Comparative LCA of Pork Production for Midland Pig Producers

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Executive Summary

The Earth’s climate is changing, with a scientific consensus that global warming is a serious threat to our planet, and that human activity especially from the release of Green House Gases (GHG) from the burning of fossil fuels is the principle cause1. The UK government has now set a national target to reduce all greenhouse gas emissions by 80% by 20502. In the meantime, the world population is increasing rapidly and set to pass 8 billion by 2030. As a result, a range of solutions is needed if the world population is to be fed equitably and sustainably i.e. adapting to climate change and mitigating other severe environmental impacts including respects to animal welfare3.

Within this context, Midland Pig Producers (MPP) is planning to develop a groundbreaking new farm at Foston (Derbyshire, UK). The farm will draw on best practice standards from around the world, uniquely combining them into a site which will aim to be self-sustaining, reduce food production GHG emissions by increasing production efficiency and improve the resilience of the farming industry by mitigating external factors such as volatile weather, yields and food prices while respecting animal welfare best practices.

As part of its environmental commitments, MPP commissioned Sustain Ltd to carry out a comparative study of the main environmental impacts of producing pig meat at the planned Foston farm and a defined (following BPEX and DEFRA guidelines) typical outdoor breeding farm (or comparison farm) where the sows and weaners live outdoors. In this system the finishing and fattening stages occur indoors. The Foston farm is an indoor breeding system.

The new farm at Foston will follow a large scale sustainable model, which will include locally grown or bought in animal feed, anaerobic and bio-gas digesters, water efficiency measures, recycling of most materials and an aim for nitrate neutrality. The project is well aligned with the UK current national, regional and sectoral policies on climate change mitigation, waste reduction and renewable energy generation.

The study followed a Life Cycle Assessment (LCA, ISO 14040) approach. The approach takes a systematic view of the supply chain from raw material extraction through to the final disposal of the product. This approach crucially prevents decisions being made which may shift the environmental burden up and down the supply chain. LCA takes a systems perspective and can quantify multiple environmental categories.

A specific comparative model was created for the study to capture the GHG emissions over the life cycle phases of the pork production for the two farms. The model was built from BPEX figures, literature resources, DEFRA funded research, established Foston farm plans, discussions with MPP and Sustain previous relevant research work in the sector and available in the public domain.

The study compared the main environmental impacts of pig farming for the two farms namely:
- Global Warming Potential (GWP): GHG emissions and contribution to climate change
- Eutrophication: Damage to water resources such as lakes and rivers
- Acidification: Quality reduction of soil through its acidification

The results of the comparative study have been expressed per kg of pork produced (i.e. not per kg of pig) for the three main environmental impacts:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Foston Farm</th>
<th>Comparison Farm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Warming Potential (kg CO₂e)</td>
<td>2.2</td>
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<tr>
<td>Eutrophication Potential (kg PO₄e)</td>
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<td>0.0265</td>
</tr>
<tr>
<td>Acidification Potential (kg SO₂e)</td>
<td>0.0349</td>
<td>0.0523</td>
</tr>
</tbody>
</table>

1 Fourth Assessment Report, Intergovernmental Panel on Climate Change
2 UK Climate Change Bill, 28th October 2008
3 Professor Sir John Beddington, Chief Scientific Adviser to the UK Government, 2009
Key points:

• The nature of agricultural GHG emissions is very different from other sectors of the economy such as electricity generation, transport, manufacturing etc. The principal greenhouse gas for most industries is carbon dioxide (CO$_2$) from fossil fuel combustion, while for agricultural systems methane and nitrous oxide are the main GHGs. Determining these emissions is much more complex than measuring CO$_2$, and they are bound up in highly complex natural soil and animal microbial processes.

• The final results show that the environmental impacts are lower for the Foston farm compared to the alternative outdoor farming system, especially for GWP and acidification.
  o The GWP of the Foston farm was calculated at 2.2 kg CO$_2$e per kg of pork produced, (compare to 4.7 kg CO$_2$e for the outdoor farm)
  o The Eutrophication Potential of the Foston farm was calculated at 0.0215 kg PO$_4$e per kg of pork produced (compare to 0.0265 kg PO$_4$e for the outdoor farm)
  o The Acidification Potential of the Foston farm was calculated at 0.0349 kg SO$_2$e per kg of pork produced (compare to 0.0523 kg SO$_2$e for the outdoor farm)
  o For the GWP, this is primarily due to the manure management system (slatted floor and pit charge flush slurry management system) at Foston which result in low N$_2$O emissions and the anaerobic digestion and CHP plant capturing most of the methane emissions from the manure
  o For the acidification, this is primarily due to the manure management system reducing the ammonia release on soil compared to the outdoor farm system

• The main contributors to these impacts are the production of feed and the manure management.

• The contribution from transport, energy and abattoir is much lower compared to the above for all environmental impacts especially for the Foston farm.

• The GWP of the Foston farm can be further reduced by exporting electricity and heat from a CHP plant hence displacing the need for national grid electricity generation and natural gas consumption.

• Impact of feed production:
  o Per tonne of feed, the GWP and acidification potential of the Foston farm feed mixture is lower. This is mainly due to the higher use of by-products from other industries
  o However, the Eutrophication potential of the Foston farm feed mixture is slightly higher than the alternative outdoor farm per tonne of feed
  o Per kg of pork, all environmental impacts are lower for the Foston farm. This is primarily due to the reduced amount of food required for the pigs at Foston compared to the outdoor farm.

• For each of the environmental impacts, the Foston and outdoor farms describe similar trends when the environmental impact are broken down by source:
  o For the GWP potential, the main contributor is the Feed production (around 50% on average between the two farms) and the manure management (around 40% on average between the two farms)
  o For the Eutrophication potential, the main contributor is the feed production (around 75% on average between the two farms) and the manure management (around 20% on average between the two farms)
  o For the acidification potential, the main contributor is the manure management (around 70% on average between the two farms) and feed production (around 25% on average between the two farms)
  o The contribution from energy, transport and the abattoir is much lower compared to the feed production and manure management system for all environmental impacts.

Acknowledgement
We would like to thank the following contributors to this study: Martin Barker (MPP Director), James Leavesley (Leavesley Group Director), Andrew Knowles (Head of Communication and Supply Chain Development, BPEX) and Mick Hazzledine (Pig Nutritionist, Premier Nutrition).
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1.0 Study Objectives

The objectives of the study were to compare the main environmental impacts of producing pig meat at the planned Foston farm and a defined typical outdoor breeding farm where the sows and weaners live outdoors. Some recommendations on reducing the embodied carbon of the construction material for the Foston farm have also been provided. The next section looks at the policy context of the Foston farm project and lists a number of policies with which the project is aligned.

2.0 Policy Background

Some key aspects of the Foston Farm project are relevant to current European, National and Regional policies on GHG emissions reduction, renewable energy generation growth, waste reduction and energy from waste increase through anaerobic digestion. These policies are listed below along with a brief description:

- **EU 2020: EU Carbon Reduction Policy and EU Renewable Energy Generation Policy:**
  In 2010, the EU agreed to set targets for GHG emissions reduction and renewable energy generation as part of a 10-year strategy for reviving the economy of the European Union. For sustainable growth, the targets included:
  - Reducing greenhouse gas emissions by 20% compared to 1990 levels by 2020.
  - Increasing the share of renewables in final energy consumption to 20%
  - Moving towards a 20% increase in energy efficiency

- **UK Climate Change Act 2008:**
  The UK climate change Act 2008 makes it the duty of the Secretary of State to ensure that the net UK carbon account for all GHG for the year 2050 is at least 80% lower than the 1990 baseline. The UK government set the first three carbon budgets in May 2009, covering the periods 2008-2012, 2013-2017 and 2018-2022 to ensure progress towards the 2050 target. UK economic sectors (power generation, industry, surface transport…etc) prepare strategy and plans to meet their reduction commitments under each budget.

