Recalculate Pork Industry emissions inventory

MAF Technical Paper No: 2012/05

Report prepared for Ministry of Agriculture and Forestry
By Massey University College of Sciences
2011

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ISSN 2230-2794 (online)
ISBN 978-0-478-38791-9 (online)

March 2012

Ministry of Agriculture and Forestry
Te Manatū Ahuwhenua, Ngāherehere

BIOSECURITY NEW ZEALAND

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Publisher

Ministry of Agriculture and Forestry
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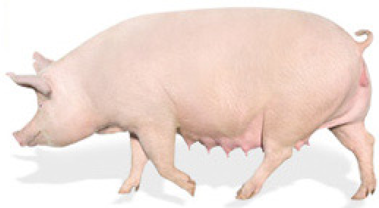
Pastoral House, 25 The Terrace
Wellington 6140
www.maf.govt.nz
Telephone: 0800 008 333
Facsimile: +64 4 894 0300



Title: Recalculate Pork Industry Emissions Inventory

Milestone 4: Document animal numbers and research: calculate current emissions, manure management categories, emissions factors and re –calculate total emissions estimates

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Executive Summary

To date, due to its small contribution to New Zealand's total greenhouse gas (GHG) emissions profile, the NZ Pork industry has been assigned default international standards provided by the Intergovernmental Panel on Climate Change (IPCC) for a majority of the calculations undertaken to determine its GHG emissions profile. In some categories such as Agricultural Soils, NZ specific default data has been included. However, values have been extrapolated from research conducted on dairy, beef and sheep farming rather than from specific data on pig production. As a result there is a degree of uncertainty on emission values provided in the Greenhouse Gas Inventory Report for the NZ Pork Industry.

This project aimed to improve the accuracy of data currently used in the NZ Greenhouse Gas Inventory Report (GHGIR) by undertaking an assessment of the NZ pork industry's management practices. During the project over 56 farms were surveyed which represented over 68% of NZ's pork production. Surveying recorded current methods being used on farms for practices relevant to GHGIR such as the animal waste management system (AWMS) that is being used on each site and diet compositions for animals on farms.

Results from the survey where complied and compared against existing default values used within the NZGHGIR with the aim of determining if the international standards currently being applied are relevant to the NZ Pork industry.

As a result of the investigation the project recommends the following adjustments to default values;

1. The adjustment of the proportions of various Animal Waste Management Systems (AWMS) being used by NZ Pork producers (MS values);
2. The recalculation of Gross Energy (GE) based on examination of animal diets in NZ (GE from 37MJ animal $^{-1}$day^{-1} to 26.9MJ animal^{-1}day^{-1});
3. The recalculation of enteric fermentation emissions factors from 1.5 kg CH_4 Yr^{-1} animal^{-1} to 1.06kg CH_4 Yr^{-1} animal^{-1};
4. The recalculation of volatile solid excreted (VS) from animals values calculated from the study from 0.5 VS head^{-1}day^{-}to 0.23-0.26kgVS head^{-1}day^{-1}; and
5. The recalculations of nitrogen excreted from animals (Nex) from 16kg N animal^{-1}Yr^{-1} to 10.8kg N animal^{-1}Yr^{-1}

Table 1 below outlines a comparison of GHG emissions from NZ pork producers where the current IPCC default values are applied, compared against changes to the proposed default values using both the IPCC 1996 and 2006 methodologies.

Table 1: Summary of results for the 1990 and 2009 calendar years

	Default values from the IPCC 1996 Guideline	Calculated EF using the IPCC 1996 Guideline 1990 Gg CO_2-e	Calculated EF using the IPCC 2006 Guideline	Default values from the IPCC 1996 Guideline	Calculated EF using the IPCC 1996 Guideline 2009 Gg CO_2-e	Calculated EF using the IPCC 2006 Guideline
Enteric Fermentation: CH_4	12.433	9.100	9.100	10.168	7.085	7.085
Manure Management CH_4	165.774	51.867	48.062	135.571	39.576	36.640
Manure Management : Direct N_2O	16.459	19.418	20.324	13.460	15.880	16.621
Manure Management : Indirect N_2O	NA	NA	5.707	NA	NA	4.667
Agricultural Soils N_2O: Direct	27.688	18.721	13.235	22.643	15.310	10.793
Agricultural Soils N_2O:	3.076	2.080	1.323	2.516	1.701	1.079

Indirect Volatilisation						
Agricultural Soils: N_2O Indirect Leaching	4.403	3.640	0.695	5.384	2.977	0.567
TOTAL	229.833	104.827	98.447	189.742	82.530	77.453

The results show a significant reduction in the quantity of CO_2-e being released from the NZ pork industry, with calculated emissions reducing the CO_2-e total by 59% when comparing the current default values used to date with the NZ-specific values determined in this investigation. The reduction was largely driven by a recalculation of emissions from the CH_4 manure management section. This sector represents the largest source of emissions from the NZ Pork industry. All calculations in 2009 show a reduction in emissions when compared against the baseline level set in the 1990 calendar year. This reduction is due to the reduced number of pigs being bred in NZ by pork producers with animal numbers down by approximately 18 % over the last 19 years.

The research also identified a number of gaps within the current knowledge when examining GHG emissions for the NZ Pork industry. This is particularly relevant to the manure management sector where only limited amount of research has been conducted specifically on pigs at a national level. Given the significance of this hot spot to the NZ Pork industry further work is required to remove uncertainty in the emissions profile.

1 Introduction

NZ is required under its obligations to the Kyoto Protocol to calculate its Greenhouse Gas (GHG) emissions. GHG emissions are reported in an inventory each calendar year, known as 'New Zealand's Greenhouse Gas Inventory Report' (GHGIR). For the 2008 calendar year total emissions from the agricultural sector were reported at 34,826.3 Gg CO_2-e (46.6 % of total emissions) (MfE, 2010). Of these emissions the pig industry was calculated to contribute approximately 190 Gg CO_2-e or 0.5% of agricultural emissions (MfE, 2010). This small contribution is due to the industry's size when compared against the dairy, beef and sheep industries in New Zealand. Additionally as pigs are monogastric animals, they contribute relatively limited CH_4 emissions through enteric fermentation.

To date, due to its small contribution to New Zealand's GHG emissions profile, the NZ Pork industry has been assigned default international standards provided by the Intergovernmental Panel on Climate Change (IPCC) for a majority of the calculations undertaken in the emissions profile. In some categories such as Agricultural Soils, NZ specific default data has been included, however, values have been extrapolated from research conducted on dairy, beef and sheep farms rather than specific data on pig production. As a result there is a degree of uncertainty on emission values provided in the GHGIR for the NZ Pork Industry.

1.1 NZ Pork Industry

The NZ pork industry is relatively small with less than 230 registered commercial producers. The industry is regulated by government and industry controls and is administrated by the New Zealand Pork Industry Board (NZPIB), known as NZPork which is a statutory producer board funded by producers through a levy paid on all pigs at the time of slaughter. (NZPork, 2010a)

Production of pork within NZ focuses on the domestic market contributing approximately 54% of pork consumed in NZ with imported products from countries such as Australia, USA Canada and Finland contributing 46% of consumption (NZPork, 2010). Over the last 20 years the total numbers of pork producers as well as pig numbers reared in NZ have been reducing with current numbers being 18% lower than values recorded in 1990 (see Figure 1).

Figure 1: Trends in populations from breeding sows (includes mated gilts) and other pigs (suckers, weaners, grower's, finishers and boars) 1990-2009 (adapted from StatsNZ, 2010)

This decrease been driven primarily by a strong NZ dollar over the last 10 years driving down the price of imported pork (MAF 2003) as well as an increased cost in production domestically. For the 2009 calendar year NZ pig production was recorded to be 10% down on the previous year. This was due to a number of influences, however the strong NZ dollar resulted in the largest quantity of imported pork into NZ recorded to date (39,536 tonnes carcass weight)(NZPork 2010).

Production in NZ is split between the North and South Island. The 2009 StatsNZ census indicates that production levels are higher in the South Island which has approximately 58% of NZ's producing sow population (StatsNZ, 2010). The range of environmental conditions experienced within New Zealand result in a wide range in management and housing techniques being required from intensive indoor systems to outdoor free range techniques.

1.2 NZ Greenhouse Gas Inventory (GHGIR)

On a national scale NZ undertakes monitoring of its GHG emissions and sinks through the NZ GHGIR. The report is part of NZ's commitment to the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol (MfE 2009). The inventories set a baseline level, being the 1990 calendar year, and record changes in emissions from that date. The annual inventory is compiled by the NZ Ministry for the Environment (MfE) using guidelines provided by the IPCC and UNFCCC. To date, the MfE has published inventories recording emissions from 1990-2008.

In NZ, the agricultural sector is the largest source of GHG emissions. The sector is responsible for emissions from the following activities: enteric fermentation, manure management, agricultural soils, rice cultivation, prescribed burning of savannas, and field burning of agricultural residues (MfE, 2010). For the NZ pig industries the primary sources of emissions which will be examined further within this report are:

- manure management systems: (producing CH_4 and N_2O).
- agricultural soils: (producing CH_4 and direct and indirect N_2O emissions).
- enteric fermentation (producing CH_4).

1.3 IPCC Methodology

In order to provide transparency of reporting between countries, the IPCC have developed guideline methodologies for countries which compile an inventory. Currently, the MfE in its 2008 GHGIR is using the IPCC's 'Revised 1996 Guidelines for National Inventories' as well as Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2001). However, the IPCC has recently updated its guidelines to bring them in line with the latest research on climate change and emissions sources and as a result have published the '2006 IPCC Guidelines for National Greenhouse Gas Inventories'. Currently the 2006 methodology has not been incorporated into national inventories as it is undergoing a review period to determine its suitability for use. In this document we examine the methodologies currently being used in the 2008 GHGIR as well as any proposed changes to methodology from the 2006 guidelines.

In both the revised 1996 and proposed 2006 IPCC guidelines the methodology includes three tiered levels which range in complexity to determine GHG emissions from a given source. This approach allows participating countries to select appropriate methodologies for reporting that meets their level of information and data available to them.

A brief summary of the tiers is as follows:

- **Tier 1** consists of simple equations and default emission factors provided in the IPCC-Guidelines (IPPC GL) and IPCC-Good Practice Guide (IPPC-GPG) which can be used in the absence of country-specific data;
- **Tier 2** uses the IPCC-GL default equations but requires country-specific parameters that better account for local climate, soil, management, and other conditions; and

- **Tier 3** methods are based on more complex models and inventory systems, typically using more disaggregated activity data that better capture variability in local conditions (IPCC, 2007).

In the NZGHGIR 1990-2008, Tiers 1 and 2 are used depending upon the availability of data for the agricultural industry (MfE 2010). It should be acknowledged that the current 2008 GHGIR inventory has been estimated to have an uncertainty in total emissions of ±9.5 per cent (MfE, 2010). The MfE (2009) reported that the high uncertainty was dominated by agricultural emissions particularly enteric fermentation and N_2O emission from agricultural soils. For the pig industry there is a heavy reliance on Tier 1 approaches particularly for calculating CH_4 emissions which constitutes 77% of the pig industry's emissions. The use of a Tier 1 approach limits the accuracy of the report as it does not account for all parameters that may be applicable at a local or even national scale.

1.4 Project Objective

To establish accurate data that can be used in calculations in the GHGIR for the NZ pork industry. It is envisaged that the project will provide:

- practicable options for further improving the accuracy and reliability of pork industry emissions data;
- options for managing any issues associated with system boundaries and allocation of emissions to pork or other sectors; and
- Identify follow-up work to address and mitigate net emissions from the pork industry.

1.5 Scope

The IPCC encourages countries to improve the default values used in their equations by undertaking research to obtain country specific values. This project is proposing to evaluate the emissions factors applied to the pork industry in New Zealand's GHGIR and to provide data to support the inclusion of more specific NZ data for the pork industry in the inventory.

On-farm analysis of operational practices such as manure management techniques and animal diet will be undertaken to obtain data that can be applied to the IPCC Tier 2 methodology in upcoming inventories as well as in the proposed Emissions Trading Scheme (ETS). This project does not propose to undertake on farm sampling to determine GHG emissions rather it provides a review of management practices that can be used to establish more accurate emissions factors in the inventory.

1.6 Project Aims

A review of literature undertaken as Milestone 1 for this project identified the following aims for this work.

Enteric Fermentation Aims: CH_4

Aim 1: to develop New Zealand-specific values for GE for pigs at varying stages of their life cycle.
Aim 2: to develop a New Zealand-specific value for the enteric fermentation emissions factor from pigs at varying stages of their life cycle.

Manure Management Aims: CH_4

Aim 3: to develop a New Zealand-specific value for the fraction of pig manure entering each AWMS (MS).
Aim 4: to develop a New Zealand-specific VS value for piggery effluent factoring in life cycle effects.
Aim 5: to calculate a New Zealand-specific Manure Management CH_4 emissions factor for the pig industry.

Manure Management Aims: N_20 direct emissions

Aim 6: to develop a New Zealand-specific Nex value for pigs.
Aim 7: To develop a New Zealand-specific value for the fraction of pig manure entering each AWMS (MS).
Aim 8: to calculate a New Zealand-specific Manure Management N_2O emissions factor for the pig industry.

Manure Management Aims: N_20 indirect emissions

Aim 9: To quantify indirect N_2O emissions from volatilisation in NZ pork manure management systems.

Agricultural Soils Aims: N_2O direct emissions

Aim 10: To compare direct N_2O emissions from agricultural soils using the current method applied to the NZ GHGIR and the proposed IPCC 2006 method.

Agricultural Soils Aims: N_2O indirect emissions

Aim 11: to calculate N_2O emissions from volatilisation from Agricultural Soils.
Aim 12: to calculate N_2O emissions from leaching from Agricultural Soils.

Carbon Offsetting: Plantings

Aim 13: to calculate carbon offsets from forestry plantings in the pig industry.

1.7 Methodology

Data for the calculations undertaken in this study was obtained from on farm surveying, NZPork, consultation with industry experts and available literature including IPCC guidelines. All IPCC default values used were obtained for a temperate environment (20°C).

Surveys of NZ pork producers were undertaken over a 3 month time frame (March – May). Efforts were made to contact as many pork producers as feasible. Seminars introducing the project to farmers were held at two NZ Pork field days in both the North and South Island. Additionally two articles were placed in February's and May's 2010 'Pork Outlook' Newsletter which gets distributed to all NZ pork producers in order to introduce the project.

Emails introducing the project were also sent to over 80 farms. Each email was followed up with a phone call to talk through the objectives of the project.

Over the 3 month period 68% of pork production in NZ was surveyed, consisting of 56 of NZ pork production. Surveying was conducted on both the North and South Islands. A breakdown of proportion of farms surveyed can be seen below.

Table 2: Division of Surveyed Populations North and South Island

	North Island	South Island
Population surveyed	95107	122516
%	44%	56%

Surveyed farms consisted of a variety of production types (indoor, outdoor etc.) and sizes ranging from over 3300 sows on one site to small scale producers with approximately 130 sows. Site visits were limited by bio security concerns with 21 farms undertaken. However due to the industry concerns of bio-security phone surveys were undertaken on the remaining 35 farms surveyed.

Surveys focused on the population data for each farm (weights, average lifespan of market animals), feed information (the quantity and composition of feed being consumed by animals on each farm) and the animal waste management systems (AWMS) being used on farm (e.g. method used and retention time of manure prior to land application). Additionally the survey examined any forest plantations on properties.

See Appendix 1 for survey forms provided to farmers.

Where conversions have been applied to convert GHG emissions to CO_2-e factors, global warming potential factors have been applied as to those currently used within the GHGIR (21 for CH_4 and 310 for N_2O).

2 Population

In order to undertake calculations it was important to establish population's data that can be used at both a Tier 1 and Tier 2 level. The following section outlines NZ pork population for the 2009 calendar year.

2.1 Tier 1: NZ Pork Populations

Currently in the NZ GHGIR (2010) the MfE are using StatsNZ data for pig populations in a given year. This data is derived from a series of census examining NZ farm populations. The survey is part of an on-going program by StatsNZ and MAF and is undertaken in June on an annual basis (StatsNZ, 2010).

While it is acknowledged the use of census data can lead to errors for animals that have seasonal reproductive cycles (e.g. lambs, where populations can expand during the spring months) this is not a concern for pigs, as production numbers are relatively constant throughout the year. As a result StatsNZ census of animals seems an appropriate method for identifying population data for NZ pork and is an accepted method in the IPCC guidelines.

For the 2009 Agricultural Production Survey released in May, StatsNZ used a stratified sample design by regional councils to select a sample from the NZ pig population for surveying. StatsNZ concludes that for the pork industry there is a 1% sampling error around the 95% confidence interval and 13% imputation level for total pig numbers in NZ (StatsNZ, 2010).

While census have been undertaken from 1990-2009, StatsNZ notes that methodologies for data collection has changed over time. This change in methodology has the potential to limit accuracy when comparing data between years. However, in StatsNZ data is the most accurate indicator of animal populations over this time frame.

2.1.1 Method: Tier 1

2.1.2 StatsNZ data for NZ pig populations was obtained for the 1990 base line year as well as 2009. Results: Tier 1

Table 3 below shows the breakdown of population numbers that are used in Tier 1 calculations in this study.

Table 3: Tier 1 Population NZ pig numbers (Source: StatsNZ, 2010)

	Breeding Sows, over 1 Year Old	Mated Gilts	Other Pigs	Total Pigs
1990	44,665	6,325	340,013	394,701
2009	33,771	5,701	283,317	322,788

Where:

Mated gilts - young female pigs mated for the first time.
Other pigs - these include boars, finishers, porkers and any piglets still on the farm at 30 June.
Total pigs - this is the count of all animals on the farm on 30 June. It includes breeding sows, mated gilts and other pigs.

2.2 Tier 2: NZ Pork Populations

Both the revised 1996 and proposed 2006 IPCC guidelines recommend livestock population be divided into subcategories where detailed data analysis is being undertaken as an animal's GHG emissions profile changes over its life cycle. The division of a population into sub categories allows calculations to be made that better reflects the GHG emissions profile of an animal over its life cycle. The IPCC 2000 Good Practice Guidelines notes that it is preferable to classify the swine population into the following sub-categories: sows, boars, and growing animals. Sows could be further classified into farrowing and gestation sows, and growing animals further divided into nursery, growing and finisher pigs.

In the NZ pork industry there have been changes to production levels over the course of the last 20 years which has affected the population profile of the pig industry. Prunier et al. (2010) summarises that during the past decades, production levels for pigs globally have increased due to genetic selection, the acceleration of the reproductive cycle (interval between two farrowing times 155.8 days in 1968 to 148.7 days in 2006 (Prunier et al., 2010)) as well as improvements in feeding regimes, animal housing and husbandry. All of these parameters need to be taken into account when determining population subclasses for the year 1990.

2.2.1 Method: Tier 2

There is currently an absence of published data on the changes in production levels over time from the NZ pork industry. As a result, information to determine appropriate assumptions for the division of animals into their subclasses was obtained from on farm surveys as well as consultation with industry experts from Massey University and representatives from NZ Pork.

Population subclasses from 1990-2009 were calculated to account for the improved efficiency of growth rates resulting in a shorter life expectancy for market pigs, increased rate of farrowing in sows as well as a decrease in boar numbers due the increased utilisation of artificial insemination (AI). For the year 2009, subclasses were determined based on survey information collected on farms to account for current farm practices (i.e. age of market animals at slaughter, boar to sow ratios). For the year 1990, subclasses were determined based on discussions with industry experts. (Assumptions used to determine populations subclasses are outlines in Appendix 2).

2.2.2 Result: Tier 2

Table 4 below outlines the subclass population used for Tier 2 calculations.

Table 4: Tier 2 Sub classification: Populations 1990 and 2009

Breeding pigs	1990	2009
Sows in gestation	42832	32,367
Sows which have farrowed	8158	7,105
Boars	3698	1,279
Total Breeding pigs	**54688**	40,751
Growing pigs*		
Suckers	56669	55,032
Weaners	99170	82,548
Growers	99170	82,548
Finishers	85003	61,911
Total Growing pigs	**340013**	282,038
TOTAL	394,701	322,789

* Growing pigs are defined by age definitions provided in Appendix 2.

3 Enteric Fermentation

Enteric fermentation in NZ's GHG inventory is regarded as the largest source of emissions in the agricultural sector, contributing 30.3% of NZ's total CO_2-e emissions and 61.4% of agricultural emissions for the 2008 calendar year (MfE 2010). This is primarily due to ruminant animals such as cattle and sheep which produce large quantities of CH_4 during their digestion process, where plant material is fermented by microbes in the rumen or the first of the four stomachs (MfE 2009, IPCC 2001, and USEPA 2009).

Pigs being monogastric animals do not have a rumen; however, they do produce small amounts of CH_4 during digestion (Clark *et al.* 2001). This is generally formed by the fermentation of carbohydrates in the digestive system, particularly in the lower gut, which results in the formation of short-chain fatty acids as acetic-, propionic- and butyric acid, as well as gasses as carbon dioxide (CO_2), hydrogen (H_2) methane (CH_4), urea and heat (Bach Knudsen and Jørgensen, 2001).

While the share of gross energy being converted to CH_4 is minimal when compared against losses in rumen animals (Farran *et al*. 2000), the amount of CH_4 produced by a pig is dependent upon the age or live weight of the aniaml as well as the type of diet that they receive (Noblet and Shi, 1993). Feeds that ferment rapidly to produce a high proportion of propionic acid (e.g. cereals) produce less CH_4 than fibrous feeds (e.g. fresh and dried grasses) (Clark *et al*. 2004). Low quality feed has a slightly higher CH_4 conversion rate while some feeds, such as distiller grains, are high in protein and are highly digestible; thereby leading to lower CH_4 production (USEPA, 2009).

In NZ there has been extensive research on enteric fermentation from ruminant animals, however, there has been limited research on emissions from monogastric animals.

3.1 Aim 1 : To develop New Zealand-specific values for Gross Energy and Digestible Energy for pigs at varying stages of their life cycle.

Aim 1 of this study was to develop a NZ Specific Gross Energy (GE) and Digestible Energy (DE) value which represents the average energy of feed being provided to pigs in NZ at varying stages of their life cycles. GE is the base unit of energy and is measured as heat generated during combustion (MJ/kg of feed). DE is calculated by examining the GE content of the food, minus the energy content of the faeces resulting from the consumption of the food material. GE values are used IPCC formulas to calculate emissions for enteric fermentation and manure management while DE is used for manure management emission calculations (see Section 4).

3.1.1 Method: Aim 1

The IPCC's Tier 2 methodology provides for calculation of GE and DE to be made based on animal requirements for life including maintenance, activity, growth and reproduction. This methodology is primarily provided for grazing animals where specific details of their diets vary depending upon grazing methods. However, pigs' diets are provided in a controlled environment on farms. This practice allows for GE and DE values in their diets to be calculated at a variety of points throughout an animal's life cycle, by analysis of the feed being provided. The use of this method is the preferred method for calculations pertaining to the pork industry in the 2006 IPCC guidelines.

The project involved surveying of animal's diets on individual farms in NZ. Surveying asked the farmers to provide details of their diets (i.e. the contents of each feed mix (% of barley, maize, wheat, milk powder etc), the quality of each feed mix used on farm over the course of a given time period) as well as the populations of animals consuming the feed.

Feed information was collected for all feed mixes provided on farms e.g. creep, weaner, grower, finisher, lactating sow and dry sow meals etc. However, a CH_4 conversion factor of zero was assumed for all juvenile pigs consuming only milk (i.e. milk-fed piglets) (IPCC, 2006).

GE values of feed mixes were calculated from 59% of NZ's production. This value is thought to be representative of NZ pig diets as commercial pig diets are formulated to standard specifications in terms of energy values and protein/amino acid balance. While the formulations will vary slightly depending on genotype, housing system, healthy status and ingredients available, the diets will be formulated to closely meet the nutritional needs of pigs, as economically as possible and fed to minimise waste. There are a limited number of ingredients available – normally cereal based using the majority of barley in the South Island with some wheat and in the North Island barley based with some inclusion of maize and wheat. In addition milling by products like broll may be used to boost the fibre content. Protein ingredients used will include meat and bone meal, blood meal, fish meal, soya bean meal, and milk powders for young pigs. Sources of energy in the form of tallow and soya oil will be used in some situations to boost the energy content if it is priced right. Given the small range of ingredients available and with the various price relativities in practice the diet formulations remain fairly constant and of a similar make up between farms because they are all trying to achieve similar outcome in terms of price and pig performance.

Nutritional information used in the study was from NZPork (1999) publication entitled 'A Standard Nutrient Matrix for NZ Feedstuff'. The matrix provides nutritional information on the primary feed for pigs used in NZ. Where GE and DE values were not available in the matrix, data was obtained from consultation with industry experts. If commercial feed mixes were used on farms, feed companies were contacted to provide nutritional data sets. However, these data sets were often limited due to confidentiality concerns. GE and DE values used for primary products in feed mixes were calculated on an 'as fed' basis which provides adjusted values for the moisture content of the feed. Values used for primary ingredients are outlined in Appendix 3. However, due to confidentiality concerns in the industry, feed breakdowns by concentration of ingredients have not been provided.

3.1.2 Results: Aim 1

The following table (Table 5) presents the GE values obtained from examining the diets of NZ pigs at varying stages of their lifecycle. Results for DE can be seen in Table 14 of Section 4.2 (see Appendix 3 for complete data set).

