GLAMUR

Global and local food asessment: a MUltidimensional performance-based approach

SEVENTH FRAMEWORK PROGRAMME

LCA of Dutch pork

Assessment of three pork production systems in the Netherlands

Carin Rougoor, Emiel Elferink, Tjerk Lap, Annelies Balkema

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Abstract: Three different pork production systems in the Netherlands are compared in a LCA using 5 environmental impact categories, namely global warming potential, fossil energy use, eutrophication potential, land use and water use. The local pork production system using locally cultivated and residual food products as feed and on farm produced bio-energy has the lowest environmental impacts in all 5 categories. Cultivation and transport of feed products and to a lesser extent manure management are the process steps where the largest environmental impacts occur for all cases.

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Content

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Summary

This report describes the method of Life Cycle Assessment (LCA) as executed to compare local and global pig meat production chains with in the European FP7 program for "Global and local food assessment a multidimensional performance based approach". In which also an Italian team executes and LCA for Italian pork production of which the results are compared.

The goal of the assessment described in this report is to compare three types of pork production in the Netherlands with respect to environmental impacts using LCA methodology. The three production systems are:

1. **Global:** The pork meat is produced by Dutch farmers locally, but most of the feed is imported. The pork meat is exported to other European countries (Good Farming Global – VION).
2. **Semi-local:** The feed is imported from abroad. The pork meat is sold locally (De Hoeve – sustainable pork chain).
3. **Local:** The feed is mostly produced locally and the meat is also sold locally (lupine pig).

The functional unit (FU) in this study is kg of non-processed dressed pork (carcass weight), and the 5 LCA impact categories that are assessed are; (1) Global Warming Potential, (2) Fossil energy use, (3) Land use, (4) Water use and (5) Eutrophication potential. To quantify these impacts for the different phases in the pork production chain the following models are used: Simapro version 8.0.3, and Feed Print model of Wageningen University (WUR) and Water footprint assessment tool of the World Wide Fund for Nature (WWF).

Overall conclusions are that the LCA results show that the environmental impacts are highest in the feed production phase (see Figure 1). The local Lupin cases scores best on all 5 impact categories assessed. The lower scores on land use, GWP, fossil energy use of the Local case Lupin results from local feed production and the use of on farm produced biofuel. The higher GWP for the Italian cases is due to the much longer breeding periods (9 and 15 months compared to 6 months in the Dutch cases). Furthermore, the higher score on land use of the Cinta Senese pigs is mainly due to living in the marginal forest.

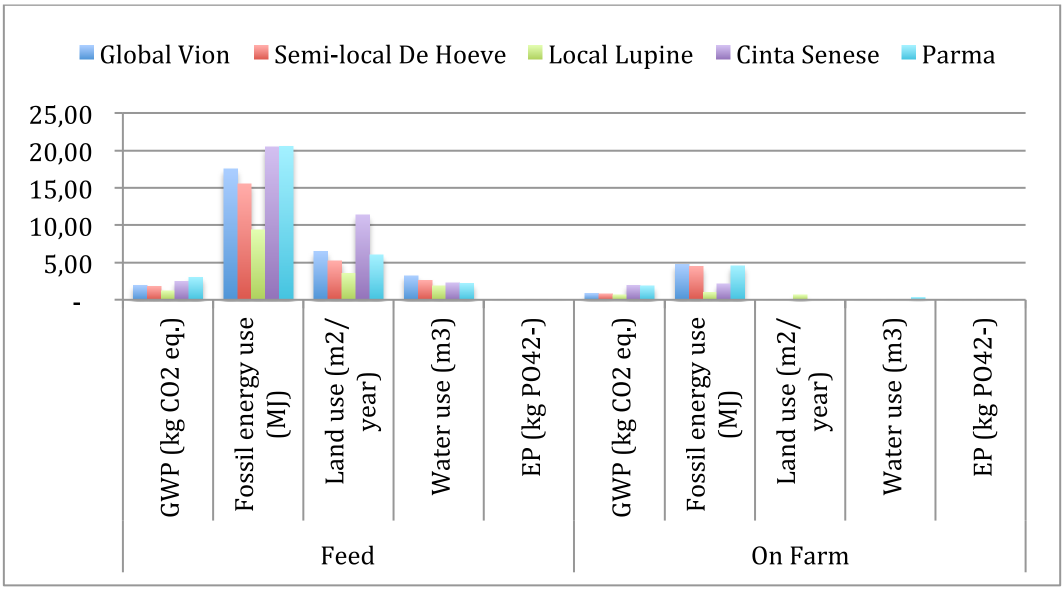

Figure 1: Comparing environmental impacts of the Feed and On Farm phase for all 5 cases, per kg carcass weight.

1

Introduction

1.1
Background: research framework

This report is written within the research framework of the European program Glamur[1]. Glamur stands for "Global and local food assessment a multidimensional performance based approach", and is a European FP7 project that aims at integrating advancement in scientific knowledge about the impact of food chains to practice, to increase food chains sustainability through public policies and private strategies. A crucial asset in Glamur methodology is the comparison of specific food items, contemporaneously, in two or more countries. To comparatively assess the various food chain performances, a crucial step in Glamur is the thorough analysis of products belonging to one of the 5 product categories studied by the project (grains, wine, fruits and vegetables, pork, dairy). Each product will be assessed through a 'farm to fork' examination in both local and global configurations simultaneously in more than one country, including imported food from non-EU countries. The database development (WP3) and assessments (WP4) of the pork production chain is done in two countries namely Italy and the Netherlands. Therefore, the CLM Research & Advice team working on the Dutch pork production chain worked in close cooperation with the Italian research team, formed by the researchers Dr. Kees de Roest and Stefano Pignedoli, of the Research Centre on Animal Production (CRPA).

This report describes the methodology and results of a Life Cycle Assessment (LCA) of the Dutch pork production systems, to be compared with Italian pork production systems.

1.2
Objective: comparing (semi-)local and global pork production systems

In the Netherlands the most consumed type of meat is pork meat, more than half of the total meat consumed is pig meat (FAOSTAT, 2014; Rossum *et al.* 2011, Kemp et al. 2014). The production of pork in the Netherlands is intensive, more than $12*10^6$ pigs are held in the Netherlands, almost all indoors in stables (CBS statistics 2014). Even though, there is growing concern on sustainability issues and animal welfare, biological meat production is still limited, in 2014 around $69*10^3$ pigs were kept biological in the Netherlands, this is only 0.6% of total number of pigs in pork production in the Netherlands (CBS data 2014). About $1,347*10^3$ ton pig meat per year is produced

[1] For more information see: http://glamur.eu

in the Netherlands, much more than the domestic consumption, the self sufficiency ratio is 238% (FAOSTAT 2014 in Lap 2014, p.13).

When assessing environmental impacts of food products, meat is a product with high environmental impacts due to the conversion of plant proteins to animal proteins. For instance pork meat products in the European Union have a Carbon Footprint around 3.5 kg CO_2 equivalents/kg product (Kool et al. 2009), while vegetables and fruits generally have a much lower Carbon Footprint. For broccoli the Carbon Footprint is 0.46 and carrots around 0.12 kg CO_2 equivalent / kg product, for strawberries cultivated in the field 0.8 kg CO_2 equivalents/kg product (Blonk et al. 2009, CLM 2009). However, strawberries cultivated in glass houses in the Netherlands have a higher Carbon Footprint, reported is 4.6 kg CO_2 equivalent / kg product (Blonk et al. 2009). Within the meat production chains, feed has a large impact on environmental indicators such as the Carbon Footprint and Eutrophication (Blonk et al. (2009) p.8). Important feed crops for pig husbandry are: wheat products, tapioca, soybean meal and barley (Blonk *et al.* 2008; Vellinga *et al.* 2013). Around 80% of the feeds for animal husbandry in the Netherlands is cultivated abroad and transported to the Netherlands (Vellinga *et al.* 2013).

There are several LCA studies about meat production in the Netherlands (Kool *et al.* 2009, Zhu and Van Ierland, 2005; Vries and Boer, 2010). These assessments do not include local feed production. Nemecek *et al.* (2008) did a LCA study on legume grains in the crop rotation for animal feed in Europe. Eriksson *et al.* (2005) did a thorough LCA research about the replacement of soybean meal in a pork production system, by peas, rapeseed meal and some additives. The results are given per kilogram of pig growth and show that the impact of the local chain is larger with respect to land use and smaller for energy use and greenhouse gas emissions. However, the feed mixtures used by Eriksson *et al.* (2005) are not comparable to the feed mixtures in the Netherlands (Blonk *et al.* 2008). As such, limited information on the environmental impacts of different pork production chains in the Netherlands is available and a comparison between local and global chains is missing. This assessment generates these missing insights.

The goal of this assessment of the pork production systems is to compare three types of pork production in the Netherlands with respect to environmental impacts using Life Cycle Assessment (LCA) methodology. The three production systems are:

1. **Global:** The pork meat is produced by Dutch farmers locally, but most of the feed is imported. The pork meat is exported to other European countries (Good Farming Global – VION).
2. **Semi-local:** Most of the feed is imported from abroad. The pork meat is sold locally (De Hoeve – sustainable pork chain).
3. **Local:** The feed is mostly produced locally and the meat is also sold locally (lupine pork).

1.3 Outline

In Chapter 2 the methodology of the LCA is described in detail. Methodological choices, such as defining the system boundaries and functional unit, as well as assumptions made in the definition and data collection and model calculations for the different cases, influence the LCA outcome. In this project, aligning research methodology with the Italian research team is important for the comparison for the Italian and Dutch cases.
The results of the LCA are presented in Chapter 3 and conclusions based on the results as well as discussion of the results and conclusions are describe in Chapter 4.

2

Methodology

2.1 LCA Background

Life cycle assessment (LCA) is a method to assess the environmental impacts of a process, product or activity, throughout its entire life cycle. The first LCA dates from the nineties when the first environmental studies to products where made. The "life-cycle" or "cradle-to-grave" impacts include; extraction of raw materials, processing, transportation or distribution of to the consumer, use of the product or service by the consumer, and disposal of wastes at the end of the life cycle. Since 1992, the year that CML published the first LCA-guide, there have been a lot of scientific methodological developments in LCA, resulting in a diversification of applying the LCA methodology in many different studies. LCA, although standardised[2] by the International Organisation of Standardisation (ISO), is often adapted to address the most important issues and the level of detail for the specific case. LCA is also the basis for a range of well-known 'footprint' assessments, as for instance the Water Footprint and Carbon Footprint.

For every LCA study the following questions have to be answered:

- What is the scope and goal of the study?
- What is to be defined as the functional unit of the study?
- What data is available?
- What level of detail is required?

These questions has resulted in four linked components which are used in all LCA's:

- Goal and scope definition: identifying the LCA's purpose, defining the functional unit that is most suitable to the purpose of the study, and determining the boundaries (what is and is not included in the study) and listing the required assumptions;
- Life-cycle inventory: quantifying the energy and raw material inputs and emissions to the environmental associated with each stage of the life cycle;
- Impact assessment: assessing the impacts on human health and the environment based on the inventory;
- Interpretation: evaluating opportunities to reduce energy, material inputs, and/or the emissions to the environmental at each stage of the life cycle.

[2] See for instance http://www.iso.org/iso/catalogue_detail?csnumber=37456.

In the following paragraphs the methodology for the LCA aiming to compare 3 different pork production chains in the Netherlands is described.

2.2 The Functional Unit (FU)

The purpose of this study is to compare three types of pork production chains. The type of feed and management choices in the husbandry stage has an impact on the amount of meat produced per pig per year. Therefore, comparisons per animal are not desirable. Furthermore, many co-products are generated, these differ per slaughterhouse, based on the demand during a year and per production system. Therefore, the functional unit is based on the carcass or dressed weight of the pig after it is slaughtered. Dressed or carcass weight is the weight of an animal after all the internal organs and the head as well as inedible (or less desirable) portions of the tail and legs are removed. It includes the bones, skin, cartilage and other body structure still attached after this initial butchering.

Different parts of the pig or different meat qualities are not considered and all non-processed meat is assumed to have the same value for the consumer. This is plausible when comparing different pork production system because it can be expected that even though there are quality differences the relative value between the different parts of pork from a production system will be comparable.

The functional unit (FU) in this study is kg of non-processed dressed pork.

2.3 System Boundaries

2.3.1 Production chain

The production chain of pork consists of different production steps, namely;

1. **Feed production**: all activities required for the production of feed, in addition including also bedding materials like straw. Feeds include crop products (e.g. maize) processed products (e.g. molasses, cheese whey) and processed feeds (e.g. concentrates).
2. **Pig husbandry:** all activities to raise and fatten pigs. This includes feeding of pigs, production of sows, piglets and fattening pigs, and also the processing of manure.
3. **Processing:** the process of slaughtering pigs and processing into meat products leaving the slaughterhouse.
4. **Retail and wholesale:** the transport and storage of meat products in cooled warehouses or in shops.
5. **Consumption:** transport, storage and preparation of the meat by consumers.

These steps are schematically represented in Figure 2.

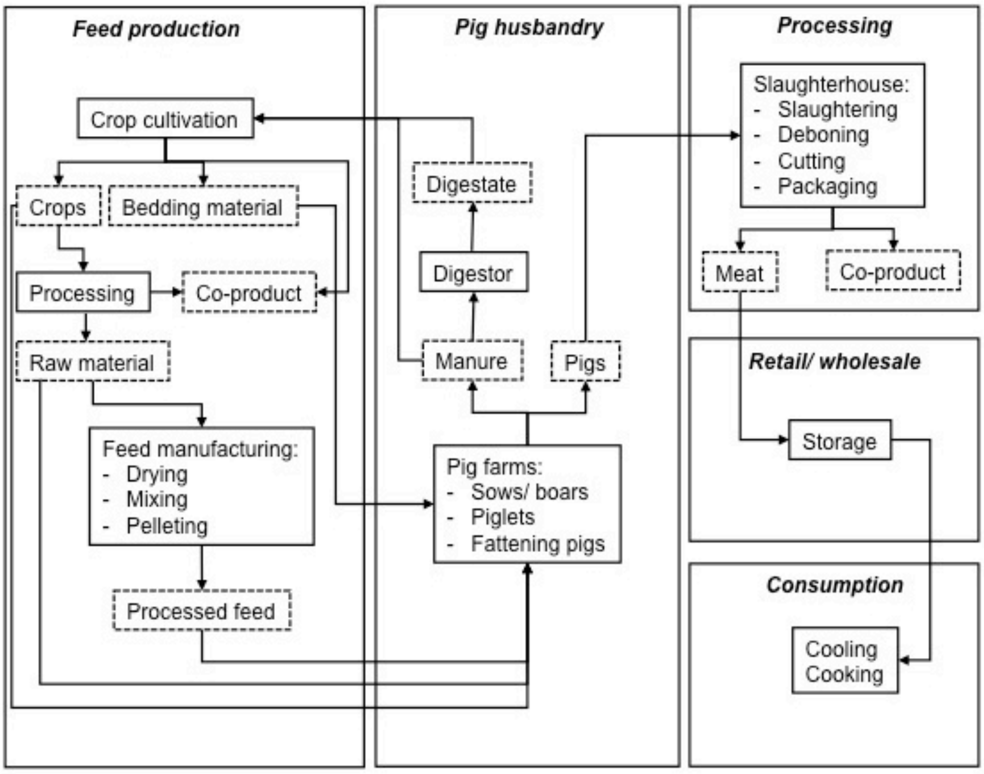

Figure 2: Overview of pork production chains (Note: boxes represent processes and production stages, while boxes with dotted outlines represent transport of products).

2.3.2
Included inputs

In line with LCA protocol (Guinée, 2002; BSI *et al.* 2008) all processes and activities that contribute at least 1% to the impact categories are included in the assessment, including at least 95% of all resources. Based on previous conducted LCA of pork, the following resources are not included in the LCA: production of capital goods (buildings, machinery, vehicles etc.), transport and nutrition of employees, production of pesticides.

2.4
Allocation

In the pork production chain different co-products are generated. To distribute the impacts between co-products allocation is required. In ISO allocation is defined as: partitioning the input and/or output flows of a process to the product system under study.

The following activities and co-products are recognised:

- Crop cultivation: crops (grains, beets, roots), bedding material (straw), co-products not used in the pork chain (leaves, stems).
- Processing of crops: raw materials for feed (molasses, meal, milling products, peels), co-products not used in the pork production chain (oils, food products).
- Pig farms: pigs and manure
- Slaughtering: fresh meat (including bone), co-products not used as food (intestines, blood).

In lifecycle assessment different types of allocation can be used. The allocation used can have a large effect on the results and often explain a large part of the difference found between studies (Voet et al., 2009).

