authors do not describe the range of criteria used to allocate farms to different technological levels (Gallardo *et al.*, 2006; Ochoa and Ortega, 2005; FAO, 2002). Using the FIRA classification (1993), Ramirez (2005) defined three kinds of farm: technical farm, semi-technical farm and backyard pig production.

Technical farms: This kind of farms use high technological equipment, could have vertical and horizontal integration, own a feed mill, have strict bio-security control and slaughter their pigs in an abattoir with federal inspection. Ramirez (2005) said that these kind of farms possibly contribute 50% of national pigmeat production in Mexico.

Semi-technical farms: These farms could have similar genetic quality of breeding stock as technical farms, but their production is lower and their facilities and bio-security systems are not optimum. They use commercial compound feed, slaughter pigs in private or municipal abattoirs and contribute 20% of domestic pigmeat consumption.

Backyard pig production: P*ig* produces animals for rural or personal supply. Ramirez (2005) characterises these units as farms where genetic quality is poor but well adapted to low quality feed materials. They contribute the remaining 30% of national production.

These definitions are imprecise and vague because they do not permit a clear classification. The absence of official parameters allows farmers or data collectors to classify pig farms in different ways, with different estimations of their contribution to national pig production (Tejera and Santos, 2007; Ochoa and Ortega, 2005).

Whilst some reports classify pig farms by technology level, others have adopted the breeding herd size as classification criterion (Sagarnaga *et al.*, 1999). The main difference in adoption of new technology between technical and semi-technical farms is their investment capacity. The low investment capacity also limits the expansion possibilities and market sharing (Tejera and Santos, 2007). Thus, considering this direct relationship between farm size and intensification, the breeding herd size is also an indicator of intensification. Thus breeding herd size was used to classify pig farms into three categories for the current study. In accordance with the characteristics modelled for the different scenarios in the methodology of this study (section 3.3.1) three categories were defined:

Family farms: Farms with less than 100 sows as a breeding herd.

Local pig farming (locMEX): Farms where the breeding herd was between 100 and 500 sows.

Standard pig farms (stdMEX): Pig herds with more than 500 sows in the breeding herd.
Mexican pig production was split between these three categories to building the study farm classification. Firstly, national pig production was divided into regions. Secondly,

the expert panel of Veterinary specialists in pig production was consulted to define the scenarios parameters.

A1.2 Regional distribution of pig production

There are 32 states in Mexico, with a wide range of geographic conditions, communication services and traditions. This diversity has influenced the historical evolution of pig production in Mexico. Pig production exists throughout the country (Table A1.I). The development of the pig herd is explained better by region than by state. In the most recent report of the national situation on pig production, Gallardo et al. (2006) explained the possible causes of changes in the national pig herd distribution by state and the general conditions for the highest producing Mexican states. Arguments in Gallardo's report, and the annual report of Agricultural and Fisheries Service of Statistics and Information in Mexico during 2005 (SIAP, 2007) for pig carcass weight production in different states, were used as the basis for building the classification for different regions. Four regions were defined. Table A1.II summarises pig production by state and the grouping into regions.

A1.2.1 Region one

The traditional pig farming region, defined as region one, was near the principal grain production areas, which are the central and central western states of Mexico. Pig farms have been changing as new technologies appear. However, at the same time this has been the principal region affected by changes in national grain production and pig and pigmeat imports (Gallardo *et al*., 2006). Producers that have increased in their scale of production are more dependent on the national pigmeat market shared with importations, and the remaining pig producers have problems in purchasing raw materials and selling pigs. Pig purchases are frequently monopolised by intermediaries. This region includes Jalisco, Guanajuato, Michoacán and Puebla states where traditional pig farmers have been either scaling up their business or maintaining their traditional farms. Additionally, there is a wide distribution of peasants with pigs. This region is responsible for almost 40% of national production of pigs (Table A1.II).

Table A1.I Pig pigmeat production per State in Mexico during 2005 (SIAP, 2006)

STATE	PARTICIPATION (%)	LOCATION	ANNUAL PRODUCTION, tonnes
JALISCO	19.3	01°	210,240
SONORA	18.7	02°	213,475
YUCATÁN	9.3	03°	90,456
GUANAJUATO	8.5	04°	100,565
PUEBLA	7.1	05°	83,468
VERACRUZ	5.8	06°	72,992
MICHOACÁN	4.4	07°	42,219
OAXACA	2.9	08°	26,227
MÉXICO	2.6	09°	28,520
GUERRERO	2.1	10°	22,490
TAMAULIPAS	2.1	11°	26,774
CHIAPAS	2	12°	21,955
HIDALGO	1.8	13°	19,436
SINALOA	1.6	14°	17,249
NUEVO LEÓN	1.5	15°	16,400
QUERÉTARO	1.4	16°	13,171
TABASCO	1.3	17°	13,812
TLAXCALA	1.2	18°	11,340
SAN LUIS POTOSÍ	0.8	19°	8,314
QUINTANA ROO	0.8	20°	8,499
CHIHUAHUA	0.7	21°	6,089
COAHUILA	0.7	22°	7,793
ZACATECAS	0.6	23°	6,543
CAMPECHE	0.6	24°	4,834
AGUASCALIENTES	N.S.	25°	10,526
NAYARIT	N.S.	26°	5,012
DURANGO	N.S.	27°	4,195
COLIMA	N.S.	28°	3,367
MORELOS	N.S.	29°	2,788
DISTRITO FEDERAL	N.S.	30°	1,708
BAJA CALIFORNIA	N.S.	31°	1,628
BAJA CALIFORNIA SUR	N.S.	32°	858
TOTAL NACIONAL	**100**		**1,102,941**

A1.2.2 Region two

Region two covers Central, Central southern and Gulf coast regions, which have long tradition of pig production and local commercialization. This region has a lower part of the pigmeat market than the biggest urban areas of Mexico (17%, Table A.II). Thus, size of farms has been limited to local pig markets in Mexico, Hidalgo, Morelos, Queretaro, and Oaxaca states. In addition Gulf of Mexico coast states of Veracruz and Tamaulipas were considered to be in this region of pigmeat.

A1.2.3 Region three

North-western and South-eastern states were considered as the third region. This has the most consolidated pig farm production and account for 27.6% of national production. It is, so far, the only region with an export market (often deep-sea export to Japan). Their logistic position allows easy access to imported grains and meals. Seaports and industrial parks supply good commercial channels, and geographic locations provide territorial isolation, facilitating regional bio-security control. These reasons allow Sonora and Yucatan states to be the 3rd and 4th most important contributors to national production.

A1.2.4 Fourth region

In the forth region were included all other states in Mexico. These states have forms of varying size farms spread over their territory, and not concentrated in any specific area. This means that the principal owners of pigs are peasants, small farmers or people with another activity as their principal source of income. Regularly, pigs are part of a multi-species herd without any defined animal husbandry scheme, or they are in small farms without specialist consultants.

Table A1.II Mexican pig production by region and principal contributor states in 2005

		Contribution		
		State	Region	
Region	State	tonnes	tonnes	%
1	Jalisco	210,240	436,492	39.6
	Guanajuato	100,565		
	Michoacán	42,219		
	Puebla	83,468		
2	Mexico	28,520	189,908	17.2
	Hidalgo	19,436		
	Queretaro	13,171		
	Morelos	2,788		
	Oaxaca	26,227		
	Veracruz	72,992		
	Tamaulipas	26,774		
3	Sonora	213,475	303,931	27.6
	Yucatan	90,456		
4	Other States		172,612	15.7
Total national		1,102,941		100

A1.3 Regional distribution of pig farms

A1.3.1 Farm size

A farm was defined as all buildings and equipment used to accommodate a breeding herd and its progeny. If the business has separate units (site 1, 2 or 3) but the progeny from the breeding herd is moved between them, they were considered as part of the same farm. Thus enterprises that have several breeding sites were not considered as one farm, but owning as many farms as fulfilled the farm definition. Following the characteristics for the scenarios (section 3.3.1), and the predominant farm sizes by region (Sagarnaga et al., 1999), the following farm size categories were defined:

- Farms with 500 or more sows in the breeding herd.
- Farms with a range between 100 to 500 sows in the breeding herd, and
- Farms which have less than 100 sows in the breeding herd.

A1.4 Panel of experts

A team of experts was formed from veterinary consultants for pig production either at a national level or in the regions defined in section A1.II. Consultants were Members of the National Association of Veterinarian Specialists on Pig Production that agreed to participate in the expert panel team. (Table A1.III).

Table A1.III Veterinary consultants included in the expert panel.

Name	Activity
Marco Antonio Carvajal	National consultant for Lily group
Luis F. Morales-Santini	Ex-President of the National Association of Veterinarian Specialists in Pig Production
Adelfa del Carmen Garcia	Independent consultant in most of the states in region 2
Jose Maria Wence-Angel	National consultant for Avimex Group and private practice
Rafael Chorne-Urruchua	Planning and Development in the Mexican Market for Diamond V, Mexico group
German Borbolla-Sosa	National consultant on pig nutrition, private practice

A1.5 Scenario contribution by region

With defined farm size, the regional distribution of pig production and the opinion of the expert panel were used to estimate the pigmeat contribution by regions and farm size. Farms with more than 500 sows contribute 62% of Mexican pigmeat production, whilst those between 100 and 500 sows contribute 22%. Finally, those with less than 100 breeding sows contribute only 16 % of Mexican pigmeat production (Table A1.IV).

A1.6 Mexican scenarios

The two biggest contributors to national pigmeat production formed the basis for the two scenarios chosen for Mexico.

- Farms with more than 500 sows were considered as the standard scenario (stdMEX), because they are the principal contributor to Mexican pig production.

- Farms with a range between 100 and 500 sows were defined as the local scenario (locMEX) because this kind of farm is located principally in regions where there is local commercialization.

Table A1.IV Pig carcass production in Mexico in 2005: Regional and farm size distribution (source: SIAP, 2006 and experts' panel criteria).

Region*	National contribution		>500	Farm size, 100 to 500	<100
	tonnes	436,492	305,544	87,298	43,649
1	%	39.6	70	20	10
	tonnes	189,908	75,963	94,954	18,991
2	%	17.2	40	50	10
	tonnes	303,931	288,734	9,117	6,079
3	%	27.6	95	3	2
	tonnes	172,612	8,631	51,783	112,198
4	%	15.7	5	30	65
	Tonnes	1,102,943	678,873	243,154	180,916
Total	%	100	62	22	16

* Mexican region: 1-Central & central-western; 2-Central-southern & Gulf cost; 3- North-western and south-eastern; 4-Remaining country states.

A1.7 Parameterisation of scenarios on farm sector

Specialist opinion from the panel of experts (see Section A1.4), and data from the literature were used to derive parameters where these were necessary to build the required information base for each scenario. For example the composition of diets for the Mexican scenarios was contrasted with available data in literature.

Appendix 2 Distribution of e-burdens for the PPC pre-assessment

In the Mellon Green Design Institute model (2006), pig farming is included in the animal production except cattle, poultry and eggs production sector. Sectors involved in supply commodities were tracked 100 million of increase economic activity in animal production sector. Values for indicators were transformed to correspondent percentage of total weight per indicator and tabulated (Table A2.I and Table A2.II)

Table A2.IMain sectors burdens for animal production (% of total weight)

	$	SO2	CO	NOx	VOC	Lead	PM10	CO2	CH4	N2O	CFCs	Energy	Air	water	land	Unground
Total %	71	93	95	88	86	98	99	83	94	100	100	80	85	88	98	82
Animal production, except cattle and poultry and eggs	34				9		88	23	88	13		25				
Power generation and supply		50		18		2		29			33	23	20		7	
Nitrogenous fertilizer manufacturing		2	1	5	2			6		6		8	31	22		34
Grain farming	7		4	11	2			8	3	60		8				
Agriculture and forestry support activities			54		26		9									
Other animal food manufacturing	8	22		2				1				2	2	26		
Copper, nickel, lead, and zinc mining															58	4
Pesticide and other agricultural chemical manufacturing		3		3	27									5		22
Truck transportation	2		24	9	10			7		0		3				
All other crop farming	7		4	20	3		1			16						
Waste management and remediation services			3		2	29			3						7	5
Primary nonferrous metal, except copper and aluminum						29					13		2		3	
Industrial gas manufacturing											44					2
Soybean processing	2												16	7		
Iron and steel mills						13								7	1	
Rice milling		11		6	3											
Secondary processing of other nonferrous						16										
Gold, silver, and other metal ore mining															16	
Petroleum refineries	1	1						2				3	2	5		
Other basic inorganic chemical manufacturing		1										2	4	6	2	
Rail transportation		1		11				1								
Other basic organic chemical manufacturing										0			2	4		8
Oilseed farming	1		1	3				2		4		2				
Phosphatic fertilizer manufacturing								3				5	2			
Wholesale trade	4		3													

Table A2.II Minor sectors' burdens for animal production (% of total weight)

	$	SO2	CO	NOx	VOC	Lead	PM10	CO2	CH4	N2O	CFCs	Energy	Air	water	land	Unground
Primary aluminum production											7					
Other oilseed processing					2								4			
Petrochemical manufacturing														2		4
Synthetic dye and pigment manufacturing						4										1
Real estate	4															
Air transportation						4										
Oil and gas extraction		1							2							
Animal, except poultry, slaughtering														3		
Semiconductors and related device manufacturing											3					
Primary smelting and refining of copper						0									2	
Cattle ranching and farming									2	1						
Secondary processing of copper						2										
Noncellulosic organic fiber manufacturing																2
Scenic and sightseeing transportation and support activities for transportation			1													
Coal mining									1						0	
Pipeline transportation									1							
Stone mining and quarrying		1														
Water, sewage and other systems									0	0						
Couriers and messengers			0													
Ferroalloy and related product manufacturing															0	
Cotton farming										0						
Natural gas distribution									0							
Warehousing and storage							0									
Accounting and bookkeeping services											0					
AC, refrigeration, and forced air heating											0					
Abrasive product manufacturing											0					
Cement manufacturing						0										
Adhesive manufacturing											0					

Appendix 3 Modelling the diet nutrient content

A3.1 Diet composition

There is a wide variation in diet composition. Feedstuffs can change frequently and availability depends totally on supply and demand from national and international markets. Pig farming systems to which the scenarios modelling have been applied are in countries that have access to a wide variety of feedstuffs. Among these available ingredients are synthetic amino acids that increase the possibilities for optimum nutrient balance in feed formulation. The orgUK scenario is the exception, since organic farming is not allowed to use synthetic raw materials for animal feed. However availability and variation in the quality of raw materials is not a limitation to deliver a good and stable quality of feed to the pig industry. In practice, the four modelled scenarios are in countries where animal nutritionists make continuous adjusts to feed ingredient inclusions to maintain stable feed nutrient composition. For the modelled scenarios, it was assumed that diets are balanced to provide the nutritional requirements of pigs according to the productive stage as the model scenario requires.

A3.1.1 Mexican scenarios

According to the expert panel's opinion, there was no difference between Mexican scenarios regarding access to compound feed or feed nucleus (premixes) with high quality (Expert panel, 2007). The principal differences in feed efficiency between scenarios arise from genetic quality of livestock, and equipment and accommodation facilities. There was no available detail on nutrient requirements or nutrient composition for pig feed mixes in accessed national reports and scientific literature for these scenarios. The expert panel (2007) agreed that the principal data source for balancing nutrients in diets is the NCR (1998) tables. Most specific data on nutrient balances for pig diets remain in confidential databases of individual companies or nutrition consultants. However, these data do not substantially differ from NRC (1998) recommendations (Expert panel, 2007). Since basic raw materials for pig diets in Mexico are the same as in the USA, the Mexican pig industry depends on imports from the US (Expert panel, 2007). Also, the nutrient composition for basic pig diets used for experimental trials in Mexico are documented and these are balanced for nutrient requirements stated in the NRC swine nutrient requirements (1998). Therefore, the NRC (1998) recommendations for different pig productive stages were used as the basis to establish dietary nutrient content for both Mexican scenarios' diets (*Table 3.I*). Phosphorus content was reduced from standards stated in *Table 3.I* since phytase enzyme was modelled as part of ingredients included in pig diets (this is explained further in *Table 3.III*).

Table 3.I Crude protein and phosphorus[1] for Mexican scenarios pig diets

Stage of production	weight, kg	CP, %	P, %
Weaners	<25	20.9	0.60
Grower	25-50	18.0	0.50
Finisher	50-110	14.4	0.43
Gestating sow		12.4	0.60
Lactating sow		17.2	0.60

[1]basic P content without phytase inclusion, source NRC, 1998.

A3.1.2 British scenarios

For the stdUK scenario there were several variations in pig nutrient recommendations between sources. Thus a short discussion is presented to clarify the nutrient parameters which were used (section A5.1.3). Edwards *et al.* (2002) analysed pig nutrient recommendations in pig diets with different nutrient ranges and for different productive stages. They formulated diets minimising nutrient excretion without sacrificing productivity. These ranges were compared with the Nutrient Requirements Standards for

Pigs (BSAS, 2003) to derive the best figure for nutrient content in pig diets for the British scenarios. Phosphorus content in diets, and the amount retained in pigs was modelled accordingly to Van der Peet-Schwering (1999), Edwards *et al.* (2002) and Nutrient Requirement Standards for Pigs in the UK (BSAS, 2003). Martins et al. (2002) provided nutritional values for organic pig diets in the UK and these values were used to model the orgUK scenario **(***Table 3.IV***).**

A3.1.3 Crude protein for non-organic scenarios

In practice, pig diets are formulated to maximise nutrient use and minimise costs, thus the best figure for a diet is when both of these factors are in equilibrium. This means that nutrient losses can increase if more digestible feedstuffs have an uncompetitive price, because cheaper but less digestible protein raw materials will be used. Thus diet composition depends on raw material prices and availability. Hence real amounts of Nitrogen through protein content can vary from standard parameters. The Nutrient Requirements Standards for Pigs (BSAS, 2003) offer a set of dietary protein recommendations as minimum levels of standardised ileal digested protein (ideal protein). These recommendations were transformed to dietary protein, using the BSAS (2003) recommended standard factors (0.84 for lactating sow and growing pig diets and 0.74 for pregnant sow diets). According to physical parameters used to model the stdUK scenario (Table 3.2) the BSAS intermediate category of performance for growing pig dietary protein recommendations was used to model basic requirements for finishing pig diets for this scenario. Edwards *et al.* (2002) stated crude protein content for pig diets under commercial practice, and also the best figure to minimise Nitrogen losses whilst maintaining competitive prices and amino acid equilibrium. Both sources were compared with dietary protein recommendations in the IPCC (2003) guidelines for established dietary changes in growing pigs. *Table 3.II* shows the four dietary protein information sources. Crude protein content under commercial conditions collected by Edwards *et al.* (2002) was chosen to model the stdUK scenario, because this complies with minimum requirements stated in the Nutrient Requirements Standards for Pigs (BSAS, 2003) and in the IPCC guidelines. According with Edwards *et al.* (2002) it is also the most common composition in pig diets.

Table 3.II Dietary protein recommendations used to model the stdUK scenario.

Source Stage of production	weight, kg	IPCC, 2001	Edwards *et al.* [a], 2002 Common	 Lowest	BSAS 2003	stdUK scenario
Weaner	<25	17.5-19.5	21.46	19	17.9	21.5
Grower	25-50	15-17	17.37	16	15.5	17.4
Finisher	50-110	14-15	15.1	14.5	13.1	15.1
Gestating sow	PGW= 40kg	13-15	12.5	11.5	12.2	12.5
Lactating sow	DYM= 8-12kg	16-17	17	14.8	14.3	17

[a] *Common* refers at the current commercial formulation and for *Lowest* at minimum requirements when is formulated for ileal amino acid digestibility (Edwards *et al.*, 2002).

PGW is Pregnant Gain weight; *DYM* is Daily Yield Milk as is in the Nutrient Requirements Standards for pigs.

A3.2 Phosphorous

Principal differences in dietary phosphorus content among scenarios relate to the phosphorus source and phytase inclusion. Phytase is an enzyme that increases availability of endogenous grain phosphorus. Phytase inclusion in pig diets is a common practice for farms used to model the two Mexican scenarios. Most feed mills have access to a uniform mixture of micro-ingredients, commercially named as a “feed nucleus”, which commonly includes phytase in its formulation (Garcia, 2009, Personal communication; Santiago, 2008, Personal communication). Since the UK animal feed mills also have access to the most advanced animal nutrition, it was assumed that phytase inclusion in pig diets is a common practice for the stdUK scenario. For the orgUK scenario diets, the principal phosphorus source is phosphoric rock because, for organic certification, it is not accepted that processed phosphorous sources can be included in the pig diet. Available phosphorus from allowed sources under organic farming modifies diet total phosphorus content, and this is modelled forward (see section A5.3).

A3.2.1 Phytase

Phosphorous plant content is enough to cover pig needs, but normally only a third of total phosphorous plant content is available to the pig. About 66% of plant phosphorous is present as phytate which is indigestible to the pigs and excreted in the faeces (Edwards *et al.*, 2002; Van der Peet-Schwering *et al.*, 1999). Therefore inorganic forms of phosphorous should be included to balance pig diets, increasing phosphorous losses. Van der Peet-Schwering et al. (1999) state that the digestibility of P increases by 27-30 percentage units if microbial phytase is added to the diet, but this has a small effect on the ileal digestibility of crude protein and some essential amino acids (2% of improvement). Edwards *et al.* (2002) reported that adding phytase to pig diets can reduce total phosphorus in the feed by ~0.1 percent units (a 15-20% reduction). Pig diets modelled for the stdUK were assumed to add phytase, considering that since 1991 microbial phytase has been commercially available in Europe and in 1995 this became a common practice (Van der Peet-Schwering *et al.*, 1999).

A3.2.2 Phosphorous content for non-organic pig diets

Table 3.III presents phosphorous content recommendations stated in the Nutrient Requirements Standards for Pigs (BSAS, 2003), the IPCC guidelines and NRC (NRC). The best available technique, to be implemented under the IPCC guidelines and referred to by Edwards *et al.* (2002), proposes the maximum levels of phosphorus inclusion in order to reduce nutrient excretion. The Nutrient Requirements Standards for Pigs (BSAS, 2003) state phosphorus inclusion rates in terms of digestible phosphorus which is more precise to

fulfil pig requirements, but does not provide knowledge of the average of total phosphorus supplied. The total Phosphorus consumption is necessary to model surpluses that are excreted in the manure, but the Nutrient Requirements Standards for Pigs (BSAS, 2003) do not present standard factors to calculate total phosphorus content. In contrast, NRC (1998) gives total phosphorus recommendations that are more appropriate for modelling phosphorus output. Is expected that the NRC (1998) phosphorus recommendations also match phosphorus amounts used under commercial conditions in the UK, as happens for crude protein (see *Table 3.II*). Thus the NRC (1998) phosphorus standards were used to model the basic necessities for the stdUK scenario pig diets. Assuming that phytase is added to pig diets in the stdUK scenario, phosphorus content was adjusted according to Van der Peer- Schwering et al. (1999) and Edwards *et al.* (2002). Therefore, for the three scenarios where phytase was allowed to be used in pig diets, phosphorus content was reduced between 0.1 and 0.05 percent units on average, following the findings of Van der Peet-Schwering et al. (1999.) for phytase-induced phosphorus availability. *Table 3.I* shows total phosphorus modelled for stdUK and Mexican scenarios and alternative data sources for phosphorus content for pig diets.

Table 3.III Phosphorous recommendations for non-organic scenarios pig diets.

Source		**IPCC**	**BSAS, 2003**	**NRC, 1998**	**P + phytase**[1]
Stage of production	weight, kg	Total P, %	Digest P, %	Total P, %	Total P, %
Weaners	<25	0.60-0.70	0.34	0.60	0.54
Grower	25-50	0.45-0.55	0.25	0.50	0.48
Finisher	50-110	0.38-0.49	0.23	0.43	0.43
Gestating sow		0.43-0.51	0.23	0.60	0.50
Lactating sow		0.57-0.65	0.32	0.60	0.48

[1]Total P diet content when Phytase is included (van der Peet-Schwering et al. 1999)

A3.3 Crude protein and phosphorous content for organic pig diets

Since some grown crops in organic farming contain anti-nutritive factors, and because of the ban on the use of synthetic amino acids and phytase enzyme (synthetic compounds), it is seldom possible to meet protein requirements from home grown crops for animal production. Non-GM soya or organic soya is frequently imported from other organic crop farms (Martins *et al.*, 2002). Hence an oversupply of crude protein is generally necessary in order to meet the requirements of the limiting amino acids. Therefore, in some cases, crude protein requirements for organic pig farming look higher than standard recommendations. Maribo and Fernandez (2002) stated that, due to feedstuff restrictions, between 0.5 and 1.0 percent extra crude protein should be added in organic growing-finishing pig feed. In this context, Millet et al. (2006) assessed crude protein content following organic restriction to feed formulation, using balanced diets to meet ileal digestible lysine content on isocaloric rates. They concluded that diets with 20% of CP are adequate from 20 to 40 kglw and for the second phase onwards (45 kglw), at least with isocaloric diets, a decrease in protein content (corresponding to a 10% reduction in dietary ID Lysine) at 18% may be used in organic growing-finishing pig nutrition. These findings are similar to crude protein and phosphorus contents suggested by Martins et al. (2002). In a review of organic pig farming coordinated by Martins et al. (2002), the suggested nutrient content for a set of five different diets was given. The authors qualify that these diets are the most common practice for organic pig farming. Thus the crude protein and phosphorus content for the orgUK scenario diets were modelled accordingly to Martins et al. (2002) and summarised in *Table 3.IV*.

Table 3.IV Nutrients recommendations for organic pig diets

Stage of production	**characteristics**	**CP, %**	**P, %**
Weaners	<25	20.0	0.60
Grower	25-50	20.0	0.50
Finisher	50-110	16.0	0.50
Dry sow & boar		13.0	0.60
Lactating sow		17.0	0.70

Source: Martins et al., 2002

Appendix 4 Weather conditions for each scenario

One of the main differences between scenarios is their geographic position, which means that therefore weather conditions are very different. In the case of the UK scenarios, there were no modelled differences between the stdUK and orgUK scenarios, because the farm distribution within the UK was assumed to be similar for both scenarios. However, for Mexican scenarios there are more extreme weather condition differences and more specific distribution of the pig farms representing the scenarios.

A4.1 Annual average temperature for the UK scenarios

Even though the weather can change from one day to the next, temperature variation throughout the year is relatively small. The notoriously changeable and often unsettled weather is explained by warm tropical air and the cold polar air that meets over the UK. Generally the country has cool to mild winters and warm summers with moderate variation in temperature throughout the year. In England the average annual temperature varies from 8.5 °C in the North to 11 °C in the South (www.metoffice.gov.uk/weather/). Under this annual temperature, the most useful conversion factor to calculate methane emission for the UK scenarios is to use 10 °C as average temperature stated in the IPCC guidelines (IPCC, 2006).

A4.2 Annual average temperature for Mexican scenarios

According to the geographic position of Mexico, the Tropic of Cancer effectively divides Mexico into temperate and tropical zones. Land north of the twenty-fourth parallel experiences cooler temperatures during the winter months, whereas that South twenty-fourth parallel experiences temperature that are fairly constant all year round and vary solely as a function of elevation (Figure A4.1). Thus areas with elevations up to 1,000 m, such as the southern parts of both coastal plains as well as the Yucatan Peninsula, have a yearly median temperature of 26°C (range 24°C to 28°C). Temperatures here remain high throughout the year, with only a 5°C difference between winter and summer median temperatures. Low-lying areas north of the twentieth-fourth parallel generally have lower yearly temperatures, averaging 22°C (from 20°C to 24°C) because of more moderate conditions during the winter, although they are hot and humid during the summer. Pig farms modelled for the stdMEX scenario are typically located either in the Yucatan peninsula or in the northwest region of Mexico (INEGI, 2005), where annual weather temperatures are either 26°C or 22°C.

On the other hand, for the locMEX scenario towns and cities between 1,000 and 2,000 m south of the twenty-fourth parallel have relatively constant, pleasant temperatures throughout the year, with an average of 18°C (range of 16°C to 20°C) (INEGI, 2005). Pig farming for the locMEX scenario is principally situated in this region. Thus, for this study, 24°C was the yearly average temperature considered for the stdMEX scenario and 18 °C for the locMEX scenario.

All scenarios have a wide temperature variation during the year, with higher temperatures during the summer season and lower temperatures in the winter season. It is expected that during the hottest periods, more methane will be produced and the methane production during winter will decrease. The model assumed that using the annual average temperature to fix the methane emission factor provided by IPCC (2006), compensated for the increases and decreases of methane during the year.