Table 5: Average GE values calculated from feed provided to NZ pigs (GE ($MJhead^{-1}Day^{-1}$)

	Average value GE ($MJhead^{-1}Day^{-1}$)	Range GE ($MJhead^{-1}Day^{-1}$)	SDE
Breeding swine			
Sows in gestation	40.14	28.5-55.8	6.89
Sows which have farrowed	132.46	88.8-183.26	28.25
Boars	41.3	32.12-61.38	7.23
Growing swine			
Suckers	4.69	1.41-14.47	2.56
Weaners	15.63	6.42-34.20	6.10
Growers	29.14	17.33-48.71	6.98
Finishers	39.25	20.3-53.38	7.36
Average value (adjusted for population)	26.9MJ $animal^{-1}day^{-1}$		

3.1.3 Discussion: Aim 1

The results show some variability in the range of GE values being provided within NZ pig diets. However, this range is in keeping with the differences in farming methods being employed across NZ pig farms. In NZ there is a large range of environmental conditions, housing, age, genetic differences and feeding methods used on site, all of which have the potential to alter the nutritional requirements of an animal. For sows the dietary energy requirements will also vary with body weight, with the requirements of an animal in parity 1 and 2 different from older animals (Young et al. 2005). Therefore herds with a high replacement rate will have a higher GE requirement than older herds.

The results show an average GE value of 26.9MJ animal^{-1}day^{-1}. This value is substantially lower than the current IPCC default value of 37MJ animal^{-1}day^{-} recommended by Crutzen et al. (1986) (IPCC, 1996 and 2006). Crutzen et al. (1986) calculated this value based on an average value of 12.5MJ animal^{-1}day^{-} for growing animals and 90MJ animal^{-1}day^{-}for lactating sows. The value was adapted based on weight class population statistics for West Germany. However, the exact population breakdown used to determine Crutzen's et al. (1986) average value was not provided and it is unclear how this value may have changed over the last two decades where herd structures have altered due to improvements in genetic selection, acceleration of the reproductive cycle, improvements in housing and feed as well as husbandry and herd management (Prunier et al. 2010).

The results from this study fall in the range of nutritional requirements recommended for NZ pigs by National Animal Welfare Advisory Committee (2005) standards 'Animal Welfare (pigs) Code of Welfare' (2005). This provides us with confidence in values being used.

Surveying was unable to define data on diets of animals in 1990. Rather farmers were asked to comment on how they believe their feed has changed over the last 19 years. In general most farmers believed that their basic feed mix has not changed significantly over the time period, with the exception of changes to their vitamin and mineral premixes. However, a greater reliance on by-products such as bread and cereals was noted on some of the smaller farms.

As a result of the limited information and high uncertainty surrounding actual diets for the year 1990, it is recommended that the calculated GE value determined in Table 5 be applied for both 1990 and 2009 calculation.

3.2 Aim 2 : to develop a New Zealand-specific value for Enteric Fermentation Emission Factor (EF) from pigs

Aim 2 for the project was to use the GE values obtained above to develop a NZ specific EF value for enteric fermentation the NZ pig industry. Given that pig industry does not contribute large quantities of GHG emissions from enteric fermentation due to the pigs' monogastric digestive systems, the proposed 2006 IPCC recommends that a Tier 1 method is sufficient to quantify emissions from enteric fermentation (IPCC, 2006). While this approach is acknowledged, data was obtained during this study for manure management that allowed for calculations to be made at a Tier 2 level and as a result we propose to undertake a comparison between the two different IPCC methodologies. It is also proposed that from the analysis of data we can develop a NZ specific EF for enteric fermentation that can be used in a Tier 1 equation.

3.2.1 Method: Aim 2

<u>Tier 2 equation</u>

The IPCC 1996 Tier 2 method was used for the calculations in this study. This method assumes CH_4 emissions are a function of the animal population and the quantity of GE being consumed by an animal.

The GE value can be adjusted dependent upon the animal's diet as it moves through its life cycle, providing a more accurate representation of emissions from each animal subclass (See Equation 1). In the equation the IPCC recommend that a methane conversion factor (Ym) of 0.6 % of the GE consumed by an animal be applied in the formula. A review of literature undertaken for Milestone 1 of this project noted that there was limited NZ specific data for this value and as a result the IPCC default value will be applied in the following calculations.

$$EF = \left[\frac{GE \bullet \left(\frac{Y_m}{100} \right) \bullet 365}{55.65} \right]$$

Equation 1

Where:

EF = emissions factor, kg CH_4 head^{-1} yr^{-1}.

GE = gross energy intake, MJ head^{-1} day^{-1} (obtained from on farm analysis).

Y_m= the methane conversion rate. IPCC default is 0.6%.

The factor 55.65 (MJ/kg CH_4) is the energy content of methane.

Emission factors are then applied to the Tier 1 methodology utilizes the following equation.

$$CH_4 \text{ enteric fermentation} = Pn * EF$$

Equation 2

Where;

Pn = is the adjusted pig population of NZ.

EF = the emissions factor for enteric fermentation from pig.

3.2.2 Results: Aim 2

Table 6 outlines proposed EF for NZ pig industry.

Table 6: Proposed Emissions factors for Enteric Fermentation in NZ pigs (kg CH_4 head^{-1} yr^{-1}) based on GE calculations

	Emission factor for enteric fermentation (kg CH_4 head^{-1} yr^{-1})	WEIGHTED VALUE (kg CH_4 head^{-1} yr^{-1})
Sows in gestation	1.58	
Sows which have farrowed	5.21	
Boars	1.58	
Breeding Animals		2.21
Suckers	0.18	
Weaners	0.62	
Growers	1.15	
Finishers	1.55	
Growing Animals		0.893
Weighted Value for NZ Pork		1.059

3.2.3 Discussion: Aim 2

Historically, CH_4 emissions have been analysed from animals to determine any reduction of productivity that may be occurring in the form of carbon loss (Christensen and Thorbeck 1987 and De Lange 2006). However, CH_4 is now also being investigated due to its global warming potential. While enteric fermentation in ruminant animals has been extensively studied, information on gas production by pigs is limited (Jørgensen 2007).

Diet variability has the potential to affect the concentrations of CH_4 emitted from an animal and can result in a range of emissions. Christensen and Thorbeck (1987) reported a linear increase in CH_4 emissions with food intake for thirty-six castrated male pigs. Their study reported an emissions range of 0.33-0.42 $kgCH_4head^{-1}Yr^{-1}$for an animal 20-25kg to 1.98-2.17 $kgCH_4head^{-1}Yr^{-1}$for 105-120kg animals when fed a commercial feed mix. In NZ the average weight of a finished market animal is 91kg, which when compared against Christensen and Thorbeck (1987) results based on weight class of animals has a emission rate between1.34-1.96 $kgCH_4head^{-1}Yr^{-1}$. The finisher diet had calculated within this investigation was 1.55 $kgCH_4$ $head^{-1}Yr^{-1}$, our diets fall in this range of emissions.

Jørgensen (2007) also undertook a study to measure CH_4 emissions in growing pigs and adult sows and measured an average emission of 2.5 $kgCH_4head^{-1}Yr^{-1}$for a sow and 0.86$kgCH_4head^{-1}Yr^{-1}$for a growing animal. Jørgensen (2007) measurements show a good correlation with the results from this study which calculated an average value of 2.21 $kgCH_4head^{-1}Yr^{-1}$and 0.893 $kgCH_4head^{-1}Yr^{-1}$ determined for breeding animals and growing animals, respectively.

The data also shows good agreement with a study from Whittenmore (1996), who calculated the daily average CH_4 production from a 60kg pig is about 0.2MJ/day. This equates to an emissions factor of 1.31$kgCH_4head^{-1}Yr^{-1}$, which falls in our grower and finisher range of 1.15-1.55$kgCH_4head^{-1}Yr^{-1}$.

Currently, the value used as an IPCC default value for enteric fermentation rates for pigs in NZ is 1.5$kgYr^{-1}$ $animal^{-1}$ as calculated by Crutzen et al. (1986) and is being used as the value for all developed nations with pigs. The value has been reported to have a ±20% accuracy rating (IPCC 1996) while in the 2006 proposed IPPC guidelines, this value has been increased to an uncertainty of +30-50% for Tier1 calculations.

Based on the data outlined above this study has found that an emission factor of 1.06 $kgCH_4head^{-1}$ Yr^{-1} would better represent the CH_4 being produced by enteric fermentation from pigs in NZ.

3.3 Calculations Enteric Fermentation

3.3.1 Tier 1 calculations

The following table provides a comparison between the IPCC default values for the calendar year 1990 and 2009 and the proposed NZ specific EF identified from this study.

Table 7: Tier 1 Calculations for Enteric Fermentation for 1990 and 2009

Category	Number of animals (single yr) (1000s)	Emission factor for enteric fermentation1 (kg CH_4 $head^{-1}$ yr^{-1})	Emissions from enteric fermentation (Gg)
IPCC default EF 1990	395	1.5	0.59
IPCC default EF 2009	323	1.5	0.48
Study Calculation 1990 Proposed EF	395	1.06	0.42
Study Calculation 2009 Proposed EF	323	1.06	0.34
Difference between IPCC default and study			29%

The recalculation based on NZ specific data equates to an approximate reduction of 29% from the IPCC default calculations.

3.3.2 Tier 2 calculations

A Tier 2 approach to calculate emissions from enteric fermentation aims at reducing the level of uncertainty in the emissions estimate.

Table 8: Tier 2 Calculations for Enteric Fermentation for 1990 and 2009

	1990			2009		
	Number of animals (single yr) (1000s)	Emission factor for enteric fermentation (kgCH_4 head^{-1} yr^{-1})	Emissions from enteric (CH_4 Gg)	Number of animals (single yr) (1000s)	Emission factor for enteric fermentation (kgCH_4 head^{-1} yr^{-1})	Emissions from enteric fermentation (CH_4 Gg)
Sows in gestation	43	1.58	0.068	32	1.58	0.051
Sows which have farrowed	8	5.21	0.043	7	5.21	0.037
Boars	4	1.58	0.006	1	1.58	0.002
Suckers	57	0.18	0.010	56	0.18	0.010
Weaners	99	0.62	0.062	85	0.62	0.053
Growers	99	1.15	0.114	85	1.15	0.097
Finishers	85	1.55	0.132	56	1.55	0.087
Total			0.433			0.337

3.4 Summary: Enteric Fermentation

The follow table outlines a summary of Tier 1 and Tier 2 results calculated in this study for the 1990 and 2009 calendar years.

Table 9: Summary Table: Enteric Fermentation for 1990 and 2009

Year	Category	Emissions from manure management (CH_4 Gg)
1990	IPCC Default EF	0.59
	Study Calculation with Proposed EF	0.42
	Study Calculation at a Tier 2 level	0.43
2009	IPCC Default EF	0.48
	Study Calculation with Proposed EF	0.34
	Study Calculation at a Tier 2 level	0.34

- The investigation of diets of over 59% of NZ pork production identified that the IPCC default factor for GE value of 37MJ animal $^{-1}$day^{-1} overestimates the energy being provided to the average NZ pig. Rather a value of 26.9MJ animal^{-1}day^{-1} better represents the nutritional diets being provided.

- As a result the study concluded that the current IPCC default value does not accurately reflect the enteric fermentation emissions and recommends that an EF value of 1.06 kgCH_4Yr^{-1} animal^{-1} at a Tier 1 level better reflects NZ conditions.

- While a Tier 2 calculation provides a better level of detail on emissions across a profile, it is acknowledged that enteric fermentation in the pig industry contributes approximately 0.5% of NZ's GHG emissions from animals. Therefore the findings of this study would recommend that at the IPCC Tier 1 equation be applied with the adjusted value of 1.06 kgCH_4Yr^{-1} animal^{-1} for future calculations in the NZ Greenhouse Gas Inventory.

4 Manure Management: Methane (CH_4)

In the IPCC definitions, manure management refers to emissions of CH_4 and N_2O produced from the management and treatment of manure from agricultural processes (IPCC, 1996). (The emissions from the disposal of the manure once treated either in solid or liquid form is considered in the Agricultural Soils section below).

The 2008 NZ GHGIR reported that Animal Waste Management Systems (AWMS) across NZ contribute 776.3Gg of CO_2-e annually, due largely to the countries use of anaerobic lagoons to treat wastewater (MfE, 2010). Intensive farming practices, where animals are kept in close proximity to each other (e.g. dairy or pig production units) often rely on wastewater treatment technologies to treat and then dispose of their waste. However, these processes can result in the generation of GHG emissions. Currently in the 2008 GHGIR, CH_4 emissions from manure management in the pork industry have been calculated at 136.6 Gg CO_2-e yr^{-1} (MfE, 2009) comprising 72% of the pork industry's total emissions.

The production of CH_4 from animal effluent depends largely upon the concentration of volatile solids (VS) excreted by an animal and the environmental conditions by which the AWMS stores or treats the effluent (e.g. anaerobic or aerobic environments). Some liquid wastewater treatment systems such as lagoons, ponds or tanks depend on their anaerobic nature to encourage other treatment processes such as reducing BOD_5 and COD, however, in doing so they have the potential to produce large quantities of CH_4. Alternatively, manure that is left in a solid state i.e. not treated with water but disposed of in stock piles, mixed with straw or saw dust or directly onto pastures, is more likely to decompose aerobically and therefore produce less CH_4 (IPCC 1996).

In this section we propose to undertake surveying of NZ Pork-producing farms to determine the extent of each AWMS in use within NZ, as well as calculate a VS excretion rate of NZ pigs.

The IPCC currently has two methodologies available to calculate CH_4 emissions from manure management being the revised 1996 IPCC guidelines and the proposed 2006 IPCC methodologies. We propose to undertake a comparison between the two guidelines to determine the methodologies' impact on reported CH_4 emissions from manure management.

4.1 Aim 3: to develop a NZ-specific value for the fraction of pig manure entering each AWMS (MS)

In NZ, no information was available that provides a breakdown of AWMS being used in the pork industry. As a result in previous calculations of CH_4 emissions in the GHGIR an IPCC default value calculated for the 'Oceanic Region' has been applied. The current breakdown of animal waste being treated by each AWMS as defined by the IPCC can be seen in Table 10 (below) based on a study under taken by Safley et al. (1992). However, members in the NZ pork industry have expressed concern about these default values; outlining that the values do not reflect the management practices being used on the ground.

Table 10: Current breakdown of animal waste management systems applied to NZ (Source: IPCC 1996 Oceanic region and MfE 2009)

Animal Waste Management System	Default proportion of wastewater treated (%)
Anaerobic Lagoons	55
Solid Storage and dry lot	17
Pasture range and paddock (Grazing animals)	0
Other	28

Given that for the NZ pig industry, manure management emissions comprise 72% of all pork emissions calculated in the 2008 GHGIR, further work was required to reduce the uncertainty for the industry in this sector. As a result, Aim 3 of this study was to undertake an investigation of the AWMS being used on NZ farms.

4.1.1 Method: Aim 3

Site visits and phone surveys were undertaken on 56 pig farms comprising over 67% of NZ pork production, with the goal of determining the AWMS being used on farms. For each site, farm managers were asked to provide a schematic drawing of their manure management systems on site. Where available the residence time of manure in management systems, solid separation techniques undertaken and the number of animals using each system at a subclass level similar to that applied for enteric fermentation were recorded. The data was then collated into the IPCC's Manure Management Classification System (see Table 12).

In doing so it became apparent that sections of the IPCC methodology were not compatible with what was occurring at a farm level. Surveying of NZ Pork producers showed the following problems associated with applying the IPCC guidelines.

1) *On farm manure can be treated by more than one AWMS system*

In New Zealand, AWMS are often tailored to onsite conditions both from a farm management perspective, but also as a result of the sensitivity of the surrounding environment. As a result there are a wide range of AWMS options available for the treatment of pig manure and it is not uncommon for manure to be treated by more than one system. The use of more than one manure treatment system to treat a sample of manure presents a problem in ascribing discrete MS values for each treatment system. For example, consider a farm that treats its manure by passing it through a deep litter system first and then subsequently composts it before spreading it to land. The current inventory method cannot account for this multiple treatment step process. In fact, 100% of the manure would be assigned to a deep litter treatment system, and 100% of the manure would also be ascribed a composting system, creating an obvious imbalance in the proportion of manure treatment systems being used.

Onfarm surveying showed that manure does indeed pass through a number of different AWMS for treatment prior to being applied to land. For the purposes of this study the two main systems were noted that use more than one AWMS to treat manure. These were:

a) Pull plug systems, where manure is stored under the animal enclosure for a period of time up to a month and may then be treated by an anaerobic lagoon (because most of the degradable volatile solids are converted to CH4 in the anaerobic lagoon, only the proportion of effluent going into lagoons is considered in calculations proposed for this study).

b) Deep litter systems, which will also use a form of composting on site prior to applying the material to land (to eliminate double counting of treatment system contributions, grouping of these two systems was undertaken).

Further clarification is required from the IPCC for the appropriate methodology if more than one system is in use.

2) *The use of solid separator techniques on farm.*

Surveying of NZ farms concluded that the use of solid separators is common on liquid based systems and that more than one system can be in operation. Solid separation techniques limit the VS loading rate from a system, with some separation techniques such as settling recorded to reduce VS loading rates in the liquid fraction by as much as 70% (Hashimoto and Chen, 1976;

Powers et al., 1995; Zhang and Westerman, 1997). The IPCC (2006) guidelines noted that it is important to carefully consider the fraction of manure that is managed in each type of system if a solid separator is in use. However does not provide a method for their inclusion.

Three main techniques for solid separation where identified through surveying of NZ farms, these techniques are outlined below;

a) *Screens* -Screens are simple low cost methods of solid removal from effluent. Screens are usually formed by wedged bars spaced 0.5-1.5mm apart and are widely used in the NZ pig industry. The efficiency of a screen depends largely on the size of the screen: flow rate, solid percentage of the slurry (loading rate) and viscosity of the media.

b) *Screw Press*- A screw press system is a cylindrical screen with a screw-conveyor in the centre. The conveyor pushes solids up against screen removing moisture (FSA Consulting, 2002). For screw press systems the rate of VS removal is highly dependent upon the solid loading in each system.

c) *Settling* -Settling systems such as weeping wall systems and sand traps have a large impact on VS loading rates to piggery wastewater management systems. For piggery effluent, estimates indicate that approximately 70% of both the large and small particles can settle out after 10-20 minutes of sedimentation (Hashimoto and Chen, 1976; Powers et al., 1995; Zhang and Westerman, 1997).

A review of literature was undertaken to determine the effects these solid separation techniques have on the VS loading rates and Nitrogen (N) of an AWMS treating piggery effluent (see Appendix 4). As a result of the review the following removal rates were identified as appropriate if a solid separator was used on site.

Table 11: Effect of sediment removal techniques on VS and N loading rates to AWMS

Sediment Removal System	Percentage of VS removal	Percentage of N removal
Screens	20%	6.1%
Screw press	30%	9.2%
Settling	60%	20%

Where a solid separator was in use on farm VS and N loading rates were adjusted using the following formula;

$$\text{Liquid fraction}_{Pn} = (100\text{- \% removal rate}) * Pn$$

$$\text{Solid fraction}_{Pn} = \text{\% removal rate} * Pn$$

Equation 3

Where:

Liquid fraction $_{Pn}$ = the proportion of manure that *passes through* a solid separator system and then goes to a particular animal waste management system, weighted to a given farm's pig population.

Solid fraction $_{Pn}$ = the proportion of manure that is *captured* by a solid separator system and then goes to a particular animal waste management system, weighted to a given farm's pig population.

% removal rate = rates determined for VS and N depending on method of solid separation used on site (Table 11).

Pn= animal population assigned to the AWMS on farm.

If a solid separator was used on site surveying took note of the AWMS that was used to treat both the solid and liquid fraction of the manure. The loading rate calculated by Equation 3 for both the solid and liquid fraction was assigned to the appropriate AWMS. For example if a screw press was used on site prior to a anaerobic lagoon the liquid fraction would be assigned to the lagoon while the solid fraction separated would be assessed to determine the AWMS used to treat the removed materials.

3) *The deep litter definitions provided in the proposed 2006 IPCC methodology are not compatible with common farm practices used in the NZ pork industry and as a result would overestimate emissions from that point source.*

The deep bedding category in the proposed 2006 IPCC guidelines provides two categories for the use of deep litter bedding, being litter used for greater than or less than 30 days. We believe that it was the intention of the IPCC to derive the two categories to accommodate the two different deep litter practices being used on farms; one, being the use of material such as straw for a batch of animals during a limited period of time prior to it being removed from the stalls, and the second being the use of deep litter such as saw dust that is kept onsite often between 6 months to a year and is not changed between animal batches.

The review of literature revealed that there is limited data globally on the release of CH_4 from deep litter use in piggeries. In general, deep litter systems where faecal matter is kept predominantly dry are thought to contribute less CH_4 emissions than anaerobic systems (IPCC 2006). The IPCC 2006 guidelines have calculated their MCF value for deep litter through an expert panel while examining studies undertaken by Moller et al. (2004) and Mangino et al. (2001) which are not studies that look specifically at deep litter systems. The panel determined that if the litter is changed regularly (< 30 days) only 3% of the Bo is converted to CH_4. However, if the litter is changed less frequently, anaerobic conditions can develop leading to greater CH_4 emissions. As a result a MCF of 42% of the Bo is recommended in the guidelines (IPCC 2006).

However, these values would vary dependent upon whether the bedding was being used for cattle deep litter systems or piggery systems. Sommers (2006), comments that emissions from deep litter mats for pig houses may be considerably different from those from cattle houses due to the social behavior of pigs such as nest building which mixes the straw bedding and provides aeration. In comparison cattle's hoofs tend to compact their bedding increasing temperature in the bedding as well as reducing the oxygen content; conditions which are favourable for the production of CH_4 emissions (Sommers, 2006).

For the NZ pork industry it is common practice to use straw on site for weaner and grower batches that have a retention time of between 4-7 weeks. This practice excludes applying the 30 day cut off value for deep litter and increases the MCF value from 3% to 42% of the Bo. However, given the behaviour of pigs which contributes to aeration of straw the variation from 3% to 42% of the Bo loading rate does not seem appropriate for a relatively small increase in retention time. As a result it was proposed that we extend the definition that is used in the New Zealand inventory calculations of the retention time to less than or greater than 50 days to accommodate this common practice on NZ farms (see Section 4.3 for further details on the adapted MCF value).

As a result of these concerns, definitions of AWMS had to be altered to accommodate on farm practices. The following table outlines the definitions used in this study for classifying AWMS in operation in NZ. Where changes have been made from IPCC definitions they have been outlined. Additionally, we propose the use of two additional categories that combine deep litter and composting for greater and less than 50 days.

Table 12: IPCC Manure Management Classification Systems and project definition manure management systems

	IPCC Manure Management Classification System	Project Definition
Uncovered Anaerobic lagoon	Characterised by flush systems that use water to transport manure to lagoons. The manure resides in the lagoon for a period of 30 days to over 200 days. The water from the lagoon may be recycled as flush water or used to irrigate and fertilise fields.	As per IPCC definition however provisions have been made for VS and N loss if solid separation has occurred. Definition includes emissions from pit storage if Pit storage (pull plug) systems are followed by an anaerobic lagoon.
Pasture/Range /Paddock	The manure from pasture and range grazing animals is allowed to lie as deposited, and is not managed.	As per IPCC definition (see photos Appendix 4)
Liquid/ Slurry	Dung and urine are collected and transported in liquid state to tanks for storage. Liquid may be stored for a long time (months). To facilitate handling water may be added.	As per IPCC definition
Daily Spread	IPCC 1996 definition Dung and urine are collected by some means such as scraping. The collected waste is applied to fields. IPCC 2006 definition Manure is routinely removed from a confinement facility and is applied to cropland or pasture in 24 hours of excretion.	Manure is routinely removed from a confinement facility and is applied to cropland or pasture in 48 hours(retention time expanded to accommodate 5 day/week direct to land pumping
Solid storage	Dung and urine are excreted in a stall. The solids (with or without litter) are collected and stored in bulk for a long time (months) before disposal, with or without liquid runoff into a pit system.	As per IPCC definition
Dry Lot	In dry climates animals may be kept on unpaved feedlots where the manure is allowed to dry until it is periodically removed. Upon removal the manure may be spread on fields.	As per IPCC definition
Pit Storage Below animal confinement	Combined storage of dung and urine below animal confinements: <1 month >1 month	As per IPCC definition however provisions have been made to extend the retention time for used in Daily spread. Combined storage of dung and urine below animal confinements pull plug systems where manure is stored for >48hours before being applied directly to land.
Anaerobic Digesters	The dung and urine in liquid/slurry are collected and anaerobicaly digested. CH_4 may be burned and used, flared or vented.	For the purposes of this project this includes covered anaerobic pond systems..
Cattle swine deep bedding	As manure accumulates, bedding is continually added to absorb moisture over a production cycle, possibly for as long as 6 to 12 months. This manure management system is also known as a bedded pack manure management system and may be combined with a dry lot or pasture. Less than 30 days and Greater than 30 days	*Most pig rotations on deep litter last for a period of 6-7 weeks at which point the deep litter is removed from each system and composted Therefore for the NZ pork industry the definition of <30 days does not meet requirement Retention time extended to less than or greater than 50 days
Composting static pile	In-Vessel Composting, typically in an enclosed channel, with forced aeration and continuous mixing. Static Pile: Composting in piles with forced aeration but no mixing.	As per IPCC definition
Composting windrow	Intensive window Composting in windrows with regular (at least daily) turning for mixing and aeration. Passive windrow Composting in windrows with infrequent turning for mixing and aeration.	As per IPCC definition
Dual AWMS groupings		
Cattle swine deep bedding less than 50 days + composting		Bedding used on site for <50 days followed by composting of manure
Cattle swine deep bedding		Bedding used on site for >50 days followed by composting of manure

greater than 50 days + composting		

At each farm surveyed information was recorded on the type of AWMS being used on site for each sub-class of animal. E.g. for some outdoor farms in NZ all sows, boars and suckers are housed outdoors and weaners, growers and finishers in doors on deep litter. For this case the number of animal in each subclass using the AWMS classified above was recorded.

In order to calculate MS values the number of animals calculated in each AWMS over 56 farms were compared against the total population of animals surveyed.

4.1.2 Results: Aim 3

The results from surveying indicated the following breakdown of AWMS in operation across NZ pork farms.