Allocations used in LCA are for example mass allocation, area allocation sometimes used in crop growing, energy content allocation sometimes used for bio-fuels, or by-product vs. main product allocation. However, these types of allocation do not always represent the main reasons a food product is produced or represents the (societal) value of a food product.
The basic methodologies for allocation in LCA's are described in ISO 14040. The ISO norm states: *"Where physical relationship (i.e. kg, m2, m3, etc.) cannot be established or used as the basis for allocation, the inputs should be allocated between the products and the functions in a way which reflects other relationships between them. For example, environmental input and output data might be allocated between co-products in proportion to the economic value of the products "*.

The Handbook on LCA (Guinée 2002) advises to use economic allocation as baseline for most allocation situations in a detailed LCA. Due to the complexity of a food production system, the different functions of products and the availability of data required for allocation, economical or revenue allocation is used in this study. This is also in consensus with most LCA's for food. Economic allocation means that the shares of upstream impacts are divided between co-products based on their relative value fraction. Which is based on the sum of all revenues of all co-products produced in a specific production stage.

However, in the case of manure the price in the Netherlands is negative. This is the result of the large amounts of manure generated by intensive livestock in the Netherlands and Dutch regulation on the amount of manure allowed on the own farmland. Combined with stringent regulation to process excess manure, makes that farmers have to pay to process and dispose manure. Pig farmers pay arable farmers to use their manure. A negative price means that the impacts due to application of manure, not used for feed crops for pigs, should be allocated to the pork production chain. Allocation wise this is correct but it does not take into account the intrinsic value of minerals that fertilize the plant. Therefore, these impacts of application are not allocated to the pork production chain.

2.5
Impact Categories

In this LCA study, five impact categories are assessed. These impact categories are described in the following subparagraphs.

2.5.1
Greenhouse gas emissions

The greenhouse gasses considered in the assessment to the pork production chain are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).
Carbon dioxide is mainly emitted due to use of energy for field activities related to crop growing, for production of inputs (mainly fertiliser), for an energy demand in stables (lighting and climate control), for processing of feed, and for storing and cooking meat. Furthermore transport between production stages requires fossil fuels resulting in CO_2 emission.
Nitrous oxide is mainly emitted from nitrogen sources used in arable farming like manure, fertiliser, biological nitrogen fixation and decomposition of crops residues. In pig farm nitrous oxide emissions are due to manure management. This results in direct and indirect nitrous oxide

emissions, which are calculated as a result from nitrogen intake and nitrogen retention (for details see Kool et al. 2009, annex 2). For direct and indirect nitrous emission the emission factors in the Dutch NIR CRF 2014 are used.
Methane is mainly emitted in the pig husbandry stage from manure management and enteric fermentation of pigs. For methane emissions the Tier 2 methodology is used (see Kool et al. 2009), determining methane emissions based on feed characteristics and the manure management system. The latter determines which fraction (MCF) of the potentially formed methane is emitted. For each pork production system the feed composition and MCF is determined.

The unit used for greenhouse gas emissions is carbon dioxide equivalency, kg CO_2-eq/FU. This is a measure that describes for a greenhouse gas the amount of CO_2 that would have the same radiative forcing (global warming potential) over a specified time. We used the GWP_{100} factor as published by the IPCC in 2007[3].

Table 1: Global Warming Potential (GWP).

Greenhouse gas	GWP (time horizon 100)
Carbon dioxide (CO_2)	1
Nitrous oxide (N_2O)	298
Methane (CH_4)	25

Source: IPCC 2007 AR4 p.212

2.5.2
Fossil energy use
The fossil energy use of pork represents the direct and indirect fossil energy use throughout the life cycle, including the energy consumed during the extraction, manufacturing and disposal of the raw materials. The term fossil fuel refers to a group of resources that contain hydrocarbons like coal, oil and gas and their derivatives diesel and electricity. Fossil energy is mainly used for feed production (diesel for land management, gas for fertilizer), on farm processes (predominantly electricity and gas), transport (diesel), and processing and storing (gas and electricity).

The unit used to express fossil energy use (PEU)[4] is MJ/FU.

2.5.3
Land use
The land use impact category is use to see how efficient land is used in each pork production chain. This gives more or less a reflection (proxy) of the damage to ecosystems and the loss of biodiversity. There are of course many more aspects than just the amount of land that have an effect on the loss of biodiversity. Besides occupation also the transformation of land from one function (nature, grass, dessert, etc.) to another function (arable land, build area), the type of land management (intensive or extensive) and the location (EU, South America) of the land used are important in such a case. However, in this study we focus on occupation of a certain area of land during a certain time (a year). In the pork production chain 99% of the land required is used for

[3] There is still scientific debate on the GWP for methane, which is increased from 21 (SAR), to 25 (AR4) to 34 (AR5) (IPCC Assessment Reports), meaning that the environmental impact of animal products is increasing, in this assessment the AR4 GWP is used.

[4] PEU stands for Primary Energy Use.

feed production. The share of factories, farm stables and shops is negligible and not determined in this study.

The unit used to express land use (LU) is m^2/ y / FU.

2.5.4
Water use

There are different methods to determine the impact category water use. In this study we use the water footprint method of Hoekstra (Hoekstra et al. 2011). This method includes direct and indirect water use. Furthermore, the method distinguishes between water of different origin. Three types of water are distinguished; (1) Green water is the volume of rainwater evaporated or incorporated into a product, (2) Blue water is the volume of surface or groundwater evaporated or incorporated into a product, and (3) Grey water is the volume of polluted water.

In the pork production chain the bulk of the water is used for crop cultivation. Less water is used during processing and on farm. Water used in retail, wholesale or by consumers for cleaning and cooking is assumed to be negligible and not determined.

The unit used to express water use is m^3/FU.

2.5.5
Eutrophication potential

Eutrophication can be defined as nutrient enrichment of the natural environment. Eutrophication as a result of human activities is one of the major factors that determine the ecological quality of an environment.
In LCA eutrophication only takes into account those nutrients that are limiting the yield of aquatic biomass (algae and duckweed). Although there are many abiotic and biotic factors that can limit growth of biomass the availability of the so-called macro-nutrients phosphorus and nitrogen are dominating factors for algal blooms. Therefore, eutrophication potential is based on substance that include phosphorus and nitrogen and that are emitted water, soils and air. The latter are predominantly ammonia (NH_3) and nitrogen oxide (NO_x). Airborne phosphorus accounts less than 3%. There are various routes along which P and N containing compounds can enter the natural environment. Diffuse emission through nutrient supply on agricultural land is distinguished from point emission by wastewater treatment plants (N and P). In agriculture a distinction is made between manure and fertilizer as these differ in fractions of N that is released to the air during application. Due to diffuse emission nutrients enter environments by surface run-off and erosion (N and P), leaching from soils after agricultural supply (N) or by atmospheric deposition (NH_3 and NO_x) and subsequent transport to surface water through groundwater drainage.

In the pork production chain N and P are emitted during crop cultivation as a result of the application of manure and fertilizer and by pork farms due to ammonia (NH_3) and N_2O emission resulting from manure management. In the Netherlands there is stringent regulation on the amount of ammonia emitted by farms. Dutch farmers have taken measures to reduce ammonia emissions.

The unit used to express eutrophication potential is phosphate equivalency, kg PO_4^{2-}-eq/FU.

2.6 Data Collection

For the three systems assessed data was collected differently, as described in the following paragraphs.

2.6.1 Global case; VION

The global pork production chain, Vion case, data is used from different sources that give average data on Dutch pork production. Important sources are Dutch Central Bureau for Statistics (CBS)[5] and BINternet[6]. The latter collects yearly data from 4,000 pig farms in the Netherlands. This data is aggregated in size and type of pig farm. In this assessment averages corrected for the present of other animals are used. An overview of all data sources is presented in Table 2.

Table 2: Overview of data sources used for the LCA of the global pork production chain.

Inventory data	Source
Technical data on the number of animals per farm, life weight, number of piglets/sow etc.:	LEI and CBS 2012
Feed consumption	LEI and CBS 2012
Feed composition	Blonk *et al.* 2008 and questionnaire
Energy and Water use on farm	LEI and CBS 2012
Manure production	NIR CRF 2004 and Coenen *et al.* 2014
Ammonia emissions stables	CBS
Ammonia emissions management & application:	NIR CRF 2004
Transport distances	Blonk *et al.* 2008
Energy and water use for processing feed	Vellinga and Blonk, 2012
Energy use for processing meat	Ramirez *et al.* 2006
Energy use for retail, wholesale and consumption	CLM

2.6.2 Local cases; De Hoeve and Lupine

For the local cases, De Hoeve and Lupine, data is collected through questionnaires and interviews. A questionnaire was developed in Dutch for the farmers. This questionnaire was sent by email and instructions where discussed by phone so it was clear which data was required. After the phone call farmers had some time to collect the data and fill in the questionnaire. An appointment was made to discuss the collected data and answers given in the questionnaire. Problems in data interpretation and quality where solved during this meeting. If required additional data was collected by the farmer after the meeting and sent by email to CLM. Farmers collected also data on other stages in the production chain, for instance the composition of their feed or transport distances, by contacting their suppliers or clients.
For the lupine case data refers only to one farm that is still in development. De Hoeve provided average activity data of over 500 pig farms that produce according to their standards. Each farm

[5] CBS publishes statistics also on the Internet http://statline.cbs.nl/StatWeb/?LA=en.
[6] BINternet databases by LEI Wageningen University: http://www3.lei.wur.nl/binternet_asp/index.aspx.

that produces pork with a "De Hoeve"-label sends for inspection annually all farm data to the main office of De Hoeve. This data is aggregated by De Hoeve and provided to CLM. When no specific De Hoeve data was available this was usually because the "De Hoeve"-label does not have additional criteria compared to the average Dutch pig farmer. In these cases, for example slaughter weight percentage, average Dutch data was used.

2.7 Models used

To calculate the different impact categories we used predominantly Simapro, version 8.0.3. Additionally we used the Feed Print model of Wageningen University (WUR) and Water footprint assessment tool of the World Wide Fund for Nature (WWF) to determine the impacts of feed production. Results of these models where used as input for Simapro. A more detailed description of the models used is given in the following paragraphs.

2.7.1 SimaPro

SimaPro (System for Integrated environMental Assessment of PROducts) is developed by the Dutch PRé Consultants. It is a well-known, internationally accepted and validated tool. Since its development in 1990 it has been used in a large number of LCA studies by consultants, research institutes, and universities. The software allows to model and analyse complex life cycles in a systematic and transparent way, by building your own processes from scratch or connecting/combining/changing processes already available. SimaPro follows the recommendations of the ISO 14040 series of standards. There are different versions of SimaPro depending on the profession and purpose of its use. For this study we used SimaPro version 8.0.3 (Lap 2014, p.50).
SimaPro is delivered with several inventory databases (or libraries) that contain a range of data on most commonly used materials and processes, such as electricity production, transport and materials such as plastics or metals. One of the databases included is the EcoInvent database, developed by the Swiss Centre for Life Cycle Inventories. This is one of the more commonly used LCA databases and includes a large number of up-to-date processes, covering a broad range of materials and processes with uncertainty data. The SimaPro database is one of the most comprehensive ones available for LCA an all of the embedded data are fully referenced. Furthermore SimaPro includes multiple standard impact assessment methods and allows the user to add or edit these methods.

2.7.2 FeedPrint

The FeedPrint model is developed by Wageningen University and Blonk consultants for the Dutch feed production sector. The model calculates the carbon footprint of feed raw materials during their complete life cycle. This ranges from crop production, via processing of crop and animal products, compound feed production to utilization by the animal, including transport and storage between all steps of the production chain. The scope of the model is on the emissions of the greenhouse gases CO_2, CH_4 and N_2O. The ISO standards (14040/44) and the PAS 2050 of the British Standards Institute are the basis of the methodology. And all calculations done are consistent with IPCC requirements on calculating GHG emissions. More specific, the 2006 IPCC Guidelines for the National Inventory Reports are used in FeedPrint. The model uses therefore the same criteria as used for the other emission sources used in this study. Data used in FeedPrint is collected in a two-step process. First data from the public domain is collected (Scientific literature, FAOstat, Eurostat, etc.). Secondly draft reports are discussed with experts from industry. Data quality has been assessed using the Pedigree Matrix, developed by EcoInvent. Related to this, an uncertainty range and a distribution type have been attributed to all data. The FeedPrint developers used the Modular Extrapolation of Agricultural LCA (MEXALCA) method for assessing missing data. For more details and an in-depth description of the FeedPrint model see Vellinga et al. (2013).

2.7.3
Water Footprint assessment tool

The Water Footprint Network has developed an online assessment tool, Water Footprint assessment tool, based on the methodology of Hoekstra (2011). The tool is available online[7] since September 2013 and enables a user to calculate the fresh water use of a product or industrial process. The Water Footprint assessment tool (WFAT) uses a comparable approach as LCA starting with determining goal and scope definition and accounting of all direct and indirect water sources. The tool uses global database like the WaterStat database or it allows for entering own collected data. In this study the tool is used for determining the water used to produce the feed used in the pork production chain. Data on composition of the feed was collected from the farmers for the local case or from literature for the global case. Furthermore, we used the FeedPrint model to determine how much crop is required to produce a feed component. By use of import statistics we determined a weighted average for the origin of the feed crops. For each feed used a product assessment was made using the WFAT.

2.8
Overview LCA methodology for Dutch pork

The table below shows per stage an overview of the data used and its source.

Table 3: Overview LCA data sources.

Stage:	**Emission/ indicator:**	**Source:**
Emission factors for energy use are taken from the EcoInvent 3.0 database. This includes electricity from the Dutch grid, natural gas and diesel as well as emissions from transportation.	GWP and PEU: CO_2	EcoInvent database 3.0, Weidema et al. 2013
Emission factors for methane (25 times CO_2) and nitrous oxide (298) to calculate the global warming potential are based on the IPCC 2007 100 year method.	GWP: CH_4, N_2O	IPCC 2007 AS4 (from SimaPro 8.0) Vellinga *et al.* (2013)
Stage 1: Feed production		

[7] http://www.waterfootprint.org/?page=files/waterfootprintassessmenttool

Use of the FeedPrint model to show the environmental impact of different feed sources. The FeedPrint model shows the impact per kg of feed. Environmental indicators used are:		Vellinga and Blonk (2012)
- global warming potential (g CO_2-eq./kg),	GWP: CO_2, CH_4, N_2O	Vellinga and Blonk (2012)
- energy use (MJ/kg), land use (m^2/ y /kg)	Energy use: CO_2	Vellinga and Blonk (2012)
- eutrophication potential (EP in: g P eq./kg converted to PO_4^{2-} eq.)[8]	EP: NH_3, P-eq. and PO_4^{2-} eq., N_2O	
- water use (litres / kg product)	Water Footptint	Hoekstra et al. 2011
Stage 2: Pig production at the farm		
The housing of the pigs determines ammonia emissions. The emission factors for ammonia are given per animal per year and are subdivided per housing type. Another source of ammonia emission is the manure storage where also nitrous oxide is formed. The emissions are given per ton manure, again different types of storage are taken into account.	EP: NH_3 and N_2O emissions converted to PO_4^{2-} eq.	Coenen et al. 2014, Van Bruggen *et al.* 2012 IEC 2008
Manure statistics are present in the national inventory report of greenhouse gas emissions. From these statistics methane and nitrous oxide emissions can be calculated.	GWP: CH_4 and N_2O	NIR NL 2014
By enteric fermentation methane is lost to the environment.	GWP: CH_4	NIR NL 2014
Energy use is given per farm. The data is gathered by a questionnaire filled in by the participants.	GWP and PEU: CO_2	VION
Water use on the farm is given per animal	Water: litres	VION
Stage 3: Post farm gate		
Emissions from the slaughterhouse are given per slaughterhouse. The average number of processed	GWP and PEU:	Ramirez et al. (2006) and

[8] Note that the eutrophication potential is given in gram P equivalents. This is converted into PO_4^{2-} equivalents because the methodology for calculating the eutrophication potential is based on the EDP 2008 method (IEC, 2008), which shows EP in PO_4^{2-} equivalents. The conversion from P to PO_4^{2-} requires the number to be multiplied by 3.06.

fattening pigs is given as well.	CO_2	Infomil
Water use per slaughterhouse	Water: m^3	CLM Env. worksheet pig processing
Packaging: the amount of plastics (PP and LDPE) is given per 600 gram of pork meat. Emission factors from PP and LDPE are obtained from the EcoInvent database.	GWP and PEU: CO_2	Kingston et al. 2009, EcoInvent v3.0
Energy use for cooling: at supermarket, in MJ/kg/day, and the average storage time, at consumer, in MJ/kg, and the average storage time	GWP and PEU: CO_2	CLM Climate Yardstick
Refrigerated transport is assumed to consume 20% more energy	GWP and PEU: CO_2	Webb et al. 2013

3

LCA results

3.1
Data

3.1.1
Technical data per case

The technical data for the different pork production chains are presented in Table 4. It is important to realize that LCA results are based on the amount of pork produced per year. When carcass weight is higher the total meat produced is also higher. However this does not necessarily mean that the environmental impact is lower because this may require a higher amount of feed per pig.