- **UK agriculture GHG action plan:**
  The agriculture sector is committed to playing its part in contributing to meeting the national target set by the Climate Change Act 2008. Published in April 2011, the agricultural industry Greenhouse Gas Action Plan is a statement of intent and a commitment to reduce the sector’s annual GHG emissions by 3 million tonnes CO$_2$ (equivalent) in England by 2020. The focus for reduction is based on the following principles:
  - Production efficiency gains: Improve the resource efficiency of production and reduce emissions per unit of output (CO$_2$)
  - GHG inventory for agriculture improvement: taking into account new practices such as in livestock management systems, livestock diets, nutrient management and manure management (methane)
  - Reduce Nitrogen emissions: From animal manures, crop residues, fertilisers and animal feeds impacting on nitrous oxide emissions
  - Energy and fuels: GHG costs and benefits from contribution of on-farm renewable energy and the storage of carbon in vegetation and soils
• **UK Anaerobic Digestion Strategy and Action Plan:**

The strategy is part of the Coalition Government’s commitment to work towards “zero waste” (May 2010) and was published in conjunction with the Waste Review to increase energy from waste through anaerobic digestion. The overall objectives of the strategy are to:

- Deal with organic waste and reduce waste streams into landfill
- Capture GHG emissions from waste
- Recover energy and generate biogas
- Increase production of biofertilisers

The strategy has no specific targets but the action plan is specifically set to ensure that no obstacles remain to prevent growth of the anaerobic digestion industry. The plan will support the:

- Information dissemination to landowners, communities, LA, AD operators, financiers…etc
- Development of Best Practice case studies
- Details of financial incentives available (FITs, RHI, RO)
- Set up a new loan fund to stimulate investment (£10m over 4 years)

• **Derbyshire Waste Policy (Derbyshire Waste Management Strategy (July 2006))**

European waste legislation and policy, adopted into UK law has a direct effect on local authority waste collection and disposal practices. The UK Landfill Directive provides the principal legal framework influencing municipal solid waste (MSW) management and strategy development in the UK. The most significant requirement of the Directive is to significantly reduce the quantity of biodegradable municipal waste (BMW) landfilled over future years as shown below:

- Reduce BMW landfilled to 75% (by weight) of that produced in 1995 by 2010
- Reduce BMW landfilled to 50% (by weight) of that produced in 1995 by 2013
- Reduce BMW landfilled to 35% (by weight) of that produced in 1995 by 2020

The Landfill Directive is transposed into UK law through the Waste and Emissions Trading Bill and the Landfill Allowance Trading Scheme (LATS). Under the scheme, Derbyshire County Council and Derby City Council have been allocated landfill allowances which set the maximum quantity of BMW that the Councils can landfill in each year up to 2020.

In response, Derbyshire and Derby City have set up The Joint Municipal Waste Management Strategy to provide a framework for strategic decisions to be taken on the management of MSW in Derbyshire and Derby City over the next 20 years (since 2006) and has been jointly prepared by Derbyshire County Council, Derby City Council and the eight Derbyshire borough District Councils.

Within Derbyshire, there has been a heavy reliance on landfill as the principal disposal route for a high proportion of municipal waste (77%). This situation has to change with the introduction of systems which serve to increase recycling, composting and recovery of waste and therefore, over time, greatly reduce the proportion of the waste stream sent to landfill.

The principal processes for treatment and disposal of waste are:
• Anaerobic/Aerobic Digestion for treatment of the residual biodegradable fraction
• Energy from Waste
• Advanced thermal treatment processes (Gasification & Pyrolysis)
• Mechanical Biological Treatment
• Landfill
• Or combinations of the above.

• **East Midlands Climate Change Partnership:**  
  South Derbyshire District Council and Derbyshire County Council are both members of the East Midlands Climate Change partnership. The partnership is coming to the end of its Regional Plan of Action (2009-2011). The parties are currently consulting on their successor plans.

  The Plan had two headline targets, one for carbon reduction and one for adaptation which were agreed between local and central government in April 2008, in the nine Local Area Agreements for the East Midlands. These targets are:

  • To reduce carbon dioxide emissions per capita by an average of 10% across the East Midlands (according to National Indicator 186)
  • To achieve an average of Level 3 against National Indicator 188 (Planning to Adapt to Climate Change)

  The Coalition Government has signalled the end of Local Area Agreements, National Indicators, etc. though as climate change remains a priority the parties are still continuing to initiate and support projects that help reduce carbon and/or improve the climate resilience of local organisations.

• **Ammonia emissions - UNECE Gothenburg Protocol**  
  Under the UNECE Gothenburg Protocol to the Convention on Long Range Transboundary Pollution, the UK has agreed that by 2010 its emissions, excluding those from natural sources, will be below 297 thousand tonnes. Agriculture accounts for around 90% of UK total ammonia emissions.

  Ammonia emissions are predominately from livestock manure, particularly from cattle and pigs. Emissions of ammonia are estimated using national data on farm animal numbers (cattle, poultry, pigs and sheep) as well as on fertiliser application, crops and non-agricultural emissions (including traffic and contributions from human sources, wild animals etc).

  Total ammonia emissions in 2009, excluding those from natural sources, were 288 thousand tonnes, although the estimates are subject to a relatively high degree of uncertainty.

3.0 LCA methodology

Carbon footprinting as an approach is relatively new and has been developed from Life Cycle Assessment (LCA), which has been around since the late 1960s. Both methods take a systematic view of the supply chain from raw material extraction through to the final disposal of the product. This approach crucially prevents decisions being made which may shift the environmental burden up and down the supply chain. The impact can be quantified as a total or can be broken down to present the results as its constituent sub-systems. The latter can be used to identify priority areas for improvements.
LCA takes a systems perspective and can quantify multiple environmental categories such as ecotoxicity, carcinogens and greenhouse gases. It draws on databases such as ecoinvent V2.2 (ecoinvent, 2010). As carbon footprinting only looks at one issue, it can be seen as a single issue LCA. As such it has the advantage of simplifying the assessment and providing a focus for what is, for many, the key environmental concern at present; global warming. However, as it does not deal with other environmental categories and as there are other important environmental issues such as ecotoxicity, carcinogens, and waste, it cannot be seen as a panacea. For products which have known impacts outside global warming an LCA approach could be preferable.

A streamlined methodology was used in this assessment to allow for a high-level carbon footprint, which provides a quick and cost-effective assessment of the carbon impacts across the full life cycle of goods and services. Using accepted LCA methodology the focus is on gathering data from the activities under the direct control of the client supported by data from previous studies and industry data. The work is also undertaken in such a way that can provide the basis for a more detailed study later in accordance with the PAS 2050 (PAS 2050, 2008) carbon footprinting standard or emerging standards from the CEN TC350 for sustainability of construction works due later this year, the WRI/WBCSD product carbon footprinting standard due late 2011 or the ISO 14067 on product carbon footprinting due in 2012.