Table 13: Breakdown of manure management systems being applied to piggery manure in the NZ Pork Industry

Animal Waste Management System	Percentage of manure treated (MS) (%)
Anaerobic Lagoons	18.25
Composting Passive Windrow	9.18
Cattle swine deep bedding less than 50 days + composting	18.99
Cattle swine deep bedding greater than 50 days + composting	6.69
Deep litter less than 50 days	0.68
Daily Spread	22.35
Anaerobic Digesters	1.90
Pasture/Range/Paddock	8.89
Pit storage below animal confinement	13.08

4.1.3 Discussion: Aim 3

The results of the study show that the breakdown of animal waste being treated by AWMS in NZ is significantly different to that assumed in the GHGIR.

Surveying revealed that the practice of daily-spreading of manure is also widely used, treating approximately 22.35% of manure. Alternatively, anaerobic lagoons are used on 18.25% of the surveyed farm, a substantial reduction from the 55% currently assumed in the inventory.

At a subclass level there were a number of differences noted between the uses of AWMS, for example pasture range and paddock for breeding animals was recorded at between 33-39% while for growing animals direct-to-pasture was 0.2-0.4% (with the exception of suckers).

4.2 Aim 4: to develop a NZ-specific VS value for piggery effluent factoring in life cycle effects.

The aim of this section is to calculate an average VS value excreted by NZ pigs at a variety of subclass levels from survey data of the animals' diet using both the IPCC's revised 1996 and the proposed 2006 equations.

While environmental conditions such as temperature have the ability to influence CH_4 emissions, ultimate CH_4 yields from animal waste have been shown to relate primarily to animal type and that animal's diet (Safely and Westerman, 1990, McGrath and Manson, 2004). An animal's diet plays an important role in the quantity of VS produced from its excreta as livestock manure comprises mostly urinary excretions (urine energy (UE)) as well as the fraction of the diet undigested by the animal (i.e. faeces and energy) (McGahan et al. 2009) (see Figure 2).

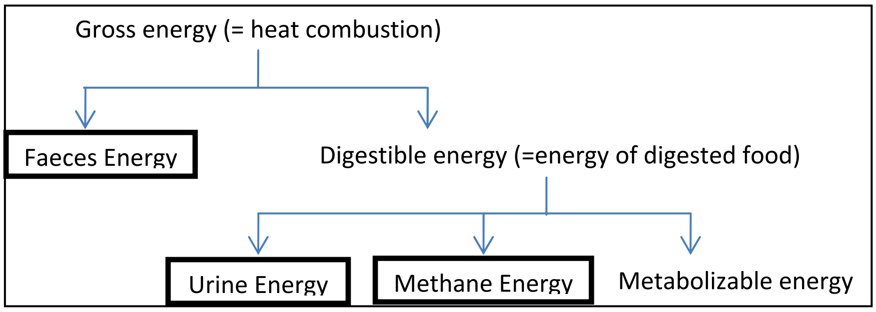

Figure 2: The partition of food energy in an animal (Adapted from McDonald et al.1995)

This diet undigested fraction is known as the total solids (TS) and is comprised of volatile solids (VS) and ash (indigestible compounds) (McGahan *et al.* 2009). Both IPCC formulas use the relationship between gross energy (GE) and digestible energy (DE) to determine the amount of undigested energy passing through the animal in the form of manure. The concentration of VS in the excreta is directly related to CH_4 emissions, as under anaerobic conditions microorganisms such as methanogens use the VS in the waste as a source of energy converting the organic matter to CH_4.

4.2.1 Method: Aim 4

GE and DE values were obtained by using the methodology outlined in Section 3.1. DE% was obtained by using the following formula:

$$DE\% = \frac{DE}{GE} * 100$$

Equation 4

These GE and DE% values were applied to two IPCC formulas outlined below.

<u>Revised IPCC 1996 equation</u>

$$VS(kgdm/day) = GE * \frac{1}{18.45} * \left(1 - \frac{DE\%}{100}\right) * \left(1 - \frac{ASH\%}{100}\right)$$

Equation 5

Where:

VS = volatile solid excretion per day on a dry-organic matter basis, (kg VS day^{-1}).
GE = gross energy intake from feed (MJ day^{-1}).
18.45 = conversion factor for dietary GE per kg of dry matter (MJ kg^{-1}).
DE = digestibility of the feed in per cent.
ASH = the ash content of the manure in per cent. IPCC default 2%.

<u>Proposed IPCC 2006 VS equation</u>

The IPCC 2006 equation includes urinary energy expressed as fraction of GE in the equation.

$$VS(kgdm/day) = [GE * \left(1 - \frac{DE\%}{100}\right) + (UE * GE)] * \left(\frac{1 - ASH}{18.45}\right)$$

Equation 6

Where:

VS = volatile solid excretion per day on a dry-organic matter basis, (kg VS day^{-1})

GE = gross energy intake, (MJ day^{-1})
DE% = digestibility of the feed in percent
(UE * GE) = urinary energy expressed as fraction of GE (Default 0.02 for swine).
ASH = the ash content of manure calculated as a fraction of the dry matter feed intake (Default value of 2%).
18.45 = conversion factor for dietary GE per kg of dry matter (MJ kg^{-1}). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock.

4.2.2 *Results: Aim 4*

Table 14 below outlines the results for this section for digestibility of feed (DE%) as well as the VS excretion rates of animals using both the 1996 and 2006 equations (see Appendix 4 for data). The Table also provides a comparison against an Australian Study of predicted VS (kg/yr) production per life cycle of pigs undertaken by FSA Consulting, in 2007.

Table 14: Average DE% and VS loading rates from surveyed data

Breeding swine	DE%	IPCC 1996 (VS kg animal $^{-1}$ yr^{-1})	IPCC 2006 (VS kg $animal^{-1}$ yr^{-1})	FSA Consulting, (2007) (VS kg $animal^{-1}$ yr^{-1})
Sows in gestation	80.88	149.23	164.79	151
Sows which have farrowed	84.17	401.81	453.17	215
Boars	81.62	146.59	161.18	151
Growing swine				
Suckers	87.46	10.99	12.80	11
Weaners	85.75	43.08	49.60	47
Growers	83.74	90.75	102.92	90
Finishers	82.91	129.47	145.38	149

4.2.3 *Discussion- Aim 4*

Average VS values calculated from the study indicate that the revised 1996 IPCC guidelines of 0.5 kg VS $head^{-1}$ day^{-1} may overestimate VS emissions of NZ animals. This appears to have been addressed in the 2006 IPCC guidelines where the default values have been adjusted to represent a market and breeding animal. These values show a better agreement with the VS excretion concentration calculated in this study. Table 15 below shows a recommended average value for VS rates found in this study using the 1996 and 2006 equation compared against the current default values recommend by the IPCC.

Table 15: Average VS values determined from this study compared against IPCC default values

Method applied	Average value for population (kg VS $head^{-1}day^{-1}$)	Average value for breeding and market pigs (kg VS $head^{-1}day^{-1}$)
IPCC 1996 default values VS	0.5	
IPCC 2006 default values VS		Market pig: 0.28 Breeding pig 0.50
Weighted Average Study calculated values 1996 IPCC	0.23	Market pig: 0.19 Breeding pig 0.53
Weighted Average Study calculated values 2006 IPCC	0.26	Market pig: 0.22 Breeding pig 0.59

There is limited NZ literature calculating VS excretion from animals from each subclass. The NZ Agricultural Engineering Institute (1984) estimated 87.6 kg VS $animal^{-1}yr^{-1}$ for an average 50Kg animal. Heubeck and Craggs (2010) reported a VS loading rate of 46.4 kg VS $animal^{-1}yr^{-1}$ for grower animals (50kg) at a single site in the Waikato. However, this is a pond loading rate value which has been calculated in the field after the effluent has passed through a solid separator. Calculations based on feed intake indicate on the same site a VS loading prior to the solid separator was 68.69 kg VS $animal^{-1}day^{-1}$ before solid separation (Heubeck and Craggs 2010).

An animal's diet and age plays an important role in the quantity of CH_4 produced from its excreta (McGahan *et al*. 2009) and as a result there can be a large variation in the VS excreted by different animals. Results from our study correlate well with a study by FSA Consulting, in Australia (see Table 14) who examined VS concentration changes in effluent through the life cycle of a pig. The exception to this is the VS concentrations being excreted from sows which have farrowed and are nursing young, where both IPCC formulas are approximately a factor of 2 greater than FSA Consulting, values.

Given the wide range of VS values that have the potential to be emitted on farms we believe that the average values calculated in this study provide a good reflection of VS loading rates from animals on NZ pig's farms at a subclass level.

4.3 Aim 5: to calculate a NZ-specific Manure Management CH_4 emissions factor for the pig industry

The VS and MS factors determined above can now be applied to IPCC formulas to calculate CH_4 emissions for manure management from NZ pigs. In order to account for the effect of different AWMS, both IPCC's 1996 and 2006 methodologies advocate the use of a methane conversion factors (MCF). MCFs influence the percentage of CH_4 emitted from an AWMS by adjusting the Bo (or total CH_4 that can be produced by the animal manure). The value varies depending on the environmental conditions of the management process.

Between 1996 and 2006 the IPCC has undergone a review of MCF values applied in their formulas and as a result two separate calculations are undertaken to determine the effect of these changes.

4.3.1 Method: Aim 5

The following three steps were undertaken to meet the objectives of Aim 5:

1) Assigning MCF factors

The review of literature undertaken as Milestone 1 of this project identified a limited number of NZ studies undertaken on GHG emissions from AWMS that treat piggery manure. The review concluded that further work is needed to measure emissions on farms before NZ specific CH_4 emission factors can be introduced. As a result, IPCC default MCF values should be applied to calculations undertaken in this study.

However, as outlined in Section 4.1, results from surveying on NZ farms did not show a good correlation with definitions proposed in the IPCC guidelines and as a result two additional categories were introduced. Table 16 below outlines the MCF values used in the calculations in this study. It should also be noted that currently the IPCC 2006 methodology reports that breakdown of bedding materials (straw, sawdust, chippings, etc.) are not included in the modelling of CH_4 emissions under the Tier 2 method as their contribution would not add significantly to overall CH_4 production (IPCC 2006). As a result emissions that are derived directly from the breakdown of bedding material have not been included in these calculations. For the composting component used within the combined definition proposed below no 'In-Vessel Composting' was noted in surveying and only one 'Static Pile Composting' with forced aeration but no mixing was recorded. As a result the MCF factor for 'Composting Passive Windrow' has been applied as this was the prevailing method noted in surveys.

Additionally the IPCC guidelines provide a wide range in emissions from anaerobic digesters given the wide range of technology being applied in the field. The 1996 guideline provides a range from 0-15% while the 2006 guidelines range is 0-100% for its MCF. The IPCC recommends the following formula be used to calculate emissions from energy recovery systems;

$$MCF = [\{CH_4\ prod - CH_4\ used - CH_4\ flared + (MCFstorage /100 * Bo * VSstorage * 0.67)\}/ (Bo* VSstorage * 0.67)] *100$$

Equation 7

Where:
CH_4 prod = methane production in digester, (kg CH_4). Note: When a gas tight coverage of the storage for digested manure is used, the gas production of the storage should be included.
CH_4 used = amount of methane gas used for energy (kg CH_4).
CH_4 flared = amount of methane flared, (kg CH_4).
MCFstorage = MCF for CH_4 emitted during storage of digested manure (%).
VSstorage = amount of VS excreted that goes to storage prior to digestion (kg VS).

When a gas tight storage is included: MCFstorage = 0; otherwise MCFstorage = MCF value for liquid storage.

However there is currently insufficient data on covered pond systems available to undertake an analysis. Further analysis is required to determine a NZ specific value for this AWMS in New Zealand.
As a result a conservative MCF factor of 15% has been applied.

Table 16: MCF conversion factors AWMS used for the pig industry at temperature 20°C (temperate environment)

AWMS	IPCC MCF Default value: Temperate Climate 1996 (%)	IPCC MCF Default value : Temperate Climate 2006 (%)
Anaerobic lagoon	90	78
Pasture/Range/Paddock	1.5	1.5
Liquid/ Slurry	35	With natural crust cover = 26 Without natural crust cover =42
Daily Spread	0.5	0.5
Solid storage	1.5	4
Dry Lot	1.5	1.5
Pit storage below animal confinement	< 30 days =18 >30 days = 35	< 30 days= 3 >30 days = 42
Anaerobic Digesters	15 (Range 5-15)	15 (Range 0-100)
Deep litter less than 50 days		< 30 days =3 >30 days = 42
Composting Passive Windrow		1
Proposed New Categories		
Cattle swine deep bedding + composting	< 50 days =4 >50days = 43	< 50 days =4 >50days = 43

2) Calculating manure management emissions

Both the IPCC Tier 2 methodologies use the following equation to calculate emissions from the manure management sector:

$$MEF = [VS_{(t)} * 365\ (B_o * 0.67kg/m^3 * \sum MCF*MS\ \%]$$

Equation 8

Where;
MEF = Emissions factor (manure management) (kg CH_4 $animal^{-1}yr^{-1}$).
$VS_{(t)}$ = Daily volatile solids excreted from a pig, (Kg VS dry matter $animal^{-1}yr^{-1}$).
365 = conversion from days to year.
B_0 = maximum methane producing capacity for manure produced from pig excreta (m^3CH_4 kg^{-1} of VS excreted).

0.67 = conversion factor of m^3 CH_4 to kg CH_4.
MCF = methane conversion factor for each manure management system, (decimal).
MS = Fraction of pig livestock manure using AWMS (decimal).

The MEF value is then applied to the following formula to calculate the total CH_4 emissions from the manure management sector. To calculate the Tier 2 emissions in this study values were calculated and entered into the following equation at a sub class level:

$$CH_4 \text{ emissions} = MEF*N$$

Equation 9

Where:
CH_4 emissions = the CH_4 emissions from a pig population emitted from manure management ($kgyr^{-1}$).
MEF is the emissions factor for manure management (kg CH_4 $animal^{-1}yr^{-1}$).
N = the NZ pig population.

3) Proposed alternative value for a Tier 1 equation

It is proposed to develop a NZ specific value that can be used in the IPCC Tier 1 formula that better represents emissions from manure management procedures used in NZ.

Results from the Tier 2 assessment will be used to calculate an average EF value based on the current distribution of animals in the NZ pig population profile determined from Table 3.

4.3.2 Results: Aim 5

The results from the Tier 2 investigation from 1996 and 2006 IPCC methodologies from manure management in the NZ pork industry are as follows:

Table 17: Emissions calculated for manure management using both IPCC's 1996 and 2006 methodologies

Year	Emissions from manure management (Gg)
Revised 1996 IPCC method	
1990	2.47
2009	1.89
Proposed 2006 IPCC method	
1990	2.29
2009	1.75

Calculations show that the IPCC 2006 methodology reduces emissions by approximately 7.4% at a Tier 2 level when compared against the 1996 IPCC Tier 2 method.

CH_4 emissions from the manure management sector can be broken down according to the various AWMS being used (see Figure 3 below). The analysis shows that for manure management CH_4 emissions from anaerobic lagoons contributes 69 -73% of the industry's emissions.

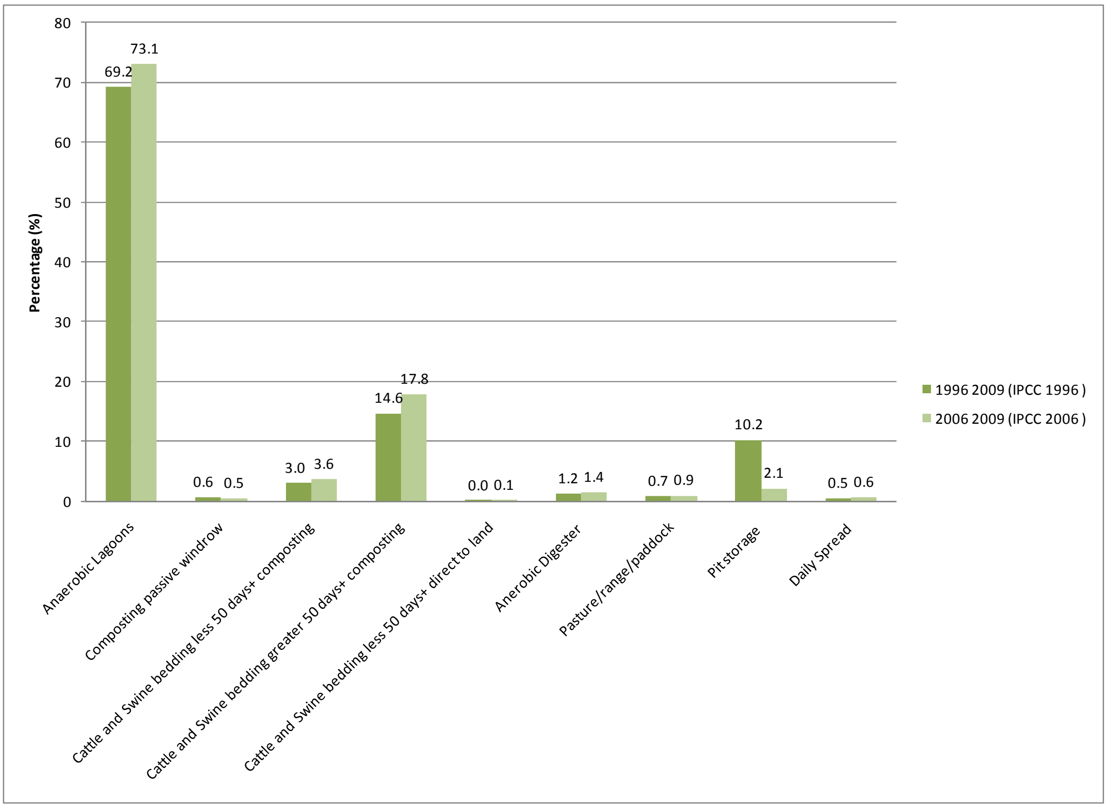

Figure 3: Distribution of CH_4 emissions by percentage from AWMS for the 2009 calendar year

Based on the results from this study we can also recalculate an average CH_4 emissions factor (MEF) for the manure management sector per pig for NZ animals. This approach calculates emissions based on a subclass level and assigns an average emission factor based on the population distribution of the animals on NZ farms. Proposed emissions factors based on IPCC 1996 and 2006 methodologies are outlined below.

Table 18: Calculated NZ emission factor for Manure Management in the pig industry

IPCC Guideline Year	Emission factor for manure management (kg CH_4 head^{-1}yr^{-1})
Calculated default value 1996	5.94
Calculated default value 2006	5.48
Current default value 1996 IPCC	20
Current default values 2006 IPCC	Market Swine= 13 Breeding swine 23

4.3.3 Discussion: Aim 5

The results of the investigation indicated that for the 2009 calendar year, Tier 2 calculated emissions from manure management practices used in the NZ Pork industry were 39.58GgCO_{2-e} and 36.63GgCO_{2-e} using the 1996 and 2006 IPCC guidelines respectively. These emissions are primarily produced by anaerobic lagoons which were recorded to be the largest source of CH_4 contributing between 69-73% of the total emissions recorded from this sector.

The study also allows for comparisons to be made between the 1996 and 2006 IPCC methodologies at a farm level. The study found that the 2006 IPCC methodology increased the calculated VS loading rates for each AWMS by approximately 11% through the introduction of urine energy into the equation. However, the increase in this parameter was offset in the equations by a review of the MCF's. The review of MCFs, particularly the reduction in Bo from anaerobic lagoons, from 90 to 78% led to an overall reduction in calculated CH_4 emissions from the manure management sector by 7.4% from the 1996 to the 2006 IPCC guidelines.

The study also found that an emissions factor for NZ pigs of 5.48-5.94kg CH_4 head^{-1}yr^{-1} better reflects the CH_4 emissions being released from NZ's manure management practices. This is a substantial reduction from 20 kg CH_4 head^{-1}yr^{-1} currently being applied in the NZ GHGIR assigned to the '*Oceanic Region'* (MFE 2009). The reduction is primary due to a recalculation of MS values that are being applied; particularly the reduction in the perceived reliance of anaerobic lagoons, from 55% use in the NZ industry to 18% use found in this study.

4.4 Calculations Manure Management

In the following section we compare Tier 1 and Tier 2 calculations for CH_4 emissions from manure management sector for the 1990 and 2009 calendar years.

The IPCC 1996 Tier 1 methodology assigns only one default value per head (20kg CH_4 head^{-1}Yr^{-1}) while the 2006 IPCC methodology breaks down the pig population of a country into two categories for pigs; Market Pigs (13kg CH_4 head^{-1}Yr^{-1} for nursery, finishers, gilts and growing boars) and Breeding Pigs (23kg CH_4 head^{-1}Yr^{-1} sows for in gestation or farrowed and nursing young as well as boars). Table 19 below outlines the predicted emissions from the 2009 and 1990 calendars year calculated at a Tier 1 and 2 levels from manure management.

Table 19: Summary calculations for the NZ pork industry

1996 IPCC	Emission factor for manure management (kg CH_4head^{-1}yr^{-1})	2009 Emissions from manure management (Gg)	1990 Emissions from manure management (Gg)
Tier 1 default Swine	20	6.46	7.89
2006 IPCC			
IPCC Breeding swine	23	0.91	1.26
IPCC Market swine	13	3.68	4.42
2006 Total		4.59	5.68
Difference between IPCC 1996 default and 2006		-29%	
Tier 2 results 1996 IPCC		1.88	2.47
Tier 2 results 2006 IPCC		1.75	2.29
Country specific Tier 1 EF 1996	5.940	1.92	2.34
Country specific Tier 1 EF 2006	5.484	1.77	2.16

The 1996 methodology does not provide any scope to consider the changes in emissions that occur over the lifecycle of an animal without undertaking a Tier 2 analysis; rather it provides an average value for VS and Bo emissions for a pig. As shown in Table 14, VS concentrations excreted from an animal can vary depending on the pigs' age; with sows having the potential to release 453 kg VS yr^{-1} compared to 12.80 kg VS yr^{-1} for suckers. The 2006 IPCC guidelines divide the nation's animal population into breeding and market swine and by doing so allow for more accurate VS concentrations to be included into the equations. This division into basic subclasses reduced emissions from IPCC 1996 to 2006 methodology by 29% at a tier 1 level.

The following figure outlines the variation in results between the three different methodologies tried in this study for the 2009 calendar year.

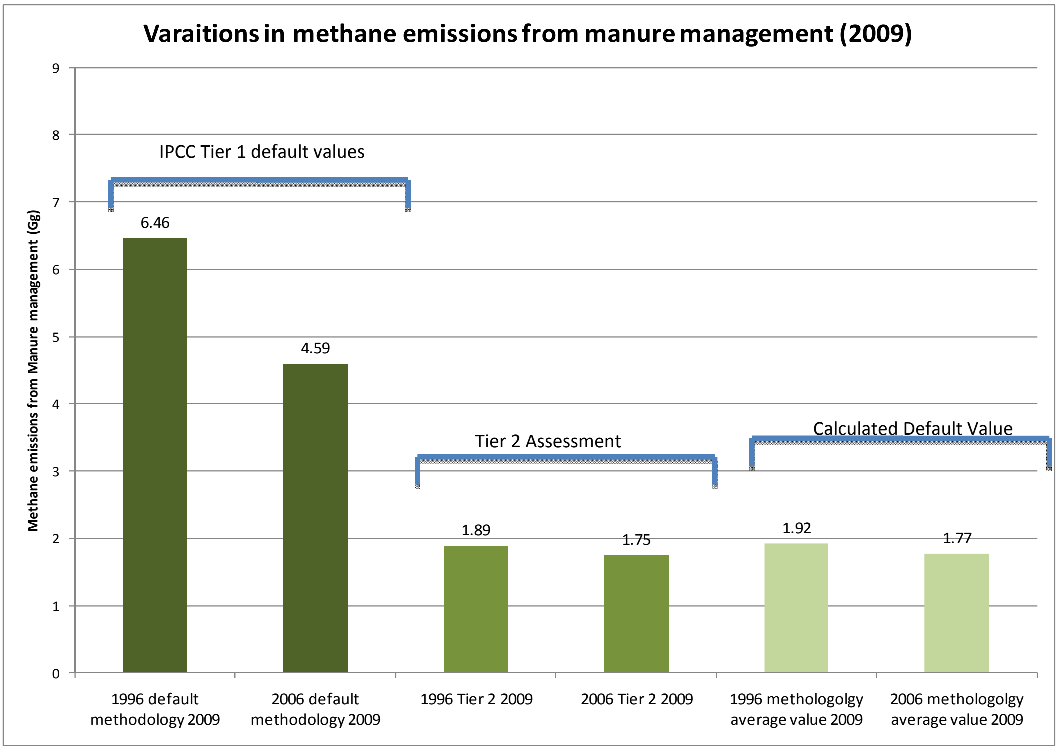

Figure 4: Calculated CH_4 emissions from Manure Management from the calendar year 2009 using 3 different methodologies.

Temperature

The MCF values applied in this study have been developed based on factors for temperate environments in accordance with values currently being applied within the NZ GHGIR. The 1996 IPCC guidelines note that 'temperate climate' has an average temperature of 15°C-25°C inclusive, while a 'cool climate' has an average temperature below 15°C. However, it should be noted that NIWA reports that the average temperature in NZ for the 2009 calendar year was 12.3°C, with a 10 year average temperature of 12.6°C NIWA 2010). This indicates that New Zealand's climate should be classified as 'cool' when determining values for the Manure Management sector.

This has a large effect on CH_4 emissions from the Manure Management sector, as the MCF values are linked to temperature. Table 20 below shows the CH_4 emissions from manure management if NZ's climate was classified as 'cool' with average temperatures of 13°C (MCF values used are reported in Appendix 3).