Table 4: Technical data for the different pork production chains.

	unit	Vion Global	De Hoeve Semi-Local	Lupin Local
Piglets	n/sow/year	31	29	28
Production rounds	n/year	3.09	3.34	3.11
Growth	kg/day	0.8	0.9	0.9
Live weight	kg/animal	115	118	125
Carcass weight	kg/animal	93	92	102
Feed, piglet	kg/animal	29	30	30
Feed, sow	kg/year	46	46	50
Feed, fattening pig	kg/animal	247	224	265
Bedding, straw	kg/ kg carcass	0	0	0.27

3.1.2
Transport distances per case

Table 5 lists the transport distances used in this assessment. Transport occurs between the different stages. Distances for feed ingredients are not shown. However, these are incorporated in the FeedPrint model. Transport data are based on the questionnaire for the local cases and on literature for the global case.

Table 5: Transport distances for different pork production chains.

	Vion Global	De Hoeve Semi-Local	Lupin Local	Mode of transport
Fattening pigs to abattoir	100	100	100	Truck

Abattoir to slaughter	0	0	0	
Slaughterhouse to retail	600	100	50	cooling truck
Retail to consumer	5	5	5	Car

3.1.3 Feed composition per case

The global case: VION

Data on feed composition in the Vion case is based on Kool (2008). However, the percentage of soybean meal can vary between feed suppliers and over time due to market prices. To see what the effect will be on the impact we studied besides the average feed composition also feed mixtures with a share of 10% and 15% soybean meal. The feeds compared are equal in the amount of protein and nutritional energy value.

Table 6: Feed composition of the global case VION.

Feed ingredient	Source country	Diet share		
		Average	**15% soy**	**10% soy**
Barley	B, D, FR	10%	11%	11%
Wheat	D, F, NL, UK	8%	8%	9%
Tapioca	Thailand	21%	22%	24%
Peas, dry	Aus, D, F	5%	5%	6%
Rapeseed expeller	D, F	8%	8%	9%
Palm kernel expeller	Malaysia, India	6%	6%	7%
Soy bean meal	Arg, Braz	**20%**	**15%**	**10%**
Sunflower seed meal	Ukr, Ch, Arg	7%	8%	9%
Sugar beet molasses	NL, D	5%	6%	6%
Wheat feed meal	D, NL, UK, F	10%	11%	11%

The semi-local case: De Hoeve case

Pig farmers of De Hoeve are obligated to use feeds that are low in heavy metals copper and sink and low in phosphorus (P). There are no additional requirements with regard to origin of feeds, production or composition. Furthermore, De Hoeve farmers do not purchase their feed from a specific feed manufacturer. Neither farmers of De Hoeve nor the main office of De Hoeve know the feed ingredient composition. Therefore, we used a feed with the same feed ingredients as the average pig feed, however with a diet share that is low in heavy metals and phosphorus.

Table 7: Feed composition for the semi-local case; de Hoeve.

Feed ingredient	Source country	Diet share
Barley	B, D, F	11%
Wheat	D, F, NL, UK	14%
Tapioca	Thailand	24%
Peas, dry	Aus, D, F	5%
Rapeseed expeller	D, F	17%
Palm kernel expeller	Malaysia, India	7%
Soy bean meal	Arg, Braz	10%
Sunflower seed meal	Ukr, Ch, Arg	0%
Sugar beet molasses	NL, D	6%
Wheat feed meal	D, NL, UK, F	6%

Local case: Lupin

For the Lupin case data on feed composition originates from the feed processing plant of the Lupin farm. The Lupin farm currently uses dry concentrate. However they are making a switch to wet feeds. In this study both feed types are assessed. In the comparison between global and local cases the wet feed case is used.

Table 8: Average concentrate feed composition for the local case; Lupin.

Feed ingredient	Source country	Diet share
Complement	Miscellaneous	42%
Wheat flour	Netherlands	16%
Rey	Germany	13%
Lupin	Netherlands	14%
Barley flour	Belgium	15%

Table 9: Average wet feed composition for the local case; Lupin.

Feed ingredient	Source country	Diet share
Complement	Miscellaneous	10.3%
Wheat	Netherlands	5.8%
Barley	Netherlands	4.3%
Lupin	Netherlands	3.2%
Whey	Germany	28.4%
Potatoes peels	Netherlands	8.3%
Brewery waste silage	Netherlands	7.1%
Water	Netherlands	32.6%

3.2
LCA outcomes for the different stages in production

In this paragraph the LCA results are presented for the different production stages for which an overview is shown in Figure 3. LCA outcomes are described per in paragraph 3.3 starting on page 23, and per impact category in Appendix 1 the LCA results are discussed per impact category.

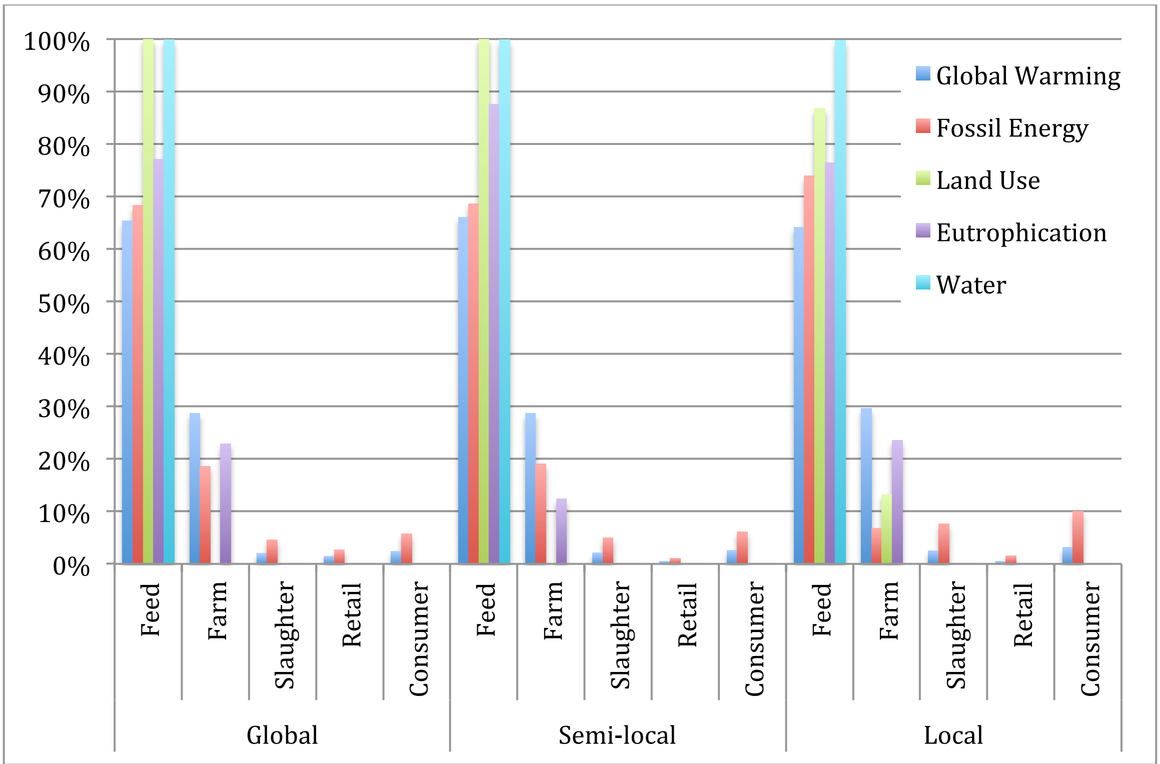

Figure 3: Contribution of different production stages to environmental impacts for the 3 different pork production systems in percentage.

3.2.1
The Feed stage: production and transport of pig feed

As shown in

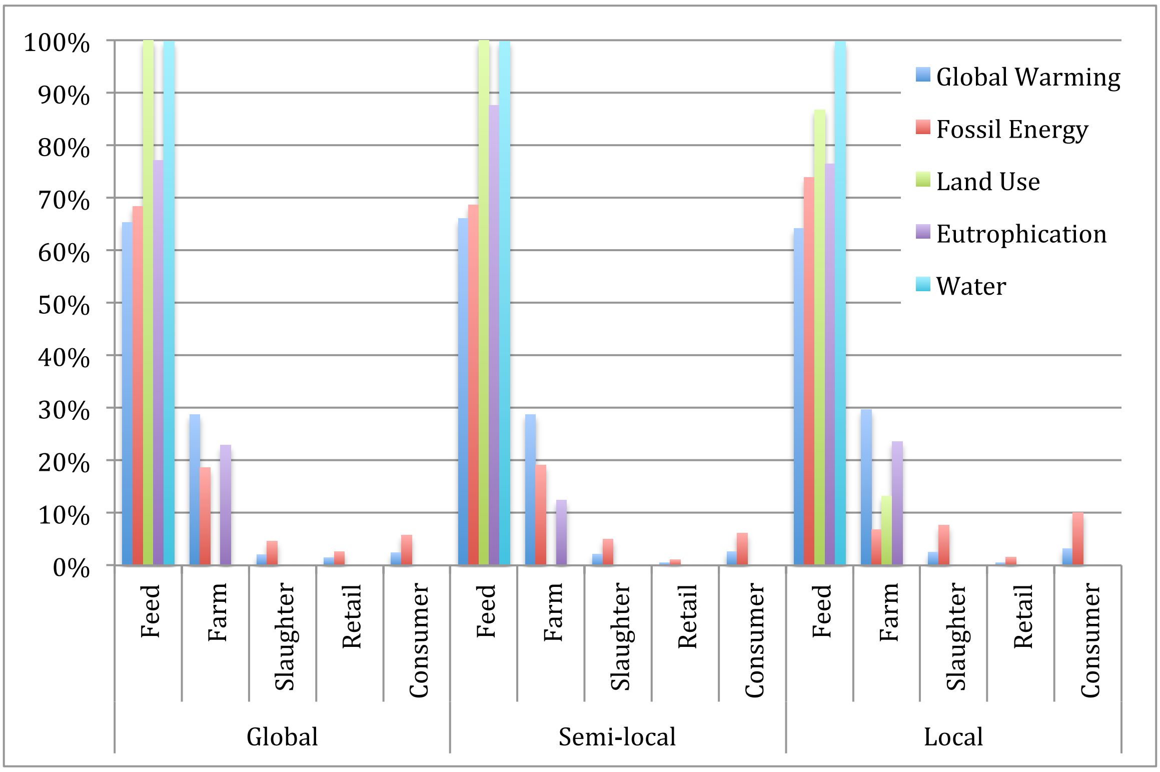

Figure 3, above, the feed production stages has the larges impact on the environment in all 5 impact categories assessed for all the 3 cases included in this study. In Figure 4, the absolute impacts are shown for the Feed stage for the 3 different cases, revealing that the impacts are largest for the global case. The feed stage includes cultivation, processing and transport of pig feed. The Global Warming Potential (GWP) is shown in Figure 5, for the Local case the GWP is lower for transport but higher for processing as in this case pig feed is produced on the farm locally.

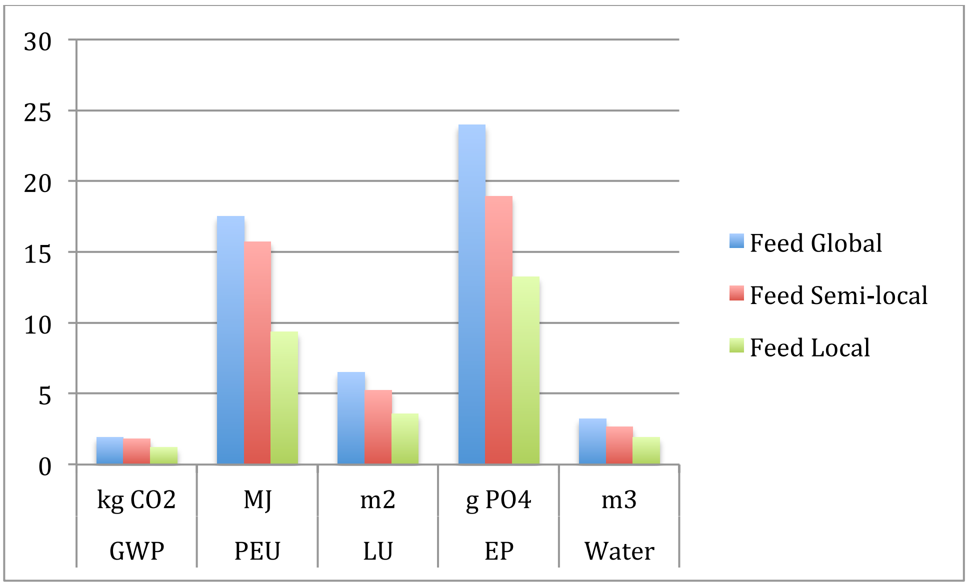

Figure 4: Environmental Impacts for the Feed stage for the 3 different cases.

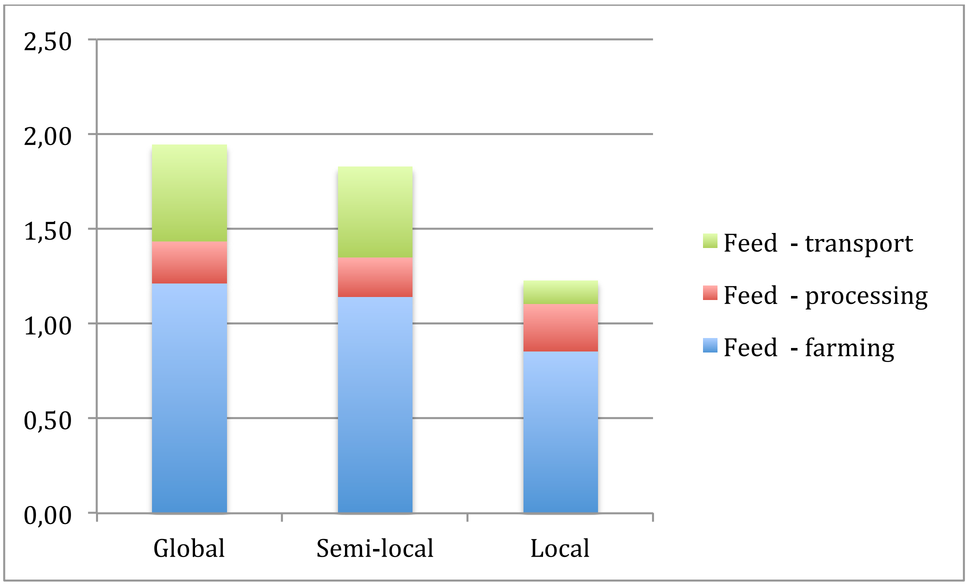

Figure 5: Global Warming Potential of the Feed stage for the 3 different cases (in kg CO_2 eq./kg carcass weight).

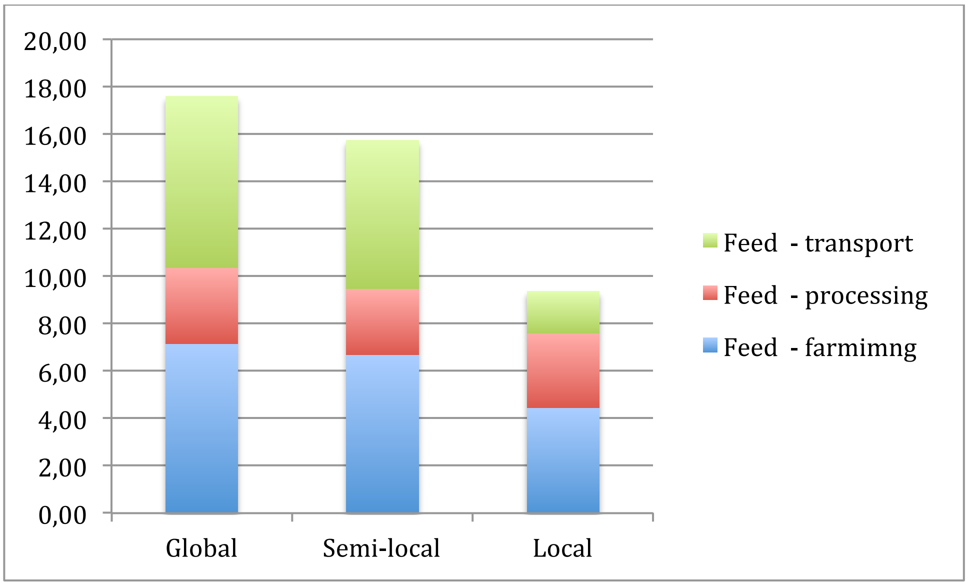

Figure 6: Fossil energy use for the Feed stage for the 3 different cases (in MJ/kg carcass weight).