4.0 Goal and Scope

4.1 Goal

The goal of study was to determine the main environmental impacts of producing pork at the Foston site and to compare this with a defined alternative UK farm. The main impacts of pig farming are widely considered to be global warming potential, eutrophication and acidification. These impacts are described below.

4.1.1 Global Warming Potential (GWP)

Global warming potential is a measure of the potential contribution to climate change. These are the carbon footprint results. All IPCC GHG were included in this assessment and converted to CO₂ equivalents (CO₂-e) using the latest IPCC (2007) global warming potentials (GWP). The GWP conversion factors were taken from PAS 2050 (BSI, 2008).

Methane is assumed to have a GWP of 25 and nitrous oxide 298. The carbon dioxide emitted into the atmosphere was assumed to have a GWP factor of zero, as it forms parts of the short term carbon cycle (absorbed during plant growth, released shortly afterwards).

In other words 1 kg of nitrous oxide (N₂O) emitted into the atmosphere is equivalent to emitting 298 kg of carbon dioxide.

4.1.2 Eutrophication

Eutrophication occurs when extra nutrients (such as nitrates and phosphates) get into water resources such as rivers and lakes. These nutrients can cause extra plants to grow in the water, for example algae blooms. When the plant growth becomes excessive the oxygen in the water drops, with implications for the local fish. Some fish will die out and the local ecology can change negatively.

The main substances of relevance to pig farming and eutrophication are phosphates and nitrogen-containing substances. Phosphates are inherent in pig manure and contribute to eutrophication. However a larger environmental problem of pig farming is ammonia emissions. When manure breaks down it can slowly release some of the nitrogen as
ammonia (NH₄). Ammonia doesn’t contribute to GWP (carbon footprint) but it does contribute to eutrophication and acidification.

4.1.3 Acidification

Acidification of soils can occur when nutrients in the soil are leached from the soil or when a proton donor is added to the soil. This reduces the pH level of the soil. It can affect the surface or sub-surface soils. Sub-surface soil acidification can be difficult to overcome. Ammonia is the main substance from pig farming that contributes to acidification.

4.1.4 Functional Unit

Product carbon footprints are represented in terms of a reference unit called the functional unit. It is usually chosen based on the main function that the product performs. For simplicity, in this assessment, each functional unit is based on the individual products assessed. The functional units for the study are given below:

The functional unit for comparison with other works is:

\[ \text{Functional unit} = 1 \text{ kg of pork leaving the abattoir} \]

This should not be confused with 1 kg of pig (live weight). Some studies display results per kg of pig.

The difference would be that approximately 100 kg pig = 75 kg of pork. It is therefore important to consider the functional units of the results.

4.1.5 System Boundary

The system boundary includes processes and activities seen as ‘material’ that occurred over the lifecycles of each functional unit (i.e. from cradle to gate). In this case the gate is the exit to the abattoir. The following life cycle stages were included: raw materials, energy, manufacturing, operation of premises and transportation.

Exclusions were made where processes and activities were seen as ‘immaterial’ and their exclusion would not significantly change the results and conclusions. The following exclusions were made during this study:

1. Packaging of raw materials delivered to the farm
2. Emissions from treatment of general waste leaving the farm. This doesn’t include manure or fertiliser, which has been captured.

Other exclusions were also made, which are typically excluded in product carbon footprint studies (and in accordance with the PAS 2050 carbon footprint methodology). These comprise:

1. Capital goods (e.g. manufacturing of vehicles, roads, buildings, machinery etc.)
2. Human energy inputs to processes
3. Transport of employees to and from the place of work
4. Animals providing transport services
5. Offsetting of emissions

The most recent data available were used, covering a period of the calendar year in 2010. The period of GHG assessment (i.e. the temporal boundary) is 100 years, which is in line with PAS 2050 and all global warming potential factors are based on a 100 year timeline.
4.1.6 Allocation

In some cases an allocation must be made to divide up emissions and energy consumption fairly to the products under study. This occurs where multiple outputs (i.e. products and co-products) are produced from the same system and where it is not possible to divide the system into sub-systems. For example, a farm or factory may produce many different products but only measure total energy use of the entire site. If the system cannot be divided into sub-systems, an allocation to co-products is usually made on the basis of economic or physical relationships (i.e. mass, volume etc). This method involves apportioning total outputs to each product based on the proportion it makes up total revenue or total mass.

For the use of by-products in the feed an economic allocation was used. This was determined to be the most accurate and is generally the most commonly applied approach.

The functional unit was per kg of pork, rather than the type of meat so no allocation was required for the products leaving the farm. The manure created on the farms was modelled to be used as a fertilizer to grow the feed. This avoided the need for allocation to by-products (fertilizer).

4.1.7 Assumptions

With any carbon footprint assessment, it is inevitable that assumptions are needed to fill data gaps. The key assumptions may be found in the appendix at the back of this report. Figures from BPEX, DEFRA or published and peer reviewed scientific literatures were the preferred data resources. Where uncertainty was presented in the literature a conservative assumption was made that would be considered in line with a robust, objective and fair study.

5.0 Farming and manure management practices and systems - Foston Farm versus Comparison Farm

The proposed farm at Foston is an indoor farming system with slatted floors and a pit charge flush slurry management system. As shown in Appendix 1 this flushing system can reduce in-house ammonia emissions by 70% versus a normal slatted floor system. Normal slatted floor systems are known to have high ammonia emissions.

The slurry from the pigs at Foston drops down through the slats, with a small quantity of straw, into a slurry collection pit. This pit has a few inches of standing water to mix with the slurry and dilute it. The presence of the water reduces the amount of ammonia created when the slurry is being stored in the pit. The pit is flushed every 48 hours and it goes onto a solid-liquid separation stage.

The slurry and water mixture now is very dilute, about 90% water and 10% slurry/straw. This is therefore passed through a solid and liquid separator. This separator creates a separated solid fraction, which has a higher solids content so that it may be used in the anaerobic digestion (AD) plant. The liquid fraction has a low solids content but contains many nitrogen and phosphate nutrients. Pig waste in both solid and liquid form is normally stored for periods of 6 months or so before being used as fertilizer. Such long storage durations are responsible for high emissions in traditional farming techniques.

The liquid fraction is therefore passed through an aerobic treatment plant to remove much of the nitrogen content of the liquid by nitrification and denitrification. This process does release some $\text{N}_2\text{O}$, $\text{NH}_3$ and $\text{CH}_4$ which often occur during storage stages. However much of the nitrogen is released as $\text{N}_2$, which is harmless nitrogen gas.
The aerobic treatment plant creates a biological sludge from the solids in the liquid fraction. This is passed onto the AD plant.

The Foston site will be equipped with anaerobic digestion chambers and a CHP unit to generate electricity and heat for the Foston farm and to export. The solid fraction from the manure will be premixed with up to 45,000 tonnes of wastes collected from the locality. These will break down to create biogas which is approximately 60% methane and 40% carbon dioxide. The methane may be burnt for heat and to power a CHP unit. Some excess electricity and heat may be sold to the national grid or the local community.

After the wastes break down to create methane an AD digestate remains. This still contains the nitrogen and phosphate nutrients and therefore may be used as fertilizer. The Foston farm proposes to separate the solid and liquid fraction of this digestate to be stored and then used as solid and liquid fertilizers. This natural fertilizer will be used by local farmers to grow the wheat and barley fractions of the pig feed.