Table 20: CH_4 emissions from manure management if NZ's climate classification is adjusted from 'temperate' to 'cool' for the 2009 calendar year

	Emission factor for manure management (kg $CH_4 head^{-1} yr^{-1}$)	Emissions from manure management (Gg) 2009 calendar years
Study Cool Calculation 1996 IPCC	5.082	1.64
Study Cool Calculation 2006 IPCC	4.636	1.50
Study Temperate Calculation 1996 IPCC	5.94	1.92
Study Temperate Calculation 2006 IPCC	5.484	1.77

4.5 Summary: Manure Management

- The study of over 68% of NZ's pork production noted that the current breakdown of MS factors does not accurately reflect the manure management processes being used by NZ producers. The IPCC (1996) notes that there are limitations to the Tier 1 approach used to calculate manure management CH_4 emissions if the MS default values do not accurately reflect the manure management systems in operation in any given country (IPCC 1996). This investigation found a large variation between the IPCC MS values for the 'Oceanic Region' and the management systems in operation on farm. This is primarily due to the default value's prediction that 55% of manure from the NZ pork industry is treated by anaerobic lagoons. However, this study has indicated that lagoons treat only 18% of NZ's piggery manure.

- The results from the study indicate that the current Tier 1 default values applied to the NZ pork industry overestimate emissions from the manure management section by 70%, based on the current 1996 methodology. As a result we would not recommend the use of Tier 1 default values to calculate emissions from manure management for NZ Pork.

- The study recalculated two proposed NZ specific emission factors based on IPCC 1996 and 2006 methodologies from investigations of animal feed as well as the method of AWMS being used on NZ farms. The values of 5.94kg CH_4 animal^{-1} yr^{-1} and 5.484 kg CH_4 aniaml^{-1} yr^{-1} for 1996 and 2006 methodologies respectively showed a good relationship with the results of the Tier 2 investigation.

5 Manure Management: Direct N_2O Emissions

Nitrous oxide (N_2O) is a potent GHG with a global warming potential estimated at 310, relative to CO_2 (IPCC 2007, MfE 2010). Emissions of N_2O make up approximately 16% of NZ's total GHG budget and have been recorded to have increased by 21.8% between 1990 to 2008 to their current level at 11.9Mt CO_2-e in 2008 (MfE 2010). Of these emissions it is estimated that approximately 90% are derived from agricultural practices (MfE 2009).

N_2O emissions are mainly produced during aerobic storage and treatment of animal excreta as well as after land-spreading (Saggar et al. 2004). Data strongly suggests the type of AWMS applied to piggery effluent has a major impact on N_2O emissions (Redding 2009).

N_2O emissions from manure management encompasses the release of N_2O from nitrification and/or denitrification processes in the AWMS both from direct emission sources (i.e. from the AWMS) or indirect sources (e.g. from N that has volatilised or through nitrogen leaching from an AWMS as these losses have the potential to redeposit into another environment releasing N_2O). Environmental conditions present in each AWMS will have an impact on the quantity of N_2O emissions released.

The 2008 NZ GHGIR recorded that manure management systems accounted for N_2O emissions amounting to 56.9 Gg CO_2-e yr^{-1} (MfE 2010). Of this figure, 13.5 Gg CO_2-e yr^{-1} (24%) was contributed by the NZ pork industry. In this section we examine the parameters used to calculate N_2O emissions from AWMS used by the NZ pig industry.

5.1 Aim 6 : to develop a NZ-specific nitrogen excretion value (Nex) for pigs

Currently in the NZ GHGIR an IPCC default value for N excreted from an animal (Nex) is being applied to equations calculating N_2O emissions from pigs. N_2O emissions from animal wastes are dependent upon the concentration of N that is contained in animal's excreta. This value is known to vary depending upon the animal's diet as well as the age of the animal. To date this value has been reported at 16 kg N $head^{-1}yr^{-1}$ in the current NZ GHGIR for pigs, which is derived from a default value for the 'Oceanic Region' in the IPCC 1996 guidelines (MfE 2010 and IPCC 1996).

The proposed 2006 IPCC methodology uses a different approach to calculate the Tier 1 Nex value for animals, proposing to adjust the Nex value by animal weight. Pigs in NZ are often lighter than the international average, as they are sent to market at a younger age. This reduces the Nex excreted by an animal, as it consumes less feed than a typical pig in other countries required to reach the higher weight brackets. As a result the proposed 2006 IPCC method may provide a more accurate reflection of Nex values excreted from NZ animals.

Aim 6 of this project proposes to develop a NZ specific Nex value using the IPCC 2006 Tier 1 methodology.

5.1.1 Method: Aim 6

The IPCC 2006 Tier 1 to calculate Nex concentrations excreted from NZ pigs is outlined below

$$Nex = N\ rate * TAM/1000 * 365$$

Equation 10

Where:
Nex = annual N excretion for pigs, kg N $animal^{-1}$ yr^{-1}.
Nrate = default N excretion rate, kg N (1000 kg animal mass)$^{-1}$ day^{-1} (Default values for market pig 0.53 and for breeding pigs 0.46 kg N (1000 kg animal mass)$^{-1}$ day^{-1}).

TAM = typical animal mass for livestock category T, kg animal^{-1} (obtained on farm).

The following parameters have been applied to the above equation.

Default N Excretion Rate (NRate)

For pigs in the 'Oceanic Region' the 2006 IPCC default values for Nrate have been estimated at two points of an animal's life cycle with values being provided for market animals which have an estimated 0.53kg N/1000 Kg of pig per day and for breeding animals at 0.46kg N/1000Kg of pig per day. These values are in line with two NZ studies of pig manure where Shilton et al. (2003) recorded an average value of 0.549 g N/Kg of pig, while a Massey University trial, examined N in excreta in three populations of pigs with varying diets and found N concentrations in excreta ranged between 0.35-0.55 g TN/kg/pig/day (Morel unpublished data). As a result IPCC default values for Nrate have been applied to Equation 10.

It should be noted that the IPCC 2006 Guidelines (Table 10.19) also provide an average Nrate value for swine: 0.74kg per 1000 kg of pig. The guidelines outline that this has been developed assuming a population consisting of 90% market animals and 10% breeding animals. This value appears to overestimate Nrate emitted from pigs. Given the parameters outlined in the guidelines we would recommend this value be altered to 0.525kgN/1000 Kg of pig per day for Oceanic pigs.

Typical Animal Mass (TAM)

In order to apply the above equation, Typical Animal Mass (TAM) values were estimated for NZ pigs for each subclass level defined in Section 3.1.1. Finishing weights for animals were developed using an average value for kill weights for market animals in NZ for the 2009 calendar year (excluding chopper weights) (NZPork 2010). Kill weights were then converted to live weights using a conversion factor (See Appendix 5 for further information). For sows it is proposed to develop an average TAM value that accommodates both sows in gestation and sows which have farrowed. Sows increase in weight as they age. Young sows at parity 1-3 are generally still increasing in body weight. Additionally a sow's weight will increase as she moves from mating to farrowing age. Weights will then decrease during the weaning stage.

The average TAM weights for sows used in this project were calculated based NZPork (2009) data for 'Chopper' weights. It is acknowledged that chopper weights are generally at the lighter range of a sow's weight range and therefore an additional 25kg was added to the sow's live weights to accommodate the range that a sow's weight will change as she moves from mating to weaning (Verstegen et al, 1987). Noblet et al. (1990) estimate a total of 45 kg of gestational weight gain by the sow (22.25kg average matting to weaning), while Alltech (2002) estimate a 50kg weight gain (averaged 25 over mating to weaning).

Average weights assigned to each subclass can be seen Table 21 below.

Table 21: Typical Animal Mass (TAM) NZ pigs by subclass (adapted from NZPork 2010c)

Animal subclass	Weight Range kg	Typical Animal Mass (TAM) kg
Breeding swine		
Sows		201
Boars		181
Growing swine		
Suckers	1.4-7	4.20
Weaners	7.1-30	18.55
Growers	31-70	50.50
Finishers	71-91.59	81.30

5.1.2 Results: Aim 6

The Table below outlines the average Nex values excreted by each of the animal subclasses calculated using the 2006 IPCC Tier 1 equation.

Table 22: Nex values calculated for NZ pigs based on Equation 10

Animal subclass	Nex (kg N animal^{-1} yr^{-1})
Breeding swine	
Sows	33.7
Boars	30.4
Weighted average – breeding pigs	33.6
Growing swine	
Suckers	0.8
Weaners	3.6
Growers	9.8
Finishers	15.7
Weighted average – Market pigs	7.5
Weighted average NZ pigs based on population distribution*	10.8
IPCC 1996 default value	16

*See Appendix 5 for calculations on weighted average

The results indicate that the average Nex value excreted for the population of NZ pigs is 10.8 kg N animal^{-1} yr^{-1} compared with the IPCC 1996 default value with was reported at 16 kg Nanimal^{-1} yr^{-1}.

5.1.3 Discussion: Aim 6

Diet requirements of pigs at varying stages of their life cycle can affect Nex concentrations. Table 23 below shows a summary of Nex concentrations from varying sub classes of pigs as reported in a number of Australian and International guidelines (FSA Consulting, 2007).

Table 23: Comparisons of N excretion from each pig sub class kg/yr (Source: FSA Consulting, 2007(Effluent at Work (Kruger et al. 1995); the ASAE Standards-ASABE (2005), Midwest Plan Service-MWPS (1993) and the National Piggery Guidelines (APL 2006).

Pig Class	Weight Range (kg)	Average weight (kg)	Effluent at work (1993)	ASAE (2005)	MWPS (1993)	National Piggery Guidelines
Gilts	100-160	130	24.7	-	15.9	12
Boars	100-250	175	33.2	10.2	11.7	15
Gestating Sows	160-230	195	37.0	11.7	12.9	13.9
Lactating Sows	230-160	195	37.0	31.0	10.4	27.1
Suckers	1.4-8	4.7	0.9	-	1.0	2.3
Weaners	8-25	16.5	3.1	2.3	3.4	3.9
Growers	25-55	40	7.6	10.4	4.9	9.2
Finishers	55-100	77.5	14.7	17.6	9.4	15.8

The results from the guidelines show a good agreement with results from our study for 'Growing Animals' providing confidence in the Nex excretion rates calculated above. For 'Breeding Animals' there is a wide range in results between guidelines e.g. gestating sows range between 11.7-37kg animal^{-1}yr^{-1}. The results obtained from using the IPCC 2006 equation appear to be in the higher range of Nex rates calculated at 33.7 animal^{-1}yr^{-1}.

The weighted average result from our study was 10.8 kg N animal^{-1}yr^{-1} based on the population distribution of NZ pigs. The value indicates that the current default value applied in the NZ GHGIR (i.e. 16kg Nhead^{-1}yr^{-1}) may overestimate N excretion rates from NZ pigs. We would recommend the use of 10.8 kg N head^{-1}yr^{-1} to be applied in future NZ inventories for pigs. This proposed reduction is consistent with the lighter weights that pigs are slaughtered at in NZ being an average of 91 kg live weight (NZPork 2010) compared with an average of 123 kg live weight in the USA (USDA 2010).

5.2 Aim 7 : To develop a NZ-specific value for the N fraction of pig manure entering each AWMS (MS)

As identified in Section 4, the proportion of animal waste being treated by each AWMS in the NZGHGIR is currently defined through the use of default IPCC values for the 'Oceanic Region'. However, these values are not thought to adequately represent AWMS being used by NZ pig farmers.

The IPCC 2006 Guidelines notes that the MS values assigned to calculations for N_2O emissions from AWMS should be the same as those used for CH_4 emissions. However, the inclusion of solid separation techniques into the formula means that the MS values need to be recalculated specifically for N as solid separation affects the loading rates of VS and N. Unlike for VS loading rates the primary N form in pig manure is ammonium (NH_4^+) which is largely soluble in water and therefore associated with liquid fractions that moves through the separator. As a result physical separation by the solid separators will result in a smaller percentage of N being impacted when compared against VS. As a result the MS values calculated for CH_4 emissions need to be revised.

Aim 7 of this project proposes to recalculate the MS factor for N entering each AWMS used to treat or store manure from NZ pigs.

5.2.1 Method: Aim 7

The method applied to calculate N specific MS values is similar to that outlined in Section 4.2.
Table 11 in Section 4.2 above shows the breakdown of N removal rates as a result of solid separation applied in the study. It should be noted that the IPCC use a slightly different definition in the N_2O sector than for the CH_4 emissions. This appears to be relevant for the deep litter sector where N_2O emissions are classified according to mixing and non-mixing of the litter. Very little information is provided within the 2006 IPCC guidelines as to the definition of mixing and non-mixing and further information is required.

It should also be noted that for N_2O emissions there are slight changes to the AWMS definition used within the IPCC guidelines due to the changing parameters that need to be considered when examining emissions from this source compared with CH_4. For the purposes of this study short term bedding use e.g. straw that is removed from the pens in less than 50 days has been applied to no mixing category for deep litter while deep litter material such as saw dust that is used for greater than 50 days which is often turned to aid in decomposition has applied to the mixing value.

5.2.2 Results: Aim 7

The results from surveying indicated the following breakdown of AWMS treating N across NZ pork farms.

Table 24: Breakdown of AWMS being applied to treat N from piggery manure in the NZ Pork Industry

Animal Waste Management System (AWMS)	Percentage of manure treated (MS) %
Anaerobic Lagoons	20.58
Composting passive windrow- solid separated	2.94
Deep litter composting (No Mixing - straw) (less than 50 days)	18.99
Deep litter + composting (mixing- sawdust) (greater than 50 days)	6.69
Deep litter less than 50 days direct to land	0.68
Daily Spread	25.68
Anaerobic Digester	2.47
Pasture/Range/Paddock	8.89
Pit storage below animal confinement	13.08

5.2.3 Discussion: Aim 7

The variation in chemical properties between VS and N found in pig manure causes MS proportions to change when solid separation techniques are included in calculations. The results indicate that solid separation increases the quantity of N being treated in the liquid fraction of effluent when compared against the results from Section 3.2 as more N is found in the liquid fraction than is separated by soild removal techniques. This increases the N loading rate entering liquid systems such as daily spread systems and anaerobic lagoons while reducing the loading rates to the solid fraction i.e. composting.

The results indicate that the daily spread technique is used to treat the largest proportion of N from pig manure treating 25.7% of the total manure produced. Anaerobic lagoons were calculated to treat 20.6% and with deep litter systems (including both straw and saw dust) treating 26% of the total manure produced.

5.3 Aim 8: to calculate a NZ-specific Manure Management N_2O emissions factor for the pig industry

The aim of this section is to recalculate direct N_2O emissions from manure management using the revised NZ specific Nex and MS valued calculated above as well as comparing the results obtained by using the current GHGIR method and default values in the proposed 2006 IPCC method.

5.3.1 Method: Aim 8

Calculations to determine the direct N_2O emissions from manure management systems will be undertaken at both a Tier 1 level using 1996 IPCC default values currently applied in the NZGHGIR and using the 2006 Tier 2 method where country specific parameters for MS and Nex will be introduced.

The following IPCC equation will be applied to calculate N_2O emissions;

$$N_2O_{D(mm)} = [\sum(N*Nex*MS)]*EF_3*44/28$$

Equation 11

Where:

$N_2O_{D(mm)}$= direct N_2O emissions from manure management.
N = Population.
N_{ex} = Annual average N excretion per head (2007 GHGIR default for pigs, 16 $kgNhead^{-1}yr^{-1}$, will be compared with 10.8 $kgNhead^{-1}yr^{-1}$ calculated in this study).
MS = fraction of total annual other livestock excretion in each manure management system (1996 default levels will be compared against results calculated in Section 5.2).
EF_3 = emission factor for manure in management system (1996 IPCC values and 2006 IPCC values will be used, see Table 25).

As with CH_4 emissions, the review of literature undertaken as part of Milestone 1 of this project found limited NZ literature for the release of N_2O from AWMS. As a result the review concluded that the IPCC default EF_3 should be applied to calculation undertaken in this study.

Table 25: Emissions factors (EF3) for N_2O emissions from AWMS IPCC 1996 and IPCC 2006 (Source: adopted from IPCC 1996 and 2006)

Animal waste management System	Emission factor EF_3 1996	Emission factor EF_3 2006 kg N_2O-N/kg N excreted
Anaerobic Lagoon	0.001	0
Liquid Systems	0.001	0
Daily spread	0.0	0
Solid Storage and dry lot	0.02	Solid Storage 0.005 Dry Lot 0.02
Pasture range and Paddock	N/A	NA
Other	0.005	
Solid storage		0.005
Pit storage below animal confinement		0.002
Anaerobic Digester		0
Cattle and pig deep bedding		Active Mixing 0.07 No Mixing 0.01
Composting in vessel and Static pile		0.006
Composting intensive window		0.1
Composting Passive window		0.01
Aerobic treatment		Natural aeration 0.01 Forced aeration 0.005
Combined Categories		
Deep litter + composting (Active mixing)		0.08
Deep litter + composting (No mixing)		0.02

5.3.2 Results: Aim 8

The results obtained from applying the current NZGHGIR default values for the 2009 calendar year can be seen in Table 26 below. By comparison, the results from using a Tier 2 investigation from the 2006 IPCC inventory can be in Table 27.

Table 26: Results using IPCC 1996 Tier 1 default direct N_2O emissions factor from manure management

	Percentage	Nitrogen (kg N)	kg N_2O-N/kg N excreted	Annual direct N_2O emissions from Manure Management kgNO_2 Yr^{-1}
Anaerobic Lagoon				
Swine 1990	55	3,473,369	0.001	5458
Swine 2009	55	2,840,543	0.001	4464
Solid storage and drylot				
Swine 1990	17	1,073,587	0.02	33741
Swine 2009	17	877,986	0.02	27594
Other management systems				
Swine 1990	28	1,768,260	0.005	13893
Swine 2009	28	1,446,095	0.005	11362
Total 1990				43420
Total 2009				53093

Table 27: Direct N_2O emissions factor from manure management 2009 ad 1990 results using IPCC2006 Tier 2 default

Manure Management System (MMS)	Fraction of total annual nitrogen excretion managed in MMS for each species/livestock category	Total nitrogen excretion for the MMS (kg N yr^{-1})	Emission factor for direct N_2O-N emissions from MMS [kg N_2O-N (kg N in MMS)$^{-1}$]	Annual direct N_2O emissions from Manure Management kg N_2O yr^{-1} 2009	Annual direct N_2O emissions from Manure Management kg N_2O yr^{-1} 1990
Anaerobic Lagoon	0.21	718778	0.000	0	0
Daily Spread	0.26	896924	0.000	0	0
Direct to pasture	0.09	310411		IE	IE
Pit storage	0.13	456788	0.002	1435.62	1755.45
Composting (passive windrow)	0.03	102717	0.010	1614.12	1973.72
Deep litter (no mixing)	0.01	23748	0.010	373.19	456.33
Deep litter (no mixing)+ composting	0.19	663002	0.020	20837.19	25479.37
Deep litter (Mixing) + composting	0.07	233521	0.080	29356.91	35897.13
Anaerobic Digester	0.02	86138	0.000	0.00	0.00
Total				53617.03	65562.00

*IE – N deposited direct to pasture through grazing animals is included in the Agricultural Soils section below.

5.3.3 Discussion: Aim 8

The results from this study show the dominant contribution of dry solid application, particularly from deep litter systems, in the production of N_2O emissions (see Figure 5). The IPCC (2006) notes that the ratio of N_2O to N increases with increasing nitrate concentrations, increasing acidity and a low water content. As a result dry storage options such as deep litter beds have the potential to release higher quantities of N_2O in comparison with liquid systems such as anaerobic lagoons.

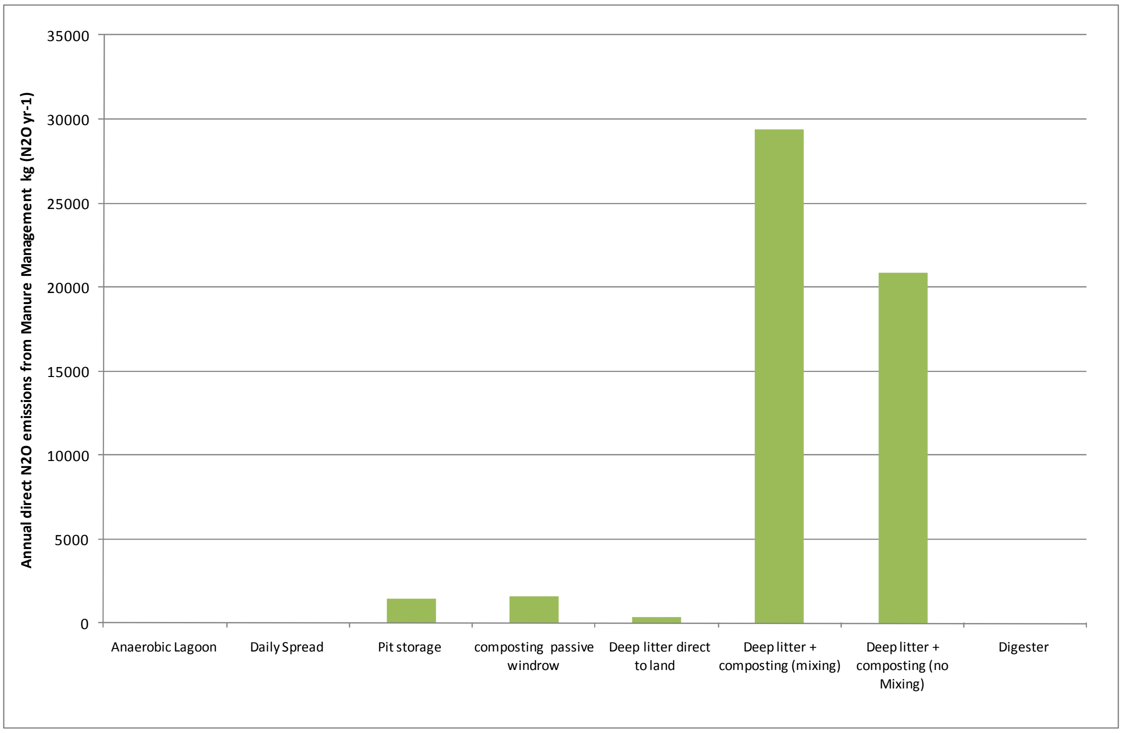

Figure 5: Profile of N_2O emissions from NZ Manure Management systems

This dominance of emissions from predominately dry AWMS is thought to be due to aerobic and anaerobic microsites found on deep litter systems, allowing for the production of N_2O through a number of chemical processes. Additionally deep litter beds provide a source of N, a soluble carbon source, moisture and heat, all of which results in favourable conditions for N_2O production (Thorman et al. 2007). Rotz (2004) noted that there is a complex decomposition process occurring in deep litter with the primary microbial processes including aerobic and anaerobic degradation of organic matter, urea hydrolysis, nitrification, denitrification and N immobilization. Alternatively in liquid systems the 2006 IPCC EF_3 assumed that the anaerobic nature of lagoons drives the denitrification reaction through to completion releasing mostly N_2 and little to no N_2O (see Figure 6). As a result EF_3 values for anaerobic liquid based systems have been altered from 0.01 to 0.

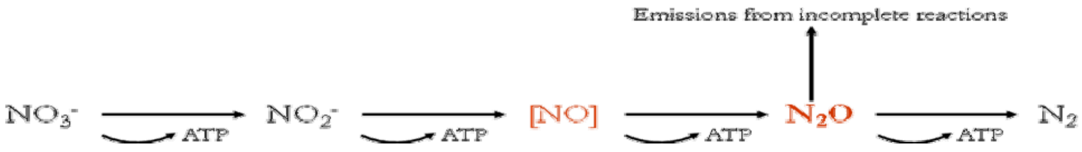

Figure 6: denitrification reaction

For the 2009 calendar year this study noted a 15% increase in emissions when comparing the current method used in the NZ GHGIR (the 1996 IPCC default data) with the proposed 2006 IPCC guidelines. The study estimated emissions of 15.9 Gg CO_2-e from the 1996 IPCC methodology and 16.6 GgCO_2-e for the 2006 IPCC methodology.

Table 28: Summary Table N_2O emissions from manure management

1996 IPCC	**Emission factor for manure management (Nex kg N head^{-1}yr^{-1})**	**2009 N_2O Emissions from manure management (Gg)**	**1990 N_2O Emissions from manure management (Gg)**
Tier 1 default Swine	16	0.043	0.053
2006 IPCC			
Tier 1 default Swine	10.8	0.029	0.036
Difference between IPCC 1996 default and 2006		-32%	
Tier 2 results 1996 IPCC		0.051	0.063
Tier 2 results 2006 IPCC		0.054	0.066

The change in emissions profile has been driven primary by the recalculation of MS values for each AWMS indicated that a larger proportion of manure was being treated through non anaerobic methods such as deep litter. The current IPCC default values assigns 17% of the Nex produced to a solid storage and dry lot system, while values calculated within this study show that the rate is 29%.

5.4 Summary: Direct N_2O emissions from Manure Management

- As with CH_4 emissions from manure management, the study of over 68% of NZ's pork production revealed that the current breakdown of MS factors does not accurately reflect the manure management practices being used by NZ producers and recommends the use of the revised MS values calculated in this study.

- Recalculation of MS values between VS and N calculations may be required if solid separation techniques are commonly used in a country.

- The 2006 proposed IPCC guidelines allows for countries to calculate their average Nex emissions based on the weight of an animal. As NZ pigs are killed at a lighter weight than animals in other countries, the quantity of Nex being excreted is reduced. The recalculation of Nex rates for NZ reduced the average quantity of N being excreted per animal from 16kg $animal^{-1}Yr^{-1}$ to 10.8kg $animal^{-1}Yr^{-1}$. The recalculation of Nex values has reduced the N loading rates to AWMS. The study recommends the reduction of Nex values from 16kg N $animal^{-1}Yr^{-1}$ to 10.8kg N $animal^{-1}Yr^{-1}$ based on the small weights of finished animals in NZ.

- The study also notes an error in IPCC 2006 default values for swine Nrate in Table 10.19. The table outlines an Nrate of 0.74kg per 1000kg to be used as an average Nrate for pigs. The guidelines outline that this has been developed assuming a population breakdown of 90% market animals and 10% breeding animals. This value appears to be incorrect, overstating Nrate emissions from pigs. Given the parameters outlined in the guidelines we would recommend the value be adjusted to 0.525kg N per 1000Kg of pig per day.