3.2.2
The On Farm stage: pig farming

As shown in Figure 7, impacts in the On Farm stage are for the Global case slightly higher than for the Semi-local case, and lowest for the Local case. With exception of Land Use, due to the fact that in the Local case, Lupin, Feed is produces on the farm as well as biomass for energy generation requiring land area. Global warming mainly results from manure management and to a lesser extend from electricity use and enteric fermentation, see Figure 8. Fossil Energy is mainly electricity use and gas, except for the Local case due to the bio-energy production system, see Figure 9. Eutrophication Potential results from manure management and enteric fermentation, respectively 60 and 40% of the EP in this stage for both the Global and Semi-local case. Fro the Local case, 71% of the Eutrophication Potential in this stage results from manure management, 21% from enteric fermentation and 4% from the straw used in the stables.

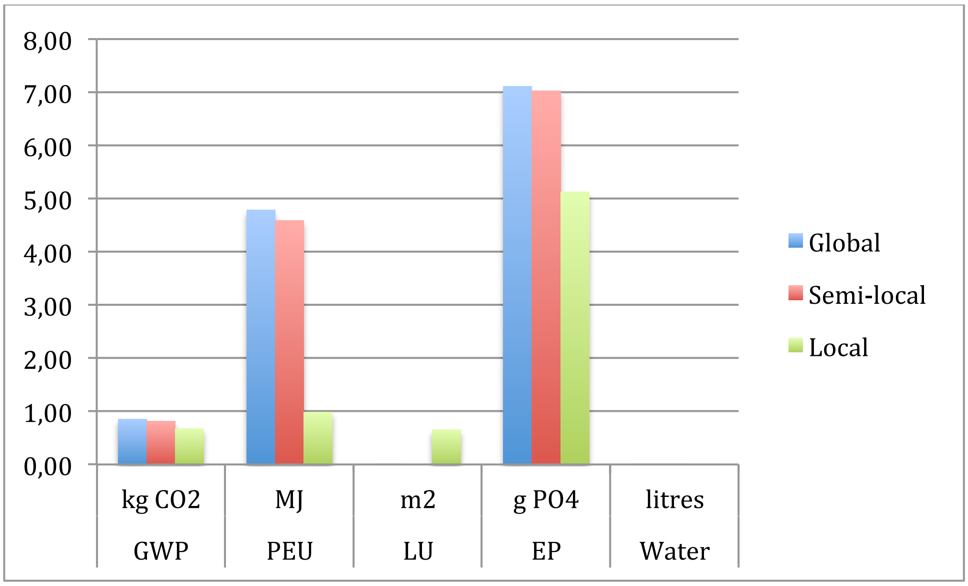

Figure 7: Environmental impacts of the On Farm Stage for the 3 different cases.

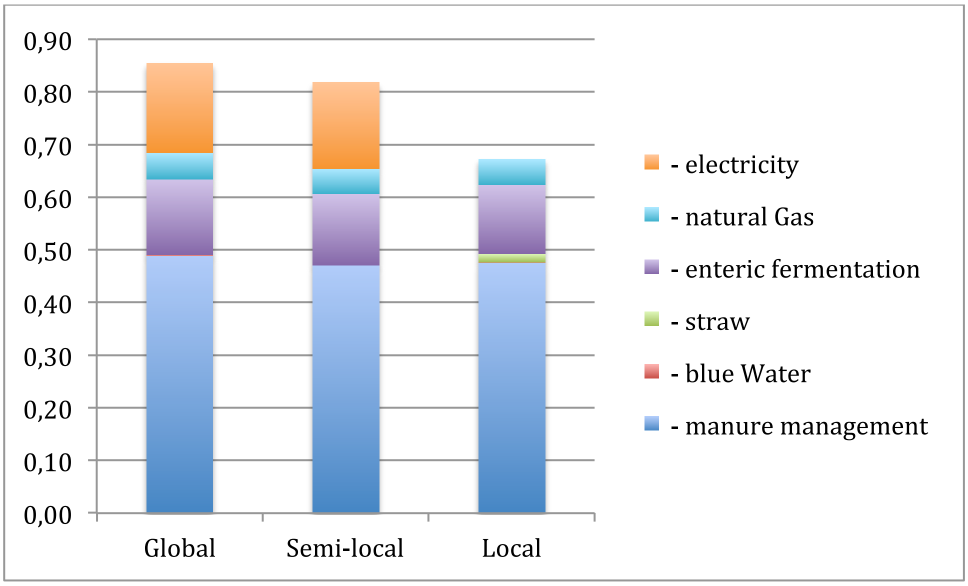

Figure 8: Global Warming Potential for the On Farm stage for the 3 different cases (in kg CO_2 eq./kg carcass weight).

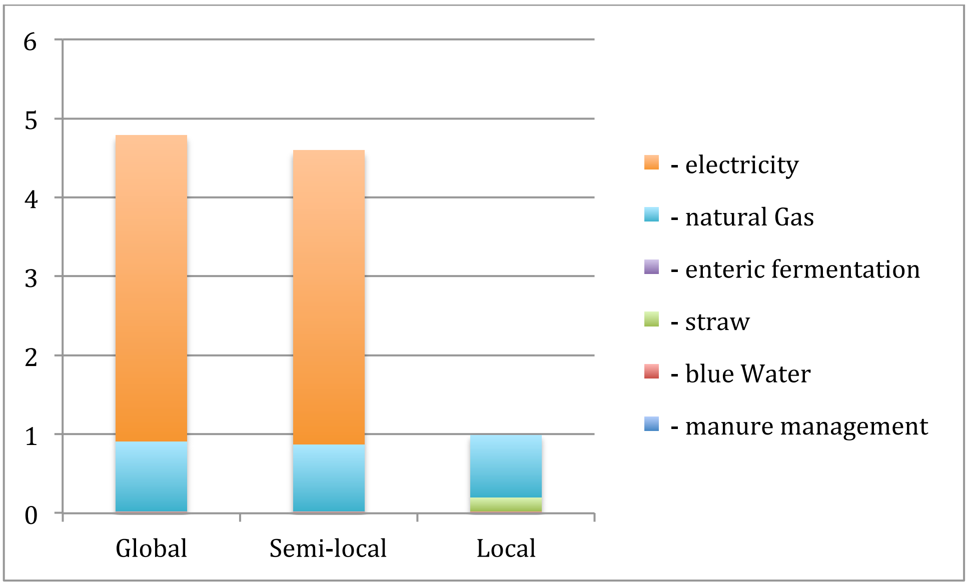

Figure 9: The fossil energy use for the On Farm stage for the 3 different cases in (MJ PEU / kg carcass weight).

3.2.3
The slaughterhouse stage

The Slaughterhouse stage impact is mainly energy and water use, in lesser extent also some energy is contained in packaging and used in transport.

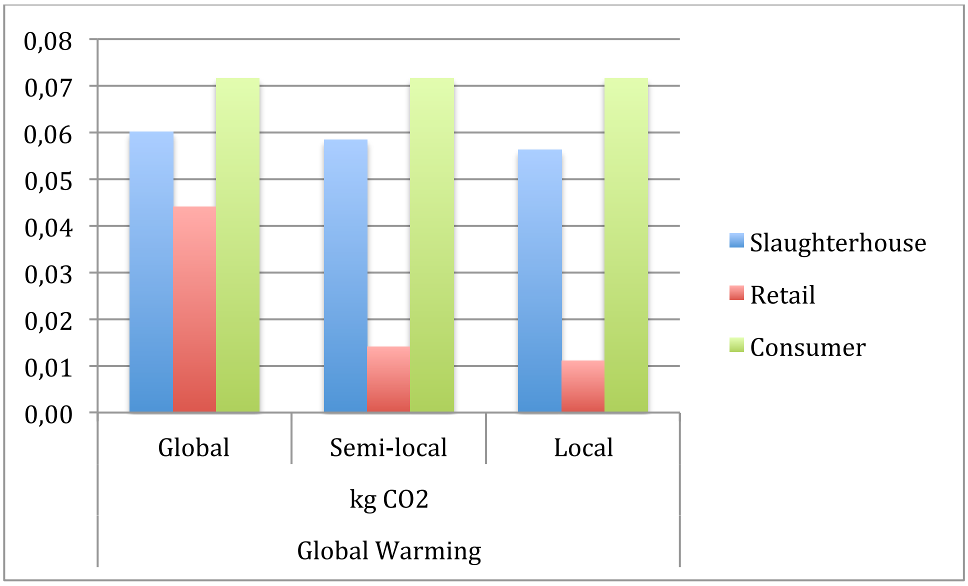

Figure 10: The Global Warming Potential for the slaughterhouse, the retail and the consumer stage for the 3 different cases in (MJ PEU / kg carcass weight).

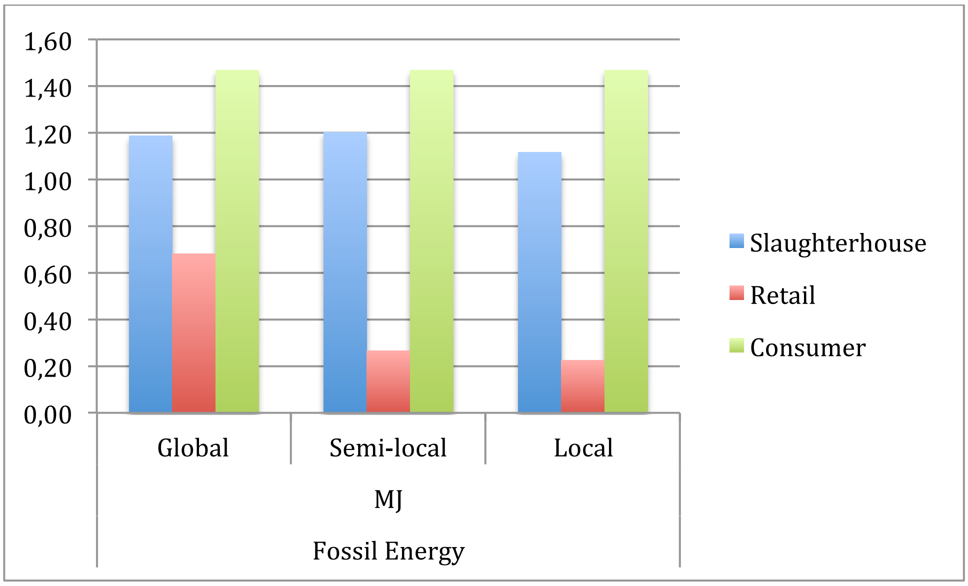

Figure 11: The fossil energy use for the slaughterhouse, retail and consumer stage for the 3 different cases in (MJ PEU / kg carcass weight).

3.2.4
The Retail stage

The environmental impacts in the Retail stage as assessed in this LCA is mainly due to transport for the Global case, with less transport in the Semi-local case and no transport in the Local case the effect of cooling is equally important and the main impact respectively.

3.2.5
The consumption stage

Transport, cooling and preparation taken into account in this LCA for the Consumption stage, and cooling (0,91 MJ PEU) and preparation (0.56 MJ PEU) take more energy than the transport (0 MJ PEU) as the estimated average trip is only 6.4 km and pork makes up only an estimated 3% of the food basket for this stage.

3.3
LCA outcomes per case

In this paragraph the LCA results per case are presented.

3.3.1
Global pork production: VION

For all impact categories feed production represents the largest contribution (see Figure 12). The largest contribution is made in the production of feed products, with a contribution of transport and less by processing (see Figure 13). The farm stages contribute considerable to the impact categories global warming potential, fossil energy use and eutrophication potential. The contribution of the slaughterhouse to global warming is mainly energy use. For the retail the contribution to global warming potential is in transport, for the consumer mainly cooling and preparation.

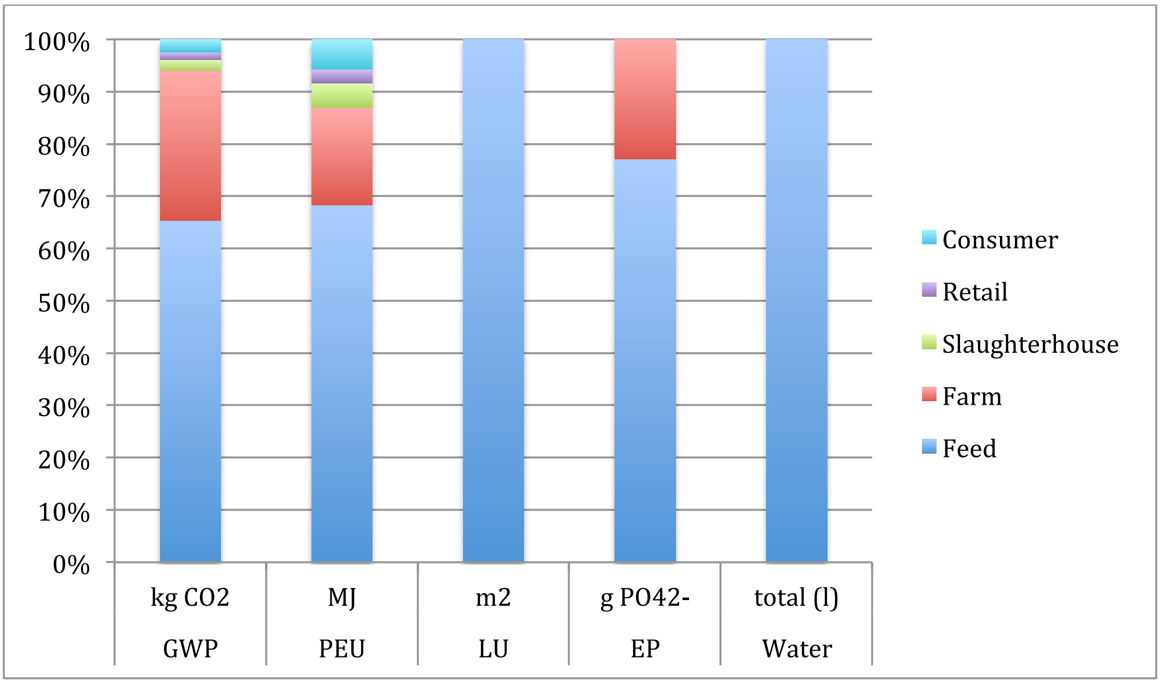

Figure 12: Environmental impacts for the global pork production system.

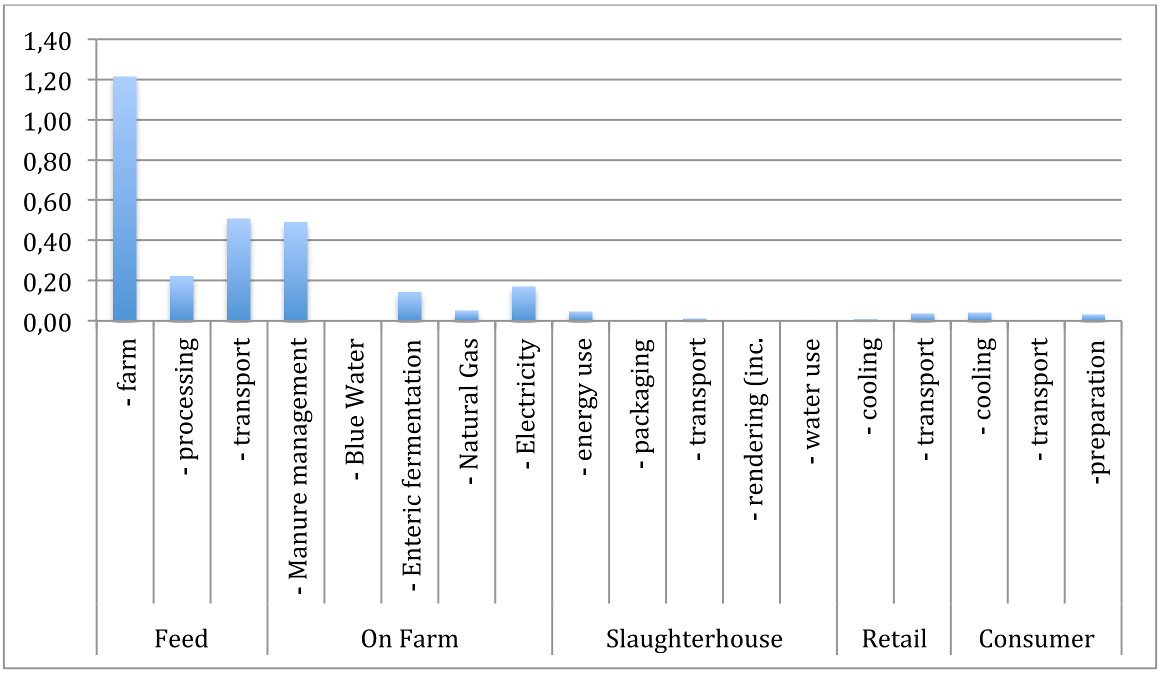

Figure 13: GWP for the global pork production system, detailed with contributions in different production steps (GWP in CO_2 eq./kg carcass weight).

