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Determining the Carbon Footprint
of a National Trust Country Estate

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of a National Trust Country Estate

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ABSTRACT

The UK Government aims to reduce greenhouse gas emissions by 80 % by 2050 against a 1990 baseline. Agriculture makes up around 7 % of UK emissions and the industry is under pressure to meet these targets (and to produce more food). To achieve reductions it is necessary to be able to calculate emissions. This study looks at methods to calculate the carbon footprint of a National Trust estate with livestock, arable farming and a stately home. Methods explored include greenhouse gas inventories, life cycle analysis and carbon calculators. A carbon calculator designed for farms was selected (the CALM Calculator) and applied to Wimpole Hall, Cambridgeshire. Key greenhouse gas sources were identified and estate activity data gathered to calculate the footprint. A comparison was made between current arable practices and proposed organic methods. Emissions from estate energy and water consumption were also included. The arable non-organic farm emitted 1018 tCO₂e, 73 % due to N₂O emissions from nitrogen fertilizers. The livestock farm emitted 686 tCO₂e, 44 % from cattle. Estate emissions from electricity, heating oil and water supply were 303 tCO₂e. The total estate footprint was calculated as 2007 tCO₂e. A change to organic arable methods was predicted to deliver an estate footprint of 1361 tCO₂e but yields will be less (organic wheat is said to yield only 68 % of non-organic). The removal potential of conversion of areas of arable to grassland (41 tCO₂e) and particularly of farm woodland (1430 tCO₂e) was noticeable. Combined these can offset 73 % of total estate emissions using non-organic arable methods and 103 % of total estate emissions using proposed organic arable methods. Shortcomings of the method are identified along with the high level of uncertainty connected to the results. The issue of reduced yield expected under organic arable cultivation is highlighted and the implications of balancing reduced emissions with maintaining food production are explored.

Keywords:

Greenhouse gases, emissions, livestock, arable, organic, non-organic, removals

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1 Introduction

1.1 Background

The Intergovernmental Panel on Climate Change (IPCC) is the world's leading scientific body for the assessment of climate change. It says that, "warming of the climate system is unequivocal", and that the rate of increase is growing (IPCC, 2007a, p.30). The effects include sea level rise, more frequent heat waves, bouts of heavy precipitation and earlier spring events (IPCC, 2007a, p.30). This is understood to be caused by the increase in the atmosphere of certain greenhouse gases. CO₂ (carbon dioxide), CH₄ (methane) and N₂O (nitrous oxide) are the three main greenhouse gas emissions from agricultural practices.

"Global atmospheric concentrations of CO₂, CH₄ and N₂O have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. The atmospheric concentrations of CO₂ and CH₄ in 2005 exceed by far the natural range over the last 650,000 years. Global increases in CO₂ concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution. It is very likely that the observed increase in CH₄ concentration is predominantly due to agriculture and fossil fuel use. The increase in N₂O concentration is primarily due to agriculture". (IPCC, 2007a, p.37)

The UK Government has set targets through the Climate Change Act, 2008 to reduce greenhouse gas emissions by 80 % by 2050 relative to 1990 (UK Government, 2008). In addition the UK is signed up to targets to reduce emissions by 12.5 % through the Kyoto Protocol over the period 2008-12 (Defra, 2009a).

Farming along with other industries is under pressure to reduce emissions to meet these targets. Emissions from agriculture equated to 6.8 % of the total emissions from the UK (including the Crown Dependencies of Jersey, Guernsey and the Isle of Man) for 2007, the most recent data available from the UK Greenhouse Gas Inventory 1990-2007, submitted in April 2009 (DECC, 2009c, table ES3b).

In July 2009 the Government published “The UK Low Carbon Transition Plan” which seeks a voluntary reduction by English farmers “to at least 6 % lower than currently predicted by 2020” (DECC, 2009a p.153) with a review in 2012 to see whether more intervention is required.

The Government is required under the Climate Change Act (UK Government, 2008) to issue guidance by 1st October 2009 on how companies should report their greenhouse gas emissions, and by April 2012 to make such reporting mandatory. Hence there is a need to explore suitable methods for a farming estate to calculate emissions. Country estates are also usually responsible for emissions from activities other than agriculture, and these need to be taken into account in quantifying the total emissions of the organisation. In order for government targets and policies to reduce emissions to be effective, managers of such organisations need methods to quantify all emissions and to develop mitigation measures across the board, not just in part of their operations.

A consultation is currently (July 2009) underway on the government’s proposed guidance, with the National Trust being one of the consultees. The consultation guidance (Defra, 2009a) acknowledges that there are issues particular to agriculture and seeks to engage on these. The draft guidance (Defra 2009b p.6) is based on the Greenhouse Gas Protocol (WRI/WBCSD, (2004)). This and other methodologies for accounting for emissions on a farming estate are explored and evaluated in this study.

1.2 The Study Site

The National Trust is one of the largest land-owners in the country, being responsible for 250,000 hectares (National Trust, 2008). A paper looking at the National Trust’s carbon impacts (National Trust 2009) states that this equates to 1.5 % of the land area in England, Wales and Northern Ireland (confirmed by calculations from Defra 2009c) and accounts for 2 % of the terrestrial carbon in those countries (presumably because its land-holding is predominantly rural and contains large areas of peat moorland).

The selected study site is Wimpole Hall, Cambridgeshire. It is an 18th Century stately home set in gardens, parkland and with a working farm all amounting to 1012 hectares (0.4 % of the National Trust’s land holding). The site is the Trust’s largest in-hand farm.

The livestock farm and gardens are organic, whilst the arable farm is proposing to change to organic methods.



Figure 1.1 Cattle on pasture with Wimpole Hall in the background

The National Trust is taking steps to reduce energy use and minimise waste and, “is promoting a vision for farming which recognises the crucial importance of sustainable land management to future water supply, carbon storage, biodiversity and quality of life – as well as food production” (National Trust, 2008). This approach to farming indicates the balance they are seeking to strike between environmental protection and food production which as this study shows, is not an easy balance to achieve.

1.3 Aim and Objectives

The aim of this study is to identify and apply an appropriate methodology for determining a useful carbon equivalent budget for a National Trust working estate.

The objectives are to:

- 1) Explore available methodologies and to select an appropriate methodological framework for determining a carbon-equivalent budget
- 2) Develop an inventory of key greenhouse gas emissions and uptake for Wimpole Hall, including estimates as appropriate
- 3) Produce the budget based on the above values

- 4) Critique the key assumptions in the model
- 5) Use the model/budget to estimate how a land management change (e.g. change to organic production) could affect the carbon budget
- 6) Produce a poster of the output (possibly for public display).

1.4 Report Structure

The following chapters contain; the literature review (chapter 2), exploring the science of climate change in relation to agricultural emissions and other emission sources likely to be encountered on a country estate, a critique of several greenhouse gas accounting methodologies; the methodology (chapter 3), describing how the research in the literature review shaped the thesis methodology, how the data collection for the study site was conducted and how the results were calculated; the results (chapter 4), setting out the carbon footprint of the selected site using the chosen methodology, calculating emissions from both the existing non-organic farming methods and the proposed organic methods at the site, the reliability of the results are assessed, with an evaluation of levels of uncertainty and likely inaccuracies; the discussion (chapter 5), comparisons are made to the findings of similar studies, the methodology is critically appraised, and the issue of the maintenance of food production whilst cutting emissions is explored; conclusions and recommendations (chapter 6), highlights the main findings, looks at how far the aims and objectives of the study have been met, assesses the limitations of the research and makes recommendations for further study.

2 Literature Review

This chapter explores the key greenhouse gas emissions encountered on a country estate and the ways that land management practices can affect the extent of emissions and removals. It then explores approaches to calculating greenhouse gas emissions and appraises these against the requirements of the study.

2.1 Country estate greenhouse gas emissions and removals

2.1.1 Identifying emission sources

Warming of the climate is strongly correlated with increases in certain 'greenhouse gases' which trap incoming solar radiation by a 'blanketing effect', causing the atmosphere to become warmer (IPCC 2007b, p.96-97). There are a range of greenhouse gases recognised. The five volumes of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) help to identify the greenhouse gases likely to be involved in the activities of a country estate. The emissions considered likely to occur are shown in Appendix A. This thesis concentrates on those most likely to be encountered through the agricultural operations – carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O).

2.1.2 Global Warming Potential

Different greenhouse gases have varying impacts on the climate through their ability to trap incoming and outgoing energy, this is known as 'radiative forcing' (IPCC, 2007b, p.2). This is measured as Global Warming Potential (GWP) and is comparative to CO₂ which has a GWP of 1. The standard measure is against a 100 year period, and in 2007 the figures for CH₄ and N₂O were 25 and 298 respectively (IPCC, 2007b, p.33). (These coefficients have changed over time and in the IPCC Second Assessment Report of 1995 were 21 and 310 respectively). CH₄ and N₂O are therefore much more powerful greenhouse gases than CO₂.

2.1.3 Emissions and removals due to land management practices

Agriculture and other land management practices have interactions with the atmosphere in terms of greenhouse gas emissions and removals. Two key nutrient cycles are involved, those of carbon and nitrogen. Figures 2.1 and 2.2 display these pictorially.

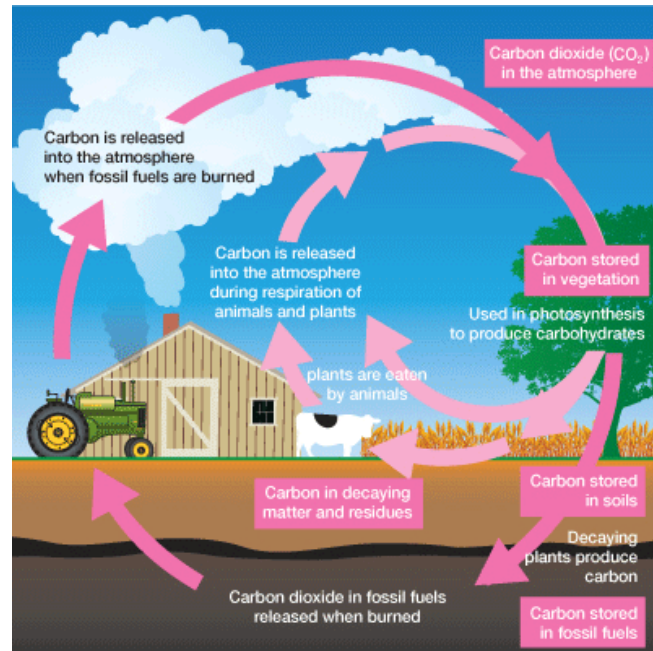


Figure 2.1 Farm carbon cycle (source www.farmingfutures.org.uk)

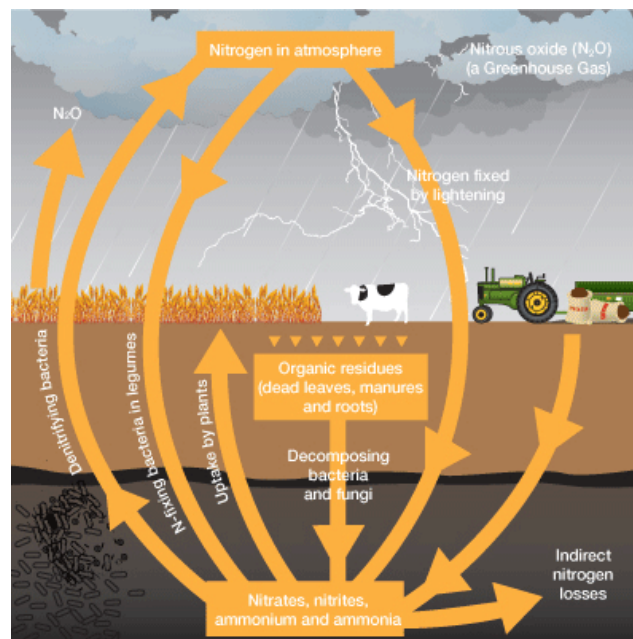


Figure 2.2 Farm nitrogen cycle (source www.farmingfutures.org.uk)

2.1.4 Arable farming effect on greenhouse gas emissions and removals

Koerber et al (2009), (citing Houghton, 2003) say that the change of land use over agricultural history from forest and grassland to arable through processes such as burning, removal of biomass and soil disturbance has led to the loss of carbon as CO_2 .

They estimate 156 Pg (Pg = 10^{15} grammes) of carbon was lost between 1850 and 1990, about half that released by fossil fuels over the same period.

As well as land use change, arable farming operations such as the addition of nitrogen fertilizers and manure contribute to greenhouse gas emissions. According to Lokupitiya and Paustian (2006), N_2O is the chief greenhouse gas emitted from agricultural soils due to microbial processes which are enhanced by increased nitrogenous inputs.

Farm woodland can act as a store for fixed carbon in woody biomass while trees are in their active growth phase (Forestry Commission, 2003 p.3). Agricultural soils can remove and store atmospheric carbon dioxide in soil organic matter and this can be increased by practices such as “no-till, organic amendments ... improved crop rotation and fertilization practices” (Lokupitiya and Paustian, 2006, citing Paustian et al., 1997, 2000; Smith, 2004; Ogle et al., 2005). However, Sauerbeck (2001) points out that the carbon sink effect is of finite duration. A saturation point is reached after only 50-100 years and levels can drop quickly if careful management is not maintained.

Farm machinery contributes to CO_2 emissions through the combustion of fossil fuels, but this is understood to be a minor scale of emission, only 3-4.5% of industrialized countries' total energy budgets. But if the boundary is changed to include food processing and transport this percentage changes greatly (Sauerbeck, 2001).

2.1.5 Livestock farming effect on greenhouse gas emissions and removals

Livestock produce methane as a result of feed digestion and storage of manure in slurry pits and manure heaps also favours methane production (Monteny et al 2006). However DECC (2009b p.376) states that solid storage of manure produces only insignificant amounts of CH_4 . N_2O is produced during storage of manure (DECC, 2009b p.377). Ruminants (cattle, sheep and goats) produce higher levels of methane than non-ruminants (horses, pigs and poultry) as their rumen, which supports microbial fermentation to digest cellulose, produces it as a by-product (IPCC, 2006, vol. 4, ch.10, p.10.24). A study by Steinfeld et al, (2006), cited by Koneswaran and Nierenberg (2008) postulates that globally, livestock farming produces 35-40% of anthropogenic methane, 65% of nitrous oxide emissions and that greenhouse gas “emissions from the animal agricultural sector surpass those of the transportation sector” (measured in CO_2 equivalents, henceforth CO_2e).

2.1.6 Organic vs. non-organic farming

Emissions from organic farming differ from non-organic farming. There are no emissions due to synthetic fertilizers and soil management practices differ in the means used to raise and maintain fertility levels. For instance organic arable systems tend to make more use of tractor-work than non-organic to control weed growth and cultivate nitrogen-fixing cover crops, both of which are emission sources. Thus Williams et al (2006) found that bread wheat production per tonne differed little in GWP between organic and non-organic production, 786 vs. 804 kgCO₂e per tonne of crop respectively. This partly reflects lower yields achieved for organic production. For livestock production, organic beef cattle showed emissions of 18,200 kgCO₂e/t as opposed to 15,800 kgCO₂e/t for non-organic (Williams et al, 2006, p.73). Flessa et al (2002) found that for two mixed farms in Southern Germany, one organic, one non-organic; “conversion from conventional to organic farming led to reduced emissions per hectare, but yield-related emissions were not reduced”.

2.1.7 Other estate emissions

A country estate will have other emissions than those relating solely to farming practices. Although no similar studies have been found of such an entity, there are other “carbon footprint “ studies of the emissions relating to for instance, London Underground (TFL, 2008), a government department (AEA, 2008), a water company (Scottish Water, 2008) and a town (Barthelmie et al 2008) which show approaches to measuring emissions from waste, waste water, transport and energy. Interestingly no examples were found which included emissions from use of paints which must be commonly used in businesses; however quantities of emissions may be minimal. One example was found for emissions from refrigerants which for Tesco in their UK operations in 2006/7, amounted to 26% of emissions by source (Tesco, 2007).

2.2 Greenhouse gas accounting methods

Various terms are used to describe the activity of carbon/greenhouse gas accounting. “Greenhouse gas inventory”, “carbon footprint”, “life-cycle analysis” and “carbon budget” are the four terms most commonly encountered. Various calculators are also available to sum emissions and removals. These are explored below.

2.2.1 IPCC National Greenhouse Gas Inventory method

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) give methods for calculating national inventories of greenhouse gas emissions. It is important to emphasise that the guidance is for national inventories and therefore takes a broader brush approach than an organisation level inventory. The method is focussed on production, not consumption and therefore cumulative emissions for products are not considered, unlike the life cycle approach (section 2.2.5). The most common measurement method is the use of emission factor coefficients applied to data on the extent of human activities. But the guidelines also use mass balance methods to measure changes in carbon stocks in the “Agriculture, Forestry and Other Land Use” (AFOLU) sector. (IPCC, 2006, vol.1, ch.1, p.1.6)

The guidelines offer three different “Tiers” of calculation of increasing levels of complexity and accuracy. Tier 1 tends to rely on averaged international data, Tier 2 on country-specific data, and Tier 3 on detailed measurements or models.

The guidelines are divided into sectors for emissions from energy; industrial processes and product use; agriculture, forestry and other land use; and waste. All of these are likely to come into play to a greater or lesser extent on a working estate. The key features of these sectors are outlined below.

Energy

IPCC National greenhouse gas inventories are concerned with fuel combustion, and not with the consumption of electrical power generated as a result. Thus they are of use to calculate the emissions from combustion of fuel in vehicles and machinery at Wimpole (and also fugitive emissions from stored fuels), but not to calculate the consumption of electricity. This equates to the “Direct Emissions” and “Indirect Emissions from Electricity” approach of the GHG Protocol (paragraph 2.2.3)

Industrial Processes and Product Use

This volume of guidance mainly covers manufacturing industry and is therefore not relevant for a country estate. However there may be emissions taking place due the use of for example, refrigerators, aerosol sprays, and machinery lubricants, (IPCC, 2006, vol. 3, ch.1). These emissions are likely to be on a small scale and were not explored during this project.