5.5 Indirect Emissions from Manure Management (2006 IPCC only)

Indirect emissions from AWMS are currently not recorded in the 2008 NZ GHGIR. Rather current methodology accounts for volitisation and leaching of N from AWMS once it is applied to soil (see Agricultural Soils Section), and is not adjusted for any N lost during storage. However, the 2006 IPCC guidelines provide a Tier 1 methodology to calculate emissions for future inventories. Indirect emissions from manure management systems comprise N that is deposited into another environment as a result of volatile loss that occurs primarily in the form of NH_4 and NO_x (volatilisation) (IPCC 2006), as well as from the fraction of N that is leached through the soils or runs off from an AWMS. For the manure management section only indirect emissions from volatilisation are considered for this review. The IPCC (2006) acknowledges that there is extremely limited data on leaching and runoff from AWMS globally and they noted that the values for $Frac_{LEACH}$ from AWMS need to be developed as a country specific value applied to a Tier 2 method. This is yet to be done for NZ.

There is a growing recognition that volatilisation of N from AWMS is an important source of GHG emissions. Volatilisation occurs when ammonia (NH_3) is rapidly converted into ammonium (NH_4) resulting in gaseous NH_4 emissions. In animal excreta simple forms of organic N such as urea and uric acid, (which make up about 50 % of the N excreted), are rapidly mineralized to ammonia-N. In contrast more complex forms of organic N found in the soils fraction of the manure mineralize more slowly, up to several years for some compounds (USEPA 2004). The IPCC notes that the fraction of excreted organic N that is mineralized to NH_4 during manure collection and storage depends primarily on time, and to a lesser degree temperature (IPCC 2006). N_2O emissions from volatilisation vary between different animal waste streams. This variation is thought to be largely due to the abundance of freely available, mineral N (Laurenson et al 2006). A NZ study by Shilton (1996) concluded that N loss from volatilisation from anaerobic lagoons significantly contributes to the overall N removal potential of a piggery pond system.

Volatilisation of N from piggery effluent occurs rapidly due to its high concentrations of mineral-N compared with organic–N, as organic-N needs to be mineralised to convert to NH_4^+ (Cameron et al. 1995). While gases such as NH_4 and NO_3- are not GHGs, there is a potential that their deposition in another environment may lead to N_2O formation (MfE 2010). Redding (2009) noted that indirect emissions of N_2O are likely to be substantial; of the same order of magnitude as direct emissions via ammonia volatilisation then deposition.

5.6 Aim 9: To quantify indirect N_2O emissions from volatilisation in the manure management systems

In this section we aim to quantify the indirect N_2O emissions released from AWMS treating manure from the NZ swine industry.

5.6.1 Method: Aim 9

The following formula is being applied to calculate the quantity of indirect emissions from manure management sources (See Equation 12 below).

$$N_{\text{volatilization MMS}} = \sum [(N * Nex * MS) * Frac_{GasMS}/100]$$

Equation 12

Where:

$N_{volatilization\text{-}MMS}$ = amount of manure N that is lost due to volatilisation of NH_3 and NO_x, kg N yr^{-1}.
N = populations of pigs in the country
N_{ex} = annual average N excretion per head (study Nex value of 10.8kg N $animal^{-1}Yr^{-1}$).
MS = fraction of total annual N excretion that is managed in manure management system (see Section 5.2.2).
$Frac_{GasMS}$ = percent of managed manure N that volatilises as NH_3 and NOx in the manure management system (see

Table 29 below).

The amount of N_2O emissions produced from the quantity of N volatilised are then calculated as follows;

$$N_2O = (N_{volatilization\text{-}MMS} * EF_4) *44/28$$

Equation 13

Where

N_2O = indirect N_2O emissions due to volatilisation of N from Manure Management, kg N_2O yr^{-1}.
EF_4 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, kg N_2O-N; (IPCC default value is 0.01 kg N_2O-N (kg NH_3-N + NOx-N volatilised)$^{-1}$).

Percent of managed manure nitrogen that volatilises

Table 29 below outlines IPCC default values for N loss form AWMS due to volatilisation of N-NH_3 and N-NOx. These values are based on studies undertaken by Rotz (2004), Hutchings et al. 2001 and the USEPA (2004) and are the default values applied in this equation. The table also outlines the range of values for each AWMS. It is noted that there can be wide variations of emissions depending upon environmental conditions and management parameters. For example, NH_4 emissions from anaerobic lagoons range from 25-75% of the N inputted. As the $Frac_{GasMS}$ factor has not been derived for NZ conditions there will be a degree of error built into the results.

Table 29: Default Values for N loss due to volatilisation from manure management of pig effluent (IPCC 2006).

AWMS	N loss from MS due to volatilisation of N-NH_3 and N-NOx (%) b $Frac_{GasMS}$ (Range of $Frac_{GasMS}$)
Anaerobic Lagoon	40% (25-75)
Pit Storage	25% (15-30)
Deep Bedding	40% (10-60)
Liquid slurries	48% (15-60)
Solid storage	45% (10-65)
Daily spread (Dairy Cattle)	7% (5-60)

It should be noted that no value is provided for swine daily spread and as a result the value for Dairy cows has been applied above. The IPCC notes that there is a large range associated with this value of 5-60%. Further work needs to be undertaken to develop a specific value for pigs.

5.6.2 Results: Aim 9

The results of indirect emissions from AWMS can be seen in Table 30

Table 30: Indirect N_2O emissions for AWMS treating pig derived manure 1990 and 2009

Manure management System (MMS)	Fraction of managed livestock manure nitrogen that volatilises	Amount of manure nitrogen that is loss due to volatilisation of NH_3 and NOx kg N yr^{-1}	Emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces [kg N_2O-N (kg NH_3-N + NOx-N volatilised$)^{-1}$]	Indirect N_2O emissions due to volatilization from Manure Management (kg N_2O yr^{-1}) 2009	Indirect N_2O emissions due to volatilization from Manure Management (kg N_2O yr^{-1}) 1990
Anaerobic Lagoon	0.4	287511.05	0.01	4518.0	5524.6
Daily Spread	0.07	62784.69	0.01	986.6	1206.4
Direct to pasture	NA			0.0	0.0
Pit storage	0.25	114197.04	0.01	1794.5	2194.3
Composting static pile	0.45	46222.53	0.01	726.4	888.2
Deep litter direct to land	0.4	9499.37	0.01	149.3	182.5
Deep litter + composting (no mixing)	0.45	298350.68	0.01	4688.4	5732.9
Deep litter + composting (Mixing)	0.45	105084.38	0.01	1651.3	2019.2
Digester	0.4	34455.09	0.01	541.4	662.1
Total				15056	18410.1

*I.E calculated in Agricultural Soils section below

5.6.3 Discussion: Aim 9

The results from the investigation of indirect N_2O emissions from AWMS for the 2009 calendar year indicate that 4.68Gg CO_2-e emissions are released from indirect deposition of N into a receiving environment through volatilisation. These results equate to approximately one third of the total direct emissions from manure management, highlighting a substantial contribution of N_2O emissions from this source.

5.6.4 Summary: Aim 9

- The results indicate that the release of gasses from volatilisation has the potential to become an important source of N_2O emissions and should be considered for future NZGHGIR.
- There is currently a wide range of values provided by the IPCC for N loss from MS due to volatilisation of N-NH_3 and N-NOx ($Frac_{GasMS}$) values applied in the equation. Further work is required to determine the relevance of the IPCC default values for the NZ environment.

5.7 Summary: N_2O emissions from Manure Management

2009	Direct N_2O emissions manure management (Gg CO_2-e)	Indirect N_2O emissions manure management (Gg CO_2-e)	Total N_2O emissions manure management (Gg CO_2-e)
1996 Value Tier 1 default	13.5	NA	13.5
Proposed IPCC Tier 2 1996	15.9	NA	15.9
Proposed IPCC Tier 2 2006	16.6	4.7	21.3
1990			
1996 Value Tier 1 default	16.4	NA	16.4
Proposed IPCC Tier 2 1996	19.4	NA	19.4
Proposed IPCC Tier 2 2006	20.3	5.7	26

6 N_2O Emissions from Agricultural Soils

The IPCC defines emissions from agricultural soils as emissions of N_2O that result from the anthropogenic input of N or N mineralisation that occurs through both direct and indirect pathways (IPCC 2006). Currently the inventory methodology does not consider CH_4 emissions from agricultural soils.

In the following sections we examine N_2O emissions from agricultural soils for the NZ pork industry during the 2009 calendar year.

6.1 Direct N_2O Emissions – Agricultural Soils

Historically in NZ, effluent from piggeries has been treated using a two pond system (anaerobic and aerobic) with the treated effluent being discharged directly into streams. However, since the introduction of the Resource Management Act in 1991, councils have been advocating the application of treated animal manure to land (Saggar et al. 2004). As a result, a large proportion of treated animal manure is currently disposed of to land. However, the change in policy was made without due consideration to the practice's impacts on air quality (Bhandral 2007).

Direct emissions from agricultural soils are calculated based on the amount of N being applied to soils either from AWMS, synthetic fertilizers, animal grazing, N-fixing crops or through the applications of crop residues to land, or N that is mineralised in the soils associated with soil C if a land use change has occurred. However, from the pig industry direct emissions from agricultural soils are solely the result of products from AWMS being applied to soil as well as effluent excreted direct to pastures from grazing animals.

6.2 Aim 10 : To compare direct N_2O emissions from agricultural soils using the current method applied to the NZ GHGIR and the proposed IPCC 2006 method.

A review of IPCC methodology between 1996 and 2006 has led to substantial changes in the way that the proposed 2006 IPCC guidelines calculate N_2O emissions from agricultural soils. The aim of this section is to undertake a comparison of the existing method used for the NZ GHGIR (being the IPCC 1996 method) with the proposed IPCC 2006 method.

In order to calculate N_2O emissions from agricultural soils we first need to calculate the quantity of N being applied to soils as a result of activities undertaken by the NZ pork industry.

6.2.1 Method: Quantity of N being applied to soils from animal manure

The primary change in the method between the 1996 and the 2006 IPCC guidelines for calculating N_2O emissions from agricultural soils is in determining the quantity of N that is being applied to the soils as a result of the type of AWMS in use. The current method used in the NZGHGIR seen in Equation 14 (below) does not take into consideration N lost from the system during storage and treatment of manure; rather it only considers N lost through indirect methods once manure has been applied to soils.

However, as seen in Section 5.5 losses of N during the treatment and storage process can be significant. The proposed 2006 IPCC methods take into account these losses when calculating the quantity of N being applied to soils (See Equation 15).

The two IPCC formulae are outlined below;

2) Formula currently used in the NZ GHGIR (IPCC 1996)

The 1996 IPCC methodology allows for emissions to be calculated using the following formula. The formula takes into account any N that may have been lost through volatilisation from soils ($Frac_{Gasm}$).

$$F_{AW} = N_{AW} * (1-Frac_{gasm,})$$

Equation 14

Where:

F_{AW} = the total amount of animal manure N applied to soils from waste management systems (other than discharge to pasture or paddock) after adjusting for indirect emissions that occur once the manure has been applied to soils.

N_{AW} = the amount of animal manure N in each waste management system minus the N applied directly to pasture and paddock.

$Frac_{GASM}$ = Fraction of total animal manure emitted as Nox or NH_3 (NZ specific default value 0.1).

2) Proposed IPCC 2006 Formula

The above methodology does not account for the total N lost in AWMS through volatilisation and leaching which therefore is no longer contained in the manure to be applied to soils. N losses from some AWMS, such as anaerobic lagoons, are substantial accounting for an estimated 55 – 99% loss of the total N entering the system (IPCC 2006). This loss of N needs to be taken into account in order to improve the estimates of N being applied to agricultural soils.

The 2006 IPCC methodology proposes to include these losses in their new methodology, by using the following formula:

$$N_{MMS\_} = \sum_{S} \left\{ \sum_{(T)} \left[\left[\left(N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)} \right) \bullet \left(1 - \frac{Frac_{LossMS}}{100} \right) \right] + \left[N_{(T)} \bullet MS_{(T,S)} \bullet N_{beddingMS} \right] \right] \right\}$$

Equation 15

Where;

N_{MMS_Avb} = amount of managed manure N available for application to managed soils or for feed, fuel, or construction purposes, kg N yr^{-1}.

N(T) = population of pigs in NZ.

N_{ex}(T) = annual average N excretion per animal, (defined in section 5.1).

MS(T,S) = fraction of total annual N excretion that is managed in a manure management system

$Frac_{LossMS}$ = amount of managed manure N for livestock category T that is lost in the manure management system % (see Table 29).

$N_{beddingMS}$ = amount of nitrogen from bedding (IPCC default values where applied), kg N $animal^{-1}$ yr^{-1}.

The quantity of the $Frac_{LossMS}$ from each AWMS proposed by the 2006 IPCC guidelines is outlined in Table 29 below. The table also demonstrates the range of values reported in various studies of each AWMS. The rates calculated include losses in the forms of NH_3, Nox, N_2O, and N_2 as well as from leaching and runoff from solid storage and dry lots (IPCC 2006).

Table 31: Default values for total N loss from manure management of pig effluent (IPCC 2006).

AWMS	Total N loss from MMS $Frac_{LossMS}$ (Range of $Frac_{LossMS}$)
Anaerobic Lagoon	78% (55 – 99)
Pit Storage	25% (15 – 30)
Deep Bedding	50% (10 – 60)
Liquid slurries	48% (15 – 60)
Solid storage	50% (20 – 70)
Daily spread (dairy cattle value)	22% (15–60)

The 2006 IPCC methodology also requires consideration of animal bedding as a source of N being applied to soils. Default values are provided for market and breeding swine and these are 0.8 and 5.5 kg N animal^{-1} yr^{-1}, respectively. However, the IPCC notes there is limited data to support these values. The methodology also recommends that where deep litter systems are in use, the figures outlined above for animal litter should be doubled. IPCC default values have been applied in these equations.

6.2.2 Results: Quantity of N being applied to soils from animal manure

Table 32 below outlines the results from the current methods applied in the NZGHGIR, while
Table 33 outlines the results from the 2006 methods;

Table 32: Quantity of N being applied to soils: default values IPCC 1996

Year	Animal waste		N input from animal waste (kg N)
	N excretion spread from all AWMSs (kg N)	Fraction of N excretion emitted as NO_x or NH_3	
1990	6,315,216	0.1	5,683,694
2009	5,164,624	0.1	4,648,162

Table 33: Quantity of N being applied to soils: default values IPCC 2009

	Manure Management System (MMS)	Amount of managed manure nitrogen available for application to managed soils or for feed, fuel, or construction purposes (kg N yr^{-1}) 1990	Amount of managed manure nitrogen available for application to managed soils or for feed, fuel, or construction purposes (kg N yr^{-1}) 2009
AWMS	Anaerobic Lagoon	193360	158131
	Daily Spread	855460	699601
	Pit storage	418915	342591
	composting static pile	62800	51358
	Deep litter direct to land	18415	14933
	Deep litter + composting (mixing)	514105	416893
	Deep litter + composting (No Mixing)	219381	176914
	Digester	54770	44792
AWMS Total		1905213	2337207
Direct to pastures	Grazing animals	379566	310411
Total		2215624	2716773

Table 34: Summary Table; Calculated N applied to agricultural soils from revised 1996 and proposed 2006 guidelines

	N applied to soils (kg N yr^{-1})		
	Revised 1996 guidelines using IPCC default values	Proposed 2006 guidelines Using study EF	Difference %
2009	4,648,162	2,215,624	53
1990	5,683,694	2,716,773	53

6.2.3 Discussion: Quantity of N being applied to soils from animal manure

It is widely acknowledged in scientific literature, that gaseous loss of N from effluent stored for a long period of time may be a major pathway of N movement, particularly under high temperatures (McCrory and Hobbs, 2004). A recent study by FSA Consulting, (2007) on Australian piggery deep litter systems noted a 47% movement of N from stockpiled litter. The fraction of N emitted from livestock manure depends on several variables including concentration and chemical composition of the N, pH, and temperature of the manure in the AWMS (USEPA 2004). Currently, the default values for $Frac_{LossM}$ have a wide range incorporated into each MS value. Further work is required to determine the relevance of the IPCC default values for the NZ environment.

The variation in methods between the 1996 and 2006 IPCC guidelines has a significant effect on the quantity of N being applied to NZ soils as a result of manure produced by the pig industry, reducing the N loading rates of soils by 53%. The results based on IPCC default values show a significant effect on N loading rates when N losses from AWMS are included in the equation. In the absence of NZ specific values it is recommended that IPCC default values be incorporated into the NZGHGIR.

6.2.4 N_2O emissions from N input into soils (EF_1): Direct emissions

In the 2008 NZ GHGIR, emissions of N_2O from agricultural soils in the pig farming sector have been calculated at 22.7Gg CO_2-e. Currently these emissions are being recorded using an IPCC 1996 Tier 1 approach as NZ specific research has been used to develop an emissions factor for N_2O emitted from animal waste being applied to soils (EF_1) (MfE 2009).

In the following sections we apply two IPCC methodologies to determine variations in N_2O emissions from soils.

6.2.5 Method: N_2O emissions from N input into soils (EF_1): Direct emissions

Emissions factors EF_1 and EF_3

As with all natural systems the rate of conversion of N to N_2O in soils is highly dependent upon the environmental conditions that are occurring onsite with studies showing that N_2O emission rates are highly variable throughout the seasons. These variations are linked to parameters such as soil oxygen content, temperature, the carbon: nitrogen (C:N) ratio and soil pH, all of which affect nitrification and de-nitrification reactions in soils , reactions that have the potential to emit N_2O.

The current NZ specific value for EF_1 is 0.01 kg N_2O-N/kg N and has been developed based on three NZ studies which yielded average (geometric) values equal to 0.013, 0.0232 and 0.0036 kg N_2O-N/kg N. The geometric average of these three values is 0.0103 kg N_2O-N/kg N. Consequently, on average, the data is thought to support the NZ specific value for EF_1 (Kelliher et al. 2007). It should be noted that these values appear to be based on the application of urea to the soils and does not specifically account for the application of piggery effluent/manure to soils. However, in the absence of data specifically pertaining to pig manure this NZ default value will be applied in both of the IPCC methods outlined below.

Additionally, the review of manure management practices (MS) in the pig industry indicated that approximately 9% of N derived from manure is applied directly to land through grazing animals. As a result, N_2O emissions direct to pastures need to be considered (EF_3). N deposited on pastures as a result of animal deposition is not deposited uniformly across a pasture but in highly concentrated, small patches in the soil profile. Urine is often the principal source of N entering the soils of grazed pasture systems. The main component of N in urine is urea ($(NH_2)_2CO$), which rapidly hydrolyses to form NH_4^+. This in turn undergoes nitrification (De Klein and Eckard 2008). Urine patches also contain a high water content, enhancing conditions appropriate for denitrification.

Studies of N_2O emissions from urine patches indicated that of the total N entering the soils from urine, anywhere from 0% to 16.3% can be converted to N_2O with an average value of 1.3% of the total N deposited as urine being emitted as N_2O (Van Groenigen et al 2005). Changes in these emission factors are linked to environmental parameters such as soil moisture content and temperature. The IPCC recommends an emissions factor for urine-derived N_2O of 2.0% for total nitrogen present in urine patches (IPCC 2001). However, there is some concern about the accuracy of this figure; as the use of artificial urine in experimental work may have exacerbated N_2O release (De Klein et al 2003). As a result, most studies in NZ use a conversion factor of 0.7% of the total N entering the pasture from urine (MfE 2009). In contrast to urine which contains N that rapidly hydrolyses to NH_4^+, the N component in dung is largely organic, and is not readily available to undergo nitrification (Klein and Eckard 2008). Dung has a high carbon content used by the microorganisms as a source of biomass and energy. Consequently, as a result of dung deposits there can be an increase in activity of microorganisms in the soil which can enhance anaerobic conditions via the consumption of available soil oxygen.

As a result, a NZ specific emissions factor for animal manure applied directly to pastures through animal grazing has been developed and is currently applied in the GHGIR. This value of 0.01 kg N_2O-N/kg N excreted has been developed based on studies by Carran et al. 1995; Muller et al. 1995; de Klein et al. 2003; and Kelliher et al. 2003 for N_2O in NZ conditions However, this value has not been developed specifically for pig excreta. The IPCC 2006 default values for EF_3 provides two different figures, depending on the type of animal being considered. $EF_{3PRP,CPP}$ for cattle, poultry and pigs and $EF_{3\ PRP,SO}$ for Sheep and 'Other Animals. These values have been developed using work undertaken by de Klein (2004). However again has not been developed specifically for pig manure as a result the NZ Specific value of 0.01 kg N_2O-N/kg N excreted has been applied.

EFs discussed above were applied to the following two formulae.

1) Current formula used in the NZ GHGIR (IPCC 1996)

$$N_2O_{\text{direct from AW-N}} = F_{AW} * EF_1 * 44/28$$

Equation 16

Where;

F_{AW} = the total amount of animal manure N applied to soils from waste management systems (other than direct application to pasture and paddock) after adjusting for indirect emissions that occur once the manure has been applied to soils.

EF_1 = proportion of direct emissions from N input to soil (0.01 kg N_2O-N/kg N, NZ specific for all animal manure).

2) IPCC 2006 Formula

$$N_2O_{Direct} = (N_2O-N_{N\ inputs} + N_2O-N_{OS} + N_2O-N_{PRP}) * 44/28$$

Equation 17

Where:

$N_2O_{Direct-N}$ = annual direct N_2O–N emissions produced from managed soils, kg N_2O–N yr^{-1}.

$N2O–N_{N\ inputs}$ = annual direct N_2O–N emissions from N inputs to managed soils, kg N_2O–N yr^{-1}.
$N_2O–N_{OS}$ = annual direct N_2O–N emissions from managed organic soils, kg N_2O–N yr^{-1}.
$N_2O–N_{PRP}$ = annual direct N_2O–N emissions from urine and dung inputs to grazed soils, kg N_2O–N yr^{-1}.

$$N_2O\text{–}N_{N\ inputs} = \begin{bmatrix} \left[\left(F_{SN} + F_{ON} + F_{CR} + F_{SOM}\right) \bullet EF_1\right] + \\ \left[\left(F_{SN} + F_{ON} + F_{CR} + F_{SOM}\right)_{FR} \bullet EF_{1FR}\right] \end{bmatrix}$$

$$N_2O\text{–}N_{OS} = \begin{bmatrix} \left(F_{OS,CG,Temp} \bullet EF_{2CG,Temp}\right) + \left(F_{OS,CG,Trop} \bullet EF_{2CG,Trop}\right) + \\ \left(F_{OS,F,Temp,NR} \bullet EF_{2F,Temp,NR}\right) + \left(F_{OS,F,Temp,NP} \bullet EF_{2F,Temp,NP}\right) + \\ \left(F_{OS,F,Trop} \bullet EF_{2F,Trop}\right) \end{bmatrix}$$

$$N_2O\text{–}N_{PRP} = \left[\left(F_{PRP,CPP} \bullet EF_{3PRP,CPP}\right) + \left(F_{PRP,SO} \bullet EF_{3PRP,SO}\right)\right]$$

Equation 18

Where:
F_{SN} = annual amount of synthetic fertiliser N applied to soils, kg N yr^{-1} (NA).
F_{ON} = annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils (Calculated in Section 6.2.1), kg N yr^{-1}.
F_{CR} = annual amount of N in crop residues (above-ground and below-ground), including N-fixing crops, and from forage/pasture renewal, returned to soils, kg N yr^{-1}(NA).
F_{SOM} = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes to land use or management, kg N yr^{-1} (NA).
F_{OS} = annual area of managed/drained organic soils, ha (Note: the subscripts CG, F, Temp, Trop, NR and NP refer to Cropland and Grassland, Forest Land, Temperate, Tropical, Nutrient Rich, and Nutrient Poor, respectively) (NA).
F_{PRP} = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N yr-1 (Calculated in Section 6.2.1).
EF_1 = emission factor for N_2O emissions from N inputs, kg N_2O–N (kg N input)$^{-1}$(0.01 kg N_2O-N/kg N NZ specific parameter applied).
EF_{1FR} is the emission factor for N_2O emissions from N inputs to flooded rice, kg N_2O–N (kg N input)$^{-1}$(NA).
EF_2 = emission factor for N_2O emissions from drained/managed organic soils, kg N_2O–N ha^{-1} yr^{-1}; (NA).
EF_{3PRP} = emission factor for N_2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals, kg N_2O–N (kg N input)-1; (0.01 kg N_2O-N/kg NZ specific default value).

It should be noted that the 2006 formula no longer considers N losses from volatilisation (NH_3 and NOx) that may occur from application of N to soils.

6.2.6 Results: N_2O emissions from N input into soils (EF_1): Direct emissions

The results from the investigation are outline in and Table 35 below:

Table 35: Summary Table: Direct N_2O emissions from agricultural soils using IPCC 1996 and 2006 Guidelines

IPCC method	Annual direct N_2O emissions produced from managed soils (kg N_2O yr^{-1}) 2009	Annual direct N_2O emissions produced from managed soils (kg N_2O yr^{-1}) 1990
Revised 1996 guidelines using IPCC default values	73043	89315
Proposed 2006 guidelines	34817	42692
Difference	52%	52%

6.2.7 *Discussion*

- Effluent from pigs being applied to soils takes a number of different forms: being either liquid application (slurries direct to land and post anaerobic digestion), or dry application (from deep litter beds containing straw and sawdust to composted manure). Further work should be undertaken to determine if the condition of the manure at the time it is applied to land affects EF_1 rates.