Table 10: Environmental impacts per kg carcass weight for the global pork production system.

	Global Warming Potential ($kg\ CO_2$)	Fossil Energy use (MJ)	Land Use (m^2)	Eutrophication Potential ($g\ PO_4^{2-}$)	Water se (litre)
Feed	1.94	17.53	6.52	23.98	3240

On Farm	0.85	4.75	0	7.11	4
Slaughterhouse	0.06	1.19	0	0	0.1
Retail	0.04	0.68	0	0	0
Consumer	0.07	1.47	0	0	0
Total	**2.97**	**25.66**	**6.52**	**31.09**	**3244**

Soy scenarios
Figure 14 shows the results of feeds with different shares of soy in the global case. A reduction in soy percentage, of the current 20% to 10%, results in a reduction of impacts. The impact category eutrophication shows the highest reduction, while global warming potential decreases only slightly.

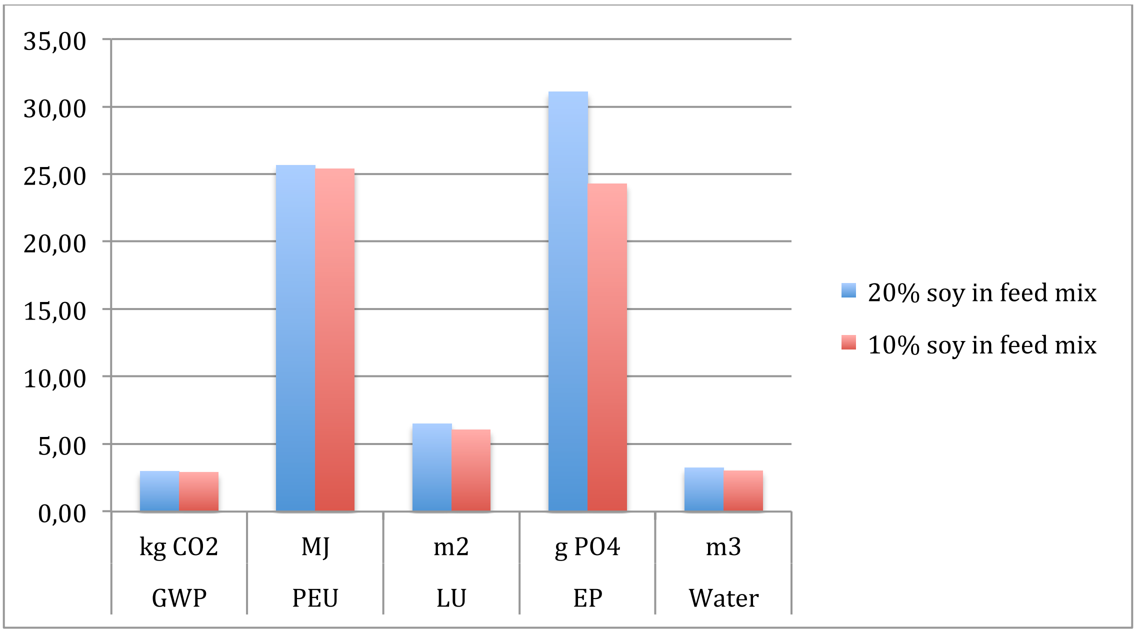

Figure 14: Environmental impacts compared for different percentages of soy in the feed mix of the global pork production system.

3.3.2
Semi-local pork production: De Hoeve

The results for the semi-local case De Hoeve are shown in the table and figures below. Although total impact is lower than in the global case, relative contribution of the different production stages is comparable. Feed production results in the largest contribution to the different impact categories. For global warming potential it is mainly the cultivation of feed (41% of GWP), and transport of the feed products and manure management on the farm (both 17% of GWP see Figure 15). And the farm stage contributes also in De Hoeve case considerable to the impact categories greenhouse gas emission, fossil energy use and eutrophication potential.

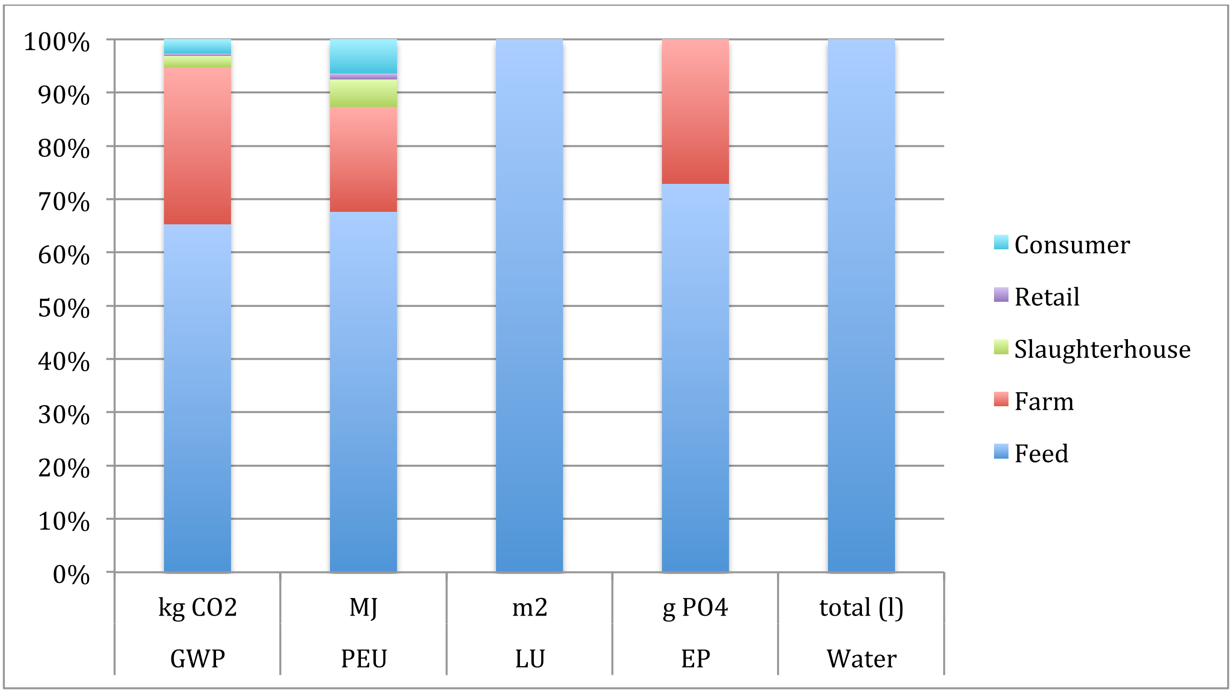

Figure 15: Environmental impacts for the semi-local pork production system.

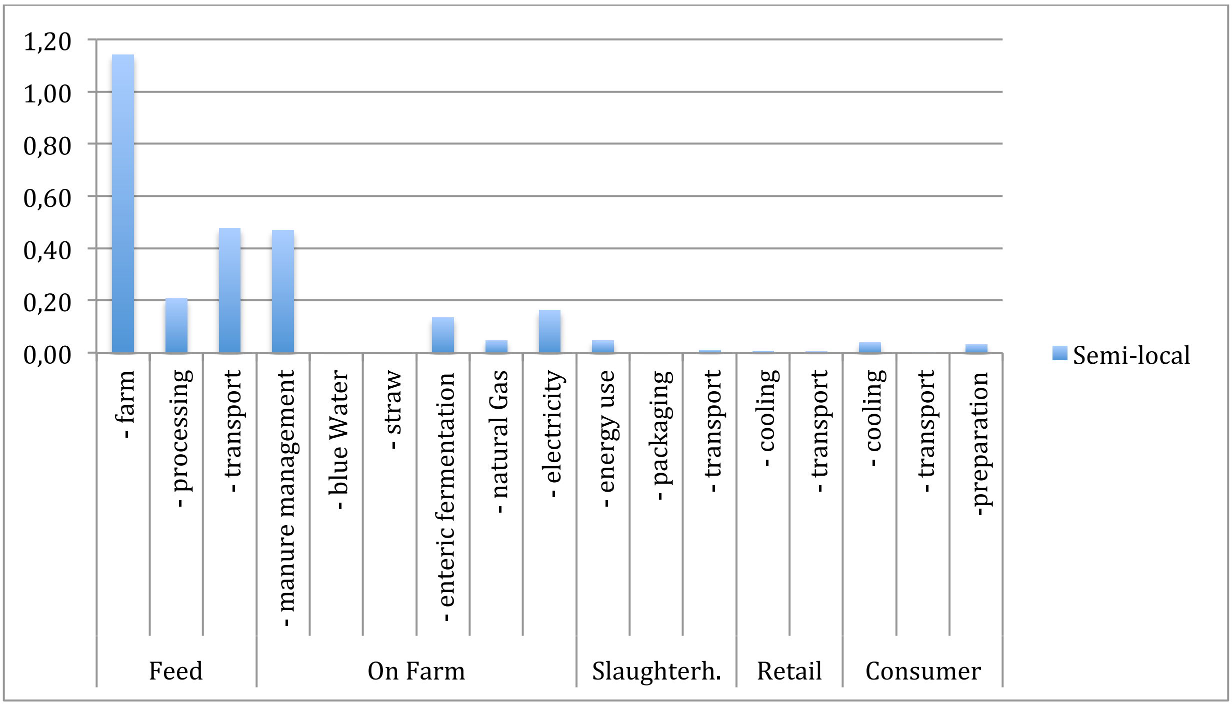

Figure 16: GWP for the semi-local pork production system per production step (kg CO_2 eq./kg carcass weight).

Table 11: Environmental impacts for the semi-local pork production system.

	GWP (kg CO_2)	PEU (MJ)	LU (m^2)	EP (g PO_4^{2-})	Water (litre)
Feed	1.82	15.75	5.25	18.95	2653
On Farm	0.82	4.59	0	2.83	4.35
Slaughterhouse	0.06	1.20	0	0	0.14
Retail	0.01	0.27	0	0	0
Consumer	0.07	1.47	0	0	0
Total	2.78	23.28	5.25	25.98	2657

3.3.3
Local pork production: Lupin

The Lupin case has the lowest impact in all five impact categories assessed. And although feed is also in this case the highest contributor for each impact category, its share differs somewhat in comparison with the other cases (see Figure 17). For global warming potential, the share of feed is lower due to a feed composition with a lower impact compared with the other cases. For fossil energy use the share of feed is somewhat higher even though the fossil energy use of feed is lower in comparison with the other cases. The reason for this is that in the Lupin case energy is produced on farm by co-digestion, which results in a very low fossil energy use in the farm stage, and consequential a higher share for feed. Furthermore, due to the use of biomass in the co-digester land is required to grow this biomass.

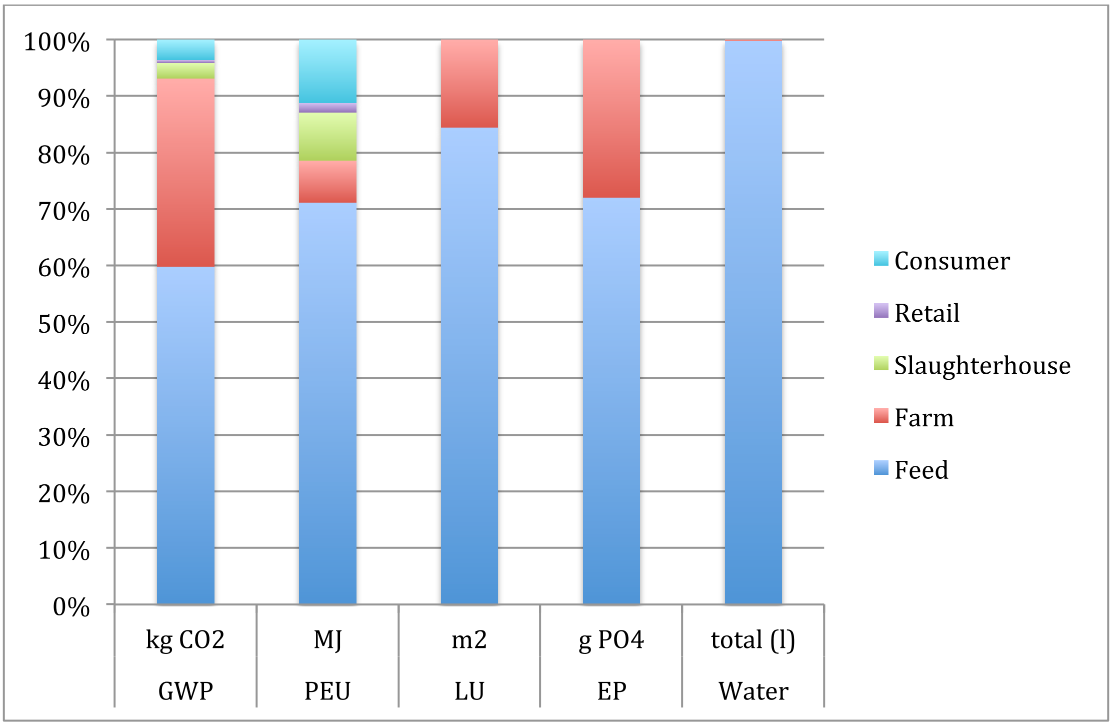

Figure 17: Environmental impacts for the local pork production system.

Table 12: Environmental impacts for the local pork production system.

	GWP (kg CO_2)	PEU (MJ)	LU (m^2)	EP (g PO_4^{2-})	Water (litre)
Feed	1.23	9.37	3.58	13.27	1912
On Farm	0.67	0.9	0.66	5.13	4.89
Slaughterhouse	0.06	1.12	0	0	0.13
Retail	0.01	0.23	0	0	0
Consumer	0.07	1.47	0	0	0
Total	2.04	13.17	4.24	18.40	1917

Wet and dry feed scenario

Figure 18 shows the results LCA for the wet and dry feed scenario for the local pork production chain. The dry feed scenario results in an increase in environmental impacts assessed. This increase is not just the result of drying and pelleting of feed ingredients but is mainly because of a different feed composition.

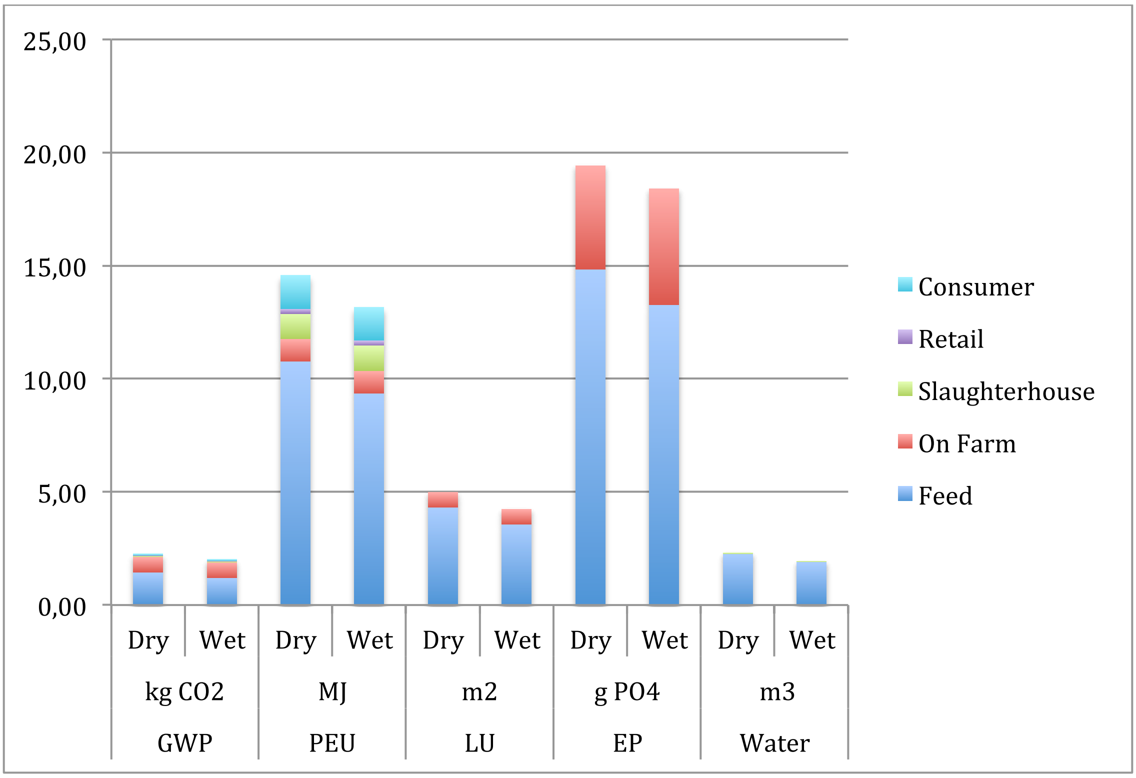

Figure 18: Comparing environmental impacts for wet and dry feed scenario in the local pork production system.