The typical outdoor pig farm (or comparison farm) is an outdoor breeding system. In this system the sows and weaners live outdoors. When the pig is ready for fattening and finishing the pig is moved indoors. The average weaning age of an outdoor weaner is 27 days (BPEX figures). They are then likely to spend another 20 weeks or so indoors. The indoor bedding system was assumed to be a straw litter system. This creates farm yard manure, which may be used as compost. It was assumed that the compost was used to grow the wheat. This farm doesn’t create as much natural compost as the Foston farm because of the outdoor sows and weaners and also because the Foston farm is importing wastes to use in the AD plant.

The comparison of the two farming systems is shown in Table 1.

<table>
<thead>
<tr>
<th>Description</th>
<th>Foston Farm</th>
<th>Comparison</th>
</tr>
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<tr>
<td>Breeding</td>
<td>Indoor</td>
<td>Outdoor</td>
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<tr>
<td>Weaning</td>
<td>Indoor</td>
<td>Outdoor</td>
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<tr>
<td>Finishing</td>
<td>Indoor</td>
<td>Indoor</td>
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<td>Housing type</td>
<td>Slatted Floor</td>
<td>Straw Litter</td>
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<td>In-house manure management</td>
<td>Pit recharge flush system</td>
<td>Solid manure handling</td>
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<td>Manure management</td>
<td>Solid-liquid separation: Liquids – aerobic treatment Solids – anaerobic digestion</td>
<td>Farm Yard Manure Storage and composting</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>Onsite CHP</td>
<td>National Grid</td>
</tr>
</tbody>
</table>

Table 1 Comparison of Foston Farm vs Comparison Farm system

6.0 Key Substances in manure management

The key substance to track for the LCA was Nitrogen containing emissions. These include ammonia (NH₃), which is an issue for eutrophication and acidification, nitrous oxide (N₂O), which has a particularly high global warming potential, and nitrates (NO₃). The latter are mainly an issue at the field level or where manure breaks down in a field.

Pig manure also contains phosphates, which contributes to eutrophication. Methane is another key emission, which mainly occurs from the breakdown of manure in storage and to a lesser extent from enteric fermentation of the pigs.

Please see the appendix for more elements of the key methods and assumptions.
7.0 LCA Results

The environmental impacts for the two farms are quantified and compared in this section. The impact of feed production for both farms is initially presented to study the impact of feed production in more detail and provide useful data for feed selection from an environmental impact perspective.

The overall results are also broken down by emissions sources i.e. feed production, manure management, transport, energy and the abattoir.

7.1 Feed Production

The Foston farm will grow wheat, barley and field beans locally with the fertilizer from the AD plant. The feed also contains oil seed rape and almost 30% by-products, which are leftovers from food-producing industries. The composition of the feed is shown in the appendix along with more details of the method and assumptions. The global warming potential (GWP) of each feed ingredient used at Foston is shown in Figure 2.

![Figure 2: The carbon footprint of feed ingredients and the Foston feed - per tonne of feed](image)

The feed of the comparison farm has a more diverse mix of ingredients, as shown in the Appendix. Figure 3 shows the carbon footprint of all feed ingredients and compares the Foston feed mix with the comparison farm mixture.
Figure 3 shows that the impacts of the Foston feed per tonne of feed is lower than the comparison farm. A large factor in this is the higher by-product fraction in the Foston feed, which lowers the carbon footprint of the Foston feed. These by-products, such as biscuit meal or molasses, have low environmental impacts because the main food making process takes the larger share of environmental burdens. The environmental burdens are typically divided up on the basis of relative economic value between the main food item and the waste product (the by-product).

Likewise the analysis was completed for eutrophication and acidification, Figure 4 and Figure 5.
Figure 5: Acidification potential of each feed ingredient and the feed mixtures per tonne of feed

The results of eutrophication showed that the Foston feed was marginally higher for eutrophication potential per tonne of feed. This was attributed to the higher use of natural fertilizers. The nitrogen content of natural fertilizer is not as acceptable to plants as mineral equivalents (see appendix). In fact the N content of the natural fertilizer is only 70% as available to plants as synthetic fertilizer. This means that there is extra N nutrients when natural fertilizers are used. These extra nutrients, which were not absorbed by the plants, can increase the eutrophication potential of farming a crop. Natural fertilizers also have higher ammonia emissions. A combination of such factors means that natural fertilizers have a higher contribution to eutrophication than their synthetic counterparts.

However, the above results are per tonne of feed. The Foston farm has a better feed conversion efficiency because the sows outdoors require a bit more feed. Therefore the feed per pig is slightly less for Foston than the comparison farm.

The results for acidification show that the Foston farm is lower impact per tonne of feed. The higher use of by-products was one of the main reasons for this. The use of soya, which normally comes in a processed form from South America or China adds to the average impacts of the feed for the comparison farm. Soya from South America often has land use change issues associated with the farming, long transport distances.

The impact of the feed per pig produced is shown in Figure 6 for all three impact categories.
These results showed that the Foston feed had a notably lower carbon footprint and acidification potential per pig produced and a marginally lower eutrophication potential per pig. The eutrophication is lower because of a slightly lower feed requirement per pig.

7.2 Breakdown of LCA Results at all stages

The final results are displayed in Figure 7. They include the impacts from feed production, manure management, energy consumption on the farm, transport and the abattoir. See the appendix for method and assumptions. Figure 7 is the total results, there is a more detailed breakdown in Figure 8 for Foston and Figure 9 for the comparison farm.

Figure 7 shows that the GWP (carbon footprint) is estimated to be considerably lower per kg of pork produced at Foston than for the comparison outdoor breeding farm. There is a
similar benefit for acidification and a notably reduced eutrophication per kg of pork produced.

The reasons for the lower impacts per kg of pork produced were investigated and much can be learnt from Figure 8 and Figure 9 below. Further representation of the environmental impacts by source is also presented in Appendix 2.

Figure 8: A breakdown of impacts by activity for Foston

Figure 8 shows that the main contributor to the GWP impact is the growing of the feed. This is followed by the manure management. The abattoir is notable but a small contributor. The manure management GWP came mainly from methane emissions and there was a small contribution from N₂O emissions. The methane emissions come from a combination of the aerobic treatment of the separated liquid fraction of the slurry. During the aerobic treatment the liquid sits at various parts of the treatment stages for a period of time. When any slurry or manure is stored there will be emissions of some gases in various forms.

The methane emissions also come from fugitive emissions during the breakdown of the solids in the AD chambers and combustion in the CHP plant. For example these fugitive emissions can come from periods of maintenance where hatches will need to be opening releasing some gas, or from incomplete combustion during the operation of the CHP. A fugitive emission of 2% of the methane generated was assumed.

Transport is barely notable in the contribution to GWP. The transport on this figure includes transport of the UK feed to farm and the pigs to the abattoir. The energy consumption has been given no burden. The emissions to operate the CHP plant were considered as part of the manure management.

Figure 8 also shows the main contributor to eutrophication. It is here clear that eutrophication is mainly an issue for the growing of feed. This is by far the largest contributor to eutrophication impacts of producing pork at Foston. Transport and the abattoir were very small contributors.

However acidification has a different trend. The main contributor to acidification from the Foston farm is the release of ammonia during pig farming and manure management. The feed also provides a notable contribution. Transport and the abattoir were once more very small contributors to acidification.
Figure 9 shows the breakdown for the comparison farm. It is also important to place it in the perspective of the total amount of impact in each category (Figure 9).