Agriculture, Forestry and Other Land Use (AFOLU)

The AFOLU sector guidance covers all managed land, in order to identify anthropogenic effects on greenhouse gas emissions and removals. Managed land is defined as “land where human interventions and practices have been applied to perform production, ecological or social functions” (IPCC, 2006, vol.4, ch.1) which covers most parts of a working estate.

In measuring changes in carbon stocks for land use categories, the AFOLU guidance is measuring “net biome production”. This is most easily described by means of Figure 2.3, where GPP is Gross Primary Production (the uptake of CO₂ by photosynthesis); NPP is Net Primary Productivity (total plant biomass net of respiration); NEP is Net Ecosystem Productivity (NPP minus respiration from decomposition); NBP is Net Biome Productivity (NPP minus losses from disturbance, i.e., harvest and land clearance). (IPCC, 2006, vol.4, ch.1 p. 1.6-1.7).

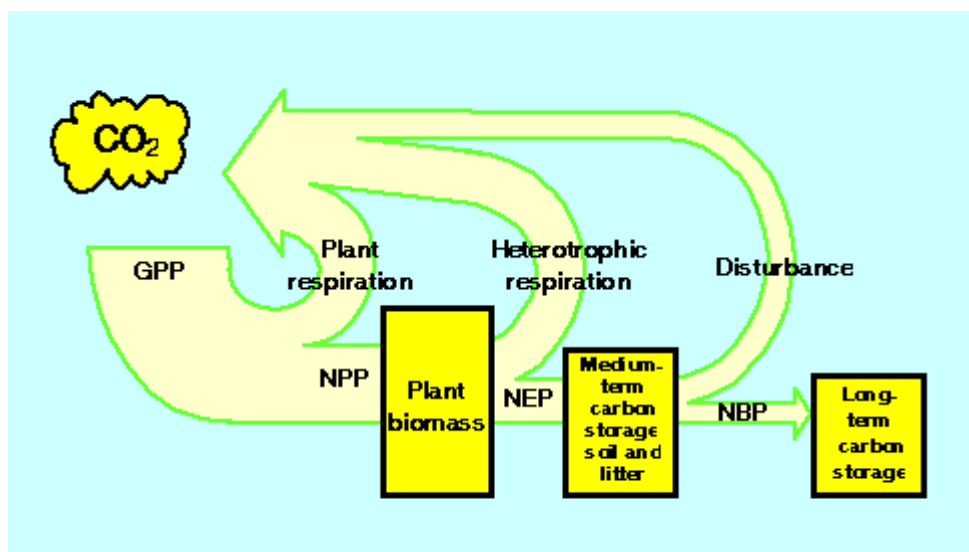


Figure 2.3 Net biome production - carbon stocks reported in national greenhouse gas inventories (Source: <http://www.ecologyandsociety.org/vol1/iss2/art2/inline.html>)

In terms of accounting categories, the AFOLU guidance identifies six land use types to be considered for emissions and removals of greenhouse gases (IPCC, 2006, vol.4, ch.1 p.1.9) forest land, cropland, grassland, wetlands, settlements (trees, lawns and perennial vegetation in gardens), other land (unmanaged land, bare soil, rock and ice). The national greenhouse gas inventories are concerned with changes from one land

use category to another; say from cropland to forest, or unmanaged land to grassland which affects carbon stocks. The guidance requires each of these categories to be subdivided according to carbon pools of above and below ground biomass, dead organic matter and soil organic matter. Measurement of changes between land use types is too broad a level for a country estate, but methods are available for calculating emissions on a smaller scale.

Waste

A country estate is likely to produce solid waste, waste water and sewage. These wastes are most likely to be taken off site for treatment and may be disposed of by different methods depending on their nature. Methane emissions from landfill disposal are likely to be the biggest source of emissions in this sector. Most treatments are likely to produce nitrous oxide, but the extent is said to depend greatly on the conditions during treatment. (IPCC, 2006, vol.5, ch.1, p.1.5)

2.2.2 UK Greenhouse Gas Inventory

The latest UK Greenhouse Gas Inventory report for 1990-2007 (DECC, 2009c), submitted in April 2009 follows the 1996 IPCC guidance (as it is required to) and its Annexes (DECC, 2009b) are a source of methods appropriate to the UK for the assessment of emissions and removals.

2.2.3 The Greenhouse Gas Protocol

The Greenhouse Gas Protocol, (WRI/WBCSD, 2004) is for businesses wanting to compile a GHG inventory. It does not, however make reference to agriculture. It covers (CO₂), (CH₄), (N₂O), (HFCs), (PFCs), and (SF₆) – the Kyoto gases. Other GHG's may be included optionally. It uses three “scopes” of emissions (Figure 2.4 represents these). Direct Emissions (Scope 1) “occur from sources that are owned or controlled by the company, for example, emissions from combustion in owned or controlled boilers, furnaces, vehicles, etc” (WRI/WBCSD, 2004, p.25). Indirect Emissions from Electricity (Scope 2) – purchased electricity will have emissions at the point of generation. Other indirect GHG emissions (Scope 3) are “a consequence of the activities of the company, but occur from sources not owned or controlled by the company [e.g.], extraction and production of purchased materials; transportation of purchased fuels; and use of sold products and services”. (WRI/WBCSD, 2004, p.25)

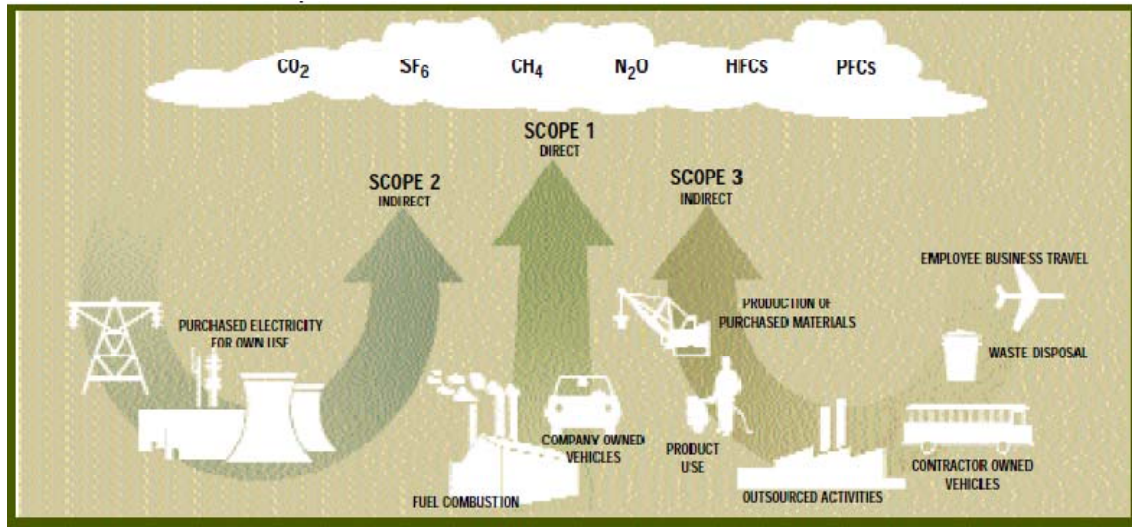


Figure 2.4 Scopes and emissions described by the Greenhouse Gas Protocol (WRI/WBCSD, 2004, p.25)

2.2.4 Carbon footprints

Wiedmann and Minx (2007) noted the rising use of the term “carbon footprint” in their paper that looked at the lack of a clear definition of the term. There is still no clear definition of a carbon footprint. The one postulated by Wiedmann and Minx is, “The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product” (Wiedmann & Minx, 2007). Their word “activity” includes those of “individuals, populations, governments, companies, organisations, processes, industry sectors etc”. “Product” includes goods and services. The Carbon Trust describes the term “carbon footprint” as, “commonly used to describe the total amount of CO₂ and other greenhouse gas (GHG) emissions for which an individual or organisation is responsible. Footprints can also be calculated for events or products”. (Carbon Trust 2007, p.2). There is therefore disagreement over what gases are included.

2.2.5 Life cycle approach

Wiedmann and Minx

Wiedmann and Minx’s view is that all “direct (on-site, internal) and indirect emissions (off-site, external, embodied, upstream, downstream) need to be taken into account” (Wiedmann & Minx, 2007). They highlight the need for clarity over what exactly is included within the scope and boundaries. In the case of indirect emissions one needs to avoid under- and over-counting of emissions and this is why they used the word “exclusive” in their definition. The meaning they place on this word is not clear, but presumably in assessing the carbon footprint of one widget, for example, you would

need to isolate the energy inputs to that widget alone regardless of the fact that it was no doubt produced in a batch along with hundreds of other widgets.

They only include CO₂, arguing that if you include other greenhouse gases, many are not carbon-based, and would therefore represent not a “carbon footprint” but perhaps a “climate footprint”. In addition, they say some gases are hard to quantify, and if you chose to include an easy one like methane they argue that little is gained by giving a “partially aggregated indicator that includes just two of a number of greenhouse gases.” (Wiedmann & Minx, 2007).

PAS2050

Another life cycle approach is put forward in PAS2050:2008 (Publicly Available Specification). It takes the view that “life cycle GHG emissions are the emissions that are released as part of the processes of creating, modifying, transporting, storing, using, providing, recycling or disposing of goods and services” (BSI, 2008, p. iv). The gases it includes are those covered by the IPCC guidelines (IPCC, 2007b, p.33).

Life cycle plus systems modelling approach

In a study of a selection of agricultural and horticultural commodities, Williams et al, (2006) used the life cycle approach to assess the emissions arising from different production options. Emissions of CO₂, N₂O and CH₄ were aggregated into tonnes of CO₂e. In addition, emissions were used to assess impacts on eutrophication and acidification, and other resource inputs such as fertilizers, animal feed and machinery use were calculated back to the use of primary resources such as coal, ores and crude oil. Pesticide dosage, land use area and irrigation water used were also assessed. This study therefore covered a wider range of environmental impacts than a carbon footprint, or the PAS 2050 approach. The study compared organic production with various “conventional” (i.e., non-organic) options.

2.2.6 Carbon budgets

Although many scientific papers were found that talked about carbon budgets, there was no attempt found to define what was meant by the term. In many cases it seemed to represent the balance between emissions and removals of greenhouse gases. A paper by a firm of sustainable energy consultants was found that gave the definition; “a carbon budget is a set amount of carbon that can be emitted in a given amount of time, either by the whole economy, or a pre-selected sub-population or set of activities”.

(ECOFYS, 2006). The same meaning is implied by the UK Government's introduction of a Carbon Budget in the Climate Change Act, 2008 (UK Government, 2008) which requires the setting of caps on emissions. As this term is not defined sufficiently in the scientific community and has accepted meaning in economic circles it is not proposed to use this term for the thesis methodology.

2.2.7 CALM calculator

The CALM (Carbon Accounting for Land Managers) calculator (CLA, 2009) has been produced by the Country Land and Business Association. It is a web-based tool to work out emissions and sequestration for farms and estates. It uses the IPCC (Tier 1) and GHG Protocol methodologies. Users are enabled to work out their Scope 1 (direct emissions from fuel combustion, livestock and wastes, and from the application of nitrogen fertilizers) and Scope 2 (from the purchase of electricity) GHG Protocol emissions. Scope 3 emissions are optional and would include indirect emissions from the manufacture of fertilizers (which the calculator can do) and animal feeds (which it can't). (CLA, 2008). This seems to be a comprehensive, clear and simple calculator.

2.2.8 Other calculators/models

A number of other calculators were found. These were investigated but not taken further due to shortcomings. CPLAN, set up by two UK farmers, two versions are on offer, both similar to CALM calculator, but less comprehensive. FarmGHG, tailored to a dairy farm so not applicable to the study site. Farm Adapt, seems to be more related to enhancing farm profitability in response to changing policies and other scenarios.

FarmSim, two sites were identified with this name, one based on Mid West USA farms, the other on Australian farms so neither would seem appropriate.

2.2.9 DNDC simulation method

Topp & Rees (2008) compare the application of two footprinting tools: IPCC 2006 guidelines (presumably the Guidelines for National Greenhouse Gas Inventories) and DNDC (DeNitrification and DeComposition, ver.92) (University of New Hampshire, 2007) which they describe as "a systems-based mechanistic model that simulates carbon and nitrogen flows in agricultural ecosystems" and, "widely acknowledged as a state-of-the-art model for use in assessing nutrient fluxes in arable farming systems". The IPCC method was able to "account for all the carbon flows on the farm" but not in a very detailed way, and was not able to "take account of the effect of subtle changes in management or weather" (Topp & Rees, 2008). In contrast, the DNDC method did provide a "detailed analysis of the origin of carbon fluxes" which they point out is

“potentially helpful in designing management to reduce the footprint” (Topp & Rees, 2008). However, it does not look at methane emissions from livestock. The depth of information required was too detailed to gather given the time available and the fact that this project is only looking at greenhouse gas emissions.

3 Methodology

This section sets out the reasons for selecting the chosen methodology and describes the methods used to arrive at the results.

3.1 Background

The method for data collection was designed to provide sufficient information to enable a thorough carbon footprint to be calculated for the estate for both the existing non-organic and future organic operations. It was decided to limit the boundaries to the farm gate – that means counting only those sources of greenhouse gas emissions and removals that are within the direct control of the estate manager. Therefore Life Cycle Analysis was discounted as a method as it takes into account emissions relating to the manufacture of items brought onto the farm, and in theory should also account for emissions relating to the use and disposal of items exported from the farm gate. This would provide a lot of information but it is doubtful how much practical use it would be to the estate manager.

A purposive sampling technique was used whereby information was sought to meet the needs of the study (Robson, 2002, p.265). Semi-structured interviews were conducted with the farm manager and National Trust regional advisor to obtain information about the farm and estate practices.

As the aim of the thesis was to select an appropriate methodology to establish a carbon footprint and to apply it to a UK-based country estate, the CALM calculator was chosen as the basis of calculations as it is based on the UK Greenhouse Gas Inventory methods, is widely used by the agricultural community, it has been the subject of a study by Natural England (2008), and is already in use at Wimpole. As the farm manager had already applied the CALM calculator to the existing, non-organic operations it was decided to use this as the starting point for working out the carbon footprint of the proposed organic methods as a comparison. Access was provided to the estate's CALM reports (online) so that input data and results could be examined. It was found that very little detailed information was provided by CALM about what it was calculating as it is clearly designed for a non-scientific audience. Calculations made by

the author to assess emissions and removals of greenhouse gases therefore also served as a means of verifying the results produced by CALM.

In order to judge the accuracy of the results produced by CALM they were independently calculated by the author using the most appropriate, authoritative, up to date sources of calculations which were identified as the UK Greenhouse Gas Inventory; the Annexes to which provide detailed calculation methods for emissions and removals (DECC, 2009b). CALM is based on the previous version of the UK Greenhouse Gas Inventory. In some cases it was necessary to consult other sources of data to provide results. These are detailed in the appropriate section below.

The Annexes to the UK Greenhouse Gas Inventory, 2009 (DECC, 2009b) were explored to identify agricultural and land-use related emission calculations which should be included. All those that were relevant have been subject to calculations set out below. The equations used are reproduced at Appendix B.

Calculations relating to waste were not possible as data were not available. Calculations relating to visitor travel were to be calculated as a separate addition (they were considered to be outside the project boundaries but were of interest to the sponsor). However data were considered insufficient for calculation as although numbers of visitors to the site paying the entrance fees to house, farm and gardens were known, there are many more that just pay the car park fee and walk around the estate, but numbers of these were not available. Average distance travelled is said to be known from a survey but was not available. Investigation of the emissions from, for example refrigerants, lubricants and paints was not possible within the time available.

The N₂O and CH₄ emissions were converted to CO₂e using the same GWP factor as used by the UK Greenhouse Gas Inventory, 310 and 21 respectively. (These factors were chosen to make the results comparable to the UK inventory).

The existing CALM report for the estate is divided into two; one for the livestock farm and one for the arable farm. As a result, CALM transfers an amount of manure from the livestock farm into the arable farm. The author has kept the two halves separate as all the changes under organic operations will take place on the arable side. All emissions relating to the animals are kept on the livestock side even though some emissions will

occur due to manure use on the arable side (manures are not shown as exported and imported from one side to the other). The CALM report also calculates emissions of CO₂ due to the manufacture of nitrogen fertilizers, but as the decision had been made to keep to emissions directly under the estate's control, these are excluded from the author's calculations. CALM also has included a small amount of electricity consumption, but this has been taken out as electricity consumption for the whole estate has been calculated separately.

3.2 Livestock farm calculations

This side of the farm is already operated organically (as far as factors affecting greenhouse gases are concerned), so these calculations will also apply when the whole farm goes organic.

3.2.1 Fuel consumption by farm machinery and vehicles

Calculations at Appendix C, Table C.1.

CO₂, CH₄, N₂O and CO₂e were calculated using Defra 2009 emission factors (Defra, 2009d), the 2008 version used by CALM only shows CO₂e. The UK Greenhouse Gas Inventory provides very similar conversion factors for fuels, but it was decided to use the most up to date available.

Gas oil (red diesel) Emissions were calculated by multiplying litres of fuel by the Gas Oil conversion factors (Defra, 2009d, Annex 1). CALM had not calculated anything for this, despite the amount of litres being input to the spreadsheet. This seems to be a glitch in the software.

Diesel Emissions were calculated by the author by multiplying litres of fuel used by the Diesel conversion factors (Defra, 2009d, Annex 1).

3.2.2 Energy used by contractors

Calculations at Appendix C, Table C.2.

This refers to fuel used by farm contractors at Wimpole. The CALM calculator lists contractors' energy inputs partly through hours worked at various hp (horsepower) ratings. It does not show how the emissions are arrived at from this, but by a process of back calculation, it was possible to see that the under 100 hp machinery calculation was based on approximately 15 litres per hour, and the 100-150hp machinery on approximately 23 litres per hour. In order to verify this it was necessary to consult tractor test information.