  The methodology assumes that all animal manures will produce the same amount of N_2O emissions per kg of N applied to the land and does not take into account variations due to changes in manure composition (e.g. the C:N ratio) from different manure forms such as slurries and deep litter. In NZ, effluent irrigation to pasture has been identified as a major source of N_2O emissions (Saggar 2004, Wang 2004). The rate and method of land application have the potential to impact N_2O emissions from soils. Slurries applied to soils can restrict oxygen diffusion with the soil surface becoming anaerobic (Sherlock et al. 2002) contributing to denitrification. Alternatively, the application of dry litter to soils has been shown to result in a decrease in N_2O emissions (less than 0.01% of N converted to N_2O, Thorman et al. 2007). Further work is required to develop EF_1 for dry and liquid manure.

- While the methodology uses NZ specific data to calculate the direct N_2O emissions from agricultural soils (EF_1), the current emissions factor is limited as it applies a blanket approach to estimating emissions, assuming that emission rates will be the same across all disposal manure sources e.g. cattle, sheep and pigs.

  NZ studies on N_2O emissions from soils have provided a range in results. Chadwick et al. (2000) found that N_2O emissions were significantly higher from dairy cattle than from piggery effluent at emission rates of 1.51kg N_2O-N ha^{-1} and 0.77kg N_2O-N ha^{-1}, respectively when slurry was applied to land. This finding, however, was contradicted by Bhandral et al. (2007) who found that treated piggery farm effluent contributed higher N_2O-N emissions after application to soils when compared with treated and non-treated dairy effluent as well as treated meat works effluent. Bhandral et al. (2007) reported a peak emissions rate of 0.585kgN ha^{-1} from treated piggery farm effluent, corresponding to a total of 2.17% of the total added effluent N during an autumn application. Whalen et al. (2000) hypothesized that the difference was primarily due to the rapid mineralisation of NH_4-N present in piggery effluent. Bhandral et al. (2007) suggest that the difference in N_2O emissions was due to the concentration of easily mineralized N at the time of effluent application.

  In a NZ study, Sherlock et al. (2002) found that 2.1% of N in pig slurry applied to land was emitted as N_2O. The study found higher N_2O emissions from a plot applied with effluent (1gN/$ha^{-1}h^{-1}$) than a control plot (0.08g N $ha^{-1}h^{-1}$) for the first 14 days after application. Additionally, it was noted that the significance of environmental parameters on N_2O emissions, such as rain, created a spike in N_2O emissions to 15.8gN $ha^{-1}h^{-1}$ 67 days after the slurry application (Sherlock et al. 2002).

  Further work is required to determine how the source of N affects the rate of N_2O production.

6.3 Summary: Direct N_2O Emissions - Agricultural Soils

- The 2006 IPCC methodology allows for countries to account for N loss from manure management systems prior to the application of N to land. The results from this investigation noted a reduction in N loading to soils by 52% when compared the current method used in the NZGHGIR. As a result of the reduction in N loading rates, the quantity of N_2O emitted from the soils has also been reduced. Given the significance of the reduction found in this study it appears that the consideration of N loss from AWMS during treatment and storage processes is important when calculating GHG emissions from the application of effluent to soils. It is acknowledged that currently there is a large range of values incorporated into the IPCC default figure for $Frac_{LossMS.}$ Further work is required developed NZ specific values and reduces uncertainty in this area.

6.4 Indirect emissions from Agricultural Soils

Indirect emissions from agricultural soils are produced by two main processes: 1) volatilisation of NH_3 and NO_x and 2) leaching and runoff of N mainly in the form of NO_3^-. While neither process produces GHGs directly, they both have the potential to produce N_2O emissions from the subsequent deposition of agriculturally derived N into another environment (IPCC 2006).

6.5 Indirect Emissions from agricultural soils – Volatilisation

Laurenson et al. (2006), in a review of major N losses from soils following the application of piggery effluent to land, concluded that volatilisation is perhaps the most significant pathway for N loss. However, environmental conditions play an important role in the rate of volatilisation that occurs from soils. Volatilisation rates are known to increase when urine or fertilizers such as urea are applied to soils particularly under moist, warm (above ~15°C) and windy conditions (McLaren and Cameron, 1996). Volatilisation is site-specific and its rate can vary in accordance with soil and climate factors such as soil pH, soil moisture, soil texture, soil cation exchange capacity, temperature and wind velocity (Saggar 2004).

6.6 Aim 11 : to calculate N_2O emissions from Volatilisation from Agricultural Soils

The GHGIR calculated N_2O emissions as a result of piggery effluent being applied to agricultural soils were 2.5Gg CO_2-e, for the 2008 calendar year. This value has been calculated using a New Zealand specific factor for indirect emissions from volatilisation.

6.6.1 Method: Aim 11

The methodology assumes that of the total N applied in the form of animal excreta, 10% will volatilize (MfE 2009). The IPCC then assumes that of the N that has volatilized, 1% will be re-deposited back to the soil and form N_2O (MfE 2009). To determine pigs' contributions to this source the following equation is used.

1) IPCC 1996 and current NZGHGIR method

$$N_2O_{(G)} = [(N * Nex) * Frac_{gasm}] * EF_4 * 44/28$$

Equation 19

Where:

$N_2O_{(G)}$ = N_2O produced from atmospheric deposition.
N = Population of pig.
Nex = Annual average N excretion per head (IPCC default for pig 16 kg head^{-1} yr^{-1}).
$Frac_{GASM}$ = Fraction of total animal manure emitted as NOx or NH_3 (NZ specific 0.1).
EF_4 = proportion of nitrogen input that contributes indirect emissions from volatilised nitrogen (IPCC default 0.01 kg N_2O-N/kg NH_4-N & NOx-N deposited).

2) IPCC 2006 method

$$N_2O_{(ATD)} = (F_{SN} * Frac_{GASF} + (F_{ON} + F_{PRP}) * Frac_{GASM} * EF_4) * 44/28$$

Equation 20

Where;

$N_2O_{(ATD)}$ = annual amount of N_2O produced from atmospheric deposition of N volatilised from managed soils, kg N_2O yr^{-1}.
F_{SN} = annual amount of synthetic fertiliser N applied to soils, kg N yr^{-1}.
$Frac_{GASF}$ = fraction of synthetic fertiliser N that volatilises as NH_3 and NOx, kg N volatilised (kg of N applied)$^{-1}$.
F_{ON} = annual amount of managed animal manure, compost, sewage sludge and other organic N additions applied to soils, kg N yr^{-1}.
F_{PRP} = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N yr^{-1}.
$Frac_{GASM}$ = fraction of applied organic N fertiliser materials (F_{ON}) and of urine and dung N deposited by grazing animals (F_{PRP}) that volatilises as NH_3 and NOx, kg N volatilised (kg of N applied or deposited)$^{-1}$
EF_4 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, [kg N–N_2O (kg NH_3–N + NOx–N volatilised)$^{-1}$].

Fraction of N that volatilises as NH_3 and NOx,

Studies on volatilisation rates from piggery effluent have shown a wide range of results. Pain et al. (1989) studied emissions after a pig slurry application to soil. They found that 5 to 27% of the applied 574kg of N ha^{-1} volatilized, with the majority occurring in 12 hours of application. Smith et al. (2001) found a volatilisation rate of 12% of the N irrigated to an Australian silage cropping system using a central pivot irrigation system. In contrast, Sharpe and Harper (1997) reported volatilisation losses of 13kg N ha^{-1} or 50% of the N applied to the site, in a USA study of a single sprinkler irrigation event. These variations can be attributed to a range of environmental factors associated with the soils (temperature, moisture content, wind etc.).

In NZ, there has been a wide range of studies that have examined N losses from dairy effluent. However, studies on piggery waste have been limited. Cameron et al. (1995), in a study examining piggery effluent application to stony soils in Canterbury, NZ, found that an application rate of 200kg N ha^{-1} resulted in 10% of the applied N being lost by ammonia volatilisation. By comparison, a study by Carey et al. (1997) noted 15–26% of N was lost via volatilisation during an application to semi-free draining soils in the same region with approximately 70% of N loss occurring in the 48 hours after application. New Zealand in the 2008 GHGIR have incorporated a NZ specific value for the fraction volatilised being 10% of the N applied to soils volatilizes. As a result this value will be applied in this investigation.

6.6.2 Results: Aim 11

The results for Aim 11 can be seen below.

Table 36: Summary Table: Indirect Volatilisation N_2O emissions from agricultural soils using IPCC 1996 and 2006 Guidelines

IPCC method	**Indirect N_2O emissions from atmospheric deposition (kg N_2O) 1990**	**Indirect N_2O emissions from atmospheric deposition (kg N_2O) 2009**
Revised 1996 guidelines using IPCC default values	9924	8116
Proposed 2006 guidelines with EF	4269	3482
Difference	57%	57%

6.7 Indirect Emissions from Agricultural soils – N leaching and runoff

Agricultural-derived N can also be lost from soils due to leaching or from drainage water runoff from the soils. In general, N in leachate and runoff occurs in the form of nitrate (NO_3^-). Leaching and runoff can cause agricultural-derived N to be deposited in another environment (such as groundwater, wetlands) where denitrification can occur, producing N_2O emissions (IPCC 1997).

6.7.1 Aim 12 : to calculate N_2O emissions from leaching from Agricultural Soils

The 2007 NZ GHGIR has calculated that indirect emissions from N leaching from N derived from the pig industry amounted to 4.4GgCO_2-e yr^{-1}.

6.7.2 Method: Aim 12

In the 2008 NZ GHGIR, the MfE has used a NZ specific default value for the amount of N that leaches through soils ($Frac_{leach}$). This value has been calculated based on a review undertaken by Thomas et al. (2005) which examined N leaching in field studies and simulation modelling of leaching from a number of different agricultural environments (i.e. dairy, sheep and beef, arable and intensive vegetable farms) in NZ.

As with volatilisation, the methodology assumes that a proportion of the leached N is subsequently deposited in another environment where nitrification or denitrification can then take place.

Currently the IPCC methodology anticipates that 2.5% of the leached nitrogen (7% of total nitrogen applied) will convert to N_2O (EF_5) i.e. 0.175% of the total N applied (MfE 2009).

IPCC1996 and current method used in the NZ GHGIR

$$N_2O = (MS * Nex * N) * Frac_{leach} * EF_5 * 44/28$$

Equation 21

Where:

N = population.

N_{ex} = annual average N excretion per head (IPCC default for pig 16 kghead^{-1}yr^{-1}).

MS = proportion of manure applied to pastures (kg).

$Frac_{leach}$ = fraction of N input to soils that is lost through leaching and runoff (0.07, NZ specific fraction).

EF_5 = proportion of N input that contributes to indirect emissions from leached nitrogen (IPCC default 0.025).

Proposed IPCC 2006 method

$$N_2O_{(L)} = [(FS_N + F_{ON} + F_{PRP} + F_{CR} + F_{SOM}) \bullet Frac_{LEACH-(H)} \bullet EF_5]*44/28$$

Equation 22

Where;

$N_2O_{(L)}$= annual amount of N_2O produced from leaching and runoff of N amendments to managed soils in regions where leaching/runoff occurs, kg N_2O yr^{-1}.

FSN = annual amount of synthetic fertiliser N applied to soils in regions where leaching/runoff occurs, kg N yr^{-1} (NA).

F_{ON} = annual amount of managed animal manure, compost, sewage sludge and other organic N additions applied to soils in regions where leaching/runoff occurs, kg N yr^{-1} (see section 6.2.1).

F_{PRP} = annual amount of urine and dung N deposited by grazing animals in regions where leaching/runoff occurs, kg N yr^{-1} (section 6.2.2).

F_{CR} = amount of N in crop residues (above- and below-ground), including N-fixing crops, and from forage/pasture renewal, returned to soils annually in regions where leaching/runoff occurs, kg N yr^{-1}(NA).
F_{SOM} = annual amount of N mineralised in mineral soils associated with loss of soil C from soil organic matter as a result of changes to land use or management in regions where leaching/runoff occurs, kg N yr-1 (from NA).
$Frac_{LEACH-(H}$) = fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kg N (kg of N additions)$^{-1}$ (NZ specific value of 0.07% of N applied to soils).
EF_5 = emission factor for N_2O emissions from N leaching and runoff, kg N_2O–N (kg N leached and runoff)$^{-1}$ (default value of 0.0075 kg N_2O-N/kg of N leached & runoff applied).

Fraction leached through soils ($Frac_{Leached}$)

The rate of leaching is largely dependent upon environmental conditions such as soil type and rainfall. The movement of NO_3^- through the soil profile is closely linked to the drainage characteristics or porosity of the soil as well as the application method and application rates (Laurenson et al 2006). High application rates causing preferential flow of contaminants through the soils rather than a low application rate that has the potential for contaminants to be retained in the root zones. There have been several NZ studies on the movement of N through soils from slurry piggery effluent. No data was found regarding N leaching from deep litter. Carey et al. (1997) noted that of the N applied to soils, 8-19% was lost in the leachate on semi free-draining pasture soils in Canterbury, NZ. The variation in results can be explained by a change in N loading rates to the soil which varied between 200-400kg N By comparison, a study by Cameron et al. (1995) using lysometers filled with Canterbury stony soils, showed that an application rate of 200 kg N/ha resulted in 5% of N being leached (11 kg N/ha) in the first year and less than 2.5% of applied N being leached in the second year.

Currently in the IPCC guidelines, there is a large amount of uncertainty regarding the $Frac_{Leached}$ default value. The 2006 IPCC guidelines outlines that studies have found a range of leaching factors between 0.1-0.8(IPCC 2006) and recommends a default value of 0.3 be applied. NZ has developed a country-specific default value which was developed by Thomas et al. (2005) using the OVERSEER® nutrient budget model. The model predicted a $Frac_{Leached}$ value of 0.03-0.1 from NZ agricultural conditions with a mean of 0.07 (Thomas et al. 2005) which has been applied as the current default value. It should be noted that piggery waste was not one of the components tested as part of Thomas el al.'s (2005) study. However, given the value was determined under NZ environmental conditions, it will be applied in the equation used in this investigation.

N_2O that is produced from N deposition back into another environment (EF_5)

Additional to the rate of N being leached through soils there is still considerable uncertainly behind the quantity of N_2O that is produced from N deposition back into another environment (EF_5). This emission factor incorporates emissions from three components, being N_2O emissions as a result of the deposition of anthropogenic sourced N in 1) groundwater, 2) surface drainage (rivers) and 3) estuaries. The IPCC from 1996 to 2006 have altered the EF_5 value from 0.025 to 0.0075kg N_2O-N/kg N leached or in runoff water based on the findings of recent research (IPCC 2006).

6.7.3 Results

Results from the investigation into indirect N_2O emissions from N leaching are as follows:

Table 37: Summary Table: Indirect N_2O Leaching emissions from agricultural soils using IPCC 1996 and 2006 Guidelines

IPCC method	Indirect N_2O emissions from atmospheric deposition (kg N_2O) 1990	Indirect N_2O emissions from atmospheric deposition (kg N_2O) 2009
Revised 1996 guidelines using IPCC default values	17367	14202
Proposed 2006 guidelines	2241	1828

6.8 Discussion: Indirect emissions

- There is a large degree of uncertainty surrounding indirect N_2O emissions from agricultural soils from volatilization as well as from runoff and leaching, particularly relating to the emission rates that occur as a result of N being deposited into another environment.

- The results from this study have shown that the use of the 2006 IPCC substantially reduces indirect N_2O emissions when compared with the current methods used in the NZ GHGIR. This reduction is primarily due to two changes in methodology: one being the recalculation of Nex values for NZ pigs estimated at 10.8kg animal^{-1} yr $^{-1}$ compared with 16 kg animal^{-1} yr $^{-1}$; the second is the consideration of N losses from AWMS during treatment and storage processes.

6.9 Emissions from Agricultural soils

Table 38: Summary N_2O emissions from Agricultural Soils for the 2009 calendar year (GgCO_2-e)

	Current method (IPCC1996)	Proposed NZ specific method (IPCC 2006)
2009		
Direct N_2O emissions Agricultural soils (Gg CO_2-e)	22.643	27.688
Indirect N_2O emissions (Gg CO_2-e) Volatilisation	2.516	3.076
Indirect N_2O emissions (Gg CO_2-e) Runoff leaching	5.384	4.403
Total emissions manure management (Gg CO_2-e)	30.543	35.167
1990		
Direct N_2O emissions Agricultural soils (Gg CO_2-e)	11.386	9.281
Indirect N_2O emissions (Gg CO_2-e) Volatilisation	1.139	0.928
Indirect N_2O emissions (Gg CO_2-e) Runoff leaching	0.598	0.487
Total emissions manure management (Gg CO_2-e)	13.122	10.696

7 Plantings for offsetting

Forests are an important component of the global carbon (C) cycle as they provide a temporary C sink which offsets GHG emissions. Plants sequester C by converting atmospheric CO_2 to sugars (e.g. cellulose). In commercially-planted forests (plantations) short-term net C sequestration occurs as forests store C in their biomass during the growth of the plantation. C will then be released during the harvesting stage (deforestation) at a rate dependent upon the end use of the wood products i.e. wood used for building products will have a longer carbon storage life than that burnt directly for heat. The amount of C uptake in forests depends on the species composition, age, and environmental conditions (e.g. soils, water and temperature) (MAF 2009).

Many native forests grow at the same rate as their biomass is lost due to decomposition and the net result is a 'carbon neutral' forest. In NZ, C balance in natural forests was evaluated using a Tier 1 IPPC approach in the 2007 GHGIR. The results from the investigation indicated that NZ natural forests are considered to be in a steady state or acting as a small C sink. As a result indigenous forest established before 1 January 1990 are not included in the NZ ETS. This is because the C stocks in these forests are in a steady state (MAF 2010).

7.1 Aim 13 : to calculate carbon offsets from forestry plantings in the pig industry

The project proposed to calculate the carbon offsetting provided by from Kyoto Forest plantings that are occurring on pig farms in NZ.

7.2 Method: Aim 13

In order to standardise 'forest' definitions that are used for C trading globally the Kyoto Protocol outlines a definition of land eligible for trading as a 'Kyoto forests'. These can either be implemented or adapted by a country for use in trade. The following is the NZ definition of a Kyoto Forest as defined by MAF (2009a);

'an area of land of at least one hectare, with forest species (tree species capable of reaching at least five meters in height in the place that they are located) that have, or are likely to have, at maturity crown cover of more than 30 percent on each hectare 'and an average width of at least 30 meters.' (MAF 2009a).

This definition has been applied in this study.

In NZ there has been a large amount of research conducted on forest systems particularly on Radiata Pines over the last 20 years. As a result of the research MAF has developed "Look-up Tables" which could be used as a Tier 2 approach to accounting. The Look-up Tables predict the growth of C stocks in forests according to the age of trees, forest type and in some cases (*Pinus radiata*) variations in C storage according to geographical location in NZ (MAF 2009). The C stock values in the tables are expressed in units of tonnes of CO_2 /ha dependent upon the age of the plantation. The approach simply assumes an average density of planting and management practices and requires the user to know the age and extent of the forest which can then be multiplied by the C sequestration factor.

It was proposed that we undertake a survey of farms to determine carbon sequestration from forests, using the methodology developed by MAF using 'Look-up Tables'.

In order to use the tables for a particular forest it is necessary to answer the following questions regarding the plantation:

1) is the forest pre 1990 or post 1989?

2) what is the primary forest species? (e.g. *Pinus radiata* , exotic hardwood etc.)
3) if the forest type is *Pinus Radiata*, what region is the forest in?
4) what is the age of the forest at the time that C stocks are to be determined?
5) if the forest is a second rotation (or later) post 1989 forest what was the previous forest type, age at harvest and how long ago was it harvested (MAF 2009)?

7.3 Results: Aim 13

In the NZ pork industry there are a number of farms that undertake planting of native and commercial forest on site. However, a large proportion of these farms do not meet the definition of NZ Credited forests defined by MAF, as outlined above. Of the farms surveyed 70% of farm managers said that they had no farm plantings that meets the above definition of a Kyoto Forest. Of the remaining 28% over half (15% of total) indicated that the forestry on their properties consisted of small pocket holdings of less than 5 hectares, while the remaining 15% stated that they were involved in plantings of greater than 5 hectares.

However on a large number of farms surveying could not obtain enough information required to undertake to undertake calculations using the MAF Lookup Tables. For the smaller holdings (less than 5 hectares), farm owners had only limited information on plantations, particularly when properties had recently changed ownership. Additionally the larger holdings were often located and managed off site and information on plantations was not available. Given the lack of information available during surveying it was determined that the calculation of C offsets by forests should not be undertaken. As a result no calculations for NZ Pork forest-planting credits were undertaken in this investigation.

7.4 Discussion

- Surveying identified a number of allocation problems associated with assigning C sequestration directly to the NZ pork industry. Many of the farms surveyed were multi-disciplinary businesses, with farms running a combination of stock as well as forestry practices. Additionally, some of the forestry plantings those were not located directly on the piggery site. These problems with allocation need to be resolved if the ETS is to be developed at an industry level rather be undertaken on an individual farm basis.

- Of the 70% of farmers that stated that they had no forestry on their property most claimed to have some planting on site mostly in the form of shelter break-plantings that they thought should be included in the GHG inventory. The main parameter that limited their inclusion is the provision that any planting needs to be greater than 30m wide in order to be eligible for C credits. We note that this is a NZ specific provision and is not a component of the Kyoto definition provided in the Kyoto Protocol. In NZ, shelter belt plantings are widely used and are contributing to the temporary removal and storage of C from the atmosphere. Some shelter belts on properties are significant and can meet the definition provided in the Kyoto Protocol but not the NZ specific definition developed by MAF. Consideration should be given by MAF to include shelter belts into the NZ forest definition if its composition and size meets all the parameters of the Kyoto definition for forests.

8 Summary

To date, due to its small contribution to NZ's total GHG emissions profile, the NZ Pork industry has been assigned default international standards provided by the IPCC for a majority of the calculations used to determine its emissions profile. In some categories, such as Agricultural Soils, NZ specific default data has been included. However, values have largely been extrapolated from research conducted on dairy, beef and sheep farming, rather than from specific data on pig production. As a result there is a degree of uncertainty surrounding emission values provided in the NZGHGIR for the NZ Pork Industry.

The project aimed to improve the accuracy of data currently used for accounting GHG emissions in NZ, by undertaking an assessment of the NZ pork industry's management practices. Over a 3 month period, surveying was undertaken at 56 farms, comprising 68% of NZ pork production. Surveying recorded on farm management practices for AWMS as well as data on feed provided to animals at varying subclasses. Additionally, NZPork was approached to provide data on final finishing weights of animals sent to market in order to develop NZ-specific Nex values using 2006 IPCC methods. The survey data was then compiled to assess the current default values used in the NZ GHGIR. The project objectives are summarized below.

8.1 Objective 1: To develop practicable options for further improving the accuracy and reliability of pork industry emissions data

The use of NZ-specific data over IPCC default developed as part of this investigation would improve the reliability of the pork industries emissions. The following outlines a summary of proposed changes to the current IPCC default values.

1. The current MS values for AWMS used in the inventory do not accurately reflect farm practices being applied in NZ.

The study noted that the current breakdown of MS factors used in the NZGHGIR does not accurately reflect the manure management processes being used by NZ pork producers. The IPCC (1996) notes that there are limitations to the Tier 1 approach used to calculate CH_4 emissions from manure management if the MS default values do not accurately reflect the manure management systems in operation in any given country (IPCC 1996). This investigation found a large variation between the IPCC default MS values for the 'Oceanic Region' and the management systems in operation on farm. Of particular concern is the current estimate that 55% of all manure is being treated by anaerobic lagoons, however, this study has indicated that anaerobic lagoons treat only 18-21% of NZ's piggery manure. This reduction significantly decreases emissions from NZ pork producers as anaerobic lagoons are a significant point source of CH_4 emissions.

This finding affects the use of the current 'Oceanic Region' default emissions factor for '*Manure Management – Swine*' applied within the NZ GHGIR as this value has been developed based on the default assumptions for MS. The perceived high use of anaerobic lagoons makes the 'Oceanic Regions' default value of 20kg $CH_4 head^{-1} yr^{-1}$ the highest default value applied globally. The findings from this study note that this value currently overestimates emissions and as a result we would not recommend the use of Tier 1 default values to calculate CH_4 emissions from manure management for pigs.

The study also found that MS values may require recalculation between CH_4 and N_2O calculations if solid separation techniques are commonly used in a country and included into the MS equations. Solid separation affects the quantity of N and VS loading rates entering an AWMS at different rates due to the variation in the location of parameters as the media is partitioned into solid and liquid fraction.

2. IPCC default GE value of 37MJ $animal^{-1} day^{-1}$ overestimates the energy being provided to the average NZ pig.

The investigation undertook a study of diets being fed to NZ pigs, examining over 59% of NZ pork production. The investigation concluded that the IPCC default GE value of 37MJ animal^{-1}day^{-1} overestimates the energy being provided to the average NZ pig. A value of 26.9MJ animal-^{1}day^{-1} better represents the nutritional diets being provided. One of the primary reasons for this reduction is the younger age and as a result lighter weights of NZ animals that are sent to market compared with the international average.

This recalculation of GE values affected the emissions factors used in enteric fermentation equations as well as the VS excretion rates. As a result the emissions factor for enteric fermentation was revised to 1.08 kgCH_4Yr^{-1} animal^{-1} compared with 1.5 kgCH_4Yr^{-1} animal^{-1} at a Tier 1 level. Average VS values calculated from the study indicate that the revised 1996 IPCC guidelines overestimate VS emissions per head. The study shows that a VS loading rate of 0.23-0.26kgVS head^{-1}day^{-1} more accurately reflects excretion rates of NZ animals.

3. A reduction in Nex values from 16kg N animal^{-1}Yr^{-1} to 10.8kg N animal^{-1}Yr^{-1}.

This study recommends a reduction of Nex values from 16kg N animal^{-1}Yr^{-1} to 10.8kg N animal^{-1}Yr^{-1} based on the small weights of finished animals in NZ. This reduction results in a decrease in N loading rates to AWMS as well as to Agricultural Soils.

NZ pork producers have unique farming practices which have the potential to affect GHG emissions from their farms. As a result the default values applied within the inventory need to reflect these on-farm practices. This study has shown that the some current default values used within the NZGHGIR result in an overestimate of emissions from the NZ Pork industry. The study found that the current MS for the Oceanic Region does not reflect values on-farm practices and should be updated to the values determined in this investigation.