![Figure 9: A breakdown of impacts by activity for the comparison farm](image)

The comparison farm shows some interesting trends. To put these into perspective with the Foston farm the GWP and acidification were estimated to be much lower per kg of pork than the comparison farm and the eutrophication was notably lower. For the impact of GWP the energy consumption of the farm is now notable but it is still a small contributor. The transport is slightly larger due to a slightly longer delivery distance of the feed. However the contribution is still so small that it makes very little difference to total results.

The growing of the feed is a large contributor to the GWP but now also the manure management is a large contributor to the GWP. The straw litter system has relatively low ammonia emissions in comparison to a normal slatted floor (but not as low as the pit recharge flush system). However instead of producing ammonia the straw litter system has high N₂O emissions, which are far lower in a slatted floor. If this study was a normal slatted floor versus straw litter bedding it would be a trade off between reduced ammonia of the straw litter versus the reduced N₂O emissions of the slatted floor. N₂O emissions are particularly bad for climate change and ammonia emissions contribute to acidification and to a lesser extent eutrophication.

However the Foston system has 70% lower ammonia emissions than a normal slatted floor, which means it can benefit from lower N₂O emissions, which reduce the contribution to the carbon footprint, and reduce ammonia emission to keep acidification impacts down.

The breakdown for eutrophication for the comparison farm also shows that farming of the feed is the main contributor. However the outdoor weaning and breeding is also responsible for some eutrophication. The manure when released onto the ground breaks down and the phosphates are released into the environment. However another reason for large eutrophication potential of the outdoor stage is the breakdown of the manure to form nitrates (NO₃). These are a problem for eutrophication.

The trend for acidification showed the largest contribution was from the manure management. Higher ammonia emissions from the pig housing and manure management (including storage) contribute to a higher acidification potential.
7.3 Final Results – including the benefit of exporting energy

The above results ring-fenced the pig farming operations away from the extra electricity and heat exported from the CHP unit. However, there is an environmental benefit of selling the electricity and heat. This is because it displaces the need for national grid electricity and in the case of heat it could be assumed to replace gas. Figure 10 shows the results with the benefit of exported electricity.

The results for eutrophication and acidification do not change notably. However there is a large reduction in the GWP of pork production at Foston. The main reason for the reduction is selling electricity. Around 6,800 MWh of national grid electricity was estimated to be displaced by exporting surpluses.

![Figure 10: The final LCA results for Foston versus the comparison farm – per kg of pork produced](image)

The final results, per kg of pork produced, are shown in Table 2:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Foston</th>
<th>Comparison Farm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Warming Potential – kg CO₂e</td>
<td>2.2</td>
<td>4.7</td>
</tr>
<tr>
<td>Eutrophication Potential – kg PO₄e</td>
<td>0.0215</td>
<td>0.0265</td>
</tr>
<tr>
<td>Acidification Potential – kg SO₂e</td>
<td>0.0349</td>
<td>0.0523</td>
</tr>
</tbody>
</table>

Table 2: Impact per kg of pork produced

Lower numbers indicate a smaller impact potential. It is important when comparing with other studies to consider the functional unit of per kg pork. Many studies also report results per kg of pig.

8.0 Conclusions

The proposed farm at Foston was modelled for its LCA impacts of carbon footprint, eutrophication and acidification and compared with an alternative UK farm. The comparison farm was an outdoor breeding farm where the sows and weaners live outdoors. In this system the finishing and fattening stages occur indoors. The Foston farm is an indoor breeding system.
An LCA model was created from a combination of industry figures (BPEX), Government funded research (DEFRA) and leading academic literature. A conservative approach was taken to assumptions so that a fair, objective and robust comparison could be made.

The analysis revealed that the Foston farm would offer a lower carbon footprint, eutrophication and acidification potential per kg of pork produced by the farm. The carbon footprint was further reduced by the selling of excess energy. The main benefit of this was exporting electricity to the national grid. This displaces national grid electricity which offered a further benefit to the carbon footprint per kg of pork produced.

9.0 Embodied Carbon of Buildings (recommendations)

The pig farm at Foston would be of new construction. The embodied carbon of materials should be considered. This is the carbon footprint required to make and transport materials. There are a number of ways that embodied carbon can be effectively reduced. These include:

- Use fly ash or blast furnace slag in the concrete mixtures. Fly ash is a waste product from coal fired electricity generation and blast furnace slag is a by-product of virgin steel making. Both of these can be used to reduce the cement content, which has a high embodied carbon. This is one of the best ways to reduce embodied carbon of construction.
- Consider the use of sustainably sourced timber for cladding rather than metal equivalents.
- Effectively manage the construction waste and the amount of materials purchased. Over-ordering of materials is common in construction and can result in excessive waste generation.

These generic recommendations offer useful advice to reduce embodied carbon. Further recommendations would require a detailed embodied carbon study.
References


Anaerobic Digestion Strategy and Action Plan, DECC, June 2011


Appendix 1 – Key Assumptions

The key assumptions and parameters, taken from the literature are summarised in this section. A conservative philosophy was taken with the assumptions to provide a fair and robust basis for comparison.

Feed assumptions

Natural nitrogen containing fertilizer is not as acceptable to plants as a mineral equivalent. This is measured in mineral fertilizer equivalent (MFE). The MFE for nitrogen in the fertilizer generated by the pig farms was assumed to be 70%. This means that if 100kg of N is contained in natural fertilizer it replaced the need for 70kg of synthetic fertilizer. The P and K content of fertilizer was assumed to have the same MFE as synthetic fertilizers.

Whilst natural composts have their advantages, such as reduced manufacture of synthetic fertilizers and reduced wastes, they are not burden free. The fertilizers still contain nitrogen (N) and phosphates (P). The application of N and P fertilizer must be made with care to avoid over fertilization. When N and P nutrients are used as fertilizer there is the potential for some to be leached to soils and run-off to water resources. This can cause increased eutrophication and acidification.

The impacts of farming feed were modelled with the use of the DEFRA funded model Williams et al. (2006), the professional LCA database ecoinvent V2.2 and Dalgaard et al (2007). The impacts of each feed are provided in the main report.

Table 3 shows the average composition of the Foston feed:

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>41%</td>
</tr>
<tr>
<td>Barley</td>
<td>17%</td>
</tr>
<tr>
<td>Field beans</td>
<td>9%</td>
</tr>
<tr>
<td>Oil seed rape</td>
<td>5%</td>
</tr>
<tr>
<td>By-Products</td>
<td>29%</td>
</tr>
</tbody>
</table>

Table 3: Foston Farm Feed Composition

The feed will be grown by local wheat and barley farmers who will use the solid and liquid fertilizer created by the pig farm and wastes that are used in the anaerobic digestion plant. Field beans require no fertilization and are used in place of soya beans, which are typically sourced from either South America or China for the protein content of pig feed. It was assumed that 30% of by-products, which are wastes from food-making industries but suitable for pig feed, is used in the feed in place of all ingredients except for the oil seed rape which provides the minerals for the pigs (i.e. 30% of the mix if oil seed rape was taken out). This is a relatively high by-product content of pig feed.