In order to calculate how many litres of fuel might be used by contractors' machinery per hour in the under 100hp and 100-150hp categories, two typical tractors were identified from OECD Tractor Test Results which test fuel consumption amongst other factors. The two selected tractors were manufactured by Massey Ferguson (chosen as they are a well-known make) and fall within the two hp categories. They were listed on the OECD website by kWh rather than hp, so hp was converted to kWh using the conversion factor, $\text{hp} \times 0.7457 = \text{kWh}$ (Carbon Trust, 2009). The mean fuel consumption per hour for these two tractors was 18.44 l/hr for the lower hp category and 30.66l/hr for the higher. As these are verifiable sources of information, these rates were used in preference to the CALM data.

Powered machinery under 100hp - the hours of work supplied by contractors' machinery was multiplied by the mean litres per hour for the typical tractor identified, (Massey Ferguson 6445, (OECD, 2006)) this amount was then multiplied by the gas oil conversion factors (Defra, 2009d, Annex 1).

Powered machinery between 100-150 hp – the same method as for machinery under 100 hp was used (tractor type, Massey Ferguson 7475, (OECD, 2008)).

Other operations carried out by the contractor (using diesel) – this was more straightforward to calculate, as CALM gives the litres used as opposed to hours worked. The author multiplied the litres used by the Diesel conversion factors (Defra, 2009d, Annex 1).

3.2.3 Cattle, sheep and other livestock

Calculations at Appendix C, Tables C.3 to C.7.

The calculation of CH₄, N₂O and CO₂e emissions for all animals followed the same format. CH₄ was calculated for enteric fermentation using emission factors from the Annexes to the UK Greenhouse Gas Inventory, 1990-2007 (DECC, 2009b, Table A 3.6.2) for the appropriate animal type. CH₄ emission was not calculated for manures as it is stored as a solid or deposited on the pasture and decomposes aerobically therefore producing insignificant methane (DECC, 2009b p.376).

N₂O from solid storage of manures and as deposited on pasture was calculated using equation 1 at Appendix B. N₂O emissions from the application of previously stored manures was calculated using equation 2 at Appendix B which is corrected to take account of losses of N₂O already accrued through storage. The calculation only took into account the fraction of manures produced while the animals were housed as this is

what goes into storage. Indirect N_2O emissions from atmospheric deposition of NH_3 & NO_x from the application of manures was calculated using equation 3 at Appendix B. All manures, whether applied from storage, or deposited on pastures were included as it is all liable to atmospheric deposition. Indirect emissions of N_2O from leaching & run-off due to application of animal manures was calculated using equation (4) at appendix B. All manures whether applied from storage or deposited on the pasture was counted as it is all liable to leaching and run-off.

3.2.4 Farm woodland

Calculations at Appendix C, Table C.8.

A suitable method for calculating annual removal rates in woodland could not be found (without very complex data requirements) in the UK Greenhouse Gas Inventory (DECC, 2009b). By following a worksheet provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006, vol.4, Annex 1, p. A1.9) to calculate "Forest Land Remaining Forest Land: Annual increase in carbon stocks in biomass (includes above-ground and below-ground biomass)" an annual carbon stock increase of 4 t C yr^{-1} per ha was calculated. As this is based on broad figures for European temperate oceanic forest, confirmation of this amount was sought by other, more UK-based data. A Forestry Commission paper which their website publicises as the most up to date information, says that, "the maximum rate of carbon accumulation during the full-vigour phase of fast growing stands in the UK is about $10\text{ tC ha}^{-1}\text{ yr}^{-1}$, although a realistic average over a full commercial rotation may be no more than $3\text{ tC ha}^{-1}\text{ yr}^{-1}$ " (Forestry Commission, 2003, p.4). To err on the side of caution, this figure of $3\text{ tC ha}^{-1}\text{ yr}^{-1}$ was adopted, although the Wimpole woodland is not a commercial rotation the figure fits with other research cited in the publication. The carbon was then converted to tonnes of CO_2 using the accepted conversion factor of 44/12. CALM has calculated different rates of removal for different age category of woodland, a rate for young woodland was not found, so the standard rate was applied to all age classes. This is an aspect of the method that can be improved upon.

3.3 Arable (non-organic) farm calculations

The farming operations on this side of the farm will differ when the farm changes to organic operations therefore two sets of calculations were undertaken. This section covers existing non-organic methods. Section 3.4 covers proposed organic methods.

3.3.1 Fuel consumption by farm machinery and vehicles

Calculations at Appendix C, Table C.9.

The method used was as described in paragraph 3.2.1.

3.3.2 Fuel used by arable contractor

Calculations at Appendix C, Table C.10.

The default of 180l litres per hectare used by CALM was agreed by the farm manager as a fair approximation of the total consumption of fuel over the year in cultivation procedures by the contractor. This was therefore multiplied by the 240 hectares under arable crops and then by the emission factor for gas oil (Defra, 2009d).

3.3.3 Fertilizer use

Calculations at Appendix C, Table C.11.

The N₂O emissions from the application of the three types of nitrogen fertilizer used were calculated using the nitrogen content of each and equation 5 at Appendix B. Indirect emissions from atmospheric deposition of NH₃ and NO_x from the application of nitrogen fertilizers were calculated using equation 6 at Appendix B. Indirect emissions of N₂O from leaching & run-off due to application of nitrogen fertilizers was calculated using equation 7 at Appendix B.

3.3.4 Emissions due to ploughing-in crop residues

Calculations at Appendix C, Table C.12.

This was calculated using equation 8 Appendix B for the total production of winter wheat and oilseed rape. The CALM method takes into account straw that is exported from the farm, but it was not clear whether this was deducted from the wheat calculations or counted separately. The author could not see a reason to treat the straw separately from the crop (if it is not ploughed in) and CALM does not count straw used on the farm (say, for animal bedding which may get subsequently ploughed in), also the UK Greenhouse Gas Inventory methods do not take straw into account, therefore no calculation was made involving straw. The elements of the equation relating to legumes/nitrogen fixing crops and field burning were excluded as neither of these apply.

3.3.5 Carbon removals due to land use change

Calculations at Appendix C, Table C.13.

The potential gain of carbon stored due to the conversion of some arable land to grassland was calculated using DECC, 2009b, Table A3.7.19, p. 400. This table shows

“weighted average change in equilibrium biomass carbon density (kg m^{-2}) to 1m deep for changes between different land types in England”. The gain factor of $0.08\text{kg/m}^{-2}/\text{yr}^{-1}$ was applied to the 12ha of land converted in the last 20 years and also the 2 hectares declared as converted within the last 12 months on the assumption that this could be rounded up to a full 12 months. Carbon was converted to CO_2 using the factor 44/12.

3.3.6 Farm woodland

Calculations at Appendix C, Table C.14.

The method described in paragraph 3.2.4 was applied.

3.4 Organic practices

As previously noted there will be no changes in practice of livestock operations under the organic regime. The calculations below therefore only apply to the arable side.

The rotation will be 3/5 crop, 2/5 grass/clover ley over the total of 240ha. Therefore 144ha will be crop, and 96ha ley.

3.4.1 Fuel consumption by farm machinery and vehicles

On advice from the farm manager, the assumption was made that fuel use would remain the same under organic as non-organic methods; therefore calculations at paragraph 3.3.1 apply.

3.4.2 Fuel consumption for arable cultivation

Calculations at Appendix C, Table C.15

On the advice of the farm manager, the default of 180l per hectare was again used to calculate fuel consumption under organic cultivation. The land will be cultivated by the National Trust instead of a contractor as the contractor does not wish to operate organic methods. Although the methods will be different, including plans to use a lighter powered tractor than the contractor, it was felt that overall the consumption of fuel would be roughly the same for arable crops and grass/clover ley as for non-organic cultivation. This decision is borne out by a report on organic agriculture in England and Wales (Jones & Crane, 2009, p.46) which cites reports by Lampkin et al, (2006), Nix (2007) and Pelletier et al (2008) stating that fuel and machinery usage is broadly similar in organic and conventional methods.

3.4.3 Fertilizer use

Synthetic nitrogen fertilizer use will cease; the calculation was therefore zero.

3.4.4 Ploughing in of crop residues

Calculations at Appendix C, Table C.16.

Equation 8 Appendix B was used for the crops planned - wheat, oats, beans (48ha each) and grass/clover ley (96 ha) based on estimated crop yields. Although the farm manager is intending to instigate a shallower depth of plough cultivation than under the current non-organic method, it was decided to still calculate this element as the crop residue will become incorporated into the soil. As for the non-organic calculation the fate of straw was not entered into the calculation. Standard yields identified were decreased by a proportion for organic production indicated by Jones and Crane (2009, p.32-33). A wheat yield of 290.4t was calculated as 68% (Jones & Crane, 2009, p.32) of standard yield for first winter wheat of 8.9t/ha (Agro Business Consultants, 2008, p.13). An oats yield of 106.8t was calculated as 42% (Jones & Crane, 2009, p.32) using a standard yield for milling spring oats of 5.3t/ha (Agro Business Consultants, 2008, p.19). A beans yield of 159.4t was calculated as 83% (Jones & Crane, 2009, p.33) using a standard yield for winter field beans of 4.0t/ha (Agro Business Consultants, 2008, p.128). A yield for grass/clover ley of 677.76t was calculated as 83% of that for medium term grass ley (including white clover) at 8.5t/ha as the nearest comparator (Agro Business Consultants, 2008, p.256). 83% of yield was chosen as the crop is partly leguminous (Jones & Crane, 2009, p.33). The calculation for nitrogenous crops – the beans and clover, required a fraction of the amount of crop removed from the field; this was estimated at 40% of above and below ground biomass.

3.4.5 Emissions due to biological fixation of nitrogen by crops

Calculations at Appendix C, Table C.17.

The UK Greenhouse Gas Inventory (DECC, 2009b) identifies this as a source of emissions. There are none under the non-organic rotations so estimates were based on yield calculations for beans and grass/clover ley in paragraph 3.4.4. Equation 9 at Appendix B was used. As above the fraction of crop removed from the field was estimated at 40%. For the clover/grass ley further estimation was required as the legume element was not the whole of the crop and the proportion of mixture was unknown. The total crop yield was used as the basis of the calculation. However the latest IPCC guidance discounts biological fixation as a source at all. It cites research concluding that there is “lack of evidence of significant [N₂O] emissions from the fixation process itself” and that emissions should be accounted for in the incorporation of crop residues to the soil. (IPCC, 2006, vol.4, ch.11, p.11.6). Therefore although the calculation was made, the result was excluded from the carbon footprint calculation.

3.4.6 Removals through woodland and conversion of arable to grassland

These calculations remain unchanged from non-organic operations.

3.5 Other emissions calculated

Appendix C, Table C.18.

Non-agricultural emissions due to estate-wide consumption of electricity, heating oil and water were calculated.

3.5.1 Electricity consumption

Billed consumption in kWh for 2008 across the various estate buildings including farms, restaurant, shop and Hall were totalled and Defra (2009d, Annex 1) emission factors applied.

3.5.2 Heating Oil

Emissions from consumption for 2008 (kWh) was calculated using emission factors for "Burning Oil" (Kerosene) from Defra, 2009d, Annex 1, Table 1a which gives the slightly higher net calorific value since it was not known whether the gas was supplied as net or gross value.

3.5.3 Water

Both supply of mains water and treatment of waste water produce greenhouse gas emissions. Only supply quantities were known for the estate so emissions from waste water are not included in calculations. Metered mains supply for various estate buildings including the Hall, farms and restaurant was summed. (This excludes unmetered supply for an unused building, storage yard and a residential house). A report by Scottish Water (Scottish Water, 2008, p.5) gives a UK average factor for emissions from water supply, (including extraction, treatment and pumping) which was applied the total consumption figure.

4 Results

This chapter sets out the key results arising from the calculation of the estate emissions, the carbon footprint, and removals of greenhouse gases, with comparisons to results produced by CALM. The emissions from the livestock and arable sides of the farm are presented with removals shown separately followed by the non-agricultural emissions. Then the results relating to the move to organic procedures are presented and compared with existing procedures. Results related to yield and per hectare emissions are presented. The reliability of the results is critically discussed.

4.1 Livestock Farm

The CALM programme estimated that the annual greenhouse gas emission from the livestock farm was 597 tonnes of CO₂e (Table 4.1). This is within 13% of the value (686 tCO₂e) calculated by the author. Most differences occur due to fuel calculations. The calculated result (47 tCO₂e) for the fuel used by the farm machinery is greater than the 11 tCO₂e calculated using CALM, which did not include the gas oil consumption.

Table 4.1 Summary of annual greenhouse gas emissions from the livestock side of the farm as estimated by the author and by the CALM programme

Data provided		Author's calculations				CALM Calculations		
Component	Quantity	CO ₂ (t)	CH ₄ (tCO ₂ e)	N ₂ O (tCO ₂ e)	Total tCO ₂ e		Total tCO ₂ e	
						(%)		(%)
Fuel used by farm machinery	12000l gas oil 4000l diesel	43.7	0.04	3.3	47.0	7	11	2
Fuel used by contractors	200hrs @100hp 11—hrs @100-150hp 1000l diesel	106.0	0.1	9.9	116.0	17	78	13
Cattle	157	0.0	144.1	155.0	299.1	44	293	49
Sheep	850	0.0	92.4	72.2	164.6	24	164	27
Pigs	94	0.0	3.2	21.7	24.8	4	19	2
Poultry	100 hens, 50 turkeys	0.0	0.0	2.9	2.9	0.5	11	2
Horses	12	0.0	4.6	14.0	18.6	3	15	3
Goats	20	0.0	2.1	10.5	12.6	2	6	1
Totals		149.7	246.5	289.5	685.7	100	597	100

Fuel used by contractors in pasture management was partly based on hours worked by two different horsepower tractors as required by the CALM calculator (not based upon actual tractors in use on the farm). The results calculated by CALM are very close for the diesel calculation, but those relating to hours of work are less close as they are obviously based on a different fuel consumption rate to the author's.

The animal emissions comprise CH₄ from enteric fermentation; N₂O from manure in solid storage and manure deposited on pastures; N₂O from manures applied to fields after storage; indirect N₂O from volatilisation of nitrogen as NO_x and NH₃ and subsequent deposition on other land and water surfaces; and N₂O emitted through the leaching and run-off of manures into drainage systems. (Emissions from cattle for the latter three, amounting to 77.5 tCO₂e could be classed as emissions on the arable side as cattle manure is applied as an arable fertilizer but have been kept on the livestock side with like calculations). Animal emissions do not include those from imported feeds.

Emissions from cattle dominate the livestock emissions. The 157 cattle are producing 1.9 tCO₂e each; compared to the 850 sheep, which only produce 0.19 tCO₂e. This is a considerable impact per animal. The 94 pigs produce 0.27tCO₂e per animal. Whilst horses and goats produce 1.55 and 0.63 tCO₂e each respectively. For the ruminants (cattle and sheep) CH₄ from enteric fermentation is the single biggest emission source, 48 % and 56 % respectively, but this is not the case for goats (also ruminants) where CH₄ amounts to only 17 %.

Results for the animals (except poultry and goats) were very similar to those CALM calculated, and as they follow UK Greenhouse Gas Inventory (DECC, 2009b) methods, are considered to be reliable. It should be noted however, that the calculations for horses do not allow compensation for size, and those at Wimpole range from Shetland ponies to Shire horses which must have very different scales of emissions, averaged out though, the emissions are considered reasonable. Results for poultry do not match those of CALM, which calculated 10 tCO₂e for the 100 hens and 1 tCO₂e for the 50 turkeys. The author's calculations, using DECC, (2009b) calculated 3 tonnes. The author's results for goats were twice that of CALM. The reason for these discrepancies is not known, unless the equation or emission factors on which CALM is based differed significantly from DECC, (2009b).

4.2 Arable Farm

The CALM estimate of arable farm emissions (806 tCO₂e) was within 21 % of the estimate (1018 tCO₂e) made by the author (Table 4.2). Again most of the difference is a result of fuel calculations. CALM's results for diesel and unleaded petrol are very close to the author's, but the CALM programme again failed to calculate a result for gas oil.

Table 4.2 Summary of annual greenhouse gas emissions from the arable side of the farm, as estimated by the author and the CALM programme

Data provided		Author's calculations				CALM Calculations		
Component	Quantity	CO ₂ (t)	CH ₄ (tCO ₂ e)	N ₂ O (tCO ₂ e)	Total tCO ₂ e		CO ₂ e tonnes	
						(%)		(%)
Fuel used by farm machinery	7000l gas oil 360l diesel 150l unleaded petrol	20.6	0.02	1.9	22.5	2	1.0	0
Fuel used by contractors	240ha @ 180l/ha	119.3	0.1	11.4	130.8	13	0.0	0
Synthetic nitrogen fertilizer	368t ammonium nitrate 284t urea 79t other N fertilizer	0.0	0.0	744.0	744.0	73	731.0	91
Ploughing in crop residues	1062t wheat 134t oilseed rape	0.0	0.0	120.9	120.9	12	74.0	9
Totals		139.9	0.1	878.2	1018.2	100	806.0	100

The calculation of fuel consumption by contractors on a "stubble to stubble" contract was based on a standard default used by CALM and agreed by the farm manager. The amounts are therefore considered to meet accepted norms but do not necessarily reflect actual fuel consumption in the field. CALM did not calculate a result in this sector as the inputter (unknown) had failed to enter litres consumed.

Emissions of N₂O due to the use of synthetic nitrogen fertilizers have been calculated from three sources; direct emissions due to enhanced nitrogen levels which boosts nitrification and denitrification, releasing N₂O; indirect N₂O from volatilisation of nitrogen as NO_x and NH₃ and subsequent deposition on other land and water surfaces; and

N₂O emitted through the leaching and run-off of fertilizers into drainage systems. (As noted under livestock, emissions due to the application of manure have been kept on that side of the farm although may need to be included if comparisons are made to other farms' results). Combined together, N₂O emissions from all three sources for all three types of nitrogen fertilizer used contribute 73 % of all the emissions from the arable side of the farm. Of the three types of fertilizer, the most potent emitter is urea at 4.21 tCO₂e per tonne applied. Ammonium nitrate emits 3.33 tCO₂e per tonne applied and the other nitrogen fertilizer is much less potent at 1.89 tCO₂e per tonne applied. (Probably a reflection of the differing Nitrogen concentration in each fertilizer). Results were very similar to those CALM calculated, and as they follow UK Greenhouse Gas Inventory (DECC, 2009b) methods, are considered to be reliable.