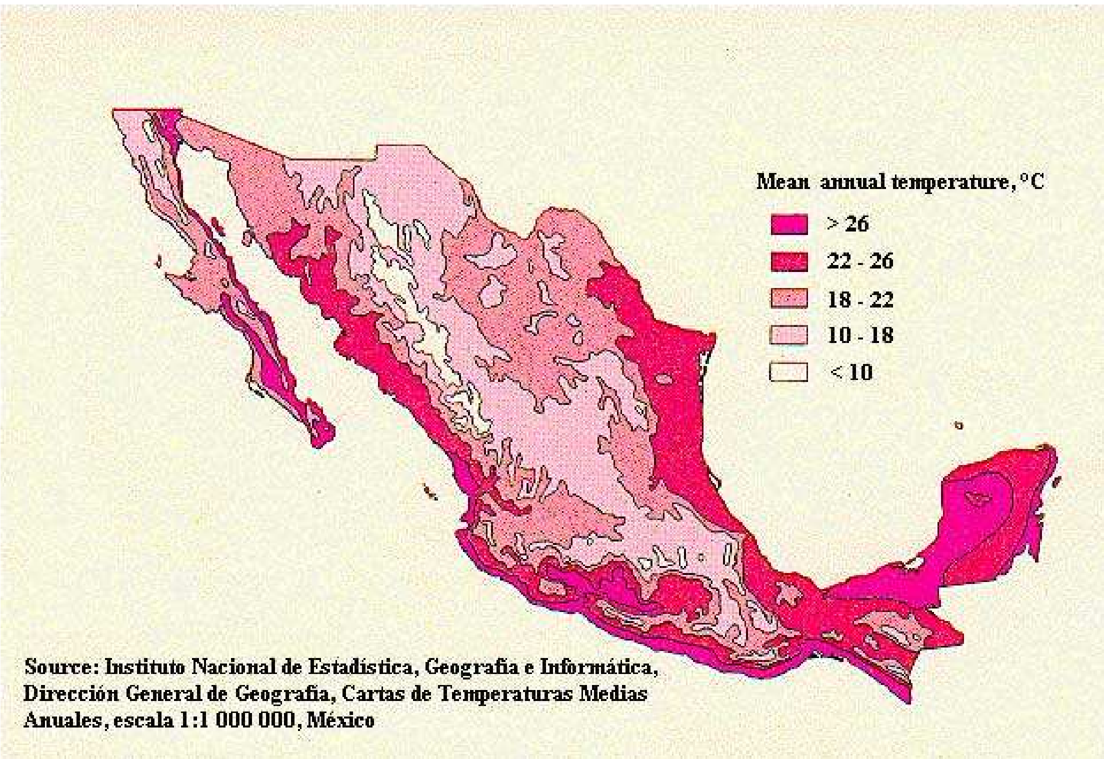

Figure A4-1 Average annual temperature for Mexican regions (INEGI, 2005)

Appendix 5 General formulae

A5.1 Formulae of the herd inventory tlw^{-1} production.

Equation 1

$$Lactating_{sow} = \frac{W_a \bullet L_y \bullet 1000}{Y \bullet PM}$$

Equation 2

$$Dry_{sow} = 1 - L_{sow} \bullet \left(\frac{1000}{PM}\right)$$

Equation 3

$$Gilt = \frac{R_r \bullet I_s \bullet 1000}{100 \bullet Y \bullet PM}$$

Equation 4

$$Growers = Gy \bullet \left(\frac{R_p}{Y}\right) \bullet \left(\frac{1000}{PM}\right)$$

Equation 5

$$Finishers = Fy \bullet \left(\frac{F_p}{Y}\right) \bullet \left(\frac{1000}{PM}\right)$$

$$Gy = W \bullet L_Y \bullet \left(\frac{100 - Rm}{100}\right)$$

$$Fy = Gy \bullet \left(\frac{100 - Fm}{100}\right)$$

$$PM = Fy \bullet Fw$$

Where:

W_a = Weaning age, days

L_y = Litter year^{-1}

Y = 365 days

PM = Pigmeat sow^{-1} year^{-1}, kg

R_r = Replacement rate,

I_s = Time to first service, days

Gy = Annual growers sow^{-1}, heads

R_p = Age at end of rearing period, days

Fy = Annual finishers sow^{-1}, heads

F_p = Days during finishing period
W = Weaners litter^{-1}, heads
Rm = Rearing mortality,
Fm = Finishing mortality,
Fw = Slaughtering weight, kg

A5.2 Formulae of methane production during the different manure management stages (MM-stage) tlw^{-1} production.

Equation 6

$$VS_t = \sum VSs_i \bullet I_i$$

Equation 7

$$CH_{4j} = VS_j \bullet Bo_j \bullet 0.67 \bullet MCF_j \bullet Y$$

Equation 8

$$VS_j = VS_k - \left(VS_k \bullet \left(\frac{MCF_k}{100} \right) \right)$$

Where:

VS = Daily volatile solids by MM-stage, kg dry matter tlw^{-1} day^{-1}
S = standard values
t = total
i = pig production stage
j = MM-stage (Collection, storage or disposal)
k =previous MM-stage of the MM-stage where is the calculation
I = Inventory by productive stage
CH_4 = Methane production per MM-stage, kg tlw^{-1}
Bo = Maximum methane producing capacity for methane produced by MM-stage, m3 CH4 kg^{-1} of VS in the MM-stage
0.67 = conversion factor of m3 to kilograms CH4
MCF = Methane conversion factor for each MM-stage j by scenario conditions

A5.3 Formulae of Nitrogen mass balance, tlw^{-1}

Equation 9

$$N_a = \sum F_i \bullet \frac{CP_i}{6.25}$$

Where:

N_a = Feed-N, Kg tlw^{-1}

F_i = Feed consumption by pig productive stage *i*, kg tlw^{-1}

CP_i = Crude protein content of feed consumed by pig productive stage *i*,

6.25 = Conversion factor for N content in proteins.

i = pig productive stages

A5.4 Formulae of pig meat

Equation 10 total pig meat

$$Mt = PM + \left(Cw \bullet \frac{R_r}{100} \right)$$

Equation 11 finishers pigmeat

$$Mf = \frac{1000}{Mt} \bullet PM$$

Equation 12 cull pigmeat

$$Mc = \left(\frac{1000}{Mt} \right) \bullet \left(Cw \bullet \frac{R_r}{100} \right)$$

Where:
Mt = total pigmeat, kglw tlw^{-1}
PM = Finishers pigmeat, kglw sow^{-1}
Cw = Cull weight, kglw
R_r = Replacement rate,
Mf = Meat proportion of finisher pigmeat by tonne of pigmeat, kg
Mc =Meat proportion of cull pigmeat by tonne of pigmeat, kg

Equation 13 Pig-N

$$N_p = \left(Mf \bullet \frac{CP_f}{6.25} \right) + \left(Mc \bullet \frac{CP_c}{6.25} \right)$$

Where:

N_p = Pig-N, Kg tlw^{-1}
Mf = Meat proportion of finisher pigmeat by tonne of pigmeat, kg
Mc =Meat proportion of cull pigmeat by tonne of pigmeat, kg
CP_f = Protein content of finisher meat =170g kglw^{-1}
CP_c = Protein content of cull meat =156g kglw^{-1}

6.25 = Conversion factor for N content in proteins.

A5.5 Formulae of N manure systems

Equation 14 N economy during MM- systems

N losses by MM-system *i*

$$N_i = Ndo_i + Na_i + Nn_i$$

Direct N_2O-N losses in the MM-system *i*

$$Ndo_i = Np_i \bullet dFo_i$$

Ammonia-N and NOx-N losses in the MM-system *i*

$$Na_i = (Np_i - Ndo_i) \bullet Fa_i$$

Nitrate and NOx-N losses in the MM-system *i*

$$Nn_i = (Np_i - Ndo_i - Na_i) \bullet Fn_i$$

Indirect N_2O-N losses in the MM-system *i*

$$Nio_i = (Na_i \bullet iaFo_i) + (Nn_i \bullet inFo_i)$$

Total N_2O losses from the *i* systems

$$No_t = \sum Ndo_i + \sum Nio_i$$

Total ammonia-N losses from the *i* systems

$$Na_t = \sum (Na_i - Nio_i)$$

Total nitrate-N losses from the *i* systems

$$Nn_t = Nn_i \bullet Nio_i$$

Available plant-N

$$Np = Nt - Ndo_t - Na_t - Nn_t$$

Where:
i = Manure management system of collection, outside storage or disposal

Np = Total N at beginning of the *i* MM-system
dFo =Conversion factor of direct N_2O-N emissions in the *i* MM-system
iaFo = Conversion factor of indirect N_2O-N emissions from ammonia in the *i* MM-system
inFo = Conversion factor of indirect N_2O-N emissions from nitrate in the *i* MM-system
Fa = Conversion factor of ammonia-N in the *i* MM-system
Fn = Conversion factor of nitrate-N in the *i* MM-system
Nt = N excreted (manure-N)

A5.6 Formulae of P mass balance

Equation 15 P input (feed-P)

$$P_a = \sum (F_i \bullet P_i)$$

Where:

P_a = Feed-P, Kg tlw^{-1}

F_i = Feed consumption by pig productive stage *i*, kg tlw^{-1}

P_i = Phosphorus content of feed consumed by pig productive stage *i*,

Equation 16 Pig-P

$$P_p = (Mf \bullet Pf) + (Mc \bullet Pc)$$

Where:

P_p = Pig-N, Kg tlw^{-1}
Mf = Meat proportion of finisher pigmeat by tonne of pigmeat, kg
Mc =Meat proportion of cull pigmeat by tonne of pigmeat, kg
P_f = P content of finisher meat =170g $kglw^{-1}$
P_c = P content of cull meat =156g $kglw^{-1}$

Equation 17 P losses and credits calculations

Total manure-P

$$Pm = \Pr + Ps + Pp$$

Total phosphate-P losses

$$\Pr = Pm \bullet Fp$$

Soil-structure-P credit

$$Ps = (Pm - \Pr) \bullet Fs$$

Plant-P credit

$$Pp = Pm - \Pr - Ps$$

Where:
Fp = Conversion factor of phosphate-P losses
Fs = Conversion factor for soil structure-P

A5.7 Formulae of Diet ingredients

Equation 18 diet ingredient by scenario

$$I_{ij} = \sum \left(F_{jk} \bullet \frac{D_{ijk}}{100} \right)$$

Where:

I_{ij} = Ingredient amount *i* in scenario *j*, Kg tlw^{-1}

F_{jk} = Feed consumption by pig productive stage *k* in scenario *j*, kg tlw^{-1}

D_{ijk} = Diet ingredient *i* in scenario *j* and by the productive stage *k* on 100 kg diet basis

A5.8 Formulae of feed and feed ingredients transportation

Equation 19 transportation distance by feed or ingredient

$$T_{ij} = T_i \bullet I_{jk}$$

Where:

Tij = Total transportation distance *i* by feed or ingredient *j*

Ijk = Amount of feed or ingredient *j* in the scenario *k*

A5.9 Formulae of the stdMEX commodity values

Equation 20 detailed commodities values for the stdUK scenario using data from Table 4.25

$$D = \frac{(a \bullet c)}{b}$$

where:
D is the single commodity value for the stdMEX scenario
a is the single commodity value for the locMEX scenario
c is the aggregated value for the stdMEX scenario
b is the aggregated value for the locMEX scenario

Appendix 6 Networks of e-impacts for nutrients flow

In the network figures, boxes represent principal commodities used to produce pig feed demanded for each tlw. At the top of the box are the commodity amount and name. In the lower left corner the gCO_2 eq per tlw contribution (E= exponent). The bar on the right side represents the burden contribution by commodity. Arrow width is related to percent contribution by pathway or commodity.

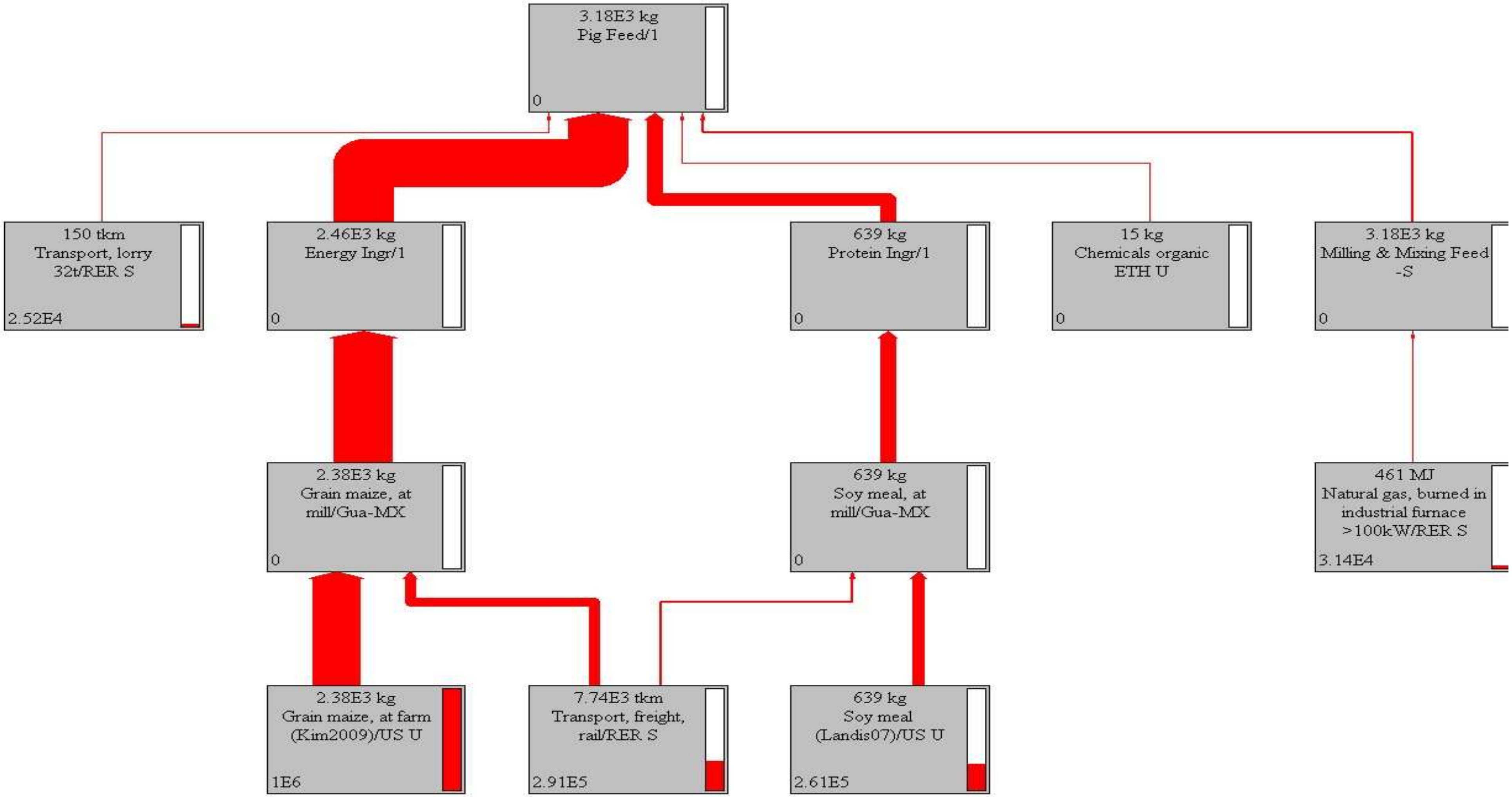

Figure 6.I Network of GWP_{100} distribution for feed and crop production in the locMEX scenario, gCO_2 eq tlw^{-1}

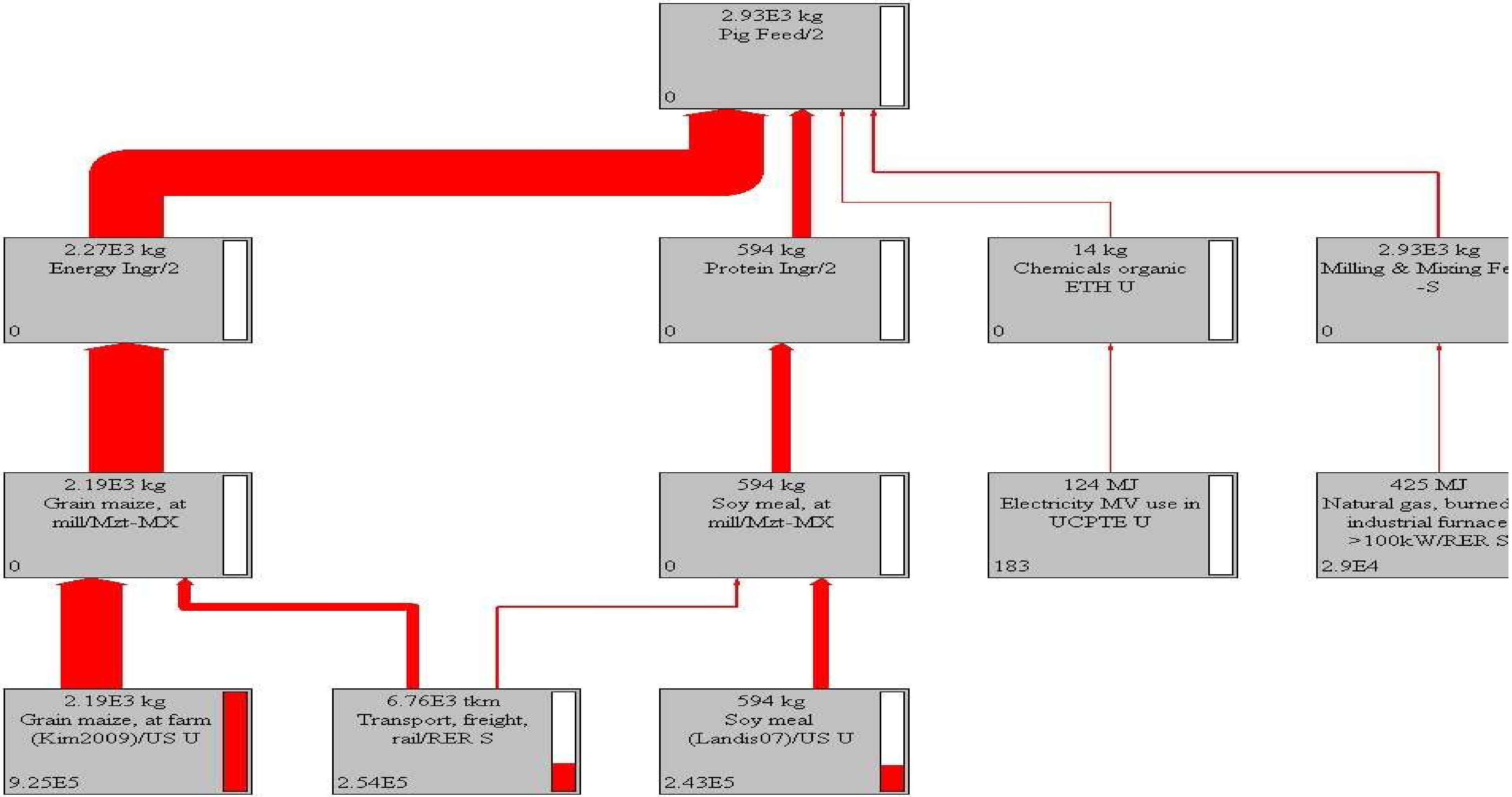

Figure 6.II Network of GWP_{100} distribution for feed and crop production in the stdMEX scenario, gCO_2 eq tlw^{-1}

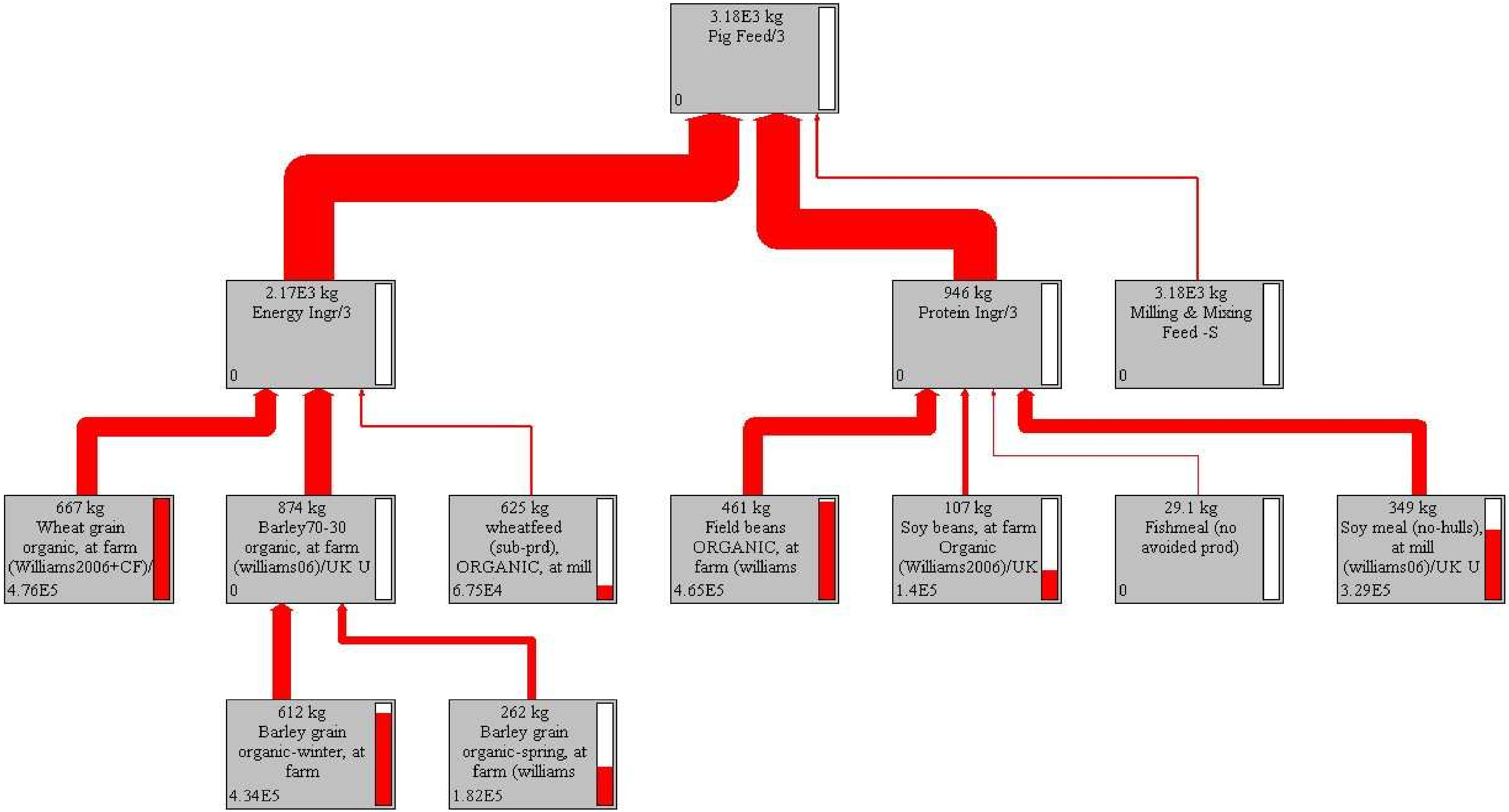

Figure 6.III Network of GWP_{100} distribution for feed and crop production in the orgUK scenario, gCO_2 eq tlw^{-1}

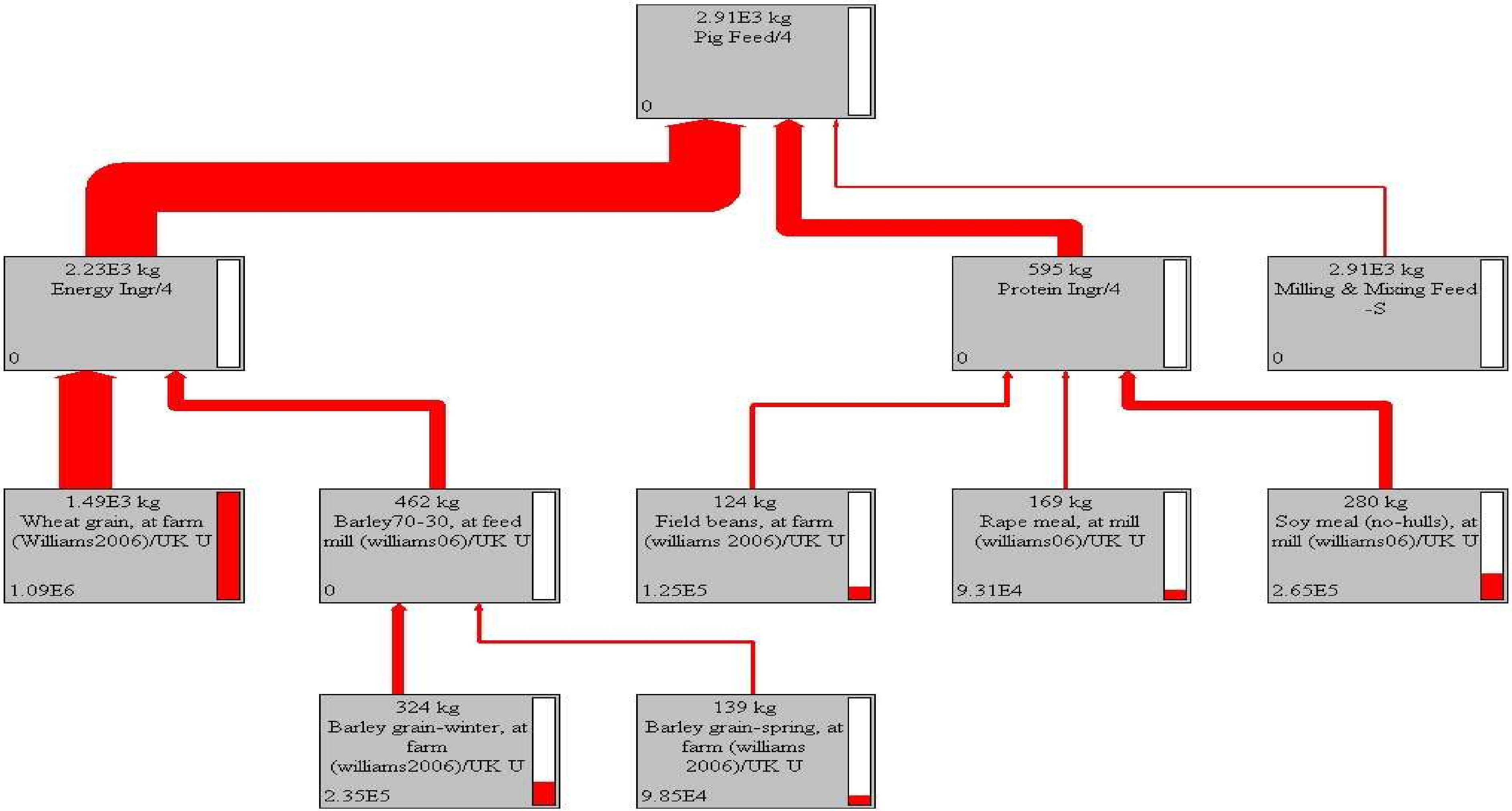

Figure 6.IV Network of GWP_{100} distribution for feed and crop production in the stdUK scenario, gCO_2 eq tlw^{-1}