Additionally the study proposes changes to default values for Enteric Fermentation, Nitrogen Excretion and Volatile Solid excretion rates. Given the significance of these changes to the NZ pork industry, further work could be undertaken to verify that these changes. E.g. undertake on farm sampling to determine Nex and VS excretion values for various subclasses for NZ pigs.

The figures determined in this study are baseline values upon which all calculations used within the inventory are derived. The use of verified NZ-specific values for the above parameters would provide greater accuracy and reliability within the NZGHGIR.

8.2 Objective 2: Options for managing any issues associated with system boundaries and allocation of emissions to pork or other sectors

The project identified systems boundary issues particularly in the application of manure to land, as well as any off sets by plantings when GHG emissions are considered at an industry level.

Many of the farms surveyed were multi-disciplinary businesses, with farms running a combination of stock as well as forestry practices. Alternatively emissions and offsets could be spread over a number of properties such as in the case of manure applied to land. Application of manure can occur outside the source property, as it can replace the need for synthetic fertilizer in some operations. This removal of effluent from the pig farm removes the ability of the owner to undertake mitigation strategies to reduce the rate of N_2O being emitted from soils either through the development of good practices (such as using a wintering pad in wet conditions) or through the application of soil amendments such as nitrification inhibitors (NIs) (these restrict the microbes that convert NH_4^+ to NO_3^- , as a result they inhibit or reduce the amount of soil NO_3^- available for reduction to N_2O via denitrification.). For land application, the use of pig manure removes the need for using chemical fertilizers that would otherwise be applied to the soil releasing N_2O emissions.

Further work is required to determine the impact on system boundaries on the GHG emissions profile of the NZ Pork industry.

8.3 Results

The results of GHG emissions calculated from each agricultural sector considered in this investigation are summarised below. The table provides a breakdown of the core values attributed to NZ Pork industry these include emissions from enteric fermentation, manure management as well as Agricultural Soils emissions.

Table 39: Summary of results for the 1990 and 2009 calendar years

	Default values from the IPCC 1996 Guideline	Calculated EF using the IPCC 1996 Guideline	Calculated EF using the IPCC 2006 Guideline	Default values from the IPCC 1996 Guideline	Calculated EF using the IPCC 1996 Guideline	Calculated EF using the IPCC 2006 Guideline
	1990 Gg CO_2-e			2009 Gg CO_2-e		
Enteric Fermentation: CH_4	12.433	9.100	9.100	10.168	7.085	7.085
Manure Management CH_4	165.774	51.867	48.062	135.571	39.576	36.640
Manure Management : Direct N_2O	16.459	19.418	20.324	13.460	15.880	16.621
Manure Management : Indirect N_2O	NA	NA	5.707	NA	NA	4.667
Agricultural Soils N_2O: Direct	27.688	18.721	13.235	22.643	15.310	10.793
Agricultural Soils N_2O: Indirect Volatilisation	3.076	2.080	1.323	2.516	1.701	1.079
Agricultural Soils: N_2O Indirect Leaching	4.403	3.640	0.695	5.384	2.977	0.567
TOTAL	229.833	104.827	98.447	189.742	82.530	77.453

All calculations note a reduction in emissions when compared against the baseline level set in the 1990 calendar year. This reduction is due to the reduced number of pigs being bred in NZ by pork producers with animal numbers down by 18.7 % over the last 19 years.

Overall, the results show a significant reduction in the quantity of CO_2-e being released from the NZ pork industry. The reduction was largely driven by a recalculation of CH_4 emissions from the Manure Management section. This sector is the largest source of emissions from the NZ pork industry contributing 72% of the total emissions of the default values for 2009. A breakdown of emissions by category for the 2009 calendar year can be seen in Figure 7 below.

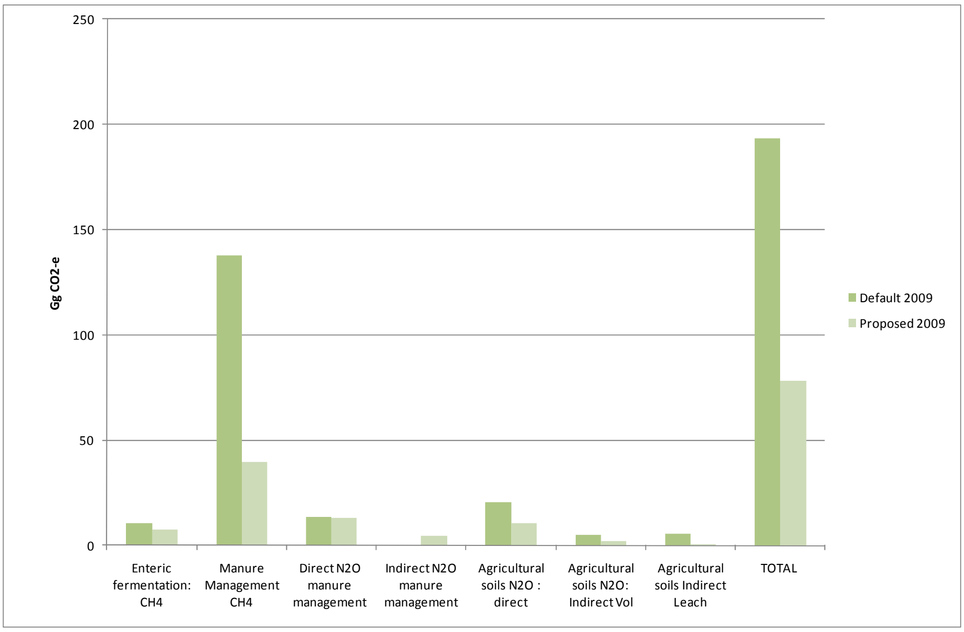

Figure 7: Changes in CO_2-e results between using the current default IPCC and GHGIR values and the proposed 2006 method with revised NZ specific emissions factors for the 2009 calendar year

These reductions have been primarily driven by the changes to the default values outlined above, but also by changes in IPCC methodologies between the 1996 and 2006 IPCC guidelines. For the NZ Pork industry the proposed 2006 IPCC guidelines have two significant changes that have affected results from this study and these are outlined below.

a) Quantity of N being applied to soils: The variation in methods between the 1996 and 2006 IPCC guidelines has a significant effect on the quantity of N estimated to be applied to NZ soils from manure produced by the pig industry. It is widely acknowledged in scientific literature that gaseous loss of N from effluents stored for a long period of time may be a major pathway of N movement, particularly under high temperatures (Mc Crory and Hobbs, 2004). In the absence of NZ-specific values it is recommended that IPCC default values for N loss from AWMS be incorporated into the NZGHGIR.

b) Change in EF: The IPCC has also undertaken a review of emissions factors used in calculations. These revisions are based on the latest international data and have reduced emissions from NZ pork. Two examples of changes that have impacted on emissions from the NZ pork industry are as follows 1) a reduction in the EF_5 value for indirect emissions from leaching N applied to agricultural soils from 0.025 to 0.0075 kg N_2O-N/kg N leached & runoff. 2) The reduction of MCF factor for anaerobic lagoons from 90% to 78% of its VS conversion.

8.4 Objective 3: Further work to address and mitigate net emissions from the pork industry.

The following outlines further work required to improve on GHG emissions factors identified within the project;

1) The research has identified anaerobic lagoons as a significant hot spot of emissions. Given their importance within the emissions profile for the NZ pork industry, further work is required to verify emissions factors being applied to the NZ environment. The IPCC between the 1996 and 2006 reduced the MCF of anaerobic lagoons from 90% to 78% for a temperate environment; however these MCF factors have yet to be verified in NZ environments. During this investigation only 2 studies were referenced on anaerobic ponds used to treat pig manure within New Zealand, with both studies reporting results on the same pond in the Waikato region. Ponds within NZ are subjected to a wide range of environmental conditions such as temperature as well as design parameters. Further work needs to be undertaken to determine if the MCF

applied in the IPCC guidelines is suitable for the NZ Pork industry. Additionally the definition of NZ in the current GHGIR as a 'temperate' environment over a 'cool' has the potential to overestimate GHG emissions from the NZ pork industry particularly within the Manure management section. Further clarification of this definition is required.

2) Given the significance of anaerobic lagoons to the emissions profile, work is being undertaken to develop mitigation strategies for farms where anaerobic lagoons are in use. One mitigation options that is being developed and is currently on trial in a number of farms in NZ is covered ponds systems. These systems involve covering existing ponds with an impermeable layer or constructing purpose-built lagoons to capture CH_4 emissions. Emissions can then be flared off or converted to energy. For the NZ Pork industry there is widespread interest in these systems as they provide a number of environmental benefits on-farm, particularly odour reduction which is a common concern for the industry. Given the relatively new introduction of this technology there is a large amount of uncertainty around the MCF values which can be applied. The 1996 IPCC guidelines provide an MCF range for digesters of 0-15% while the 2006 IPCC guidelines provide a range of 0-100%. For the purposes of this work an emissions factor of 15% has been applied, however, there is a high amount of uncertainty surrounding this factor. Further work is required to examine fugitive emissions from covered pond systems to provide more certainty for farmers who are using these systems as well as those who are considering adopting these systems.

3) There has been a limited amount of research globally on emissions (both CH_4 and N_2O) from animal bedding, with no NZ studies outlining emissions from piggeries. This project noted that use of deep litter within NZ was not consistent with the IPCC guidelines, particularly in reference to the average retention time used. Within the NZ pork industry straw is widely used for bedding generally for batches of animals for 6-7 weeks before being replaced. This practice means that most NZ pork farms would exceed the parameter of 30 days provided by IPCC and would result in a higher emission factor being applied in calculations. This study found that there is limited data available that supports the 30 days parameter and as a result for the purposes of this study the retention time was increased to 50 days. Further work is required to understand emissions profile from pigs litter over time. Additionally the social behaviour of pigs (nest making and digging) may result in a different emissions profile from cattle that tend to compact their litter. As a result studies need to be undertaken specifically on deep litter emission from the pig industry instead of values being extrapolated from other sectors.

4) Further work is required to develop emissions factors for N_2O emissions from piggery manure. Currently values applied have been extrapolated from NZ specific research undertaken on the sheep, beef and dairy industries. Consideration also needs to be given to the different forms that pig manure can be treated. E.g. composted deep litter, dry solids or liquid slurries. Given the different environmental parameters for these media it is plausible that they can release different quantities of N emissions. Further work is required to classify these emissions from piggery-derived manure.

5) It is important that the MS figures developed in this investigation are used as a baseline value and further work is needed to note any changes recorded within the NZ pork industry over time. This will record changes and mitigation strategies developed by the NZ pork industry and provide incentive for driving continual improvements within the industry.

6) The size of the NZ pork industry offered a unique opportunity to examine the IPCC guidelines being applied at a farm-scale level. The project noted a number of inconsistencies between on ground practices and what is provided within the inventory, particularly within the AWMS definition for Manure Management. Of particular note, the project concludes that further work is required to develop methodologies for the numerous cases where more than one AWMS is being applied onsite to treat manure before it is applied to land.

7) It is currently proposed to extend the work undertaken in this project to include a life cycle analysis of pork being produced in NZ using PAS 2050 methodology. Life Cycle Analysis (LCA), also termed Life Cycle Inventory, Life Cycle Assessment or Carbon Footprinting examines the emissions associated with the life cycle of a product often termed 'cradle to grave'. The method involves examining the GHG emissions of a product from the raw materials through to consumption and disposal of the product. The result of a product LCA would be a quantity of GHG emitted per unit of product made. A LCA is seen as an important next step in determining an emissions profile for the pork industry as the evaluation includes a holistic approach to GHG emissions examining parameters not investigated in an inventory examination such as energy which is thought to be a major contributor to the GHG profile of the pig industry, particularly in indoor farming operations. The project also has the potential to examine allocation issues raised in this project.

8) It was clear from conversation with farmers that further work has to go into education at a farm level of the potential sources of GHG emissions from their operations. There is currently in the NZ pork industry limited knowledge concerning where GHG emissions are produced as a product moves through its production phases. It is important that producers are provided with an accurate breakdown of emissions so that hot spots can be identified and mitigation strategies can be developed.

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Appendix 1: Survey Form

Pork Industry Survey: GHG Inventory report

Farm / Name:
Location:
Date:

1) Herd Numbers and Structure

Pig Class	Population (number of animals)	Average weight (kg)
Mature Swine		
Sows in gestation		
Sows which have farrowed and are nursing young		
Boars that are used for breeding purposes		
Growing Swine		
Nursery (Suckers and Weaners)		
Growers and Finishers		
Gilts that will be used for breeding purposes		
Growing boars that will be used for breeding purposes		

What is your average number of offspring per Sow /yr? ___________________________________

Average Age at slaughter (weeks);

Market animals ____

Sows ____

Boars ____

Notes

2) Feed requirements of the herd

What are your feed mixes?

How much of each mix do you use on a weekly base?

Creep		Weaners		Grower		Finisher		Dry Sow		Lactating sow	
Ingredient E.g. Barley	**Kg** **700kg**	**Ingredient** E.g. Barley	**kg**	**Ingredient** E.g. Barley	**kg**	**Ingredient** E.g. Barley	**kg**	**Ingredient** E.g. Barley	**kg**	**Ingredient** E.g. Barley	**kg**

Total of each mix used every week. (Tones) ?

Creep	Weaners	Grower	Finisher	Dry Sow	Lactating sow

Does you feed supplier provide you with nutritional information or specifications Y/N
If yes can we obtain a copy?

Animal Manure Management Methods

- **Can you take me through your animal waste management system? (Draw flow diagram of the system from each housing facility)**

Can you answer the following questions for each effluent system you might use?

AWMS
Anaerobic Lagoon The manure resides in the lagoon for period from 30 days to over 200 days. The water from the lagoon may be recycled as flush water or used to irrigate and fertiliser fields. **Questions** What is the retention time of your lagoon? ____________________ Do you separate solids?____________________ What method i.e. weeping wall, mechanically separated?____________________ If yes what do you do with the solids?____________________ What proportions of solids are removed? ____________________
Liquid slurries Dung and urine are collected and transported in liquid state to tanks for storage. Liquid may be stored for a long time (months). To facilitate handling water may be added. **Questions** Retention time of the slurry?____________________
Daily spread Manure is routinely removed from a confinement facility and is applied to cropland or pasture in 24 hours of excretion. **Questions** Retention time of the slurry?____________________ Do you separate solids?____________________ If yes what do you do with the solids?____________________ What proportions of solids are removed? ____________________ What is your method of land application (irrigator , truck spread)? __________

Solid Storage Dung and urine are excreted in a stall. The solids (with or without litter) are collected and stored in bulk for a long time (months) before disposal, with or without liquid runoff into a pit system.
Dry lot In dry climates animals may be kept on unpaved feedlots where the manure is allowed to dry until it is periodically removed. Upon removal the manure may be spread on fields.
Pasture range and Paddock Manure deposited directly to land (free range)
Pit storage below animal confinement **Questions** How long is the manure kept in pit? (please circle the retention time that best represents your system) <1 month >1 month
Anaerobic Digester The dung and urine in liquid/slurry are collected and anaerobicaly digested. CH_4 may be burned, flared or vented. **Questions** Do you know how much CH_4 is produced? ____________________ How much energy is produced? ____________________ Amount of CH_4 flared? ____________________ Do you store the manure prior to entering the digester? if so how?____________________ What is your VS loading rate? ____________________ Quantity of Sludge applied to land? (do you know the N concentration) ____________________
Swine deep bedding As manure accumulates, bedding is continually added to absorb moisture over a production cycle and possibly for as long as 6 to 12 months. This manure management system also is known as a bedded pack manure management system and may be combined with a dry lot or pasture **Questions** How often do you change the bedding? < 30 days =3% >30 days = 42%

What material do you use for bedding?______________________________ What do you do with the bedding after removal?______________________ Is the bedding actively mixed as more bedding is added? __________________ What is your average bedding volume? ______________________________
Composting in vessel and Static pile In Vessel Composting, typically in an enclosed channel, with forced aeration and continuous mixing. Static Pile: Composting in piles with forced aeration but no mixing.
Composting intensive window Composting in windrows with regular (at least daily) turning for mixing and aeration.
Composting Passive window Composting in windrows with infrequent turning for mixing and aeration.
Aerobic treatment **Question** Passive or mechanical aerated? ______________________________

If other give a brief description

____

____

____

____

Have you undertaken any lab analysis of your wastewater/sludge /composting (i.e. TN TS VS?)

If yes do you know the results for TN, TS or VS?

____

____

____

____

How often do you hose out the pens?

Is your effluent applied to land? Y/N
What is your application method and rate?

Did you own your farm in 1990? Y/N
If yes, have you increased herd numbers since 1990?

How have you adapted your wastewater treatment system since 1990?

Have you altered your diet requirements since 1990?

Carbon Credits: Forestry

Do you have any plantings?
Y/N
If yes,

What is the area? _______

Is the forest pre 1990 or post 1989?__________________________

What is the primary forest species? (e.g. Pinus radiata , exotic hardwood

etc.)______

If the forest type is Pinus Radiata, record the region Northland

etc____________________

What is the age of the forest/ how long ago was it planted?

If the forest is a second rotation (or later) post 1989 forest what was the previous forest type, age at harvest and how long ago was it harvested?

Additional information / comments?

Appendix 2: Population

Population statistics (source Stats NZ)

Variable by Total New Zealand (Annual-Jun) Total New Zealand

	Breeding Sows, over 1 Year Old	Other Pigs	Total Pigs	Mated Gilts	Total sows	Piglets weaned on the farm during the year
1990	44,665	340,013	394,701	6,325	50,990	..
1992	45,583	355,917	411,148	5,741	51,324	..
1995	51,140	371,755	431,004	8,110	59,250	..
1996	49,835	367,009	424,073	7,230	57,065	..
1999	53,883	308,261	368,887	6,743	60,626	..
2002	40,774	295,309	342,015	5,932	46,706	..
2003	43,109	327,868	377,249	6,272	49,381	778,708
2004	41,187	340,187	388,640	7,266	48,453	803,691
2005	36,931	298,867	341,465	5,668	42,599	731,131
2006	36,507	312,195	355,501	6,799	43,306	757,448
2007	39,743	319,760	366,671	7,168	46,911	787,756
2008	37,004	281,967	324,594	5,623	42,627	763,059
2009	33,771	283,317	322,788	5,701	39,472	725,737

Table information:
Units:
Breeding Sows, over 1 Year Old: Number, Magnitude = Units
Other Pigs: Number, Magnitude = Units
Total Pigs: Number, Magnitude = Units
Mated Gilts: Number, Magnitude = Units
Piglets weaned on the farm during the year: Number, Magnitude = Units

Footnotes:
There was no agricultural survey conducted in 1997 or 1998. Horticulture was excluded from the 1999 agricultural production survey.
Prior to 1994, the population base for the agricultural production survey's was businesses recorded on Statistics New Zealand's Business Directory that engaged in horticulture, cropping, livestock farming or exotic forestry operations.
Between 1994 and 1996, the population base for the agricultural production survey's was those businesses registered for GST and recorded on Statistics New Zealand's Business Frame as being engaged in horticulture, cropping, livestock farming or forestry.
The population base for the 1999 Agricultural Production Survey was all units recorded on AgriQuality New Zealand's national database 'AgriBase' as holding livestock and/or engaging in grain/arable cropping.
Users should note that 2004 deer figures are not directly comparable with 2002 and 2003 figures. Statistics New Zealand estimates an undercount of about 70,000 deer at 30 June 2002, and 50,000 at 30 June 2003.
Symbol: .. figure not available
R: Revised
P: Provisional
C: Confidential
E: Early Estimate
S: Suppressed

Status flags are not displayed

Table reference:
AGR001AA

Last updated:
Breeding Sows, over 1 Year Old: 26 February 2010 10:45am
Other Pigs: 26 February 2010 10:45am
Total Pigs: 26 February 2010 10:45am
Mated Gilts: 26 February 2010 10:45am
Piglets weaned on the farm during the year: 26 February 2010 10:45am

Source: Statistics New Zealand
Contact: Information Centre
Telephone: 0508 525 525
Email:info@stats.govt.nz

Subclass assumptions and definitions

Year	2009		1990		
Boars	3.24%	Of Total Sows	6.8%		
Sows In Gestation	18%	Of Total Sows	16%		
Subclass growers	**Age (Weeks)**	**Proportion of grower population**	**Age (Weeks)**	**%**	**Proportion of grower population**
Suckers	4	0.2	4	weeks	0.1666667
Weaners	6	0.3	7	weeks	0.2916667
Growers	6	0.3	7	weeks	0.2916667
Finishers	4	0.2	6	weeks	0.25
TOTAL	20.5	1	24		1

Appendix 3 Enteric Fermentation

GE and DE values applied to diets

	As Fed GE (MJ/kg)	As Fed DE (MJ/kg)	Reference
Barley	16.30	13.20	SNM NZF (1999)
Blood meal	22.35	18.43	SNM NZF (1999)
Broll	17.60	11.54	SNM NZF (1999)
FF Soya bean meal	22.84	20.01	SNM NZF (1999)
Imported fish meal	20.05	17.14	SNM NZF (1999)
Maize	16.50	14.49	SNM NZF (1999)
Meat and Bone Meal	15.80	6.76	SNM NZF (1999)
Peas	16.23	14.33	SNM NZF (1999)
Skim Milk Powder	17.68	16.97	SNM NZF (1999)
Soy Bean Meal	17.70	15.86	SNM NZF (1999)
Soya bean oil	39.27	38.36	SNM NZF (1999)
Tallow	39.90	37.70	SNM NZF (1999)
Wheat	16.20	14.27	SNM NZF (1999)
Whole Milk Powder	23.27	22.39	SNM NZF (1999)
Milk Powder Blend	20.48	19.68	0.5 SMP + 0.5 WMP
Palm Kernel Meal	19.90	13.20	J.A. Agunbiade et al (1999) Animal feed Science and technology 80 165-181
Bread	11.22	10.32	Per com Dr Patrick Morel Dry matter content is around 60%
Whey	14.50	14.00	Per com Dr Patrick Morel Assumes 96% Dm values adjusted if wet feed was used
Cheese			
Poultry Offal meal	19.40	16.87	Per com Dr Patrick Morel Value used for poultry assuming 85% water content
Fish Oil	39.00	38.00	Per com Dr Patrick Morel
Lysin	22.00	21.50	Per com Dr Patrick Morel
meth	24.00	23.90	Per com Dr Patrick Morel
threonin	18.00	17.70	Per com Dr Patrick Morel
Linseeed oil	39.00	38.00	Per com Dr Patrick Morel
coconuts oil	39.00	38.00	Per com Dr Patrick Morel
Casein	21.00	19.50	Per com Dr Patrick Morel
meat	5.34	5.07	Per com Dr Patrick Morel
Wheat Bran	16.65	10.13	Per com Dr Patrick Morel
soybean	19.81	17.75	Per com Dr Patrick Morel
Sugar	16.00	15.00	Per com Dr Patrick Morel

Gross Energy (GE) values calculated on sites

Sows in gestation MJ head^{-1} day^{-1}	Lactating Sows MJ head^{-1} day^{-1}	Boars MJ head^{-1} day^{-1}	Suckers MJ head^{-1} day^{-1}	Weaners MJ head^{-1} day^{-1}	Growers MJ head^{-1} day^{-1}	Finishers MJ head^{-1} day^{-1}
38.71	93.03	38.71	4.63	10.08	26.18	38.25
42.80	169.92	42.80	1.75	16.93	35.85	35.85
38.68	115.59	35.97	3.15	13.07	34.68	35.97
32.12	158.18	32.12		14.11	20.36	38.19
35.93	151.58	35.93	3.66	6.42	28.21	33.96
28.45	93.30	36.11	3.26	15.80	31.45	36.11
45.84	130.47	45.84	3.65	20.49	34.57	45.87
34.85	175.52	34.85	2.93	16.08	24.96	40.86
35.78	116.75	31.54	5.30	12.92	22.14	31.54
31.46	120.59	35.99	6.04	14.56	28.52	35.99
35.64	120.80	41.14	4.96	16.99	27.43	41.14
46.16	119.44	46.16	14.47	27.20	21.87	21.87
32.30	119.67	32.30	7.37	24.41	48.71	48.71
37.64	130.70	37.64	7.16	34.20	34.36	51.49
36.37	156.76	58.79	4.61	17.83	22.74	34.12
40.90	115.60	40.90	3.24	8.29	26.81	35.36
47.21	90.91	47.21	6.28	7.92	17.51	40.93
38.59	167.19	38.59	3.24	10.95	18.33	20.30
39.93	163.24	39.93	4.72	11.79	20.35	36.71
52.53	108.09	52.53				
				12.32	31.12	37.18
				13.38	25.74	36.63
55.76	127.49	61.38	2.45	15.05	30.86	46.19
43.75	92.26	43.75	3.54	29.09	33.38	43.70
49.03	152.73	49.03	5.05	24.37	43.76	53.38
32.75	136.17	32.75	2.91	8.08	26.79	33.36
31.26	132.36	35.63	3.25	12.28	28.85	35.63
48.30	143.75	48.30	4.13	13.69	38.98	49.43
31.76	108.96	41.16	1.41	8.60	32.47	41.16
36.30	157.29	36.30	5.49	11.36	31.03	43.72
48.50	137.76		3.60	15.96	29.79	45.57
36.11	109.33	36.11	3.40	20.95	27.80	32.12
44.67	88.87	44.67	3.18	14.57	26.31	35.42
43.06	183.26	43.06				
52.57	174.15	47.19	8.03	13.68	37.98	47.19
44.50	177.50	44.50	8.85	16.01	33.73	49.17
				16.01	28.82	44.82
			3.61	15.24	30.48	47.41
35.57	137.75	35.57	1.79	13.02	20.04	33.36
39.27	91.63		8.28	11.67	17.33	30.93
				24.27	35.97	41.21
Average						
40.14	132.46	41.31	4.69	15.63	29.14	39.25

