EMISSIONS AND REMOVALS OF GREENHOUSE GASES AT AN INSTITUTION LEVEL:

A Case Study of Massey University Turitea Campus

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ABSTRACT

The first commitment period of the Kyoto Protocol (2008-2012) has started. Being a signatory to the protocol, New Zealand is committed to reduce its greenhouse gas (GHG) emissions down to 1990 levels by the end of the first commitment period, or to take responsibility for any emissions above this level if it cannot meet this target. Although the inventory of New Zealand's GHG emissions is made at a national level, the actual reductions in GHG emissions required under the Kyoto Protocol will need to be made by individuals and institutions in society.

Little attempt has yet been made at an institution level, especially by the Universities in New Zealand, to determine their aggregated net emissions of the major GHGs: carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). In order to help Massey University to prepare its own emission budget, estimates of current emissions were made in four major sectors - energy, agriculture, waste and forestry - at the Turitea campus and the associated 2200 hectares of the University's farms. Greenhouse gas emissions from these sectors in 1990 were also estimated to compare the current emissions with the base year of the Kyoto protocol.

An introduction to the major GHGs, their emissions, the effect of these emissions on climate change, and an overview of the approach to calculate these emissions is provided. Total emissions from the energy sector included emissions from the electricity, gas, coal, vehicles and aviation sub-sectors, that were calculated with the help of national and international emission factors. Greenhouse gas emissions from solid waste and wastewater were calculated using the Intergovernmental Panel on Climate Change (IPCC) tier 1 approach.

Emissions from the agriculture sector were calculated using a combination of New Zealand national and IPCC default emission factors. This sector accounts for emissions resulting from enteric fermentation, animal manure management and agricultural soils.

An overview of Massey University's forest estate has also been provided. At present, forestry is the only sector contributing toward the mitigation of GHGs at Massey University through Kyoto-defined plantation forests. The amounts of C sequestered by the native and exotic tree plantations, and the total amount of CO_2 absorbed by these plantations are presented. Although an assessment of C sequestered by all Massey University's tree plantations was made, only plantations established in 1990 and after were considered for inventory purposes. In the conclusions, some suggestions to reduce GHG emissions from Massey University and to improve future inventories are given.

The annual gross GHG emissions in terms of CO_2 equivalents (CO_2e) in 2004 were 26,696±2,674 Mg which were about 7.9% above the level of 1990 emissions. It was estimated that the forestry sector removed about 4,094±439 Mg of CO_2e and therefore the overall net emissions in 2004 were 8.6% below the base-line GHG emissions of 1990. At present the major contributing sector to GHG emissions at Massey University's Turitea campus is the energy sector. This contributes 71.4% of the gross emissions, whereas the agriculture and waste sectors are producing 26.2% and 2.4% respectively of the total gross emissions. About 37% of the total GHG emissions from the energy sector were contributed by commuting traffic, whereas electricity and gas collectively produced 33% of the total 19,064±1,324 Mg CO_2e energy emissions.

The largest absolute uncertainties in emission estimates were in the energy sector and some suggestions have been made as to how Massey University might reduce these uncertainties and improve the overall accuracy of the estimates of GHG emissions.

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CHAPTER 1: GENERAL INTRODUCTION

1.1 BACKGROUND

During the last few centuries, the rapid expansion of the human population has resulted in increased use of chemical fertilisers and fossil fuels, which in turn have resulted in an overall increase in the quantities of three major greenhouse gases (GHGs), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) in the atmosphere. These increased GHG concentrations are generally believed to be causing changes in the earth's climate (IPCC, 2007; Salinger, 2005). Increased concentrations of GHGs cause atmospheric temperatures to rise (Idso and Balling Jr., 1991). Many studies have used the surface air temperature as an indicator of climate change (Limsakul and Goes, 2008; Liu and Chen, 2000; Jones *et al.*, 1996). During the last 150 years, an increase between 0.3 and 0.6°C in the global mean annual surface temperatures has been observed (Nicholls *et al.*, 1996), and another 1.1 – 6.4° C has been predicted by the end of this century (IPCC, 2007).

Ever-growing concentrations of GHGs in the atmosphere and the resulting possible climate change can affect the global environment and human life in a number of ways. For example, rising sea levels are not only threatening the submergence of many coastal areas of the world, but also can cause extinction of many coastal forest species (Desantis *et al.*, 2007). The effect of climate change on agriculture may create food security problems in many developing countries (Easterling and Apps, 2005). Similarly, climate change can also be a risk for human health (Lam, 2007; Haines *et al.*, 2006).

In response to this concern about GHGs causing climate change, and its negative effects on human life, the Intergovernmental Panel on Climate Change (IPCC) and an international treaty, the United Nations Framework Convention on Climate Change (UNFCCC), came into being. The main task of the IPCC is the assessment, publication and dissemination of available scientific information about the environment and climate change.

The global environment and economic development are facing a potential threat from climate change (IPCC, 1996). The launching of UNFCCC in 1992 and its ratification by 188 countries was a timely response of the world community to this threat. Article 2 of the UNFCCC describes the objective of the convention as to stabilise the atmospheric concentrations of GHG at a level that should prevent dangerous anthropogenic interference with climate change (UNFCCC, 2004). As a part of the UNFCCC and with the help of the IPCC guidelines, member countries perform national GHG inventories that include all anthropogenic sources. The magnitude of GHG emissions and the changes in total emissions since 1990 are assessed and reported to UNFCCC. A series of IPCC guidelines for "National Greenhouse Gas Inventories" provide guidelines for preparing these national GHG inventories of emissions and removals. The fourth assessment report by IPCC "Climate Change 2007" is the most up-to-date scientific assessment and an integrated view of the world's climate system that discusses the emissions and feedbacks, and mitigation and adaptation options in detail.

The Kyoto Protocol is an agreement under which industrialized countries will reduce their collective emissions of GHGs by at least 5% cent below 1990 levels in the period 2008-2012. The Kyoto Protocol was adopted on 11 December 1997 and New Zealand ratified the Kyoto Protocol in December 2002.

New Zealand follows a number of IPCC guidelines when preparing its national inventory report. These include: the "Revised 1996 IPCC guidelines for national GHG inventories" (IPCC, 1997), the "Good practice guidance and uncertainty management in national GHG inventories" (IPCC, 2000), and the "Good practice guidance for land use, land use change and forestry" (IPCC, 2003). This annual inventory of emissions and removals of GHGs is part of New Zealand's obligations under UNFCCC and the Kyoto Protocol (Ministry for the Environment (MfE), 2006).

New Zealand's total GHG emissions in 2005 were 77,159 Gg CO_2 equivalents (CO_2e), while in 1990 these emissions were 61,900 Gg CO_2e. This is a 24.7% rise since 1990 (MfE, 2007). The gases included in the New Zealand national inventory are CO_2, CH_4, N_2O, hydrofluorocarbons (HFCs), perfluorocarbons

(PFCs) and sulphur hexafluoride (SF_6) from six sectors: energy, industrial processes, solvents, agriculture, LULUCF (land use, land-use change and forestry), and waste.

Local businesses, industries, individuals and communities in New Zealand are being encouraged by the government to reduce GHG emissions (MfE, 2003). In order to reduce net GHG emissions from institutions, it is first necessary for them to develop an inventory of GHG emissions and sinks for their enterprise. In New Zealand, however, little attempt has yet been made at an enterprise or institutional level to determine the aggregated net emissions of the major GHGs. This thesis reports on the attempt to develop an inventory of GHG emissions and sinks for a large institution – Massey University.

There are important differences between national and institutional inventories. For example:

1- Not all the sectors and gases represented in a national inventory may be present in an institutional inventory. In the case of Massey University for example, only three major gases (CO_2, CH_4, and N_2O) are considered from four sectors: energy, agriculture, waste, and forestry.
2- It is difficult in some cases to draw 'boundaries' around the institution and its activities. An important example is the consideration of commuting traffic. Should the GHG emissions resulting from staff and/or customers travelling to or from an institution be included in its GHG inventory?

A direct comparison between the national inventory and the inventory of an institution such as Massey University is therefore difficult, because of three main reasons: the scale of the inventory, the number of gases considered, and the number of sectors taken into account. Two of the sectors considered in the New Zealand national inventory (industrial processes and solvents) have not been considered in Massey University's inventory, because emissions in these sectors include releases from industrial processes that chemically or physically transform materials and are not present at Massey University.

The differences in scale often mean that different approaches have to be taken into account for estimating GHG emissions. As an example, in the energy sector, when calculating emissions from transport, the New Zealand national inventory takes into account all the fuel consumed during one year and the data on the consumption of fuel are extracted from the "Deliveries of Petroleum Fuels by Industry Survey" conducted by Statistics New Zealand (MfE, 2007). In case of Massey University, there is no comparable direct data on the quantity of fuel used by commuting vehicles and so emissions from commuting vehicles have to be estimated by directly counting the number of commuting vehicles, estimating the distance covered by these vehicles and then back calculating the quantity of fuel required to cover that particular distance.

According to its environmental mission statement, "Massey University is committed to the principles of environmental responsibility and sustainable resource management at local, national and international levels. It will meet this commitment through community involvement and leadership in education, research, and sustainable management practices" (Massey University, 2002). Although this study is not directly related to Massey University's environmental mission statement, it can still be helpful in establishing a comprehensive University-wide GHG inventory (including all the campuses) which will help the University to develop an inventory management plan. The University can also set a University-wide GHG reduction goal with the help of the inventory management plan and track its progress towards achieving the goal of emission reductions. Knowledge of the magnitude of the total GHG emissions and implementation of techniques to mitigate, control, and reduce these emissions would demonstrate Massey University's commitment to its environmental mission statement.

1.2 THESIS OBJECTIVES

- To develop and improve the methodology for calculating the current[1] emissions of GHG from the Turitea campus of Massey University and its agricultural farms.
- To estimate the GHG emissions from Massey University and its agricultural farms in 1990.
- To identify and recommend strategies to limit and/or reduce GHG emissions in order to meet the Kyoto target for University-related GHG emissions and removals.
- To provide information that may assist other institutions/organisations to estimate their GHG emissions.

1.3 METHODOLOGY

- Potential sources of GHG emissions and sinks at the Massey University Turitea campus and its agricultural farms were identified.
- All the sources and sinks were divided into four major sectors, namely: Energy, Agriculture, Waste, and Land-Use Change & Forestry.
- The available data on GHG sources and sinks for all the major sectors were collected. Where there were gaps in the available data, a variety of approaches were used to estimate the missing values. The validity of these approaches was assessed and discussed. The uncertainties associated with each of these estimates of GHG emissions were assessed.
- Emissions and removals of the three major GHGs, i.e. CO_2, CH_4, and N_2O were calculated for the years 2004 and 1990 by using a combination of IPCC tier 1 and tier 2 approaches and NZ-specific emission factors. The IPCC default emission factors were also used in some cases where the NZ-specific emission factors were not available.

[1] 2004 is considered as current year for this inventory

- The estimated emissions of CH_4 and N_2O were then converted into CO_2 equivalents (CO_2e) using the Global Warming Potentials (GWP) of CH_4 and N_2O of 21 and 310, respectively.
- Emission estimates were compared with the 1990 emission levels to assess the magnitude of total emissions and the relative change in each sector.

1.4 SCOPE OF THE STUDY

This study calculates the GHG emissions and removals from the energy, agricultural, waste and forestry sectors at the Turitea campus[2], and associated agricultural farms of Massey University in Palmerston North – New Zealand.

The campus at Turitea is forty hectares (ha) in area with more than 16000 full time equivalent students and staff. It houses the Colleges of Business, Sciences, and Humanities and Social Sciences, along with all the administrative and maintenance groupings normally associated with a large university. Associated with the campus are a number of farms. This study included all the Massey-owned farms immediately adjacent to the campus (amounting to 980 ha) as well as a hill country sheep and beef cattle farm (Tuapaka) which has an area of 476.5 ha and is located 12 km from the campus. Massey University also manages the Riverside farm owned by the Sydney Campbell Foundation, which is 90 km away from the campus. Because the livestock on the farm are managed on day-to-day basis by University staff, emissions due to agricultural activities on Riverside farm were included in this inventory, but the trees on this private farm were not included when calculating the carbon (C) sequestration, because, it was not certain whether the farm would still be under the University's management by the time these trees reach their maturity age. Fig. 1.1 shows an aerial view of the Massey University's Turitea campus and adjacent farms.

[2] Only the Turitea campus is included in this inventory. Massey University has another small campus in Palmerston North (the Hokowhitu campus) that houses the College of Education. This campus, which is situated on the other side of the Manawatu River, is not included in this inventory.

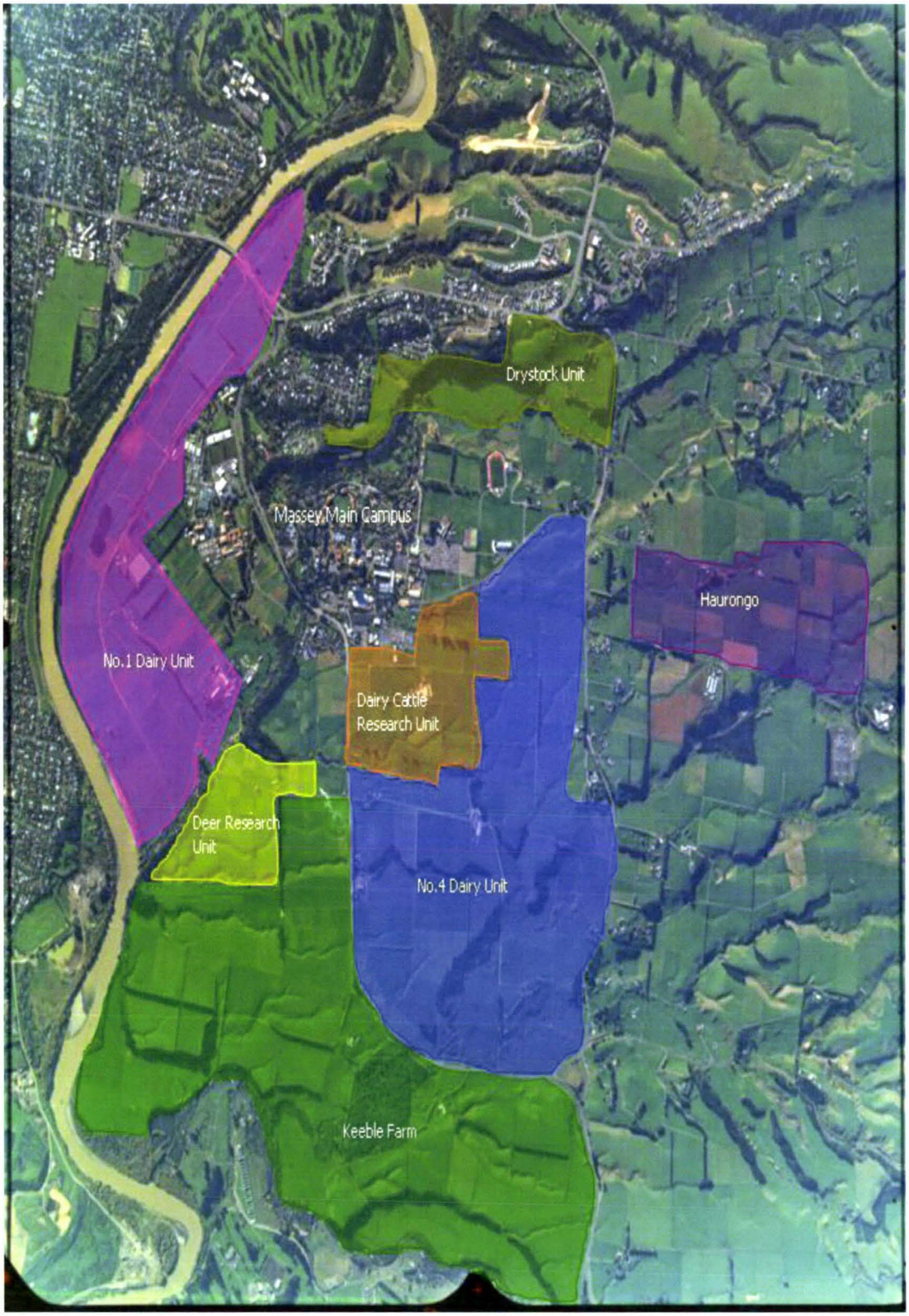

Figure 1.1: An aerial photograph showing Massey University's main campus and adjacent farms.

1.4.1 Thesis Structure

The structure of the thesis (Fig. 1.2) follows the recommended structure of an inventory, in terms of categories. **Chapter 1** gives an introduction to GHG emissions, the effect of these emissions on climate change, and an overview of the approach used to calculate emissions. The chapter also outlines the objectives of the thesis. **Chapter 2** provides a literature review by briefly introducing the major GHGs, different source/sink categories and inventory preparation. **Chapter 3** reports on GHG emissions resulting from the use of different forms of energy. Emissions from the energy sector at Massey University have been calculated by dividing this sector into electricity, gas, coal, vehicles and aviation sub-sectors. **Chapter 4** describes the quantity of municipal solid waste (MSW) produced and resulting GHG emissions due to the disposal of this waste. Emissions due to wastewater handling are also described. **Chapter 5** accounts for the GHG emissions due to enteric fermentation, animal manure management and agricultural soils. **Chapter 6** gives an overview of Massey University's forest estate. The amount of C sequestered by the native and exotic tree plantations and total amount of CO_2 absorbed by these plantations is estimated. **Chapter 7** presents a synthesis and summary of the results from the previous chapters along with the main conclusion and some suggestions to improve GHG inventory for Massey University.

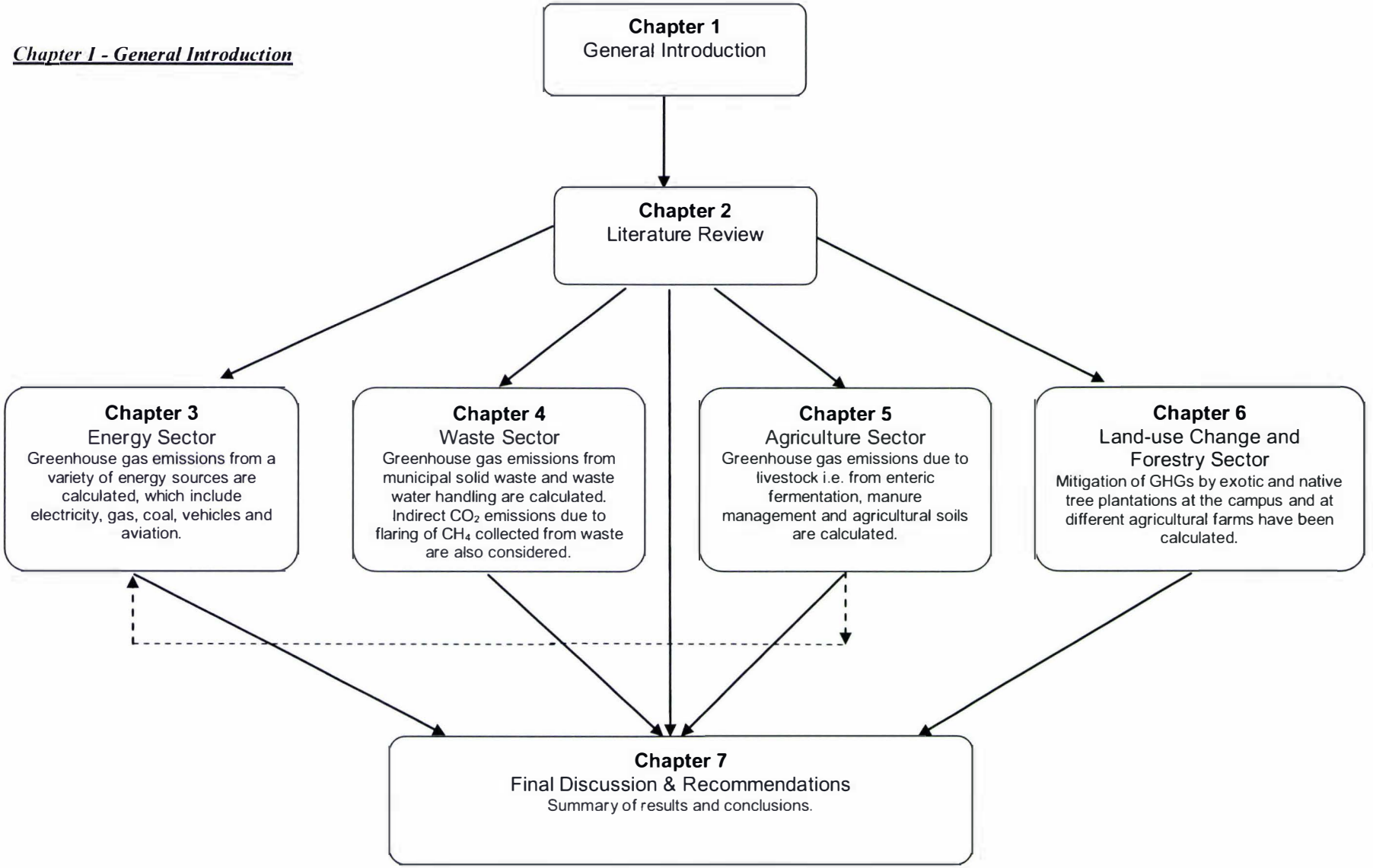

Figure 1.2: Structure of the thesis. The dashed line indicates that the energy consumed in the Agricultural sector has been included in the Energy sector for emission calculations

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CHAPTER 2: LITERATURE REVIEW

2.1 THE GREENHOUSE EFFECT

The Sun is the largest source of energy for the Earth. A major portion of the solar radiation coming from the Sun is absorbed by the Oceans and Earth's surface, while the rest is reflected back. The outgoing solar radiation is trapped by certain trace gases in the atmosphere resulting in increased atmospheric temperatures. This phenomenon is called the greenhouse effect (GHE) and the gases causing this effect are called the greenhouse gases (GHGs). The name "GHE" is given due to the resemblance of this process with the traditional greenhouse used in plant nurseries and gardens to trap heat and provide optimum temperatures to the growing plants. Certain kinds of barriers like glass panels and plastic sheets are used in a garden greenhouse to trap heat, while in nature, GHGs act like a blanket to trap the escaping radiation.

A simplified illustration of the GHE is shown in Fig. 2.1. A layer of GHGs, shown as a white band in the figure, acts as a shield which absorbs and re-emits the infrared radiation reflected from the surface of the Earth. Due to this process, the Earth's surface gains more heat which again results in additional infrared radiation. This repeated emission and absorption of the Sun's radiation increases the temperature on Earth and its environment. It is important to note that without the extra warming created by a GHE, the temperature of the Earth would have been much lower than it is at present and it would have been too cold to support life in its present form. Unabated accumulation of GHGs in the atmosphere however, may create too strong a GHE that could raise the temperature of the Earth so high that existing ecosystems would be threatened.

The GHE can be divided into two broad categories i.e. the natural GHE, and the enhanced GHE. The natural GHE can be easily understood from its name, whereas the enhanced GHE is considered to be the result of anthropogenic activities i.e. the effect created directly by human activities or as the result of natural processes that have been affected by human activities (IPCC, 1997b).