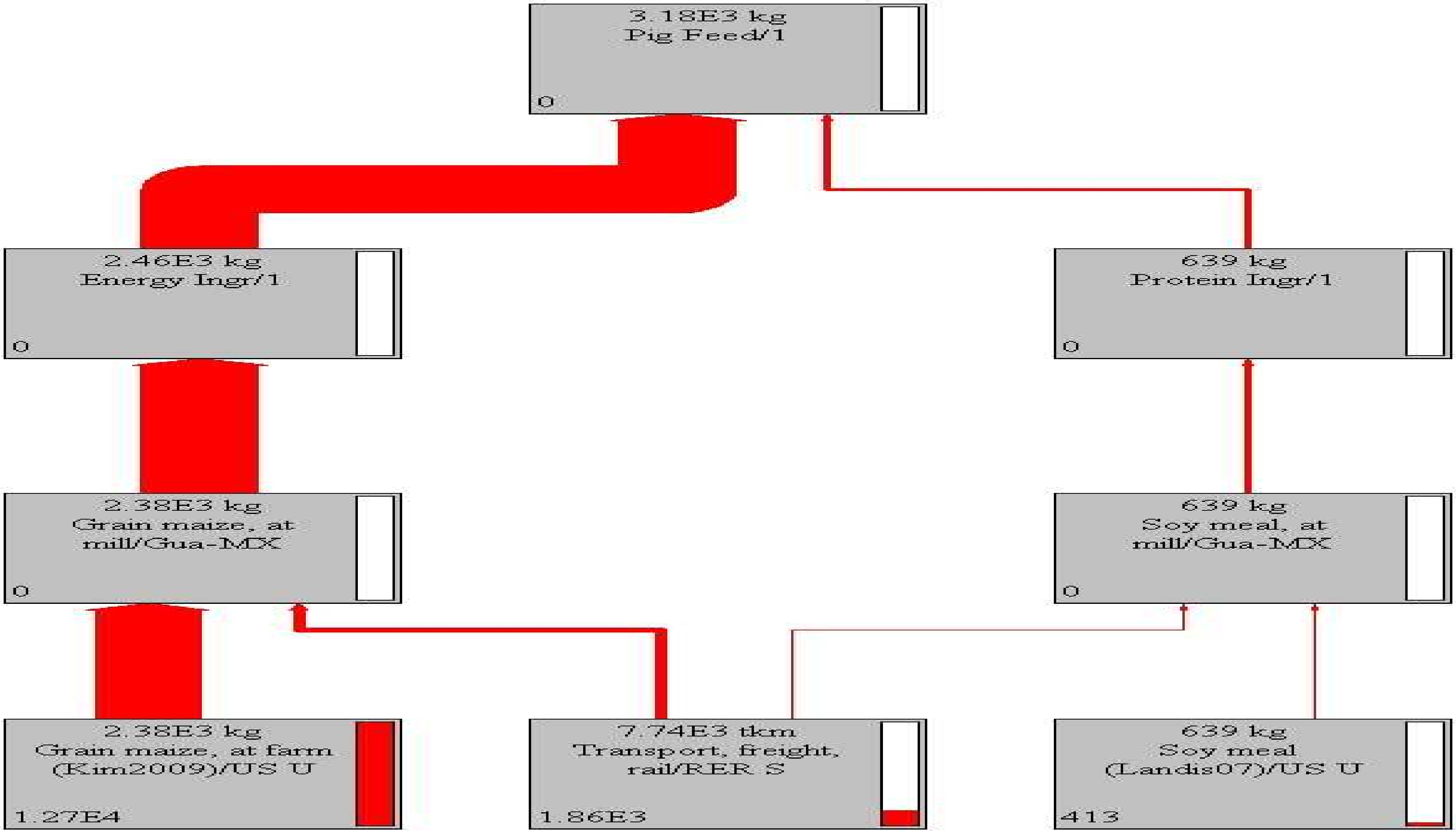

Figure 6.V Network of AP distribution for feed and crop production in the locMEX scenario, gSO_2 eq tlw^{-1}

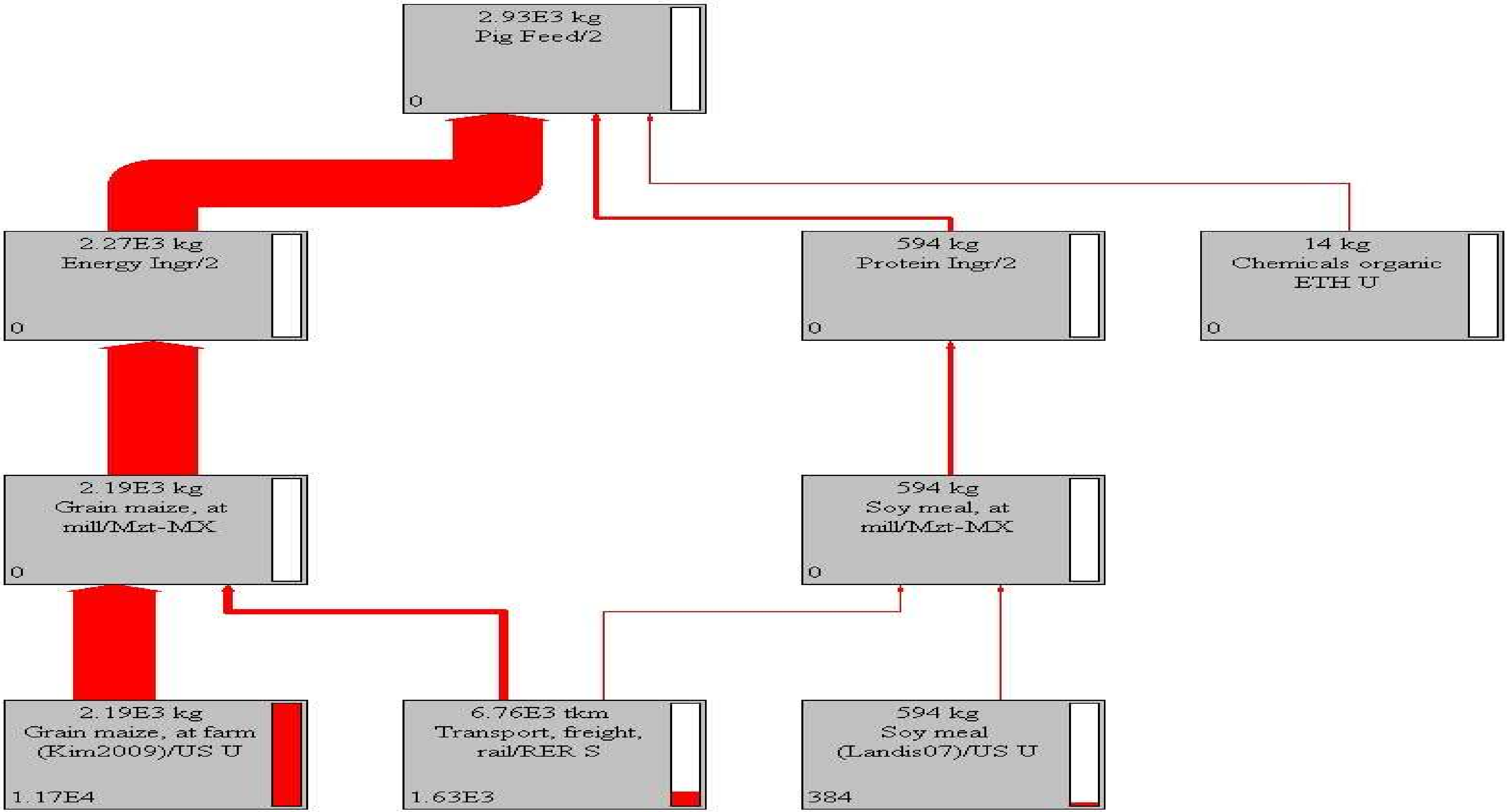

Figure 6.VI Network of AP distribution for feed and crop production in the stdMEX scenario, gSO_2 eq tlw^{-1}

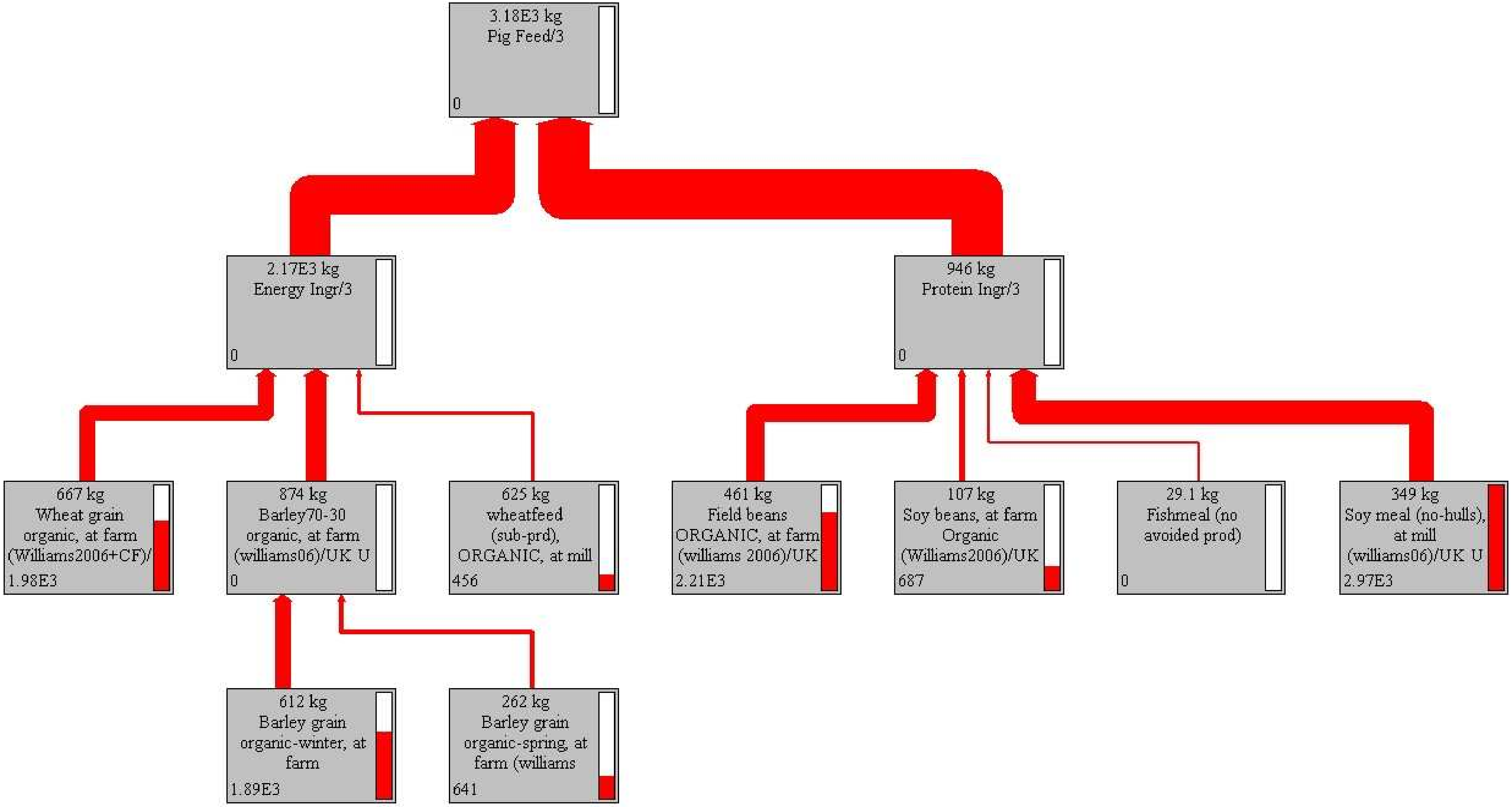

Figure 6.VII Network of AP distribution for feed and crop production in the orgUK scenario, gSO_2 eq tlw^{-1}

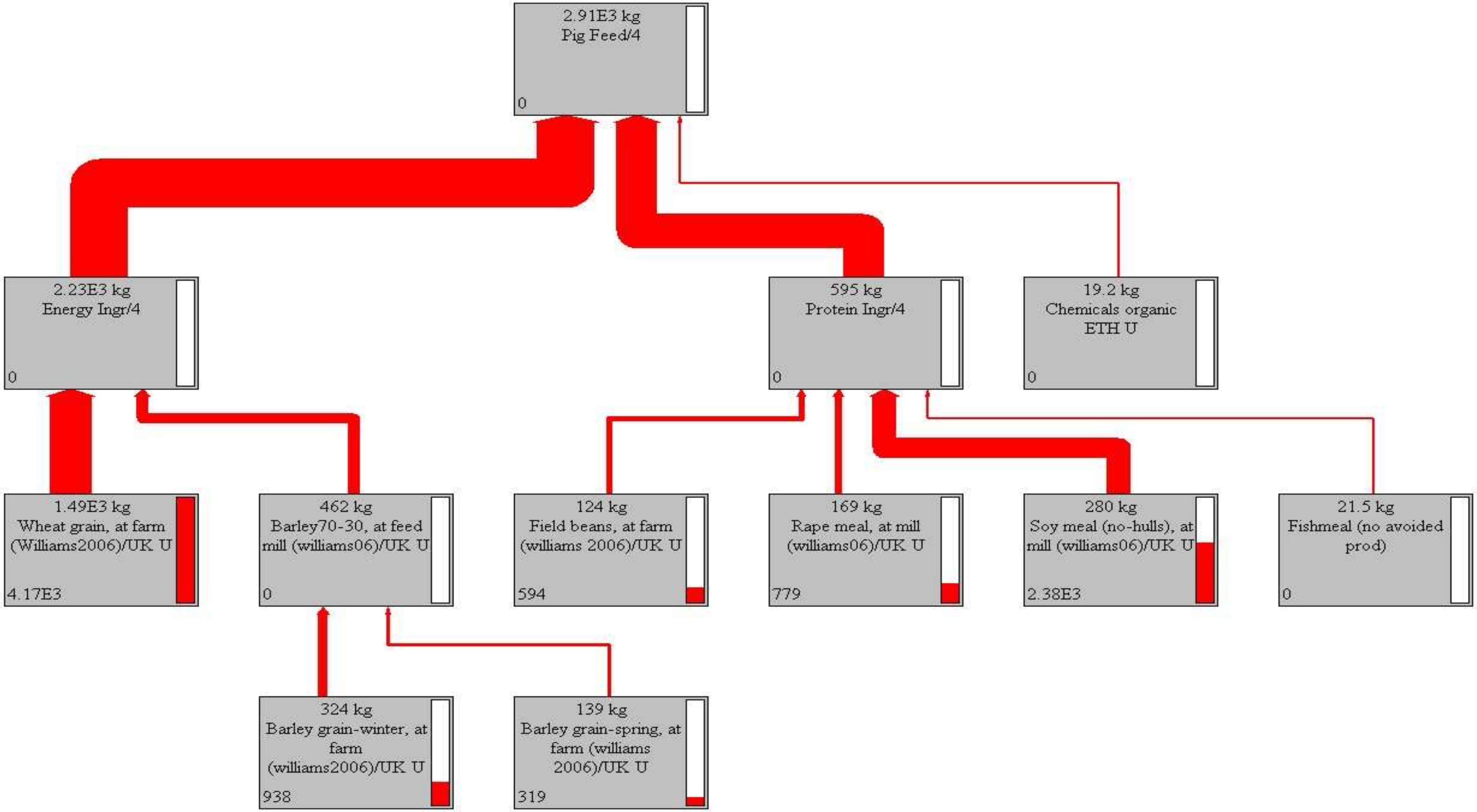

Figure 6.VIII Network of AP distribution for feed and crop production in the stdUK scenario, gSO_2 eq tlw^{-1}

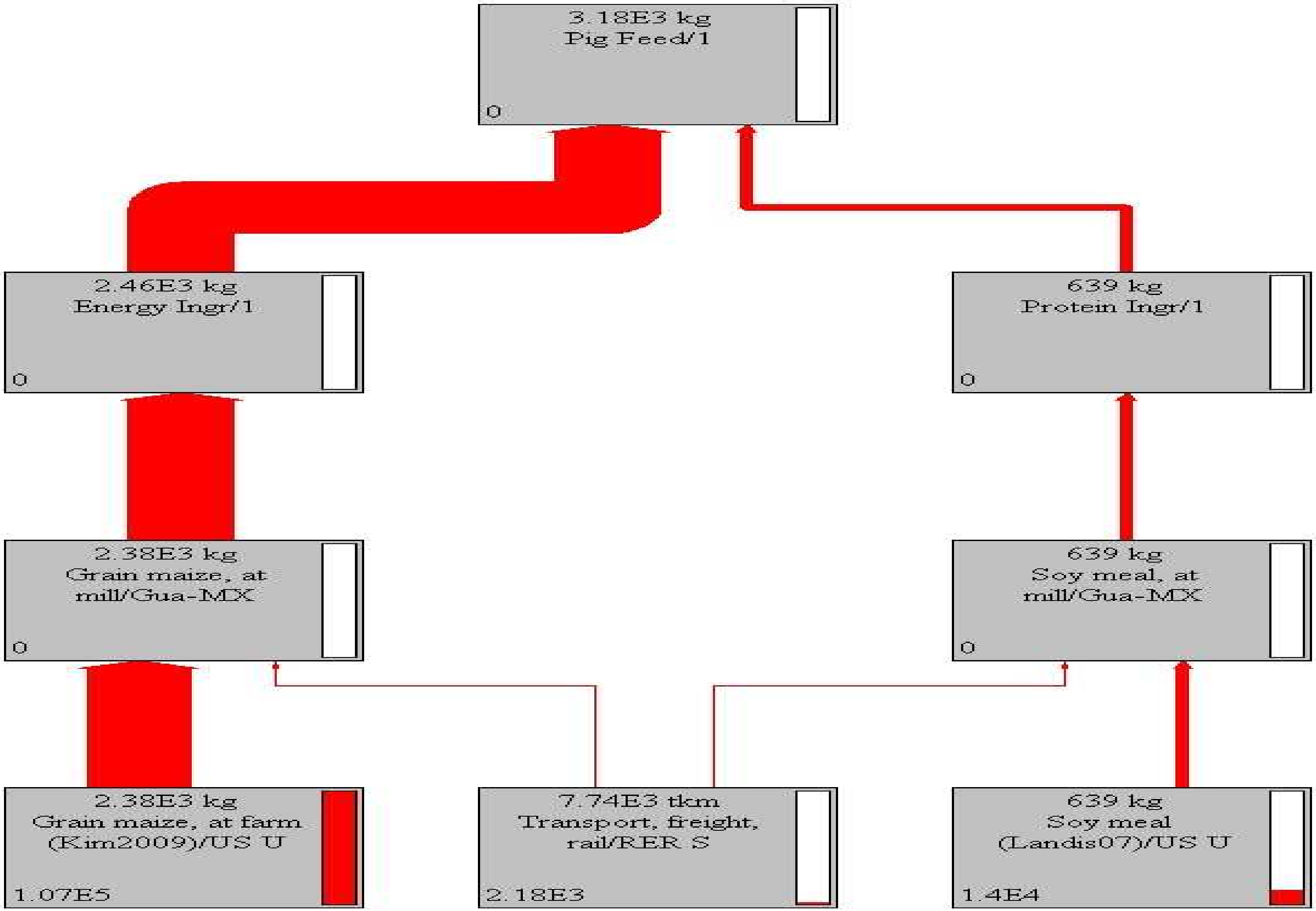

Figure 6.IX Network of EP distribution for feed and crop production in the locMEX scenario, gNO_3 eq tlw^{-1}

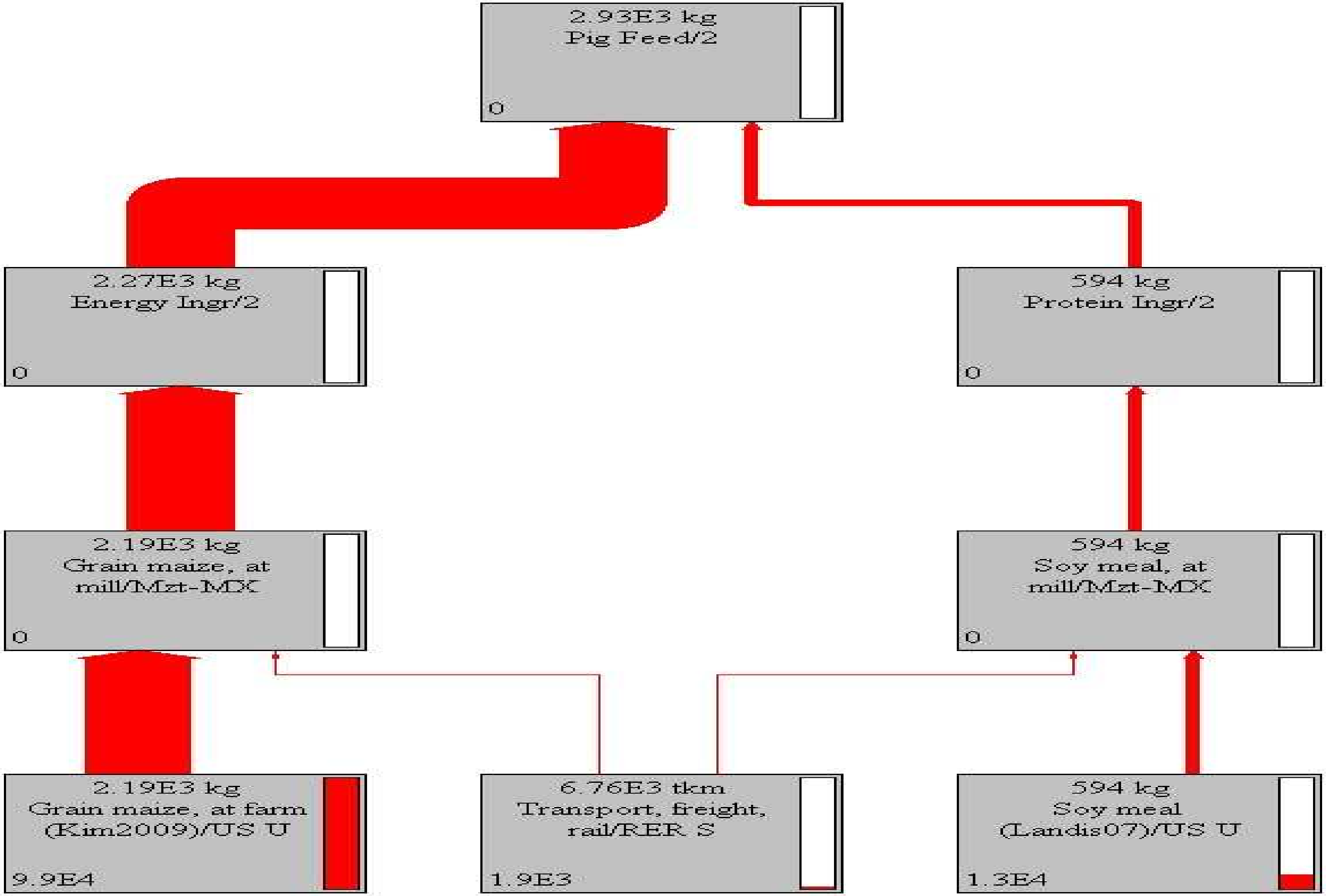

Figure 6.X Network of EP distribution for feed and crop production in the stdMEX scenario, gNO_3 eq tlw^{-1}

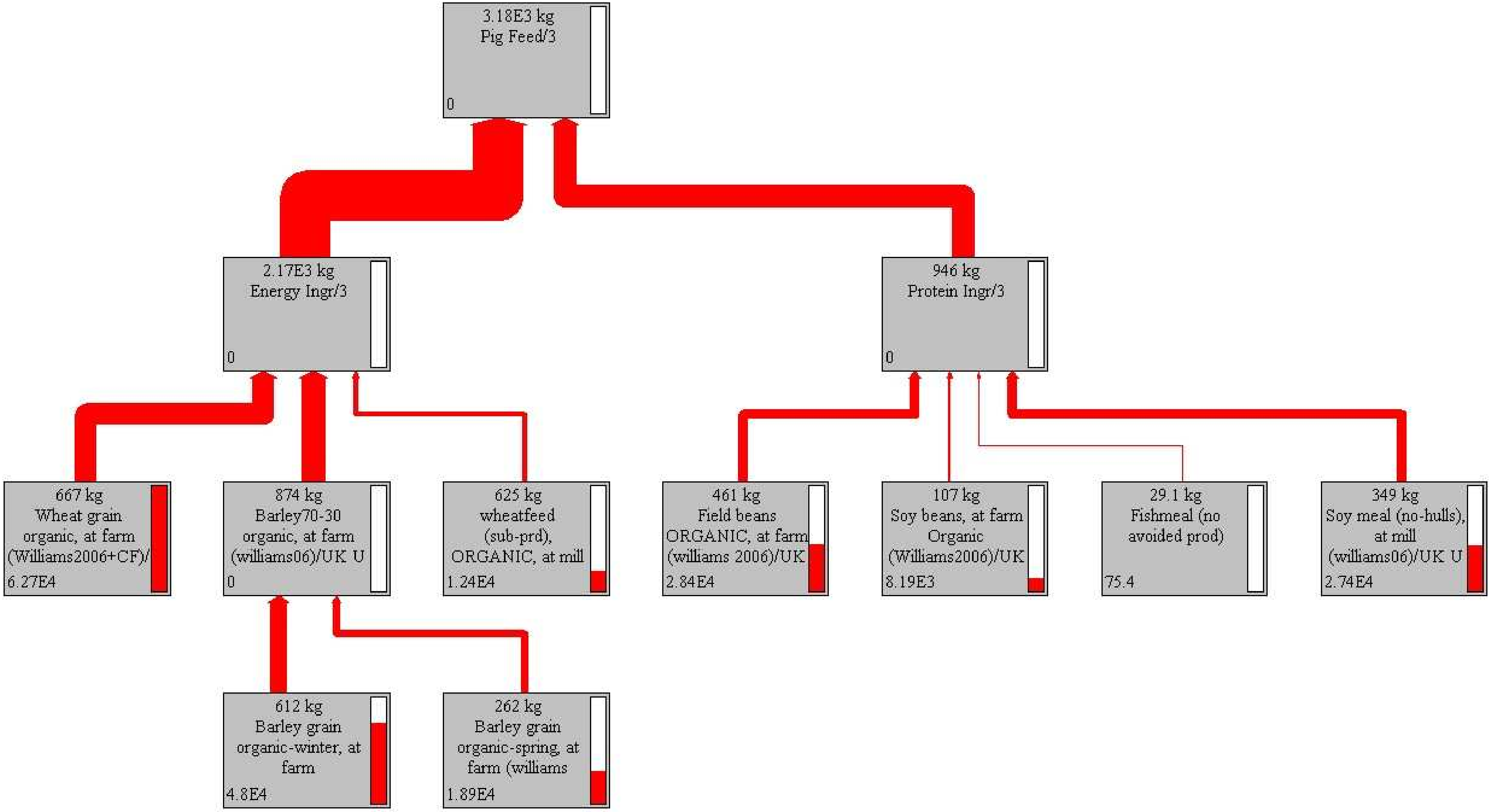

Figure 6.XI Network of EP distribution for feed and crop production in the orgUK scenario, gNO_3 eq tlw^{-1}

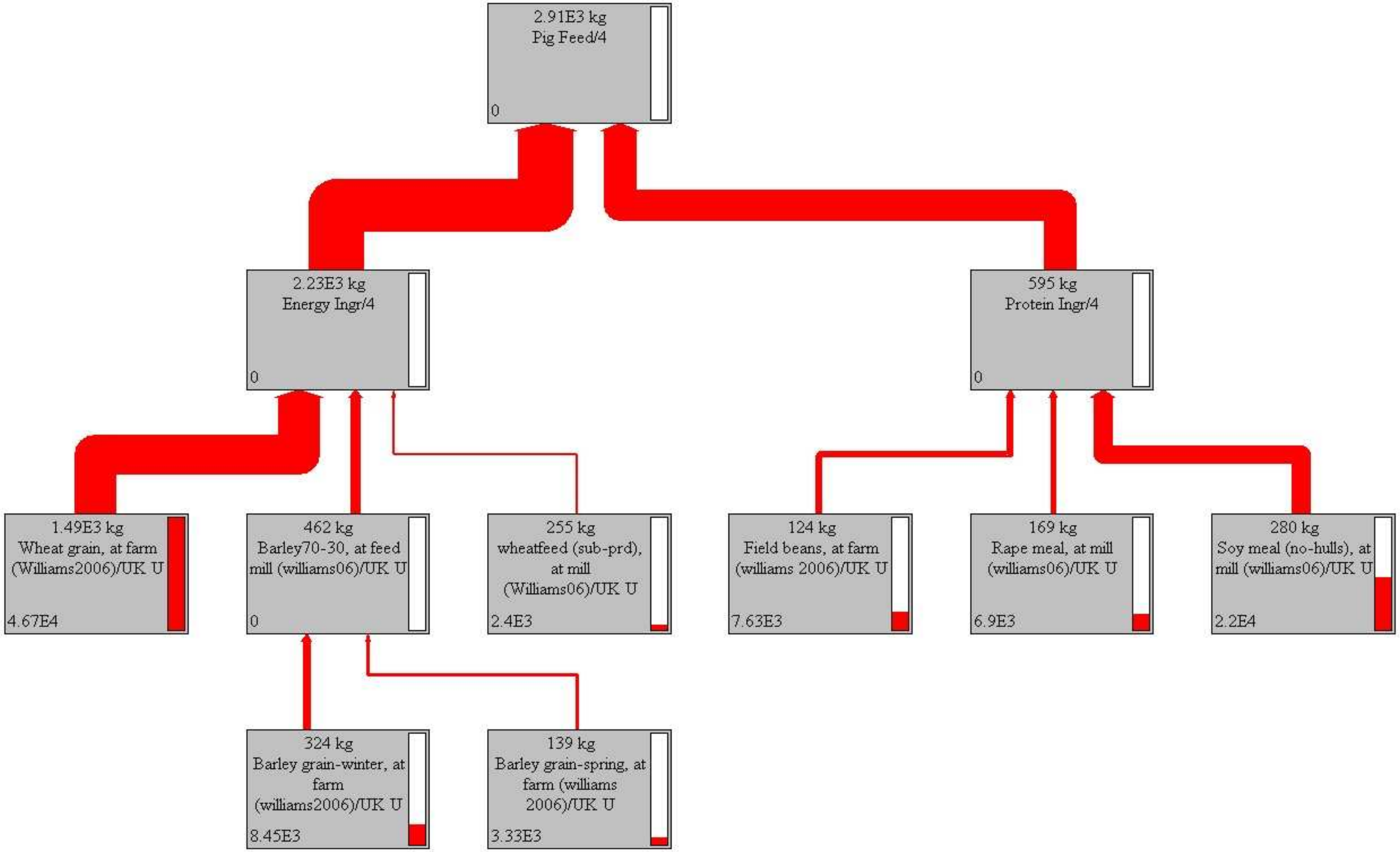

Figure 6.XII Network of EP distribution for feed and crop production in the stdUK scenario, gNO_3 eq tlw^{-1}

Appendix 7 Details of budget characterisation

A7.1 Characterisation of Mexican scenarios

Mexican pig production studies classify pig farms into high and intermediate technology farms and backyard farms (Ramirez, 2005). Farms are classified according to adoption of technological advances, more than breeding herd size. However, there is a close relation between farm size and adoption of new technology because access to capital, the cornerstone to invest in new equipment and facilities, is scarcer for intermediate and small farmers than for large enterprises. Thus, farms that have been considered as having high technology also have increased their pig accommodation capacity. For example, Sagarnaga *et al*. (1999) made farm descriptions with different herd sizes, but they did not assign any technological level. However, farms in the range of 260-310 sows and 600 to 1200 sows match with descriptions from other studies for intermediate and high technology farms, respectively. Thus, the financial performance reported for intermediate and high technology farms was assumed to be useful to contrast and complement the financial budgets of locMEX and stdMEX scenarios, respectively.