Results for N₂O emissions due to the ploughing-in of crop residues followed DECC (2009b) methodology which bases calculations on crop production, but does not account for straw in any way. The CALM calculator takes into account straw but it is not clear how. The input screen requires tonnes of straw from a crop which is removed off the farm to be entered, whilst ignoring straw retained on the farm. The author's results for oilseed rape almost exactly matched CALM's, whilst the author's results for wheat straw almost exactly matched CALM's result for wheat, but it is not clear how the straw element came into play. As the author was following the DECC (2009b) method, the result for wheat itself has been taken, but the result for straw ignored. This makes the author's combined result for oilseed rape and wheat emissions higher than CALM's (120.9 tCO₂e as opposed to 74 tCO₂e). If the straw result were to be deducted from the wheat result, the author's result would be lower than CALM's at 47.5 tCO₂e, therefore to err on the side of caution the higher figure was taken as the result.

4.3 Removals of carbon by woodland and land-use change

CALM calculated removals separately for both sides of the farm and the author followed this split in calculations (Table 4.3).

4.3.1 Removals by woodland

There is a total of 132 ha of woodland on the farm which CALM calculates as removing 1421 tCO₂ per year. The author calculates it at 1430 tCO₂ per year. As CALM does not show how the result was arrived at, the author's calculation, based upon Forestry

Commission research for UK woodland was applied equally across all age ranges of trees. It is understood that different ages of tree have differing carbon absorption capacities so the results may not be correct within each age range.

Table 4.3 Removals of carbon by woodland and conversion of arable to grassland as estimated by the author and the CALM programme

Data provided		Author's calculations		CALM calculations	
Component	Quantity	tCO ₂ e		tCO ₂ e	
			(%)		(%)
Livestock farm woodland	116ha	-1276.0	87	-1272	87
Arable farm woodland	16ha	-154.0	10	-149	10
Arable farm conversion of arable to grassland	14ha	-41.1	3	-38	3
Totals		-1471.1	100	-1459	100

4.3.2 Removals due to land-use change

A total of 14ha of arable has been converted to grassland within the last 20 years. This was calculated by CALM as removing 38 tCO₂e/yr. The author's calculation, based on DECC, (2009b), which calculates gain in biomass carbon density, was 41.1 tCO₂e/ yr. This equates to 2.9 tCO₂e/ha/yr which in turn equates to 0.79 tC/ha/yr. This figure is within the range set out in three studies, firstly by Conant et al, (2001) which looks at effects on carbon sequestration rates by improved grassland management techniques and conversion of cropland to grassland, they found a range of 0.11 to 3.04 tonnes C/ha per year with conversion from cultivation at the top end of this range; secondly by Jones & Donnelly (2004) who found rates of carbon sequestration of 0 to over 8 tonnes C/ha per year; and thirdly by Vleeshouwers and Verhagen (2002) who found that conversion of arable to grassland sequestered 1.44 tonnes C/ha per year.

4.4 Estate Utilities – electricity, heating oil and water

Electricity, heating oil and water supply are responsible for 303 tCO₂e (Table 4.4). Electricity (198 tCO₂e) and heating oil (kerosene) (100.2 tCO₂e) were calculated using

Defra conversion factors (Defra, 2009d) so should be reliable. CALM did calculate a small amount of electricity on the arable side but this does not cover the whole estate so the result was not compared. It is understood that the electricity consumption and heating oil figures provided to the author are comprehensive. Water supply figures are understood to cover the majority supplied and the emission factor is based on UK average figures quoted by a water company (Scottish Water, 2008) so is thought to be reliable (4.9 tCO₂e). However data were not available for waste water and sewage leaving the site so the emissions resulting from water treatment are not calculated. The average UK emission factor for waste water treatment is 0.74 gCO₂e/litre (Scottish Water, 2008) which is 2.5 times higher than the factor for water supply so if 16,996,000 litres were treated (the same quantity as that supplied) the emissions would be 12.57 tCO₂e. Although it is unlikely that this amount leaves the site to be treated as a large proportion must get used on irrigation and in animal care, thus by-passing site main drains.

Table 4.4 Summary of annual greenhouse gas emissions by estate consumption of electricity, heating oil and water as calculated by the author

Data provided		Author's calculations				
Component	Quantity	CO ₂ (t)	CH ₄ (tCO ₂ e)	N ₂ O (tCO ₂ e)	Total tCO ₂ e	(%)
Electricity	365,885 kWh	197.8	0.1	1.3	198.2	65
Heating oil	386,000 kWh	99.8	0.2	0.3	100.2	33
Water supply	16,996,000 litres	-	-	-	4.9	2
Totals		297.6	0.30	1.6	303.3	100

4.5 Organic procedures

The differences in the change to organic cultivation will all take place on the arable side of the farm. The differences will accrue in a number of ways which are summarised (Table 4.5). (None of these emissions were calculated by CALM as organic practices had not been entered).

Fuel consumption was calculated as the same amount for non-organic cultivation on advice from the farm manager as this was felt to be a reasonable approximation. As

organic cultivation methods have not yet commenced it is hard to establish a difference at this stage.

Table 4.5 Summary of annual greenhouse gas emissions on arable side of farm under proposed organic methods as calculated by the author

Data provided		Author's calculations				
Component	Quantity	CO ₂ (t)	CH ₄ (tCO ₂ e)	N ₂ O (tCO ₂ e)	Total tCO ₂ e	(%)
Fuel used by farm machinery	7000l gas oil 360l diesel 150l unleaded petrol	20.6	0.02	1.9	22.5	6
Fuel use for crop cultivation	43,200l gas oil	119.3	0.1	11.4	130.8	35
Ploughing in crop residues	290.4t wheat 106.8t oats 159.4t beans 677.7t grass/ clover ley	0.0	0.0	218.9	218.9	59
Biological nitrogen fixation (excluded from totals)	159.4t beans 677.7t grass/ clover ley	0.0	0.0	297.0	297.0	0
Totals		139.9	0.1	232.2	372.2	100

Ploughing-in of crop residues was calculated at 218.9 tCO₂e. This was somewhat more speculative as standard yields for non-organic crops had to be identified with a deduction calculated for reduced yields understood to occur under organic practices. In addition, the fraction of the crop removed from the field had to be estimated for beans and grass/clover ley. The highest crop emissions were calculated to come from the grass/clover ley (1.55 tCO₂e/ha), which is more than double that of the next highest, wheat (0.65 tCO₂e/ha). The accuracy of the grass/clover ley figure is doubtful due to the lack of appropriate conversion factors in the IPCC and UK Greenhouse Gas Inventory methodologies.

Nitrogen fixing crops were calculated to contribute 297 tCO₂e based on the method used in the UK Greenhouse Gas Inventory (DECC, 2009b). However, as previously stated, the latest IPCC guidance discounts biological fixation as a source at all. And as such these emissions have been excluded from the total. (It is to be noted again that emissions due to the application of manure are not included).

4.6 Summary of the carbon footprint and comparison of organic to non organic cultivation

A summary of all emission sources, comparing non-organic to organic procedures is displayed (Table 4.6 and Figure 4.1).

Table 4.6 Summary of annual greenhouse gas emissions and removals, comparing non-organic to organic methods as calculated by the author

Emission source	Emissions (tCO ₂ e) Non-organic	(%)	Emissions (tCO ₂ e) Organic	(%)
Electricity	198.2	10	198.2	15
Heating Oil	100.2	5	100.2	7
Water supply	4.9	0	4.9	0
Fuel used in farm machinery and vehicles	69.5	3	69.5	5
Fuel used for pasture management	116.0	6	116.0	9
Livestock	522.7	26	522.7	38
Fuel used for crop cultivation	130.8	7	130.8	10
Synthetic fertilizer application	744.0	37	0.0	0
Ploughing in crop residues	120.9	6	218.9	16
<i>Biological nitrogen fixation (excluded from calculation)</i>	<i>0.0</i>	<i>0</i>	<i>297.0</i>	<i>0</i>
Total emissions	2007.4	100	1361.2	100
Carbon Footprint				
Total removals (woodland and conversion from arable to grassland)	-1471.1		-1471.1	
Net balance	536.3		-109.9	

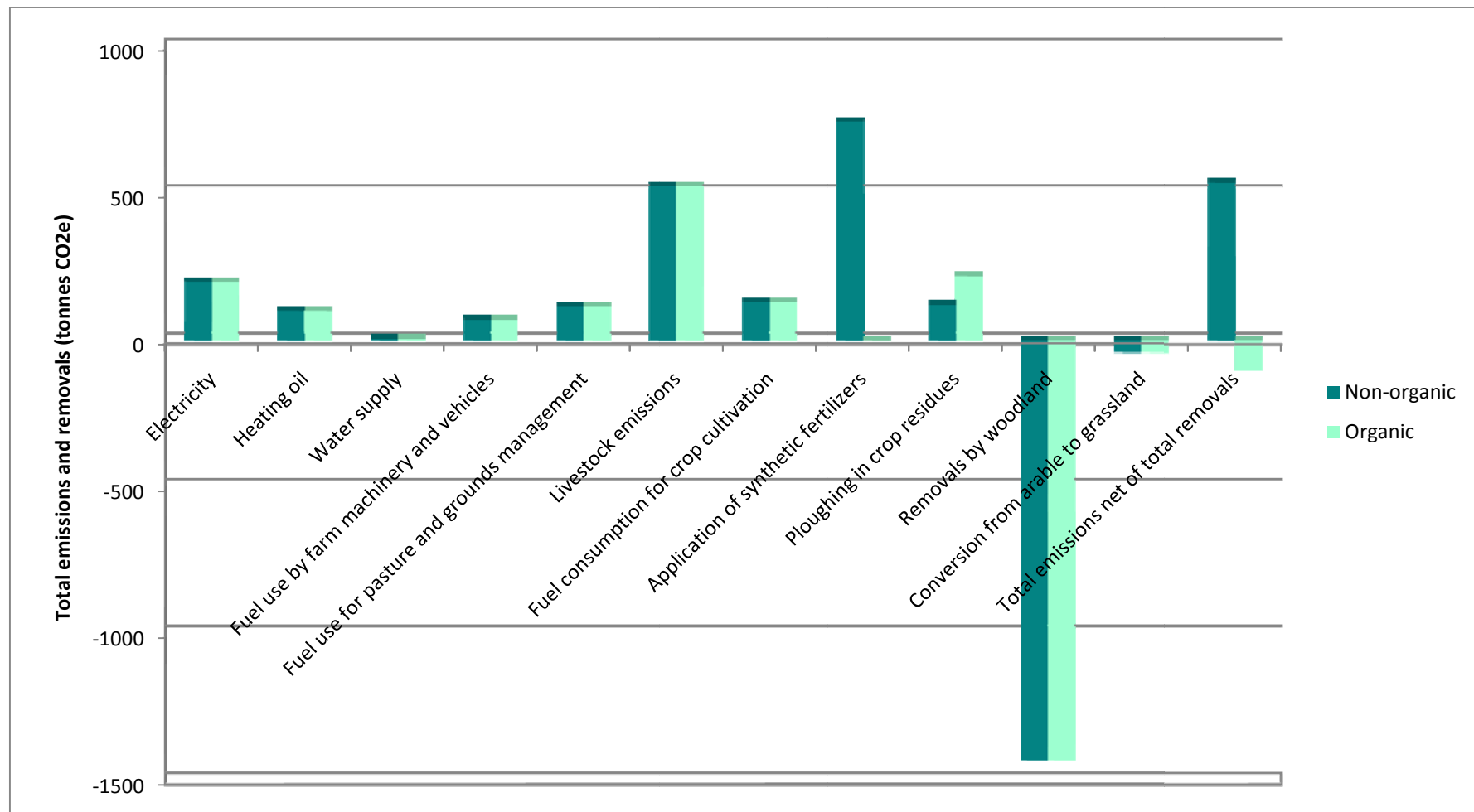


Figure 4.1 Summary of annual greenhouse gas emissions and removals (tCO₂e), comparing non-organic to organic methods as calculated by the author

Total emissions (including all sources) for non-organic production is 2007 tCO₂e - this is the “carbon footprint”. Whilst organic amounts to 1361 tCO₂e. This difference is accounted for largely through the non-use of synthetic fertilizers in organic cultivation, which contributes 744 tCO₂e under non-organic. Emissions from ploughing-in crop residues are much higher under organic (219 tCO₂e) as opposed to non-organic production (121 tCO₂e). This is due to the high level of emissions calculated as due from the grass/clover ley, making up almost 68% of the 219 tCO₂e.

The total difference between the two methods, of 646 tCO₂e represents a 32% reduction in emissions under organic practices (including all estate emissions).

The contribution to removal of carbon by woodland is striking in Figure 4.1. The total of 1430 tCO₂e sequestered by woodland represents 71 % of non-organic emissions and 105 % of organic emissions (including all estate emissions). When the contribution of arable land converted to grassland is included this comes to 73 % and 108 % respectively.

A poster for possible public display showing the carbon footprint has been produced. (Appendix D). It has been limited to the current, non-organic footprint for clarity of presentation.

4.6.1 Yield related results

Emissions per tonne of crop have been calculated under non-organic (Table 4.7) and organic methods (Table 4.8). It is only possible to compare wheat as the other crops are only grown under one or the other method, but it can be seen that there is a considerable reduction in emission under organic methods, 0.26 tCO₂ per tonne of crop as opposed to 0.64 tCO₂ per tonne of crop under non-organic methods. This is based upon the calculated non-organic yield from a three year rotation involving first and second winter wheat. The yield, which equates to 6.64 t/ha is less than the national average data (8.90t/ha) used to calculate the reduction of yield under organic methods where the application of a reduction of yield of 32 % gave a yield of 6.05 t/ha. If the 32 % reduction is applied to 6.64 t/ha, the organic yield will be 4.51 t/ha and the emissions per tonne of crop will then be 0.34 tCO₂e/t. Emissions due to application of manure are not included. Yields have been related to the hectares upon which the crops are grown as this reflects how the emissions are dispersed over the land.

Table 4.7 Annual emissions (tCO₂e) per tonne of crop under non-organic methods as calculated by the author

Emission source	Emissions (tCO ₂ e)	Total emissions per hectare	Crop (tonnes)	Hectares per crop	Emissions per tonne crop (tCO ₂ e)
Fuel used by farm machinery	22.51	1018.26t CO ₂ e/240ha = 4.24	Wheat 1062	160	0.64
Fuel use for crop cultivation	130.85				
Fertilizers	744.00		Oilseed rape	80	2.53
Ploughing in crop residues	120.90		134		

Table 4.8 Annual emissions (tCO₂e) per tonne of crop under organic methods as calculated by the author

Emission source	Emissions (tonnes CO ₂ e)	Total emissions per hectare	Crop (tonnes)	Hectares per crop	Emissions per tonne crop (tonnes CO ₂ e)
Fuel used by farm machinery	22.51	372.23t CO ₂ e/240ha = 1.55	Wheat 290.40 (or 216.48 using yield reduction based on Wimpole yield)	48	0.26 (or 0.34 using yield reduction based on Wimpole yield)
Fuel use for crop cultivation	130.85		Oats 106.80	48	0.70
Ploughing in crop residues	218.87		Beans 159.40	48	0.47
Biological fixation	52.70		Grass/clover ley 677.76	96	0.22

Emissions per tonne of carcass produced have been calculated based on information supplied by the farm manager (Table 4.9). Again this includes emissions due to the application of manures on the arable side. It excludes those relating fuel use and to feed production.

Table 4.9 Emissions (tCO₂e) per tonne of carcass produced as calculated by the author

Animal	Emissions per head (tCO ₂ e)	Carcass weight (kg)	Emissions per tonne of animal carcass (tCO ₂ e)
Cattle	1.90	340	5.59
Pigs	0.26	65	4.00
Sheep	0.19	30	6.33

Emissions per hectare on the total areas of the livestock and arable sides have been calculated (Table 4.10). This has excluded the estate emissions of electricity, heating oil and water supply since, as a large stately home and visitor attraction, these figures are likely to make comparisons with other farms difficult. Emissions due to the application of manure have been included on the livestock side and are also shown “adjusted” to the arable side (by 77.5 tCO₂e, see Appendix C, Table C.3) in the table to allow comparisons with other farms. It is clear that the arable, non-organic farm has much higher emissions than the organic farm, due largely as previously stated to the high level of emissions from synthetic fertilizers.

Table 4.10 Total emissions (tCO₂e) per hectare by farm type as calculated by the author

Farm type	Total emissions (tCO ₂ e)	Total hectares	CO ₂ per hectare	CH ₄ (tCO ₂ e) per hectare	N ₂ O (tCO ₂ e) per hectare	Total emissions per hectare (tCO ₂ e)
Livestock	685.70	330	0.45	0.75	0.88	2.08
Livestock (adjusted)	608.20	330	0.45	0.75	0.64	1.84
Arable non-organic	1018.26	240	0.58	0.0006	3.66	4.24
Arable non-organic (adjusted)	1095.76	240	0.58	0.0006	3.98	4.57
Arable organic	349.72	240	0.50	0.0005	0.96	1.46
Arable organic (adjusted)	427.22	240	0.50	0.0005	1.28	1.78

4.6.2 Uncertainty

Uncertainty is an important issue in calculating greenhouse gas emissions. The UK Greenhouse Gas Inventory 1990-2007 calculates this for both size of source and emission factor for various inventory categories. The nearest applicable uncertainties for emission factors for this study are summarised (Table 4.11), (DECC, 2009b, Table A7.6.1, p.495-496). It is apparent that particularly N₂O can have very high levels of uncertainty, and when further multiplied by Global Warming Potential the effect is magnified. This indicates part of the range of error that may be contained within the results of this study. Uncertainty by size of source is not listed here as it applies to nationally collated data.