4

Conclusions & Discussion

4.1
Differences between the 3 Dutch pork production systems

When assessing environmental impacts for pork production systems, a general conclusion is that the impact in the feed production stage is dominant for all 5 impact categories in this assessment, see Figure 19 and Figure 20. Differences between the pork production systems are due to on farm feed cultivation and biomass production for bioenergy replacing electricity in the local pork production chain. Visual in Figure 19, as for the local pork production system there is more land use in the on farm production stage. In Figure 20, it is clear that the local pork production system has lower environmental impacts, for all 5 categories assessed. The differences are large for fossil energy use, global warming potential and land use and water.

The main difference between the three products is caused by the choice of feed products. The feed mixture in the global pork production system contains soybean originating from Brazil and Argentina and tapioca from Thailand. In the local pork production system, pigs are fed on a feed mix consisting residual products from food industry and locally cultivated food products. The feed mix of the semi-local production system is also global oriented but contains more local products than the global pork production system. Transport of feed products is an important factor in global warming potential and fossil energy use. Also cultivation of feed products is lower in the local system, obviously due to use of local feed products (no transport) and residual feed products (about 13% of wet feed mix).

Another difference is that the energy delivered at the farm of the lupine pigs is coming from co-digestion. The overall impact of energy to the environment is therefore lower. However, the co-digester is fed not only with manure but also with other products. This results in higher land use in the on farm production stage for the local systems. However, the total land use in the local system is still lower than in the other systems.

In the global pork production system transport is obviously larger than for the other systems. In the global system the contribution of transport to total fossil energy use is 31%, for the semi-local system this is 28% and for the local case only 15%. Transport for feed products is the lion share; 28% of fossil energy use in the global pork production system.

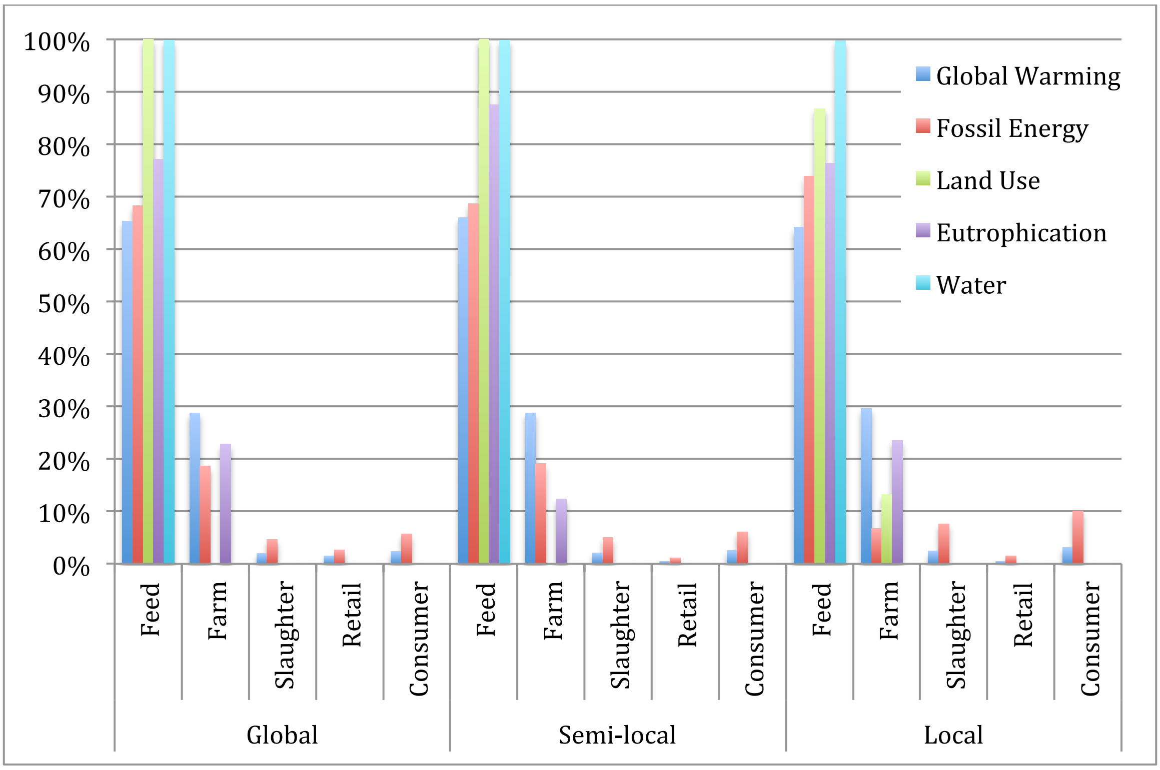

Figure 19: Contribution of different production stages to environmental impacts for the 3 different pork production systems in percentage.

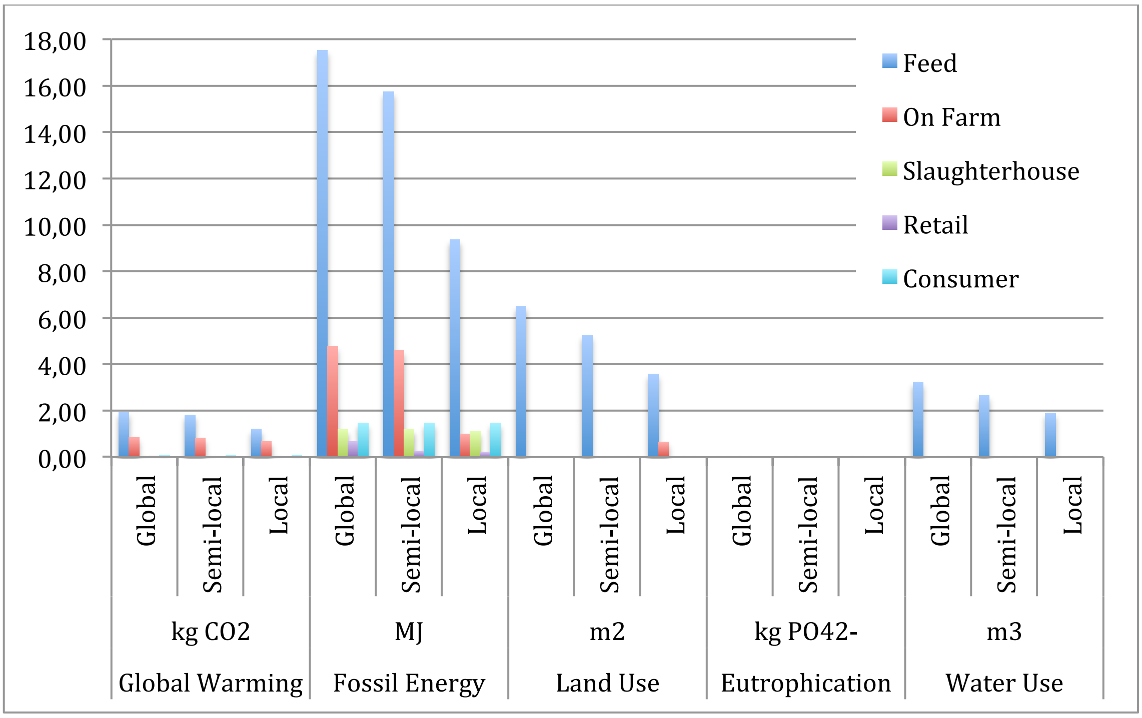

Figure 20: Environmental impacts assesses for the production steps for the 3 different cases in absolute values.

4.2
Comparison with data Italian pork LCA in GLAMUR

This assessment is part of the European project on Global and Local food assessment (GLAMUR) within this project the comparison of the Dutch pork LCA with the Italian is one of the objectives. The main difference between the Dutch (Global, Semi-local and Local) and the Italian (Cinta Senses and Parma and Generic = Dutch Global case) cases is the different length in period that the pigs are on the farm. In the Dutch cases the pigs are kept at the farm for 6 months while the Italian Cinta Senese pigs are kept 15 months and the Parma pigs 9 months. As shown by the results of the LCA the feed given to the pigs, has a major impact. There are differences in diet in the different cases influencing the LCA results, and of course the longer the pigs stay at the farm the longer they are fed. Another difference is in how the pigs are kept. Pigs can be kept in stables as in the Global case called Italian Parma and Dutch VION case. The Dutch VION case is the same as the Italian Light pig or Generic Case as the pork is imported. Pigs can also be kept (partly) outdoors as for instance in the Dutch Local (Lupin) case and in the case of Italian Cinta Senese pigs that live in the forest. This influences land use, feed, and manure management.

Figure 21 gives an overview of LCA results for the different cases (see also Table 13). As expected, land use is highest for the Cinta Senese pigs that live in the forest. Since the forest is marginal the total area is allocated to be pig farming only. The fact that also fossil energy use and global warming potential are quite high for this case, although higher for Parma pigs, is probably due to imported feed combined with the longer period that the pigs stay on the farm. The low energy use for the local case Lupine is due to local feed production and the use of on farm produced bioenergy. Water use is highest for the Global VION case, in all Dutch cases water use for feed production (2 m^3 for the local case and 3 m^3 for the global case), as it is much higher than water used for pig farming (0.004 and 0.005 m^3). Looking at eutrophication, see Figure 22, it is remarkable that both Cinta Senese and Parma pigs have a higher eutrophication potential, this is caused by longer stay at the farm and to a lesser extend due to manure management. In the Dutch LCA results the eutrophication potential is the highest for feed production (13-15 g PO_4^{2-}), and much less for the pig farming (5 -7 g PO_4^{2-}).

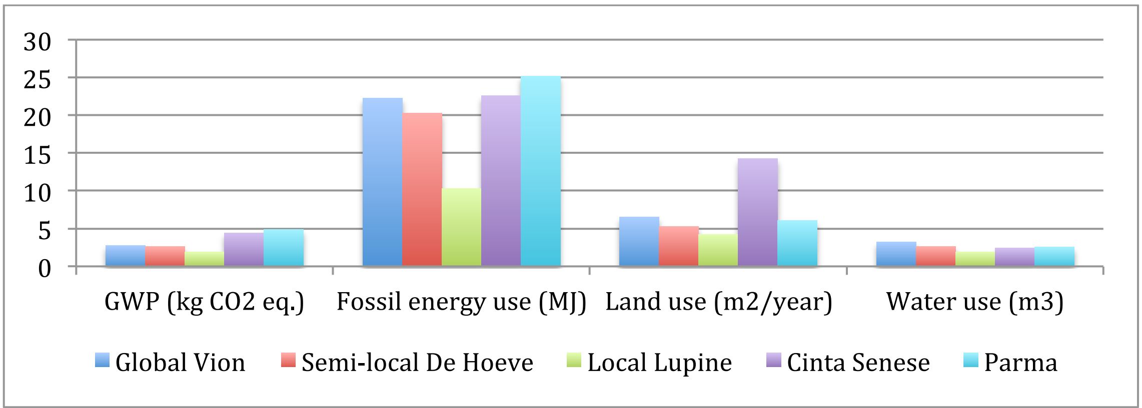

Figure 21: Comparing the Dutch an Italian GLAMUR pork LCA based on the functional unit kg carcass weight at farm gate.

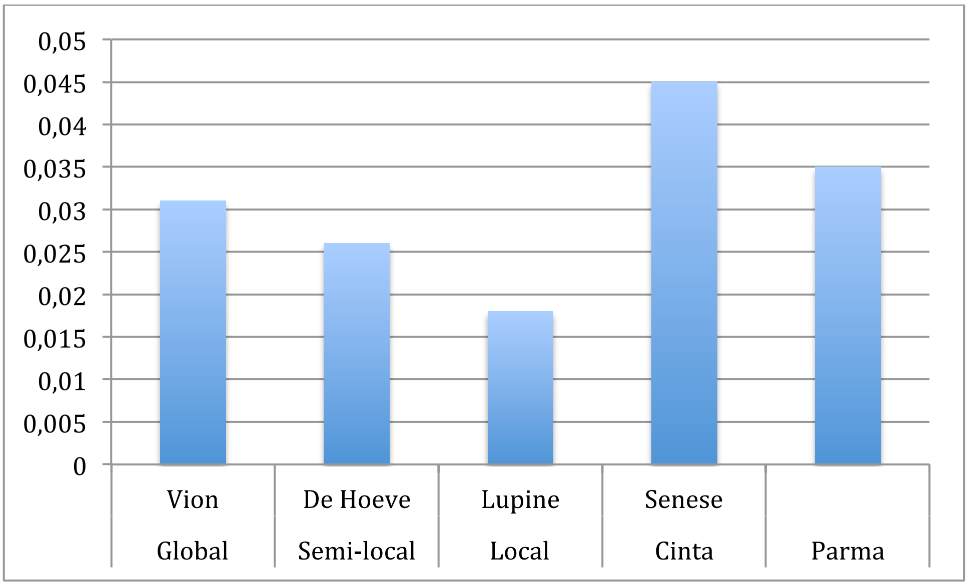

Figure 22: Comparing Eutrophication Potential (kg PO_4^{2-} equivalent) for Dutch and Italian GLAMUR LCA cases, based on the functional unit kg carcass weight at farm gate.

Table 13: Comparing Dutch and Italian LCA data for the pork at farm gate.

	Dutch Pork			Italian Pork	
Functional unit	*kg carcass weight at farm gate*			*kg carcass weight at farm gate*	
	Global VION	**Semi-local De Hoeve**	**Local Lupine**	**Cinta Senese pig**	**Parma Pig**
GWP (kg CO_2 eq.)	2.8	2.7	1.9	4.4	4.9
Fossil energy use (MJ)	22	20	10	23	25
EP (kg PO_4^{2-})	0.03	0.03	0.02	0.03	0.04
Land use (m^2/year)	6.5	5.3	4.2	11	6.1
Water use (m^3)	3.2	2.7	1.9	2.4	2.6
Breeding cycle (months)	6	6	6	15	9
Remarks	*Including the Feed and On Farm pork production stages.*			*The original FU was live weight. This is converted for comparison to carcass weight assuming carcass weight is 80% of the live weight, by multiplying impacts by 1.25.*	

Table 14: Comparison of the 5 cases on environmental impacts in the Feed and the On Farm phase.