The accessible data on financial and economic results of pig farms in Mexico were too aggregated and few details could be obtained. Magana-Magana *et al*. (2002) split the input cost into only a few categories for farms suitable for the stdMEX and locMEX scenarios (Table A 7-I). They classified as commercial and industrial commodities the consumption of commodities purchased from other productive sectors in the economy. Fixed costs included labour and depreciation cost. Commercial commodities were made up mainly by feed (Magana-Magana *et al.*, 2002) and added value combined the profit and shared interest. Additional details for more specific costs were not provided.

Table A 7-I Main production cost for farms suitable for stdMEX and locMEX scenarios in the southern region of Mexico during 2002, adapted from Magana-Magana et al. (2002). Costs are expressed as a percentage of sale prices

Category (% unless otherwise shown)	Technological level stdMEX	locMEX	Difference
Commercial commodities	53.6	65.5	-11.9
Industrial commodities	15.5	13.7	1.8
Fixed costs	6.6	5.6	1.0
Other costs	1.3	1.8	-0.5
Added value	23.1	13.5	9.6
Sale price M$(2002) $kglw^{-1}$	11.74	11.71	0.03

In another study on pig production in the whole of Mexico during 2005, Gallardo *et al* (2006) calculated the main production cost and added value for farms suitable for stdMEX and loc MEX scenarios (Table A 7-II). They aggregated the financial concepts in different way to that of Magana-Magana *et al*. (2002). Even so, there is little difference to the values from Magana-Magana when variable costs are combined (Commercial and industrial commodities in Magana-Magana, *et al*., 2002). In both cases, variable costs are higher for farms representative of locMEX scenarios than for those representing the stdMEX scenarios. Also Gallardo *et al* (2006) presented the most disaggregated data.

Table A 7-II Pig farm budgets for farms suited for the Mexican scenarios in 2005 adapted from Gallardo et al (2006), Costs are expressed as a percentage of sale prices

Category (% unless otherwise shown)	Scenarios stdMEX	locMEX	Difference
Feed	46.0	60.5	-14.5
Medicine	9.3	4.2	5.1
Electricity, fuel, sundries, transport, fees, maintenance of buildings and machinery, miscellaneous	9.3	7.2	2.2
Labour	1.4	5.2	-3.8
Financial cost	18.3	11.1	7.2
Profit	15.6	11.9	3.7
Sale price M$(2005) $kglw^{-1}$	15.4	15.4	0.0

Nava *et al*. (2009) used regional prices to analyse the financial performance of farms suited for the stdMEX and loc MEX scenarios in the main pig production areas of Mexico in 2005. They also found higher variable cost for the farms in the locMEX scenario when they aggregated, as internal cost, the fixed costs, other costs and added value (Table A 7-III). Internal cost was considered as a cost that does not have an international price in the open market, such as labour, depreciation and loan interest. Farms typical of the stdMEX scenario had a higher percentage contribution of internal costs than those typical of the locMEX scenario. The lack of detailed costs do not allow further comparisons but the differences in production cost using local sale price are similar to other studies.

Table A 7-III Production cost of farms suitable for Mexican scenarios in the main pig production regions of Mexico during 2005, adapted from Nava et al. (2009). Costs are expressed as a percentage of sale prices

	Scenarios		
Category (% unless otherwise shown)	stdMEX	locMEX	Difference
Variable costs	63.1	70.1	-7.0
Internal costs	36.9	29.9	7.0
Sale price M$(2005) kglw^{-1}	14.97	15.97	-1.0

FAO (2002) reported the net input distribution for a sample of pig farms in the central States of Mexico (Michoacán and Jalisco States) in 2002, states that better represent farms for the locMEX scenarios. Table A 7-IV provides the average values of the main commodity costs. Unfortunately these values do not allow comparisons between scenarios, but adding the feed and medicines cost (the only variable costs detailed) the percentage value is similar to that reported previously for farms suitable for modelling as the locMEX scenario.

Table A 7-IV Production cost and profit for farms suited for the locMEX scenario in the central States of Mexico, adapted from FAO (2002). Costs are expressed as a percentage of sale prices

Category (% unless otherwise shown)	locMEX scenario
Herd size, sows	217
Feed	62.2
Medicine	7.5
Labour	9.4
Other costs	7.6
Profit	13.2
Sale price M$(2002) $kglw^{-1}$	12.7

Hernandez-Martinez *et al*. (2008), in another local study, carried out a survey of 60 pig farms in the State of Mexico (in the central region of Mexico) during 2006, Table A 7-V shows the financial performance of surveyed farms with herds of more than 100 breeding sows. Based on region and breeding herd size, these farms are also suitable for providing data the locMEX scenario. This study, as well as the FAO (2002) study, showed a high percentage contribution of variable costs to the net income distribution. Variable cost showed an inverse proportion to breeding herd size.

Table A 7-V Financial performance of pig farms in the State of Mexico (Hernandez-Martinez *et al.*, 2008). Costs are expressed as a percentage of sale prices

Category	%
Variable costs	80.2
Fixed costs	10.0
Net profit	9.7
Sale price M$(2006) $kglw^{-1}$	14.56

Summarizing the financial assessments in the different studies, even though costs were aggregated in different ways, some comparisons can be done. All analyses can be divided into variable costs, representing purchases from other sectors in the economy, and internal costs that include fixed costs and profit (fixed cost included labour, depreciation, rent and shared interest). Aggregating the studies in this way, the variable costs were higher for farms representative of the locMEX scenario than for those typical of the stdMEX scenario. Consequently, the internal costs had the opposite behaviour (Table A 7-VI).

Table A 7-VI Financial performance of suitable farms for stdMEX and locMEX scenarios. Costs are expressed as a percentage of sale prices

	Variable cost			Internal cost		
Author	stdMEX	locMEX	Dif	stdMEX	locMEX	Dif
Magana-Magana *et al*., 2002	69.1	79.2	-10.1	30.9	20.8	10.1
Nava, *et al*. 2009	63.1	70.1	-7.0	36.9	29.9	7.0
Gallardo *et al*., 2006	64.7	71.8	-7.2	35.3	28.2	7.2

A7.1.1 The locMEX scenario

Since accessed data were insufficient to disaggregate the percentage contribution of other economic sectors in the pig farm operation for any of the scenarios, a detailed financial performance over one year of a typical pig farm in the State of Jalisco was used to split out detailed purchases. The average breeding sow herd was 305 sows. Farm identity is not provided to maintain confidentiality. Data were accessed through members of the expert panel. This detailed financial analysis, for a farm which matches the characteristics for the locMEX scenario, was then compared to the range of farms suitable for the locMEX scenario in the studies previously reviewed. The financial performance of the Jalisco farm was aggregated in the same form as those in Table A7-VI. The Jalisco farm was within the range of data reported for farms suitable for inclusion as a locMEX scenario (Table A 7-VII).

Table A 7-VII Comparison of the data range of farms suitable for the locMEX scenario stated in Table A 7-VI and aggregated data from the financial report of a Jalisco farm. Costs are expressed as a percentage of sale prices

Category	Range of data	Jalisco farm
Variable costs	70.1-79.2	74.24
Internal costs	20.8-29.9	25.67

Additionally, the Jalisco farm data were contrasted with the most detailed source of published data. Table A 7-VIII shows the Jalisco farm data aggregated in the same form as Gallardo *et al*. (2006) for farms typical of the locMEX scenario.

Table A 7-VIII Contrasting data for farms suited for the locMEX scenario in Gallardo et al. (2006) and aggregated data on the financial performance of a farm in the Jalisco State, Mexico. Costs are expressed as a percentage of sale prices

	LocMEX scenario		
Category (%)	Jalisco farm	Gallardo *et al*., 2006	Variation
Feed	62.1	60.5	1.6
Financial	6.7	11.1	4.3
Other cost such as electricity, fuels, sundries, transport, fees, machinery and buildings maintenance, miscellaneous	8.8	7.2	1.6
Medicines	3.4	4.2	0.8
Labour	7.3	5.2	2.1
Total	88.2	88.1	0.1
Profit	11.7	11.9	0.2

The low variation between benchmarks in Table A 7-VIII permits the assumption that the Jalisco farm financial performance can be used as representative data to model the locMEX scenario. Section 6.2.1 in Chapter 6 explains the data disaggregation and Table 6.2 in the same chapter shows the disaggregated data.

A7.1.2 The stdMEX scenario

As discussed in Section 6.2.2, financial data for the stdMEX scenario were derived from those of the locMEX scenario using equation 20 in appendix 5. Results of this calculation are shown in Table A7-IX.

Table A 7-IX Individual calculations for the stdMEX cost categories, calculated from Equation 20 in Appendix 4. Costs are expressed as a percentage of sale prices

	locMEX values		stdMEX values	
Category (%)	Single	Aggregate	Aggregate	New
Feed	62.06	62.06	47.61	47.61
Replacement	2.14	8.80	10.97	2.67
Vet & Medicine	3.38	3.38	8.49	8.49
Transport	3.03	8.80	10.97	3.78
Electricity & Gas	2.23	8.80	10.97	2.78
Water	0.40	8.80	10.97	0.50
Straw & bedding	0.00	8.80	10.97	0.00
Marketing	0.24	8.80	10.97	0.29
Miscellaneous	0.35	8.80	10.97	0.44
Labour	7.28	7.28	3.51	3.51
Machinery & Equipment				
-Repairs & maintenance and running cost				
-repairs & maintenance	0.05	8.80	10.97	0.06
-running cost	0.05	8.80	10.97	0.06
-Depreciation	0.10	6.72	13.94	0.20
Buildings				
-Repairs & maintenance	0.09	8.80	10.97	0.11
-Rental or depreciation charges	0.88	6.72	13.94	1.82
Land				
-Rental charge	0.48	6.72	13.94	0.99
Bank charges, professional fees and insurance	2.36	6.72	13.94	4.90
General farm overheads &sundries	0.22	8.80	10.97	0.28
Interest charges	2.91	6.72	13.94	6.03
Profit	11.67	11.67	15.49	15.49

A7.2 Validation of data for the stdUK scenario

The main sources of financial assessments accessed to characterize the pig production for the stdUK scenario were the Specialist Pig Farm survey (Defra, 2007), The Pig Yearbook 2006 (BPEX, 2006) and The 2005 Pig Cost of Production in Selected EU Countries (Fowler, 2006). The main data consulted were for the year 2005.

In all sources it was necessary to disaggregate or join data for comparative purposes. For the Defra (2007) data, it was necessary to disaggregate expenditures for cropping from that on other farm activities. BPEX (2006) had data split out in different parts of the document (data coming mainly from pages 33 and 35), and in Fowler (2006) data were split throughout the document in different tables. Table A 7-X shows the main financial categories. Although it was possible to compare the variable costs in more detail, the fixed costs from Fowler (2006) were not complete so it was not possible to compare them because all data were not available, whilst Defra (2007) had specific data for the financial assessment.

Table A7-X Main sources of data for the stdUK scenario, expressed as a percentage of total income, except sale price that was £(2005) kglw^{-1}

Source	FBS, 2006	BPEX, 2006	Fowler, 2006	Stdev
Variable costs	57.8	55.6	56.5	1.11
-Feed	47.0	46.0	46.8	0.54
-Vet & Medicine	3.3	3.4	2.9	0.26
-Other livestock costs	7.5	6.2	6.8	0.65
Fixed costs	34.4	33.8	NA	0.45
Profit	7.7	10.6	NA	2.00
Sale price	NA	0.791	0.783	0.005

NA = not available

Table A7-X shows that there was low variation between data sources (Table A 7-X). Since Defra (2007) was the most disaggregated data set, this was used as the basic source of data. Inputs and outputs from other activities were split out as described below.

A7.2.1 Disaggregation of the Specialist Pig Farm Business survey

Data come from specialist pig farms in England (Defra, 2007). Inputs and outputs from agricultural activities were split off from recreational, rental and retailing activities. Agricultural incomes were made up from animal production at 96% and crop production at 4% (Table A 7-XI). The variable costs were specific for animal and crop production but fixed costs were shared between them and it was necessary to allocate these.

Table A 7-XI Outputs for specialist pig farms in 2005, adapted from Defra (2007)

Category	£	%
Agricultural activities		
Cropping (excluding subsides)	8,525	3.3
Pig production	248,937	95.8
Other livestock outputs	511	0.2
Miscellaneous outputs	1,948	0.7
Non-agricultural activities		
Agri-Environmental activities and other payments[1]	548	0.2
Diversification out of agriculture [2]	16,821	6.5
Single payment scheme	4,545	1.8

Agri-Environmental activities such as agri-environmental schemes
Diversification out of agriculture such as food processing and retailing, tourism, recreation, rental and others diversified outputs.

Contract cost, casual labour and miscellaneous costs were variable costs that were not specific for any one activity (Table A 7-XII). However, according to instructions for collecting the data in the Farm Business Survey (Defra, 2009), most of the purchases and expenses under these concepts come from cropping cost, so these were allocated as variable costs for crops.

Table A 7-XII Variable costs for cropping and livestock activities in specialist pig farms in 2005, £ farm^{-1} (adapted from Defra, 2007)

Category	Crops	Livestock	Total
Variable costs:			
Seed	605		605
Fertilizers	807		807
Crop protection	1,485		1,485
Other crop cost	145		145
Purchased feed & fodder		116,059	116,059
Home grown feed & fodder		3,006	3,006
Veterinary fees & medicines		8,417	8,417
Other livestock costs		18,801	18,801
Subtotal	3,042	146,283	
Contract cost	3,925		3,925
Casual labour	657		657
Miscellaneous variable cost	1		1
Total	7,625	146,283	153,908

Fixed costs for agricultural activities were allocated between animal and crop production on their monetary output basis and are shown in (Table A 7-XIII).

Table A 7-XIII Cropping and livestock fixed costs, allocated on their monetary output basis, for data of specialist pig farms for 2005 (Defra, 2007).

Fixed cost	Crops, £	Livestock, £	Total, £
Regular labour	1,239	28,689	29,928
Machinery cost			
-Machinery running cost	407	9,412	9,819
-Machinery depreciation	383	8,866	9,249
General farming cost			
-Bank charges & professional fees	108	2,497	2,605
-Water, electricity and other general costs	475	10,990	11,465
-Share of net interest payments	275	6,366	6,641
Land and property costs			
-Rent paid	357	8,254	8,611
-Maintenance, repairs and insurance	28	646	674
-Depreciation of buildings and works	352	8,152	8,504
Miscellaneous fixed costs	492	0	492
Total	4,115	83,873	87,988

Livestock output mainly came from pig production. 97.4% of the output was from pig sales, and so the impact of other animals on costs was considered negligible. Thus, the total monetary value of output and costs for livestock production was considered to be from pig production. Finally, the monetary costs of commodities required by the pig farm were calculated as a percentage of the animal output income (Table A 7-XIV). Since replacement cost is discounted from sales before the final output, the replacement cost, as a percentage, was added and calculations adjusted. Whilst these commodities were considered suitable to model the stdUK scenario, further disaggregation was necessary.

Table A 7-XIV Participation of cost categories for the stdUK scenario, as a percentage of sale price, adapted from Defra (2007)

Category	%
Variable costs:	
Replacement	1.53
Feed	46.98
Veterinary fees & medicines	3.32
Other livestock costs	7.42
Fixed costs:	
Labour	11.32
Machinery cost	
-Machinery running cost	3.71
-Machinery depreciation	3.5
Bank charges & professional fees	0.99
Water, electricity and other general costs	4.34
Share of net interest payments	2.51
Land and property costs	
-Rent paid	3.26
-Maintenance, repairs and insurance	0.25
-Depreciation of buildings	3.22
Profit	7.61

Whilst most of the commodities were disaggregated, other categories contained several commodities grouped together, so other livestock costs and water, electricity and other general costs were disaggregated from this.

Disaggregation of grouped concepts

Alternative sources of data used to validate the main data showed low variation from those of Defra (2007), as detailed in Table A 7-X. However, every data source had different data disaggregation and, taking advantage of these forms of data distribution, the details of commodities reported in the alternative sources were used to disaggregate the Defra categories.

Other livestock costs

Other livestock costs were split accordingly to the list of categories given in the instructions for completing the Farm Business Survey (Defra, 2009). Other livestock costs were divided into transport, marketing, straw and bedding and daily sundries. Transport and marketing were subtracted at a level of 5.0% as reported by BPEX (2006). Meanwhile, marketing was separated from transport as accounting for 2.17% for transport as stated in Fowler (2006). Table A 7-XV shows these calculations. Straw and bedding cost was assumed to be considered as by-products in forage and cultivations outputs from crop production, transferred as input cost for pig production and split from other livestock costs (Defra, 2009). Daily sundries were the remainder of the other livestock cost category after discounting transport, marketing and straw costs (Table A 7-XV). In the sundries cost, it was assumed that general chemical substances such as detergents and disinfectants, lamps or minor equipment were included. Table Ap6.15 shows disaggregation of other livestock costs using alternative source of data. Defra (2007) is the original source of data; BPEX (2006) and Fowler (2006) were the alternative sources, as percentage of sale price.

Table A 7-XV Disaggregation of other livestock costs, as a percentage of pig sale price.

Category (%)	Defra, 2006	BPEX, 2006	Fowler, 2006	Final
Other livestock costs	7.42		6.77	
Transport & marketing		4.97		
Transport			2.17	2.17
Marketing				2.80
Straw		0.59		0.79
Daily sundries			0.95	1.66
Total	7.42			7.42

Water, electricity and gas category

Water cost was separated from electricity and gas cost using the water cost to electricity and gas cost ratio of 1:2.65 obtained from BPEX (2006). Thus from the 4.41% shared cost, water was weighed with 1.19% and electricity and gas with 3.15% (Table A 7-XVI).

Table A 7-XVI Disaggregation of Water electricity and gas costs, as percentage of pig sale price

Category	Defra, 2006	BPEX, 2006	Final
Water, electricity and other general costs	4.34		
-Water		0.68	1.19
-Electricity & Gas		1.81	3.15

Machinery running cost

There were no reference values in the accessed data. These were divided according to the experience of the support team for the Farm Business Survey (Charles Scott, personal communication) on a 50-50 percentage basis. Further category division was not possible. Thus fuel consumption cost and repair costs were weighed at 1.86% each.

Slurry handing

Finally, slurry handing was not allocated an economic value and equipment used for management and storage of slurry were considered as being included in the general equipment costs.

Appendix 8 Environmental impacts flows for a tonne of pigmeat live weight.

Instructions:

- Data for commodities or processes appear in boxes
- Width of connection arrows is on proportion of impacts wight
- Distribution of boxes information is as follow:
  - Information on top line is the amount of commodity or process
  - Name in second line is the commodity or process name in SimaPro
  - Amount on left bottom corner is the accumulated weight of the impact
  - Negative values mean credits.