Table 4.11 Uncertainty elements in emission factors

Emission category	Uncertainty in emission factor (%)		
	CO ₂	CH ₄	N ₂ O
Oil	2		
Auto fuel	3.5		
All fuel		50	170
Other combustion			195
Forest	25		
Grassland	70		
Enteric fermentation		20	
Manure management		30	414
Agricultural soils			424

5 Discussion

The key findings of the calculation of the estate's carbon footprint are set out and compared with other studies in terms of overall figures and related to crop and meat yields. The uncertainty in the results is highlighted and the strengths and weaknesses of the selected approach are discussed. Finally the issue of meeting Government targets to reduce emissions is considered alongside the need to maintain, or even increase food production.

5.1 Key findings and comparisons

The carbon footprint for the estate has been calculated under the existing practices (arable being non-organic, whilst the livestock side is already largely organic) as 2007 tCO₂e (Table 4.6). The majority of emissions come from synthetic fertilizer application 744 tCO₂e (37 %) and from livestock 522 tCO₂e (26 %). Fuel usage altogether amounts to 316 tCO₂e (16 %). Heating and lighting for the entire estate amount to 298 tCO₂e (15 %). Under the proposed switch to organic arable production, the overall total of emissions for the estate is 32% lower, at 1361 t CO₂e. The reduction being largely due to the non-use of synthetic nitrogen fertilizers. Under organic operations, livestock emissions become the largest single factor (38 % with the amount the same as the non-organic total). It was not possible find a carbon footprint for a similar organisation so there no comparison that can be carried out. However, by treating the arable and livestock sides of the farm separately it is possible to make comparisons.

By dividing the estate into the livestock and arable components and excluding the estate emissions for electricity, heating oil and water consumption which may distort the figures, (indeed CALM does not include water in its calculations) it is possible to compare the results with other farms using the CALM method. Natural England has carried out a benchmarking study of 200 farms using CALM (Natural England, 2008) with results split between different farm types. For "cereal" farms they found a mean of total emissions of 3.16 tCO₂e/ha, with a standard deviation of 2.63 tCO₂e/ha. CALM accounts for importation of manure on the arable side so it is assumed that these farms have done this as appropriate, therefore these figures are compared with the adjusted figures from Table 4.10. (Only the non-organic are compared as the Natural England study did not include organic farms). This study found 4.57 tCO₂e/ha which falls within

the standard deviation. The Natural England study noted for its sample of cereal farms, that N₂O from fertilizer application dominated the emissions as they do at Wimpole (Natural England, 2008 p.36). For Natural England's "lowland grazing" category, they found mean total emissions of 7.05 tCO₂e/ha, with a standard deviation of 6.88 tCO₂e/ha. This study found 1.84 tCO₂e/ha (adjusted figure) which is low, but within the standard deviation. It may be that Wimpole's stocking density is lower than more commercial operations.

Emissions per tonne of non-organic wheat were found to be 0.64 tCO₂e (Table 4.7) and for oilseed rape, 2.53 tCO₂e. A study by Williams et al found non organic bread wheat to emit 0.80 tCO₂e/t and rape, 1.70 tCO₂e/t (both studies are excluding manure related emissions). (Williams et al 2006, p.66 & 68). Their study, being a life cycle study included emissions from, for example, the manufacture of fertilizers, machinery and buildings so totals would be expected to be higher. The reason for the Wimpole rape emissions being higher than Williams et al's could be because the yield of 134t has been allocated to an average hectareage across the three year rotation, rather than to one one-fifth of the total plot available. If calculated on this basis, on 48 hectares instead of 80 hectares, the emissions come down to 1.52 tCO₂e/t which fits well with Williams et al's findings.

For organic crops the predicted emission figure per tonne of wheat was 0.34 tCO₂e (Table 4.8) (using yield adjusted based on Wimpole's non-organic yield, rather than national averages). Williams et al found 0.79 tCO₂e per tonne of wheat produced organically. (Williams et al 2006, p.66). Again the higher figures in their study would be due to the inclusion of more upstream emissions.

Emissions per tonne of carcass from this study were 5.59 tCO₂e for cattle, 4.00 tCO₂e for pigs and 6.33 tCO₂e for sheep (Table 4.9). These are raised organically so are compared with Williams et al's organic results. Theirs were 18.2 tCO₂e for beef, 5.64 tCO₂e for pigs and 10.1 tCO₂e for sheep. Again Williams' study included upstream emissions such as those involving the production and harvesting of forage and concentrate crops, building construction and feed manufacture, but the difference in results for cattle is striking.

The contribution to carbon removals by conversion of arable to grassland and particularly by woodland was noticeable, with a total of 1471 tCO₂e being removed annually. This represents 73 % of total estate emissions using non-organic arable methods and 108 % of total estate emissions using proposed organic arable, making the estate carbon neutral or even negative under organic operations. However this situation would need to be carefully managed to ensure the woodland was maintained in an active growth condition or removals would diminish over time. Removals by conversion of arable land to grassland would also slow and peak. Sauerbeck states that, “ecosystem carbon repositories are ephemeral” and “even if most carefully preserved, both forests and soils, with the exception of unmanaged wetlands, have a finite capacity to sequester carbon, which gets saturated within less than 100 years”. (Sauerbeck, 2001)

5.2 Reliability of results

The IPCC guidance on uncertainties in national inventories identifies a range of error sources as arising for example, from omissions and double counting of emissions, the level of understanding of real world processes, extrapolation beyond model validity, and measurement error. It encourages compilers to identify and quantify uncertainties in order that efforts can be focussed on improvement in future (IPCC, 2006, vol.1, ch.3). In this study, the measures applied have mostly been based upon equations used in the UK Greenhouse Gas Inventory so to the extent that they are reliable, so are the results achieved here. Other parts of this study, for example where an identified standard tractor fuel consumption has been applied, use calculations solely applied by the author, and not ratified elsewhere. In such cases a more robust approach might be justified. The uncertainty in emission factors has already been shown to be high, particularly in the case of N₂O where uncertainties are over 400 %. Overall, the method applied is broad-brush and not related to factors on the site such as soil condition, local climate, specific machinery types used and timing of cultivation activities in relation to weather events and so forth which will all influence real-life emissions and removals. However, the cost involved in creating a site-specific report would be high and could not be justified across all farms in the UK.

5.3 Critique of methodology

The application of the CALM methodology to this study has provided results that follow a widely used format, and extends the use of it already made at Wimpole. As CALM does not make public the calculations that are going on “behind the scenes”, this study has followed CALM’s use of the UK Greenhouse Gas Inventory calculation methods where possible, but used a more up to date version (DECC, 2009b). It thus provides a verification of the results obtained from CALM. In most cases the author’s results are very close to CALM’s, except where data has been omitted, or the calculator has failed to calculate. There are a couple of noticeable anomalies however, in the case of poultry where the CALM result is more than four times the author’s and goats where the author’s result is twice as high as CALM’s. The significance of the difference is small in terms of amount, but should be investigated. Wheat straw is the only other anomaly which CALM requires users to enter the amount removed off the farm, but ignores straw retained on the farm. It is not clear how this removed straw is then calculated. This also needs to be clarified.

The study by Natural England previously mentioned (Natural England, 2008), used CALM to try to benchmark emissions across a variety of farm types. This study did not include upstream emissions, other than those from electricity generation. It found that differences in practice within farm types (e.g., dairy) could give rise to big differences in emissions. They also point out that the fact that the approach is farm-area based rather than product or output based makes comparison less useful. However they found it a useful tool for individual farmers to identify emission sources and potential reductions on their own farms. In making a comparison between different farms it would be necessary to look at the differing practices behind the results, to understand the reasons.

Pollock, (2008, p.12) points out that as emissions for livestock in CALM are based on standard per head factors, any mitigation actions that involved reducing emissions per head, say through a different feed input, would not show up as reduced emissions. This is a drawback to the approach based on national inventory methods which make local variances in approach invisible to the footprint.

This study has not followed CALM’s approach of calculating the emissions from the manufacture of synthetic fertilizers applied. The reason for this was in order to keep the

emissions calculated very close to the estate boundaries, so that only emissions for which the estate is directly responsible for by its use of certain materials, utilities and farming methods are counted. The question might be posed as to why in that case emissions due to electricity and water consumption were included. It was considered that although the emissions for these take place off-site, they are directly related to actions within the farm gate as a consumer, whilst emissions relating to fertilizer production are one step removed – the manufacturer is much more in control of his processes and emissions. In addition to this it not just fertilizer production that has emissions attached but every commodity used on the estate, from stationery used in the office, to crockery in the restaurant and fencing used to keep the stock in. It is important to be able to draw a pragmatic line as to what to include in order that the carbon footprint calculated can be acted upon by the organisation changing its' own actions. In addition, keeping boundaries close to the organisation, and excluding upstream and downstream emissions should make the Government's monitoring of sector emission reduction targets easier to manage as double-counting is avoided.

This study has presented the carbon footprint of the estate in terms of mass. This follows the approach of Wiedmann and Minx (2007). Their view is that the conversion to area (common in ecological footprints) requires certain assumptions and brings in uncertainty and error. In contrast, Kitzes & Wackernagel (2009) suggest that a carbon footprint is made more meaningful by expressing emissions in terms of an area required to absorb them, rather than units of mass. However, Kitzes and Wackernagel unintentionally introduce a point of doubt about the applicability of this in an example for a cow grazing one hectare, which they say would have the same hectare to absorb its wastes, so the hectare should only be counted once. However, this does not take into account the GWP of methane or nitrous oxide emitted which are many times that of CO₂ and are not absorbed by plants. Furthermore, the carbon footprint guidance provided on calculating ecological footprints (Kitzes et al, 2008 p.61) makes it clear that it is forest land that is used to calculate the hectares required to absorb carbon dioxide emissions (thus not including the removal potential of improved land management techniques), states that the methodology is still under discussion, and is not clear on whether it only counts CO₂ or other greenhouse gases. This uncertainty does not inspire confidence in the calculation of a carbon footprint in terms of area.

This study did not however, follow Wiedmann and Minx's proposal of only including CO₂ emissions in the carbon footprint. By just including carbon dioxide, you are getting only part of the picture, particularly where agricultural processes are concerned where most of the emissions are not in the form of carbon dioxide, but methane and nitrous oxide. In addition, Wiedmann and Minx ask whether a carbon footprint should measure "all sources of emissions, including those that do not stem from fossil fuels" (Wiedmann & Minx, 2007). These emissions are still anthropogenic where they involve land use and farming practices and this study has therefore included them. Williams et al (2006, p.5) even argue that a "carbon footprint" is not adequate for agriculture, it should be thought of as a "carbon-nitrogen footprint". The term "carbon footprint" has however been maintained for this study as it is a term, although not clearly defined, it is in common parlance.

The general consensus in the scientific community (and in the methodology applied in this study) is that non-woody vegetation is discounted as a carbon store, as within a year it either decomposes or is consumed and CO₂ stored is returned to the atmosphere. However, Dick et al (2008) suggest that the CO₂ removed from the atmosphere by photosynthesis should be a credit in calculating net emissions on a farm. Their argument is that discounting short-lived biomass is fine for national inventories, but it penalises farmers as they are liable for the N₂O emissions from grain production, but not credited with carbon sequestered in it, but when the grain is fed to cattle they are then liable for the CH₄ production. They see this as "double accounting at the farm unit" (Dick et al 2008, p.15). The accepted approach seems reasonable though as although the farmer is not credited with carbon sequestered short-term, neither is he debited with carbon released by its decomposition or consumption.

The study has concentrated on the three key greenhouse gases, CO₂, CH₄ and N₂O, but it is recognised that there are other gases emitted from estate operations such as HFC's from refrigerants and CO and SO₂ from fuel combustion. However the CALM methodology does not include these and neither do the Defra conversion factors for fuel consumption (Defra, 2009d). A further study would be needed to ascertain the extent of these emissions.

The CALM method does not include carbon stocks in soils under arable cultivation or pasture (it seems to take this into account in calculations relating to woodland and land

converted from arable to grassland though). CALM is based on the UK Greenhouse Gas Inventory methodology (version published April 2008) and neither that version nor the more recent version (published April, 2009 (DECC, 2009b)) assess soil carbon fluxes due to land management regimes (such as different tillage practices). The reason for this not clear as it is covered in the 1996 IPCC guidelines upon which the UK Greenhouse Gas Inventory is based (IPCC, 1996).

5.4 Meeting Government targets and maintaining food production

With the UK Government seeking to reduce greenhouse gas emissions by 80 % by 2050 compared to a 1990 baseline (UK Government, 2008), industries including agriculture are under pressure to cut emissions. English farmers are also being asked to reduce emissions to 6 % below predicted levels by 2020 (DECC, 2009a p.153). A 32 % reduction in emissions could be achieved at Wimpole through their plan to switch to organic arable as shown by this study. However the impact on crop yield would be a predicted reduction in wheat yield from 1062 tonnes to 290 tonnes. Only a small part of this is contributed by the lesser yield per hectare of crop grown. Most comes from the need to divert a large area to other crops to maintain field fertility levels. From the current situation where over a 3 year rotation, 2/3 of 240 hectares (160ha) is devoted to wheat each year on average, under the proposed organic seven year rotation, only 1/5 of 240 ha (48ha) is devoted to wheat each year, another 1/5 is planned to grow oats. 3/5 of the area is used each year for nitrogen fixing crops of beans and grass/clover ley. Although these are productive crops and the ley will go to animal feed there is still a large reduction in wheat production (73 %). If the area planned for oats were turned to wheat production, the yield would be reduced by 45 %.

As well as reducing emissions, removals could be increased, by devoting more land to woodland, and increasing the area of arable converted to grassland. However this would affect the cultivable area and therefore impact on food production again. If the livestock were removed to cut out their emissions (523 tCO₂e) there would be a loss of meat production amounting to 28 tonnes of carcass. This would also cut out the source of manure to fertilize the arable crops and would leave the grass/clover ley crop to be sold off, thus removing a productive cycle. The difficulty of reducing emissions whilst maintaining food production is apparent.

6 Conclusion and Recommendations

This chapter summarises the main findings of the study to determine the carbon footprint of a country estate. It then looks at whether the aims and objectives of the thesis have been met. The limitations of the work done are described along with recommendations for further study.

6.1 Main Findings

The greenhouse gas emissions for the estate have been quantified as far as information was available for the estate's consumption of electricity, heating oil and water (303 tCO₂e), emissions from the livestock farm (686 tCO₂e) and emissions from the arable farm (1018 tCO₂e). The total carbon footprint was calculated as amounting to 2007 tCO₂e. A comparison was made with emissions from arable practices under the proposed change to organic practices resulting in arable emissions of 372 tCO₂e and a total carbon footprint of 1361 tCO₂e. The removals by woodland and due to conversion of arable land were quantified (1430 and 41 tCO₂e respectively) which offsets emissions by 73 % for total estate emissions under non-organic arable operations, and by 108 % for total estate emissions under proposed organic arable operations. The difficulties of maintaining food production whilst cutting emissions has been noted.

The CALM methodology was found to offer an approach tailored to farms and estates, it is based on the respected methods of the UK Greenhouse Gas Inventory (DECC, 2009b), offers a user friendly input method for farm managers, is widely used, has already been used at Wimpole and has been reviewed by Natural England (2008). However it does not include all emissions encountered on a country estate, for example it does not include those relating to waste produced or water consumed. It is not particularly useful for comparison with other estates, being more appropriate for monitoring a farm's emissions in isolation. It was also found to be insensitive to certain actions that would impact emissions, such as a change in livestock diet as figures are based on animal populations.

6.2 Reviewing aims and objectives

The aim of this project was to identify and apply an appropriate methodology for determining a useful carbon equivalent budget for a National Trust working estate. The extent of achievement of the objectives underlying this are appraised as follows:

- 1) Explore available methodologies and to select an appropriate methodological framework for determining a carbon-equivalent budget. Methodologies have been explored in the literature review and the CALM calculator method was chosen as the most appropriate
- 2) Develop an inventory of key greenhouse gas emissions and uptake for Wimpole Hall, including estimates as appropriate. An inventory was developed including emissions for which data were available and uptake by woodland and areas of arable land converted to grassland.
- 3) Produce the budget based on the above values. A carbon footprint has been produced based upon the inventory.
- 4) Critique the key assumptions in the model. The strengths and weaknesses of the CALM methodology have been examined.
- 5) Use the model/budget to estimate how a land management change (e.g. change to organic production could affect the carbon budget). The emission implications for the proposed change to organic arable cultivation have been assessed.
- 6) Produce a poster of the output (possibly for public display). A poster has been produced showing the key results of the carbon footprint calculation.

6.3 Study limitations and recommendations for further study

Not all site information was available on which to calculate emissions. For instance, waste produced was not quantified and visitor travel figures were not available. There was not sufficient time available to explore emissions of other greenhouse gases by, for instance, refrigerants or paints. Some calculations had to be based on standard factors such as fuel consumption by arable cultivation and tonnes of crop predicted

under organic operations. It is hoped that in future these gaps in knowledge can be filled for a more complete picture. The CALM calculator displayed a few unexplained anomalies which need to be investigated and there is scope for it to be more inclusive in the coverage of emissions it can calculate for a country estate.

It would be interesting to determine how the integration of grazing animals into an organic arable system affects the nitrogen supply and emissions. It would be interesting to investigate what is the best use grass/clover ley –whether it is preferable to use it solely as a nitrogen replenishment crop, to be fed to animals or grazed, and the optimal balance between the three options in the management of the nitrogen supply of an organic arable farm.

The IPCC factors for converting edible crops into above and below ground biomass needs to be improved, and factors relating to grass/clover ley need to be provided.