The comparison farm had an average pig feed (weaners and growers) as shown in Table 4:

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize meal</td>
<td>8.4%</td>
</tr>
<tr>
<td>Wheat</td>
<td>31%</td>
</tr>
<tr>
<td>Barley</td>
<td>12.6%</td>
</tr>
<tr>
<td>HP Distillers</td>
<td>7.5%</td>
</tr>
<tr>
<td>Wheatfeed meal</td>
<td>17.5%</td>
</tr>
<tr>
<td>GLW Biscuit Meal</td>
<td>4.3%</td>
</tr>
<tr>
<td>HI-pro soyabean</td>
<td>9.8%</td>
</tr>
</tbody>
</table>
Rapeseed extractions 5.6%
Limestone flour 1.1%
Salt 0.25%
Rouxmol molasses 2.1%

Table 4: Comparison Farm Feed Composition

There were more ingredients in the comparison feed. There is still some use of by-products (Biscuit meal and molasses). Ecoinvent V2.2 was used for the estimated impacts of these by-products. The impacts of these by-products were given a share of the main food production impacts based on the difference in economic value of the main item and these by-products. This is known as an economic allocation.

Whilst the Foston wheat and barley was assumed to be farmed with natural fertilizer from the farm and anaerobic digestion plant, the outdoor breeding farm won't produce as much fertilizer. The straw litter bedding system will create solid manure, farm yard manure (FYM). BPEX (2004) estimates how much FYM a straw litter system generates per pig. It was estimated that for outdoor breeding, where the sows and weaners live and produce excrement outdoors, only 80% of the total slurry occurred in the fattening and growing stages (i.e. indoors). This is the manure that will be collected and used as farm yard manure. The manure was assumed to be used for the growing of the wheat for the pig feed. This makes sure that the burdens of the manure breaking down are captured in both farming systems.

Pig farming assumptions

Key parameters used in this study are presented below. Parameters for Foston were provided by Midland Pig Producers. Parameters for the comparison farm were taken from BPEX industry average figures for the UK for outdoor breeding units and indoor finishing and fattening. These figures are readily available on the BPEX website. Where parameters were missing for Foston, BPEX figures were used in their place.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Foston Farm</th>
<th>Comparison Farm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pigs per sow per year</td>
<td>25</td>
<td>21</td>
</tr>
<tr>
<td>Average weaning age</td>
<td>28.0</td>
<td>26.5</td>
</tr>
<tr>
<td>Tonnes of feed per year (Sow)</td>
<td>1.2</td>
<td>1.36</td>
</tr>
<tr>
<td>Feed conversion ratio</td>
<td>2.4</td>
<td>2.5</td>
</tr>
<tr>
<td>Average carcase weight per pig (kg pork)</td>
<td>80</td>
<td>79</td>
</tr>
<tr>
<td>Killing Out Percent</td>
<td>75%</td>
<td>75%</td>
</tr>
</tbody>
</table>

Table 5: Pig Farming Parameters

Amount of slurry produced

Figures for the amount of waste slurry that pigs produce were taken from the DEFRA funded research Williams et al. (2006). This allowed the amount of manure created by the sows and weaners, which live outdoors, to be estimated. It was estimated that approximately 20% of the total waste produced in the outdoor breeding farm was released outdoors.
The slurry was assumed to contain 6 kg N per tonne of slurry for both farming systems. This is consistent with Williams et al. (2006), which was DEFRA funded research.

**Emissions from pig housing & slurry/manure storage**

The following emissions factors were taken from Basset-Mens & van der Werf (2005) and Basset-Mens et al (2007).

### NH₃ emissions (all in kg NH₃-N)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Emission Factor (kg NH₃-N) per kg of N</th>
<th>Source Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia emissions for slatted floor building</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Slurry storage</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>For straw litter building</td>
<td>0.10 (range in paper was 0.1-0.2)</td>
<td>The low end was taken as the conservative estimate</td>
</tr>
<tr>
<td>During solid manure storage</td>
<td>0.093</td>
<td>per kg of initial N content in manure</td>
</tr>
</tbody>
</table>

### kg of N₂O-N emitted (all in kg N₂O-N)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Emission Factor (kg N₂O-N) per kg of N</th>
<th>Source Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>For slatted floor building including slurry storage</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>For straw litter building</td>
<td>0.05 (range in paper was 0.05-0.1)</td>
<td>The low end was taken as the conservative estimate</td>
</tr>
<tr>
<td>From solid manure</td>
<td>0.005</td>
<td>per kg of remaining N content in manure</td>
</tr>
<tr>
<td>From liquid manure (uncovered anaerobic lagoon)</td>
<td>0.000</td>
<td>per kg of remaining N content in manure</td>
</tr>
<tr>
<td>During (solid) manure storage</td>
<td>0.003</td>
<td>per kg of initial N content in manure</td>
</tr>
</tbody>
</table>

**Table 6: Emissions from Pig Housing and Slurry / Manure Storage**

The typical slatted floor system has high ammonia emissions. However Foston will have a pit recharge flush system where the slurry will drop down into a few inches of water. The water volume will make up approximately 90% of the slurry and water mixture. The water reduces the amount of ammonia that is released and the flushing of the slurry pit every 48 hours reduces the ammonia emissions as well. The below extracts, taken from Heber et al, provide the basis for a 70% reduction in ammonia emissions of the Foston pit recharge flush system.

“To reduce ammonia levels, avoid storing manure in the building for long periods. The rate of ammonia released from manure increases for storage times longer than about one day. However, there are no further reductions in ammonia release rates for less than one day because so much comes from dirty surfaces (slats, floor, animals, etc.). Ammonia production peaks at three days and again at 21 days. Frequent manure removal helps maintain low ammonia gas levels. Removing manure frequently to reduce ammonia is more effective with poultry than with swine because ammonia formation takes place mainly from the swine’s urine. This occurs so rapidly that cleaning intervals in swine buildings would have to be at least half-hourly and the urine, in particular, would have to be removed as
completely as possible. This can be done efficiently only with flushing systems since surface scrapers always leave behind a film of urine on the surface, from which emission takes place. European researchers are developing gutter scrapers that automatically separate the liquid from the solids."

"Researchers in The Netherlands compared the relative ammonia emissions for five different manure collection systems. Figure 1. Total slotted floors with deep pit and long term storage generated the most ammonia gas. The building with a partially slatted floor and manure pit produced 20% lower ammonia emissions. A partly-slatted floor combined with a sloping floor under the slats from which manure was flushed several times a day was 30% below that for a deep pit. Greater emission reductions were achieved when manure was collected under the slatted floor in about 4 inches of flushing water so manure that falls into liquid and solids are submerged. If the mixture was regularly pumped out and replaced by new flushing liquid (as in pit recharge), the reduction was 60%."

"Using the “pull plug with recharge” or “fill and empty” principle of manure removal, the reduction increased to 70%. In this last case, pipes were laid under the floor of the manure pit leading to the outside manure storage. Inlets to these drain pipes were placed at regular intervals in the floor. The drains could be closed with plugs, shut-off balls, or gate valves. When opened, the slurry or flushing liquid flowed out without significant surface turbulence into the outside liquid manure storage. The openings are then closed and new flushing liquid added to the pit. The results of these tests agree with Canadian researchers who stated that there is no advantage to continuous flow gutters, flush gutters, or scraped gutters over fill-and-empty gutters in terms of ammonia production." – extracts from Heber et al. (accessed 2011)

Enteric Fermentation & Methane Emissions

According to the IPCC swine produce 1.5 kg CH\(_4\) per head per year. This is not as significant as for cows. The methane emissions from manure storage and treatment vary according to treatment type, ambient temperature (lower emissions in temperate and cool climates) and solid or liquid form of the slurry.