		Global	Dutch Cases		Italian Cases	
		Global Vion	Semi-local De Hoeve	Local Lupine	Cinta Senese	Parma
Feed	**GWP** (kg CO_2 eq.)	1.9	1.8	1.2	2.5	3.0
	Fossil energy use (MJ)	18	16	9.4	21	21
	Land use (m^2/year)	6.5	5.3	3.6	11	6.1
	Water use (m^3)	3.2	2.7	1.9	2.3	2.2
	EP (kg PO_4^{2-})	0.02	0.02	0.01	0.03	0.03
On Farm	**GWP** (kg CO_2 eq.)	0.85	0.8	0.7	1.9	1.9
	Fossil energy use (MJ)	4.8	4.5	1,0	2.1	4.5
	Land use (m^2/year)	0.00	0.00	0.7	0.01	0.0
	Water use (m^3)	0.00	0.00	0.01	0.1	0.04
	EP (kg PO_4^{2-})	0.01	0.01	0.00	0.00	0.01

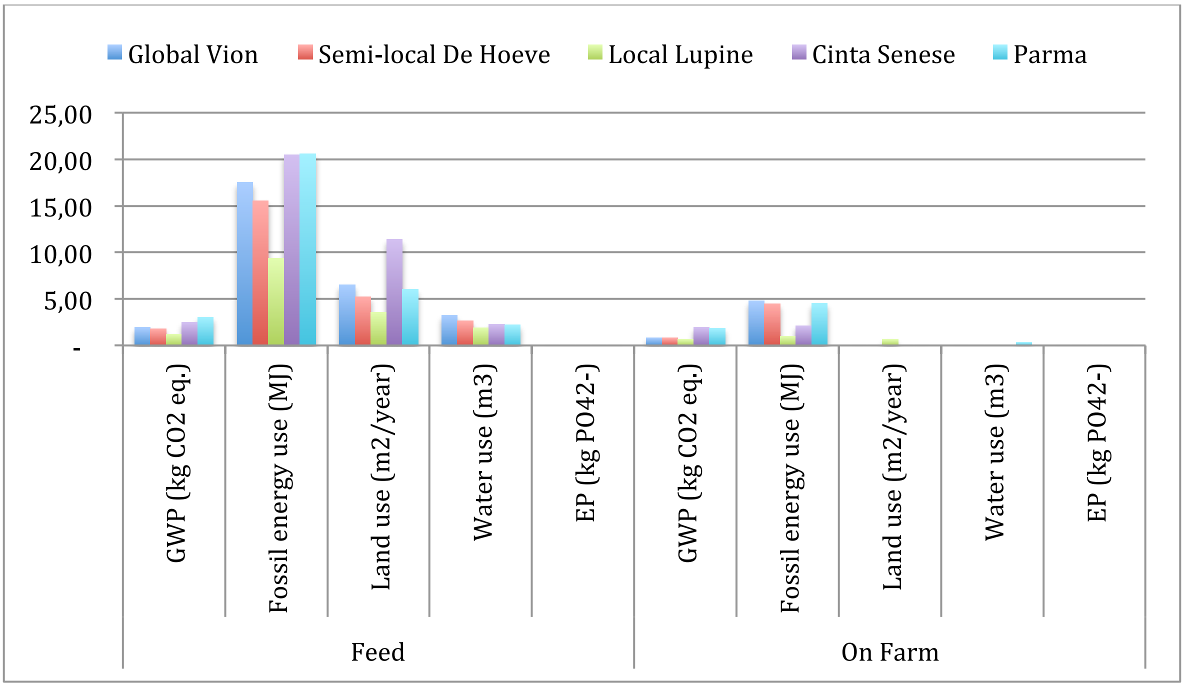

Figure 23: Comparing environmental impacts of the Feed and On Farm phase for all 5 cases, per kg carcass weight.

4.3 Discussion: comparing results with other LCAs on pork

In this paragraph the results of this study are compared with findings reported in literature. The GWP calculated in this assessment range between 2 kg CO_2 eq./kg carcass weight for the local pork production system and 3 kg CO_2 eq./kg carcass weight for the global pork production system. This is low compared to all findings in the literature listed below, ranging between 3 and 10 kg CO_2 eq./kg carcass weight. Converted to impact per kg meat consumed, which is often used in LCA, the GWP is 3 for the local pork production system and 5 kg CO_2 eq./kg meat consumed for the global pork production system (Lap 2014). This is similar to another Dutch LCA by Blonk at al. (2008), reporting 4.5 kg CO_2 eq./kg carcass weight. The literature data are summarized in Appendix 3 in Table 21: Published LCA Pork data.

Kool et al. (2013), wrote a memo to explain the differences in carbon footprint of Danish pork production reported by **Nguyen et al 2011**, which was 3.1 to 3.4 kg CO_2 eq./kg carcass weight and the 5.0 kg CO_2 eq./kg carcass weight, reported by **Leip et al. 2010**. Kool et al. (2013, p.9), concluded that in the N_2O emissions calculated with the CAPRI model need to be corrected in the JRC study (Leip et al., 2010). Furthermore, statistical data used as input in the calculation of this study resulted in a three times higher than expected N excretion.

Kool et al. (2014) conclude that the fossil energy use in the pig production chain in the Netherlands is reduced by 33% between 1990 and 2012, from 50 PJ to 34 PJ (p.5). The emission of greenhouse gasses was decreased by 17% in the same period. When all byproducts are included it was even 26%. According to Kool et al. 2013, the Dutch pork production uses les fossil energy than the Danish pork production, namely 25%. Although the emission of greenhouse gases is higher compared to Denmark. German pork production has a fossil energy use similar to the Dutch system and a lower greenhouse gas emission.

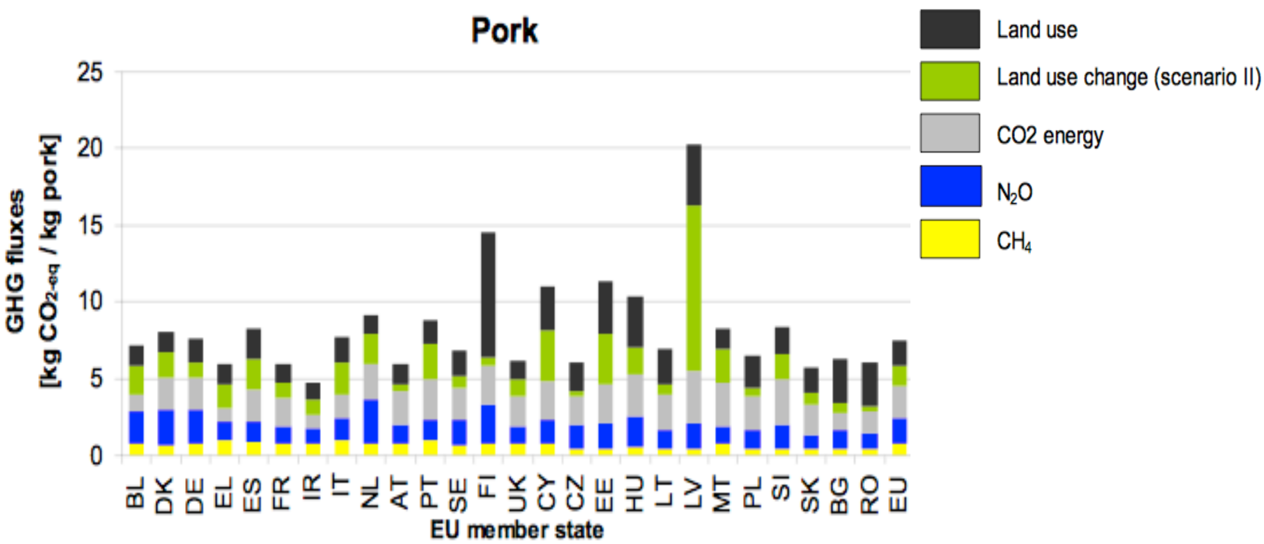

Figure 24: Greenhouse gas emissions in pork production in European countries in 2004 (source Leip et al. 2010, p.30).

Leip et al (2010, p.171) report an average global warming potential over the EU-27 countries of 7.5 kg CO_2 eq./kg pork (see figure). Note that only 0.74 kg (10%) of total GHG fluxes comes from methane, 1.7 kg (23%) from N_2O, but 4.1 kg (67%) from CO_2. Total emissions of pork production in the EU-27 amount to 165 Mio tons of CO_2-eq, which is around 86% of the total emissions from beef production within the EU-27. Among EU member states the lowest emitting countries (on a per kg basis) are Ireland (4.8 kg) and Greece (5.9 kg), while the highest emission factors can be observed in Latvia (20.3 kg) and Finland (14.5 kg). On regional level emissions per kg of pork range from 4.7 kg CO_2-eq per kg of pork in the Irish region "Southern and Eastern" to 20.3 kg in Latvia, which is not subdivided in NUTS2 regions. The variation of emissions is largest for CO_2-emissions, especially for emissions from land use and land use change, since intensive pork production systems apply diets with high shares of feed concentrates frequently imported from overseas.

Kingston et al. (2009) performed a scoping life cycle assessment on of pork production in Britain, comparing indoor versus outdoor-bred pig, compound versus liquid fed pigs, and slatted floor versus loose bedding. The reported impact on climate change is 8.8 to 9.8 kg CO_2 eq./kg pork consumed and the Eutrophication potential 0.057 to 0.1 kg PO_4^{2-} eq./kg pork consumed (Kingston et al., 2009). Kingston et al. (2009, p.31) list for their own findings Global Warming potentials ranging from 4.1 to 5.7 kg CO_2 eq./kg carcass weight, the lowest GWP is for indoor, slatted flooring, liquid feed and anaerobic digestion. The highest GWP is calculated for systems with either indoor or outdoor-bred pigs with loose bedding, due to the application of the manure on the land (p.18). Kingston et al. (2009, p.31) also list data from other studies ranging from 2.6 (Sweden, Cederberg and Flysjo 2004) to 5.6 kg CO_2 eq./kg carcass weight (Britain, Cranfield study William et al. 2006). Kingston et al (2009, p.11) conclude that almost ¾ of the carbon foot print occurs in feed production and pig farming. Pig feed contributes to 56% of the carbon footprint (p.12). Storage and preparation of pig meat accounts according to Kingston at al. (2009) for 20% of the carbon footprint. Application of manure of slurry to land contributes to 53% of the Eutrophication potential (p.14), pig feed accounts for 31% of the eutrophication potential. (p.14).

Table 15: Environmental impact British pork by Kingston et al. (2009, Table 4.1, p.28)

Environmental profile of British pork production (1 kg consumed)

	Climate change	Eutrophication	Acidification	Abiotic resource depletion
	kg CO_2 eq	kg PO_4^{3-} eq	kg SO_2 eq	kg Sb eq
BPEX, indoor, fully slatted	8.6	0.057	0.19	0.053
BPEX, indoor, loose bedding	9.8	0.10	0.38	0.052
BPEX, outdoor bred, loose bedding	9.8	0.095	0.33	0.054

Blonk et al. (2008, Table 3.1, p.16), report for pig meat a global warming potential of 4.5 kg CO_2 eq./kg sold in retail and a fossil energy use of 38.3 MJ/kg and land use of 7.7 m^2/kg, relatively low compared to beef and high compared to chicken and insects. Blonk et al. (2009, p.17) also conclude that cultivation and transport of feed products as well as fertiliser use and manure management are the dominant factors in global warming and fossil energy use.

4.4 Final Conclusions

Overall conclusions are that the LCA results show that the environmental impacts are highest in the feed production phase (see Table 14 and Figure 23). The local Lupin case scores the lowest in all 5 impact categories assessed. The lower scores on land use, GWP, fossil energy use for the Local case Lupin result from local feed production and the use of on farm produced biofuel. In global cases energy use and global warming are determined by feed production (both cultivation and transport). The slightly higher GWP for the Italian cases is due to the much longer breeding periods (9 and 15 months compared to 6 months in the Dutch cases). Furthermore, the higher score on land use of the Cinta Senese pigs is mainly due to living in the marginal forest.

It is difficult to compare the results found in this LCA with data from literature, as decisive factors such as the feed and breeding period are not always reported similarly. Furthermore, reflection on outcomes also depends on local situations. Water use for feed production may occur in water scares areas, while these feed products are exported to water rich areas like the Netherlands. Land use is another impact category that needs reflection in local context. Dutch farming is very intensive; large amounts of meat are produced for export in a highly populated area where land area is relatively scares. At the same time manure is abundant in the Netherlands and regulated by law, not reflecting the values of the nutrients. In Italy different local circumstances lead to different choices such as keeping Cinta Sense pigs in marginal forest and the production of traditional high-end quality products.

Furthermore, LCA results should be reflected on in a wider scope of the research including other dimensions of pork production as environmental impacts are just one of multiple aspects in decision taking. Other economic and socio-cultural aspects are important as well, for instance animal welfare, healthily food production, income and pricing, etc.

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Appendices

Appendix 1: LCA results described per impact category

In this paragraph the results per impact category are presented, in paragraph 3.3 starting on page 23, the outcomes are discussed per case.

Global Warming Potential

The Global Warming Potential (GWP) is shown for the different production stages for the 3 different cases in Figure 25 (and Table 16 in the appendix 2). The feed production stage has the highest contribution to the GWP in all three cases (65%, 65%, and 60% respectively), followed by the farm stage (29%, 29%, and 33% respectively). The slaughterhouse, retail and consumer stage have a relatively low contribution to the GWP. The contribution of transport to GWP is 19% for the global, 18% for the semi-local and 7% for the local pork production system. In transport the lion share is transport of feed products, 17% GWP is the result of transporting feed products in the global pork production system.

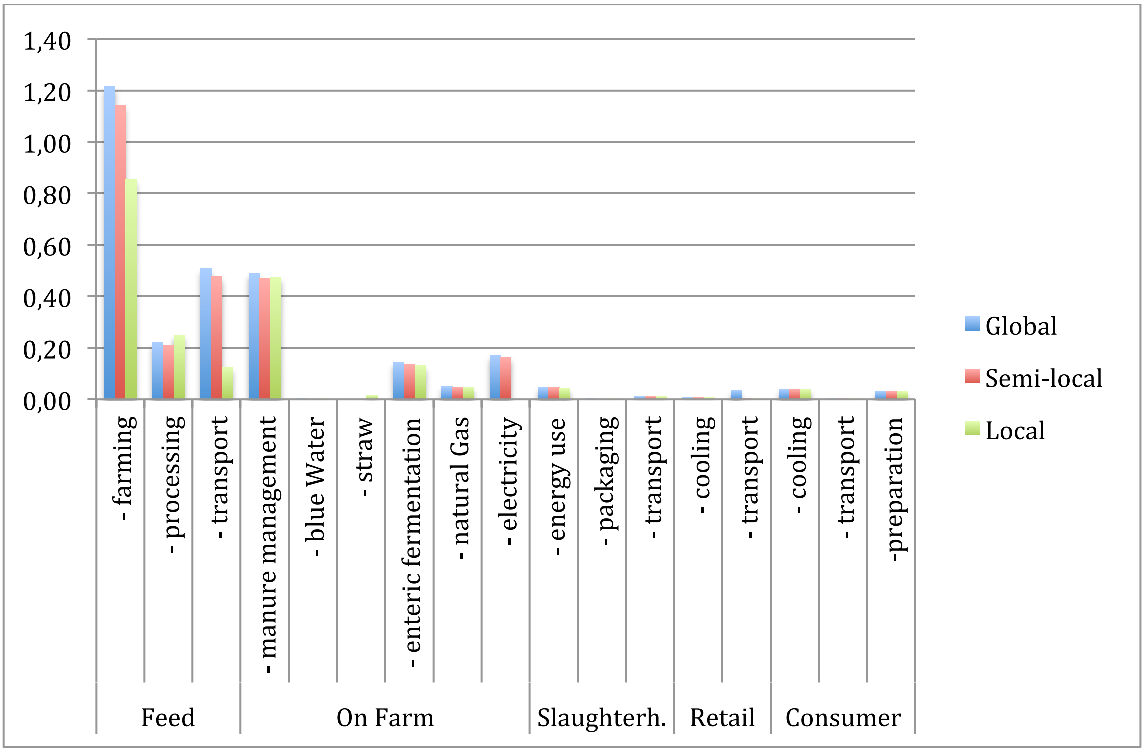

Figure 25: Global Warming Potential for the three different cases in CO_2 eq./kg carcass weight.

In comparing the cases, De Hoeve has slightly lower GWP than VION, mainly due to lower emissions in the feed production stage. The Lupine case shows the best results. This is due to:

- In the Lupine case potatoes peels, brewery waste silage and whey are used as feed products (13% of wet feed mix). These products are residual products with no or very low economical value. Due to that, the global warming is allocated to the main product and not to the potatoes peels, brewery waste silage and whey. The GWP for farming feed is for the local case 0.85, for the semi-local 1.14 and for the global case 1.23 (kg CO_2/ kg carcass weight).
- Less transport of feed, because the feed is partly produced on the farm, 0.12 (kg CO_2/ kg carcass weight) for feed transport compared to 0.51 and 0.48 in the global and semi-local.

- No emissions due to the use of electricity, because of the production of biogas at the farm. While in the global and semi-local case the GWP for electricity on the farm is 0.17 and 0.16 (kg CO_2/ kg carcass weight). Note that the co-digestion does emit a certain amount of carbon dioxide due to the burning of biogas, but this the same carbon dioxide taken up by plants. Because this carbon is short-cyclic it is not taken into account in LCA, this is common for co-digestion as it is seen as a renewable source of energy. Energy use for cultivation of the products for co-digestion and the processing of feed, however, is included in the LCA.