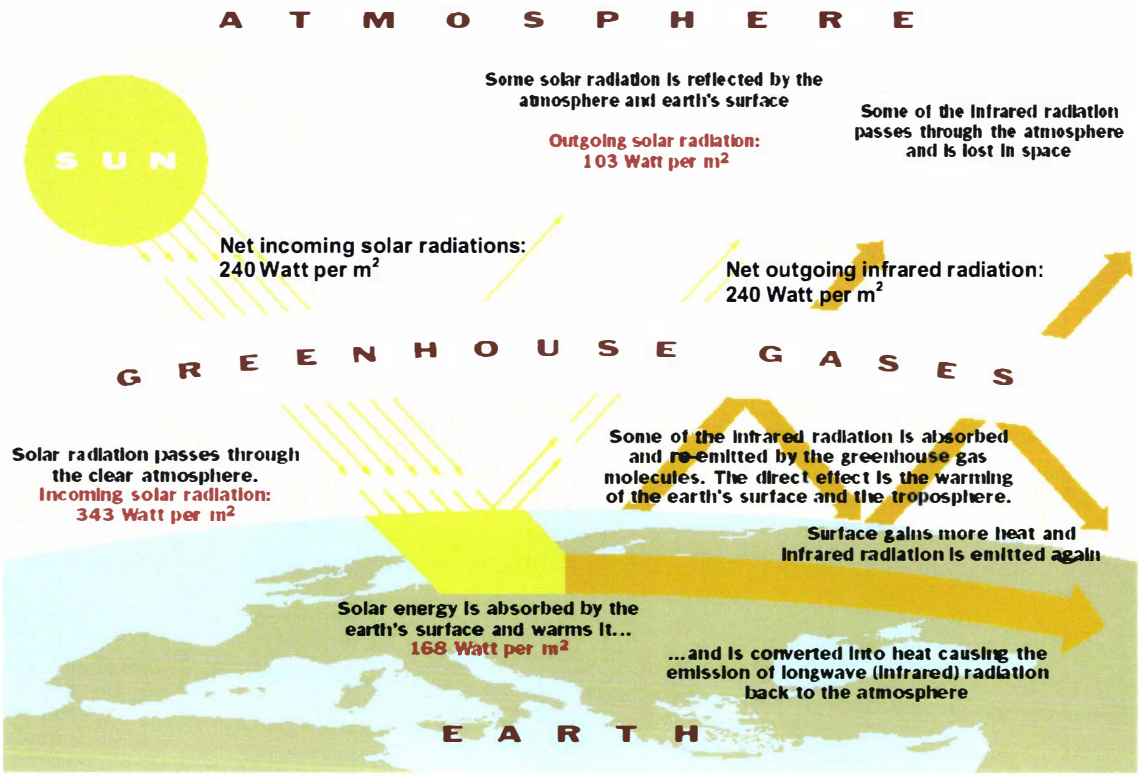
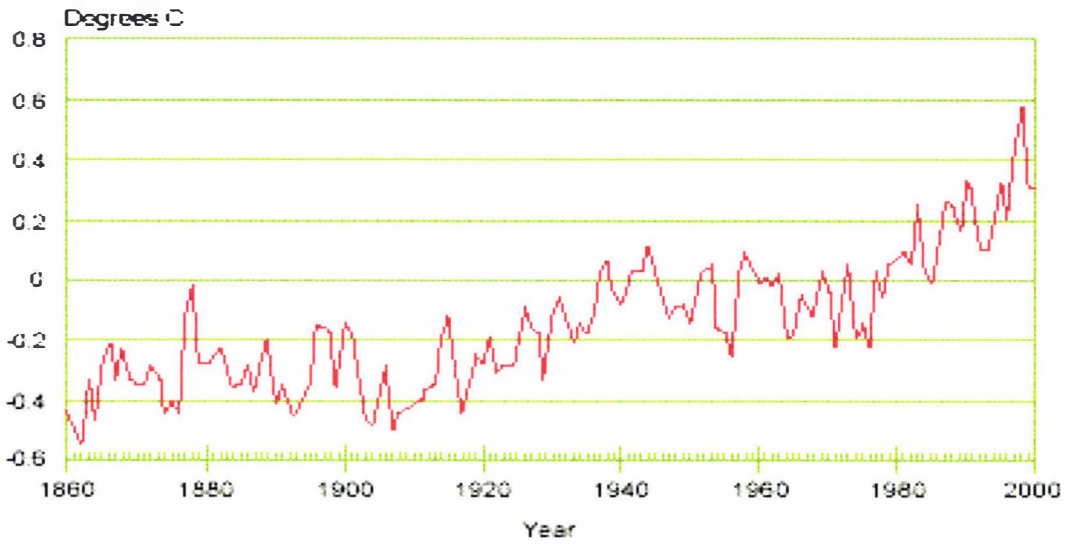


Figure 2.1: The greenhouse effect

Source: The Pew Centre on Global Climate Change (www.pewclimate.org)

As noted above, accumulation of GHGs in the atmosphere is considered a reason for increasing surface air temperature (Fig. 2.2). The reliable records for global temperatures go back to 1860 and a rise of 1°C in the average global temperature has been noticed since then. However, Barnaby (1999) has predicted that in the next 100 years, there could be a rise of another 3°C in the global mean surface temperature, if the GHG emissions continue to increase at the present rate.



Source: http://www.ec.gc.ca/climate/CCAF-FACC/Science/fact/model_e.htm

Figure 2.2: Rising global temperatures from 1860 – 2000

2.2 GREENHOUSE GASES

All the gases that have the capability of absorbing infrared radiation are called GHGs. The list of GHGs provided by the Intergovernmental Panel on Climate Change (IPCC) includes carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), carbon monoxide (CO), nitrogen trifluoride (NF_3), nitrogen oxides (NO_x), ammonia (NH_3), sulphur dioxide (SO_2), non-methane volatile organic compounds (NMVOC), trifluoromethyl sulphur pentafluoride (SF_5CF_3), halogenated ethers (e.g. $CHF_2OCF_2OCHF_2$), and other halocarbons (e.g. CF_3I, $CH_2Br_2CHCl_3$, CH_3Cl and CH_2Cl_2) (IPCC, 1997a).

Although all of the gases listed above exhibit GHG properties, the most frequently discussed gases are CO_2, CH_4, and N_2O. These are also called natural GHGs while the others are termed human-made GHGs. The gases covered by the Kyoto protocol include the above-mentioned three natural GHGs along with HFCs, PFCs, and SF_6. These three natural GHGs make up the major portion of a country's GHG inventory. For example, 98.9% of all GHG emissions in New Zealand come from these three gases (Ministry for the Environment (MfE),

2006b); similarly, about 90% of Australia's GHG emissions are covered by these three gases (Australian Government Department of Climate Change (DCC, 2008). Due to the fact that the contribution of any gas other than three natural gases in an inventory is usually small, the emphasis in this review is on these three natural GHGs.

The concentrations of all three natural GHGs have increased significantly in the industrial era (Table 2.1) and human activities are considered responsible for this increase (Forster *et al.*, 2007). Emissions of the GHGs, in terms of CO_2 equivalents (CO_2e), covered by the Kyoto Protocol have increased from 28.7 Tg in 1970 to 49.0 Tg in 2004 - an increase of about 70% (Barker *et al.*, 2007).

Table 2.1: Global atmospheric concentration of important GHGs and changes in concentration

Gas	Concentration in 2005	Change in concentration since 1998
CO_2	379 ± 0.65 ppmv	+13ppmv
CH_4	1774 ± 1.8 ppbv	+11ppbv
N_2O	319 ± 0.12 ppbv	+5ppbv

Source: (Forster *et al.*, 2007)

A number of sectors contribute significantly to global GHG emissions (Fig. 2.3). However energy supply is the single largest sector contribution and this sector has also recorded the largest percentage increase since 1990. For example, in New Zealand and Australia emissions from the energy sector have increased by 42% and 40% respectively since 1990.

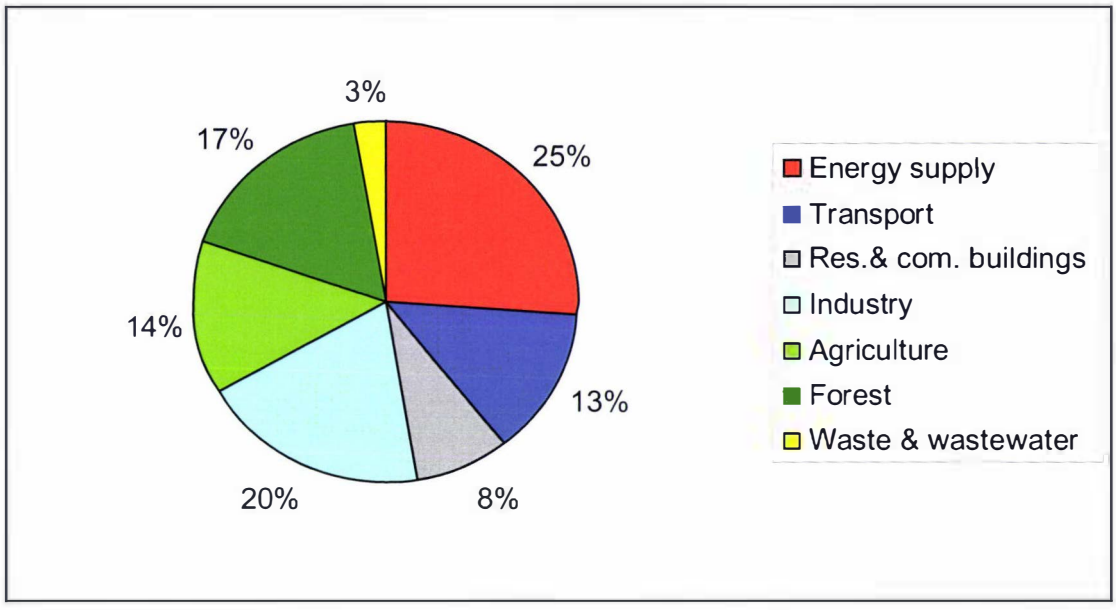


Figure 2.3: Proportion of different sectors in global GHG emissions in 2004 (source: Barker *et al.*, 2007)

2.2.1 Carbon dioxide

Carbon dioxide is the most abundant GHG (IPCC, 1997a). There has been an increase of about 32% in its atmospheric concentration in the last 150 years - from 280 ppmv in 1850 to 370 ppmv in 2000, and it is anticipated to reach 600 ppmv during the 21st century (Lal, 2002). Forster *et al.*, (2007) have also supported this trend of increasing atmospheric concentrations of CO_2 by estimating a growth rate of 1.9 ppmv/yr for the period from 1995 to 2005.

Most of the anthropogenic CO_2 emissions come from the burning of fossil fuels, and more than 28,950 million Mg of CO_2 were produced in 2004 from global fossil-fuel emissions (Marland *et al.*, 2004). The estimated average global fossil fuel emission per person on the basis of the total human population is about one Mg of C/person/year or 3.67 Mg of CO_2/person/year (IPCC, 2003).

According to Harvey (1999), about 85% of the world's total energy supply comes from three major types of fossil fuels - coal, oil, and natural gas. The quantity of CO_2 emitted per unit of energy provided varies quite considerably between these different fossil fuels (Table 2.2). The largest emissions per unit of energy provided are from coal, whereas natural gas emits the least CO_2 per unit of

energy provided among all the fossil fuels. Therefore, shifting from coal to oil or oil to natural gas in an energy production system can be a way of reducing CO_2 emissions (Granovskii *et al.*, 2007).

Table 2.2: Carbon dioxide emission per unit of energy for various fossil fuels

Source	CO_2 emission factor (kg C/GJ energy)
Anthracite coal	23.5-26.6
Lignite coal	22.2-25.9
Bituminous coal	23.9-24.5
Sub-bituminous coal	24.8-25.7
Oil	17-20
Natural gas	13.5-14

Source: (Harvey, 1999)

Land use changes such as deforestation (Houghton, 2003) and biomass burning (Andreae and Merlet, 2001) are examples of some other important sources of CO_2 emission.

2.2.2 Methane

Methane can be released into the atmosphere by both natural and anthropogenic processes. Approximately 70% of the estimated 440-640 Tg of CH_4 emitted annually to the atmosphere come from the anthropogenic sources (IPCC, 1992). Anaerobic decomposition of organic matter in biological systems is the primary source of CH_4 production. Natural wetlands are an important source and are responsible for releasing about 145 Tg of CH_4 into the atmosphere annually (Whalen, 2005). Some of the anthropogenic sources of CH_4 emission (Table 2.3) are paddy rice cultivation (Chakraborty *et al.*, 2006), enteric fermentation in animals (Garcia-Apaza *et al.*, 2008; Smita *et al.*, 2007) and the decomposition of animal and municipal solid wastes (Hao *et al.*, 2008; Sanphoti *et al.*, 2006). Landfills are estimated to account for 3-19% of global anthropogenic CH_4 emissions (United States Environment Protection Agency (EPA), 1994).

Natural gas is 90-95% CH_4, and the extraction and distribution processes associated with natural gas and petroleum production are important sources of CH_4 emission to the atmosphere (Table 2.4). Coal mining and incomplete fossil fuel combustion also produce CH_4 (Breas *et al.*, 2002).

Table 2.3: Global annual CH_4 emission from different human activities

Sources of CH_4	Emission (Tg CH_4/year)
Coal mining	15-45
Coal combustion	1-30
Extraction of oil	5-30
Extraction and use of natural gas	25-50
Total fossil	46-155
Sewage treatment plants	15-80
Sanitary landfills	20-70
Domestic animals	65-100
Animal waste	20-30
Rice paddies	20-100
Biomass burning	20-80
Total biosphere	160-460
Total	206-615

Source: Prather *et al.* (1995)

Table 2.4: Methane emission factors per unit of energy for fossil fuels

Fuel	CH_4 emission factor (kg CH_4/GJ)
Coal mining	0.13-0.53
Underground	0.46-0.49
Surface	0.12-0.13
Oil	≤ 0.03
Natural gas	0.18-0.19

Source: (Harvey, 1999)

The current rate of increase in atmospheric CH_4 concentration is about 0.8%/yr (Lal, 2002) and EPA (2003) has estimated its current level of concentration at 1.84 ppbv, which has increased by 150% since pre-industrial time (IPCC, 2001). IPCC (2001) has also reported a declining trend in the rate of increase of atmospheric CH_4 concentrations.

There are a number of options available in almost every sector to reduce the quantity of CH_4 emissions. For example, in the dairy sector which contributes a considerable amount of CH_4 into the atmosphere, some reduction in CH_4 emissions may be possible by adding dietary supplements to the feed (Grainger *et al.*, 2008). In the waste sector, it is possible to reduce CH_4 emissions by controlling/reducing the quantities of organic matter in the municipal solid waste (Pan and Voulvoulis, 2007). Similarly, CH_4 emissions from rice cultivation can be reduced if it is possible to shift from conventional puddling to no-tilling techniques (Harada *et al.*, 2007).

2.2.3 Nitrous oxide

On a global scale, agricultural activities and industrial processes are the main sources of N_2O (Table 2.5), with the agricultural sector being the dominant contributor. Soil micro-organisms that carry out nitrification and denitrification processes are the primary source of N_2O, and the quantities of N_2O emitted from agricultural systems vary depending upon the crop type and the amount of nitrogen (N) fertiliser used (Dalal *et al*, 2003). The nature of the fertiliser used, the time of fertilisation, and the soil water content of cultivated soils also affect N_2O emissions (Prather *et al.*, 1995). Considerable amounts of N_2O are also produced from the burning of agricultural residues (Ogawa and Yoshida, 2005). There has been a significant change (18%) in the atmospheric concentration of N_2O since the preindustrial age, which has increased from 270 ppb in 1750 to 319 ppb in 2005 (Forster *et al.*, 2007). Table 2.5 describes different sources and annual emissions of N_2O.

Table 2.5: Global sources and emissions of N_2O

Source of N_2O	Emission (Tg N/year)
Cultivated soils	1.8-5.3
Biomass burning	0.2-1.0
Industrial sources	0.7-1.8
Cattle and feed lots	0.2-0.5
Total	2.9-8.6

Source: Prather *et al.* (1995)

2.3 GLOBAL WARMING POTENTIAL

The ability of a gas to absorb infrared radiation, its atmospheric lifetime, and its concentration in the atmosphere, are the three characteristics that determine its contribution to the GHE (Council for Agricultural Science and Technology (CAST), 2004). The global warming potential (GWP) is an index that represents the combined effect of the first two characteristics described above i.e. the absorptivity and the lifetime of a gas. The concentration of a gas in the atmosphere is also important because a gas is not considered an important GHG unless a sufficiently high concentration of it is present in the atmosphere, or the gas has at least the potential to reach sufficiently high concentrations (CAST, 2004). According to Good *et al.* (1998), the GWP is a representative expression of atmospheric lifetime and radiative forcing of the gas molecules which helps in calculating the climatic effects of a certain GHG.

According to EPA (2008), the concept of GWP was developed by IPCC, and it is used to compare the heat absorbing ability of all the GHGs relative to a reference gas. The reference gas chosen is CO_2 and the GWP is expressed in CO_2e (Energy Information Administration (EIA), 2004; CAST, 2004).

The GWP values of a gas can differ depending on the time horizon chosen. In order to calculate the GWP, the per-unit radiation absorptivity (or radiative forcing) of a gas is multiplied by its concentration and integrated throughout time, relative to CO_2 (IPCC, 2001). Generally the 100-year time horizon is used for GWP and this has been recommended by IPCC (1998). The GWP for some of the GHGs is given in Table 2.6. These estimates of GWPs were updated by IPCC in 2001, and differ slightly from the GWPs published in 1996 in the IPCC's second assessment report, which were 1, 21, and 310 for CO_2, CH_4, and N_2O respectively. It is these earlier values that are still used in the national GHG inventories (Australian Government Department of Climate Change (DCC), 2008; EPA, 2008; MfE, 2006b).

Table 2.6: Global warming potential of some GHGs

Gas	20 - year time horizon	100 - year time horizon
CO_2	1	1
CH_4	62	23
N_2O	275	296
SF_6	15,100	470
CFC-11	6300	4600

(source: IPCC, 2001)

2.4 MITIGATION OF GREENHOUSE GASES

In order to control and reduce the GHG emissions (from any region, country, or organisation), an inventory of all its sources and sinks is the first requirement to estimate and assess the volume of emissions. Concerns over human activities and their effect on climate change have resulted in the establishment of a number of organisations, and the initiation of many international research programmes to tackle this problem. Examples include the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP), the World Climate Research Programme (WCRP), the International Biodiversity Programme (DIVERSITAS), the International Council for Local Environmental Initiatives (ICLEI), the Cities Environment Report on the Internet (CEROI), the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC).

2.4.1 Intergovernmental Panel on Climate Change

In order to mitigate the dangers of global climate change posed by the ever increasing concentrations of GHGs, the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) joined forces to establish the IPCC in 1988. Assessment of the available scientific, technical, and socio-economic information relevant to the understanding of the risk of human-induced climate change, is included in tasks of the IPCC (IPCC, 1996), and it is done through a number of working groups. Assessment of scientific aspects of the climate system and climate change is done by Working Group-1 of IPCC; the

vulnerability of socio-economic and natural systems to climate change, negative and positive consequences of climate change and options for adapting to it are addressed by Working Group-2; while Working Group-3 is assessing options for limiting GHG emissions and mitigating climate change (Ryding, 1992).

2.4.2 United Nations Framework Convention on Climate Change

The UNFCCC, that was signed by the leaders from 150 countries gathered in Rio de Janeiro, Brazil, in June 1992, has been described as the plan for prevention of Earth's environmental death (Sitarz, 1993). Participants in the Earth Summit represented about 98% of the world's population, and provided evidence that climate change is a potential threat to the world's environment and economic development (IPCC, 1997b). Since its establishment, UNFCCC has been trying to mitigate climate change and to bring atmospheric concentrations of GHGs down to an acceptable level. However, this will not be possible without an accurate knowledge of the trends in GHG emissions and a collective effort from the international community (UNFCCC, 2005).

The number of UNFCCC member countries and states, generally referred to as "parties to the convention" has grown to 190, and these have been divided into three separate groups; Annex I Parties , Annex II Parties, and Non-Annex I Parties. All the groups have different commitments to the convention depending upon the economic condition and background of the countries included in each group.

"Annex I parties include the industrialized countries that were members of the Organisation for Economic Co-operation and Development (OECD) in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States. Annex II parties consist of the OECD members of Annex I, but not the EIT Parties. They are required to provide financial resources to enable developing countries to undertake emissions reduction activities under the Convention and to help them adapt to adverse effects of climate change. Non-Annex I parties are mostly developing countries. Certain groups of developing countries are

recognized by the Convention as being especially vulnerable to the adverse impacts of climate change, including countries with low-lying coastal areas and those prone to desertification and drought" (UNFCCC, 2008).

Under the UNFCCC, all the member countries are supposed to develop and update periodically their national inventories of anthropogenic emissions. Moreover, the emission and removal inventories should be compiled using comparable methodologies.

Different strategies have been adopted by different countries to meet their obligations of reducing emissions required under UNFCCC. For example, according to the approach adopted by New Zealand, the ability of forest ecosystems to uptake and store carbon (C) will be used to reduce most of the country's CO_2 emissions (Tate *et al.*, 1993). Tate *et al.* (1993) indicated that up to 80% of the reductions in emissions required by UNFCCC could be achieved through this strategy in the next two decades by planting exotic coniferous species extensively, and keeping the current area under indigenous forests unchanged.

2.4.2.1 The Kyoto Protocol

The Kyoto Protocol to the UNFCCC was initially agreed in Japan in 1997. It entered into force on 16 February 2005 and at present countries responsible for over 55% of global GHG emissions are committed to this protocol. It committed the ratifying countries to reduce GHG emissions by 2012 with respect to the baseline year of 1990. The entire group of Annex I countries are bound to reduce their overall GHG emissions at least by 5% of the 1990 emissions (Grover, 2004). In the Kyoto Protocol, a number of options have been provided to reduce national GHG emissions. For example Articles 3.3 and 3.4 of the Kyoto Protocol provide Annex I countries [1] the possibility to reduce GHG emissions through the

[1] Annex I countries are the 36 industrialised countries and economies in transition listed in Annex I of the UNFCCC. These countries have taken emission caps – regulatory devices that set a ceiling on emissions that can be released into the atmosphere from any one country within a designated timeframe.

sequestration of C in their terrestrial ecosystems. Article 3.3 deals with afforestation, deforestation and reforestation activities, whereas, Article 3.4 emphasises the available options through improved management of agricultural soils (United Nations, 1998).

2.4.3 New Zealand Initiatives

At the national level, in New Zealand, a comprehensive annual inventory of emissions and removals of GHGs is being prepared by the MfE every year as a part of New Zealand's obligations under UNFCCC and the Kyoto Protocol. The MfE is also working with local governments to mitigate climate change. The Communities for Climate Protection™ New Zealand (CCP™-NZ) [2] is a programme delivered by ICLEI and supported by the MfE. Under this programme, a strategic framework has been provided which helps the councils and their communities in dealing with the issues of climate change and GHG emissions. The participating councils can also benefit from international best practice and experience supported by CCP™-NZ.

CCP™-NZ is a voluntary programme which is fully funded by MfE in New Zealand. Thirty two councils have joined the CCP-NZ programme since it was launched in July 2004 (CCP-NZ, 2008), representing more than 63% of the total New Zealand population (MfE, 2006a).

According to a report released by CCP™-NZ, 11 different councils can potentially save over 287,400 Mg of CO_2e emissions by achieving the emission reduction targets set by them in the community and corporate sectors (CCP-NZ, 2006). In this regard, Christchurch City Council has already achieved a 21% reduction in GHG emissions from its facilities through implementation of a diverse programme of energy efficiency projects since 1994[3]. Other participating councils of CCP™-

[2] The information about (CCP™ -NZ) is available at: http://www.iclei.org/index.php?id=3920

[3] Available at: http://www.ccc.govt.nz/SustainableChristchurch/SuccessStories/EnergyEfficiencyGreenhouseGasEmissionsProject.asp

NZ can also benefit from the experience gained by the Christchurch City Council and can considerably reduce their GHG emissions.

Many organisations in New Zealand have already started preparing annual environmental reports. Generally an overview of the organisation's environmental management and GHG emissions is provided in these reports ((e.g. "The Warehouse Society and Environment Report 2006" available at: http://www.thewarehouse.co.nz/Content.aspx?id=100000195, "Solid Energy Environmental Reports" available at: http://www.coalnz.com/index.cfm/1,138,0,0,html/Publications), and "Contact Energy Environmental Report "available at: http://www.contactenergy.co.nz/web/pdf/environmental/2002_environmental-report.pdf). It is important to note however,that these reports do not include comprehensive inventories of GHG emissions.

2.5 GREENHOUSE GAS EMISSION INVENTORIES

In simple words, an emission inventory is an accounting exercise to measure GHG emissions. In technical terms, it involves identifying, evaluating, and measuring GHG emissions from sources and their mitigation through sinks for a certain organisation, area or country. The inventories may differ in sources of emission and number/types of gasses considered, but generally the following factors are taken into account (EPA, 2005):

- "the chemical or physical identity of the pollutants included,
- the geographic area covered,
- the institutional entities covered,
- the time period over which emissions are estimated, and
- the types of activities that cause emissions".

The European Union (EU) emission inventory programme (CORINAIR) and the IPCC source and sink categories for the estimation and reporting of national inventories of GHG emissions are the two well known systems for compiling inventories. Initially there were some differences between these systems, but

both systems have been harmonised since 1994 (IPCC, 1997a). The IPCC system is considered a flexible top down approach whereas CORINAIR is considered a strict bottom up approach.