Methane emissions factors were taken from IPCC 2006 Table 10.17. For example, some methane conversion factors (MCF):

- 2% for solid storage
- 10% for liquid/slurry with natural crust cover
- 17% without crust cover
- 66% uncovered anaerobic lagoon

- 3% for deep bedding <1 month
- 17% for deep bedding >1 month
- 3% for pit storage below animal <1 month

Solid and liquid separation of slurry

At Foston the slurry and water mixture will also contain a small amount of straw, which will fall through the slats. The mixture will be dilute due to the high volume of water. This will therefore be passed through a first solid liquid separation stage by the use of a separator. This takes the incoming mixtures and creates a solid fraction, which passes onto the anaerobic digestion chambers to create methane, and a liquid fraction which is proposed to go through an aerobic treatment to remove most of the nitrogen as harmless N\(_2\) (nitrogen gas) and the phosphates removed by lime dosing.
The aim from the first solid-liquid separation stage is to achieve a solid fraction with an 8-10% solids content.

The aerobic treatment of the liquid fraction, which represents the vast majority of the volume of incoming liquid, is not emission free. There are fugitive emissions during storage stages and ammonia, methane and nitrous oxides can be released. However the main emissions are during raw slurry storage in housing and any solid fraction storage.

The emissions factors for the aerobic treatment of liquids were taken from Loyon et al (2007) and Lopez-Ridaura et al (2009). However the emissions factors were scaled proportionally from Loyon et al (2007) in relation to the nitrogen content of the liquid fraction. This same proportional scaling was done in Lopez-Ridaura et al (2009).

The liquid fraction has a low solids by volume concentration but a large volume. The solids form a sludge that is sent to the anaerobic digester to create methane. Typically the separated solids and the sludge from the aerobic treatment would be stored for many months. These long storage periods are responsible for high emissions. At Foston these solids are fed into the anaerobic digestion chambers for the creation and collection of methane.

**Anaerobic Digestion and CHP unit**

The Foston site has an anaerobic digestion and CHP plant. The anaerobic digestion chambers allow the solids to break down and create biogas, which is approximately 60% methane. This methane is captured and will be burnt in a CHP plant for the creation of low carbon electricity and heat. The proposed CHP units are just under 834 KWe Jenbacher units. Three engines are proposed for a total generation capacity of 2.5 MWe. The Jenbacher units have a good electrical efficiency of around 40% and a similar heat efficiency of 42%.

The extra electricity generated and exported to the UK national grid was assumed to have an environmental benefit. The benefit is equal to the differences in GWP, eutrophication and acidification to produce electricity from the national grid and produce electricity on the Foston CHP unit. There was very little effect on the results of eutrophication and acidification but the benefit of GWP was clear and is shown in the main report.

Fugitive losses from AD chamber and CHP units occur. These emissions are unintended but unavoidable. The range in the literature for fugitive losses vary from around 2% of the methane generated to 15% or more for a poorly operated and micro scale unit. The proposed unit size of 2.5 MWe is not small and it is assumed that it will be carefully operated. These assumptions are consistent with ecoinvent V2.2 (2010). The former figure was therefore applied in this study.