Appendix A Greenhouse gas emissions considered likely to be encountered on a country estate

Emission/removal category	Gases involved	IPCC Reference (IPCC, 2006)
Fuel combustion from road transportation (staff and visitors)	CO ₂ , CH ₄ , N ₂ O CO, NMVOC, SO ₂ , NO _x	Vol. 2, ch.3, p.3.8
Fuel combustion from farm vehicles and other machinery	As above	As above
Fugitive emissions from fuels (e.g. leaks from on site fuel storage)	CH ₄ , CO ₂	Vol.2, ch.4, p.4.35
Fuel combustion in buildings on site (e.g. heating, lighting)	CO ₂ mainly Some CO, CH ₄ , NMVOC	Vol.2, ch.1, p.1.6
Non energy products from fuels and solvent use (e.g. lubricants, solvents, paints)	CO ₂ , NMVOC, CO	Vol.3, ch.5, table 5.1
Emissions of fluorinated substances (HFC's and PFC's) (e.g. refrigerants)	HFC, PFC	Vol.3, ch.7, p.7.7
Livestock emissions from enteric fermentation	CH ₄ (CO ₂ is emitted but not estimated as "annual net CO ₂ emissions are assumed to be zero – the CO ₂ photosynthesized by plants is returned to the atmosphere as respired CO ₂ ").	Vol.4, ch.10, p.10.7
Livestock manure management -	CH ₄ , N ₂ O	Vol.4, ch.10, p.10.7
Forest management	CO ₂ removals and emissions (Possibly CH ₄ , CO, N ₂ O, NO _x from burning)	Vol.4, ch.4, p.4.7
Cropland management	CO ₂ removals and emissions	Vol.4, ch.5, p.5.6
Grassland management	CO ₂ removals and emissions	Vol.4, ch.5, p.5.6
Herbaceous perennial vegetation, trees and soil in gardens	CO ₂ removals and emissions	Vol.4, ch.8, p.8.5
Addition of fertilizers, lime and urea to soil,	N ₂ O, CO ₂	Vol.4, ch.11, p.11.5
Harvested wood products	CO ₂	Vol.4, ch.12, p.12.5
Disposal of solid waste (e.g. domestic refuse)	CH ₄ , CO ₂ , NMVOC, N ₂ O, NO _x , CO	Vol.5, ch.3, p.3.6
Disposal of domestic waste water and sewage	CH ₄ , N ₂ O, CO ₂	Vol.5, ch.6, p.6.6

Appendix B Equations used to calculate agricultural emissions

Equation 1: Emissions of N₂O from animal waste management systems (DECC, 2009b, p. 378)

$$N_{2O(AWMS)} = 44/28 \cdot \sum N_{(T)} \cdot Nex_{(T)} \cdot AWMS_{(W)} \cdot EF_{(AWMS)}$$

Where

$$N_{2O(AWMS)} = \text{N}_2\text{O emissions from animal waste management systems (kg N}_2\text{O/yr)}$$

$$N_{(T)} = \text{Number of animals of type T}$$

$$Nex_{(T)} = \text{N excretion of animals of type T (kg N/animal/yr) (DECC, 2009b, Table A3.6.7)}$$

$$AWMS_{(W)} = \text{Fraction of Nex that is managed in one of the different waste management systems of type W.}$$

$$EF_{(AWMS)} = \text{N}_2\text{O emission factor for an AWMS (kg N}_2\text{O-N/kg of Nex in AWMS) (DECC, 2009b, Table A3.6.9)}$$

Equation 2: Emissions of N₂O from application of previously stored manures (DECC, 2009b, p.386)

$$N_{2O(FAW)} = 44/28 \cdot \sum_T (N_T \cdot Nex_{(T)} \cdot AWMS_{(W)} - N_{(AWMS)}) \cdot EF1$$

Where

$$N_{2O(FAW)} = \text{N}_2\text{O emission from organic fertiliser application}$$

$$N_T = \text{Number of animals of type T}$$

$$Nex_{(T)} = \text{N excretion of animals of type T (kg N/animal/yr) net of N volatilising as NOx and NH}_3 \text{ (DECC, 2009b, Table A.3.6.7, p.379 minus 20% to net of N volatilising as NOx and NH}_3 \text{ (DECC, 2009b, p.380)).}$$

$$AWMS_{(W)} = \text{Fraction of Nex that is managed in one of the different waste management systems of type W (fraction whilst housed only)}$$

$$N_{(AWMS)} = \text{N}_2\text{O emissions from animal waste management systems as Nitrogen (kg N}_2\text{O-N/yr) (0.02 for all animals except layers (0.005), Table A3.6.9, p.381, DECC, 2009b).}$$

Equation 3: Indirect emissions of N₂O through atmospheric deposition of NOx and NH₃ due to application of animal manures (DECC, 2009b, p.387)

$$N_{2O(DWS)} = 44/28 \cdot (N_{(EX)} / (1 - \text{Frac}_{(GASM)}) - N_{(F)}) \cdot \text{Frac}_{(GASM)} \cdot EF4$$

Where

$$N_{2O(DWS)} = \text{Atmospheric deposition emission of N}_2\text{O arising from animal wastes (kg N}_2\text{O/yr)}$$

$$N_{(EX)} = \text{Total N excreted by animals (kg N/yr), net of N volatilising as NOx and NH}_3 \text{ (DECC, 2009b, Table A.3.6.7, p.379 minus 20% to net of N volatilising as NOx and NH}_3 \text{ (DECC, 2009b, p.380)).}$$

$\text{Frac}_{(\text{GASM})}$	=	Fraction of livestock nitrogen excretion that volatilises as NH_3 and NO_x
	=	0.2 kg N/kg N
$\text{N}_{(\text{F})}$	=	Total N content of wastes used as fuel (kg N/yr) (counted as 0)
EF_4	=	N deposition emission factor
	=	0.01 kg N_2O -N/kg NH_3 -N and NO_x -N emitted

Equation 4: Indirect emission of N_2O due to leaching and run-off of animal manures (DECC, 2009b, p.388)

$\text{N}_2\text{O}_{(\text{LWS})}$	=	$44/28 \cdot ((\text{N}_{(\text{EX})} - \text{N}_{(\text{F})} - \text{N}_{(\text{AWMS})}) \cdot \text{Frac}_{(\text{LEACH})} \cdot \text{EF}_5$
Where		
$\text{N}_2\text{O}_{(\text{LWS})}$ $\text{N}_2\text{O}/\text{yr}$	=	Leaching and runoff emission of N_2O from animal wastes (kg $\text{N}_2\text{O}/\text{yr}$)
$\text{N}_{(\text{EX})}$	=	Total N excreted by animals (kg N/yr), net of N volatilising as NO_x and NH_3 (DECC, 2009b, Table A.3.6.7, p.379 minus 20% to net off N volatilising as NO_x and NH_3 (DECC, 2009b, p.380)).
$\text{N}_{(\text{F})}$	=	Total N content of wastes used as fuel (kg N/yr) (counted as 0).
$\text{N}_{(\text{AWMS})}$	=	Total N content of N_2O emissions from waste management systems including daily spread and pasture range and paddock (kg N_2O -N/yr) (results from equation 1 for emissions from waste management systems used here)
$\text{Frac}_{(\text{LEACH})}$	=	Fraction of nitrogen input to soils that is lost through leaching and runoff = 0.3 kg N/ kg fertiliser or manure N
EF_5	=	Nitrogen leaching/runoff factor = 0.025 kg N_2O -N /kg N leaching/runoff

Equation 5: Emissions of N_2O due to application of inorganic fertilizer (DECC, 2009b, p.382)

$\text{N}_2\text{O}_{(\text{SN})}$	=	$44/28 \cdot \text{N}_{(\text{FERT})} \cdot (1 - \text{Frac}_{(\text{GASF})}) \cdot \text{EF}_1$
Where		
$\text{N}_2\text{O}_{(\text{SN})}$	=	Emission of N_2O from synthetic fertiliser application (kg $\text{N}_2\text{O}/\text{yr}$)
$\text{N}_{(\text{FERT})}$	=	Total use of synthetic fertiliser (kg N/yr) (based on % nitrogen content)
$\text{Frac}_{(\text{GASF})}$	=	Fraction of synthetic fertiliser emitted as $\text{NO}_x + \text{NH}_3$
	=	0.1 kg NH_3 -N+ NO_x -N / kg synthetic N applied
EF_1	=	Emission Factor for direct soil emissions
	=	0.0125 kg N_2O -N/kg N input

Equation 6: Indirect emissions of N_2O through atmospheric deposition of NO_x and NH_3 due to application of synthetic fertilizer (DECC, 2009b, p.387)

$\text{N}_2\text{O}_{(\text{DSN})}$	=	$44/28 \cdot \text{N}_{(\text{FERT})} \cdot \text{Frac}_{(\text{GASF})} \cdot \text{EF}_4$
Where		
$\text{N}_2\text{O}_{(\text{DSN})}$	=	Atmospheric deposition emission of N_2O arising from synthetic fertiliser application (kg $\text{N}_2\text{O}/\text{yr}$)
$\text{N}_{(\text{FERT})}$	=	Total mass of nitrogen applied as synthetic fertiliser (kg N/yr) (based on % nitrogen content)

$\text{Frac}_{(\text{GASF})}$	=	Fraction of total synthetic fertiliser nitrogen that is emitted as $\text{NO}_x + \text{NH}_3$
	=	0.1 kg N/ kg N
EF4	=	N deposition emission factor
	=	0.01 kg N_2O -N/kg NH_3 -N and NO_x -N emitted

Equation 7: Indirect emission of N_2O due to leaching and run-off of synthetic fertilizer (DECC, 2009b, p.387)

$\text{N}_2\text{O}_{(\text{LSN})}$	=	$44/28 \cdot (\text{N}_{(\text{FERT})} \cdot (1 - \text{Frac}_{(\text{GASF})}) - \text{N}_{(\text{SN})}) \cdot \text{Frac}_{(\text{LEACH})} \cdot \text{EF5}$
Where		
$\text{N}_2\text{O}_{(\text{LSN})}$	=	Leaching and runoff emission of N_2O arising from synthetic fertiliser application (kg N_2O /yr)
$\text{N}_{(\text{FERT})}$	=	Total mass of nitrogen applied as synthetic fertiliser (kg N/yr) (based on % nitrogen content)
$\text{N}_{(\text{SN})}$	=	Direct emission of $\text{N}_2\text{O}_{(\text{SN})}$ as nitrogen (kg N_2O -N/yr) (0.0125)
$\text{Frac}_{(\text{GASF})}$	=	Fraction of total synthetic fertiliser nitrogen emitted as $\text{NO}_x + \text{NH}_3$
	=	0.1 kg N/ kg N
$\text{Frac}_{(\text{LEACH})}$	=	Fraction of nitrogen input to soils lost through leaching and runoff
	=	0.3 kg N/ kg fertiliser or manure N
EF5	=	Nitrogen leaching/runoff factor
	=	0.025 kg N_2O -N /kg N leaching/runoff

Equation 8: Emissions of N_2O due to ploughing-in of crop residues (DECC, 2009b, p.385)

$\text{N}_2\text{O}_{(\text{CR})}$	=	$\sum_i (\text{Crop}_O \cdot \text{Res}_{O_i} / \text{Crop}_{O_i} \cdot \text{FracDM}_i \cdot \text{Frac}_{(\text{NCRO})} \cdot (1 - \text{Frac}_B) + \sum_j (2 \cdot \text{Crop}_{(\text{BFj})} \cdot \text{FracDM}_j \cdot \text{Frac}_{(\text{NCRBFj})} \cdot (1 - \text{Frac}_{R_j}) \cdot (1 - \text{Frac}_{B_j})) \cdot \text{EF}_1 \cdot 44/28$ (equation deals with both nitrogenous and non-nitrogenous crops)
Where		
$\text{N}_2\text{O}_{(\text{CR})}$	=	Emission of N_2O from crop residues (kg N_2O /yr)
Crop_{O_i}	=	Production of non-N fixing crop i (kg /yr) (residue factors, Table A3.6.11, p.384, DECC, 2009b)
$\text{Frac}_{(\text{NCRO})}$	=	Fraction of nitrogen in non-N fixing crops
	=	0.015 kg N/ kg dry mass
$\text{FracDM}_{i,j}$	=	Dry matter fraction of crop i, j. (Table A3.6.11, p.384, DECC, 2009b)
Frac_R	=	Fraction of total above and below ground crop biomass that is removed from field as crop (comes in to play for nitrogenous crops only and had to be estimated by author at 0.4)
Frac_B	=	Fraction of crop residue that is burnt rather than left on field (treated as 0)
EF ₁	=	Emission Factor for direct soil emissions
	=	0.0125 kg N_2O -N/kg N input
$\text{Crop}_{(\text{BFj})}$	=	Production of legume crop j (kg /year)
$\text{Frac}_{(\text{NCRBF})}$	=	Fraction of nitrogen in N fixing crop
	=	0.03 kg N/ kg dry mass

Equation 9: Emissions of N₂O from the biological fixation of nitrogen by crops (DECC, 2009b, p.384)

$$N_2O_{(BF)} = 44/28 \cdot 2 \cdot Crop_{(BF)} \cdot Frac_{DM} \cdot Frac_{(NCRBF)} \cdot EF1$$

Where

$N_2O_{(BF)}$ = Emission of N₂O from biological fixation (kg N₂O/yr)

$Crop_{(BF)}$ = Production of legumes (kg /yr)

$Frac_{DM}$ = Dry matter fraction of crop (Table A3.6.11(DECC, 2009b)

$Frac_{(NCRBF)}$ = Fraction of nitrogen in N fixing crop

= 0.03 kg N/ kg dry mass

EF1 = Emission Factor for direct soil emissions

= 0.0125 kg N₂O-N/kg N input"

Appendix C Calculation of emissions and removals for Wimpole Estate

Table C.1 Calculation of emissions (tonnes/year) due to fuel consumption by farm machinery and vehicles on the livestock farm

Energy - fuel consumption by farm machinery		CALM calculations	Author's calculations			
		CO ₂ e	CO ₂	CH ₄ (as CO ₂ e)	N ₂ O (as CO ₂ e)	CO ₂ e
Gas oil (red diesel) - litres used over 12 months (exc. fuel with renewable portion over national compulsory inclusion limit - 20%)	12000 litres	Calculation is absent on CALM report	12,000 l x 2.7619 = 33143 = 33.14	12,000l x 0.0028 = 33.60 = 0.03	12,000 l x 0.2642 = 3,170.4 = 3.17	12,000l x 3.0289 = 36,346.8 = 36.35
Diesel - litres used over 12 months (exc. fuel with renewable portion over national compulsory inclusion limit - 20%)	4000 litres	11	4,000l x 2.6391 = 10,556.4 = 10.56	4,000l x 0.0019 = 7.6 = 0.01	4,000 l x 0.0283 = 113.2 = 0.11	4,000l x 2.6694 = 10,677.6 = 10.68
Totals tCO₂e		11	43.70	0.04	3.28	47.03

Table C.2 Calculation of emissions (tonnes/year) due to fuel consumption by contractors on the livestock farm

Energy used in contracting	CALM Calculations		Author's calculations			
		CO ₂ e	CO ₂	CH ₄ (as CO ₂ e)	N ₂ O (as CO ₂ e)	CO ₂ e
Powered machinery under 100 hp - hours supplied by contractor	200	8	<100hp tractor, mean litres/hour = 18.44 l x 200 hrs x 2.7619 = 10186 = 10.19	<100hp tractor, mean litres/hour = 18.44 l x 200 hrs x 0.0028 = 10 = 0.01	<100hp tractor, mean litres/hour = 18.44 l x 200 hrs x 0.2642 = 974 = 0.97	<100hp tractor, mean litres/hour = 18.44 l x 200 hrs x 3.0289 = 11171 = 11.17
Powered machinery 100-150 hp - hours supplied by contractor	1100	67	100-150hp tractor, mean litres/hour = 30.66 l x 1,100 hrs x 2.7619 = 93148 = 93.15	100-150hp tractor, mean litres/hour = 30.66l x 1,100hrs x 0.0028 = 94 = 0.09	100-150hp tractor, mean litres/hour = 30.66l x 1,100hrs x 0.2642 = 8910 = 8.91	100-150hp tractor, mean litres/hour = 30.66l x 1,100hrs x 3.0289 = 102,153 = 102.15
Other operations carried out on your farm by contractor - estimate of litres of diesel used by contractor	1000	3	1,000l x 2.6391 = 2,639.1 = 2.64	1,000l x 0.0019 = 1.9 = 0.001	1,000l x 0.0283 = 28.3 = 0.03	1,000l x 2.6694 = 2,669.4 = 2.67
Total tCO₂e		78	105.98	0.10	9.91	115.99

Table C.3 Calculation of emissions (tonnes/year) from cattle on the livestock farm

		Cattle over 2 years: 69 head; grazing 57%, housed 43% of year; 100% of manure while housed stored in solid form	Cattle 1-2 years: 44 head; grazing 57%, housed 43% of year ; 100% of manure while housed stored in solid form	Cattle under 1 year: 44 head; grazing 57%, housed 43% of year; 100% of manure while housed stored in solid form	Totals (tonnes) CO₂e
CALM Calculations	CO₂e	142	90	61	293
Author's Calculations	CH₄ Emissions from enteric fermentation	69 x 48 (enteric emission factor) = 3,312kg = 3.31	44 x 48 (enteric emission factor) = 2,112kg = 2.11	44 x 32.8 (enteric emission factor) = 1,443kg = 1.44	6.86t CH ₄ x 21 = 144.06
	N₂O Emissions from waste management systems	44/28 x 69 x 56 (nitrogen excretion factor kg) x 1.0 (all manure is either in solid storage or on pasture & emission factors are same for both) x 0.02 (emission factor for pasture & solid storage) = 121.44kg = 0.12	44/28 x 44 x 56 (nitrogen excretion factor kg) x 1.0 (all manure is either in solid storage or on pasture & emission factors are same for both) x 0.02 (emission factor for pasture & solid storage) = 77.44kg = 0.08	44/28 x 44 x 38 (nitrogen excretion factor kg) x 1.0 (all manure is either in solid storage or on pasture & emission factors are same for both) x 0.02 (emission factor for pasture & solid storage) = 52.55kg = 0.05	0.25t N ₂ O x 310 = 77.50
	N₂O Emissions from application of previously stored manures	44/28 x 69 x 44.8(56-20%,N excretion net of N volatilising as NO _x & NH ₃) x 0.41(fraction of N excretion as stored manure (0.43) minus N ₂ O emission as N from storage (0.02)) x 0.0125 (emission factor for direct soil emissions) = 24.90kg = 0.02	44/28 x 44 x 44.8 (56-20%,N excretion net of N volatilising as NO _x & NH ₃) x 0.41 (fraction of N excretion as stored manure (0.43) minus N ₂ O emission as N from storage (0.02) x 0.0125 (emission factor for direct soil emissions) = 15.88kg = 0.02	44/28 x 44 x 30.4 (38-20%,N excretion net of N volatilising as NO _x & NH ₃) x 0.41(fraction of N excretion as stored manure (0.43) minus N ₂ O emission as N from storage (0.02)) x 0.0125 (emission factor for direct soil emissions) = 10.77kg = 0.01	0.05t N ₂ O x 310 = 15.50
	N₂O Emissions due to atmospheric deposition of NO_x & NH₃ from manures	44/28 x (69 x 44.8(56-20%, N excretion net of N volatilising as NO _x & NH ₃) / 0.8 (1 minus fraction of livestock nitrogen excretion that volatilises as NH ₃ and NO _x (0.2))) x 0.01 (N deposition emission factor) = 60.72kg = 0.06	44/28 x (44 x 44.8(56-20%, N excretion net of N volatilising as NO _x & NH ₃) / 0.8 (1 minus fraction of livestock nitrogen excretion that volatilises as NH ₃ and NO _x (0.2))) x 0.01 (N deposition emission factor) = 38.72kg = 0.04	44/28 x (44 x 30.4(38-20%,N excretion net of N volatilising as NO _x & NH ₃) / 0.8 (1 minus fraction of livestock nitrogen excretion that volatilises as NH ₃ and NO _x (0.2))) x 0.01 (N deposition emission factor) = 26.27kg = 0.03	0.13t N ₂ O x 310 = 40.30