Greenhouse gas inventories in most of the developed countries such as USA, Australia, and Canada are dominated by CO_2 emissions whereas in New Zealand, due to its strong agricultural base, the majority of emissions come from the agricultural trace gases, CH_4 and N_2O (MfE, 2006b;Saggar *et al.*, 2004).

2.5.1 Source/Sink Categories

As described earlier, inventories of GHGs may differ in their sources and the number and/or types of gases. It is hard to compare emissions from two different organisations or countries, if the sources of emissions are not clearly identified. The IPCC (1997a) has divided all the sources and sinks of GHGs into the following six broad sectors:

1. Energy
2. Industrial Process
3. Solvent and other Product Use
4. Agriculture
5. Land-Use Change and Forestry
6. Waste

Sector-wise division of GHG emissions not only makes the estimation easier, but also helps in comparison of emissions from different organisations or countries.

2.5.1.1 Energy

Emissions from the energy sector are responsible for more than two-thirds of the global GHG emissions addressed by the Kyoto Protocol (IPCC, 2001). In New Zealand, the energy sector produced 31,647 Gg CO_2e in 2004, representing 42.4% of total GHG emissions (MfE, 2006b). The emissions from the energy

sector have been divided into two main categories, namely emissions from fuel combustion, and fugitive emissions. The following four categories of fuel have been considered by IPCC (1997a):

1. coal
2. natural gas
3. oil and
4. biomass

Any emissions of GHGs resulting from intentional or unintentional anthropogenic activities other than the ones resulting from direct use of fuel for energy production are considered to be fugitive emissions. These can be a result of production, processing, transmission, storage and use of fuels. Emissions from combustion can also be included in fugitive emissions, if the combustion is not for a productive activity. An example of this is the flaring of natural gas at oil and gas production facilities (IPCC, 1997a). Emissions resulting from oil and gas production and coal mining are considered the most significant fugitive GHG emissions; but emissions of CO_2 and NMVOCs as by-products of energy production are also designated as fugitive emissions (IPCC, 1996).

Petroleum products such as asphalt have the capacity to store their C contents for longer periods of time. Other products made from fossil fuels (e.g. lubricants and plastics), also have the same ability when they are used for non-energy purposes, although some C is emitted when these products are burnt as waste (EPA, 2003). Therefore, not all the C contained in bitumen and coal tars is included in annual emissions inventories (IPCC, 1997c), although emissions of NMVOC from asphalt are included within the "industrial process" sector. For lubricants, a default factor of 0.5 should be used when better information on the C stored in the lubricants used in different sectors is not available. This is because an estimated 50% of the C in the lubricants is oxidised to CO_2 (IPCC, 1997a).

Burning of fossil fuels such as oil, coal, and natural gas produces all three main types of GHGs, i.e. CO_2, CH_4, and N_2O, but the emissions of CO_2 are the most

dominant. The amount of CO_2 emitted from fuel is determined by its C content (IPCC, 1997a).

2.5.1.1.1 Road transport

All types of vehicles using fossils fuels, irrespective of their size, engine type and make, are sources of GHG emissions. The emissions from the road transport sector have been increasing at unprecedented rates for the last two decades. In some countries the CO_2 emissions have increased by up to 400% over this time (Singh *et al.*, 2007). The transport sector in New Zealand produced about 14,313 Gg of CO_2e emissions in 2004 and the emissions in this sector have increased by 62.7% since 1990 (MfE, 2006b).

2.5.1.1.2 Air travel

Air travel is also a considerable source of GHGs emissions (Abeyratne, 1999). As the aircraft emissions also contain H_2O and NO_X besides CO_2, it is thought that the cumulative effect of all aircraft emissions is two to four times larger than the CO_2 emissions alone (Olsthoorn, 2001).

The contribution of the aviation industry to global anthropogenic CO_2 emissions is predicted to grow by 3–7% per year to 2050 (Penner *et al.*, 1999). The average numbers of passengers travelling by air have grown at a rate of 4% per year for the last 20 years. Over 2.1 billion passengers travelled by air in 2006, which increased the annual international passenger kilometres by around 6% (International Air Transport Association (IATA), 2007b). This increase in passenger numbers and kilometres flown is compensated to some extent by increases in fuel efficiency. A decrease of 8-10% in aircraft fuel consumption has been predicted through improvements in aircraft technology (Penner *et al.*, 1999), and airlines are targeting a 25% fuel efficiency improvement by 2020 (IATA, 2007a).

The IPCC (1997b) has suggested that emissions due to fuel used in international aviation should not be included in national inventories. Rather, these should be

reported separately. A study by Becken (2002) shows that international passenger air travel to New Zealand resulted in an extra energy use of 27.8 PJ which is about 6% of the annual energy use in the country. The inclusion of this energy use into the national inventory, can add 1.9 Tg of CO_2 to the national emissions.

2.5.1.2 Industrial Processes

This sector includes GHG emissions from different sources of non-energy related industrial activities (IPCC, 1997a). The industrial production processes that chemically or physically transform materials, such as emissions due to cement production, are included in this sector. Emissions resulting from a combination of fuel combustion and industrial process are difficult to allocate to a particular sector. The IPCC (1997a) has suggested that if the main purpose of the fuel combustion is to use the heat released, the resulting emissions should be included as energy emissions instead of industrial emissions.

The IPCC (1992) has recognised the non-combustion industrial processes resulting in N_2O emissions as important anthropogenic contributors to global N_2O emissions. This source category represents 10-50% of global anthropogenic N_2O emissions and 3-20% of all global emissions of N_2O. The main sources of industrial anthropogenic N_2O emissions described by IPCC (1992) are adipic acid and nitric acid production.

New Zealand produced 4,202 Gg of CO_2e in 2004 from industrial processes, with the maximum emissions (2,364 Gg or 56.3%) from metal production (MfE, 2006b).

2.5.1.3 Solvent and other Product Use

Significant emissions of NMVOCs are produced from solvents and other related compounds, and these are considered to be important sources of GHGs (IPCC, 1997a). This sub-sector includes emissions from chemical cleaning substances used in dry cleaning, printing, metal degreasing and a variety of industrial and household uses. Emissions resulting from the use of paints, lacquers, thinners

and related materials are also included in this sub-sector (MfE, 2006b). Moreover, N_2O emissions from medical products and emissions due to the use of HFCs in refrigeration and air conditioning are also included in this sub-sector.

Watson *et al.* (1991) have estimated that NMVOC release from solvent use is about 11% of the total global NMVOC emissions. New Zealand emissions from this sector in 2004 were 31.94 Gg, of which NMVOC emissions from paint application and other uses were the greatest contributor (MfE, 2006b).

2.5.1.4 Agriculture

The agricultural sector is responsible for a variety of GHGs and the emission of these gases varies according to the management practice. For example, conventional agricultural practices such as ploughing and burning of agricultural residues release more CO_2 to the atmosphere than to conservation agriculture e.g. a no tillage system (Bot *et al.*, 2003). According to a study by Liebig *et al.* (2005), continuous cropping under a no-tillage system instead of cultivation, increased soil organic C by 0.27 ± 0.19 Mg/ha/yr.

Domestic livestock, agricultural soils, rice cultivation, and burning of agricultural residues are the four most important sub-sectors responsible for GHG emissions in the agricultural sector (IPCC, 1997b). Domestic livestock cause both CH_4 and N_2O emissions due to enteric fermentation and manure, while agricultural soils contribute to emissions of N_2O as a result of adding chemical fertilisers. In addition, considerable amounts of CH_4 are emitted during rice cultivation, and burning of agricultural residues emits CO_2 into the atmosphere.

The importance of GHG emissions from agriculture in the overall GHG emissions from a country varies markedly between countries. For example, about 50% of the total GHG emissions in New Zealand come from the agricultural sector (MfE, 2006b), whereas the same sector in Australia produces only 16% of the total GHGs (DCC, 2008) .

2.5.1.4.1 Greenhouse gas emissions from domestic livestock

Ruminant animals contribute to GHG emissions in two ways. Firstly, they produce CH_4 during the digestion process ("enteric fermentation") and secondly, CH_4 is produced during the decomposition of their faecal waste (Lassey *et al.*, 1992). Moreover, when animal manure is applied to the soil, it creates favourable conditions for nitrification and denitrification by supplying degradable C compounds, N, and moisture to the soil (Chadwick *et al.*, 2000). The New Zealand National Inventory Report (NZNIR) for 2004 estimates that around 64.3% of agricultural emissions in New Zealand are from enteric fermentation by ruminants (MfE, 2006b).

2.5.1.4.2 Greenhouse gas emissions from agricultural soils

Agricultural soils have the potential to emit all three important GHGs, but the major emissions come in the form of N_2O (IPCC, 1997a). As described in Section 2.2.3, nitrification and denitrification processes involving micro-organisms in the soil produce N_2O. The agricultural system, crop type, nature of fertiliser used, time of fertilisation, and soil water content are some of the factors that affect N_2O emissions from the soil. The amount of N_2O emitted from the soil also depends on the soil type (Di *et al.*, 2007). Furthermore, a wide variety of sources of N (animal manure, fertilisers, or biological fixation compounds) to agricultural soils cause N_2O emissions. In New Zealand the main N inputs are animal excreta and chemical fertilisers (O'Hara, *et al.*, 2003).

In New Zealand, N_2O emissions from agricultural soils have increased by 24.3% since 1990. Annual emissions from this category in 2004 were 12,326 Gg CO_2e (MfE, 2006b). This category is identified as the key category for N_2O emissions in New Zealand and is comprised of the following three sub-categories MfE (2006b):

- direct N_2O emissions from animal production (the pasture, range and paddock animal waste management systems (AWMS)). The N_2O produced as a result of excreta deposited by grazing animals directly onto the pasture is included in this sub-category.

- indirect N_2O emissions from N lost from the field as NO_x or NH_3, which covers emissions due to N leaching and NH_3 volatilisation.
- direct N_2O emissions from agricultural soils as a result of adding N in the form of synthetic fertilisers, animal waste, biological fixation, crop residues and sewage sludge.

Further details of these sub-categories are given in Chapter 5 (Section 5.2.4.1).

2.5.1.4.3 Methane emissions from rice cultivation

Emissions from rice fields have been identified as a major source of atmospheric CH_4, and are estimated to contribute 6-29% of the total annual anthropogenic CH_4 emissions (Neue, 1993). A variety of organic materials are found in the flooded rice fields. The decomposition of these materials produces both CO_2 and CH_4, however the emission of CH_4 is more important in terms of global warming (Kimura *et al.*, 2004).

Experiments in different parts of the world show that the quantities of CH_4 emitted from rice fields vary from place to place (Sass *et al.*, 2002; Jiang *et al.*, 2006). Apart from the organic material, there are a number of other factors that can affect the amount of CH_4 emitted from rice fields. These factors include temperature, soil type, cultural practices, water management, and cultivar selection (Kwun *et al.*, 2003). Using a combination of unsaturated rice cultivation and straw mulch can reduce the overall amount of emitted CH_4 from rice cultivation (Xu *et al.*, 2004).

2.5.1.4.4 Greenhouse gas emissions from agricultural burning

All burning of biomass produces substantial CO_2 emissions. However, in the case of agricultural burning, IPCC (1997a) has suggested that the subsequent year's re-growth replaces the agricultural biomass burned in the previous year, and therefore the CO_2 released during agricultural burning should not be considered as a net emission.

Even if the CO_2 released due to agricultural burning is reabsorbed by the next year's vegetation, emissions of some other GHGs like CH_4, N_2O, and NO_x to the atmosphere cannot be avoided (IPCC, 1997a). New Zealand produced 25.2 Gg of CO_2e from the burning of agricultural residues in 1990 and emissions from this sub-category have decreased by 43.9% since then (MfE, 2007).

2.5.1.5 Land-Use Change and Forestry

Although land-use change and management can affect the net emissions of trace GHGs such as CH_4 and N_2O (Smith & Conen, 2004), the most important gas when calculating GHG emissions from the land-use change and forestry (LUCF) sector is CO_2 (IPCC, 1997a). Growing vegetation, especially trees planted in block plantations have the potential to sequester C. This provides an important tool to deal with the global problem of increasing atmospheric CO_2.

There is a general perception that forests and trees are always sinks for CO_2. In reality, the C sequestration process by a tree ceases when it reaches its maturity. Moreover, felling of trees and the fuel used in various forest operations cause CO_2 emissions. Therefore, LUCF can be a substantial source or a sink of CO_2, depending upon the amount of C sequestered or consumed in land-use change and forestry operations in a given year. For example, the LUCF sector was a net sink for Argentina and Zimbabwe and a net source for Indonesia in their inventories prepared for 1994 (UNFCCC, 2004).

The most important land-use changes recommended by IPCC (1997a) to be considered when calculating CO_2 emissions from this sector are:

- changes in forest and other woody biomass stocks,
- forest and grassland conversion,
- abandonment of managed lands, and
- changes in soil carbon.

Guo & Gifford (2002) analysed the data from 74 different publications and concluded that soil C stocks decline by 10% when a pasture is converted into a tree plantation. Conversion of native forest into exotic tree plantation reduced the C stocks by up to 13%, and converting native forest to crop, and pasture to crop, resulted in overall reduction of C stocks of up to 42% and 59% respectively. In contrast, soil C stocks increased after land use changes from native forest to pasture (+8%), crop to pasture (+19%), crop to plantation (+18%), and crop to secondary forest (+53%).

2.5.1.6 Waste

Disposal and treatment of municipal solid waste (MSW) and wastewater releases significant amounts of GHGs to the atmosphere (Jain *et al.*, 2002). In solid waste disposal sites (SWDSs), the organic matter is decomposed anaerobically by methanogenic bacteria which results in GHG emissions in the form of CH_4 (IPCC, 1997b). In addition to CH_4, SWDSs can also produce substantial amounts of CO_2 and NMVOCs. The primary source of CO_2 emissions from these sites is the decomposed organic material, which mainly originates from plant sources (IPCC, 1997b). In a similar way, wastewater streams, including domestic, commercial, and industrial wastewaters, can potentially emit significant amounts of CH_4 if they contain high amounts of organic material (IPCC, 1997b).

The landfill gas produced in SWDSs, can migrate laterally through the landfill and eventually be emitted to the atmosphere if no preventive measures are taken. High concentrations of this gas in the atmosphere are harmful for human health, and in some cases even low concentrations can cause harm when the exposure is for long periods of time (Chen and Greene, 2003). Efforts are therefore required to control the escape of landfill gas into the atmosphere.

During an experiment at a landfill site in Canada, Franzidis *et al.* (2008) used passively vented trenches and demonstrated that the lateral migration of landfill gas can be countered. Installing energy recovery systems at the landfill can help in reducing the overall environmental impact by utilising the landfill gas, as

compared to the landfills without energy recovery where all the gas produced escapes to the atmosphere (Chen and Greene, 2003; Mendes, *et al.*, 2004).

It is estimated that about 5-20% of the global anthropogenic CH_4 emissions come from the decomposition of solid waste (IPCC, 1996). On the other hand, emissions from waste water comprise 8-10% of the global anthropogenic CH_4 emissions and these are dominated by industrial wastewater (26–40Tg) rather than waste water from domestic and other business sources (IPCC, 1997b).

2.5.1.6.1 Factors influencing CH_4 generation in SWDSs

Waste disposal practices, waste composition, and moisture content, both in the waste itself and at the disposal site, are the main factors that control the generation of GHGs from SWDSs (IPCC, 1997a). The organic material in MSW is however the basic ingredient for CH_4 emission. Higher amounts of organic matter in the waste produce increased CH_4 emissions (Pan and Voulvoulis, 2007).

The moisture content in the solid waste helps bacterial growth and metabolism. It also facilitates the transporting of nutrients and bacteria within the SWDS (IPCC, 1997a). It is therefore possible to manipulate anaerobic activity in a managed SWDS through different management practices (IPCC, 1997a).

Bogner, *et al.* (1997), suggested that CH_4 from landfill can be oxidised through micro-organisms as well as by pumped gas recovery systems. Production of landfill gas can also be controlled by reducing and reusing the materials responsible for its production. For example solid and liquid organic waste in the MSW can be used as raw materials for manufacturing bio-fertilisers (Gajdos, 1998). Clemens and Cuhls (2003) have shown that mechanical and biological treatment of the MSW before sending it to the disposal site reduces the amount of GHG considerably.

2.5.2 Uncertainties in GHG Inventories

Emissions are hard to measure directly and continuously from all the sources involved in a GHG inventory. For example, for a national GHG inventory it is not possible to measure directly the amount of CH_4 produced due to enteric fermentation from each and every animal in the country throughout the year. Similarly, for an institutional inventory, calculating GHG emissions from travel by each and every member of the organisation is not possible. Therefore, a range of sampling techniques, reference values and default emission factors are used to prepare annual GHG inventories, and these then introduce a number of uncertainties. All inventories therefore contain uncertainties and an estimate of these is an essential part of a complete emissions inventory.

According to IPCC (2000) estimates of uncertainty do not challenge the validity of the inventory. Rather, they can be used to improve the accuracy of future inventories by, for example, improving data collection techniques and calculating country specific emission factors for different sources. According to the International Organisation for Standardization (ISO) (1993), not all the uncertainties in GHG inventories can be estimated through clear cut statistical rules, because some of the sources of uncertainty are outside the scope of statistics.

The factors responsible for the uncertainty in an inventory can be different for different countries or organisations. Generally, the uncertainties arise from incomplete and unclear definitions, natural variability of the emissions or uptake process, and the process used for assessment (IPCC, 2000). Furthermore, in developing countries the availability and accuracy of activity data and national emission factors, and the absence of stable national teams and institutional capacity are important factors that affect the accuracy of inventories (UNFCCC, 2001).

Ravindranath and Sathaye, (2002) have identified a list of issues that should be addressed, especially by developing countries, to reduce uncertainties in energy, LUCF and agricultural inventories. These include:

- "Lack or inadequacy of accurate data
- Lack of access to available data, such as satellite imagery and forest inventory, fuel wood survey for many countries
- Lack of nationally relevant emission factors
- Uncertainty in the quality and reliability of the existing data
- Using global or continental default values for emission factors to derive national greenhouse gas emissions
- Use of expert judgement in absence of data"

(Ravindranath and Sathaye, 2002, p.33)

Chapter 6 of the "IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories" has described and discussed in detail all the uncertainties that can be present in a GHG inventory. It has also been recommended that once determined, all the uncertainties should be combined together to show the overall uncertainty for the entire inventory in any year (IPCC, 2000).

2.6 MITIGATION

To avoid the undesirable consequences of an increase in the atmospheric concentrations of GHGs a number of mitigation alternatives need to be considered. The increased concentration of CO_2 in the atmosphere is considered one of the key reasons for climate change. The atmospheric concentration of CO_2 can be manipulated through management of ecosystems (Bouwman, 1990), and the effects of increased CO_2 concentration can be mitigated through C sequestration (Arnalds, 2004).

Energy conservation is a straightforward way to reduce CO_2 emissions and there are a number of options, including management practices and technology,

available to mitigate C emissions resulting from energy production and energy use. Imposing a tax on C emissions can also encourage individuals and companies to reduce their C emissions. This strategy has already been introduced by some European countries including the United Kingdom, Denmark, and Switzerland.

The Kyoto Protocol has recommended the Clean Development Mechanism (CDM) that allows Annex B countries to implement emission-reduction projects in developing countries which are then creditable towards the Annex B countries' own emission-reduction obligations under the protocol. The protocol also provides a specialised mechanism called Joint Implementation (JI) which allows Annex B countries to implement emission-reduction projects in another Annex B country (Ravindranath and Sathaye, 2002). The European Union (EU) introduced an emissions trading scheme in January 2005 to control CO_2 emissions. Other countries of the world have also developed or/and implemented GHG emissions trading schemes for example Korea, Norway, Canada, Australia, and some states of the USA (Kim & Haites, 2005; NRTEE, 2007).

Apart from imposing taxes on emissions, there are a number of other options available to reduce and/or remove CO_2 from the atmosphere. Examples include; storage of CO_2 in the ocean (Stewart and Hessami, 2005; Strak and Wardencki, 2007), in terrestrial ecosystems (Pregitzer *et al.*, 2008), and in geological formations (Stewart and Hessami, 2005; Strak and Wardencki, 2007; Thomas, 2000).

Precision technology for crop and forest management, proper utilisation of the underutilised land resources, plant and microbial biotechnology and use of chemicals are some of the technologies described by Metting *et al.* (2001) that can potentially be used for mitigating C emissions. These technologies are not only beneficial in reducing GHG emissions but can also help in improving the image of the organisation. Although some of these suggested technologies are still in their experimental stages, they provide a good platform to work on and opportunities to maximise C sequestration.

2.6.1 Carbon Sequestration through Soil, Crop and Forest Management

Carbon sequestration in soil can be increased considerably by certain management practices in agriculture and forestry (Metting *et al.*, 2001). Land-use change and forestry projects, such as establishing tree plantations, can be used to offset emissions of CO_2 resulting from anthropogenic activities (Cacho *et al.*, 2003), and these projects can be established on waste land that is not suitable for agriculture (Wang *et al.*, 2004). Even a short term LUCF project can be established by planting trees in any form on any suitable piece of land. This sequestration can further be enhanced by conserving existing forests and discouraging deforestation.

Agroforestry is a system in which trees are established with agricultural crops in different combinations. Agroforestry can help in achieving sustainable forest production along with agricultural production (Ruark *et al.*, 2003). This system is becoming more popular worldwide because it promotes agricultural sustainability and also helps in mitigating climate change (Albrecht & Kandji, 2003).

Precision agriculture is a concept in which management decisions are made with the assistance of modern technologies including geographic information systems (GIS), global positioning systems (GPS), satellite imagery, aerial photographs and different kinds of sensors. These systems can help to identify areas suitable for certain types of vegetation and also improve the efficiency of inputs such as fertiliser. Thus, through precision agriculture, soil C sequestration can potentially be increased while decreasing energy use considerably (Metting *et al.*, 2001).

2.6.2 Exploitation of Under-utilised Resources

Some of the underutilised substances considered by Fontenot, *et al.* (1983) are; food processing wastes, industrial non-food processing wastes, forest residues, animal wastes, crop residues, and aquatic plants. It is possible to reduce emissions and mitigate the effects of GHG by utilising these resources efficiently. For example, animal wastes and forest residues can be used as

alternative materials for energy production (Katinas, *et al.*, 2007). In addition, agricultural and forestry residues can be used as feedstock for charcoal making (Patil *et al.*, 2000).

2.6.3 Erosion Control and Soil Restoration

Accelerated soil erosion has caused large losses (about 25 Pg) of C in the past, and further losses can be avoided by adopting effective measures against soil erosion (Lal, 2002). Furthermore, restoration of eroded soils provides an opportunity to sequester a large proportion of the C that was emitted due to past erosion events. Conservation tillage is an effective technology to reduce soil erosion from agricultural lands. Adopting zero tillage techniques in temperate and tropical environments can accumulate at least 0.3 – 0.6 Mg C/ha annually (Pretty and Ball, 2001). Lal *et al.* (1998) have estimated that 1,480 to 4,900 Tg of C can be sequestered globally through conservation tillage alone.

Different soil restoration techniques on degraded soils can also be helpful in enhancing their ability to sequester atmospheric C. For example, grazing exclusion and long term application of organic manure, combined with moderate use of chemical fertiliser can greatly enhance the C storage in soil (Li *et al.*, 2008). A study conducted in Rio de Janeiro by Macedo *et al.* (2008), concluded that restoration of degraded land with the help of leguminous N fixing trees can sequester considerable amounts of C.

2.6.4 Mitigation of GHG by Forests

"Forest mitigation options include reducing emissions from deforestation and forest degradation, enhancing the sequestration rate in existing and new forests, providing wood fuels as a substitute for fossil fuels, and substituting wood products for more energy-intensive materials" (Nabuurs *et al.*, 2007, p.544). Forest soils, especially in indigenous forests, are considered good sinks of GHGs. Upland soils of boreal and temperate forests are considered important biological sinks of atmospheric CH_4 (Whalen and Reeburgh, 1996).

Menyailo and Hungate (2003) conducted a study on Siberian boreal and temperate forests involving six common tree species. They found that the rate of CH_4 consumption by the soils under hardwood species (aspen and birch) was higher than soils under coniferous species and grassland. They also found that the effect of soil moisture on CH_4 consumption under different species was not uniform. For example, under spruce, soil moisture enhanced CH_4 consumption but had the opposite effect under Scots pine and larch.