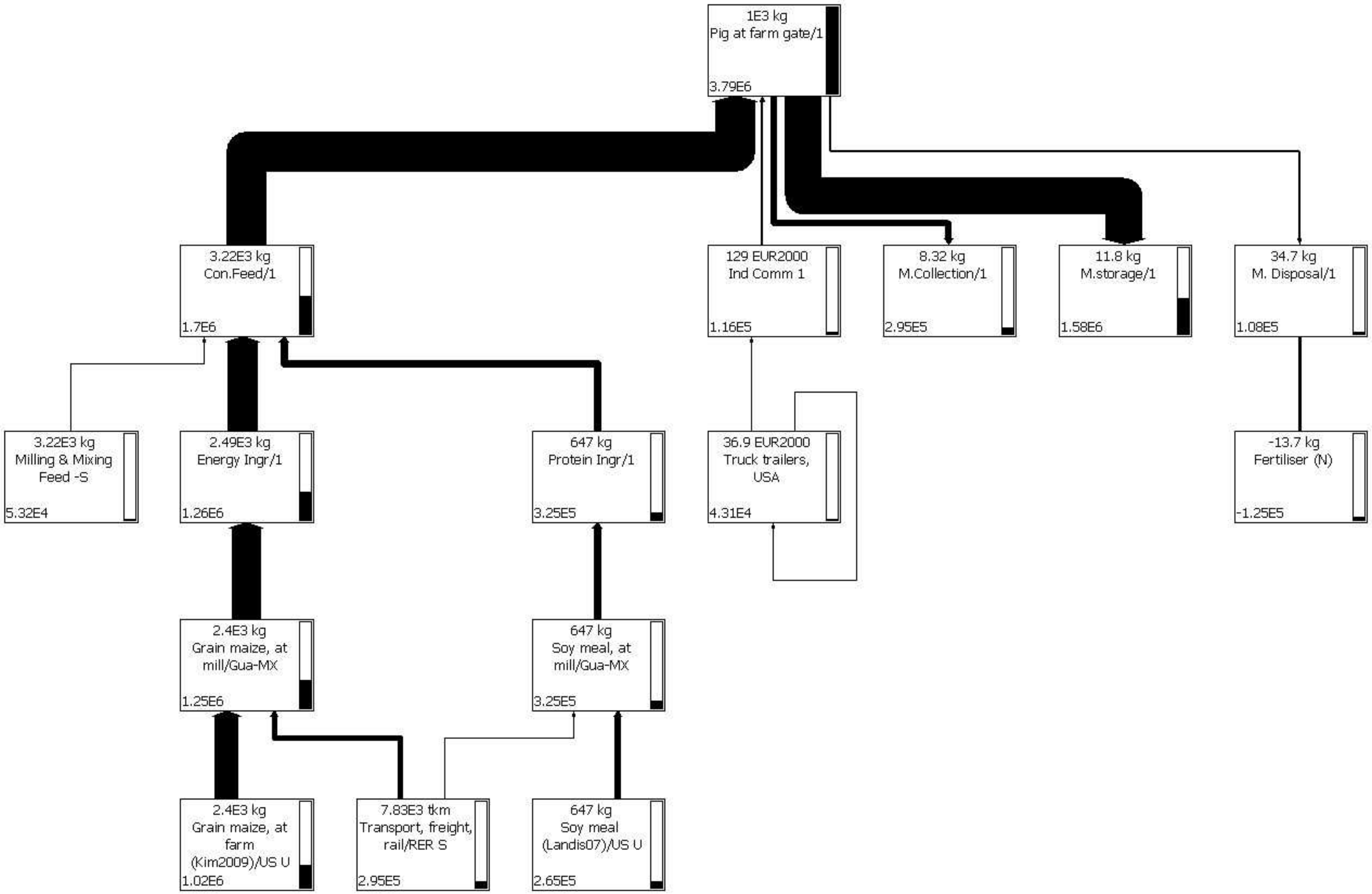

Figure A 8-I GWP distribution of 1 tlw pigmeat for locMEX scenario processes

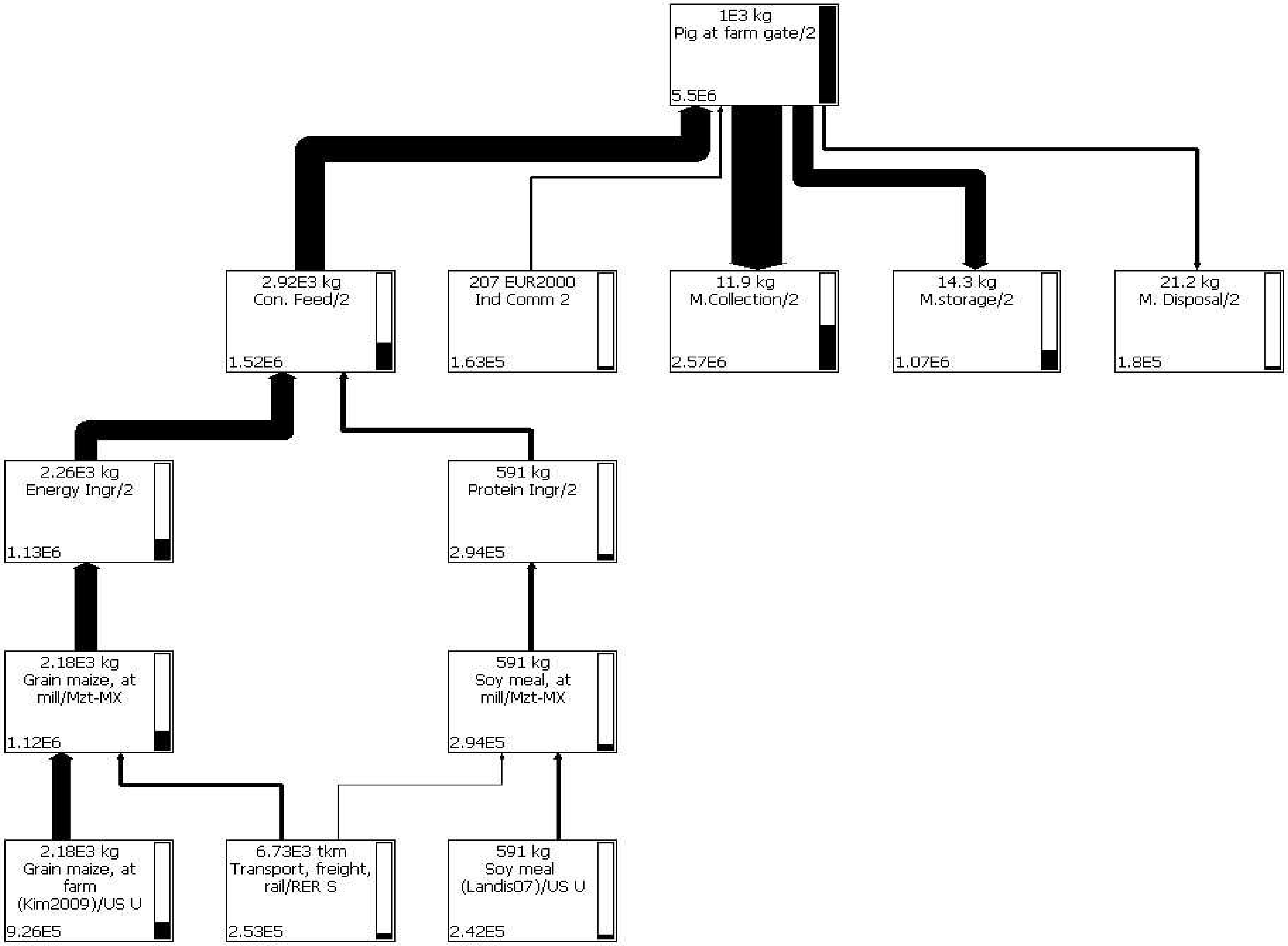

Figure A 8-II GWP distribution of stdMEX scenario processes

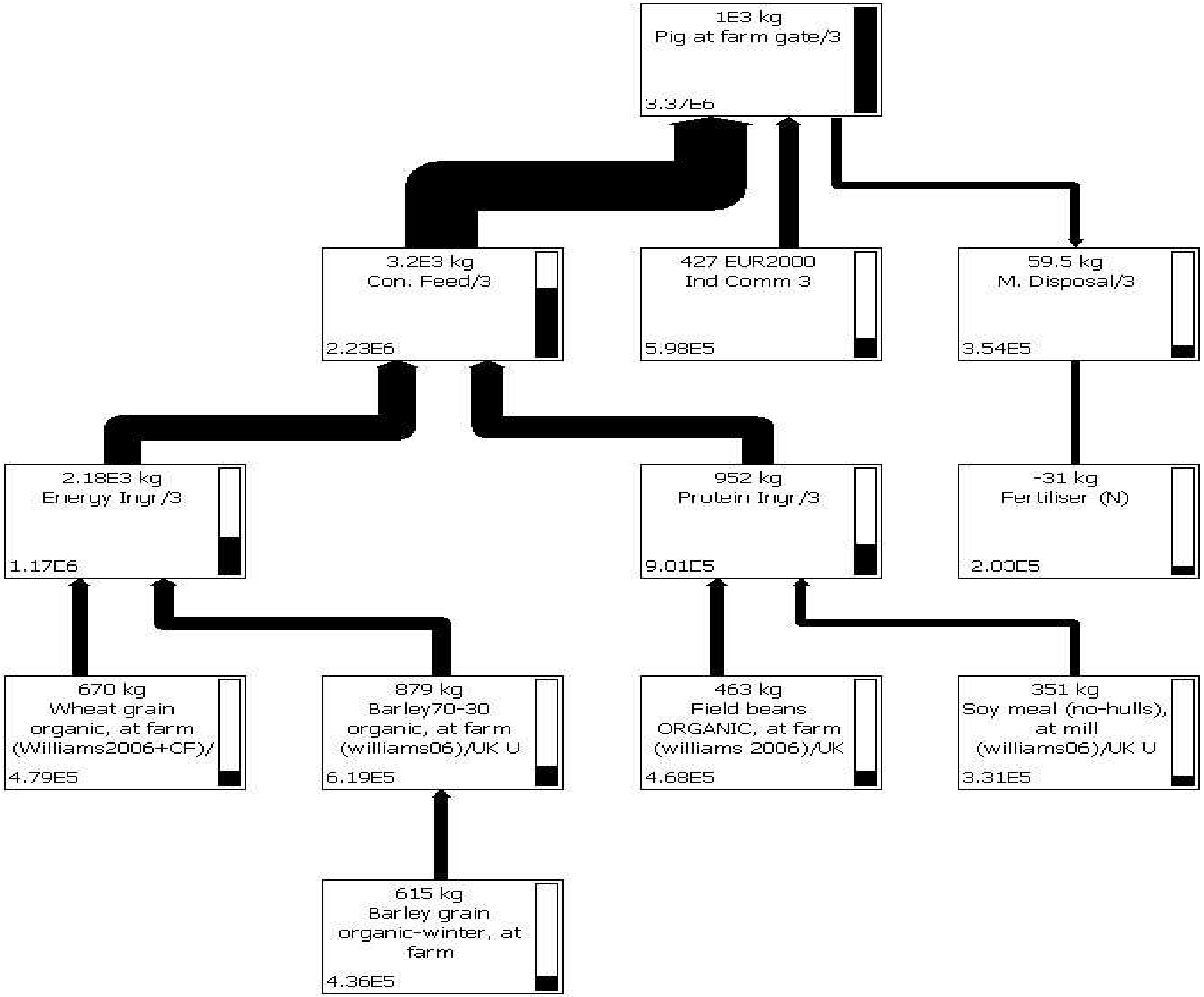

Figure A 8-III GWP distribution of orgUK scenario processes

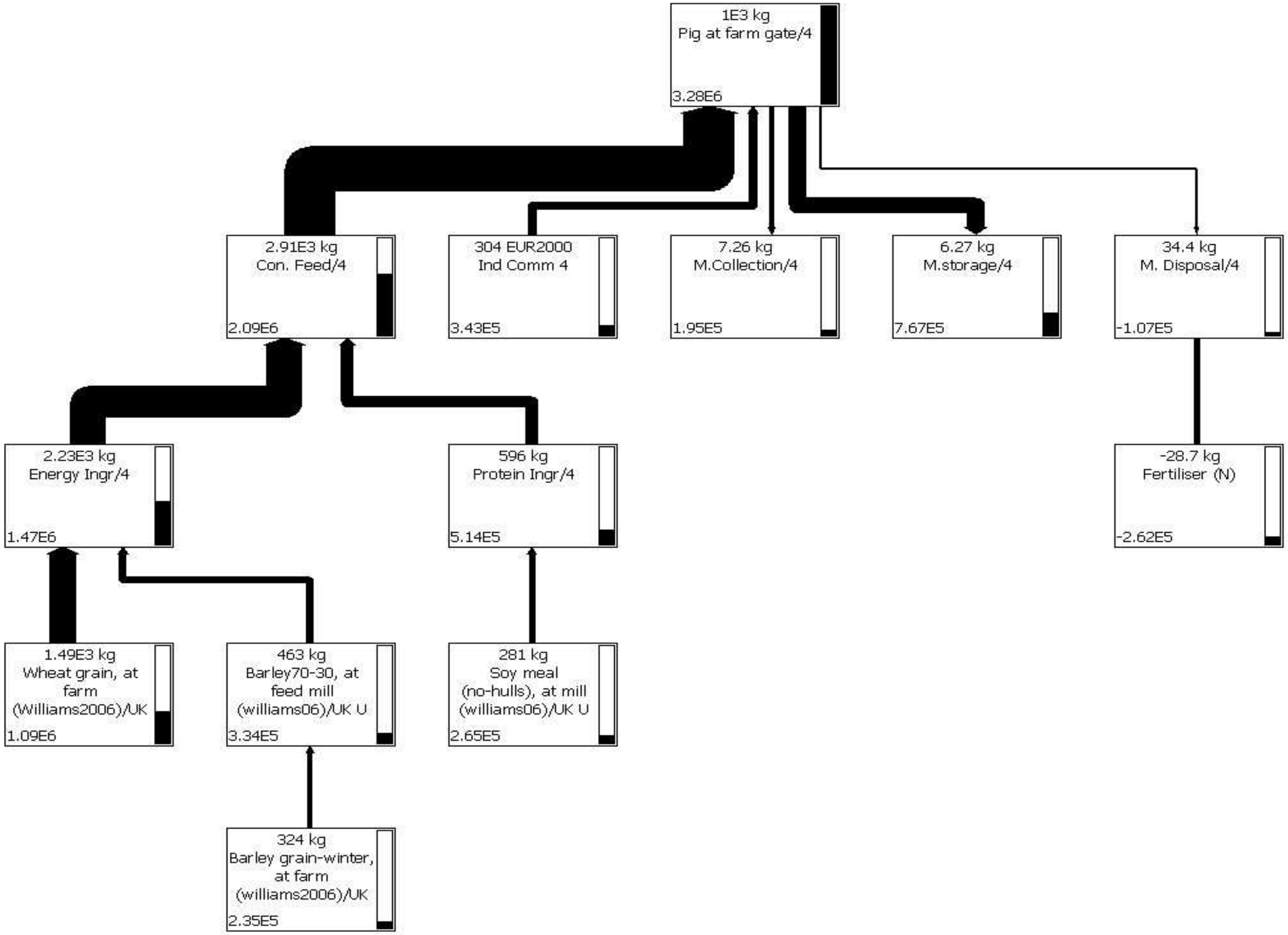

Figure A 8-IV GWP distribution of stdUK scenario processes

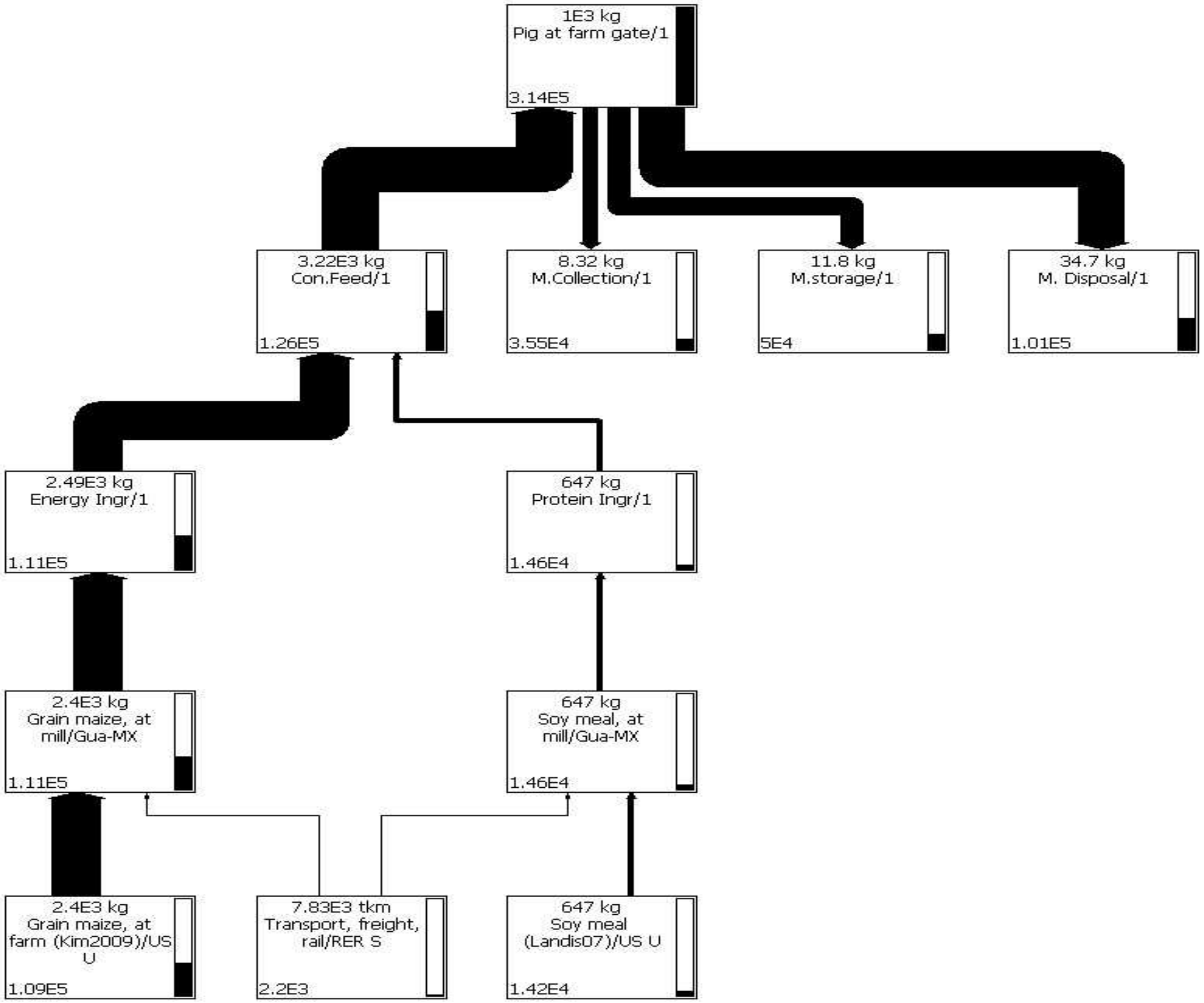

Figure A 8-V EP distribution of locMEX scenario processes

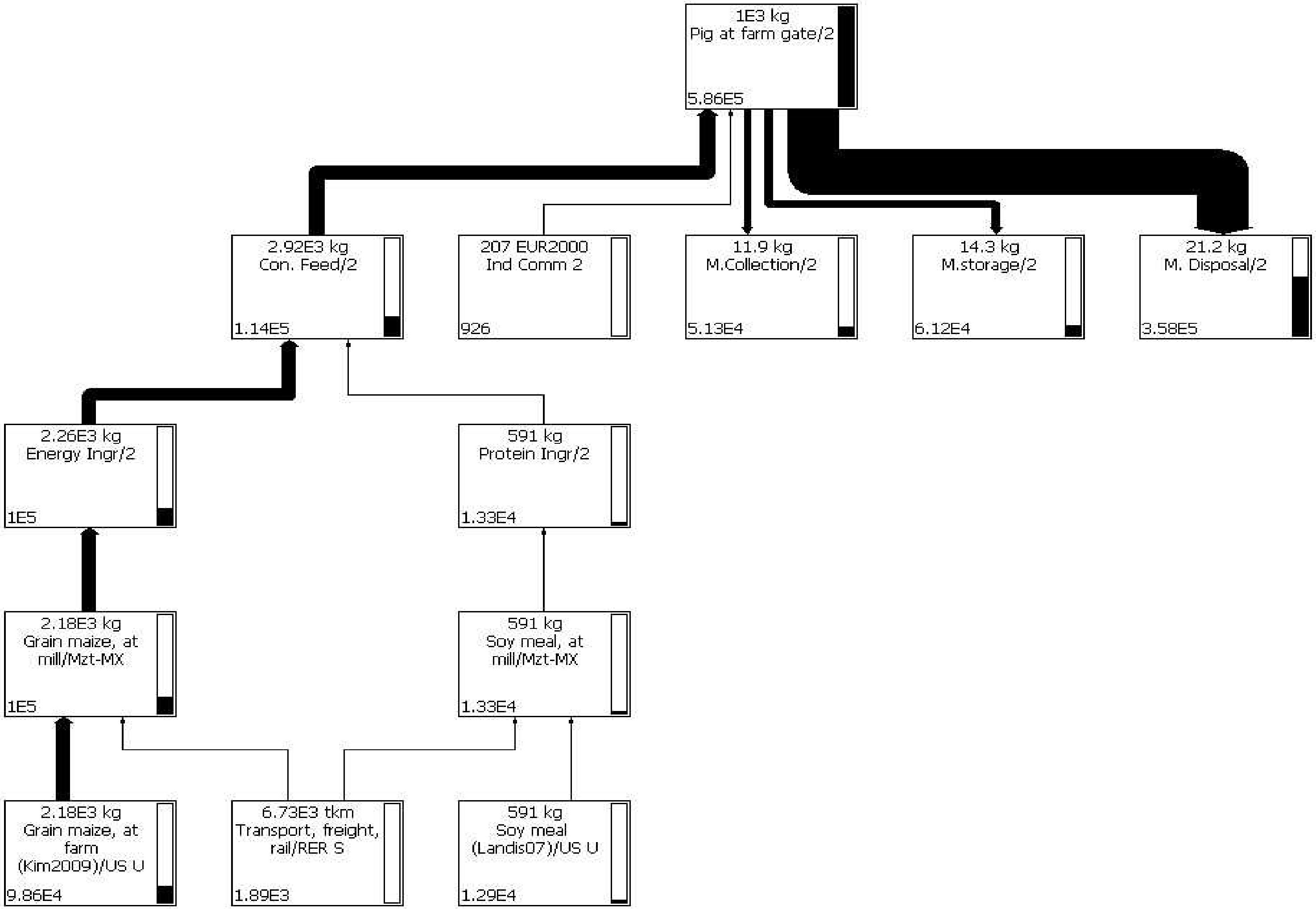

Figure A 8-VI EP distribution of stdMEX scenario processes

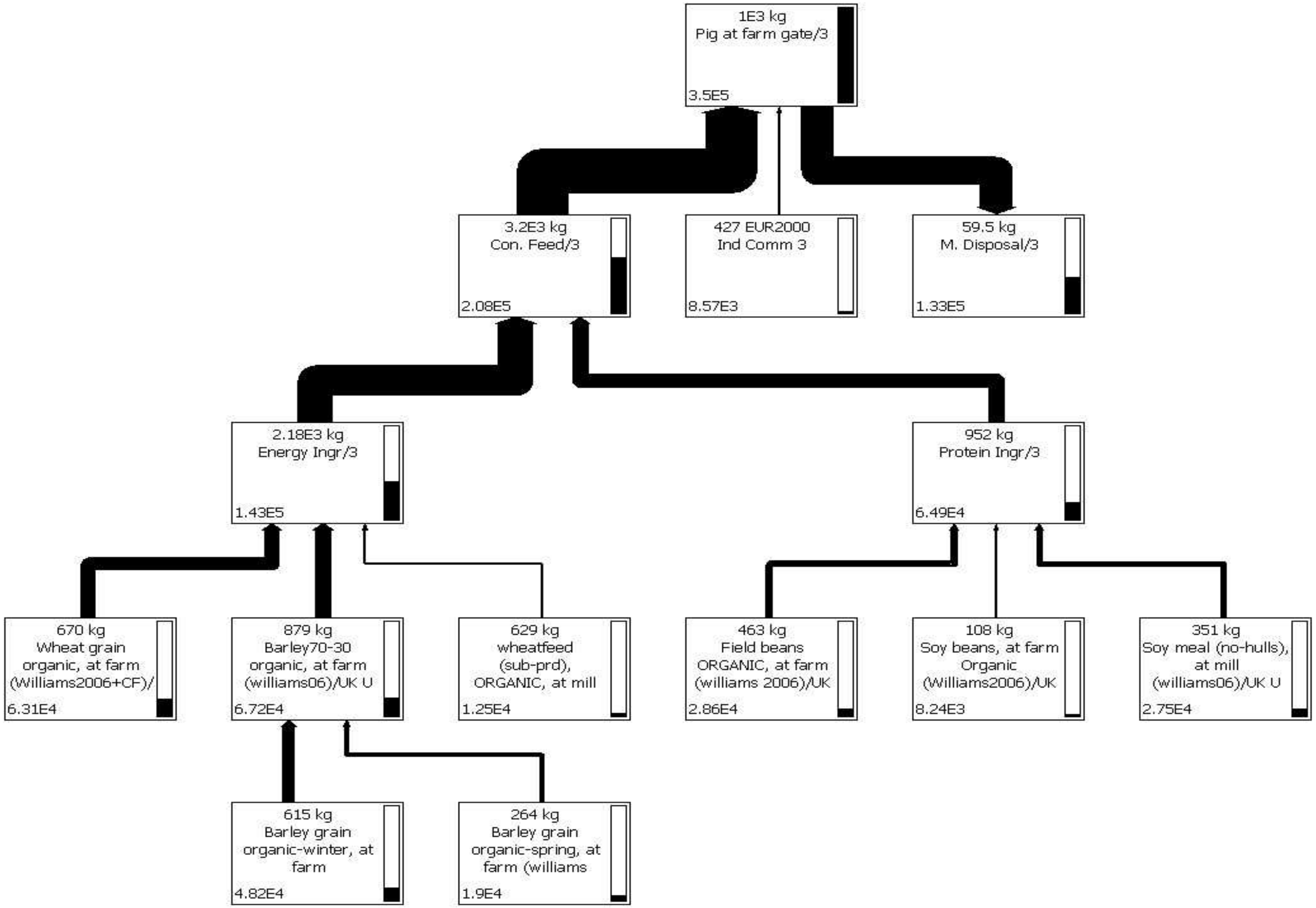

Figure A 8-VII EP distribution of orgUK scenario processes

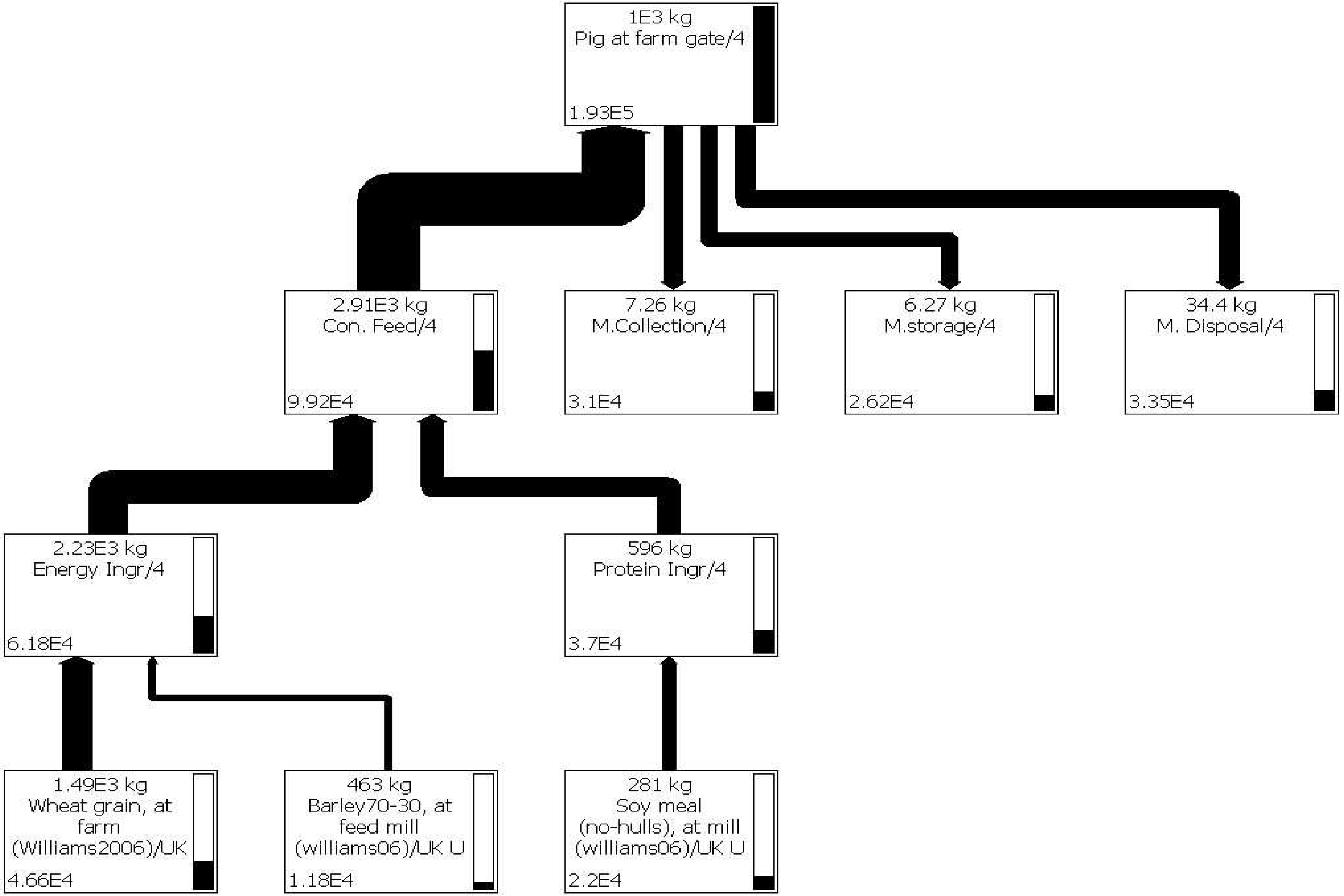

Figure A 8-VIII EP distribution of stdUK scenario processes