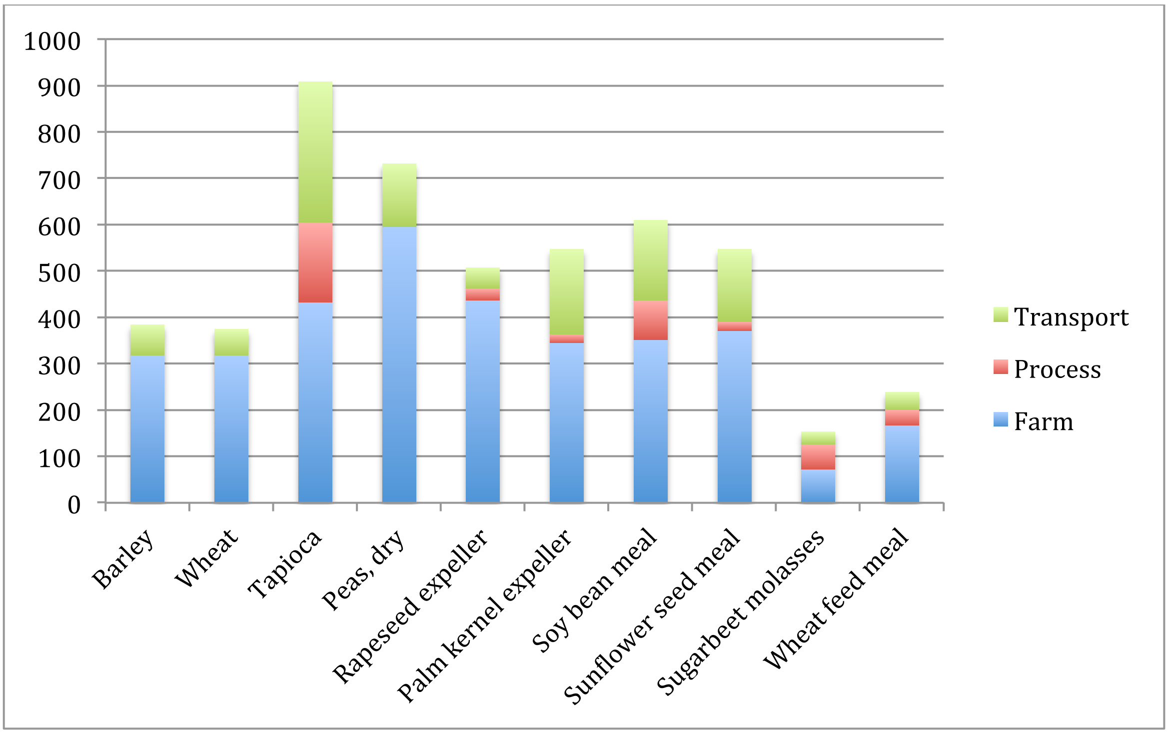

Figure 26: Global warming potential of different feed products (kg CO_2 eq./kg feed).

Fossil energy use

The most energy is used in the feed production stage (68, 68, and 71% respectively), followed by the farm stage (19, 20, and 8% respectively).

For the global case, VION, the fossil energy use is the highest (see Figure 27). This is mainly due to the feed production stage, in which farming (27% of total PEU) and transport (17% of total PEU) score higher than in the two other cases. Fossil energy use in farming in the feed production: is 7, 7, and 4 MJ/kg carcass weight for the 3 systems respectively and transport feed products is 7, 6 and 2 MJ/kg carcass weight respectively. The low fossil energy use in the local production system, Lupin, is mainly due to the feed sources used, furthermore the biogas is used instead of fossil energy in the on farm stage. In the local case the fossil energy use for electricity in the on farm stage is 0, compared with 3.87 and 3.72 MJ/kg carcass weight for the global and semi-local cases respectively.

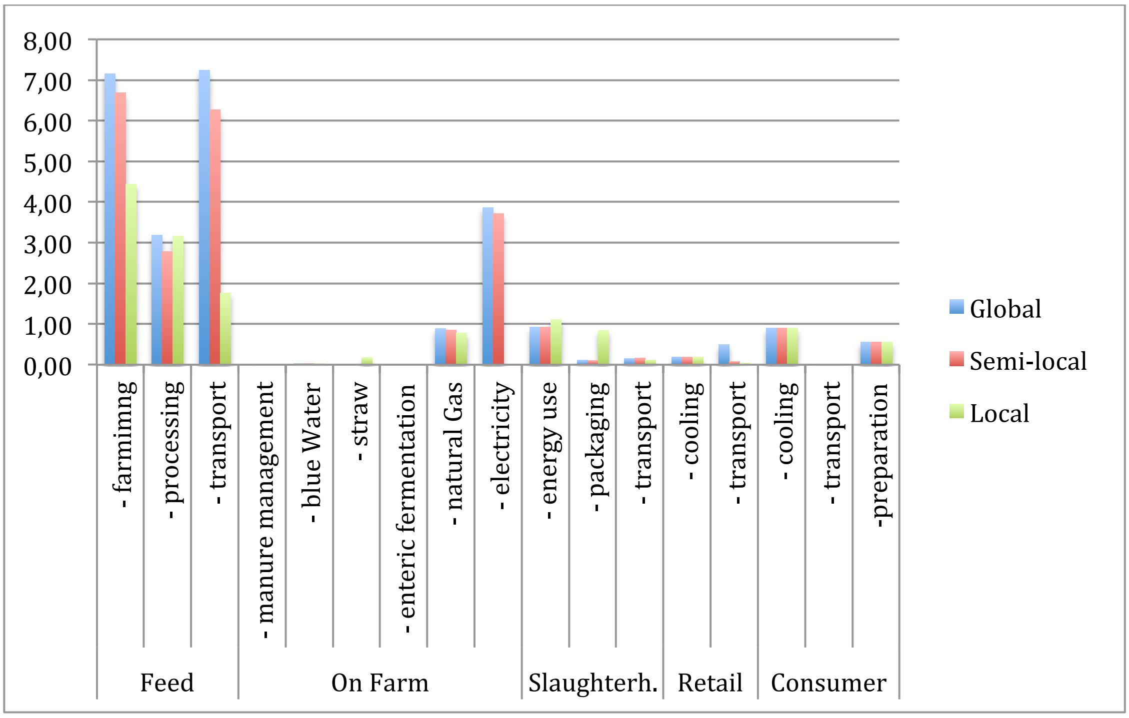

Figure 27: Fossil energy use for the different cases (PEU in MJ/kg carcass weight).

Land use

Land use is the land needed for feed production and in the local production system, Lupin, land is also needed for the production of maize for co-digestion (=0.66 m²/kg carcass weight). Still, the land use per kg carcass weight is lowest in the local pork production system, as the land use in the feed production for this case is much lower. Residual products such as potatoes peels, brewery waste silage and whey are used as feed products in the local production system. Due to that, the land use for these residual food products is allocated to the main product and no land use is assigned to the residues, being potatoes peels, brewery waste silage and whey. These residual products make up 13% of the wet feed products for the local pork production system.

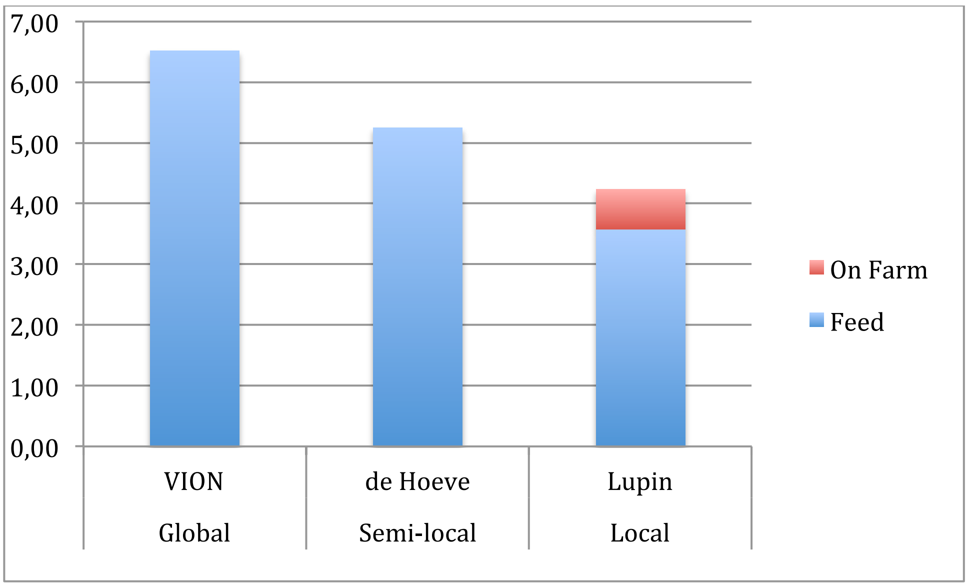

Figure 28: Land use for the 3 different cases in m²/y/kg carcass weight.

Water use

Water use per kg carcass weight is relatively low in the local case, the Lupin case. This is due to the feed composition. Soy bean, tapioca, and sunflower seed feed products have higher water needs per kilogram than other feed products such as grains and lupin. Soy, tapioca and sunflower are relatively large in the feed mix of the global case and smaller part in semi-local case and absent in the feed mix of the local case. Furthermore, the feed mix of the local case uses residual products, which lowers the water use even further. For details on the feed composition see the tables on the feed compositions in paragraph 3.1.3 on page 21.

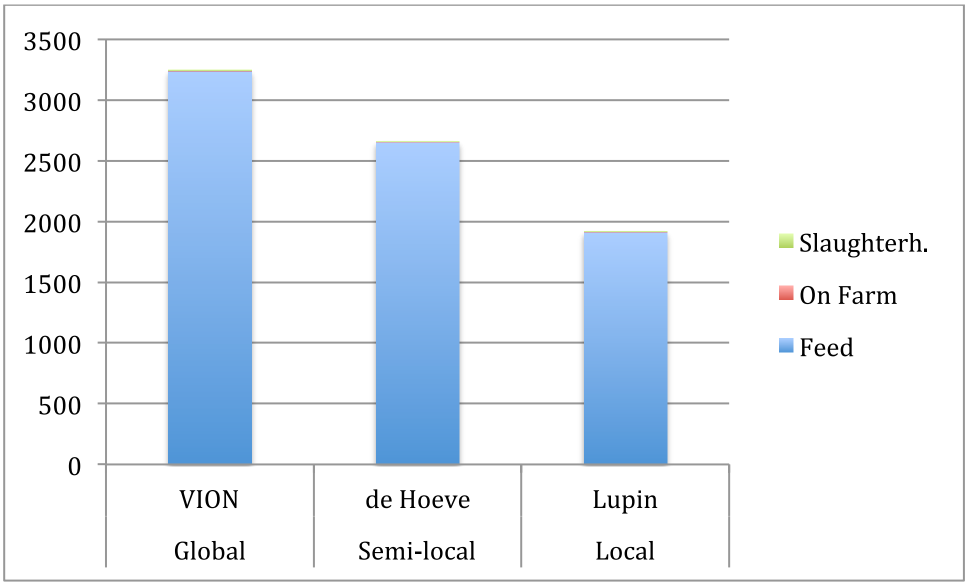

Figure 29: Water use for the 3 different cases in litres / kg carcass weight.

Eutrophication potential

Fout! Verwijzingsbron niet gevonden. shows the eutrophication potential of the 3 cases. Eutrophication occurs predominantly in the feed production stage due to use and emissions of nutrients, 77, 73 and 72% respectively. Smaller emissions are due to N-emissions (ammonia, NO_x) on farm through manure management and enteric fermentation, together 23, 27 and 28% respectively. As in the other impact categories, differences in feed composition explain the differences between the cases.

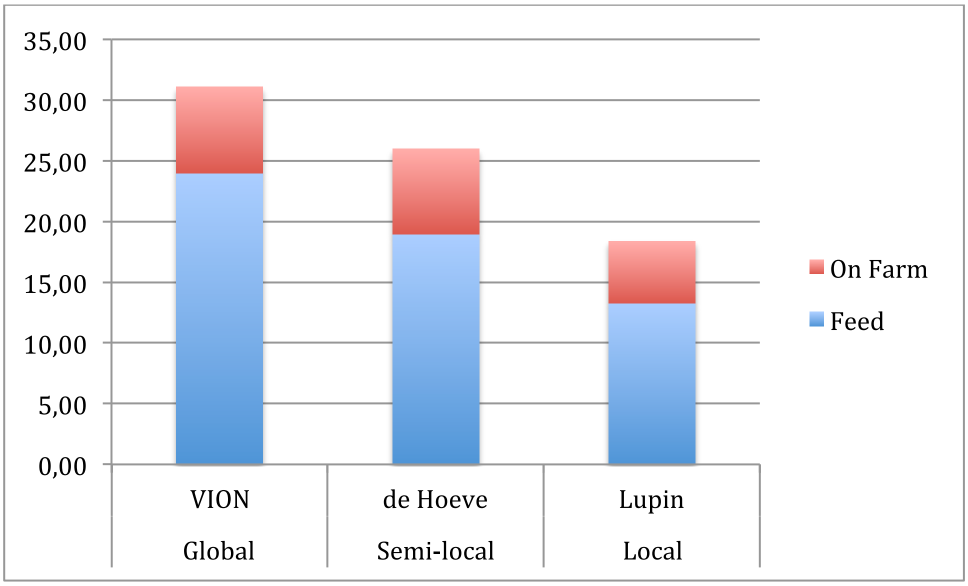

Figure 30: Eutrophication potential in g PO_4^{2-} eq./kg carcass weight.

Appendix 2: LCA results in tables per impact category

Table 16: Global Warming Potential.

Global Warming Potential (kg CO_2/ kg carcass weight)			
	VION Global	**De Hoeve Semi-local**	**Lupin Local**
Feed	1.94	1.82	1.23
On Farm	0.85	0.82	0.67
Slaughterhouse	0.06	0.06	0.06
Retail	0.04	0.01	0.01
Consumer	0.07	0.07	0.07
Total	**2.97**	**2.78**	**2.04**

Table 17: Fossil energy use for the different cases.

Fossil energy use (MJ/ kg carcass weight)			
	VION Global	**De Hoeve Semi-Local**	**Lupin Local**
Feed	17.53	15.75	9.37
On Farm	4.78	4.59	0.99
Slaughterhouse	1.19	1.20	1.12
Retail	0.68	0.27	0.23
Consumer	1.47	1.47	1.47
Total	**25.66**	**23.28**	**13.17**

Table 18: Land use for the different cases.

Land use (m^2 / kg carcass weight)			
	VION Global	**De Hoeve Semi-local**	**Lupin Local**
Feed	6.52	5.25	3.58
On Farm	0.00	0.00	0.66
Slaughterhouse	0.00	0.00	0.00
Retail	0.00	0.00	0.00
Consumer	0.00	0.00	0.00
Total	**6.52**	**5.25**	**4.24**

Table 19: Water use for the different cases.

Water use (litre/kg carcass weight)			
	VION Global	**De Hoeve Semi-local**	**Lupin Local**
Feed	3240	2653	1912
On Farm	4.35	4.35	4.89
Slaughterhouse	0.14	0.14	0.13
Retail	0.00	0.00	0.00
Consumer	0.00	0.00	0.00
Total	**3244**	**2657**	**1917**

Table 20: Eutrophication potential for the different cases.

Eutrophication potential ($g\ PO_4^{2-}$ eq /kg carcass weight)			
	VION Global	**De Hoeve Semi-local**	**Lupin Local**
Feed	23.98	18.95	13.27
On Farm	7.11	7.03	4.89
Slaughterhouse	0.00	0.00	0.00
Retail	0.00	0.00	0.00
Consumer	0.00	0.00	0.00
Total	**31.09**	**25.98**	**18.40**

Appendix 3: Table of LCA Pork data from literature

Table 21: Published LCA Pork data.

Functional unit	*kg slaughter weight at farm gate*					*kg live weight at farm gate*				*kg protein*	*kg meat sold in retail*
	Dutch cases	**Kingston et al. 2009**	**Leipp et al. 2010**	**Nguyen et al. 2011**	**Williams et al. 2006**	**Italian cases**	**Basset-Mens Werf 2005**	**Blonk et al. 2009**	**Dourmad et al. 2014**	**Zhu-XueQin et al. 2004**	**Blonk et al. 2008**
GWP (kg CO_2 eq.)	1.9 - 2.8	8.6 – 9.8	5.0	3.1 -3.4	6.1 - 6.4	3.6 - 3.9	2.3 - 3.5	3.7	2.3 - 3.5	23,00	4.5
Energy use (MJ)	10 - 22				0.02	18 - 20	16 - 18	16	16 - 14	397,000	38.8
EP (kg PO_4^{2-})	0.03	0.06 – 0.1			0.1	0.03	0.02	0.02	0.02 - 0.03		
Land use (m^2/year)	4.2 - 6.5				6.9 - 7.5	4.8 - 9.1	5.4 - 6.3	-	4.1 - 11	55,000	7.7
Water use (m^3)	2.7 - 3.2				-	1.9 - 2.1	-	-	-		-
Remark	*Comparing global and local supply chains*	*¾ of carbon foot print in feed! Differents stables and beddings in UK*	*Danish pork*	*Danish pork*	*Four different supply chains in UK*	*Comparing Cintia Senese and Parma pigs*					*Comparing different food products*