2.6.5 Waste Management

Better waste management practices provide opportunities to reduce emissions of GHGs. Bogner *et al.* (2007) have discussed a number of options to reduce GHG emissions from waste. Their management strategies include recovering gas from landfills, post-consumer recycling, composting, incineration, industrial combustion, mechanical & biological treatment, and anaerobic digestion. These options have been reviewed again in detail by Bogner *et al.* (2008), who have concluded that current technologies can effectively mitigate the GHG emissions from waste. For example, landfill gas can be used as an alternative energy source through engineered systems (Bogner *et al.*, 1997). Devising such systems will help in mitigating effects of GHG along with reduction in fossil fuel consumption. However, it is not feasible for developing countries to opt for expensive technologies, like installing gas recovery systems in the landfills, due to the lack of capital. Therefore, more emphasis is placed on cost-effective technologies – e.g. waste minimisation, recycling, and reuse of waste materials.

Reduction in waste, especially "source reduction that reduces the amount of material being produced, avoiding emissions from the outset, is the most desirable option" (Mohareb *et al.*, 2004, p.90). Similarly, recycling organic materials can reduce the toxic gas emissions resulting from incineration of waste (Abad, 2003).

2.6.6 Dairy and Livestock

In animal management systems, longevity and reproductive rate are currently the areas having the largest potential for reducing GHG emissions. Breeding dairy animals with longer survivability would allow farmers to keep the mature animals for longer periods of time. This would reduce the numbers of replacement stock required and as mature animals tend to have higher yields keeping them in the herds for longer periods will give economic advantages to the farmers along with the environmental benefits (Berry *et al.*, 2003). Apart from survivability, increasing the fertility of animals provides another way of reducing GHG emissions. For example, greater reproductive ability in sheep results in more lambs from the same number of ewes. A study by Garnsworthy (2004), has shown that improving fertility in animals up to a certain level can reduce CH_4 and N_2O emissions by up to 24% and 17% respectively.

Similarly, "ionophores[4] can reduce CH_4 production by 25% and decrease feed intake by 4% without affecting animal performance. The inclusion of monensin[5] in beef and dairy cattle diets may benefit air quality by reducing CH_4 and N in manure which can potentially leave the farm through leaching into ground water and through runoff into surface water" (Tedeschi *et al.*, 2003, p. 1591). It is important to note that most of these studies have been conducted in countries other than New Zealand and the applicability of the results under New Zealand conditions is yet to be assessed.

Luo and Saggar (2008) have presented a rather simpler option to mitigate N_2O and CH_4 emissions from animal excreta by using stand-off pads. They used screened crushed pine bark and sawdust on a stand-off pad for three months and found that the highest flux of N_2O-N from an area of 300 m^2 was ~ 3 g/day. Despite the apparent reduction in N_2O-N emissions, the use of stand-off pads is still debateable because poor management of stand-off pads may create issues

[4] An ionophore is a lipid-soluble molecule usually synthesized by microorganisms to transport ions across the lipid bilayer of the cell membrane.

[5] A broad-spectrum antibiotic, $C_{36}H_{62}O_{11}$, obtained from the actinomycete *Streptomyces cinnamonensis* and used chiefly as an additive to beef cattle feed.

of environmental damage and animal welfare. It can even cause loss of weight in farm animals (Fisher *et al*, 2003).

2.7 SUMMARY AND CONCLUSIONS

A general introduction to the GHE, GHGs, and GWPs is provided in this chapter. Global warming is believed to be a result of the excessive emission of GHGs, which is causing worldwide climate change. Global atmospheric concentrations of important GHGs are presented, the different sources of important GHGs are mentioned and some measures to reduce emissions of these gases are also outlined.

The international community is very much concerned about these issues and has responded by establishing a number of environmental organisations. The signing of the UNFCCC by around 150 countries in 1992 is the greatest response of the international community towards the widespread problem of GHG emissions and environmental degradation. The Kyoto Protocol is the agreement achieved under the UNFCCC and binds member countries to reduce their GHG emissions to certain agreed levels.

Although a number of guidelines and emission factors for calculating GHG emissions from different sectors have been provided by IPCC for national GHG inventories, a lot of work is still needed by countries in order to establish their own emission factors to develop more accurate and reliable inventories. Also it is not possible to measure emissions from all sectors directly and continuously, and therefore estimates have to be made for some GHG emissions from the available data. This process of estimation introduces a number of uncertainties into the inventories, and considerable effort is required to reduce these uncertainties to a minimum level.

Most of the developed and developing countries have already started reporting annual emissions. Although inventories can be compiled at a national level, any actual reduction in GHG emissions will require action by individuals and

institutions within society. It is for this reason that individual institutions and organisations have started taking an interest in annual emissions reporting. This initiative is still in its early stages, and most of the companies and organisations involved are doing it on a voluntary basis. As a result there is a considerable range in approaches employed, and at some stage some standard guidelines will have to be developed.

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CHAPTER 3: ENERGY

3.1 INTRODUCTION

The Energy sector is potentially the largest single contributor to greenhouse gas (GHG) emissions within the University, but within this sector there are several categories, including buildings (electricity, gas and coal), vehicles, and aviation. Accordingly, in this chapter these principal energy sources are described, and the available data from 1990 and 2004 presented. Then emissions from each source are calculated and aggregated, and the changes in these emissions presented. Finally, possible ways to improve future energy sector inventories and to reduce these emissions are outlined.

The main challenge for estimating emissions for the baseline year (1990) was the non-availability of data. Generally, the data for 1990 are less reliable than for 2004. Nevertheless, these data have been included to estimate baseline emissions, and so estimate the changes in emission levels since 1990. At the University, most of the records are kept for 7 years only in compliance with the Inland Revenue Department (IRD) rules, and therefore all the historical records have been shredded. This made it more difficult to estimate emissions in 1990.

3.1.1 Global Emissions from Energy

A variety of energy sub-sectors (for example the production, transformation, handling and consumption of energy commodities) contribute to GHG emissions (IPCC, 1997). More than two-thirds of the global GHG emissions are caused by energy use (IPCC, 2001), and about 85% of the world's total energy supply comes from three major types of fossil fuels i.e. coal, oil, and natural gas (Harvey, 1999).

The world energy consumption is growing day by day. IPCC (2005) has reported an annual growth rate of 1.4% in global primary energy consumption between 1990 and 1995 and 1.6% between 1995 and 2001. The growth rates of average

global carbon dioxide (CO_2) emissions are comparable with the growth in primary energy consumption between 1990 and 1998. However, these percentage growth rates are lower than the reported growth rates of global annual CO_2 emissions of 2.1% in the 1970s and 1980s (IPCC, 2001). Global CO_2 emissions due to fossil fuel use by sector, from 1971-2001 are shown in Fig. 3.1.

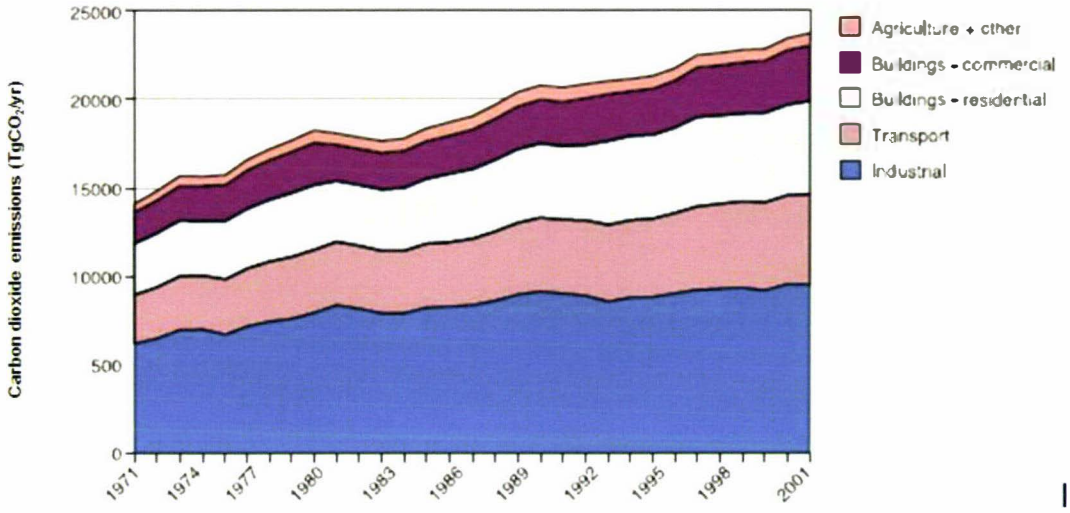

Figure 3.1: World CO_2 emissions due to primary energy use by sector, from 1971-2001 (IEA, 2003).

Public electricity generation and heat production are the major contributors to global emissions from the energy sector (IEA, 2003), but transport has been identified as the fastest growing sub-sector for the last few decades (IPCC, 2001).

3.1.2 Types of Emissions from the Energy Sector

As described in the previous chapter, IPCC (1997) has organised the emissions from energy systems into two main categories: emissions from fuel combustion and fugitive emissions. The four main groups of fuel identified by IPCC (1997) are coal, natural gas, oil and biomass.

IPCC (1996) has reported that annual fossil fuel combustion results in an average per capita emission of 4.0 Mg of carbon (C) globally. For developed countries this figure is much higher at 10.3 Mg, with a range between 5.5 and 20.2 Mg per person (IPCC, 1996).

The transport sector, particularly road transport, is a major source of fossil fuels-related GHG emissions (Anil *et al.*, 2007; Ministry for the Environment (MfE), 2006). Air travel is also an important source of GHG emissions (Abeyratne, 1999; IPCC, 1999) and inclusion of international air travel in national inventories can increase the national energy use by a considerable amount (Becken, 2002). In addition to CO_2, aircraft also emit other GHGs. Olsthoorn (2001) has estimated that the cumulative effect of all aircraft emissions is two to four times larger than the CO_2 emissions alone. The current growth rate of aviation emissions is 0.7% per year (IPCC, 2007b) and a continuous growth in global CO_2 emissions due to this sub-sector has been predicted by IPCC (1999). It is thought that this will reach 0.23-1.45 Tg C/year by 2050.

3.1.3 Emissions from the Energy Sector in New Zealand

In New Zealand the energy sector emitted 31,647 Gg CO_2 equivalents (CO_2e) in 2004, representing 42.4% of the country's total GHG emissions (MfE, 2006). There has been an overall increase of 33.8% in emissions from the energy sector since 1990 (Fig 3.2), and emissions from road transportation, which have increased by 62.7% over this period, are the major source responsible for the increased emissions from this sector in New Zealand. However, the highest percentage increase in emissions since 1990 (73.6%) has been from public electricity and heat production (MfE, 2006).

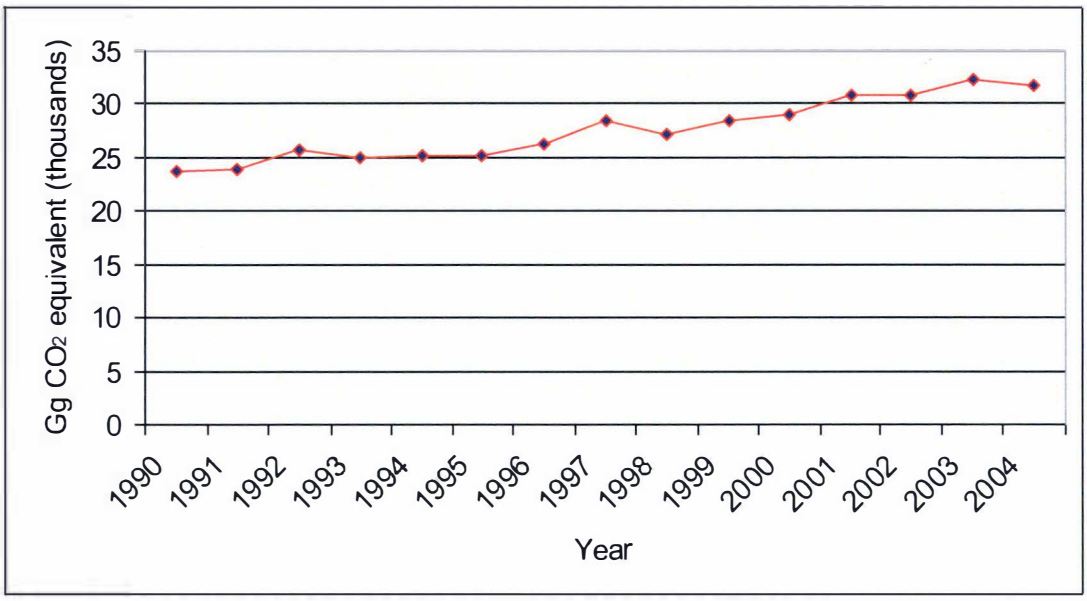

Figure 3.2: Greenhouse gas emissions from the energy sector in New Zealand from 1990 to 2004.

Source: (MfE, 2006)

3.2 METHODOLOGY

For emission calculations at Massey University the energy sector was divided into five categories: Electricity, Gas, Coal, Vehicles, and Aviation. Calculation of GHG emissions from the energy sector required the following three components:

- the quantity of the fuel or energy consumed during one year
- a national or IPCC default emission factor estimate of methane (CH_4), nitrous oxide (N_2O), and CO_2 emissions per unit source, and
- a conversion factor to standardise the results in terms of CO_2e

Direct CO_2 emissions were calculated by multiplying the amount of energy used or generated by the appropriate emission factor, and CH_4 and N_2O emissions were converted into CO_2e by multiplying the estimated emissions by the global warming potential (GWP) values for CH_4 and N_2O, i.e. 21 and 310 respectively (EIA, 2003; Houck & Tiegs, 1998).

Emissions were calculated for the current (2004) year and the baseline year of 1990. While a complete data set for 1990 was unavailable from number of sectors, some data sets were located in the Massey University archives. For example, the amounts of electricity, gas, and coal used in 1990 were obtained from documents in the archive but the amounts of diesel and petrol consumed in 1990 had to be obtained from the supplier. A variety of different approaches were adopted to provide reliable estimates of the missing information where actual data from 1990 were unavailable. These approaches are described in the appropriate sections.

In all cases, attempts were made to assign an uncertainty to each of the estimated GHG emissions. This was a very challenging process. Where the methodology involved a sampling or a survey approach then the associated uncertainty could be estimated from the variation in the data. In other cases, estimates of uncertainty for emission factors were available from national or international agencies. But in many cases information was sourced from the records and archives of Massey University, and for this information it was difficult to quantify the uncertainty associated with the data. Rather than assign no uncertainty to these data, and thereby give a misleading impression of the reliability of the calculated GHG emissions, an uncertainty was assigned that seemed to reasonably indicate the reliability of the data.

3.2.1 Electricity and Gas

Current and historical data on electricity and gas consumption were provided by the Massey University Physical Resources Manager and the Utilities Manager-Electrical (Cheryl Hutchinson and Rick Budd, personal communication). Although most of the University accounts and records are only kept for 7 years, in accordance with IRD requirements, the data for electricity use from 1991 and gas use from 1990 were available in an old computer programme held by the Utilities Manager. The amount of electricity used by Massey University in 1990 was collected from an archived energy file (Green *et al.*, 1991).

The total electrical energy consumed (kWh) was converted into MJ (3.6 MJ per kWh), and multiplied by the national emission factor i.e. 43.1 g of CO_2 per MJ (Ted Jamieson, personal communication; cited in (Ministry of Agriculture and Forestry (MAF), 2003)) (Eq. 3.1):

$$CO_2\ (g) = \Sigma E\ (kWh) \times 3.6\ (MJ/kWh) \times 43.1\ (gCO_2\ /MJ) \quad (3.1)$$

The same procedure was used for calculating emissions from the use of natural gas. Total energy consumed in kWh during the year was converted into MJ and then multiplied by a national emission factor i.e. 52.3 g of CO_2 per MJ of energy (New Zealand GHG Emissions 1990-2001; cited in (MAF, 2003)) (Eq. 3.2):

$$CO_2\ (g) = \Sigma E\ (kWh) \times 3.6\ (MJ/kWh) \times 52.3\ (gCO_2\ /MJ) \quad (3.2)$$

An uncertainty of ±5% was assigned to allow for any errors in assessing the quantity of electrical energy used based on records. This estimate of uncertainty is consistent with the approach of IPCC (2000) who noted that uncertainty in data collection on energy use can be attributed to both systematic and random errors, the combination of which is estimated to provide an uncertainty of ± 5%.

A ±10% uncertainty was assigned to the national emission factor of 43.1 g CO_2/MJ. This uncertainty includes the uncertainties on the emission factors for each fuel type used in the generation of electricity (coal, gas, geothermal, hydro, diesel), which individually are in the order of ±2-3% (MfE, 2007), and also an additional component of uncertainty to account for a possible deviation from the national value in the source of electric power used by Massey compared with the national average. It was not possible to quantify this final component of uncertainty because the sources of the electric power used by Massey University are not known, but making an allowance for this additional source of uncertainty ensured that the overall uncertainty was not underestimated. These uncertainties were propagated through the various stages of the calculation[1].

[1] refer xl spreadsheet "energy_master.xls, worksheet "electricity" in the CD attached.

Similarly in the case of gas, an uncertainty of ±5% was assigned to any possible metering error and to the value of total consumed energy. However, a comparatively smaller uncertainty of ±5% was assigned to the national emission factor for gas, because of the small differences between emission factors for gas from different regions of the country (e.g. 51.7 Mg CO_2/TJ from Maui and 52.3 Mg CO_2/TJ from Mangahewa (MfE, 2007)). These uncertainties were propagated through the various stages of the calculation[2].

3.2.2 Coal

At present there is no usage of coal on the campus or on the farms. However, until the early 1990s Massey University used a coal-powered forced circulation water tube boiler plant for heating various buildings on the Turitea campus. No records of coal use were available from Regional Facilities Management, but a report on energy management by Works Consultancy Services Limited was found in the Massey University archives. The report describes the quantities of gas, electricity and coal used by Massey University from 1986 to 1990 (Green *et al.*, 1991).

The coal used by Massey University was sourced from the Huntley coal mines, for which the energy conversion factor is 23.8 MJ/kg (Baines, 1993). The total weight of coal used (in kg) was multiplied by 23.8 to give the total energy produced in MJ. This total energy was then multiplied by the emission factor of 91.2 g CO_2/MJ to give the total amount of CO_2 produced (Baines, 1993) (Eq. 3.3):

$$CO_2\ (g) = \Sigma coal\ (kg) \times 23.8\ (MJ/kg) \times 91.2\ (gCO_2\ /MJ) \quad (3.3)$$

An uncertainty of ±5% was assigned to the total energy consumed to reflect the possible error associated with using archived records to assess the quantity of coal used (IPCC, 2000). The emission factor used to estimate coal emissions was 91.2 g CO_2/MJ was taken from the New Zealand Energy Information Handbook (Baines, 1993) and is for sub-bituminous coal. The energy emission

[2] refer xl spreadsheet "energy_master.xls, worksheet "gas" in the CD attached.

factor varies with the type of the coal, from 89 to 94 g CO_2/MJ. Therefore another ±5% uncertainty in the emission factor was included in the calculations[3], reflecting the spread of energy emission factors between different coals.

3.2.3 Vehicles

This energy sector category comprises emissions from Massey University-owned vehicles, farm vehicles, vehicles owned by Massey University's grounds department, and commuting vehicles. Massey University owns (or leases) more than 200 registered vehicles, including 67 leased fleet vehicles (Grant Storrier, personal communication) (Annex. 3.1). The Massey University fleet is controlled by a fleet manager within Regional Facilities Management. Fuel for most of the Massey University-owned vehicles is now obtained through BP fuel cards. Fuel for the farm vehicles is supplied by other fuel distribution companies, such as RuralFuel. Information on the quantity of fuel used by the Massey University fleet cars and other University-owned vehicles was collected from the fleet manager (Rick Bragger, personal communication). The amount of fuel consumed by the farm vehicles was collected from the Massey University Agricultural Services office (Geoff Warren, personal communication).

Shell New Zealand had historically supplied fuel to the campus for the use of some Massey vehicles, but this ceased in December 2003 when Regional Facilities Management removed the fuel tank from the campus (Terry Hammond, Regional Facilities Management, personal communication). The data on fuel supplied by Shell New Zealand in 2003[4] and in 1990 was collected from them directly (Dennis Clueard, Shell New Zealand, personal communication).

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[3] refer xl spreadsheet "energy_master.xls, worksheet "coal" in the CD attached.
[4] This data is a part of 2003-04 figures i.e. from 1st July 2003 to 30th June 2004

3.2.3.1 Commuting Vehicles in 2004

Apart from the fleet and other Massey University registered vehicles, there are privately owned and business vehicles that visit the University campus every day. All these vehicles were included in the commuting vehicles category. Emissions from commuting vehicles are very important and many Universities have included these emissions in their GHG inventories. For example, at the Durham campus of the University of New Hampshire (UNH) student and staff commuting was responsible for 11% of the total GHG emissions in 2004 (UNH, 2004). Similarly, 9% of the total GHG emissions were estimated to come from commuting traffic at Tulane University (TU) during the year 2000 (TU, 2002). The University of British Columbia (UBC) has been trying to reduce the number of commuting vehicle trips to and from its campus since 1997 (UBC, 2007).

The quantities of petrol and diesel consumed by commuting vehicles were estimated on the basis of a series of surveys, sampling, and physical counting of vehicles. It was assumed that all petrol vehicles consumed one litre of petrol to cover a distance of 10 kilometres, while all the diesel engined vehicles consumed one litre of diesel to cover 12 km (A. Khawaja, personal communication).

In order to estimate annual CO_2 emissions from commuting vehicles to the Turitea campus, the following parameters were required:

- Number of commuting vehicles during the year
- Type of vehicle (petrol/diesel)
- Average distance travelled by each commuting vehicle
- Ratio of student and staff vehicles

3.2.3.1.1 Calculating number of commuting vehicles to the Turitea campus

Massey University Turitea campus has six entrances for traffic, namely: Main Drive, Bourke Road, Albany Drive, Prendergast Road, Commercial Centre, and the Monro Hill entrance. The single Massey University-owned traffic counter

(MetroCount Traffic Executive vehicle counter, Fig 3.3) was installed at the Main Drive for one week periods eleven times between December 2003 and November 2004. This gave a profile of traffic using the main entrance (Table 3.1).

The estimates of traffic using other entrances were made with the help of Palmerston North City Council, by installing traffic counters at all entrances for one-week periods four times during 2003-04 (Table 3.2). The times when traffic counters were installed were carefully selected to account for all the expected variations in traffic flow to the campus due to extramural courses, study breaks, and examinations.

Figure 3.3: MetroCount vehicle counter installed at the Massey main entrance

A relationship between the number of vehicles entering and leaving through the Main Drive and the total number of vehicles entering and leaving through all the entrances was established by using the data from the four rounds of full counting (Table 3.3). On average, 61.5% of the traffic entering and leaving the campus used the Main Drive. By using this average, the total number of return trips to the campus was calculated for all 11 counting periods (Table 3.4).

Table 3.1: One-week vehicle counts[5] at the Main Drive entrance during 2003-04.

Serial Number.	Month	Total counts/week	Remarks
1	Dec-03	28,117	During the semester break
2	Jan-04	21,024	During the semester break
3	Feb-04	36,644	First week of semester one
4	Mar-04	78,413	During semester one
5	Apr-04	45,897	Study break +Extramural courses
6	May-04	44,923	During semester one
7	Jun-04	22,093	During the semester break
8	Jul-04	44,944	First week of semester two
9	Aug-04	48,545	During semester two
10	Oct-04	40,082	Examination Week
11	Nov-04	41,769	Examination Week

Table 3.2: Number of counts per week to the Turitea campus during four week-long survey periods in 2003-04.

Period of counting	Main Drive	Commercial Centre entrance	Bourke Road	Prendergast Road	Albany Drive	Monro Hill entrance	Total counts
10-17 Dec. 2003	28,117	787	2,114	5,132	5,645	6,076	47,871
11-18 Mar. 2004	78,413	2,152	7,553	17,031	17,118	8,002	130,269
28 Jun- 5 Jul, 2004	22,093	587	2,343	24	4,624	2,830	32,501
18-25 Aug. 2004	48,545	1,123	5,141	9,928	9,560	7,703	82,000

The Massey academic calendar was then divided into five sections according to the predominant activity occurring on the campus at the time (Table 3.5). The number of vehicle counts per week was then allocated to each of these five time periods, using the information in Table 3.1. Where there was more than one counting period for a particular activity occurring on campus (e.g. during semester one) an average value was calculated. Finally the total number of return trips to the campus per year was calculated by multiplying the weekly figures with the total number of weeks in each category and summing the resultant products (Table 3.5).