The weighted average mixture of locally available wastes that could be feedstocks for the AD plant are shown in Table 7 below.
<table>
<thead>
<tr>
<th>Distance - Miles</th>
<th>Site Town</th>
<th>Resource Title</th>
<th>Notes</th>
<th>Quantity Total</th>
<th>Unit Title</th>
<th>Selected Waste Type</th>
<th>Biogas Yield – m³ per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Burton On Trent</td>
<td>Fat Trap Waste/Oils</td>
<td></td>
<td>1</td>
<td>tonnes</td>
<td>Leftovers; fat rich</td>
<td>127</td>
</tr>
<tr>
<td>10</td>
<td>Barton Under Needwood</td>
<td>Compacted Kitchen Waste</td>
<td></td>
<td>1,080</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td>61,560</td>
</tr>
<tr>
<td>12</td>
<td>Linton</td>
<td>Pig slurry, manure</td>
<td>Pig slurry from abattoir, currently being land spread</td>
<td>1,050</td>
<td>tonnes</td>
<td>Pig Slurry</td>
<td>21,420</td>
</tr>
<tr>
<td>12</td>
<td>Linton</td>
<td>Effluent treatment plant sledges</td>
<td>Pig slurry, manure</td>
<td>1,400</td>
<td>tonnes</td>
<td>Pig Slurry</td>
<td>28,560</td>
</tr>
<tr>
<td>13</td>
<td>Ashbourne</td>
<td>10-40mm composted green waste</td>
<td>Potential uses could be for bio mass, land spreading etc.</td>
<td>10,000</td>
<td>tonnes</td>
<td>Grass Silage</td>
<td>1,700,000</td>
</tr>
<tr>
<td>22</td>
<td>Ratcliffe on Soar</td>
<td>General Wastes</td>
<td></td>
<td>570</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td>32,490</td>
</tr>
<tr>
<td>22</td>
<td>Stafford</td>
<td>Kitchen Waste</td>
<td>xyz01 : we can improve our recycling performance by 20% if we could cost effectively dispose of it.</td>
<td>10,000</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td>570,000</td>
</tr>
<tr>
<td>24</td>
<td>Lichfield</td>
<td>Food waste</td>
<td></td>
<td>1,000</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td>57,000</td>
</tr>
<tr>
<td>27</td>
<td>Loughborough</td>
<td>Food waste</td>
<td>From restaurant - approx 300 covers per day</td>
<td>10</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td>570</td>
</tr>
<tr>
<td>27</td>
<td>Newcastle under Lyme</td>
<td>Green waste</td>
<td>xyz01 : Household and parks</td>
<td>2,000</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td>114,000</td>
</tr>
<tr>
<td>30</td>
<td>Nottingham</td>
<td>Food and drink organic waste</td>
<td>Cat 2 ABP Milk waste was sent to incineration now sent to Biogen Ltd for biogas generation as recommended by NISP EM</td>
<td>1,560</td>
<td>tonnes</td>
<td>Whole cows milk, fresh</td>
<td>179,315</td>
</tr>
<tr>
<td>30</td>
<td>Nottingham</td>
<td>Waste Milk</td>
<td></td>
<td>3,000</td>
<td>tonnes</td>
<td>Whole cows milk, fresh</td>
<td>344,836</td>
</tr>
<tr>
<td>30</td>
<td>Nottingham</td>
<td>Fat rich sludge from DAF plants</td>
<td></td>
<td>15,000</td>
<td>tonnes</td>
<td>Leftovers - fat rich</td>
<td>1,897,734</td>
</tr>
<tr>
<td>30</td>
<td>Nottingham</td>
<td>Cat 3 ABP Milk Waste</td>
<td>Cat 3 ABP Milk Waste was land spread. Now goes to animal feed, but occasionally 20 tonne loads go to Biffa, Wanlip, Leics. For biogas as recommended option by NISP EM.</td>
<td>60</td>
<td>tonnes</td>
<td>Whole cows milk, fresh</td>
<td>6,897</td>
</tr>
<tr>
<td>30</td>
<td>Nottingham</td>
<td>Food Waste</td>
<td>0.5 tonnes per week per 8 sites nationally</td>
<td>208</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td>11,856</td>
</tr>
<tr>
<td>30</td>
<td>Nottingham</td>
<td>Green waste</td>
<td>From the flood defence work taking place along Trent from 2008 - 2011.</td>
<td>1,000</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td>57,000</td>
</tr>
<tr>
<td>30</td>
<td>Nottingham</td>
<td>Green Waste</td>
<td>5-6 tonnes of green waste per week produced from gardening/landscaping works. Produced in the Lincolnshire and Nottinghamshire areas but bulked up at Nottinghamshire.</td>
<td>312</td>
<td>tonnes</td>
<td>Grass Silage</td>
<td>53,040</td>
</tr>
<tr>
<td>30</td>
<td>Nuneaton</td>
<td>Food waste</td>
<td>xyz01</td>
<td>5,000</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td>285,000</td>
</tr>
<tr>
<td>30</td>
<td>Nuneaton</td>
<td>Garden Waste</td>
<td></td>
<td>10</td>
<td>tonnes</td>
<td>Grass Silage</td>
<td>1,700</td>
</tr>
<tr>
<td>31</td>
<td>Bakewell</td>
<td>General food waste including packaging</td>
<td>7 tonnes per week of general food waste and packaging. Currently land filled.</td>
<td>350</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td>19,950</td>
</tr>
<tr>
<td>38</td>
<td>Wolverhampton</td>
<td>Green Waste</td>
<td></td>
<td>2</td>
<td>tonnes</td>
<td>Grass Silage</td>
<td>340</td>
</tr>
<tr>
<td></td>
<td>Location</td>
<td>Type</td>
<td>Details</td>
<td>Quantity</td>
<td>Unit</td>
<td>Waste Type</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>------------</td>
<td>-----------------------</td>
<td>-------------------------------------------------------------------------</td>
<td>----------</td>
<td>----------</td>
<td>--------------------------</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>Leicester</td>
<td>Food waste</td>
<td>Produce ready meals. Currently they do not segregate waste streams so: - vegetable waste - meat waste (cooked and raw)</td>
<td>450</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>Barlborough</td>
<td>Food and Packaging Wastes - Various Streams</td>
<td></td>
<td>30,000</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>Glossop</td>
<td>Animal by product waste</td>
<td>Animal by-products, bones, fats etc. Estimated 50 tonnes</td>
<td>50</td>
<td>tonnes</td>
<td>Leftovers - Average fat</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Newark</td>
<td>Chicken Manure</td>
<td></td>
<td>10,000</td>
<td>tonnes</td>
<td>Poultry Excrement</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Birmingham</td>
<td>Green waste for recycling</td>
<td>XYZ01</td>
<td>30,000</td>
<td>tonnes</td>
<td>Grass Silage</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Newark</td>
<td>Off spec asparagus, lettuce, parsnips, potatoes and other vegetables</td>
<td>Variable amounts available from March - April. Estimated 200 tonnes</td>
<td>200</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Newark</td>
<td>Chicken Manure</td>
<td></td>
<td>10,000</td>
<td>tonnes</td>
<td>Poultry Excrement</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Newark</td>
<td>Bagged manure product</td>
<td>25 L bags</td>
<td>1,000</td>
<td>tonnes</td>
<td>Horse Excrement</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Newark</td>
<td>Bagged manure product</td>
<td>25 L bags</td>
<td>1,000</td>
<td>tonnes</td>
<td>Horse Excrement</td>
<td></td>
</tr>
<tr>
<td>51</td>
<td>Worksop</td>
<td>Unpopped corn (from making pop corn)</td>
<td>Corn mixed with rapeseed oil and sugar</td>
<td>200</td>
<td>tonnes</td>
<td>Maize silage</td>
<td></td>
</tr>
<tr>
<td>55</td>
<td>Rotherham</td>
<td>Packaged food waste</td>
<td></td>
<td>1</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td></td>
</tr>
<tr>
<td>55</td>
<td>Telford</td>
<td>B Green (Energy from waste) B Green - Waste File</td>
<td>The company have waste food products and they are looking for a site to re use these materials (do not contact the company at this stage).</td>
<td>30,000</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td></td>
</tr>
<tr>
<td>58</td>
<td>Shrewsbury</td>
<td>Garden Waste for composting</td>
<td>xyz01</td>
<td>8,000</td>
<td>tonnes</td>
<td>Grass Silage</td>
<td></td>
</tr>
<tr>
<td>59</td>
<td>Ellesmere</td>
<td>Food waste</td>
<td>xyz01</td>
<td>1,000</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>Sheffield</td>
<td>Food Waste for energy project</td>
<td></td>
<td>170,000</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>Sheffield</td>
<td>Green Shred</td>
<td>20 - 40 mm</td>
<td>30,000</td>
<td>tonnes</td>
<td>Grass Silage</td>
<td></td>
</tr>
<tr>
<td>63</td>
<td>Warwick</td>
<td>Food waste</td>
<td>xyz01 : from schools - quantity not stated</td>
<td>1</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td></td>
</tr>
<tr>
<td>62</td>
<td>Warwick</td>
<td>Green Waste</td>
<td>xyz01</td>
<td>10,000</td>
<td>tonnes</td>
<td>Grass Silage</td>
<td></td>
</tr>
<tr>
<td>63</td>
<td>Warwick</td>
<td>Kitchen Waste</td>
<td>xyz01 - collected from households</td>
<td>1,000</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>Doncaster</td>
<td>Green waste &amp; wood (4269)</td>
<td>Council are looking to find a solution for their biodegradable waste that is currently going to landfill.</td>
<td>10,000</td>
<td>tonnes</td>
<td>Grass Silage</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>Doncaster</td>
<td>Food waste</td>
<td></td>
<td>2</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>Doncaster</td>
<td>Biodegradable municipal waste (complete)</td>
<td>Council are looking to find a solution for their biodegradable waste that is currently going to landfill.</td>
<td>52,500</td>
<td>tonnes</td>
<td>Vegetable wastes</td>
<td></td>
</tr>
</tbody>
</table>
The yield of biogas largely depends upon what type of waste is placed in the AD plant. Figure 11 shows the large variation in the biogas yield of wastes. In this example pig slurry of 6% dry matter is displayed. The weighted average considers the data in Table 7 above.

Using the weighted average mix of wastes (assuming 45,000 tonnes of waste) and the amount of slurry produced by Foston the average electricity generated was estimated to be 12,000 MWhe. Taking into account the parasitic load and the electricity consumption of the Foston site it was estimated that Foston would displace 6,800 MWhe of electricity from the national grid. This was made with conservative assumptions on the amount of electricity available for sale and also on the biogas yield on input wastes.

The NNFCC anaerobic digestion calculator (Version 2.2. Developed by the Andersons Centre) was used to estimate the yield of wastes and the electrical generation of the AD and CHP plant. The AD plant also creates fertilizer which is used to grow the pig feed.

**Transport**

The impact of transporting feed and pigs was taken from the ecoinvent V2.2 database. Transport was a minor contributor to both farming scenarios across all impact categories.

**Abattoir**

The abattoir was assumed the same for both scenarios. It was assumed to be 50 miles from the farm. The energy consumption of an abattoir was taken from Dalgaard et al (2007)
and UK emissions factors were applied, as used by DEFRA for company GHG reporting guidelines.

12.0 Appendix 2 – Environmental impacts breakdown by sources

**Foston Farm GWP (kg CO2e)**

- Manure management: 35%
- Feed: 57%
- Energy: 7%
- Transport: 1%
- Abattoir: 0%

**Comparison Farm GWP (kg CO2e)**

- Manure management: 45%
- Feed: 46%
- Energy: 4%
- Transport: 4%
- Abattoir: 1%