	Cattle over 2 years: 69 head; grazing 57%, housed 43% of year; 100% of manure while housed stored in solid form	Cattle 1-2 years: 44 head; grazing 57%, housed 43% of year ; 100% of manure while housed stored in solid form	Cattle under 1 year: 44 head; grazing 57%, housed 43% of year; 100% of manure while housed stored in solid form	Totals (tonnes) CO₂e
N₂O Emissions due to leaching & run-off of manures	44/28 x ((69 x 44.8(56-20%, N excretion net of N volatilising as NO _x & NH ₃) - 121.44 (N content of N ₂ O emissions from waste management systems)) x 0.3 (fraction of nitrogen input to soils lost to leaching and runoff) x 0.025 (N leaching/runoff factor) = 35.00kg = 0.03	44/28 x ((44 x 44.8(56-20%,N excretion net of N volatilising as NO _x & NH ₃) - 77.44 (N content of N ₂ O emissions from waste management systems)) x 0.3 (fraction of nitrogen input to soils lost to leaching and runoff) x 0.025 (N leaching/runoff factor) = 22.32kg = 0.02	44/28 x ((44 x 30.4(38-20%,N excretion net of N volatilising as NO _x & NH ₃) - 52.55 (N content of N ₂ O emissions from waste management systems)) x 0.3 (fraction of nitrogen input to soils lost to leaching and runoff) x 0.025 (N leaching/runoff factor) = 15.15kg = 0.02	0.07t N ₂ O x 310 = 21.7
Total tCO₂e	140.81	93.91	64.34	299.06

Table C.4 Calculation of emissions (tonnes/year) from sheep on the livestock farm

		Breeding sheep (ewes & rams): 350 head; grazing 85%, housed 15% of year; 100% of manure while housed stored in solid form	Lambs under 1 year: 500 head; grazing 100% of time while on farm	Totals (tonnes) CO₂e
CALM Calculations	CO₂e	125	39	164
Author's Calculations	CH₄ Emissions from enteric fermentation	350 X 8 (enteric emission factor) = 2,800kg = 2.80	500 X 3.2 (enteric emission factor) = 1,600kg = 1.60	4.40t CH ₄ x 21 = 92.4
	N₂O Emissions from waste management systems:	44/28 x 350 x 10.2 (nitrogen excretion factor kg) x 1.0(all manure is either in solid storage or on pasture & emission factors are same for both) x 0.02 (emission factor for pasture & solid storage) = 112.20kg = 0.11	44/28 x 500 x 0.65 (nitrogen excretion factor kg) x 1.0 (all manure is either in on pasture) x 0.02 (emission factor for pasture) = 10.21kg = 0.01	0.12t N ₂ O x 310 = 37.20
	N₂O Emissions from application of previously stored manures	44/28 x 350 x 8.16(10.2-20%,N excretion net of N volatilising as NO _x & NH ₃) x 0.13 (fraction of N excretion as stored manure (0.15) minus N ₂ O emission as N from storage (0.02)) x 0.0125 (emission factor for direct soil emissions) = 7.29kg = 0.01	No manure applied from previous storage: 0	0.01t N ₂ O x 310 = 3.10
	N₂O Emissions due to atmospheric deposition of NO_x & NH₃from manures	44/28 x (350 x 8.16(10.2-20%, N excretion net of N volatilising as NO _x & NH ₃) / 0.8 (1 minus fraction of livestock nitrogen excretion that volatilises as NH ₃ and NO _x (0.2))) x 0.01 (N deposition emission factor) = 56.10kg = 0.06	44/28 x (500 x 0.52(0.65-20%,N excretion net of N volatilising as NO _x & NH ₃) / 0.8 (1 minus fraction of livestock nitrogen excretion that volatilises as NH ₃ and NO _x (0.2))) x 0.01 (N deposition emission factor) = 5.10kg = 0.01	0.07t N ₂ O x 310 = 21.70
	N₂O Emissions due to leaching & run-off of manures	44/28 x ((350 x 8.16(10.2-20%, N excretion net of N volatilising as NO _x & NH ₃) - 112.20 (N content of N ₂ O emissions from waste management systems)) x 0.3 (fraction of nitrogen input to soils lost to leaching and runoff) x 0.025 (N leaching/runoff factor) = 32.34kg = 0.03	44/28 x ((500 x 0.52(0.65-20%N excretion net of N volatilising as NO _x & NH ₃) - 10.21 (N content of N ₂ O emissions from waste management systems)) x 0.3 (fraction of nitrogen input to soils lost to leaching and runoff) x 0.025 (N leaching/runoff factor) = 2.94kg = 0.003	0.033t N ₂ O x 310 = 10.23
Total tCO₂e		123.90	40.73	164.63

Table C.5 Calculation of emissions (tonnes/year) from pigs on the livestock farm

		Other pigs over 50kg: 14 head; housed 100% of year; 100% of manure stored in solid form	Pigs 20-50kg: 50 head; housed 100% of year; 100% of manure stored in solid form	Pigs under 20kgs: 30 head; housed 100% of year; 100% of manure stored in solid form	Totals (tonnes) CO₂e
CALM Calculations	CO₂e	4	12	3	19
Author's Calculations	CH₄ Emissions from enteric fermentation	14 X 1.5 (enteric emission factor) = 21kg = 0.02	50 x 1.5 (enteric emission factor) = 75kg = 0.08	30 X 1.5 (enteric emission factor) = 45kg = 0.05	0.15t CH ₄ x 21 = 3.15
	N₂O Emissions from waste management systems:	44/28 x 14 x 15.16 (nitrogen excretion factor kg) x 1.0 (all manure is in solid storage) x 0.02 (emission factor for solid storage) = 6.67kg = 0.01	44/28 x 50 x 9.6 (nitrogen excretion factor kg) x 1.0 (all manure is in solid storage) x 0.02 (emission factor for solid storage) = 15.09kg = 0.02	44/28 x 30 x 3.7 (nitrogen excretion factor kg) x 1.0 (all manure is in solid storage) x 0.02 (emission factor for solid storage) = 3.49kg = 0.003	0.033t N ₂ O x 310 = 10.23
	N₂O Emissions from application of previously stored manures	44/28 x 14 x 12.48(15.16-20%,N excretion net of N volatilising as NO _x & NH ₃) x 0.98 (fraction of N excretion as stored manure (1.0) minus N ₂ O emission as N from storage (0.02)) x 0.0125 (emission factor for direct soil emissions) = 3.36kg = 0.003	44/28 x 50 x 7.68(9.6-20%,N excretion net of N volatilising as NO _x & NH ₃) x 0.98 (fraction of N excretion as stored manure (1.0) minus N ₂ O emission as N from storage (0.02)) x 0.0125 (emission factor for direct soil emissions) = 7.39kg = 0.01	44/28 x 30 x 2.96(3.7-20%,N excretion net of N volatilising as NO _x & NH ₃) x 0.98 (fraction of N excretion as stored manure (1.0) minus N ₂ O emission as N from storage (0.02)) x 0.0125 (emission factor for direct soil emissions) = 1.71kg = 0.002	0.015t N ₂ O x 310 = 4.65
	N₂O Emissions due to atmospheric deposition of NO_x & NH₃from manures	44/28 x (14 x 12.48(15.16-20%, N excretion net of N volatilising as NO _x & NH ₃) / 0.8 (1 minus Fraction of livestock nitrogen excretion that volatilises as NH ₃ and NO _x (0.2))) x 0.01 (N deposition emission factor) = 3.43kg = 0.003	44/28 x (50 x 7.68(9.6-20%, N excretion net of N volatilising as NO _x & NH ₃) / 0.8 (1 minus Fraction of livestock nitrogen excretion that volatilises as NH ₃ and NO _x (0.2))) x 0.01(N deposition emission factor) = 6.64kg = 0.01	44/28 x (30 x 2.96(3.7-20%, N excretion net of N volatilising as NO _x & NH ₃) / 0.8 (1 minus Fraction of livestock nitrogen excretion that volatilises as NH ₃ and NO _x (0.2))) x 0.01 (N deposition emission factor) = 1.74kg = 0.002	0.015t N ₂ O x 310 = 4.65

	Other pigs over 50kg: 14 head; housed 100% of year; 100% of manure stored in solid form	Pigs 20-50kg: 50 head; housed 100% of year; 100% of manure stored in solid form	Pigs under 20kgs: 30 head; housed 100% of year; 100% of manure stored in solid form	Totals (tonnes) CO₂e
N₂O Emissions due to leaching & run-off of manures	44/28 x ((14 x 12.48(15.16-20%, N excretion net of N volatilising as NO _x & NH ₃) - 6.67(N content of N ₂ O emissions from waste management systems)) x 0.3(Fraction of nitrogen input to soils lost to leaching and runoff) x 0.025 (N leaching/runoff factor) = 1.98kg = 0.002	44/28 x ((50 x 7.68(9.6-20%, N excretion net of N volatilising as NO _x & NH ₃) - 15.09(N content of N ₂ O emissions from waste management systems)) x 0.3(Fraction of nitrogen input to soils lost to leaching and runoff) x 0.025 (N leaching/runoff factor) = 4.35kg = 0.004	44/28 x ((30 x 2.96(3.7-20%.N excretion net of N volatilising as NO _x & NH ₃) - 3.49(N content of N ₂ O emissions from waste management systems)) x 0.3(Fraction of nitrogen input to soils lost to leaching and runoff) x 0.025 (N leaching/runoff factor) = 1.01kg = 0.001	0.007t N ₂ O x 310 = 2.17
Total tCO₂e	6.00	15.32	3.53	24.85

Table C.6 Calculation of emissions (tonnes/year) from poultry on the livestock farm

		Laying hens: 100 head; housed 27%, outdoors 73% of year; 100% of housed manure stored as solid	Turkeys: 50 head; housed 100% of year; 100% housed manure stored as solid	Totals (tonnes) CO ₂ e
CALM Calculations	CO ₂ e	10	1	11
Author's Calculations	CH ₄ Emissions from enteric fermentation & manure management	100 x 0 (enteric emission factor 'Not Estimated') = 0	50 x (enteric emission factor 'Not Estimated') = 0	0
	N ₂ O Emissions from waste management systems:	44/28 x 100 x 0.74 (nitrogen excretion factor kg) x 1.0 (emission factor same for layers regardless of storage system) x 0.005 (emission factor for layers) = 0.58kg = 0.0006	44/28 x 50 x 1.79 (nitrogen excretion factor kg) x 1.0 (all manure is in solid storage) x 0.02 (emission factor for other poultry) = 2.81kg = 0.003	0.0036t CH ₄ x 310 = 1.12
	N ₂ O Emissions from application of previously stored manures	44/28 x 100 x 0.59(0.74-20%, N excretion net of N volatilising as NO _x & NH ₃) x 0.25 (fraction of N excretion as stored manure (0.27) minus N ₂ O emission as N from storage (0.02)) x 0.0125 (emission factor for direct soil emissions) = 0.29kg = 0.0003	44/28 x 50 x 1.43(1.79-20%, N excretion net of N volatilising as NO _x & NH ₃) x 0.98 (fraction of N excretion as stored manure (1.0) minus N ₂ O emission as N from storage (0.02)) x 0.0125 (emission factor for direct soil emissions) = 1.38kg = 0.0014	0.0017t N ₂ O x 310 = 0.53
	N ₂ O Emissions due to atmospheric deposition of NO _x & NH ₃ from manures	44/28 x (100 x 0.59(0.74-20%, N excretion net of N volatilising as NO _x & NH ₃) / 0.8 (1 minus fraction of livestock nitrogen excretion that volatilises as NH ₃ and NO _x (0.2))) x 0.01 (N deposition emission factor) = 1.16kg = 0.0012	44/28 x (50 x 1.43(1.79-20%, N excretion net of N volatilising as NO _x & NH ₃) / 0.8 (1 minus fraction of livestock nitrogen excretion that volatilises as NH ₃ and NO _x (0.2))) x 0.01 (N deposition emission factor) = 1.40kg = 0.0014	0.0026t N ₂ O x 310 = 0.81
	N ₂ O Emissions due to leaching & run-off of manures	44/28 x ((100 x 0.59(0.74-20%, N excretion net of N volatilising as NO _x & NH ₃) - 0.58 (N content of N ₂ O emissions from waste management systems)) x 0.3 (fraction of nitrogen input to soils lost to leaching and runoff) x 0.025 (N leaching/runoff factor) = 0.69kg = 0.0007	44/28 x ((50 x 1.43(1.79-20%, N excretion net of N volatilising as NO _x & NH ₃) - 2.81 (N content of N ₂ O emissions from waste management systems)) x 0.3 (fraction of nitrogen input to soils lost to leaching and runoff) x 0.025 (N leaching/runoff factor) = 0.8kg = 0.0008	0.0015t N ₂ O x 310 = 0.47
Total tCO ₂ e		0.87	2.05	2.93

Table C.7 Calculation of emissions (tonnes/year) from horses and goats on the livestock farm

		Horses: 12 head; 50% housed, 50% grazing per year; 100% of housed manure stored as solid	Goats: 20 head; housed 100% of year ; 100% of housed manure stored as solid	Totals (tonnes CO₂e)
CALM Calculations	CO₂e	15	6	21
Author's Calculations	CH₄ Emissions from enteric fermentation	12 x 18 (enteric emission factor) = 216kg = 0.22	20 x 5 (enteric emission factor) = 100kg = 0.10	6.72
	N₂O Emissions from waste management systems	44/28 x 12 x 50 (nitrogen excretion factor kg) x 1.0(all manure is either in solid storage or on pasture & emission factors are same for both) x 0.02 (emission factor for pasture & solid storage) = 18.86kg = 0.02	44/28 x 20 x 20.6 (nitrogen excretion factor kg) x 1.0(all manure is solid storage) x 0.02 (emission factor for pasture & solid storage) = 12.95kg/1,000 = 0.01	0.03t N ₂ O x 310 = 9.3
	N₂O Emissions from application of previously stored manures	44/28 x 12 x 40(50-20%N excretion net of N volatilising as NO _x & NH ₃) x 0.48 (fraction of N excretion as stored manure (0.5) minus N ₂ O emission as N from storage (0.02)) x 0.0125 (emission factor for direct soil emissions) = 4.53kg = 0.005	44/28 x 20 x 16.48(20.6-20%,N excretion net of N volatilising as NO _x & NH ₃) x 0.98 (fraction of N excretion as stored manure (1.0) minus N ₂ O emission as N from storage (0.02)) x 0.0125 (emission factor for direct soil emissions) = 6.34g = 0.01	0.015t N ₂ O x 310 = 4.65
	N₂O Emissions due to atmospheric deposition of NO_x & NH₃from manures	44/28 x (12 x 40(50-20%, N excretion net of N volatilising as NO _x & NH ₃) / 0.8 (1 minus Fraction of livestock nitrogen excretion that volatilises as NH ₃ and NO _x) (0.2)) x 0.01 (N deposition emission factor) = 9.43kg = 0.01	44/28 x (20 x 16.48(20.6-20%, N excretion net of N volatilising as NO _x & NH ₃) / 0.8 (1 minus Fraction of livestock nitrogen excretion that volatilises as NH ₃ and NO _x (0.2))) x 0.01 (N deposition emission factor) = 6.47kg = 0.01	0.02t N ₂ O x 310 = 6.2
	N₂O Emissions due to leaching & run-off of manures	44/28 x ((12 x 40(50-20%, N excretion net of N volatilising as NO _x & NH ₃) - 1.86 (N content of N ₂ O emissions from waste management systems)) x 0.3 (Fraction of nitrogen input to soils lost to leaching and runoff) x 0.025 (N leaching/runoff factor) = 5.64kg = 0.01	44/28 x ((20 x 16.48(20.6-20%, N excretion net of N volatilising as NO _x & NH ₃) - 12.95 (N content of N ₂ O emissions from waste management systems)) x 0.3 (Fraction of nitrogen input to soils lost to leaching and runoff) x 0.025 (N leaching/runoff factor) = 3.73kg = 0.004	0.014t N ₂ O x 310 = 4.34
Total tCO₂e		18.57	12.64	31.21

Table C.8 Calculation of CO₂ removals (tonnes/year) due to farm woodland on the livestock farm

Woodland type	Hectares	CALM Calculations	Author's Calculations
		CO₂ tonnes removed p/a	CO₂ tonnes removed p/a
Broadleaved under 10 years	3	-2	3ha x 3tC/ha/yr = 9 x 44/12(convert C to CO ₂) = 33
Broadleaved 10-20 years	3	44	3ha x 3tC/ha/yr = 9 x 44/12(convert C to CO ₂) = 33
Broadleaved over 20 years	110	1226	110ha x 3tC/ha/yr = 330 x 44/12(convert C to CO ₂) = 1210
Totals	116	-1272	-1276