[5] These vehicle "counts" include vehicles both entering and then leaving the campus.

Table 3.3: Ratio of the number of vehicles using the Main Drive to the total number of vehicles entering and leaving Massey during four counting periods – each of one week

Period of counting	Main Drive vehicle counts	Total vehicle counts	% of total vehicles using the Main Drive
10-17 Dec. 2003	28,117	47,871	58.7
11-18 Mar. 2004	78,413	130,269	60.2
28 Jun- 5 Jul. 2004	22,093	32,501	67.0
18-25 Aug. 2004	48,545	82,000	59.2
Average			61.5

Table 3.4: Calculated weekly vehicle counts and return trips[6] assuming vehicle counts on the Main Drive are 61.5% of the total vehicle counts to and from the campus

	Month	Counts (Main Drive)	Estimated counts (all entrances)	Estimated return trips to campus	Remarks
1	Dec-03	28,117	47,871	23,936	During the semester break
2	Jan-04	21,024	34,169	17,085	During the semester break
3	Feb-04	36,644	59,555	29,778	First week of semester one
4	Mar-04	78,413	130,269	65,135	During semester one
5	Apr-04	45,897	74,593	37,297	Study break + Extramural courses
6	May-04	44,923	73,010	36,505	During semester one
7	Jun-04	22,093	32,501	16,251	During the semester break
8	Jul-04	44,944	73,044	36,522	First week of semester two
9	Aug-04	48,545	82,000	41,000	During semester two
10	Oct-04	40,082	65,142	32,571	Examination week
11	Nov-04	41,769	67,884	33,942	Examination week

Table 3.5: Return trips per week and total annual return trips calculated according to the activities occurring on campus

Category	No.of weeks	Return trips/week	Total trips
During semester breaks	14	19,091	267,274
During semester breaks but when extramural courses are on	7	37,297	261,079
During semester one	12	43,806	525,672
During semester two	13	38,761	503,893
During examinations	6	33,257	199,542
Total return trips to campus/year			1,757,460

[6] Return trips are calculated by dividing number of vehicle counts by 2

3.2.3.1.2 Proportion of petrol and diesel vehicles

Vehicles were also physically counted twice throughout the campus and five times at different parking areas on the campus to estimate the proportions of petrol and diesel vehicles (Table 3.6). Out of the total 5,836 vehicles counted over all the surveys, 344 were diesel vehicles, which is 5.9% of the total. A separate survey (see next section) of 385 students and staff in parking areas on the campus indicated that the proportion of diesel vehicles driven to the campus was 7.3% (Table 3.7). According to the national figures provided by LTSA at the end of 2000, around 7% of the total cars on the register were diesel cars (Ministry of Economic Development (MED), 2005).

Table 3.6: Number of petrol and diesel vehicles in selected car parks and on the whole campus

Date	Place/Parking	Number of vehicles			
		Diesel	Petrol	Total	% of Diesel vehicles
24/05/2004	Gravel free parking	46	1,116	1,162	4.0
25/05/2004	Upper level free parking	15	216	231	6.5
26/05/2004	Upper level free parking	16	212	228	7.0
1/06/2004	Upper level free parking	18	220	238	7.6
1/06/2004	Gravel free parking	45	848	893	5.0
1/06/2004	Full campus	109	1,490	1,599	6.8
29/06/2004	Full campus	95	1,390	1,485	6.4
Total		344	5,492	5,836	
Average					5.9

3.2.3.1.3 Average distance travelled by commuting vehicles

In order to estimate the average distance travelled by each vehicle coming to the campus, 385 students and staff members were interviewed on eight different dates at different parking areas. The average one-way distance travelled by staff and students was 9.5 km per trip (Table 3.7). There was a consistent difference between staff and students in the average distance travelled to the campus, with staff on average travelling 5.8 km further. Therefore, in subsequent calculations it

was assumed that on average, students and staff members were travelling 7 km and 13 km one way respectively to get to the campus.

3.2.3.1.4 Staff/student ratio for commuting vehicles

An analysis of the total number of persons on Turitea campus from 1990 to 2004 shows that the percentage of staff varied from 10 to 15% of the total number of people on campus (Table 3.8). It was therefore assumed that 15% of the total return trips to the Turitea campus during 2003-04 were made by staff i.e. 263,619 return trips. This left 1,493,841 return trips by students and other vehicles. Although the figure of 15% adopted for staff return trips is slightly higher than the average of the student/staff ratio in Table 3.8, it is believed that the proportion of staff travelling in private cars might be slightly higher than the proportion of the students.

Table 3.7: Estimation of average distances travelled by Massey University students and staff; and the proportion of diesel vehicles.

Interview Date	Interviews			Distance travelled			Ave. distance			% of diesel vehicles		
	Staff	Stds	Total	Staff	Stds	Total	Staff	Stds	Total	Staff	Stds	Total
9/08/2004	23	45	68	487	342	829	21.2	7.6	12.2	13	4.4	7.4
10/08/2004	16	43	59	161	261	422	10.1	6.1	7.2	12.5	4.7	6.8
11/08/2004	29	10	39	224	70	294	7.7	7	7.5	3.5	0	5.1
12/08/2004	33	7	40	543	101	644	16.5	14.4	16.1	3	0	2.5
13/08/2004	44	0	44	591	0	591	13.4	0	13.4	13.6	0	13.6
16/08/2004	11	34	45	64	221	285	5.8	6.5	6.3	9.1	5.9	6.7
17/08/2004	9	45	54	65	303	368	7.2	6.7	6.8	0	11.1	9.3
18/08/2004	3	33	36	18	213	231	6	6.5	6.4	0	6.1	5.6
Total	168	217	385	2,153	1,511	3,664	12.8	7	9.5	8.3	6	7.3

Table 3.8: Total number of persons and % of staff at the Turitea campus of Massey University

Year	Full time equivalent staff	Full time equivalent students	Total student + staff	% of staff
1990	1,386	10,567	11,953	11.6
1991	1,403	11,676	13,079	10.7
1992	1,483	11,874	13,357	11.1
1993	1,593	12,457	14,050	11.3
1994	1,689	12,769	14,458	11.7
1995	1,707	13,435	15,142	11.3
1996	1,762	13,522	15,284	11.5
1997	1,982	15,090	17,072	11.6
1998	1,963	15,298	17,261	11.4
1999	2,359	14,064	16,423	14.4
2000	2,358	13,287	15,645	15.1
2001	1,877	13,506	15,383	12.2
2002	2,127	13,914	16,041	13.3
2003	2,219	14,325	16,544	13.4
2004	2,155	14,083	16,238	13.3

3.2.3.2 Commuting traffic in 1990

There were no University records available of the number of commuting vehicles entering and leaving the campus in 1990. A file dated 11/6/1990 from the Palmerston North City Council showed that the average daily traffic count through the Massey main entrance was 4,570 counts per day.

An attempt was also made to relate the number of commuting vehicles to the number of parking spaces available in 1990 and at present, but unfortunately no accurate record of the number of parking spaces was available for 1990. A report from the Massey Archives shows the number of parking spaces in 1988 was 1,866. According to Dave Beattie (Manager, Traffic and Security) there are currently 3,510 available parking spaces on the campus. This is approximately an 88% increase in the parking spaces on the campus compared with 1990.

The approach used was to relate the number of commuting vehicles to the total number of full time equivalent staff and students at the Turitea campus, and to assume therefore that the numbers of return trips to the campus in 2004 and 1990 were in direct proportion to the numbers of full time equivalent students and staff on the campus in those years (Table 3.9). This approach is likely to overestimate the number of vehicle trips in 1990 because anecdotal evidence suggests that the use of bicycles by both staff and students was much greater in 1990 than in 2004. It is not however, possible to estimate the size of this possible error.

Table 3.9: Total number of return trips by commuting vehicles in 1990

Year	Full time equivalent staff + students	Ratio (return trip/staff + students)	Total return trips during the year
1990	11,953	108.23	1,293,689
2004	16,238	108.23	1,757,460

3.2.3.3 Calculations and Uncertainties

Once the number and distance of the return trips had been calculated, the quantities of fuel consumed during the year were calculated, and then the fuel consumed was multiplied by the appropriate emission factors (Table 3.10). To calculate the total GHG emissions in CO_2e from a given quantity of fuel, the quantities of CH_4 and N_2O are multiplied by their respective GWP value and then added together with the amount of CO_2 released.

Table 3.10: Emission factors for different categories of fuel

Fuel	Emissions kg/litre of fuel consumed		
	CO_2	CH_4	N_2O
Petrol	2.4	0.002052	0.000103
Diesel	2.8	0.000493	0.000115
AvGas*	2.4	0.00005201	0.00003715

Source: (Bone, *et al.*, 1993)
* Aviation gasoline

A large uncertainty (±20%) was assigned to the estimation of the annual number of commuting trips by petrol and diesel vehicles. This uncertainty is made up of uncertainties from several sources, including: the annual number of vehicles

visiting the campus via the main gate (11 weeks counted out of 52); the annual number of vehicles visiting the campus via other entrances (4 weeks counted out of 52); the number of vehicles identified as being either petrol or diesel (5,836 vehicles counted and 385 drivers interviewed); and the ratio of students to staff (and how this affects commuting distance and vehicle ownership, both of which vary between staff and students). Quantitative estimates of each of these individual uncertainties were difficult to obtain, but if it is assumed that each of these individual uncertainties was ±5%, then a value of ±20%for the overall variation seems reasonable.

A ±10% uncertainty was assigned to the distances travelled by vehicles per litre of diesel and petrol, respectively, due to the mixed ages and engine sizes of the vehicles. The calculation was made using the following parameters: a mean value of 10 km/litres for fuel efficiency (www.fuelsaver.govt.nz); a standard deviation for fuel efficiency of half the general range of fuel efficiencies (about 5-15 km/litres; www.fuelsaver.govt.nz), being equal to 2.5 km/litres; and an assumption that 1 in 2 staff and students owned a car and used it for commuting (about 8,000 out of 16,000 in 2004), making n = 8,000. The resulting calculation of the uncertainty (±2 standard errors of the mean) was ±8%. In order to not underestimate the error, this value was rounded up to ±10 %.

The uncertainty associated with the average distance per trip was calculated from the standard errors of the mean trip distances obtained from surveys of staff and students. Uncertainties of ±5%, ±50%, and ±50% were assigned to the emission factors due to fuel combustion for CO_2, CH_4, and N_2O respectively (MfE, 2007; MED, 2006). A ±20% uncertainty was assigned to the global warming potential values for CH_4 and N_2O. This covers the difference in these values calculated by IPCC in 1996 and 2007, respectively (IPCC, 1997; 2007a). The uncertainties were propagated through the various stages of calculation[7]. For the estimation of 1990 values for CO_2e emissions, an uncertainty of ±30% was used on the annual numbers of diesel and petrol commuting trips. This high value was used because

[7] refer xl spreadsheet "energy_master.xls, worksheet "vehicles" in the CD attached.

of uncertainties as to the ratio of students and staff members using private cars in 1990 compared to 2004.

3.2.4 Aviation

This category includes emissions from the fuel consumed by aircraft in the Aviation School at Massey University and the emissions resulting from Massey University staff air travel. Data on aviation fuel (AvGas) was obtained from the Business Manager-Massey Aviation School (Brent Stanford, personal communication). Data on staff air travel in 2004 was collected from Orbit Corporate Travel. All international and domestic travel by Massey University staff is supposed to be booked through Orbit Corporate Travel, as they are the official travel agents for Massey University.

Information on the amount of AvGas used by the Massey School of Aviation in the last seven years was collected. The data for AvGas was from January to December each year, except for 2004 where information on the volume of AvGas used was only available for January to November. To calculate the volume of AvGas for the inventory year (2003-04), i.e. from July 2003 to June 2004, it was assumed that equal volumes had been used in all 12 months of 2003, and in all 11 months of 2004. A monthly average was calculated for the AvGas consumed for 2003 and 2004 by dividing the total available quantities consumed in each year by 12 and 11 respectively. These monthly averages were then multiplied by 6 and combined to give the total fuel consumed during 2003-04.

Available Seat Kilometres (ASK) and Revenue Passenger Kilometres (RPK) can be used to calculate the quantity of fuel consumed by each passenger on a plane.[8] In order to use the RPK approach it would have been necessary to obtain the booking details of all the flights used by the Massey staff. This was not possible and so the ASK approach was used to calculate the fuel consumed in air

[8] The number of seats available for sale in an aircraft multiplied by the number of kilometres flown is known as (ASK). The number of passengers multiplied by the number of kilometres they fly is called the revenue passenger kilometres (RPK).

travel by Massey University staff during the inventory year. When calculating ASK, it was assumed that all seats were occupied and that there was no cargo on the plane.

It was also assumed that the travel by Massey University staff was equally distributed amongst all the aircraft types owned by Air New Zealand, and that the same grade of fuel was used by all the aircraft. An average quantity of fuel used in g/ASK has been calculated by the Danish Environmental Protection Agency (DEPA) (DEPA, 2003). For this study, the average mass of fuel required for each ASK was estimated to be 32.6 g/ASK. This was an average of the fuel required/ASK for those aircraft that are included in the Air New Zealand fleet (Table 3.11).

Table 3.11: Average fuel used (g) per available seat kilometre (ASK)

Aircraft type	Seats	Fuel (g/ASK)	Average (g/ASK)
Saab 340B	34	46-52	49
A300-600	228-270	30	30
B747-400	343-569	24 -34	29
B737-300	120-155	24-36	30
Airbus320	110-183	16-38	27
ATR 72	64-68	30-36	33
B767	168-264	23-37	30
Average fuel usage by all types of aircrafts/ASK (g)			32.6

Source: (DEPA, 2003)

Two different approaches were used to calculate the emissions from the fuel used in Massey University aircraft and the fuel used in staff air travel. For Massey University aircraft, the total volume of AvGas used was calculated in litres and multiplied by the appropriate emission factor (Table 3.10). In contrast, the total fuel consumed by staff air travel was calculated in kg, and the total emission of GHG was estimated by using the following emission factors: 3 kg of CO_2, 0.00007 kg of CH_4 and 0.000050 kg of N_2O per kg of fuel (Bone *et al.*, 1993).

Due to the non-availability of specific information about the aircraft types, and the range of fuel used a ±10% uncertainty was estimated for the average fuel use per ASK. If the uncertainty was calculated from the variation in the seven values in the last column of Table 3.11, it would have been ±17%. However, the average fuel use per ASK for the Saab aircraft is much higher than the other values, but it has much smaller passenger capacity than the other aircraft, meaning that its influence on the uncertainty may be over-represented in the calculation and result in a calculated uncertainty higher than its actual value. Using only the six other aircraft, the uncertainty on the average fuel use per ASK was ±4.8%. The actual uncertainty therefore lies between the ±4.8 % and ±17 % values. An estimate of ±10% therefore seems reasonable for the average fuel use per ASK.

Although it is University policy that all staff travel has to be booked through Orbit Travel, it is possible that some work-related travel is booked in other ways and so an additional ±10% uncertainty was included in the estimate of the total number of kilometres travelled. Uncertainties of ±5%, ±50%, and ±50% were assigned to the emission factors due to fuel combustion for CO_2, CH_4, and N_2O respectively (MfE, 2007; MED, 2006). Also, a ±20% uncertainty was assigned to the global warming potential values for CH_4 and N_2O, accounting for the difference in these values calculated by IPCC in 1996 and 2007, respectively (IPCC, 1997; 2007a).[9]

For aviation school emission calculations, the same uncertainty values were used for emission factors and global warming potentials along with a ±5% uncertainty on the amount of aviation fuel used by the school in 2004[10], as per the recommendations by IPCC (2000).

3.2.4.1 Massey School of Aviation in 1990

No record was found of the quantity of fuel used by Massey University aircraft in 1990. The record of full time equivalent students (EFTS) forwarded to the Ministry of Education by the University on 31 July 1990 shows a total number of 3.2 EFTS enrolled in Aviation Studies. These students were apparently studying

[9]refer xl spreadsheet "energy_master.xls, worksheet "aviation" in the CD attached.
[10]refer xl spreadsheet "energy_master.xls, worksheet "aviation" in the CD attached.

aviation management papers (Lucy Marsden, Massey University Archives, personal communication). There were 2 aircraft with the School of Aviation in 1990, according to a report published in January 1995 by the Committee reviewing the academic and instructional unit of the School of Aviation [11]. Because there was no record of the fuel consumed by these aircraft in 1990, fuel consumed per year per aircraft was estimated from current data and multiplied by 2 to get the annual fuel consumed by School of Aviation aircraft in 1990.

Because the 1990 aviation school value of CO_2e had to be calculated using the 2004 value adjusted proportionally by the ratio of 1990:2004 aircraft numbers, an additional uncertainty ±10% of total emissions was included in the 1990 CO_2e estimate.

3.2.4.2 Staff air travel in 1990

As no records could be found for air travel by Massey University staff in 1990, the data used in this section are very uncertain. As a consequence, calculations of GHG emissions for staff air travel in 1990 were made using data from 2004 adjusted for the number of full time equivalent staff employed by the University in 1990 compared to 2004. Because it was necessary to adopt this indirect approach to estimate the GHG emissions from staff travel in 1990 an additional uncertainty of ±10% was included in the 1990 CO_2e estimate for staff travel – over and above the other uncertainties already included in the 2004 estimate.

3.2.5 Estimates of Uncertainty

In this chapter and all subsequent chapters, uncertainties (either assumed/assigned, or calculated from measured data) were combined during the calculation of CO_2e emissions using standard rules for calculating uncertainties (Table 3.12). All the uncertainties calculated represent 95 % confidence limits about the mean values. This method of error calculation is in line with the IPCC recommendations given

[11] Preliminary comments of the Committee which has been reviewing the academic and instructional unit of the school of aviation, Massey University, January 1995, Massey University archives.

in "Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories" (IPCC, 2000).

Table 3.12: General methods of uncertainties calculation

Function	Uncertainty
$X = c \cdot A$	$\Delta X = \lvert c \rvert \cdot \Delta A$
$X = A \cdot B$ or $X = \frac{A}{B}$	$\frac{\Delta X}{\lvert X \rvert} = \sqrt{\left(\frac{\Delta A}{A}\right)^2 + \left(\frac{\Delta B}{B}\right)^2}$
$X = A \pm B \pm C \pm \ldots$	$\Delta X = \sqrt{(\Delta A)^2 + (\Delta B)^2 + (\Delta C)^2 + \ldots}$
$X = A^a$	$\frac{\Delta X}{\lvert X \rvert} = \lvert a \rvert \frac{\Delta A}{\lvert A \rvert}$

3.3 RESULTS

3.3.1 Emissions from Electricity

The Massey University Turitea campus and the Massey University farms used 16,417,039 kWh of electricity in 2003-04, which is estimated to have produced about 2,547±285 Mg of CO_2e of GHGs. In contrast, 11,939,880 kWh of electricity was consumed in 1990, which is estimated to have produced 1,853±207 Mg of GHGs as CO_2e[12].

3.3.2 Emissions from Gas

Total gas consumed during 2003-04 was 20,627,416 kWh. This resulted in total emissions of 3,884±194 Mg of CO_2e at Massey University in 2003-04. In 1990 1,366±68 Mg of CO_2e were produced from the consumption of 7,253,763 kWh of gas[13].

3.3.3 Emissions from Coal

Currently coal is not used as a source of energy at Massey University. Therefore there are no emissions from coal recorded during 2003-04. However, in 1990 the Turitea campus consumed 2,325 Mg of coal (Green *et al.*, 1991), which produced 5,047±252 Mg of CO_2e emissions (Table 3.13).

Table 3.13: Quantity of coal used by Massey University in 1990 and CO_2 emissions

Amount of coal used		Conversion factor* MJ/kg	Total energy (MJ)	Emission factor* (gCO_2/MJ)	Total CO_2 emission (Mg)
Mg	Kg				
	P	Q	R=P x Q	S	(R x S)/1000000
2,325	2,325,000	23.8	55,335,000	91.2	5,047

*Source: (Baines, 1993)

[12] refer xl spreadsheet "energy_master.xls, worksheet "electricity" in the CD attached.
[13] refer xl spreadsheet "energy_master.xls, worksheet "gas" in the CD attached.

3.3.4 Emissions from Vehicles

Emissions from vehicles are dominated (>90%) by commuting vehicles. The estimated volumes of petrol and diesel consumed by commuting vehicles during 2003-04 were 2,596,471 litres and 150,263 litres, respectively (Table 3.14). This resulted in an estimate of 6,854±1,200 Mg of CO_2e emissions from commuting traffic during the year 2003-04 (Table 3.14)[14].

The volumes of petrol and diesel purchased through BP fuel cards for the year 2003-04 were 208,826 litres and 25,033 litres respectively. Monthly details of the fuel purchased through fuel cards are presented in Annex 3.2. The volumes of diesel and petrol used by farm vehicles during the year were 21,193 litres and 17,150 litres respectively (Table 3.15). In addition, 11,325 litres of diesel and 11,307 litres of petrol were supplied by Shell during 2003-04, prior to the removal of the fuel tanks on the central campus. (Dennis Clueard, Shell New Zealand, personal communication).

[14]refer xl spreadsheet "energy_master.xls, worksheet "vehicles" for uncertainty value in the CD attached.

Table 3.14: Total CO_2e emissions due to commuting vehicles in 2004

		Type of Vehicle[1]		Total dist travelled[2] (km)		Fuel consumed[3] (lt)		CO_2 (kg)		N_2O (kg)		CH_4 (kg)		CO_2e (Mg)
	Return Trips	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	
Students	1,493,841	89,630	1,404,211	1,254,826	19,658,948	104,569	1,965,895	292,793	4,718,147	12	202	52	4,034	5,163
Staff	263,619	21,090	242,529	548,328	6,305,766	45,694	630,577	127,943	1,513,384	5	65	23	1294	1,691
Total	1,757,460					150,263	2,596,471							6,854

Table 3.14a: Total CO_2e emissions due to commuting vehicles in 1990

		Type of fuel[2]		Total dist travelled[3] (km)		Fuel consumed[4] (lt)		CO_2 (kg)		N_2O (kg)		CH_4 (kg)		CO_2e (Mg)
	Return Trips	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	
Students	1,099,636	65,978	1,033,658	923,694	14,471,210	76,975	1,447,121	215,529	3,473,090	9	149	38	2,969	3,801
Staff	194,053	15,524	178,529	403,630	4,641,748	33,636	464,175	94,180	1,114,020	4	48	17	952	1,245
Total	1,293,689					110,610	1,911,296							5,045

[1] Total trips in diesel vehicles are 6% and 8% by students and staff respectively

[2] Each return trip is 14 km and 26 km by students and staff respectively

[3] Diesel @12 km/litre, Petrol @ 10 km/lit

Table 3.15: Fuel consumed on Massey farms during 2003-04

Farm	Diesel consumed (litres)	Petrol consumed (litres)
Keebles	227	1,266
Haurongo	50	107
Tuapaka	1,622	3,424
Riverside	3,977	2,759
No.4 Dairy Unit	4,041	5,108
No.1 Dairy Unit	1,748	1,773
DCRU	155	624
Deer Research Unit	51	0
AgServices Utes	9,323	2,089
Total	21,193	17,150

A total of 2,833,755 litres of petrol and 207,815 litres of diesel were consumed by all categories of vehicles during 2003-04 (Table 3.16). Therefore total CO_2e emissions due to vehicles in 2003-04 were 7,605±1,275 Mg (Table 3.16)[18].

Table 3.16: Carbon dioxide equivalent emissions from different categories of vehicles in 2004

Category	Fuel consumed (litres)		CO_2e emissions (Mg)
	Diesel	Petrol	
Commuting vehicles	150,263	2,596,471	6,854
BP fuel card (Massey University owned vehicles)	25,034	208,827	588
Massey University AgServices (Massey University owned vehicles)	21,193	17,150	103
Shell New Zealand (Massey University owned vehicles)	11,325	11,307	60
Total	207,815	2,833,755	7,605

The number of return trips to the campus by commuting vehicles in 1990 was estimated to be 1,293,689, and these consumed 1,911,296 litres of petrol and 110,610 litres of diesel (Table 3.14a). As noted in Section 3.2.3.2, this estimate

[18] refer xl spreadsheet "energy_master.xls, worksheet "CO_2 Totals" for uncertainty value in the CD attached.

of GHG emissions from commuting traffic in 1990 makes the assumption that the patterns of vehicle use by individual staff and students were the same in 1990 as in 2004. Anecdotal evidence suggests that the use of bicycles, particularly by students, was much more common in 1990 and thus the estimate of GHG emissions due to commuting vehicles in 1990 is likely to be too high. It is not possible to quantify this over-estimation except by increasing the estimate of uncertainty.