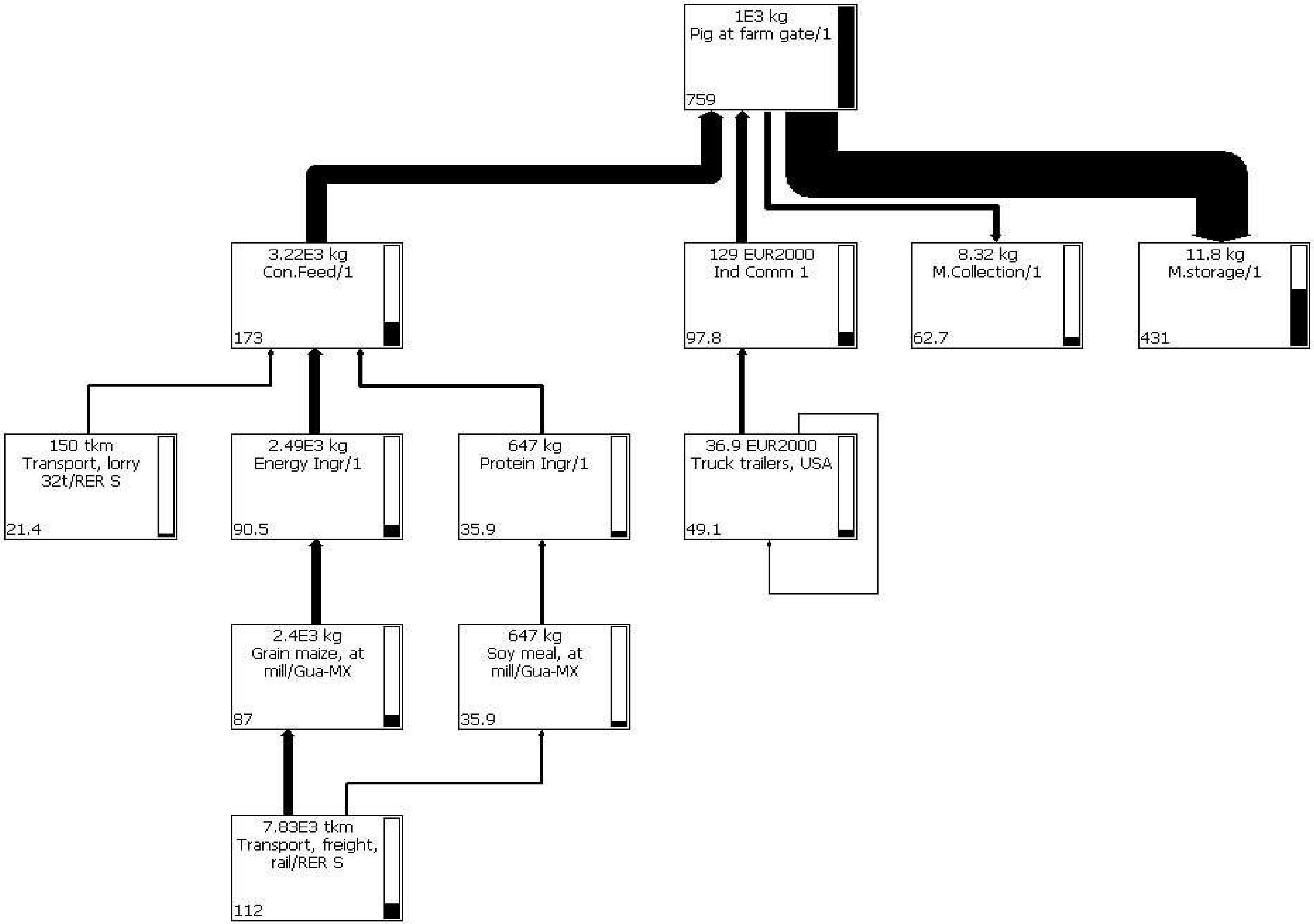

Figure A 8-IX PhS distribution of locMEX scenario processes

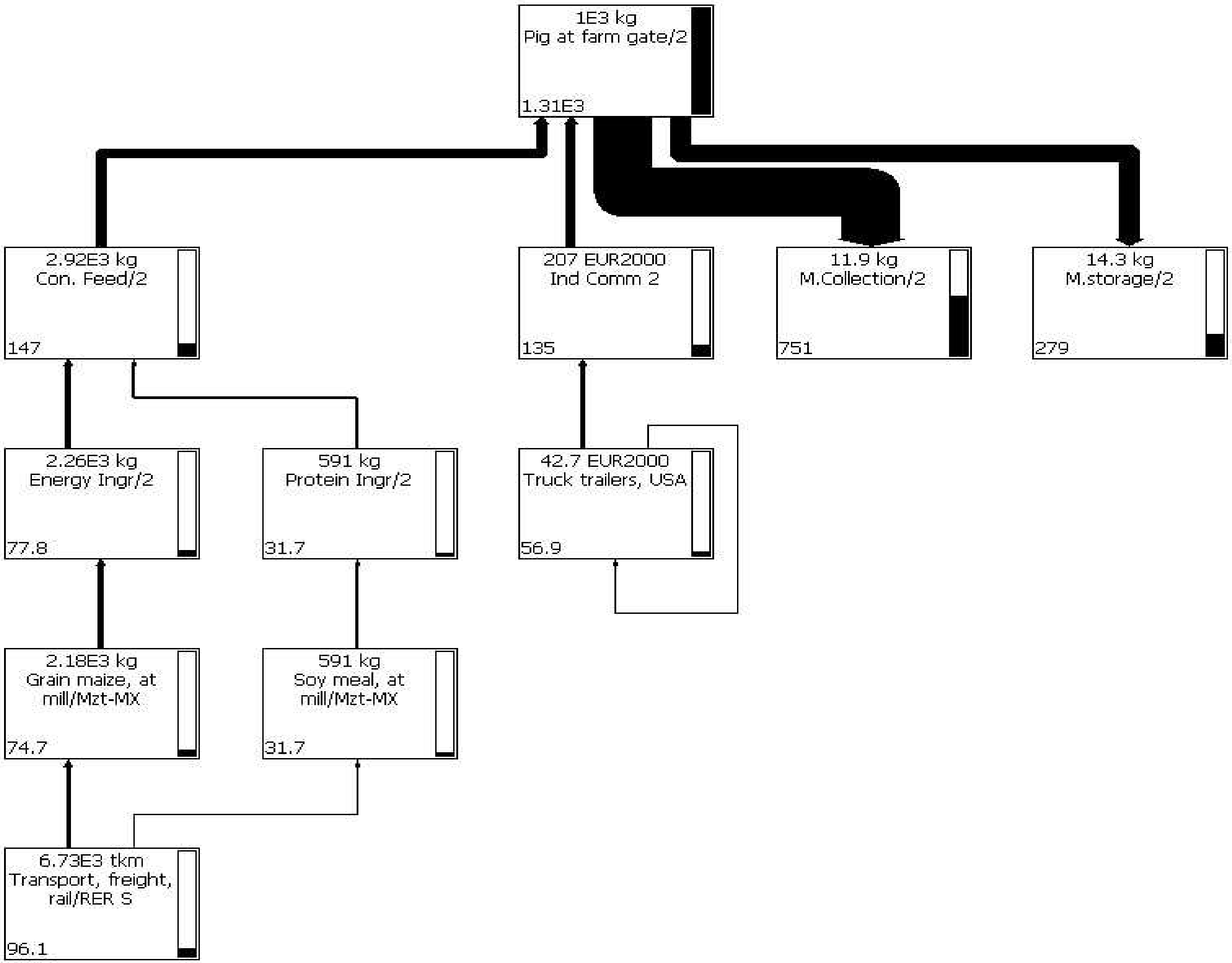

Figure A 8-X PhS distribution of stdMEX scenario processes

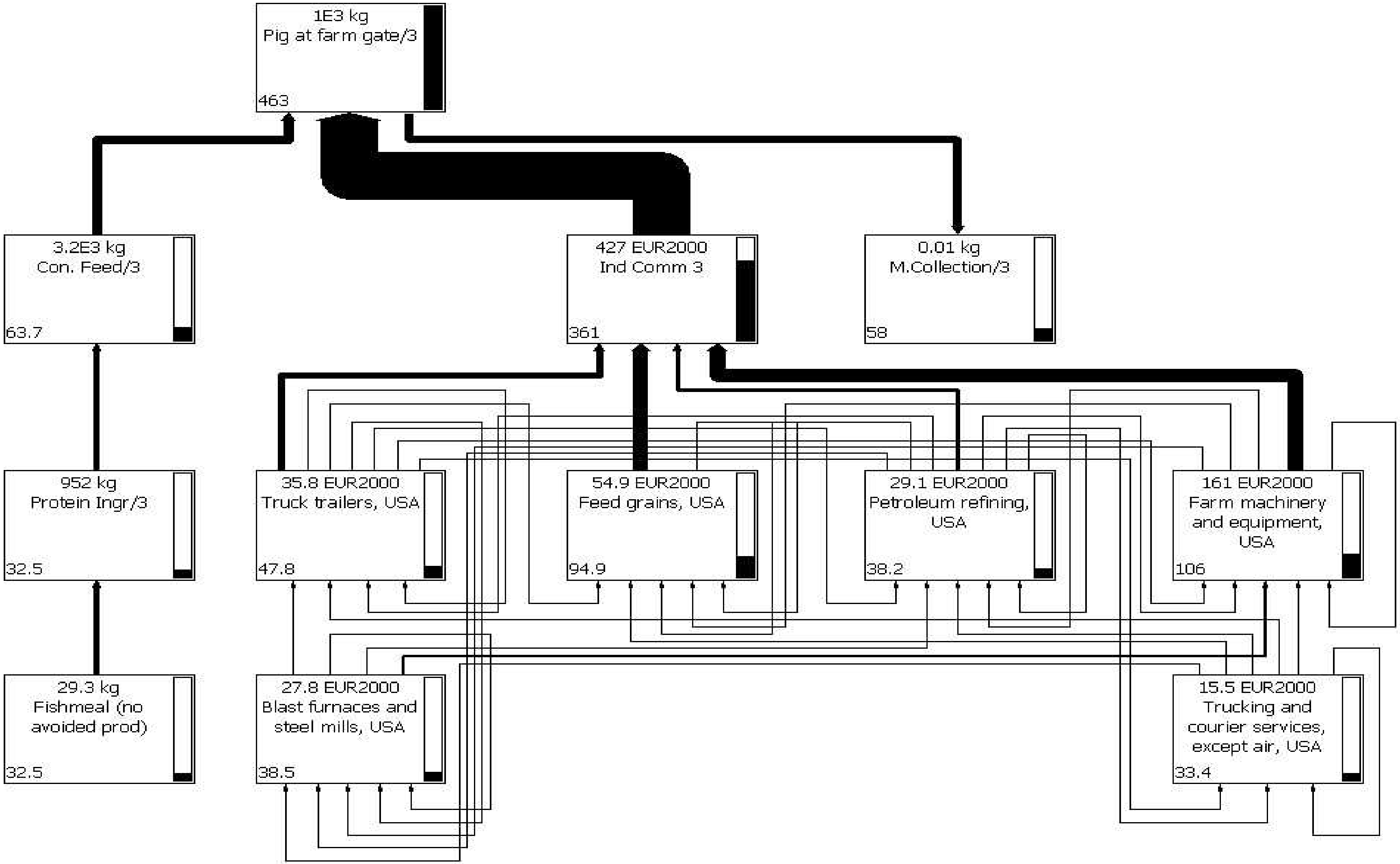

Figure A 8-XI PhS distribution of orgUK scenario processes

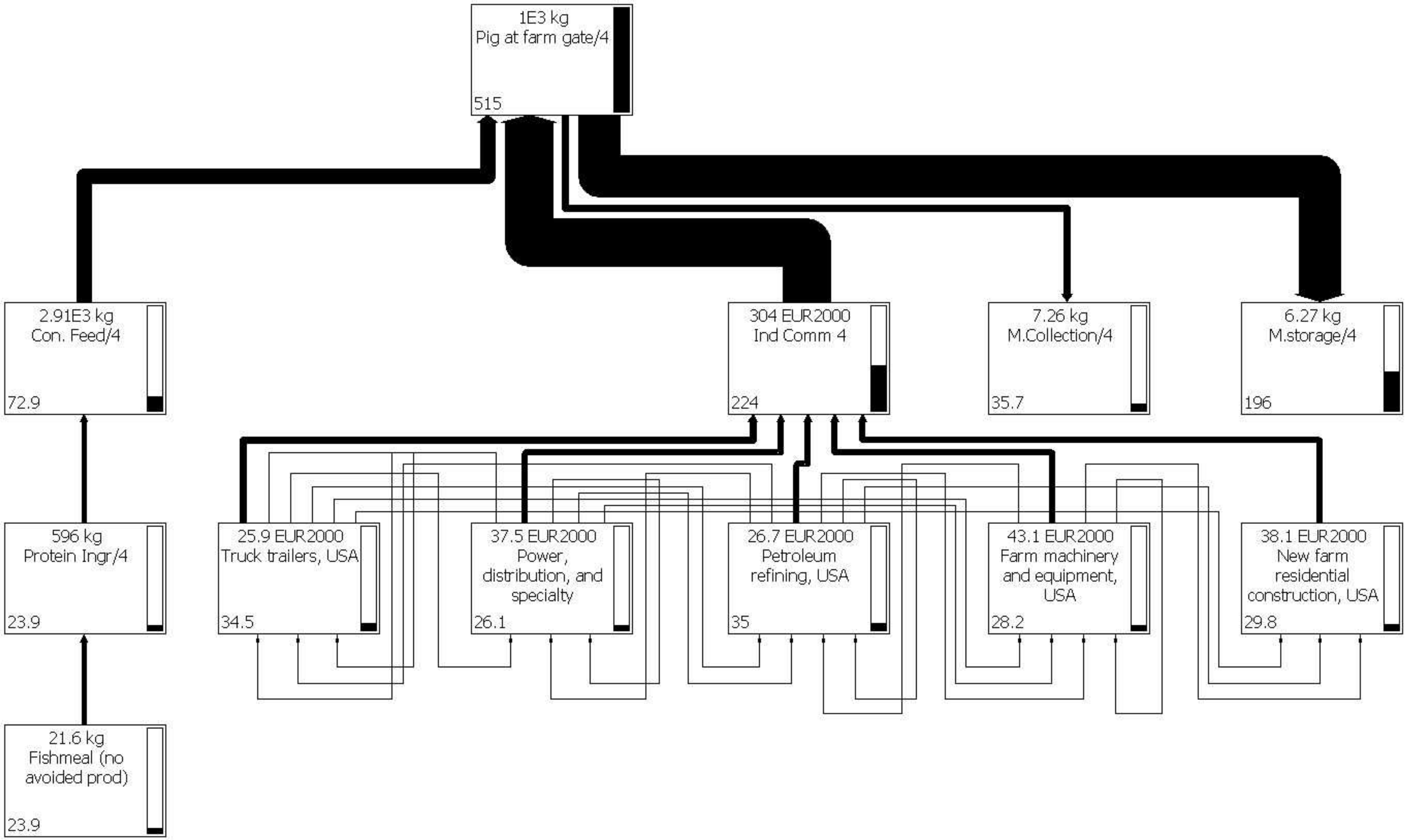

Figure A 8-XII PhS distribution of stdUK scenario processes

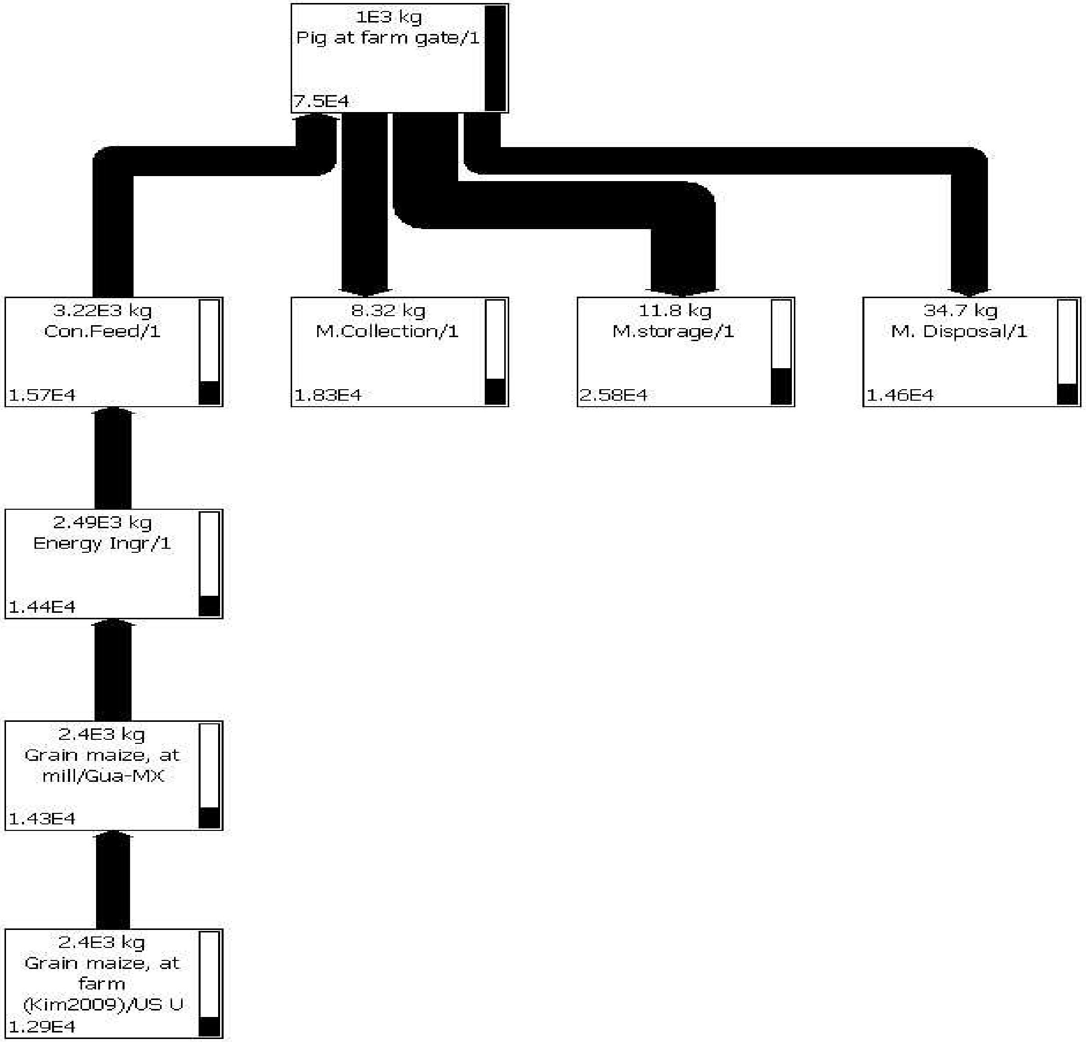

Figure A 8-XIII AP distribution of locMEX scenario processes

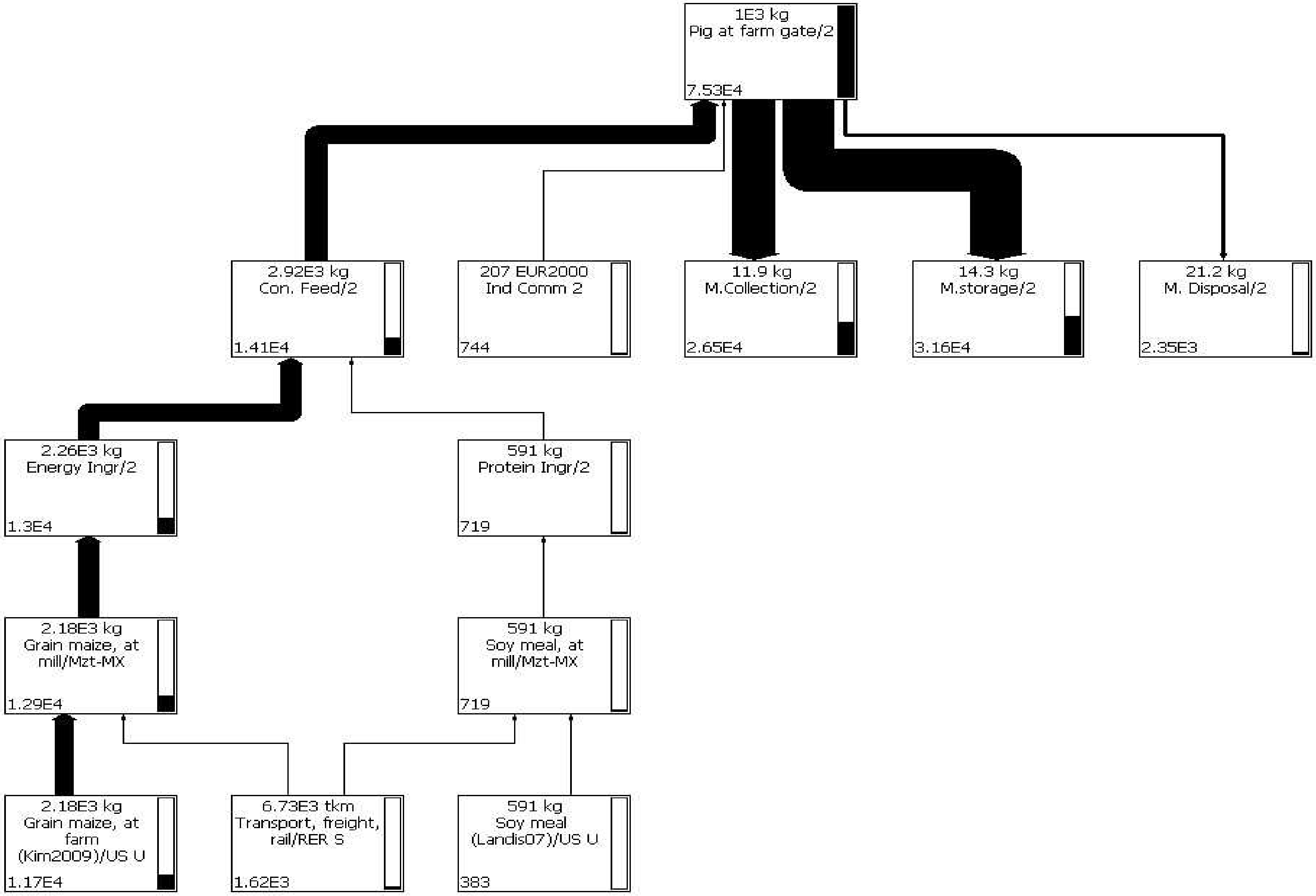

Figure A 8-XIV AP distribution of stdMEX scenario processes

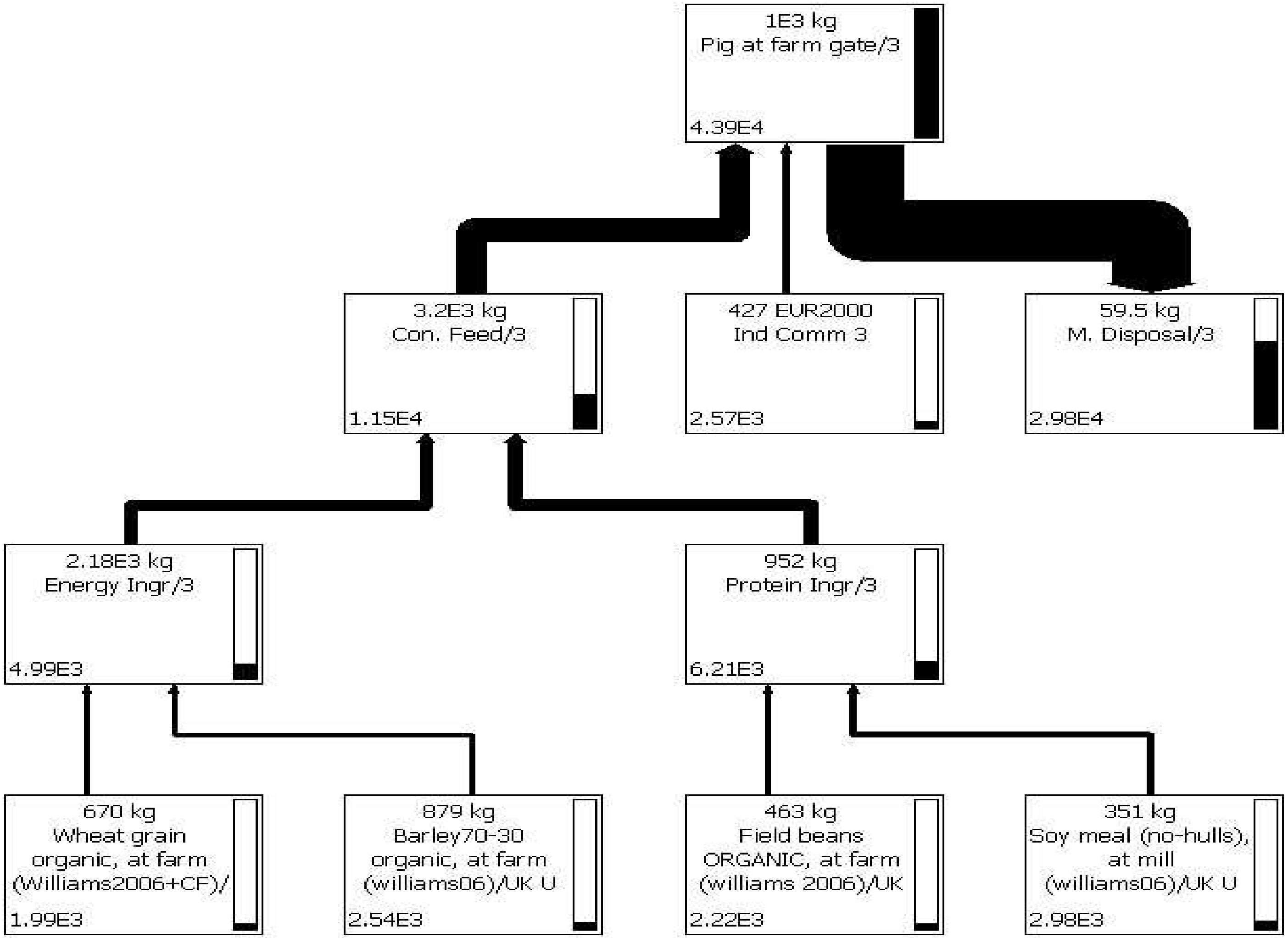

Figure A 8-XV AP distribution of orgUK scenario processes

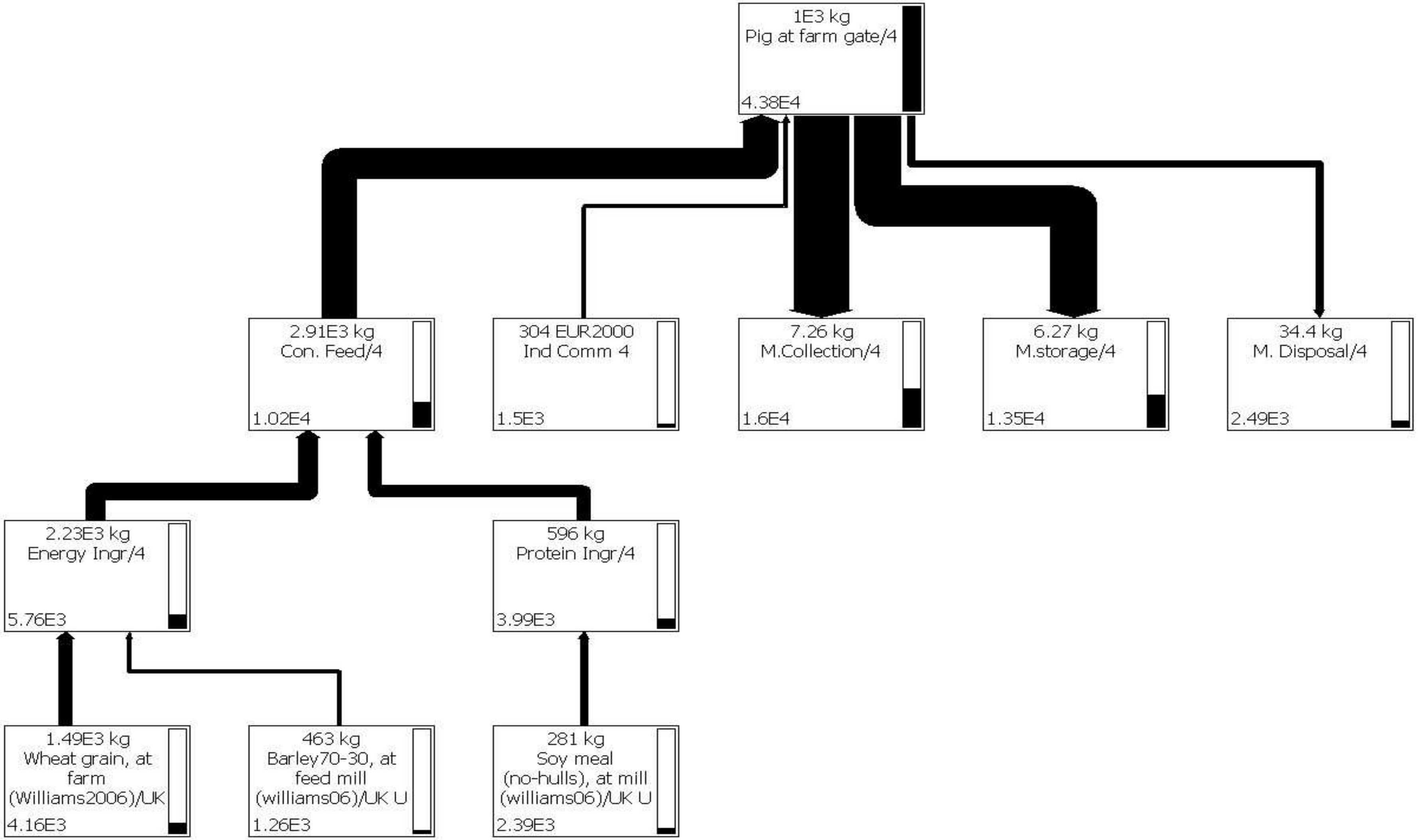

Figure A 8-XVI AP distribution of stdUK scenario processes

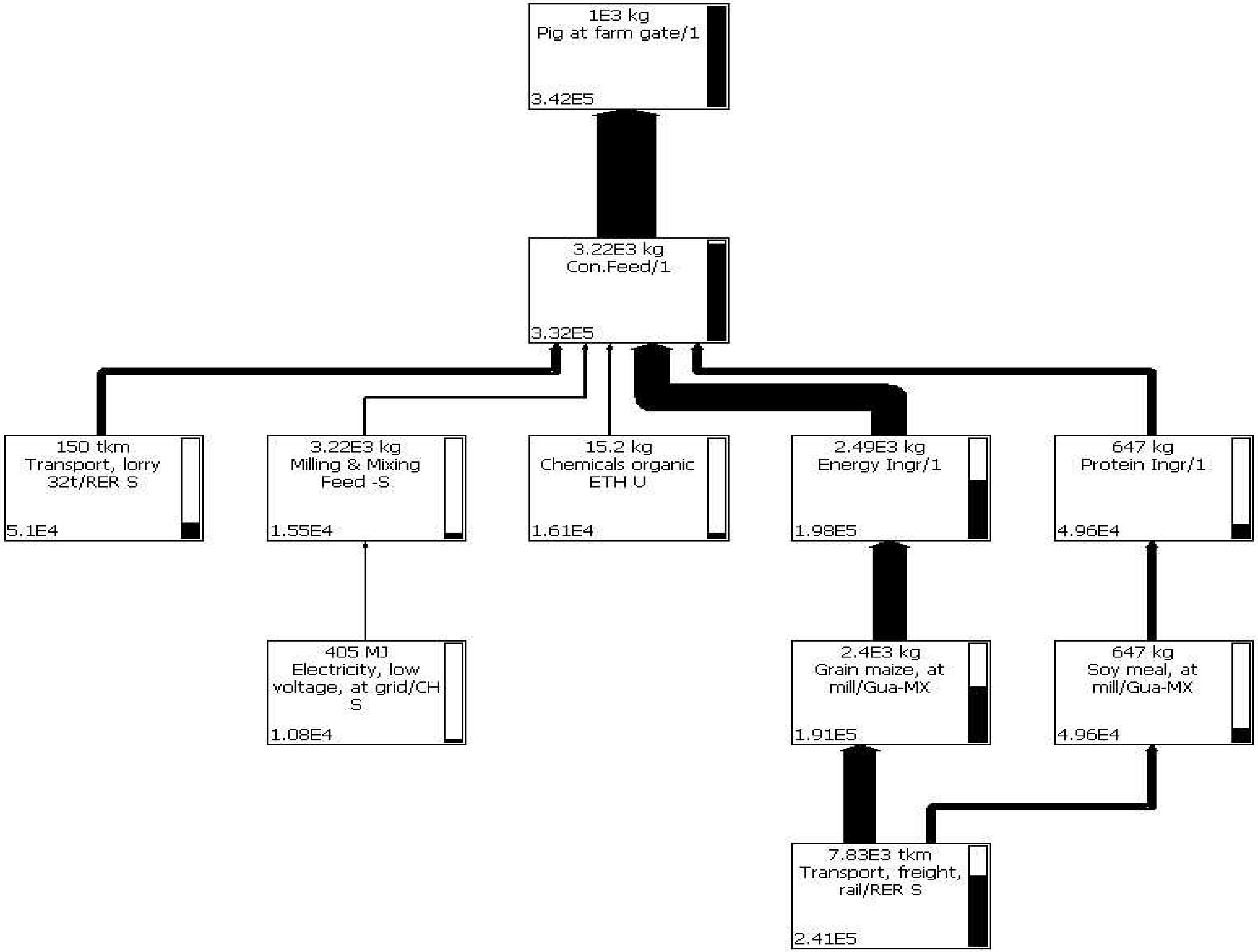