Table C.9 Calculation of emissions (tonnes/year) due to fuel consumption by farm machinery and vehicles on the arable farm

		CALM Calculations	Author's Calculations			
Energy - fuel consumption by farm machinery		CO ₂ e	CO ₂	CH ₄ (as CO ₂ e)	N ₂ O (as CO ₂ e)	CO ₂ e
Gas oil (red diesel) - litres used over 12 months (exc. fuel with renewable portion over national compulsory inclusion limit - 20%)	7000 litres	? Not calculated	7,000l x 2.7619 = 19,333/1000 = 19.33	7,000l x 0.0028 = 19.6/1000 = 0.02	7,000l x 0.2642 = 1,849.4/1,000 = 1.85	7,000l x 3.0289 = 21,202/1,000 = 21.20
Diesel - litres used over 12 months (exc. fuel with renewable portion over national compulsory inclusion limit - 20%)	360 litres	1	360l x 2.6391 = 950.08/1,000 = 0.95	360l x 0.0019 = 0.68/1,000 = 0.0007	360l x 0.0283 = 10.19/1,000 = 0.01	360l x 2.6694 = 961/1,000 = 0.96
Unleaded petrol - litres used over 12 months (exc. fuel with renewable portion over national compulsory inclusion limit - 20%)	150 litres	0	150l x 2.3035 = 345.52/1,000 = 0.35	150l x 0.0047 = 0.70/1000 = 0.0007	150l x 0.0226 = 3.39/1,000 = 0.00	150 x 2.3307 = 350/1,000 = 0.35
Totals tCO₂e		1	20.63	0.02	1.86	22.51

Table C.10 Calculation of emissions (tonnes/year) due to fuel consumption by farm contractors on the arable farm

Energy used in contracting	Data	CALM Calculations	Author's Calculations				
		CO ₂ e	Basis of calculations	CO ₂	CH ₄ (as CO ₂ e)	N ₂ O (as CO ₂ e)	CO ₂ e
Whole crop stubble to stubble - number of hectares worked by contractor	240 hectares		180 l per hectare for all annual cultivation processes. Defra Gas Oil conversion factor.	180 x 240 = 43,200l x 2.7619 = 119.31	180 x 240 = 43,200l x 0.0028 = 0.12	180 x 240 = 43,200l x 0.2642 = 11.41	180 x 240 = 43,200l x 3.0289 = 130.85t
Estimate of the number of litres per hectare likely to be consumed. As a guide 180 litres per hectare may be used.	0 litres						
Totals tCO₂e		0		119.31	0.12	11.41	130.85

Table C.11 Calculation of emissions (tonnes/year) due to nitrogen fertilizer use on the arable farm

	CALM Calculations		Author's Calculations			
	N ₂ O	CO ₂ e	N ₂ O			
Fertilizer (nitrogen only)			N ₂ O Emissions from the application of inorganic fertilizer	N ₂ O Emissions from atmospheric deposition of NOx & NH ₃ from inorganic fertilizer	N ₂ O Emissions due to leaching & run-off of inorganic fertilizer	CO ₂ e
Ammonium nitrate - quantity applied over 12 months: 116 tonnes; 34.5% nitrogen content		368	116t x 34.5% = 40,020 x 44/28 ((converts N ₂ O-N to N ₂ O) x 0.9 (1-fraction of synthetic fertiliser emitted as NOx + NH ₃) x 0.0125 (emission factor for direct soil emissions) = 0.71t	116t x 34.5%N x 44/28 ((converts N ₂ O-N to N ₂ O) x 0.1 (fraction emitted as NOx & NH ₃) x 0.01(N deposition factor) = 0.06	116t x 34.5%N = 40.02t x 44/28 ((converts N ₂ O-N to N ₂ O) x 0.8875(fraction of total synthetic fertiliser nitrogen emitted as NOx + NH ₃ minus 0.0125 (direct emission of N ₂ O as nitrogen) x 0.3 (fraction of nitrogen input to soils lost through leaching and runoff) x 0.025 (Nitrogen leaching/runoff factor) = 0.47	1.24 tN ₂ O x 310 = 384.40
Urea - quantity applied over 12 months: 67 tonnes; 46% nitrogen content		284	67t x 46% = 30,820 x 44/28 ((converts N ₂ O-N to N ₂ O) x 0.9(1-fraction of synthetic fertiliser emitted as NOx + NH ₃) x 0.0125 (emission factor for direct soil emissions) = 0.54t	67t x 46%N = 30,820 x 44/28 ((converts N ₂ O-N to N ₂ O) x 0.1 (fraction emitted as NOx & NH ₃) x 0.01 (N deposition factor) = 0.05	67t x 46%N = 30.82t x 44/28 ((converts N ₂ O-N to N ₂ O) x 0.8875 (fraction of total synthetic fertiliser nitrogen emitted as NOx + NH ₃ minus 0.0125 (direct emission of N ₂ O as nitrogen) x 0.3 (fraction of nitrogen input to soils lost through leaching and runoff) x 0.025 (Nitrogen leaching/runoff factor) = 0.32	0.91 tN ₂ O x 310 = 282.10
Other nitrogen fertilizer - quantity of other artificial nitrogen fertilisers (e.g. N Compound, N Blend, MAP, DAP): 41 tonnes; 21% nitrogen content		79	41t x 21% = 8.61 x 44/28 ((converts N ₂ O-N to N ₂ O) x 0.9 (1-fraction of synthetic fertiliser emitted as NOx + NH ₃) x 0.0125 (emission factor for direct soil emissions) = 0.15	41t x 21%N = 8.61 x 44/28 ((converts N ₂ O-N to N ₂ O) x 0.1 (fraction emitted as NOx & NH ₃) X 0.01(N deposition factor) = 0.01	41t x 21%N = 8.61 x 44/28 ((converts N ₂ O-N to N ₂ O) x 0.8875 (fraction of total synthetic fertiliser nitrogen emitted as NOx + NH ₃ minus 0.0125 (direct emission of N ₂ O as nitrogen) x 0.3 (fraction of nitrogen input to soils lost through leaching and runoff) x 0.025 (Nitrogen leaching/runoff factor) = 0.09	0.25 tN ₂ O x 310 = 77.50
Totals	2.36	731	2.4			744.00

Table C.12 Calculation of emissions (tonnes/year) due to ploughing-in of crop residues on the arable farm

	CALM Calculations	Author's Calculations	
Crops and grass	CO ₂ e	N ₂ O Emissions due to ploughing-in crop residue	CO ₂ e
W Wheat – 1062 tonnes produced	61	1,062t x 1.3(residue factor) x 0.855(dry matter fraction) x 0.015(nitrogen fraction) x 0.0125(N ₂ O-N emission factor) x 44/28(converts N ₂ O-N to N ₂ O) = 0.35	0.35tN ₂ O x 310 = 108.50
Tonnes of straw produced by this crop moved off the farm or estate to another business: 600		600t x 1.3(residue factor) x 0.855(dry matter fraction) x 0.015(nitrogen fraction) x 0.0125(N ₂ O-N emission factor) x 44/28(converts N ₂ O-N to N ₂ O) = 0.19	0.19tN ₂ O x 310 = 58.90
Oilseed Rape - tonnes of seed produced: 134	13	134t x 1.2(residue factor) x 0.91(dry matter fraction) x 0.015(nitrogen fraction) x 0.0125(N ₂ O-N emission factor) x 44/28(converts N ₂ O-N to N ₂ O) = 0.04	0.04tN ₂ O x 310 = 12.40
Totals tCO₂e	74		120.90

Table C.13 Calculation of CO₂ removals (tonnes/year) due to land use change (arable to grassland) on the arable farm

Land use change	Hectares	CALM Calculations	Author's Calculations
		CO ₂	CO ₂
Change from arable to grass (where land is still in grass) in the last 20 years. (Include any Entry Level Stewardship scheme strips):	12		$12 \times 10,000 (\text{convert to m}^2) = 120,000 \times 0.08 (\text{kg/m}^2 \text{ increase in C density on change from arable to grassland}) = 9,600/1,000 = 9.6 \times 44/12 = \mathbf{35.20}$
Area of any arable to grass change in land use within the 12 month assessment period.	2		$2 \times 10,000 (\text{convert to m}^2) = 20,000 \times 0.08 (\text{kg/m}^2 \text{ increase in C density on change from arable to grassland}) = 1,600/1,000 = 1.6 \times 44/12 = \mathbf{5.86}$
Totals		-38	-41.06

Table C.14 Calculation of CO₂ removals (tonnes/year) due to farm woodland on the arable farm

Farm woodland (for general farm use)	Hectares	CALM Calculations	Author's Calculations
		CO ₂	CO ₂
Broadleaved under 10 years	4	3	$4 \text{ha} \times 3 \text{tC/ha/yr} = 12 \times 44/12 (\text{convert C to CO}_2) = \mathbf{44.00}$
Broadleaved 10-20 years	10	146	$10 \text{ha} \times 3 \text{tC/ha/yr} = 30 \times 44/12 (\text{convert C to CO}_2) = \mathbf{110.00}$
Totals		-149	-154.00

Table C.15 Calculation of predicted emissions (tonnes/year) due to fuel use on arable crop cultivations when current arable area is under organic management

Basis of calculation	CO ₂	CH ₄ (as CO ₂ e)	N ₂ O (as CO ₂ e)	CO ₂ e
Arable crops: 180l/ha x 144ha = 25,920l Defra gas oil conversion factors	25,920 x 2.7619 = 71.59	25,920 x 0.0028 = 0.07	25,920 x 0.2642 = 6.85	25,920 x 3.0289 = 78.51
Grass/clover ley: 180l/ha x 96ha = 17,280l Defra gas oil conversion factors	17,280 x 2.7619 = 47.73	17,280 x 0.0028 = 0.05	17,280 x 0.2642 = 4.57	17,280 x 3.0289 = 52.34
Totals tCO₂e	119.32	0.12	11.42	130.85

Table C.16 Calculation of emissions (tonnes/year) due to ploughing-in crop residues under organic procedures

Crop	N ₂ O	CO ₂ e
Organic wheat	8.9t/ha x 0.68 (organic yield) = 6.05t/ha x 48ha = 290.4t x 1.3 (residue factor) x 0.855 (dry matter fraction) x 0.015 (nitrogen fraction) x 0.0125 (N ₂ O-N emission factor) x 44/28 (converts N ₂ O-N to N ₂ O) = 0.10	0.10tN ₂ O x 310 = 31.00
Organic oats	5.3t/ha x 0.42 (organic yield) = 2.23t/ha x 48ha = 106.8t x 1.3 (residue factor) x 0.855 (dry matter fraction) x 0.015 (nitrogen fraction) x 0.0125 (N ₂ O-N emission factor) x 44/28 (converts N ₂ O-N to N ₂ O) = 0.03	0.03tN ₂ O x 310 = 9.30
Organic beans	4.0t/ha x 0.83 (organic yield) = 3.32t/ha x 48ha = 159.4t x 2 (converts edible portion of crop to total biomass) x 0.86 (dry matter fraction) x 0.03 (fraction N in nitrogen fixing crop) x 0.6 (1 minus fraction of crop removed from field, author estimate) x 0.0125 (N ₂ O-N emission factor) x 44/28 (converts N ₂ O-N to N ₂ O) = 0.097	0.097tN ₂ O x 310 = 30.07
Grass/clover ley	8.5t/ha (Dry Matter) x 0.83 (organic yield) = 7.06t/ha x 96ha = 677.76t x 2 (converts edible portion of crop to total biomass) x 0.03 (fraction N in nitrogen fixing crop) x 0.6 (1 minus fraction of crop removed from field, author estimate) x 0.0125 (N ₂ O-N emission factor) x 44/28 (converts N ₂ O-N to N ₂ O) = 0.479	0.479tN ₂ O x 310 = 148.50
Totals	0.71	218.87

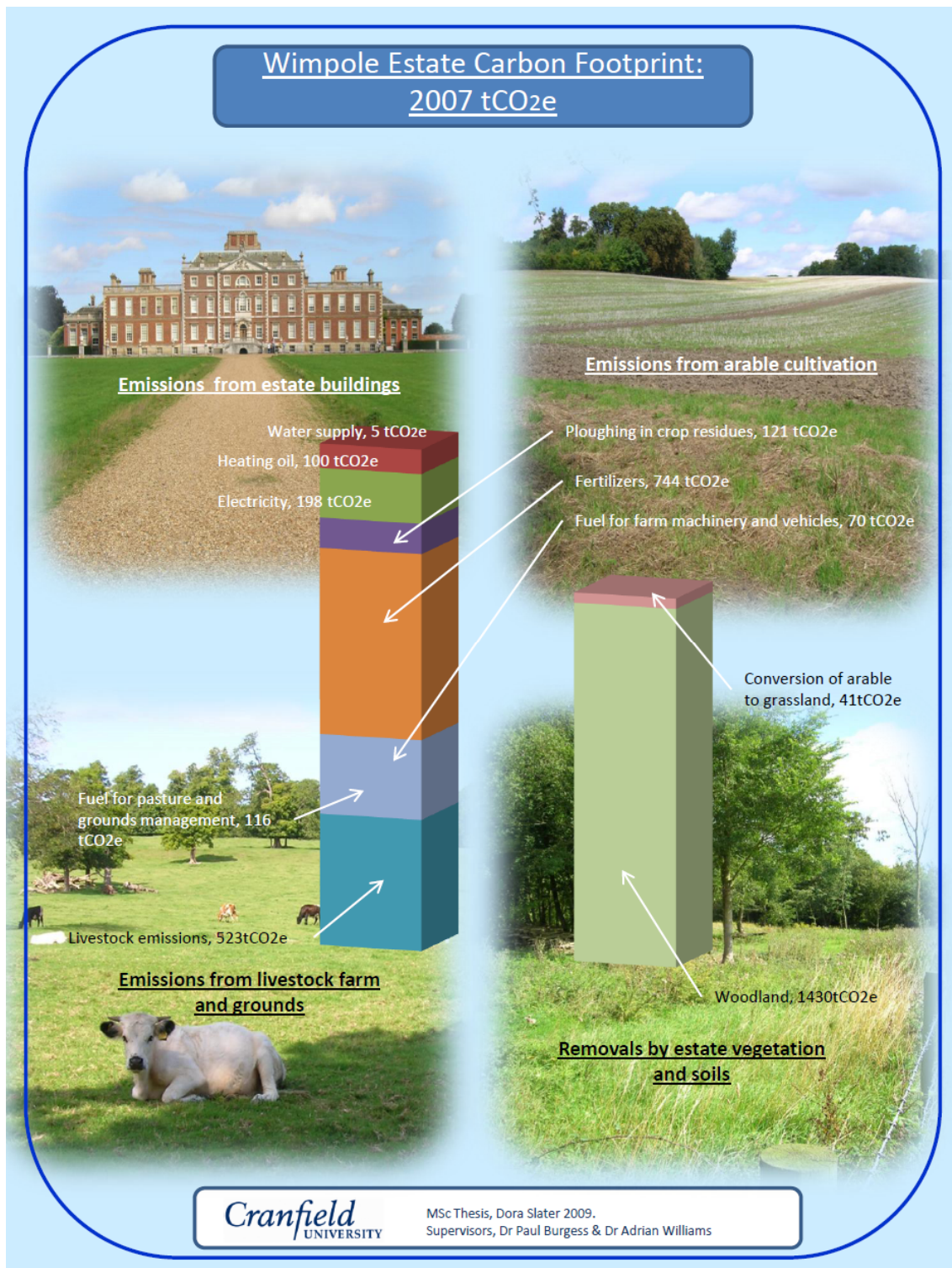
Table C.17 Calculation of emissions (tonnes/year) due to biological fixation of nitrogen by crops - Organic procedures

Crop		N ₂ O	CO ₂ e
Organic beans - N ₂ O emissions due to biological fixation of nitrogen by crops	48 hectares field beans	$4.0\text{t/ha} \times 0.83(\text{organic yield}) = 3.32\text{t/ha} \times 48\text{ha} = 159.4\text{t} \times 2(\text{converts edible portion of crop to total biomass}) \times 0.86(\text{dry matter fraction}) \times 0.03(\text{fraction N in nitrogen fixing crop}) \times 0.0125(\text{N}_2\text{O-N emission factor}) \times 44/28(\text{converts N}_2\text{O-N to N}_2\text{O}) = \mathbf{0.16}$	$0.16 \times 310 = \mathbf{49.60}$
Grass/clover ley - N ₂ O emissions due to biological fixation of nitrogen by crops	96 hectares grass/clover ley	$8.5\text{t/ha (Dry Matter)} \times 0.83(\text{organic yield}) = 7.06\text{t/ha} \times 96\text{ha} = 677.76\text{t} \times 2(\text{converts edible portion of crop to total biomass}) \times 0.03(\text{fraction of N in crop}) \times 0.0125(\text{N}_2\text{O-N emission factor}) \times 44/28(\text{converts N}_2\text{O-N to N}_2\text{O}) = \mathbf{0.798}$	$0.798 \times 310 = \mathbf{247.38}$
Totals		0.96	296.98

Table C.18 Calculation of emissions due to consumption of electricity, heating oil and water

	Data	CO₂	CH₄ (as CO₂e)	N₂O (as CO₂e)	CO₂e
Electricity	365,885 kWh	365,885 x 0.54055 (emission factor) = 197.78t	365,885 x 0.00023(emission factor) = 0.08	365,885 x 0.00340 (emission factor) = 1.24	365,885 x 0.54418 (emission factor) = 198.24
Heating Oil	386,000 kWh	386,000 x 0.25847(emission factor) = 99.77t	386,000 x 0.00055(emission factor) = 0.21	386,000 x 0.00071(emission factor) = 0.27	386,000 x 0.25972(emission factor) = 100.25
Water (metered supply only)	16,996,000 litres	–	–	–	16,996,000l x 0.29g/l (emission factor) = 4.93
Totals tCO₂e		297.55	0.29	1.51	303.43

Appendix D Poster of estate carbon footprint



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