Massey University vehicles used 57,836 litres of petrol and 42,385 litres of diesel in 1990 (Annex 3.3), and all of this fuel was supplied by Shell New Zealand (Terry Hammond, personal communication). Therefore, total GHG emissions in CO_2e due to vehicles in 1990 were 5,309±1,230 Mg, comprising 5,045 ±1,204 Mg from commuting vehicles (Table 3.14a) and 264±26 Mg from Massey University-owned vehicles (Table 3.17)[19].

Table 3.17: Greenhouse gas emissions due to Massey University-owned vehicles in 1990.

Fuel consumed		CO_2 emissions (kg)		N_2O emissions (kg)		CH_4 emissions (kg)		CO_2e (Mg)
Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	
42,385	57,836	118,678	138,806	5	6	21	119	264

3.3.5 Emissions from Aviation

According to the information provided by Orbit Corporate Travel, the total distance flown by Massey University staff in 2004 was 14,810,583 nautical miles or 27,429,200 km. Assuming an average fuel use per ASK of 32.6 g (Table 3.11), this results in an estimate of the total fuel use attributed to staff air travel of 894,192 kg. This equates to total CO_2e emissions of 2,698±402 Mg in 2004 (Table 3.18).

[19] refer xl spreadsheet "energy_master.xls, worksheet "Vehicles" for uncertainty value in the CD attached.

Massey University School of Aviation aircraft at Palmerston North used 965,838 litres of AvGas in 2004, resulting in CO_2e emissions of 2,330±164 Mg (Table 3.19).

Therefore, by combining these values the total estimated CO_2e emissions due to aviation are 5,028±435 Mg, and these emissions are divided reasonably evenly between staff travel and the activities of the Massey University School of Aviation[20].

Table 3.18: Total CO_2e emissions due to Massey University staff air travel in 2004

Fuel consumed (kg)	CO_2 emissions (kg)	CH_4 emissions (kg)	N_2O emissions (kg)	CO_2e emissions (Mg)
894,192	2,682,576	63	45	2,698

Table 3.19: AvGas used by aircraft from the Massey University School of Aviation in 2004 and the resulting CO_2e emissions

AvGas used (litres)	CO_2 emission (kg)	CH_4 emission (kg)	N_2O emission (kg)	CO_2e emissions (Mg)
965,838	2,318,011	50	36	2,330

As noted in Section 3.2.4.2, there were no data available for 1990 on either the distance flown by Massey staff on University-related business, or the amount of fuel used by aircraft in the Massey University School of Aviation. Estimates of CO_2e emissions from these two sources were therefore based on the 2004 data (Tables 3.18 and 3.19) adjusted for the number of staff and/or aircraft at Massey in 1990 compared to 2004.

In 1990 there were 1,386 full time equivalent (FTE) staff at Massey compared to 2,155 FTE staff in 2004. Therefore, assuming the same frequency of staff air travel in 1990 as in 2004, total CO_2e emissions due to air travel by staff members in 1990 were 1,735±312 Mg. Using the same approach for the 2 aircraft operated by the Massey University School of Aviation, compared with the 21 in 2004, the

[20] refer xl spreadsheet "energy_master.xls, worksheet "aviation" for uncertainty values in the CD attached.

CO_2e emissions from the operation of Massey aircraft in 1990 were estimated to be 222±27 Mg.

Combining these two emission estimates gives a total estimated CO_2e emission due to aviation in 1990 of 1,957±313 Mg[21]. Although this is the best estimate that could be made with the data available, it is likely that it is an overestimate of the actual GHG emissions due to aviation in 1990. This is because it relies on an assumption that individual staff in 1990 travelled the same distance by air in 1990 as in 2004. With the greater internationalisation of Massey University over the last 20 years this is unlikely to be the case, but it was not possible within the scope of the current study to quantify any changes in the patterns of work-related travel by individual members of Massey staff between 1990 and 2004.

3.4 CHANGES IN EMISSIONS BETWEEN 1990 -2004

In 1990, total GHG emissions from the energy sector at Massey University were 15,531±1,288 Mg of CO_2e, whereas the current emissions (2004) from the same sector are 19,064±1,324 Mg of CO_2e. Table 3.20 shows the changes in emissions between 1990 and 2004 from the different categories in the energy sector.

Table: 3.20: Changes in CO_2e emissions from different categories in the energy sector between 1990 and 2004

Emissions from ...	CO_2e emissions (kg)		% Change
	1990	2004	
Electricity + gas +coal	8,266±527	6,431±479	-22
Vehicles	5,309±1230	7,605±1275	43
Aviation	1,957±313	5,028±435	157

[21] refer xl spreadsheet "energy_master.xls, worksheet "aviation in the CD attached.

3.5 DISCUSSION

The energy sector produced about 19,064±1,324 Mg of CO_2e in 2003-04. These emissions were about 23% above the 1990 level of 15,531±1,288 Mg. The largest source of emissions in this sector were commuting vehicles, which contributed 6,854 Mg of CO_2e emissions in 2003-04. This was 37% of all the emissions from this sector (Fig. 3.4). This suggests that an efficient public transport system, that can reduce the number of staff and students commuting to the campus in their private vehicles, could potentially have a significant impact on the over all GHG emissions from the campus.

The estimates of emissions from commuting vehicles also have the largest uncertainty associated with them (±1,200 Mg)[22]. Therefore, in future inventories at the campus, it is recommended that more resources be devoted to gaining quantitative information on the number of vehicle travelling to and from the campus every day, and the distance that they travel. This information would provide a sounder base on which to make decisions on the provision of public transport.

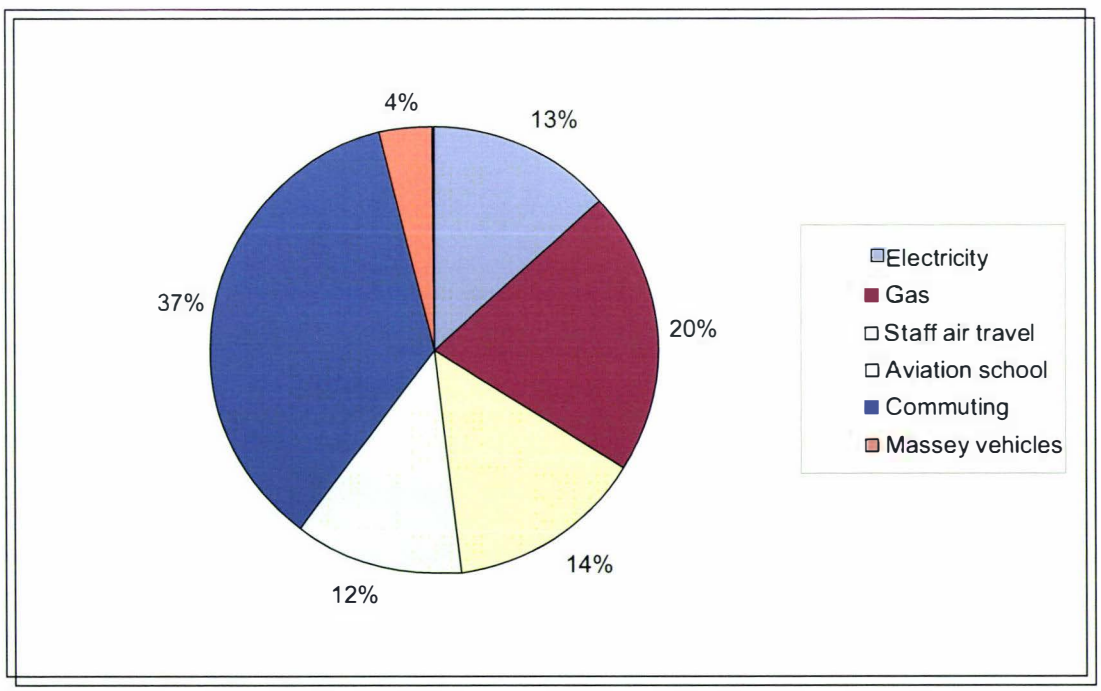

Figure 3.4: Emissions from different categories in the energy sector at Massey University in 2003-2004

[22]refer xl spreadsheet "energy_master.xls, worksheet "CO_2 Totals in the CD attached.

The combined emissions due to the use of electricity, gas, and coal have dropped between 1990 and 2004, whereas emissions from other sources have increased considerably (Table 3.20). The decrease of 22% in the combined emissions due to electricity, gas, and coal (Table 3.20) is due to the shift from a coal fuelled heating system to gas.

The greatest increase in emissions between 1990 and 2004 in both absolute and percentage terms has occurred in aviation (Table 3.20). This increase is due in part to the increased number of aircraft in the Massey University School of Aviation (i.e. 2 in 1990 and 21 in 2004), and also to the assumed increase in air travel by the greater number of staff in 2004.

A comparison of the total number of full time equivalent students and staff in 1990 and 2004, with the total GHG emissions in the energy sector from the Turitea campus and Massey farms suggests that per capita emissions in the energy sector have dropped from 1.29 Mg/year in 1990 to 1.17 Mg/year in 2004 (Table 3.21). There are a number of possible reasons for this apparent decrease in per capita emissions. The first is the improvement in the efficiency of heating with the shift from a central coal powered boiler plant to a dispersed natural gas heating system. Secondly, the increase in the Massey population (full time equivalent students and staff) from 11,953 in 1990 to 16,238 in 2004 may have resulted in more intensive and efficient use of existing facilities, with a corresponding reduction of per capita GHG emissions. A comparison of building areas on the campus in 1990 and 2004 (not done in this study) would provide more information on this point.

It was noted in Sections 3.3.4 and 3.3.5 that the estimates of GHG emissions from commuting traffic and air travel by staff in 1990 may be overestimated – although it was not possible to quantify the extent of this possible over-estimation. If in fact the emissions in 1990 from the energy sector have been overestimated, then the apparent reduction in per capita GHG emissions between 1990 and 2004 may be less than indicated above.

Table 3.21: Per capita GHG emissions from energy sector in 1990 and 2004

Year	Equivalent full time students and staff	Total GHG emissions from the energy sector (Mg)	Per capita GHG emissions (Mg)
1990	11,953	15,531	1.29
2004	16,238	19,064	1.17

3.6 CONCLUSIONS

- The energy sector is a major contributor to GHG emissions at the Massey University Turitea campus. The largest single source in this sector is commuting vehicles, which are responsible for about 37% of the total emissions from this sector. Energy used for lighting and heating is the next largest contributor of GHG emissions (33%) followed by emissions from staff air travel (14%) and the activities of the Aviation School (12%). The GHG emissions from Massey owned or leased vehicles make up only a small part (4%) of the GHG emissions from the energy sector.

- Per capita emissions due to energy use appear to have decreased slightly since 1990 although difficulties in estimating emissions in 1990 mean that there is uncertainty as to the extent of this per capita decrease in energy consumption. Clearly however, the replacement of a centralised coal-fired boiler system with decentralised gas powered facilities has made a significant reduction in GHG emissions.

- If Massey University wishes to reduce GHG emissions still further then the data presented in this Chapter provides useful information on areas to target. The largest and most obvious area is commuting traffic. In this regard it is interesting to note that since this research was conducted, Massey University in collaboration with the Horizons Regional Council has introduced a charge for parking on the campus and at the same time, has introduced a free bus service for staff and students. It is estimated that since the start of the free bus service in 2005, CO_2 emissions from commuting vehicles to the campus have been reduced by approximately 15 Mg/week or 11% (Massey University, 2006). Further expansion of the free bus service, and encouraging car pooling and cycling among the students and staff would also be beneficial. Interviews conducted as part of this study indicated that less than 5% of the 385 students and staff members interviewed were using a car pooling system.

- With 33% of the total GHG emissions from the energy sector coming from heating and lighting on the Turitea campus there may well be opportunities to improve heat retention in buildings during winter and to reduce wasteful electricity use. Reducing staff air travel by making greater use of electronic media may also have some potential. This is particularly the case in a multi-campus university such as Massey where there is extensive travel by staff between the campuses, particularly between Albany and Manawatu.

- Aircraft in the Aviation School are a significant source of GHG emissions that would not be present in most other universities, but it is probably difficult to reduce these emissions significantly. Similarly, it may be possible to have more efficient vehicles in the Massey University fleet, but this would have only a small impact on the overall GHG emissions from the energy sector on the Turitea campus.

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CHAPTER 4: WASTE

4.1 INTRODUCTION

Industrial and municipal solid waste (MSW) can emit the commonly called "landfill gas", which may contain most of the important greenhouse gases (GHGs) such as methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O) (IPCC, 1997a; Powell *et al.*, 2006). The exact composition of landfill gas at a given site may depend upon the waste composition (Allen *et al.*, 1997), but it is predominantly CH_4. Both managed and unmanaged waste disposal sites can produce landfill gas.

The presence of CO_2 and CH_4 in the landfill gas can make it an acidifying and/or a reducing agent, which can affect groundwater quality (Kerfoot *et al.*, 2004). In addition, uncontrolled emissions of CH_4 from landfills can create local environmental hazards (Ozcan *et al.*, 2006) because concentrations of 5-15% of CH_4 in air can create potentially explosive mixtures (IPCC, 1997a). Apart from the direct GHG emissions, the air pollution caused by waste treatment and disposal facilities can also be a threat to public health (Hamoda, 2006).

Along with the hazards created, there are also some benefits that can potentially be derived from waste and landfill gas. For example, the gas from MSW dumps can provide an alternative energy source that can be used for generation of electricity (Janes *et al.*, 2005; Rasmussen, 2005; Weeks, 2005). Yuko (2005) has also argued that industrial waste, such as waste from sugar mills, can be used in cogeneration power plants. Asha and Sanjeev (2007) used MSW as a component of microbially assisted phytoremediation to successfully reclaim coal mine spoil dumps.

4.1.1 Waste Generated at Massey University

A large amount of MSW and recycling material produced by Massey University staff and students is collected from the University every year. General waste is

collected in more than 60 bins of four different sizes (ranging from 1.5 to 4.5 m^3) placed at different sites throughout the campus and University farms. Besides the waste collection bins, recycling bins have also been placed at important points on the campus to promote a source separation system which was started in 2001 (Mason, 2001) (Fig. 4.1). All the recyclable materials (e.g. paper, corrugated cardboard, aluminium cans, plastics and glass) collected in recycling bins are managed by a private contractor "Fullcircle", a subsidiary of Carter Holt Harvey Limited.

The hazardous wastes from laboratories and other research facilities such as the Massey University Veterinary School and Food Technology laboratories are managed separately by Nuplex Medismart Limited. Hazardous waste is collected in approved bags that are loaded into mobile garbage bins. These bins are then transported to the Nuplex facility in Wellington where the waste is treated by a steam sterilisation process that produces no GHG emissions (Cait Barrett, Personal communication).

Figure 4.1: Recycling bins at Massey University for source separation of waste material

4.1.2 Factors Affecting Emissions from MSW Disposal

The amount of CH_4 emitted to the atmosphere from solid waste disposal depends on a number of factors that include waste composition, moisture content, temperature, pH, availability of nutrients, waste density and particle size (Agdag & Sponza, 2005; Carucci *et al.*, 2005; Liu *et al.*, 2006).

4.1.2.1 Waste composition

The composition of the waste plays an important role in determining the amount of gas emitted from solid waste disposal sites (SWDSs), and the amount of gas can also be affected by the treatment that the waste receives (Pawlowska and Siepak, 2006). Wastes from different countries and regions can have a variety of compositions, and the composition of waste can also vary from city to city. Standard of living, general habits of the people living in an area, and environmental awareness are some of the factors that can affect the composition of waste.

Municipal solid waste typically contains significant quantities of degradable organic matter (Ministry for the Environment (MfE), 1997; Byer *et al.*, 2006). For example, 50% of the residential landfilled waste in New Zealand is organic, and 35% consists of recyclable materials such as paper, plastics, glass and metal. Construction & demolition waste makes up only about 10% of the landfilled waste in New Zealand (MfE, 1997). In Perth (Australia) 80% of the total household waste is organic and the remainder is composed of potentially recyclable metals such as plastic and glass, as well as a number of inert wastes like rubble (WasteNet, 2006). The more organic waste present in a landfill, the more landfill gas is produced by the bacteria during decomposition.

4.1.2.2 Physical factors

Moisture content is an important physical factor influencing the production of CH_4 in a landfill (Visvanathan *et al.*, 1999). Moisture helps bacterial growth and

metabolism. It also facilitates the transport of nutrients and bacteria within the SWDS. The moisture content of a SWDS is controlled by the initial moisture content of the waste, infiltration from surface and groundwater sources, and the amount of water resulting from decomposition processes at the waste disposal site (United States Environmental Protection Agency (EPA), 2006).

According to IPCC (1997a) "Temperature, pH, and nutrient availability also affect the growth rate of the bacteria. Under anaerobic conditions, landfill temperatures are generally between 25-40°C. These temperatures can be maintained within the SWDS regardless of the ambient surface temperatures. Outside of these temperatures, CH_4 production is reduced. The optimal pH for CH_4 production is around neutral (pH 7.0). Important nutrients for efficient bacterial growth include soluble carbon (C), nitrogen (N), sulphur (S), phosphorus (P), sodium (Na) and calcium (Ca)" (p. 6.6).

4.1.3 Global GHG Emissions from Waste

The waste sector is the largest anthropogenic source of CH_4 in many developed countries (Bogner and Matthews, 2003). About 5-20% of global anthropogenic CH_4 emissions are produced at SWDSs by anaerobic decomposition of organic matter through methanogenic bacteria (IPCC, 1992, 1997b, 2000; EPA, 1994).

Due to the non-availability of reliable solid waste data, especially for developing countries, accurate global estimates of emissions from the waste sector are hard to make. However, Bogner & Mathews (2003) estimated that 16-57 Tg of CH_4 is generated globally by solid waste disposal every year. Oliver *et al.* (1999), also estimated that 36 Tg of CH_4 is produced from landfills all over the world.

4.1.4 New Zealand GHG Emissions from the Waste Sector

New Zealand has taken a number of initiatives to improve solid waste management practices, including preparing guidelines for the development & operation of landfills, closure & management of landfill sites and imposing consent conditions for landfills

under the Resource Management Act (RMA) (MfE, 2006b). Gradual implementation of these practices has resulted in a significant reduction in GHG emissions from the waste sector. In 2004, New Zealand produced about 1,840 Gg of CO_2 equivalents (CO_2e), including 79.8 Gg of CH_4 and 0.5 Gg of N_2O, from the waste sector. These emissions are 2.5% of all GHG produced and are now 25.9% below the 1990 baseline value (MfE, 2006a) (Fig. 4.2).

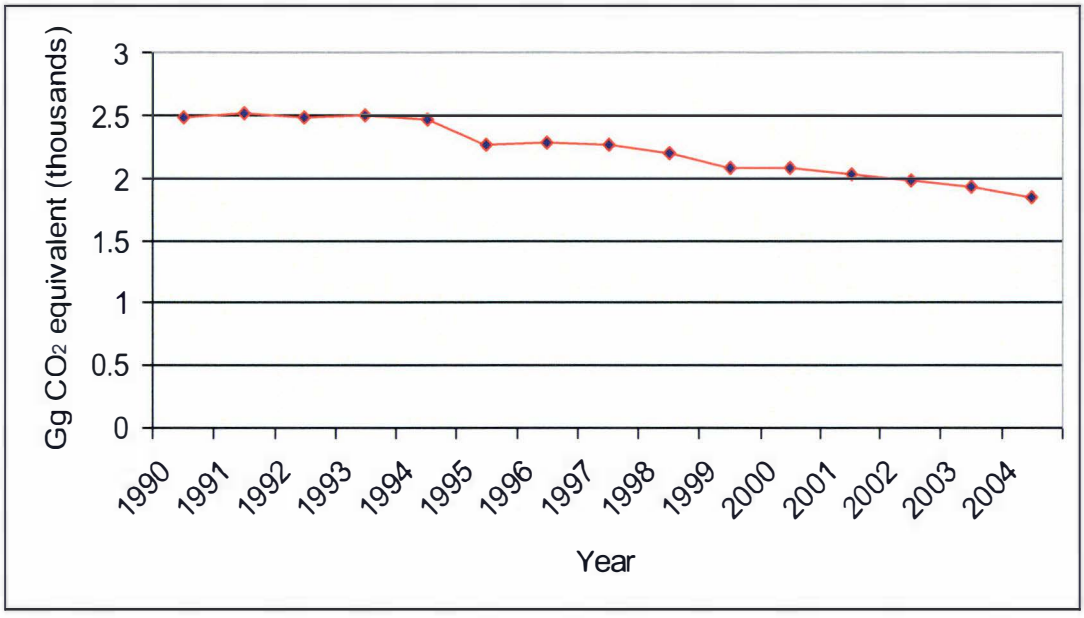

Figure 4.2: Greenhouse gas emissions from the waste sector in New Zealand from 1990 to 2004.
Source:(MfE, 2006a)

4.1.5 Objectives

The main objective of this chapter was to estimate GHG emissions from the waste produced by Massey University in 2003-04 and assess the changes in the emissions since 1990. The specific objectives were to estimate the total amount of MSW collected from the main campus and farms of Massey University during one year (2003-04), and to calculate the net amount of GHG produced by this waste in CO_2e. Emissions of GHG due to wastewater handling are also described.

4.2 METHODOLOGY

4.2.1 General Inventories for the Waste Sector

The revised 1996 IPCC guidelines for national GHG inventories have encouraged countries to calculate GHG emissions from the following sub-sectors within the waste sector (IPCC, 1997a):

- Methane emissions from SWDSs
- Methane emissions from wastewater handling
- Nitrous oxide emissions from human sewage, and
- Carbon dioxide and N_2O emissions from waste incineration

However, New Zealand has reported the emissions only from the first three categories in the waste sector (MfE, 2006a). Emissions from waste incineration are not considered as there is no incineration of municipal waste in New Zealand (MfE, 2004). Similarly, in the case of Massey University, there is no significant waste incineration at the campus or on the farms. Therefore the waste incineration sub-sector is not included.

4.2.2 Data Collection

Waste Management Ltd collects all general waste (i.e. MSW) from Massey University in 1.5 to 4.5 m^3 bins and disposes of the waste at the municipal waste disposal site at Awapuni that is managed by the Palmerston North City Council (PNCC). The volume of waste produced was estimated from the monthly returns and invoices issued by Waste Management Limited through the Massey University Regional Facilities Management (RFM) and Accounts offices. The volume data was then converted to weight using a relationship of 5 m^3 = 1 Mg (Raymond Joe, personal communication). Data on the amounts of MSW collected from the Turitea campus were available for the last four years only, so there were no data on waste production available for 1990. Total CO_2e

emissions from this sector in 1990 were therefore estimated by assuming that the annual per capita waste production in 1990 was the same as in 2003-04.

4.2.3 Estimation of CH_4 Emissions from Solid Waste Disposal

A number of methods have been used and described by IPCC and other agencies to estimate CH_4 emissions from solid waste. These methods vary in complexity, data requirements and the assumptions made to calculate the emissions. But most of these methods can be applied only to whole regions or countries (IPCC, 1997a).

Because Massey University's Turitea campus, including its farms, is a small area compared to a country or city, a simple method was used to calculate CH_4 and CO_2e emissions from its waste (Eq. 4.1). This method is a modified form of IPCC default methodology for estimating CH_4 emissions from solid waste (IPCC, 1997a). It requires information on the total amount (Gg) of waste (R), the CH_4 generation potential (L_o) (m^3 CH_4/Gg waste), the efficiency of the disposal site at CH_4 recovery, the CH_4 oxidation factor, and gives the amount of CH_4 gas generated (Gg).

Net CH_4 generated = (R x L_o – Recovered CH_4) x Oxidation factor ..... (4.1)

The methane generation potential (L_o) depends upon the composition of the refuse present in a landfill. The New Zealand Inventory Report has used waste types and statistics from the solid waste analysis protocol 2002 (SWAP) to calculate the CH_4 generation potential (MfE, 2002b). Details of the composition of Massey University waste were not available. Therefore, the value of L_o (0.0434 m^3 CH_4/Gg waste) calculated by Waste Management Ltd for the Awapuni[1] waste disposal site (S. Gulliver, personal communication) was used.