Figure A 8-XVII TxW distribution of locMEX scenario processes

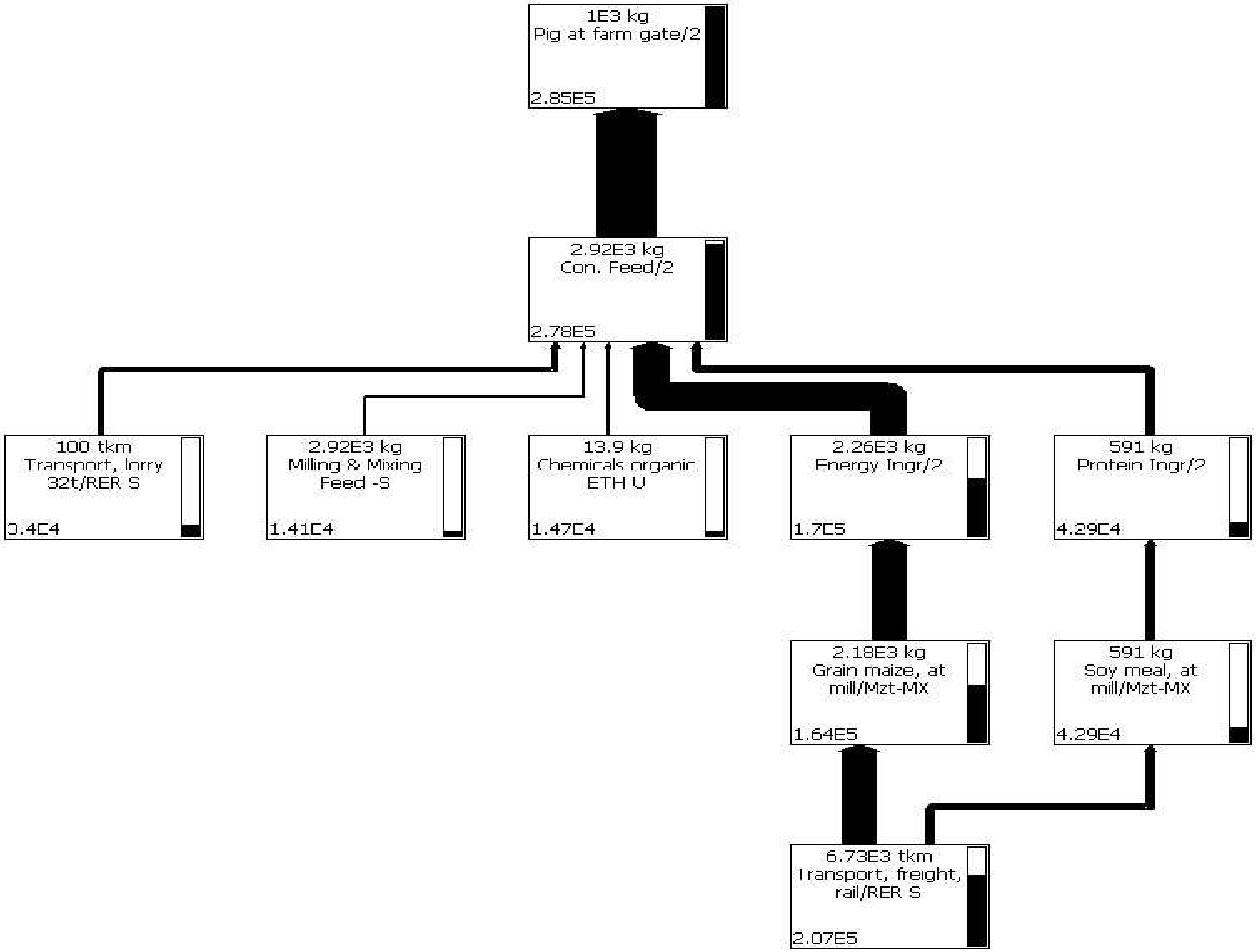

Figure A 8-XVIII TxW distribution of stdMEX scenario processes

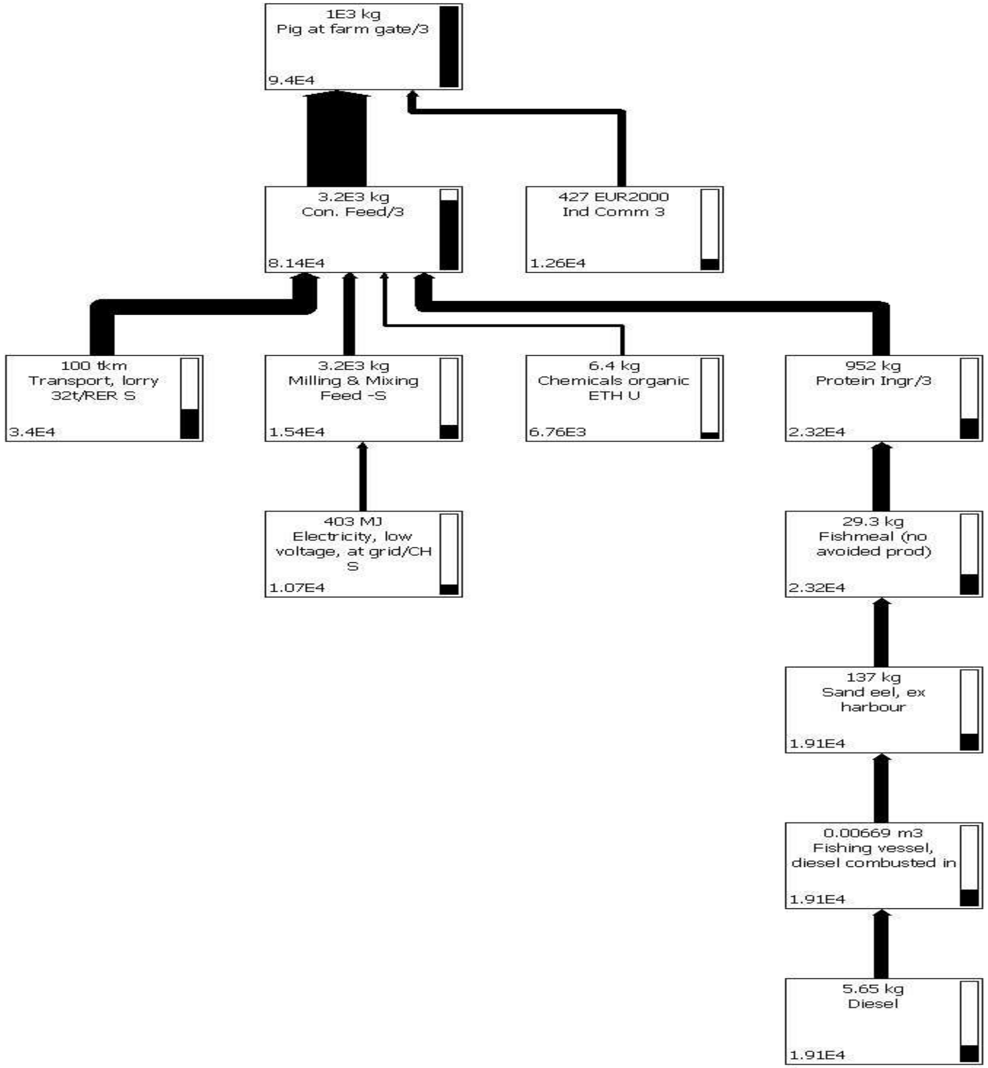

Figure A 8-XIX TxW distribution of orgUK scenario processes

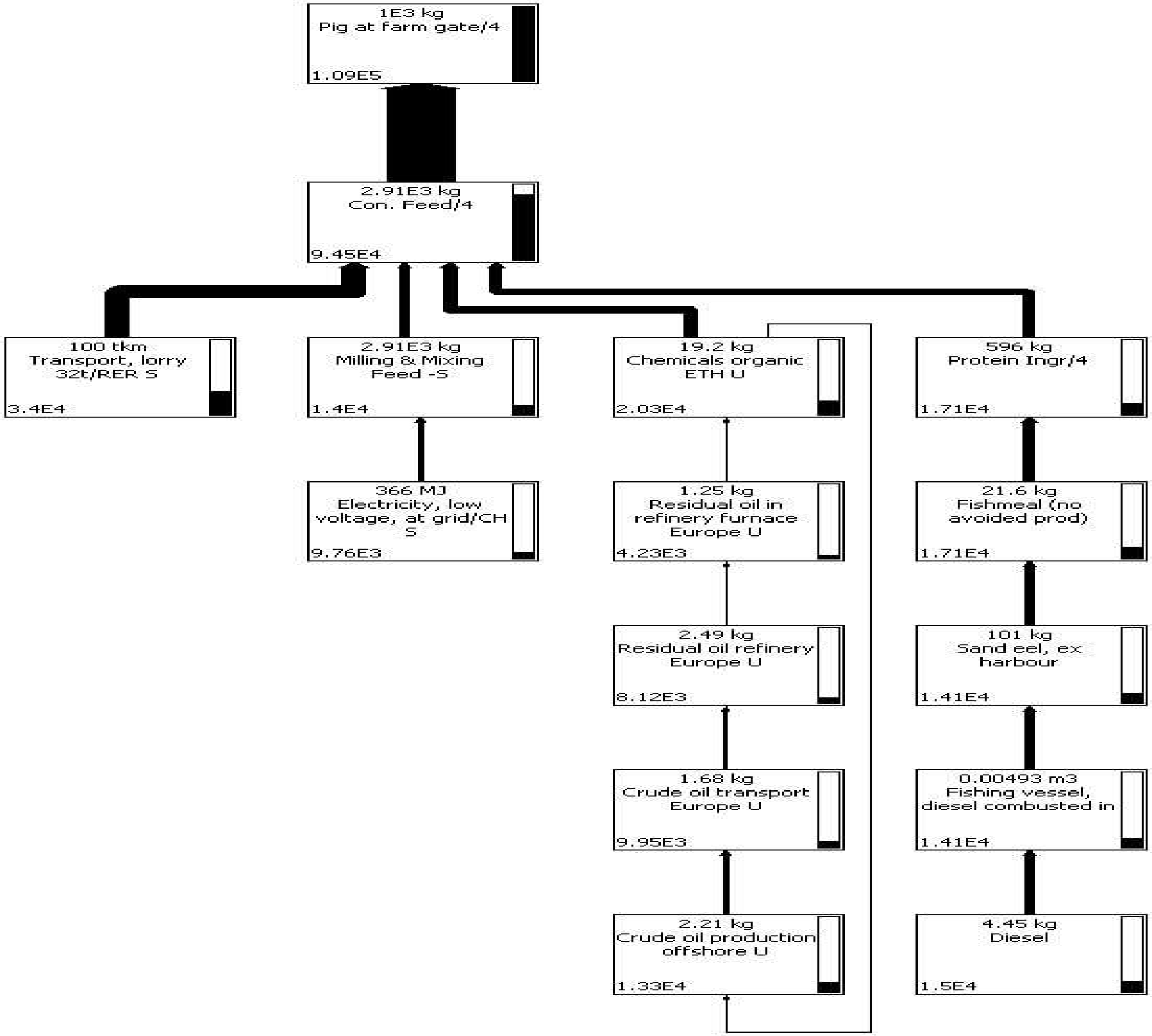

Figure A 8-XX TxW distribution of stdUK scenario processes

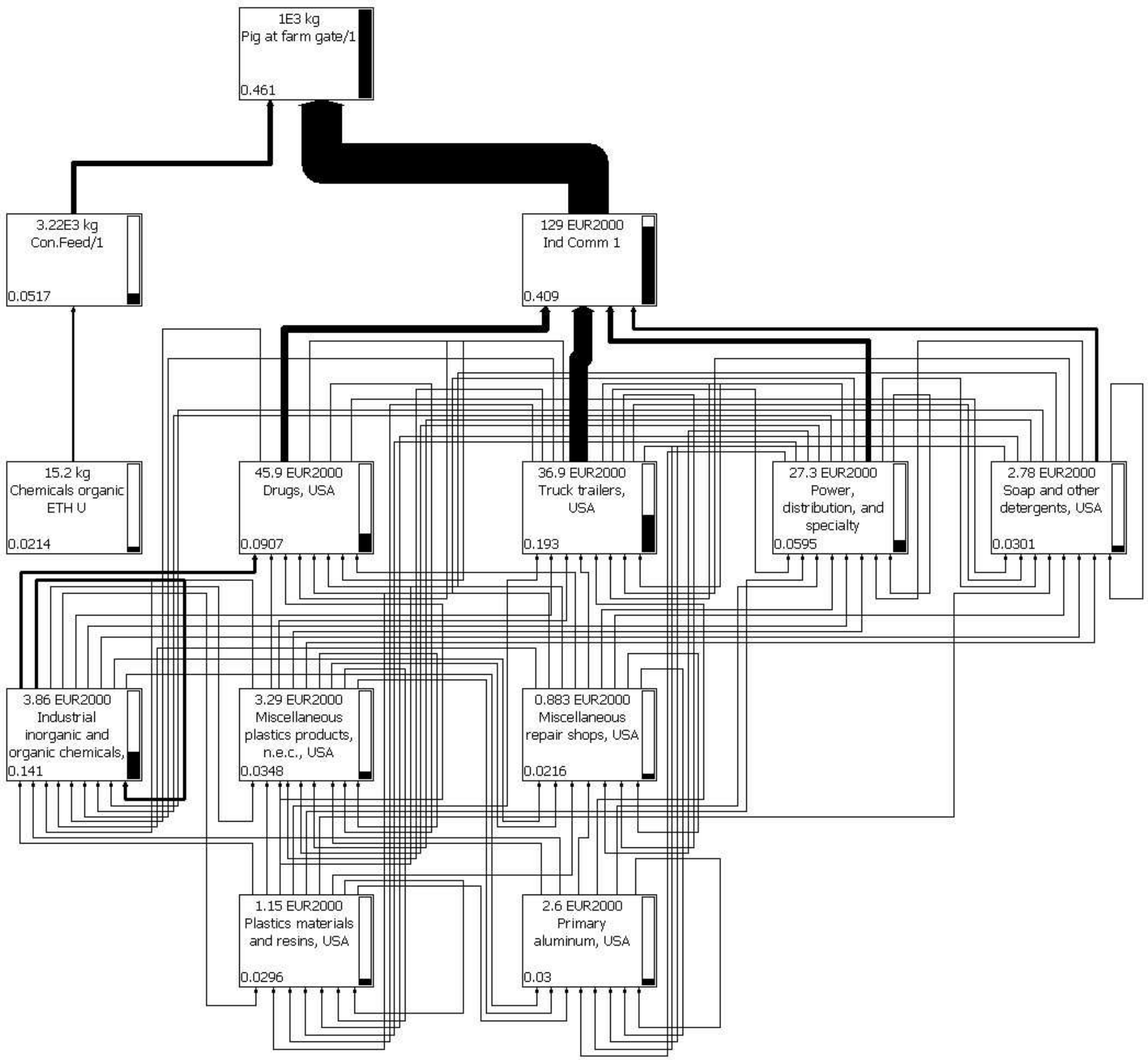

Figure A 8-XXI O_3D distribution of locMEX scenario processes

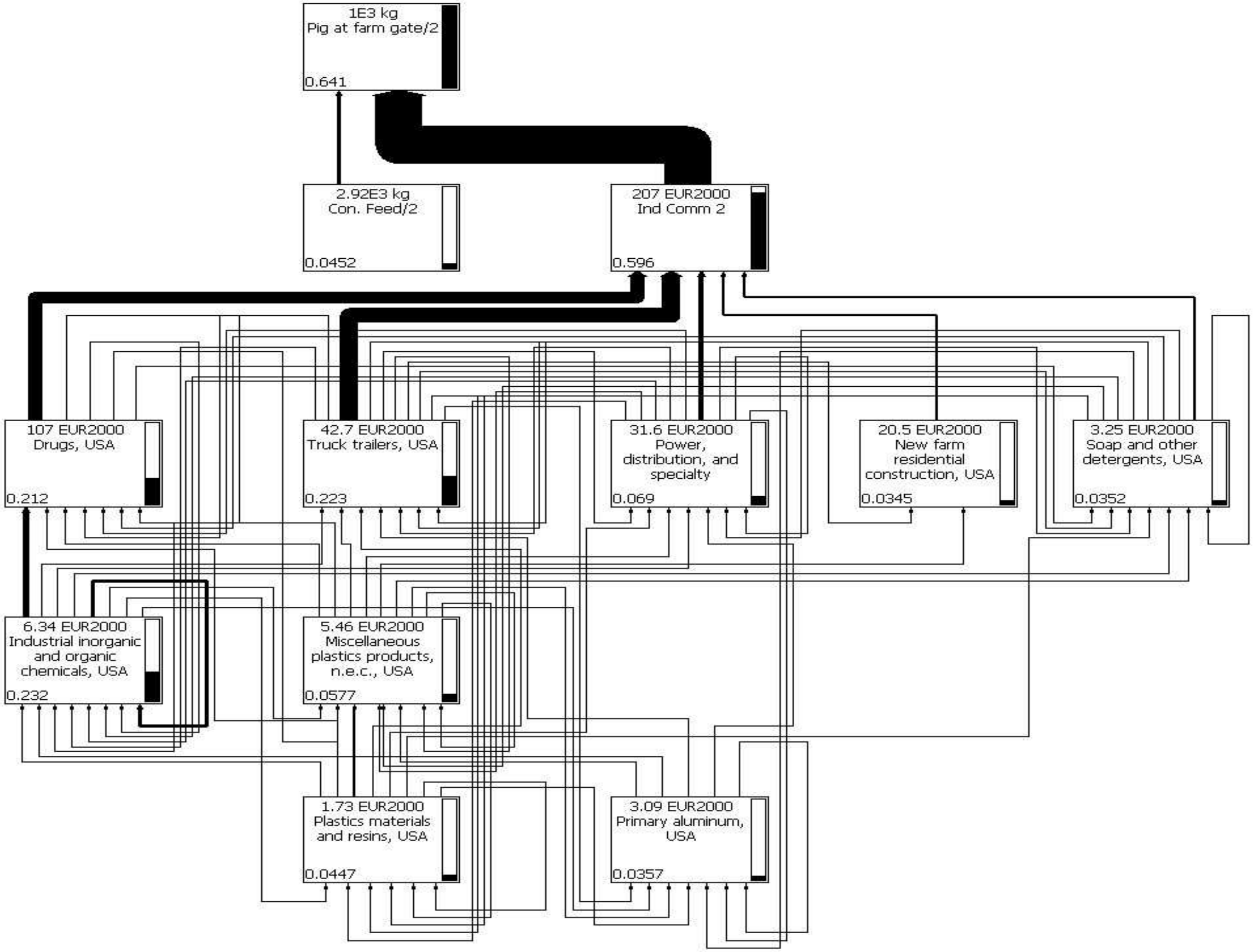

Figure A 8-XXII O_3D distribution of stdMEX scenario processes

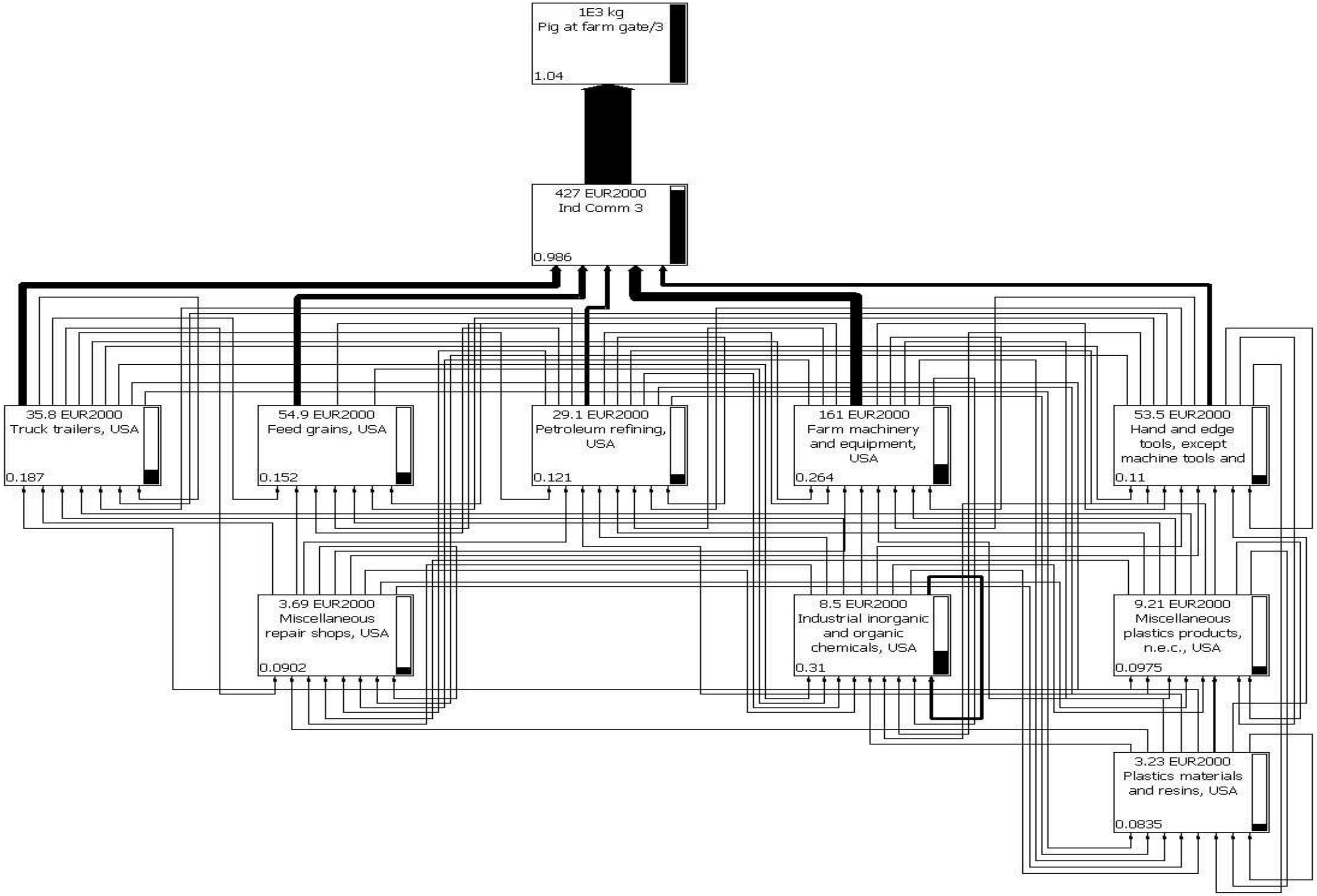

Figure A 8-XXIII O_3D distribution of orgUK scenario processes

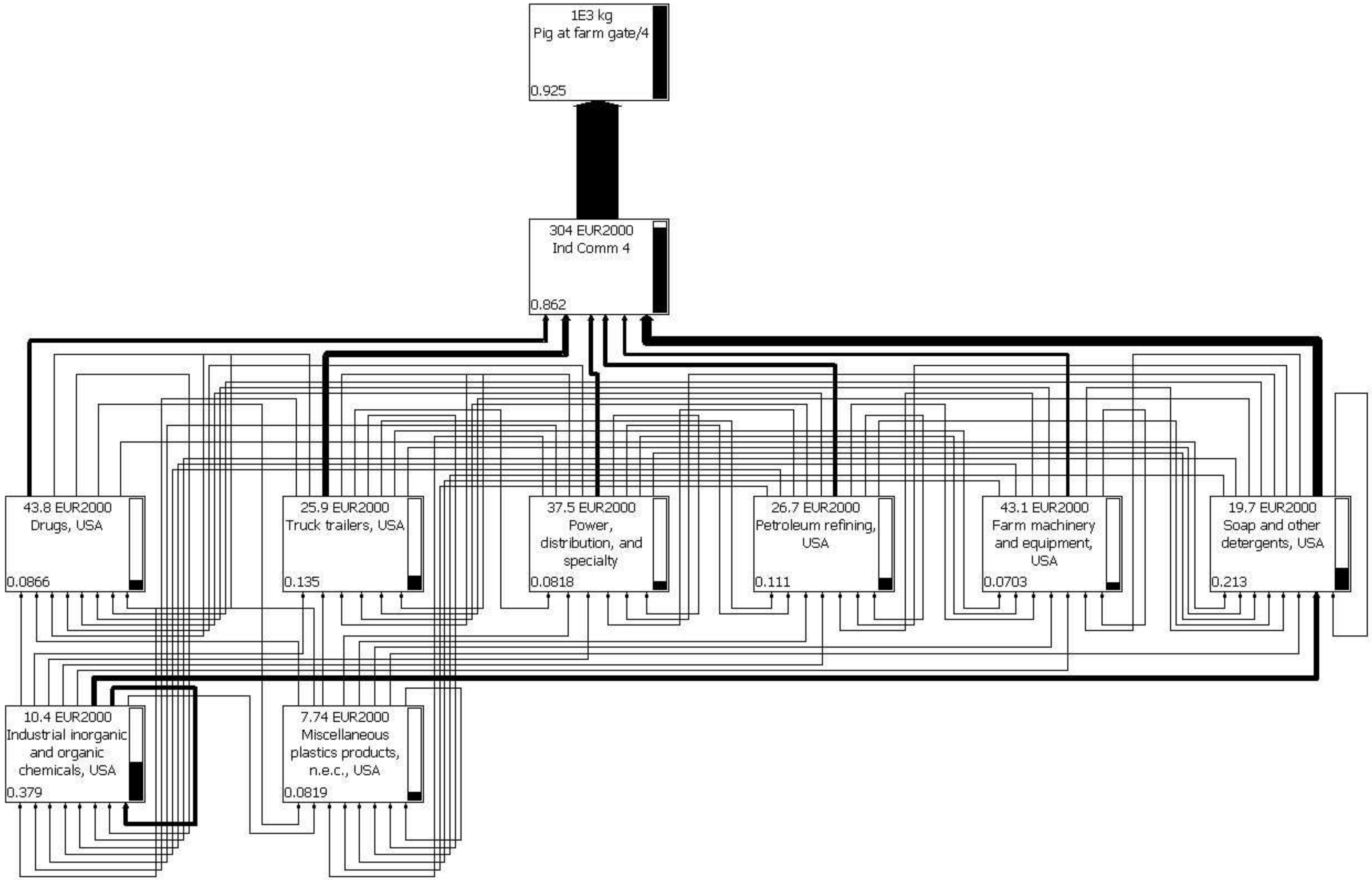

Figure A 8-XXIV O_3D distribution of stdUK scenario processes

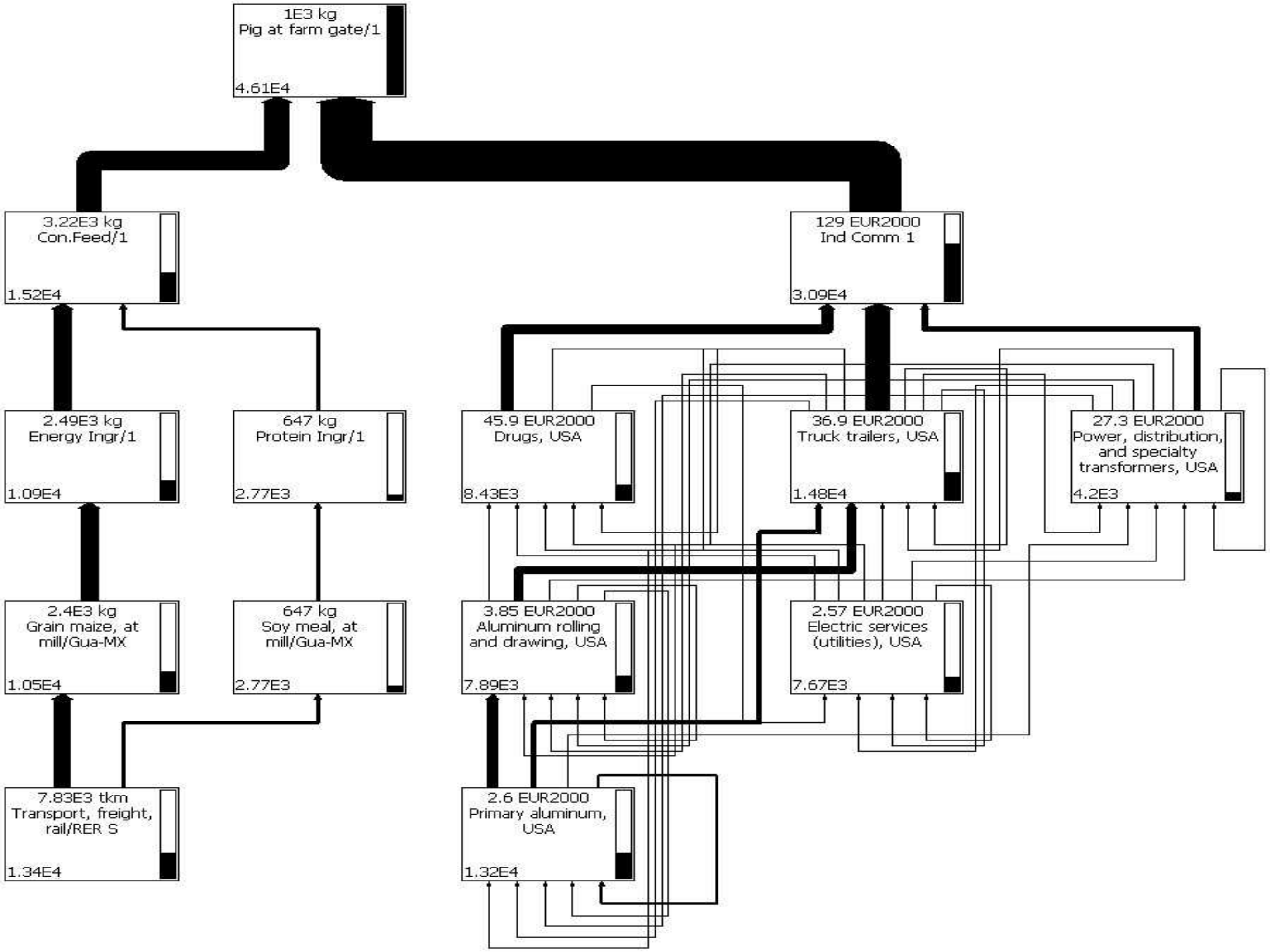