Enteric fermentation emissions factors calculated on each site

Sows in gestation kg CH_4 head^{-1} yr^{-1}	Lactating Sows kg CH_4 head^{-1} yr^{-1}	Boars kg CH_4 head^{-1} yr^{-1}	Suckers kg CH_4 head^{-1} yr^{-1}	Weaners kg CH_4 head^{-1} yr^{-1}	Growers kg CH_4 head^{-1} yr^{-1}	Finishers kg CH_4 head^{-1} yr^{-1}
1.52	3.66	1.52	0.18	0.40	1.03	1.51
1.68	6.69	1.68	0.07	0.67	1.41	1.41
1.52	4.55	1.42	0.12	0.51	1.36	1.42
1.26	6.23	1.26	0.00	0.56	0.80	1.50
1.41	5.97	1.41	0.14	0.25	1.11	1.34
1.12	3.67	1.42	0.13	0.62	1.24	1.42
1.80	5.13	1.80	0.14	0.81	1.36	1.81
1.37	6.91	1.37	0.12	0.63	0.98	1.61
1.41	4.59	1.24	0.21	0.51	0.87	1.24
1.24	4.75	1.42	0.24	0.57	1.12	1.42
1.40	4.75	1.62	0.20	0.67	1.08	1.62
1.82	4.70	1.82	0.57	1.07	0.86	0.86
1.27	4.71	1.27	0.29	0.96	1.92	1.92
1.48	5.14	1.48	0.28	1.35	1.35	2.03
1.43	6.17	2.31	0.18	0.70	0.90	1.34
1.61	4.55	1.61	0.13	0.33	1.05	1.39
1.86	3.58	1.86	0.25	0.31	0.69	1.61
1.52	6.58	1.52	0.13	0.43	0.72	0.80
1.57	6.42	1.57	0.19	0.46	0.80	1.44
2.07	4.25	2.07				
				0.48	1.22	1.46
				0.53	1.01	1.44
2.19	5.02	2.42	0.10	0.59	1.21	1.82
1.72	3.63	1.72	0.14	1.14	1.31	1.72
1.93	6.01	1.93	0.20	0.96	1.72	2.10
1.29	5.36	1.29	0.11	0.32	1.05	1.31
1.23	5.21	1.40	0.13	0.48	1.14	1.40
1.90	5.66	1.90	0.16	0.54	1.53	1.95
1.25	4.29	1.62	0.06	0.34	1.28	1.62
1.43	6.19	1.43	0.22	0.45	1.22	1.72
1.91	5.42		0.14	0.63	1.17	1.79
1.42	4.30	1.42	0.13	0.82	1.09	1.26
1.76	3.50	1.76	0.13	0.57	1.04	1.39
1.69	7.21	1.69				
2.07	6.85	1.86	0.32	0.54	1.49	1.86
1.75	6.99	1.75	0.35	0.63	1.33	1.94
				0.63	1.13	1.76
			0.14	0.60	1.20	1.87
1.40	5.42	1.40	0.07	0.51	0.79	1.31
1.55	3.61	0.00	0.33	0.46	0.68	1.22
				0.96	1.42	1.62
Average						
1.58	5.21	1.58	0.18	0.62	1.15	1.55

Weighted Average Enteric Fermentation for NZ pigs

	EF for Enteric Fermentation (kg CH_4 head^{-1}yr^{-1})	Population Distribution 2009	Kg CH_4 head^{-1}yr^{-1}	%of population	Kg CH_4 head^{-1}yr^{-1} weighted average
Sows in gestation	1.58	0.79	1.25		
Sows which have farrowed	5.21	0.17	0.91		
Boars	1.58	0.03	0.05		
Total breeding swine			2.21	12.62%	0.28
Suckers	0.18	0.20	0.03		
Weaners	0.62	0.29	0.18		
Growers	1.15	0.29	0.34		
Finishers	1.55	0.22	0.34		
Total growing swine			0.893	87.38%	0.780198
Weighted average NZ pigs					1.059586

Appendix 4: Manure Management CH_4

Review of literature on solid separator technologies effects on VS concentrations

Screen Type	Screen size and Influent TS%	VS removal	TS removal	COD /BOD removal	N removal	Reference:
Rundown	Screen: 1mm (0.0021m^3/s)	21.5%	35.2%	69%COD		Shutt et al (1975) By volume
	Screen: 1.5mm (0.0039m^3/s)	5.3%	9.8%			Shutt et al (1975) By volume
	1.83% TS	23.8%	20.6%	8.5 %BOD	8.1% TKN	Payne
	Screen 1mm (0.13-0.20m^3/s) 1-4.5% TS	22%	17.6%	12.5%COD	4.2% TKN	Piccinini and Cortellini (1987)
Vibrating	Screen: 0. 39mm (0.00111m^3/s)	28.1%	22%	16.1% BOD		Shutt et al (1975) By volume
	Screen: 0.8mm (0.13-0.20m^3/s) 1-4.5% TS	27.8%	20.9%	18% COD	3.7% TKN	Piccinini and Cortellini (1987)
	Screen: 0.635mm (0.0006-0.001m3/s) 1.83% TS		20.9%	24% COD		Hegg et al (1981)
	Screen: 1.57mm 1.55%TS		3%			Hegg et al (1981)
Rotating screen	Screen : 0.44mm (0.13-0.20m3/s) 1-4.5% TS	19.3%	13.8%	8.4% COD	8.4% TKN	Piccinini and Cortellini (1987)
	Screen :0.75mm (0.00185-0.005m3/s) 2.54% TS		4%	9% (dm) COD		Hegg et al (1981)
	Screen : 0.75mm (0.0013-0.0039m3/s) l4.12% TS		8%	16% COD		Hegg et al (1981)
				10-30%		NZ pork (2005)
Screw Press	Screen :0.5mm 4.5% TS		41.4%		11.1%	Hahne et al 1995
	Screen: 0.75 4.5% TS		64.9%		11.9%	Hahne et al 1995
	Screen 1.0mm 4.5% TS		20.1%		5%	Hahne et al 1995
	4.5% TS		60-65%			Fan Engineering
	Screen 0.5mm 5.5%TS	78.8-89.8% average 83.7%	73.7-85.7% average 79.1%			Yu (1992) Fan screw press
	Screen 0.75mm 4.5% TS	21.3-76.6% average 59.8%	22.9-71.9% Average 56.2%			Yu (1992) Fan screw press
	1.1% TS		0	34.9%		Castain (1988) Fan screw press
	4% TS		11.5%			Castain (1988) Fan screw press
	7% TS		24%			Castain (1988) Fan screw press
	1.5%-5.5% TS		15-30%		5-7% TKN 2-4% NH4+	Converse (1999) Vincent KP-10 screw separator
Settling		70%			20%	Kurger et al (1995)
	0.51-5.87% TS		71%	59.4%		Schulz and Lim (1994)
	0.004-4.5% TS	75-91%				Fischer et al (1975)
	4-5% TS		24-59%			Voermans and de Klijn (1990)
			51-71%			Payne (1984)
	0.5% TS	74.6%	65%			Payne (1986)
	1% TS	78.2%	71%			Payne (1986)
	2% TS	80.8%	71%			Payne (1986)
			80%	55%		Oleszkiewicz and Koziarski (1986)
	0.5% TS		75%	55%		Shutt et al (1975)
	1% TS		90%			Shutt et al (1975)
	0.01-1% TS		57-70			Moore et al (1975)

Adapted from EPA, (2000) and Australian Pork (2002)

However a large proportion of the data outlined above has been collected under controlled conditions in a laboratory.

Conditions in the field for solid removal are unlikely to be optimum at all times and therefore there is likely to reduce in the quantity of solids removed in field when compared to the best case scenarios outlines above. As a result industry experts were consulted, to help develop average values for VS and N removal from solid separators used in field conditions.

Table 11 outlines the values determined by this investigation. These values are can be regarded as conservative estimates as they are generally lower than the average values determined in from literature outlined above.

Surveyed animals assigned to each AWMS for VS (MS)

	Population	Anaerobic lagoon	Composting Static Pile	Bedding <50 days + composting	Bedding >50 days + composting	Bedding direct to land	Daily spread	Digester	Direct to Pasture	Pit Storage
Sows in gestation	17655.25	2844	1446.6	1242	781	0	3131.4	196	6813.25	1201
Sows which have farrowed	3944.55	707	346.6	261	0	0	826.8	50.4	1312.75	440
Boars	757.3	174.6	49.1	8	12	0	162.6	7	316	28
Suckers	0	0	0	0	0	0	0	0	0	0
Weaners	35412.4	7449.6	2814.8	2610	0	0	7892.2	574	10051.8	4020
Growers	56914.9	10491.2	7050.4	16568.7	1346	1480	12829.6	1050	180	5919
Finishers	55399.6	8559.6	3905.6	13943.2	6036	0	12659.2	420	180	9696
Gilts to be used for breeding purposes	45795.3	9302.6	4124	6673.3	6199	0	10825.4	1610	120	6941
Growing boars that will be used for breeding	1720.5	184.6	236.4	12	177	0	302.5	231	355	222
Total	23	2.9	2.1	0	2	0	0	0	16	0
%		20.58	2.94	18.99	6.69	0.68	25.68	2.47	8.89	13.08

Surveyed animals assigned to each AWMS for N (MS)

	Population	Anaerobic lagoon	Composting Static Pile	Bedding <50 days + composting	Bedding >50 days + composting	Bedding direct to land	Daily spread	Digester	Direct to Pasture	Pit Storage
Sows in gestation	17655.25	3284	468.532	1242	781	0	3611.228	254.24	6813.25	1201
Sows which have farrowed	3944.55	772.12	112.14	261	0	0	981.164	65.376	1312.75	440
Boars	757.3	190.28	15.789	8	12	0	178.151	9.08	316	28
Suckers	0	0	0	0	0	0	0	0	0	0
Weaners	35412.4	8151.76	901.933	2610	0	0	8932.3	744.56	10051.8	4020
Growers	56914.9	12532.16	2270.6	16568.7	1346	1480	15256.4	1362	180	5919
Finishers	55399.6	9446.16	1247.6	13943.2	6036	0	14305.8	544.8	180	9696
Gilts to be used for breeding purposes	45795.3	10189.16	1308.7	6673.3	6199	0	12275.8	2088.4	120	6941
Growing boars that will be used for breeding	1720.5	224.2	75.276	12	177	0	355.384	299.64	355	222
Total	23	4.324	0.676	0	2	0	0	0	16	0
%		20.58	2.94	18.99	6.69	0.68	25.68	2.47	8.89	13.08

Photo 1: Outdoor Farrowing – direct to pastures farming NZ (Barugh 2010)

Photo 2: Outdoor Farrowing – direct to pastures dry sow accommodation (Barugh 2010)

IPCC 2006 method for calculating VS excretion rates from pigs

	Sows in gestation	Lactating Sows	Boars	Suckers	Weaners	Growers	Finishers
	VS kghead-1day-1	VS kghead-1day-1	VS kghead-1day-1	VS kghead-1day-1	VS kghead-1day-1	VS kghead-1day-1	VS kghead-1day-1
	0.52	1.04	0.53	0.03	0.09	0.25	0.36
	0.44	1.38	0.45	0.02	0.13	0.34	0.34
	0.53	1.53	0.46	0.03	0.14	0.38	0.45
	0.42	1.97	0.43	0.03	0.17	0.26	0.50
	0.37	1.20	0.37	0.03	0.04	0.25	0.35
	0.25	0.76	0.28	0.03	0.12	0.24	0.28
	0.52	1.31	0.53	0.03	0.20	0.35	0.53
	0.50	1.57	0.38	0.06	0.15	0.30	0.37
	0.33	1.74	0.34	0.02	0.15	0.22	0.35
	0.22	0.83	0.23	0.04	0.10	0.18	0.22
	0.47	1.56	0.48	0.03	0.38	0.40	0.62
	0.49	1.33	0.50	0.09	0.29	0.18	0.18
	0.16	1.39	0.16	0.05	0.17	0.50	0.50
	0.41	1.35	0.68	0.04	0.15	0.19	0.35
	0.49	0.91	0.50	0.02	0.07	0.27	0.37
	0.57	0.72	0.58	0.05	0.06	0.17	0.43
	0.44	1.44	0.45	0.03	0.09	0.18	0.21
	0.45	1.40	0.46	0.04	0.10	0.20	0.39
	0.58	1.15	0.59				
					0.09	0.30	0.37
					0.09	0.20	0.33
	0.63	1.08	0.61	0.02	0.10	0.28	0.46
	0.49	0.79	0.50	0.03	0.25	0.32	0.46
	0.55	1.31	0.57	0.04	0.21	0.42	0.56
	0.39	1.08	0.40	0.02	0.06	0.27	0.35
	0.37	1.34	0.39	0.03	0.12	0.30	0.39
	0.58	1.14	0.59	0.03	0.11	0.39	0.51
	0.34	0.86	0.30	0.01	0.07	0.23	0.30
	0.40	1.10	0.41	0.04	0.08	0.29	0.44
	0.58	1.09	0.00	0.03	0.13	0.30	0.48
	0.43	0.86	0.44	0.03	0.17	0.28	0.32
	0.40	0.66	0.41	0.02	0.12	0.22	0.24
	0.48	1.95	0.49				
	0.63	1.82	0.58	0.08	0.14	0.46	0.57
	0.40	1.37	0.39	0.05	0.14	0.25	0.38
	0.49	1.25	0.50	0.06	0.11	0.32	0.49
					0.16	0.29	0.45
				0.03	0.15	0.29	0.46
	0.47	1.70	0.48	0.01	0.12	0.18	0.37
	0.47	0.72		0.06	0.10	0.16	0.34
					0.19	0.38	0.47
Average	0.45	1.24	0.44	0.04	0.14	0.28	0.40
STD	0.106766235	0.350749281	0.134044184	0.01699363	0.06476293	0.083008519	0.101157428
Max	0.63	1.97	0.68	0.09	0.38	0.50	0.62
Min	0.16	0.66	0.00	0.01	0.04	0.16	0.18
per year	164.7940175	453.1678224	161.1849556	12.79619926	49.60383497	102.9152897	145.3811158

IPCC 1996 method for calculating VS excretion rates from pigs

	Sows in gestation VS kghead-1day-1	Lactating Sows VS kghead-1day-1	Boars VS kghead-1day-1	Suckers VS kghead-1day-1	Weaners VS kghead-1day-1	Growers VS kghead-1day-1	Finishers VS kghead-1day-1
	0.48	0.94	0.48	0.02	0.08	0.22	0.32
	0.39	1.20	0.39	0.02	0.11	0.30	0.30
	0.49	1.41	0.41	0.02	0.13	0.34	0.41
	0.39	1.81	0.39	0.03	0.15	0.24	0.46
	0.33	1.04	0.33	0.03	0.03	0.22	0.32
	0.22	0.67	0.24	0.02	0.11	0.21	0.24
	0.47	1.18	0.47	0.02	0.18	0.32	0.48
	0.46	1.45	0.34	0.05	0.13	0.27	0.34
	0.29	1.55	0.29	0.02	0.13	0.19	0.30
	0.18	0.70	0.18	0.03	0.09	0.14	0.18
	0.43	1.42	0.43	0.02	0.34	0.36	0.56
	0.45	1.21	0.45	0.07	0.26	0.16	0.16
	0.13	1.26	0.13	0.04	0.14	0.45	0.45
	0.37	1.18	0.60	0.03	0.13	0.17	0.31
	0.45	0.79	0.45	0.02	0.06	0.24	0.33
	0.52	0.62	0.52	0.04	0.05	0.16	0.39
	0.40	1.26	0.40	0.02	0.08	0.16	0.19
	0.41	1.23	0.41	0.03	0.09	0.17	0.35
	0.53	1.03	0.53				
					0.07	0.26	0.33
					0.08	0.18	0.29
	0.57	0.94	0.53	0.02	0.09	0.25	0.41
	0.45	0.69	0.45	0.02	0.22	0.29	0.41
	0.50	1.15	0.50	0.03	0.18	0.38	0.51
	0.36	0.93	0.36	0.02	0.06	0.24	0.31
	0.34	1.20	0.35	0.03	0.11	0.27	0.35
	0.53	0.98	0.53	0.03	0.09	0.35	0.46
	0.30	0.74	0.25	0.01	0.06	0.20	0.25
	0.36	0.94	0.36	0.03	0.07	0.26	0.39
	0.53	0.94		0.02	0.11	0.27	0.43
	0.39	0.75	0.39	0.02	0.14	0.25	0.29
	0.35	0.57	0.35	0.02	0.10	0.19	0.21
	0.43	1.75	0.43				
	0.57	1.63	0.52	0.07	0.13	0.42	0.52
	0.37	1.24	0.34	0.05	0.12	0.22	0.34
	0.44	1.06	0.44	0.05	0.10	0.28	0.44
					0.14	0.26	0.40
				0.02	0.13	0.26	0.41
	0.43	1.55	0.43	0.01	0.10	0.16	0.33
	0.43	0.63		0.05	0.09	0.14	0.31
Average	0.41	1.10	0.40	0.03	0.12	0.25	0.35
STD	0.100772026	0.330176291	0.103559812	0.014625722	0.058993542	0.076016355	0.095207674
Max	0.57	1.81	0.60	0.07	0.34	0.45	0.56
Min	0.13	0.57	0.13	0.01	0.03	0.14	0.16
per year	149	402	147	11	43	91	129

DE% recorded on farms

	Sows in gestation	Lactating Sows	Boars	Suckers	Weaners	Growers	Finishers
	DE%	DE%	DE%	DE%	DE%	DE%	DE%
	0.77	0.81	0.77	0.91	0.85	0.84	0.84
	0.83	0.87	0.83	0.78	0.88	0.84	0.84
	0.76	0.77	0.78	0.86	0.82	0.81	0.78
	0.77	0.79	0.77	0.85	0.80	0.78	0.77
	0.83	0.87	0.83	0.86	0.90	0.85	0.82
	0.86	0.87	0.87	0.86	0.87	0.87	0.87
	0.81	0.83	0.81	0.88	0.84	0.83	0.80
	0.76	0.77	0.80	0.82	0.81	0.77	0.80
	0.84	0.83	0.84	0.87	0.85	0.86	0.86
	0.89	0.89	0.90	0.91	0.89	0.90	0.90
	0.79	0.80	0.79	0.95	0.81	0.80	0.79
	0.79	0.80	0.79	0.95	0.81	0.80	0.79
	0.82	0.81	0.82	0.90	0.82	0.86	0.86
	0.93	0.80	0.93	0.90	0.89	0.83	0.83
	0.81	0.86	0.81	0.87	0.86	0.86	0.83
	0.79	0.87	0.79	0.88	0.87	0.83	0.82
	0.79	0.87	0.79	0.88	0.87	0.83	0.82
	0.81	0.86	0.81	0.87	0.86	0.84	0.82
	0.81	0.86	0.81	0.87	0.86	0.84	0.82
	0.81	0.82	0.81				
					0.89	0.84	0.83
					0.89	0.87	0.85
	0.81	0.86	0.84	0.87	0.89	0.85	0.83
	0.81	0.86	0.81	0.87	0.86	0.84	0.82
	0.79	0.87	0.79	0.88	0.87	0.83	0.82
	0.80	0.83	0.82	0.84	0.83	0.83	0.82
	0.79	0.87	0.79	0.88	0.87	0.83	0.82
	0.82	0.87	0.88	0.86	0.87	0.88	0.88
	0.81	0.89	0.81	0.90	0.89	0.84	0.83
	0.79	0.87	0.79	0.88	0.87	0.83	0.82
	0.79	0.87	0.79	0.88	0.87	0.83	0.83
	0.85	0.88	0.85	0.89	0.87	0.86	0.89
	0.81	0.82	0.81				
	0.80	0.82	0.79	0.84	0.82	0.79	0.79
	0.81	0.81	0.85	0.82	0.87	0.85	0.85
	0.81	0.89	0.81	0.90	0.89	0.84	0.83
					0.83	0.83	0.83
				0.87	0.84	0.84	0.84
	0.77	0.79	0.77	0.88	0.85	0.85	0.81
	0.79	0.87		0.88	0.85	0.85	0.81
					0.87	0.82	0.80
Average	0.81	0.84	0.82	0.87	0.86	0.84	0.83
Stand	0.033225	0.036314	0.036379	0.031657	0.027094	0.026252	0.028174
Max	0.93	0.89	0.93	0.95	0.90	0.90	0.90
Min	0.76	0.77	0.77	0.78	0.80	0.77	0.77

Weighted Average for Volatile Soils NZ Pigs

				IPCC 1996		2006 IPCC	
	VS/day 1996	VS/day 2006	% population	Adjusted VS	Total	Adjusted VS	Total
Sows in gestation	0.41	0.45	0.79	0.32		0.36	
Sows which have farrowed	1.10	1.24	0.17	0.19		0.22	
Boars	0.40	0.44	0.03	0.01		0.01	
% of population			0.13	0.53	0.07	0.59	0.07
Suckers	0.03	0.04	0.20	0.01		0.01	
Weaners	0.12	0.14	0.29	0.03		0.04	
Growers	0.25	0.28	0.29	0.07		0.08	
Finishers	0.35	0.40	0.22	0.08		0.09	
% of population			0.87	0.19	0.17	0.22	0.19
TOTAL					0.23		0.26

Alternative MCF values based on an average temperature of 13°C

	1996 Cool environment MCF (%)	2006 Cool environment MCF (%)
Anaerobic Lagoons	0.90	0.71
Daily Spread	0.00	0.00
Direct to pastures	0.01	0.01
Pit storage	0.05	0.03
Deep litter >50 + composting	0.04	0.04
Deep litter <50 + composting	0.23	0.23
Deep litter <50 direct to land	0.03	0.03
Digester	0.15	0.15
Composting	0.01	0.01

Appendix 5: Manure Management N_2O

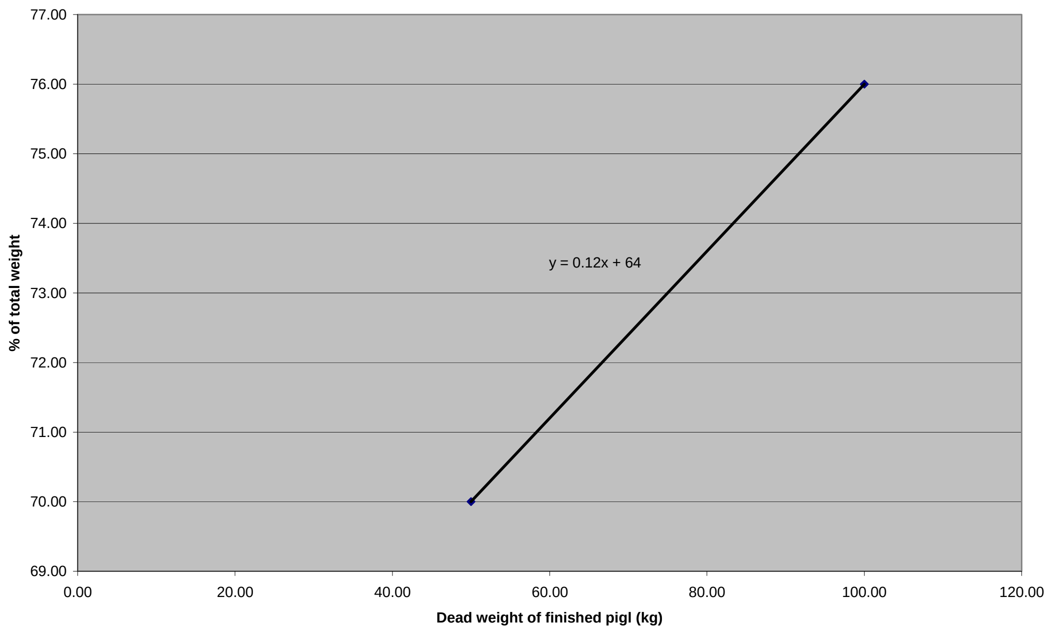
Average weight of finished animal (Source NZ Pork 2010)

	PIGS UNDER 50 KG	PIGS 50-65 KG	PIGS 65-75 KG	PIGS OVER 75 KG
	# animals	# animals	# animals	# animals
January	4,439	17,607	22,844	9,997
February	4,414	17,479	20,152	9,904
March	4,591	20,796	21,404	10,830
April	4,367	19,698	22,300	10,639
May	3,630	17,395	21,533	12,520
June	3,104	17,706	23,726	12,951
July	3,865	19,841	24,057	10,818
August	3,622	17,996	21,987	10,882
September	3,555	17,821	23,741	9,193
October	3,632	18,814	21,606	7,319
November	4,039	20,448	22,530	6,990
December	6,125	24,287	22,709	6,574
	49,383	229,888	268,589	118,617
Total DW (kg)	2020041.75	13571481.35	18627081.15	9670525.7
Average	40.91	59.04	69.35	81.53

Total animals	666,477
Total weight	43889129.95
Average DW finisher	65.85

Average values where then converted to Live weights using the following equation

Dead weight to live weight conversion used for NZ(developed from Queensland Department of Primary Industry (1997))



Average finished weight	= 0.12*65.85+64
	= 71.902%
Therefore average	=65.85/0.71902
	=91.58Kg

Weighted Average Nex for NZ pigs

	Number of animals (single yr) (1000s)	Weight (kg)	Nex	Population distribution	Total	
Sows in gestation	32,367	201.00	33.7479	79.43%	26.8048	
Sows which have farrowed	7,105	201.00	33.7479	17.44%	5.883981	
Boars	1,279	181.00	30.3899	3.14%	0.953732	
Total				12.62%	33.64252	4.247241
Suckers	56,408	4.20	0.812	19.51%	0.158535	
Weaners	84,611	18.55	3.588	29.27%	1.050292	
Growers	84,611	50.50	9.769	29.27%	2.859285	
Finishers	56,408	81.30	15.727	21.95%	3.452375	
Total				87.38%	7.520487	6.571054
						10.81829