The IPCC default CH_4 oxidation factor of 0.1 was used (IPCC, 2000; MfE, 2006a). The same value has also been used by MfE in the National Inventory Report. In

[1] Awapuni is the waste disposal site where all the MSW generated by Massey University is dumped.

contrast, the efficiency of the landfill in recovering CH_4 was provided by Waste Management Ltd., and is specific to the Awapuni landfill (S. Gulliver, personal communication).

The conversion of waste volume into weight was based on the conversion factor calculated by Waste Management Ltd. from the general waste collected from Palmerston North. Because of the waste management practices adopted at the campus, the general MSW collected from the other parts of the town could have a different composition from the waste collected from Massey University. The possible difference in waste compositions introduces an uncertainly into the conversion of waste volume to weight. Although the actual uncertainty is unknown, an uncertainty of ±10% of the value for conversion of waste volume to waste weight was assigned in order to cover the possible difference in waste composition.

The amount of annual waste produced was also assigned an uncertainty of ±10%. While the records and invoices from Waste Management Ltd might be expected to accurately record the numbers of containers collected from the University, the extent to which the containers were full (or over-full) when collected was not known. The value of ±10% was considered a reasonable estimate of the uncertainty, and given the good record system in place at Waste Management Ltd., is equal to the IPCC (2000) minimum recommended value. This is an area where more detailed study may be warranted.

The value of the CH_4 generation potential (L_o) used in these calculations is 0.0434. This was the value calculated by Waste Management Ltd. for the total waste stream entering the Awapuni landfill. As noted above, the degree of similarity between the Massey waste stream and the remainder of the MSW entering the Awapuni landfill is unknown, and therefore the appropriateness of the assigned value for L_o is not entirely certain. The default value provided by IPCC (2000) is 0.05. In countries where good records are kept, uncertainties are in the range of 15-20 % (IPCC, 2000). Given these statistics and given the fact that the value of L_o used was neither an IPCC default value nor a national average value, but rather was locally calculated, an uncertainty of ±10% was assigned to L_o.

At the moment, a gas recovery system is installed in which 65 % of the area of the Awapuni waste disposal site is covered by extractors. Given the incomplete coverage of the extractors and the fact that the composition of waste may differ spatially within the landfill, and given that the extraction system (where used) may be less than 100% efficient, a ±20% uncertainty was assigned to the efficiency of the landfill in recovering CH_4. A ±10% uncertainty was assigned to the value of the CH_4 oxidation factor because a site-specific factor was not available and the IPCC default factor was therefore used. An uncertainty of ±20% was used for the global warming potential (GWP) value for CH_4. This covers the difference in the values for the GWP of CH_4 calculated by IPCC in 1996 and 2007 respectively (IPCC, 1997a; 2007). All these uncertainties were carried through the various stages of calculation as outlined in Section 3.2.5[2].

4.2.4 Estimation of CO_2 Emissions Resulting from Solid Waste Disposal

The CO_2 emissions resulting from the incineration of waste and its burning in open spaces has been described as the most important sources of emissions from the waste sector by IPCC (2006). Because there was no burning involved in Massey University's waste disposal process, no estimates of CO_2 were made from this category. "Carbon dioxide is also produced in SWDSs, wastewater treatment and burning of non-fossil waste, but this CO_2 is of biogenic[3] origin and is therefore not included as a reporting item in this sector" (IPCC, 2006, p.1.5).

4.2.5 Estimation of CO_2 Emissions Resulting from Flaring of Recovered CH_4

A considerable amount of CH_4 produced from the MSW was recovered by the gas collection system installed at the Awapuni landfill. All of this gas is currently flared. Estimates of CO_2 emissions resulting from the flaring of this recovered CH_4 were made by considering Eq. 4.2.

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[2]refer xl spreadsheet "waste_master.xls, worksheets "table4.1" and "table4.2" in the CD attached.

[3] A biogenic substance is a substance produced by life processes. It may be either constituents, or secretions of plants or animals.

$CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$ .....(4.2)

A simple calculation based on Eq. 4.2 indicates that 1g of CH_4 produces 2.75g of CO_2. The total amount of CO_2 produced due to flaring of CH_4 was therefore calculated by multiplying the amount of recovered CH_4 by 2.75. The only uncertainty in this calculation arises from the uncertainty in the estimated amount of CH_4 recovered[4].

4.2.6 Estimation of CH_4 and N_2O Emissions from Wastewater Handling

All the wastewater from Massey University goes to the Palmerston North City Council's wastewater treatment plant at Totara Road, where it is treated under aerobic conditions (MfE, 2002a). Wastewater handling systems that provide an aerobic environment will normally produce little or no CH_4 (IPCC, 1997a; MfE, 2006a). Therefore the CH_4 emission from the Massey University wastewater was considered as nil.

The method to calculate N_2O-N production from domestic wastewater treatment described by IPCC is based on the average per capita protein intake, and this varies by a factor of 2 between countries. For example, the protein intakes/day/person for America and India are 110 and 55g respectively (IPCC, 1997a). But the New Zealand national inventory report uses available raw sewage N data to calculate a per capita domestic wastewater N production. This is 13 g/day or 4.75 kg/year (MfE, 2004, 2006a). This country-specific value of 4.75 kg N/head/year was used to estimate wastewater N output from the Turitea campus of Massey University. The IPCC default emission factor of 0.01 kg N_2O-N/kg sewage N was then used to calculate N_2O emissions from wastewater originating from the campus (IPCC, 1997a). This was multiplied by the effective (see below) number of persons occupying the campus to estimate the total emissions from waste water.

[4]refer xl spreadsheet "waste_master.xls, worksheet "table 4.2" in the CD attached.

The campus population was estimated from the number of full time equivalent students and staff. The total number of full time equivalent staff and students in 2004 was 16,238. On average, 700 students stayed at the halls of residence during the year (M. MacKenzie, personal communication). The number of students in the halls of residence was directly multiplied by the per capita N factor of 4.75 kg/year. In contrast, it was assumed that the remaining full time students and staff spend on average only 8 hours a day at the campus during the year[5]. The per capita N emission factor was then adjusted accordingly.

There was considerable uncertainty associated with several of the estimates described above. An uncertainty of ±10% was assigned to the per capita domestic wastewater N production. Although the value used (4.75 kg N/head/year) was the same as that used by MfE (2004, 2006a) in the national inventory, the correspondence between this national average and the Massey population was speculative. Nevertheless a ±10% uncertainty was considered likely to encompass any variation between the national and the University figures.

An uncertainty of ±10% was assigned to the emission factor for converting N in wastewater to emitted N_2O. Uncertainties of ±10% and ±20% were assigned to the estimates of the populations of residential students and other students/staff/visitors, respectively. Although the number and the duration of stay of residential students can be determined fairly accurately, the population of other campus occupants is hugely variable with both time of day and time of the year. Nevertheless consideration of the likely upper and lower bounds of annual campus occupation suggests that an uncertainty of ±20% would encompass the likely error in the estimate. An additional uncertainty of ± 20 % was introduced on the GWP value for N_2O[6]. This covers the difference in the values for the GWP of N_2O calculated by IPCC in 1996 and 2007, respectively (IPCC, 1997; 2007).

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[5] Although the students leave the hostels during the summer vacations, it was assumed that people attending the summer school and visitors would fill that gap.

[6] refer xl spreadsheet "waste_master.xls, worksheet "table4.3" in the CD attached.

4.2.7 Estimation of CH_4 and N_2O Emissions from the Waste Sector in 1990

Some assumptions have been made to calculate waste emissions in 1990. Firstly, it was assumed that annual per capita waste production was the same in 1990 as it was in 2000-01 i.e. just before recycling practices were introduced at Massey University (Fig. 4.3). The total number of full time equivalent students and staff in 1990 was 11,953. Multiplying the total number of full time equivalent students and staff by the estimated amount of annual waste per head in 1990 (i.e. 99 kg/head/year) gives the total amount of waste produced in 1990.

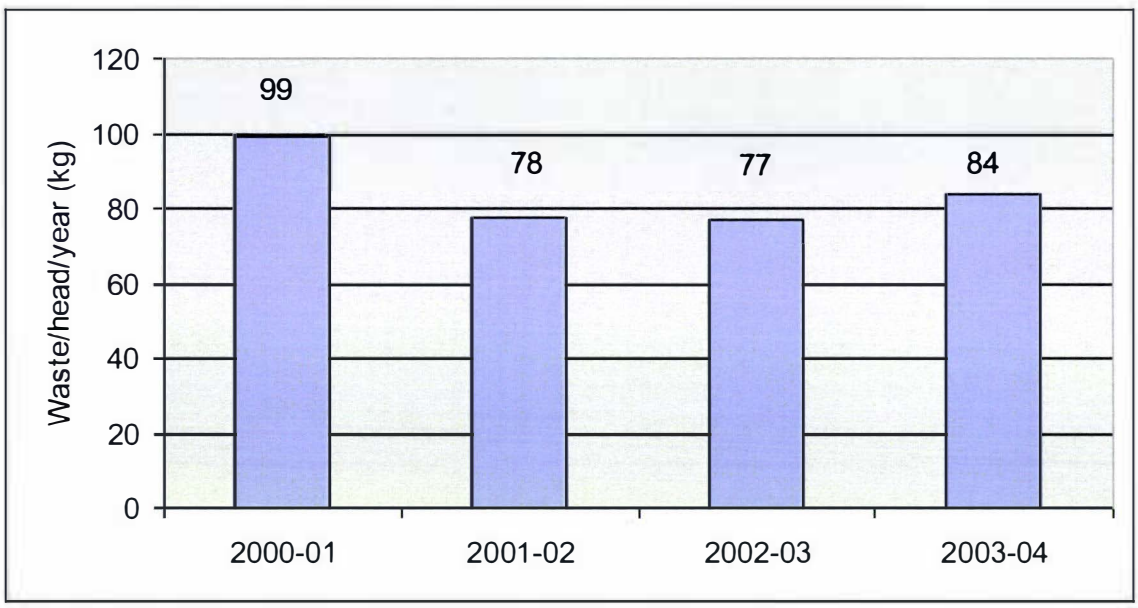

Figure 4.3: Annual per head production of waste (kg) on the Turitea campus of Massey University during the four years from 2000/01 to 2003/04

Secondly, the total number of students staying in the halls of residence in 1990 was assumed to be the same as in 2004, i.e. 700 students. The same method and level of uncertainty was used to calculate N_2O-N emissions from waste water for 1990 as described in Section 4.2.6 above.

It is believed that the overall waste composition since 1990 at Massey University may have changed due to the recycling practices introduced in the last few years. The levels of uncertainty associated with the input data for emission calculations

from MSW were unknown, especially for the waste composition, CH_4 generation potential (L_o), and the conversion factor of waste volume into waste weight. An analysis of the total quantities of waste and recycling materials (Section 4.3.1 above) shows that recycling material was almost 5% of the total waste collected in 2003-04.

4.3 RESULTS

4.3.1 Total MSW in 2003-04

Based on the monthly accounts provided by Waste Management Ltd, the volume of MSW collected annually from Massey University's Turitea campus between 2000-01 and 2003-04 ranged from 6,226 to 7,627 m^3 (Table 4.1). In addition, about 66 Mg of recycling material was collected from the campus during 2003-04. Almost 90% of the recycling volume collected consisted of paper and old corrugated cardboard (Helina Winiata, Personal communication).

Table 4.1: Total waste collected from the project area during the last 4 years

Year	Total volume of waste collected (m^3)	Total weight of waste collected (Mg)
	A	A ÷ 5
2000-01	7,627	1,525
2001-02	6,226	1,245
2002-03	6,347	1,269
2003-04	6,803	1,361

4.3.2 Methane Emission from Solid Waste

In 2004, Palmerston North City Council established a permanent gas collection system at the Awapuni landfill with a permanent flare (Fig. 4.4). The landfill gas is drawn continuously and burnt by the flare (PNCC, 2005). The Awapuni landfill is collecting CH_4 from wells installed all over the landfill site (Fig. 4.5) and is aiming to use the CH_4 gas to generate electricity.

The gross CH_4 generated from 1,361 Mg of MSW from Massey University in 2003-04 was calculated as 59 Mg. Considering the 65% recovery of gas, and an oxidation factor of 0.1, the net CH_4 emission from the Massey University waste in 2003-04 was 19±13 Mg or 391±286 Mg of CO_2e (Table 4.2). The estimated uncertainties in these final values are calculated from the uncertainties in the individual components, as described in Sections 4.2.3 and 4.2.6 above[7].

[7] refer xl spreadsheet "waste_master.xls, worksheets "table4.1" and "table4.2" in the CD attached. Please note that in the worksheet "table 4.2" these quantities are given in Gg.

As discussed earlier in the chapter, the assumed amount of annual waste per head in 1990 was 99 kg, which gives 1.18 Gg of waste generated in 1990. Estimated net CH_4 emissions from solid waste in 1990 were 49 Mg, which was equal to 1,035±362 Mg of CO_2e (Table 4.2).

4.3.3 Carbon dioxide from Flaring of CH_4

The total estimated amount of CO_2 emitted from flaring of CH_4 in 2004 was 106±27 Mg. There was no gas recovery system installed in 1990 and therefore, no CO_2 emission due to flaring of CH_4 has been calculated for 1990.

4.3.4 Nitrous Oxide Emission from Wastewater & Human Sewage

Total N_2O emissions in 2004 from wastewater originating from Massey University human sewage were 439±95 kg. Total estimated N_2O emissions from human sewage in 1990 were 332±69 kg (Table 4.3)[8].

4.3.5 Total CO_2e Emissions from the Waste Sector

Total CO_2e GHG emissions from the waste sector at Massey University in 2004 were 633±290 Mg, whereas total estimated emissions from the waste sector in 1990 were 1,138±363 Mg of CO_2e (Table 4.4)[9].

[8]refer xl spreadsheet "waste_master.xls, worksheet "table4.3" in the CD attached.
[9]refer xl spreadsheet "waste_master.xls, worksheet "table4.4")in the CD attached.

Figure 4.4. Gas flare station at Awapuni landfill

Figure 4.5: Methane collection system installed at Awapuni landfill

Table: 4.2: Methane and CO_2e emissions from solid waste from the Turitea campus of Massey University

Year	Total waste (Gg)	CH_4 generation potential (L_o)	Gross CH_4(Gg)	Recovery efficiency (%)	CH_4 recovered (Gg)	Oxidisation factor	Net CH_4 (Gg)	Net CO_2e (Gg)
1989-90	1.180	0.0464	0.0548	0	0	0.1	0.0493	1.0348
2000-01	1.525	0.0453	0.0691	58	0.0401	0.1	0.0261	0.5483
2001-02	1.245	0.0447	0.0556	45	0.0250	0.1	0.0275	0.5781
2002-03	1.269	0.0440	0.0559	45	0.0252	0.1	0.0277	0.5812
2003-04	1.361	0.0434	0.0591	65	0.0384	0.1	0.0186	0.3908

Table 4.3: Annual N_2O emissions from human sewage from Massey University

Year	Per capita wastewater N (kg/person/year)*	Total number of full time equivalent staff+students	Students staying in hostels	Students and staff staying for 8 hours at the campus	Emission factor (kg N_2O-N/kg sewage-N produced)	N_2O emission due to boarding students (kg)	Emission due to students and staff (kg)	Total N_2O emission (kg)
	A	B	C	D	E	F= AxCxEx 44/28	G=(AxDxEx44/28)/3	F+G
1990	4.75	11,953	700	11,253	0.01	52	280	332
2001	4.75	15,338	700	14,638	0.01	52	364	416
2002	4.75	16,041	700	15,341	0.01	52	382	434
2003	4.75	16,544	700	15,844	0.01	52	394	446
2004	4.75	16,238	700	15,538	0.01	52	387	439

Table 4.4: Total CO_2e emissions from waste sector at Massey University in 1990 & 2004

Sub-category	CH_4 (kg)		N_2O (kg)		CO_2e (Mg)	
	2004	1990	2004	1990	2004	1990
MSW	18,600	49,300			391	1,035
Waste water & Human sewage			439	332	136	103
$CO_2$from flaring of CH_4					106	0
Total emissions in CO_2e					633	1,138

4.4 DISCUSSION

In both 2004 and 1990 MSW was by far the largest contributor to the GHG emissions from the waste sector at Massey University (Table 4.4). This contribution was either directly in the form of CH_4 emitted from the Awapuni landfill, or indirectly as CO_2 produced from flaring of CH_4 recovered from the landfill. In 2004, 78% of the total GHG emissions from the Massey University waste sector were from MSW and 22% from wastewater handling, compared to national level figures of 82% and 18% respectively (MfE, 2006a).

The overall GHG emissions from the waste sector at Massey University appear to have decreased from 1,138±363 Mg of CO_2e in 1990 to 633±290 Mg of CO_2e in 2004. The amount of MSW produced in 2004 was 15% more than in 1990, but the net emissions of CH_4 in 2004 have reduced by 52% as compared to the emissions in 1990 (Table 4.5). The reason for this large reduction in the net emissions is the gas recovery system at the waste disposal site. In 1990 there was no such system installed and therefore, no gas could be recovered. In 2004, the gas recovery system recovered 65% of the total emitted CH_4 and flared it. As the GWP of CO_2 is only 1/21 that of CH_4, this results in a large decrease in the quantity of CO_2e emitted.

Table 4.5: Weight of MSW produced at Massey University in 1990 and 2004 and resulting GHG emissions

Year	Waste produced (Gg)	Net CO_2e emissions (Mg)
1990	1.18	1,035
2004	1.36	497*
% change	+15	-52

*This amount includes CO_2 resulting from flaring of CH_4

Emissions of N_2O have increased by 32% since 1990. This increase is simply the result of the increase in the number of full time equivalent students and staff.

The decrease in annual CO_2e emissions from the Turitea campus from 1990 to 2004 amounts to 505±653 Mg. From the size of the uncertainty associated with this apparent decrease it is possible that there has in fact been no change in GHG emissions from the waste sector at the Turitea campus from 1990 to 2004. This is unlikely. Much of the uncertainty associated with the estimated GHG emissions from the waste sector at the Turitea campus relates to the composition of the waste and its corresponding CH_4 generation potential. As any error in this constant is likely to apply equally in both 2004 and 1990, the actual uncertainty in the extent of the decrease in GHG emissions from 1990 to 2004 is likely to be smaller than indicated here.

It is interesting to note that the estimated uncertainty in the national waste emissions was ±35% (MfE, 2007, 2006a, 2004) and this resulted primarily from variability in the waste statistics, waste composition, the CH_4 generation constant and the proportion of recovered CH_4 (MfE, 2004). The corresponding uncertainty in the estimates of annual CO_2e emissions in 2004 (633±290 Mg) from Massey University was ±46%. The reason for this increased uncertainty in Massey University's emissions was an additional introduced uncertainty as to the efficiency of the CH_4 recovery system and the GWP value of CH_4.

Better waste management practices can help reduce emission of GHGs (EPA, 2001; Yasui *et al.*, 2006). It is possible to reduce the generation of solid waste at Massey University by improving recycling efficiencies. As mentioned earlier, in 2003-4 only about 5% of the total waste stream was collected for recycling.

Mason (2001) had identified a number of areas where increased recycling was possible and in recent years there has been a considerable increase in the amounts of waste material being recycled (Fig. 4.6).

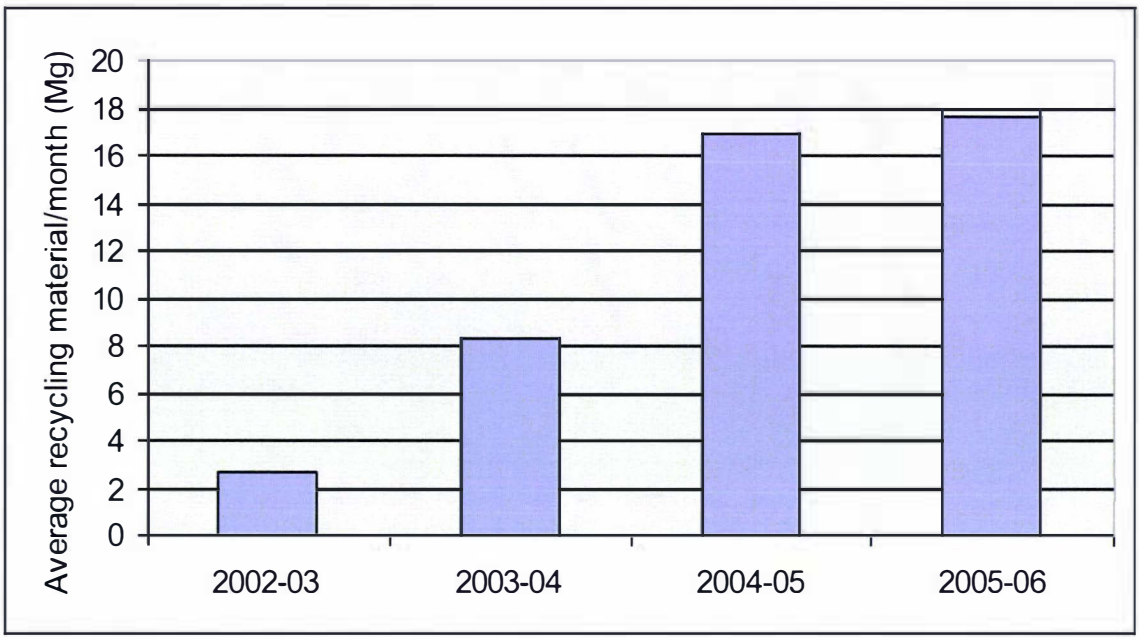

Figure 4.6: Average monthly amount of recycling material from Massey University from 2002-03 to 2005-06

Complete data on waste generation going back to 1990 were not available. However, an analysis of the available waste generation data between 2000-01 and 2003-04 (Fig. 4.3) shows a decrease per capita waste production after 2000-01 – corresponding to the introduction of recycling on the campus. Since that time there has been no further reduction in per capita waste production, and in 2003-04 there was even a slight increase. The cause of this increase in waste production is not known, however it did coincide with the demolition and renovation of several buildings during the year. Although the amount of MSW generated in 2003-04 at Massey University was 7-9% greater than the last previous two years, the net CH_4 emission was approximately 48-49 % less (Fig. 4.7). This was because of the increased efficiency of the gas recovery system at the waste disposal site.

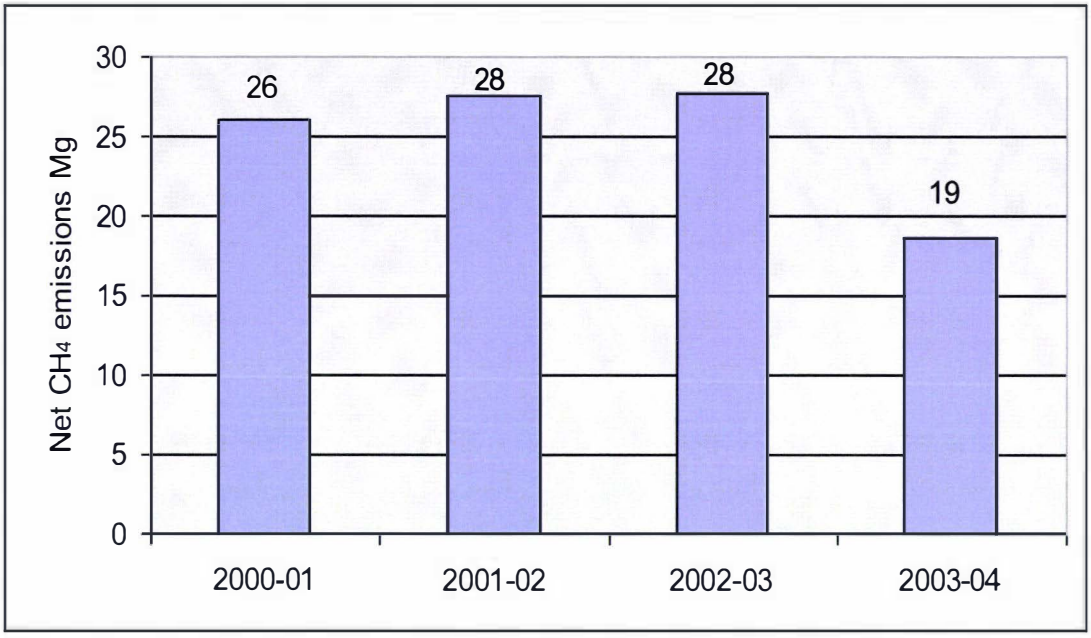

Figure 4.7: Net annual CH_4 emissions (Mg) from Massey University waste from 2000-01 to 2003-04.