Figure A 8-XXV TxS distribution of locMEX scenario processes

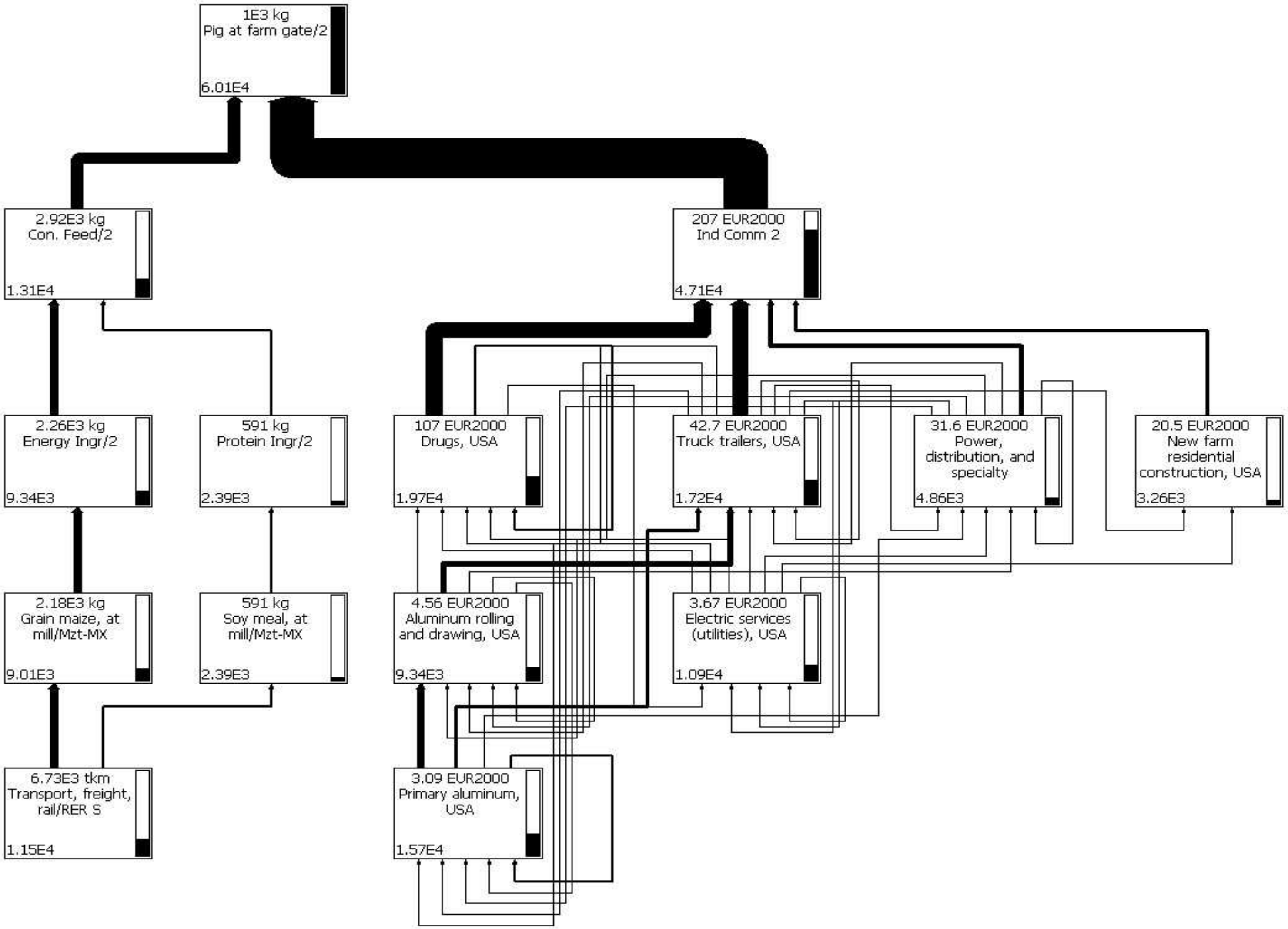

Figure A 8-XXVI TxS distribution of stdMEX scenario processes

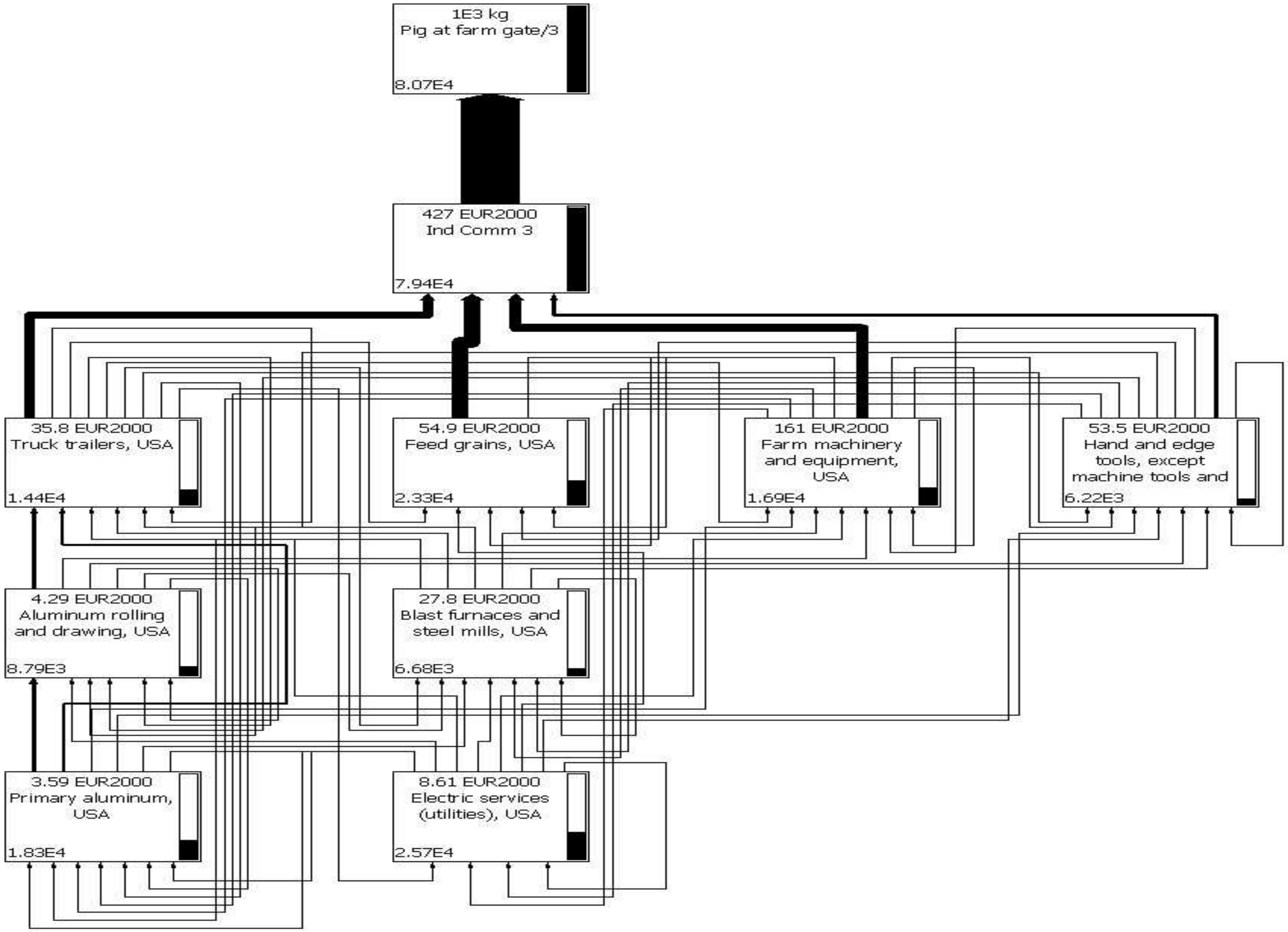

Figure A 8-XXVII TxS distribution of orgUK scenario processes

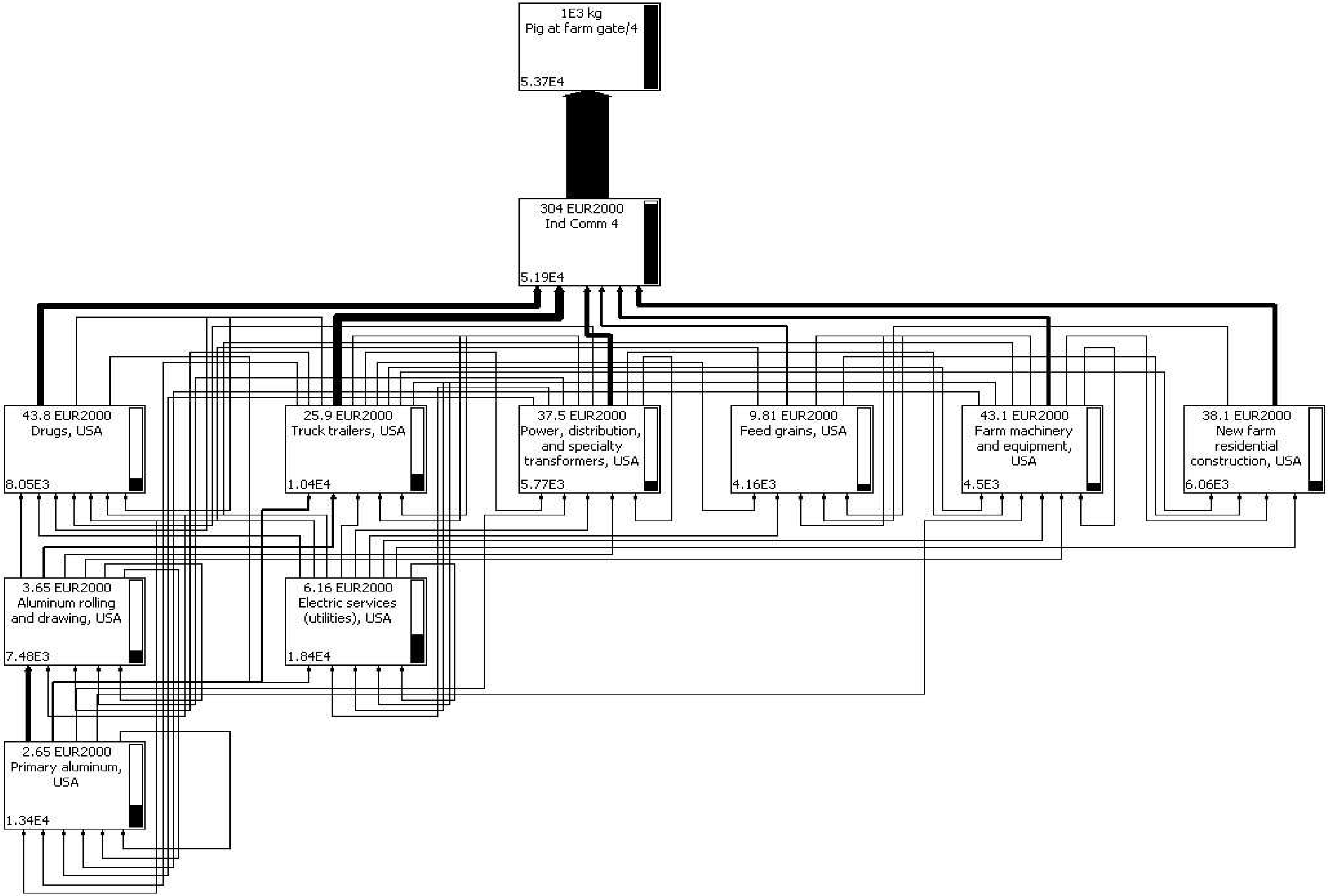

Figure A 8-XXVIII TxS distribution of stdUK scenario processes

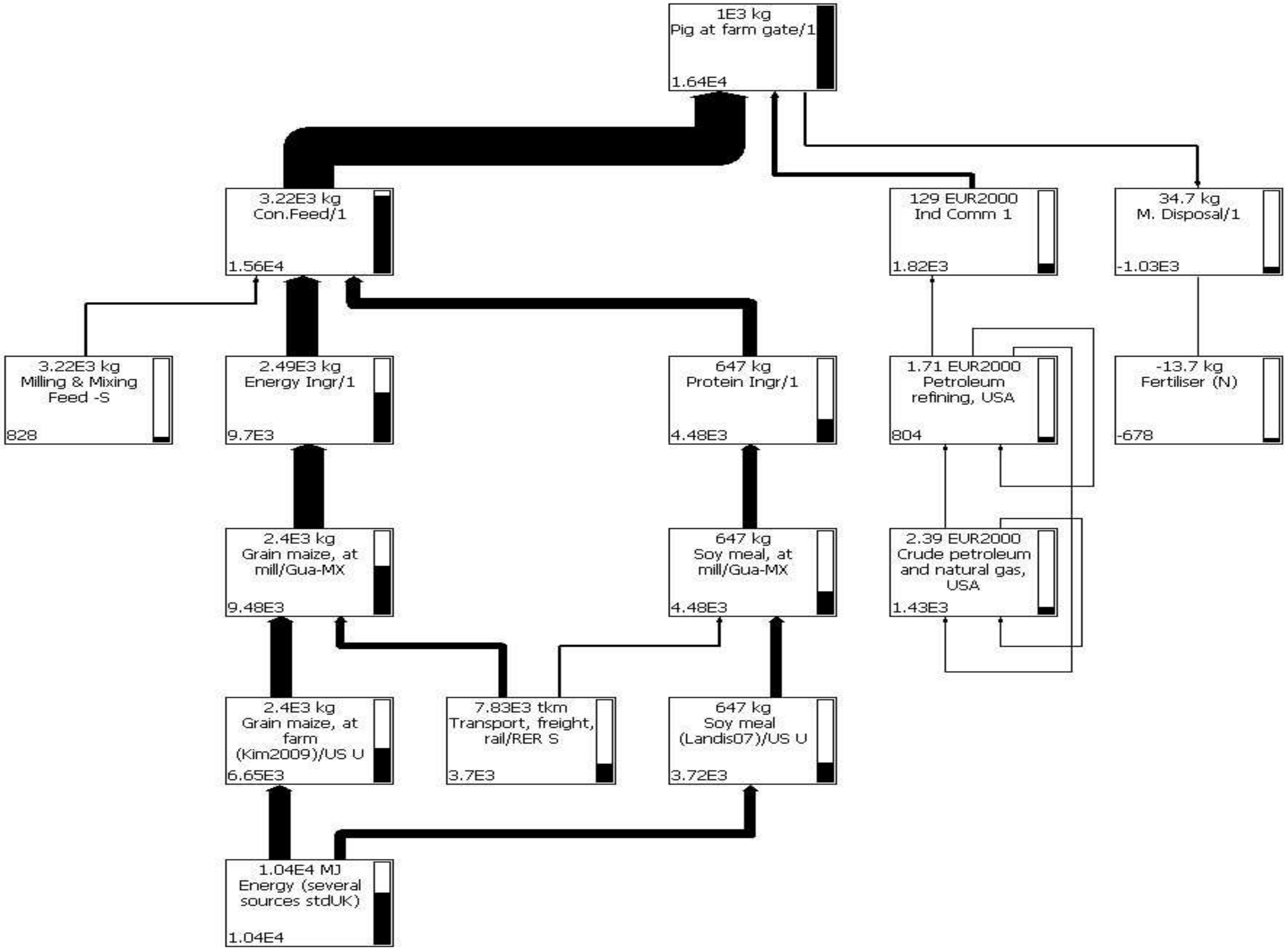

Figure A 8-XXIX Fossil energy use distribution of locMEX scenario processes

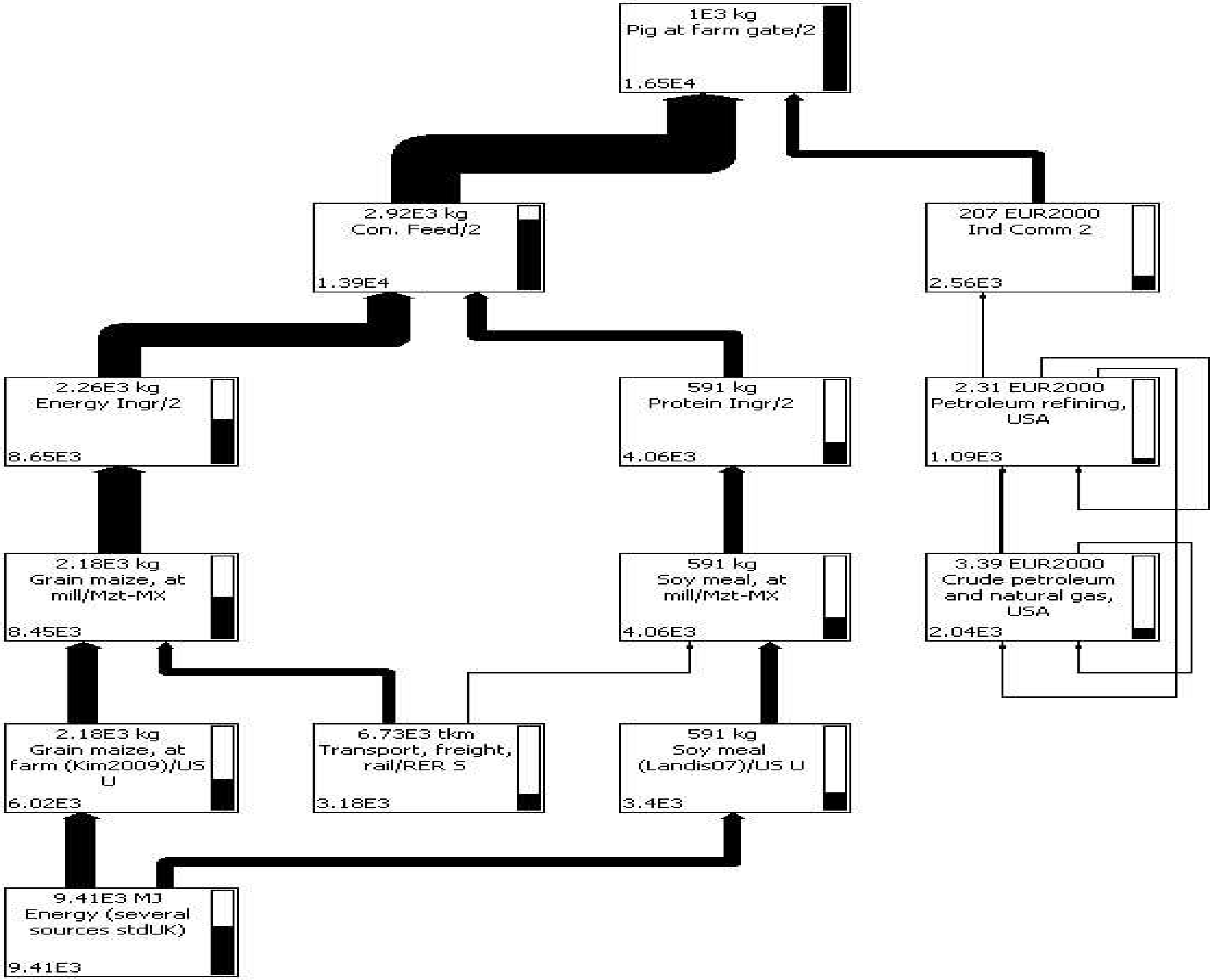

Figure A 8-XXX Fossil energy use distribution of stdMEX scenario processes

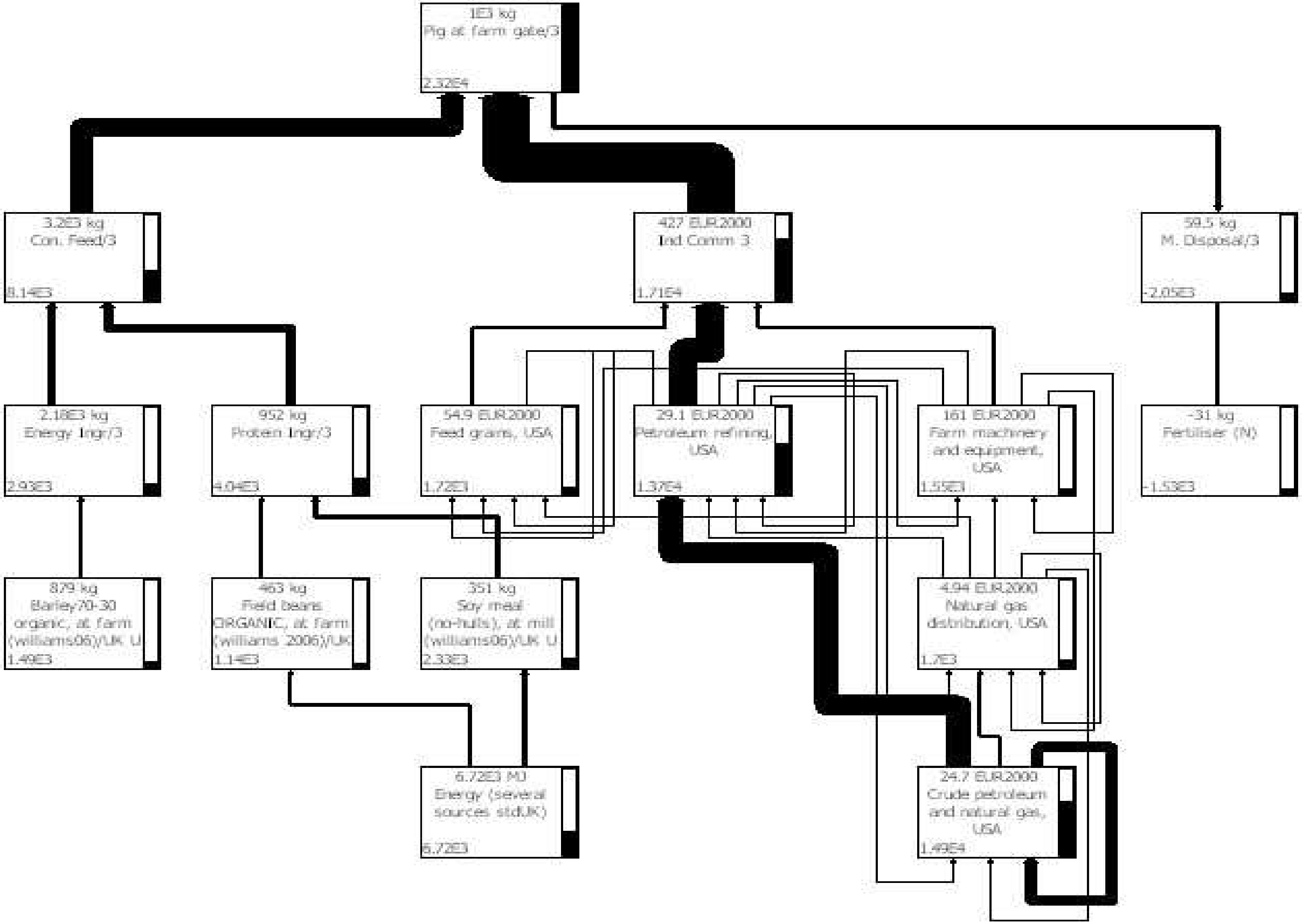

Figure A 8-XXXI Fossil energy use distribution of orgUK scenario processes

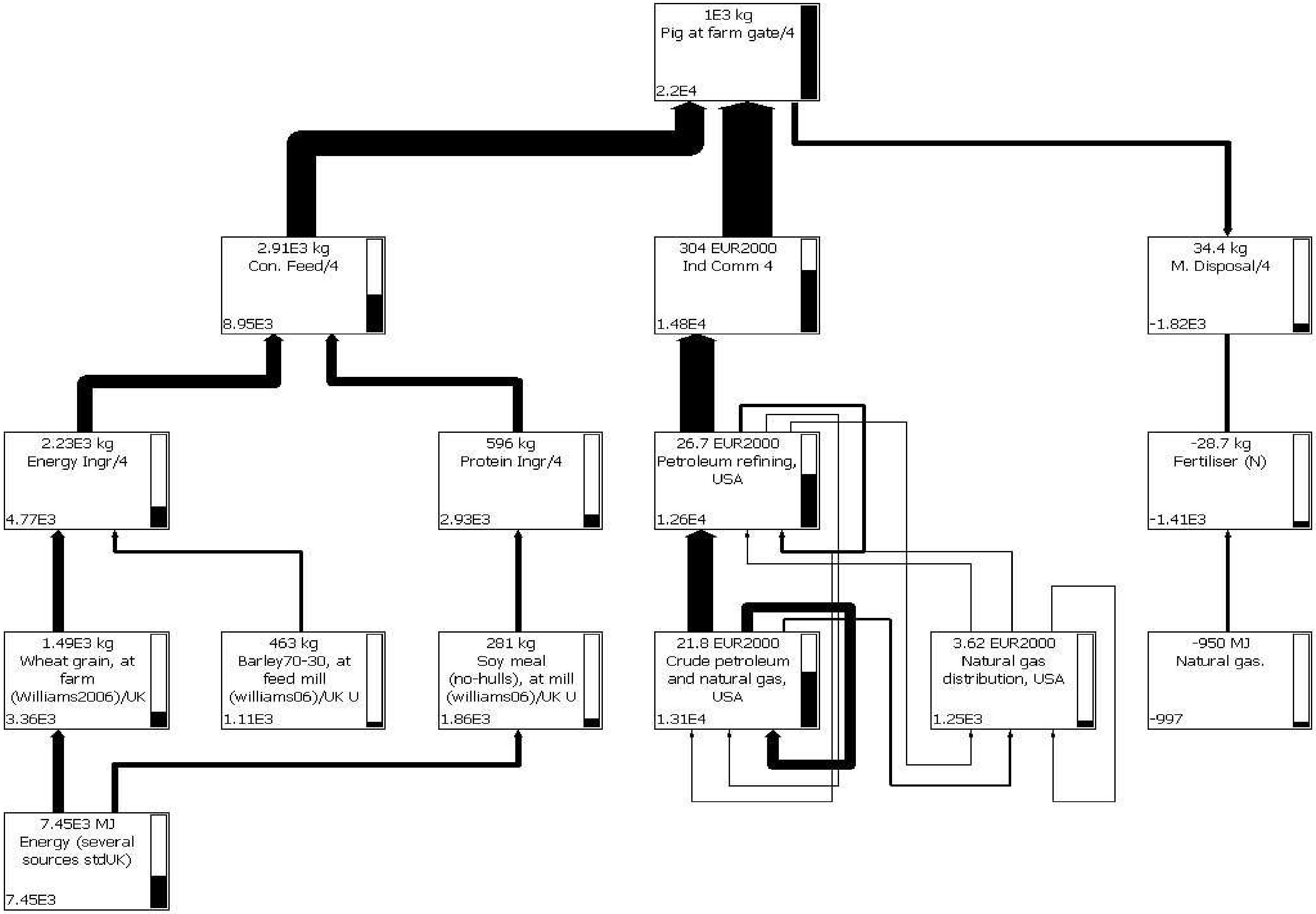

Figure A 8-XXXII Fossil energy use distribution of stdUK scenario processes