4.5 CONCLUSIONS

- The major source of GHG emissions from the waste sector at Massey University is the MSW, which contributes about 78% of the total GHG emissions in CO_2e from this sector.

- Net emissions of GHG from the waste sector at Massey University have decreased by about 44% since 1990. This is mainly a consequence of the installation of a gas recovery system at the Awapuni landfill. It is interesting to note how the GHG emissions from the waste sector in an institution such as Massey University, are affected by the subsequent handling of that waste by another agency – in this case PNCC.

- There is scope for further reduction in these emissions from the waste sector at Massey University. This can be done by further reducing the amount of waste production by introducing an intensive recycling programme at the campus, and following the famous 3Rs rule i.e. reduce-reuse-recycle.

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CHAPTER 5: AGRICULTURE

5.1 INTRODUCTION

Massey Agricultural College was established in 1926. It became a University in 1964 and retains a strong applied science bias. Over the period of interest, it had a large landholding with three dairy farms, four sheep and beef farms, one deer farm and an intensive animal research facility. The Massey University farms occupy a total area of 2000 hectares (AgServices, 2005). As the agricultural sector is a significant source of greenhouse gases (GHGs), conducting a GHG audit of these farms provides an interesting dimension to the overall estimates of carbon dioxide equivalent (CO_2e) emissions from Massey University.

There is a range of sources of GHG emissions in agricultural production systems. Methane (CH_4) emissions from ruminant animals and animal dung (Saggar *et al.*, 2003), nitrous oxide (N_2O) emissions from chemical fertilisers (Venterea, 2007) and flooded paddy rice fields (Jiang *et al.*, 2006), and burning agricultural residues (Li *et al.*, 2007) all add to the anthropogenic GHG emissions. The impact of human activities such as agriculture on the global environment has created considerable interest in measuring and mitigating agricultural emissions. The IPCC (1997b) revised guidelines on GHG inventories describe the following five sources that should be taken into account when calculating GHG emissions from the agricultural sector:

- Livestock: Enteric Fermentation and Manure Management
- Rice Cultivation: Flooded Rice Fields
- Prescribed Burning of Savannas
- Field Burning of Agricultural Residues and
- Agricultural Soils

Enteric fermentation generates only CH_4. In contrast, manure management produces CH_4 and N_2O, but the treatment of manure differs between the gases. For CH_4 all the manure dropped by animals is counted in the "manure management"

category, whether it is deposited in the paddock or in the yard. But for calculating N_2O emissions in the "manure management" category, only the manure in the yard is counted because N_2O emissions from the manure dropped directly in the paddock are counted under the "agricultural soils" category. Although the IPCC default methodology is the most frequently used methodology for calculating anthropogenic GHG emissions from agricultural soils, the uncertainty involved in emission factors and direct emissions, the limited data on animal excretion of nitrogen (N), and the variability in N_2O emissions make this methodology limited. (Saggar *et al.*, 2004a).

5.1.1 Global Emissions from the Agricultural Sector

It is estimated that 119-180 Tg of CH_4 are emitted globally every year from the agricultural sector (IPCC, 2001a). This includes emissions from ruminants, animal waste treatment, and rice production. Ruminants are a major source of these CH_4 emissions (Fung *et al.*, 1991; Mosier *et al.*, 1998; Olivier *et al.*, 1999; New Zealand Ministry for the Environment (MfE), 2006). About 28% of the total global anthropogenic CH_4 comes from enteric fermentation (United States Environmental Protection Agency (EPA), 2002).

Annual global N_2O emissions from agricultural soils are estimated to be 6.3 Tg N (Mosier *et al.*, 1998), which is about 76% of the total global anthropogenic N_2O budget (EPA, 2002). Although the agricultural sector has only small direct CO_2 emissions - contributing about 4% of total global emissions - the contribution of CH_4 and N_2O by agriculture to global anthropogenic GHG emissions, expressed as CO_2e, is over 20% (IPCC, 2001b).

5.1.2 National Emissions from the Agricultural Sector

"Agriculture is the principal industry in New Zealand, and agricultural products are the predominant component of exports" (MfE, 2006, p.52). The New Zealand National Inventory Report for 2004 indicated that emissions from the agricultural sector totalled 36,866 Gg CO_2e in 2004 and that this was almost half (49.4%) of all GHG emissions from New Zealand in that year.

Enteric fermentation by ruminants produced 64.3 % of the GHG emissions attributed to agriculture (MfE, 2006).

The other large component in this sector was the emissions from agricultural soils, which made up 33.4% of the total national emissions attributed to agriculture. This component consists almost entirely of N_2O emissions. Ninety six percent of the total N_2O emissions in New Zealand are from the agricultural sector (MfE, 2006). GHG emissions from the agricultural sector in New Zealand have increased by 14.8% since 1990 (MfE, 2006) (Fig. 5.1).

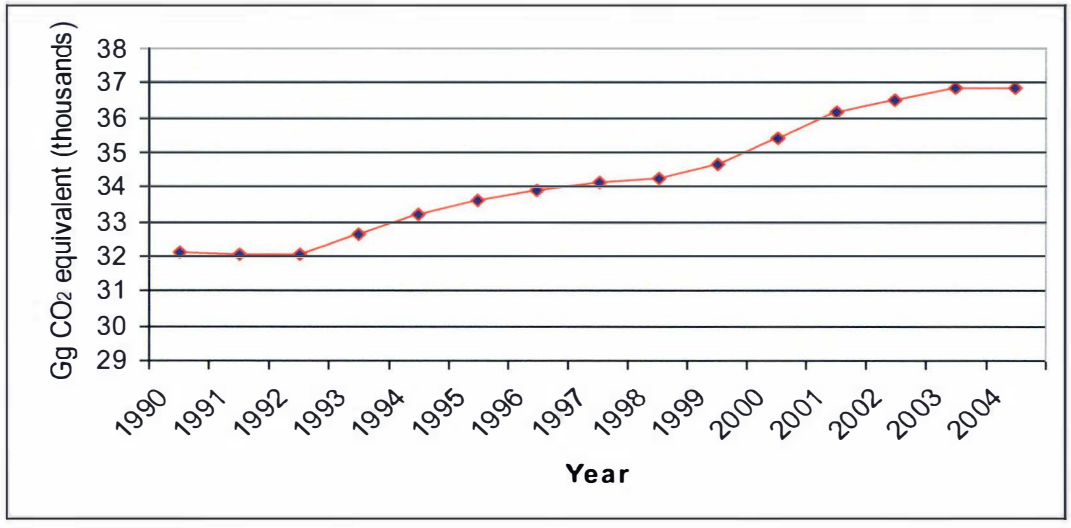

Figure 5.1 Total national agricultural sector emissions from 1990 to 2004
Source: (MfE, 2006)

5.1.3 Methane from Enteric Fermentation

Enteric fermentation is a digestive process by which carbohydrates are broken down by micro-organisms into simple molecules to facilitate their absorption into the bloodstream. The type of animal, its age and weight, the quality and quantity of feed and the energy expenditure of the animal are the factors described by IPCC (1997a) that affect the amount of CH_4 emitted during the process of enteric fermentation. Animals grazing low quality pasture are thought to produce more CH_4 (Ulyatt *et al.*, 2005). Hence CH_4 emissions can be lowered by providing high quality feed to the grazing animals (Joblin, 2001). Also, there is a positive relationship between the increase in CH_4 emissions from enteric fermentation and

dry matter intake/cow and a negative relationship between CH_4 emissions and milk production/ha (Schils *et al.*, 2006). This suggests that it may be possible to reduce the amount of CH_4 produced by increasing the efficiency of the animals.

The processes regulating CH_4 production by animals are still being debated and there are large variations in CH_4 emissions between animals (Lassey *et al.*, 1997). For example, Lassey & Ulyatt (1997) found large inter-sheep variability in daily CH_4 emission that was not related to variations in the feed intake. This variable methanogenic response is a key area for future research.

A number of published algorithms and models of ruminant digestion have been identified by MfE (2004) that can be used for estimating CH_4 emissions on the basis of feed intake (e.g. Blaxter & Clapperton, 1965; Baldwin *et al.*, 1987; Benchaar *et al.*, 2001). All these models are difficult to use for generalized inventories due to the large data requirements (MfE, 2004). For example, in the first comprehensive enteric CH_4 emissions inventory of New Zealand, Ulyatt *et al.* (1991) used the Baldwin model ((Baldwin *et al.*, 1987)) which needed quantification of 11 diet characteristics (Clark *et al.*, 2003). Also, the animals used in the experiments to produce most of these models were fed indoors and their diets were different from the diets of animals in New Zealand, which normally graze in open pastures (Clark *et al.*, 2003).

Clark *et al.* (2003) used a simple but comprehensive model that operates with a monthly time step and utilises data on direct measurements of CH_4 emissions from ruminants collected in New Zealand. The same model is used in this study.

5.1.4 Methane from Manure Management

The decomposition of animal manure under anaerobic conditions produces CH_4 (IPCC, 1997b). A considerable amount of CH_4 is produced from animal manure when a large number of animals are kept in confined areas such as on a dairy farm, and their manure is stored in large piles or disposed off in lagoons (IPCC, 1997b). On New Zealand dairy farms only a small portion (5%) of dairy animal

manure goes into the anaerobic ponds, but dung deposited directly onto pasture also has the potential to be a source of CH_4 (Saggar *et al.*, 2004a, p.518). Total national CH_4 emissions from manure management in New Zealand were 1.5% of the total agricultural CO_2e emissions in 2004 (MfE, 2006).

5.1.5 Nitrous Oxide from Soils

The emissions of N_2O from soil are estimated by assuming that agreed proportions of the N added to soils from various sources are emitted as N_2O. The proportion of added N that is subsequently emitted varies depending on the source. The emission of N_2O is therefore calculated simply by determining the amounts of N added to the soil and multiplying by the appropriate emission factors.

Applications of synthetic fertiliser and animal manure to agricultural soils are the two most important global anthropogenic inputs of N to the soil (Galloway *et al.*, 2004). Of these two sources, animal manure deposited during grazing is the single largest source of global N_2O emissions and makes up about 80% of total agricultural N_2O emissions (deKlein & Ledgard, 2005).

In New Zealand however, N fixation by clover is another important source of N. Saggar *et al.* (2004b) estimated 0.9-1.1 Tg of N out of a total annual input of about 3 Tg of N to New Zealand's agricultural systems was from N fixation. Other contributors were animal excreta (1.58 Tg N) and N fertiliser (0.33 Tg N).

In 2004 it was estimated that there were around 41.5 Gg of anthropogenic N_2O emissions from New Zealand (MfE, 2006), which accounted for about 17.4% of all GHG emissions on a CO_2e basis. The N_2O emissions from the agricultural sector were about 40 Gg, thereby contributing 96% of the total N_2O emissions. Only 14% of agricultural emissions are due to N fertiliser use (deKlein & Ledgard, 2005).

Indirect emissions of N_2O are also important (Denmead *et al.*, 2008). Nitrous oxide emissions to the atmosphere from N lost from the soil in surface run-off or leaching water are called indirect N_2O emissions. Addition of animal wastes or

mineral fertilisers to the soil in excessive amounts can be a cause of considerable leaching (Schechtner, 1991) resulting in indirect N_2O emissions. The amount of rainfall after fertiliser application also affects the total amount of N_2O emitted indirectly (Grant and Pattey, 2003). Heavy rain after the fertiliser application may cause a large amount of N to be leached.

The N_2O emitted from N that was previously emitted as ammonia (NH_3) is also included in indirect emissions. Urine and faeces from farm animals are a large source of NH_3 to the atmosphere (ApSimon *et al.*, 1987; Lockyer & Whitehead, 1990). In open grazing systems, large amounts of animal excreta are directly deposited onto pasture land. The deposition of this excreta and the application of synthetic fertilisers on agricultural land or pastures, can result in emissions of NH_3 into the atmosphere. The amount of N lost to atmosphere as NH_3 depends in part on amount of fertiliser applied and the soil moisture (Bussink, 1992). This emitted NH_3 can return to the ground in rainfall and can then be re-emitted as N_2O (MfE, 2004).

5.1.6 Nitrous Oxide from Manure Management

Animal manure has been identified an important source of N_2O (Park *et al.*, 2006). Nitrous oxide is emitted during both the storage of animal manure and its subsequent application to soils (AESA, 2004; Sirwan, 2006). The length of the manure storage time and the system of waste management used determine the amount of N_2O emitted from the animal manure (MfE, 2004). According to EPA (2002), 6% of the global anthropogenic N_2O emissions are from animal manure management, whereas only 0.5% of the total 2004 national N_2O emissions came from manure management in New Zealand (MfE, 2006).

IPCC (1997a) has identified seven alternative regimes for treating animal manure when calculating N_2O emissions from the agricultural sector. In New Zealand only four of these regimes are used and these are listed below (MfE, 2006):

(1) anaerobic lagoons (AL)
(2) pasture, range and paddock (PR&P)

(3) solid storage and dry-lot (SS&D), and

(4) other systems (OTHER)

The SS&D system is not used at Massey University.

5.1.7 Objectives

The objectives of the work described in this chapter were (a) to identify the major sources of GHGs within the agricultural sector at Massey University, and (b) to quantify these emissions. The Massey University Turitea campus also has eight rugby grounds, three soccer grounds, and an athletics track. The amounts of annual GHG emitted from the fertilisers used to maintain these facilities were also estimated.

5.2 METHODS

5.2.1 General Methodology

The main steps in estimating GHG emissions from the agricultural sector at Massey University were:

a. Gathering data on the numbers of stock and amount of fertiliser used
b. Using the literature or models to estimate the quantities of CH_4 and N_2O released to the atmosphere from the Massey farms
c. Converting these to CO_2e

Of the five standard sources (Section 5.1) of GHG emissions from agriculture that have been identified by IPCC (1997b) only GHG emissions from enteric fermentation and manure management associated with farm animals, and GHG emissions from agricultural soils have been considered in this study. The other agricultural sources of GHGs identified by IPCC (1997b) do not apply on the Massey University farms.

5.2.2 Data Collection

The Agricultural Services Division (AgServices) is the operational unit that manages the Massey University farms and specialized agricultural research units. Most of the data used in this chapter has been collected from the AgServices office. A complete data set on livestock numbers was available. There was no significant change in the numbers of dairy and beef animals from 1990 to 2004, but there was a considerable decrease in the number of sheep. The deer farm at Massey University is only a small experimental farm and the deer numbers have not changed greatly since 1990 (i.e. 106 in 1990 and 116 in 2004).

Livestock numbers for 2004 were obtained from AgServices (Geoff Warren, personal communication) while the numbers for 1990 were taken from the Annual Reports, Budget Reviews, and Farm Facts produced by AgServices that were kept in the Massey University Archives (Farm Committee Reports 1.2/1/5, Box 23-30). Poultry numbers were only available from 1996 to 2004, and were collected from the Institute of Food, Nutrition and Human Health at the Turitea campus of Massey University (Professor Ravi Ravindaram, personal communication). A summary of the total animal numbers from 1990 to 2004 is shown in Table 5.1. This table gives the total numbers of animals in each class at the end of June, but the monthly animal numbers in each sub-category of dairy, beef, sheep, and deer are shown in Annex 5.1.

Data on fertiliser used on Massey University farms and sports grounds in 2004 were collected from AgServices and Massey University's Grounds Department (Geoff Warren & Terry Walker, personal communication). No records could be found of fertiliser use in 1990.

Table 5.1: Animal numbers on Massey University farms from 1990 to 2004

Year	Dairy cattle (June yr)	Non-dairy cattle (June yr)	Sheep numbers (June yr)	Deer numbers (June yr)	Poultry numbers (June yr)
1990	825	1,014	14,589	106	not available
1991	1,027	1,562	13,956	146	not available
1992	817	1,447	14,264	185	not available
1993	951	1,680	11,357	181	not available
1994	1,062	1,695	10,558	183	not available
1995	1,179	1,869	14,183	179	not available
1996	1,246	1,666	11,673	157	3,850
1997	607	961	11,511	150	4,600
1998	1,166	1,403	11,696	156	5,460
1999	1,096	1,255	14,985	192	5,800
2000	974	988	11,577	169	6,650
2001	1,011	1,003	11,913	189	9,600
2002	833	1,135	12,889	180	11,550
2003	1,013	1,050	11,714	162	12,680
2004	1,076	1,049	10,325	116	9,700

5.2.3 Livestock

Methane emissions from enteric fermentation and CH_4 and N_2O emissions from animal manure management are calculated in this section. The categories of livestock considered here are dairy cattle, non-dairy cattle, sheep and deer. The University does not have a significant number of goats, horses or swine and these categories have not been considered.

5.2.3.1 Calculating CH_4 Emissions from Enteric Fermentation

Default emission factors are available in IPCC guidelines to calculate CH_4 emissions from enteric fermentation in different livestock categories (IPCC, 1997a). But the use of these default emissions factors results in an under-estimation of CH_4 emissions in New Zealand conditions. For example, the IPCC default emission

factor for sheep for developed countries like New Zealand is 8 kg of CH_4/head/year (IPCC, 1997b) while the New Zealand specific emission factor for sheep calculated by MfE in the New Zealand National Inventory Report is 10.6 kg of CH_4/head/year (MfE, 2006). Similarly, the IPCC default emission factors for dairy and non-dairy cattle are 68 and 53 kg of CH_4/head/year respectively (i.e. for the Oceania region (IPCC, 1997b)), whereas the New Zealand specific emission factors for these two categories are 79.1 and 56.3 kg of CH_4 per head per year respectively (MfE, 2006).

A detailed characterisation of the livestock population and records of animal productivity were used to calculate feed intake by the dairy cattle, beef cattle, and sheep, whereas an average emission factor was used to calculate the enteric CH_4 emissions from deer (MfE, 2006). The total population of livestock on the Massey University farms was divided into a number of livestock classes for use as input data in the model. All the livestock classes were then divided further into various sub-categories. For example, beef cattle were divided into two broad groups, breeding animals and growing animals, and then further sub-divided by age, sex and reproductive status. This sub-division, proposed by Clark *et al.* (2003), improves the accuracy of the emission estimates because the performance of the various sub-categories is different, and they require different amounts of feed.

The numbers of sub-categories in each animal class are given below, while the description of sub-categories and total number of animals in each category are listed in Annex 5.1.

Dairy Cattle	= 4 sub-categories
Beef Cattle	= 11 sub-categories
Sheep	= 11 sub-categories
Deer	= 7 sub-categories

The amount of CH_4 emitted was calculated using estimates of CH_4 emissions per unit of feed intake following the livestock growth model of Clark *et al.* (2003). Values for the livestock feed requirements and average annual live weights were

also taken from the same model of Clark *et al.* (2003), which used the Australian Feeding Standards equations for estimation of energy requirements for cattle and sheep. Animal numbers from the end of the previous year are used as an input in this model. It then automatically grows the stock through the year and also estimates the offspring at the appropriate time. This model estimates the dry matter intakes (DMI) for different categories of animals by calculating the energy required by these animals (MJ metabolisable energy (ME) per day) and dividing this value by the energy concentration of the diet consumed (MJ ME per kg dry matter) (Clark *et al.*, 2003). The model finally calculates the amount of CH_4 emitted, by multiplying the total DMI by a CH_4 emission factor (g CH_4/kg of DM).

The annual CH_4 emissions from sheep, dairy, and beef animals were calculated separately for both 1990 and 2004. An example of the population model used for beef animals in 2004 is shown in Table 5.2. Summary reports of the analyses of the three categories of animals for 1990 and 2004 are attached as Annex 5.2, and details of the calculations showing performance data and energy requirements by individual animal categories are in the file named "Analysis Livestock" in the attached CD[1].

Monte Carlo simulations were run to estimate the uncertainties in CH_4 emissions from each of the dairy cattle, non-dairy cattle, and sheep livestock classes. In order to run the Monte Carlo simulations, the uncertainties associated with each of the parameters required to calculate CH_4 emissions were estimated. These parameters were the animal populations, their energy requirements, the feed energy, and the CH_4 emission factor. The uncertainties were: population uncertainty ±1%; energy requirement uncertainty ±10%; feed energy uncertainty ±10%; and methane emission factor uncertainty ±52%. These uncertainty values were selected following MfE (2006)[2].

Once the Monte Carlo simulations had been run, the uncertainty in the CH_4 emission from each of these livestock classes was computed as twice the

[1] To open these files @Risk software is required. A free 15 days trial version can be downloaded from: www.palisade.com

[2] refer xl spreadsheets: Massey Dairy 1990, 2004; Massey Beef 1990, 2004; Massey Sheep 1990, 2004, in the CD attached.

standard deviation divided by the mean value as generated by the simulation in each case. The uncertainty in CH_4 emission calculated for the major livestock classes was also applied to poultry and deer, as simulations were not performed for these two animal classes.

Once the uncertainties for each of these classes had been estimated, the uncertainty in the total CH_4 emission (the sum of the CH_4 emissions for the five classes) was calculated (see Section 3.2.5)[3].

5.2.3.2 Calculating CH_4 Emissions from Animal Manure Management

To calculate CH_4 emissions due to animal manure management, the total number of animals in each category (dairy, beef, sheep, and deer) was multiplied by a New Zealand specific CH_4 emission factor for that class of animal. The emission factors for cattle were obtained from Saggar *et al.* (2003) and Sherlock *et al.* (2003) and the emission factors for sheep were taken from Carran *et al.* (2003). The factors used were 0.889 kg CH_4/head/year, 0.909 kg CH_4/head/year, and 0.178 kg CH_4/head/year for dairy cattle, non-dairy cattle and sheep respectively. All these values are based on New Zealand research (MfE, 2006).

No values were available for deer so the mean of cattle and sheep values (0.369 kg CH_4/head/year) was used. Also, a New Zealand-specific emission factor was not available for CH_4 emissions from poultry manure. The IPCC default emission factor for poultry (0.117 kg CH_4/head/year) was therefore used.

[3]refer xl spreadsheet "agriculture_master.xls, worksheets "Table5.3-5.3a" in the CD attached.

Table 5.2: Population model used to calculate enteric CH_4 emissions from beef animals at Massey in 2004

	Breeding animals					Slaughter animals						
Month	Cows	<1yr	1 - 2yr	2+ yr	Bulls	Heifers		Steers		Bulls		
						0 - 1yr	1 - 2yr	0 - 1yr	1 - 2yr	0 - 1yr	1 - 2yr	Total all
JULY	313	0	0	0	10	64	0	59	94	324	155	1,019
AUG	292	0	0	0	10	64	0	59	94	286	135	940
SEPT	286	0	0	0	10	64	0	58	94	285	135	932
OCT	283	0	0	0	10	64	0	58	94	285	135	929
NOV	276	0	0	0	10	64	0	58	93	285	129	915
DEC	276	0	0	0	10	64	0	58	93	285	72	858
JAN	276	0	0	0	9	64	0	58	56	283	72	818
FEB	276	0	0	0	9	64	0	58	56	227	7	697
MAR	276	0	0	0	9	64	0	58	56	398	109	970
APR	276	0	0	0	9	58	0	102	10	398	107	960
MAY	253	0	0	0	9	92	77	102	14	398	106	1,051
JUN	253	0	0	0	7	92	77	102	14	398	106	1,049
AVERAGE	278	0	0	0	9	68	13	69	64	321	106	

5.2.3.3 Calculating N_2O Emissions from Animal Manure Management

This category includes emissions of N_2O related to manure handling before the manure is added to the soil. The amount of N_2O released depends on the system of waste management and the duration of storage. The following AWMSs were considered in this section:

- anaerobic lagoons (AWMS=AL)
- nitrogen emissions from other management systems (AWMS=OTHER)

In order to calculate total N_2O emissions in 2004 from animal manure management at Massey University, total excretal N in the different AWMS was calculated by multiplying the number of animals in each category by the average amount of annual excretion/head that ends up in an AWMS (MfE, 2006). No New Zealand-specific emission factors were available for N_2O emissions from different AWMS, and so the amounts of N_2O emitted from these sources was calculated by multiplying the total amount of excretal N in the two systems with the IPCC default emission factors. An uncertainty of ±30 % was applied to the amount of N_2O emitted from animal manure management, reflecting the range in values for N losses from animal manure management systems as reported by IPCC (1997b)[4].

5.2.4 Agricultural Soils

To provide a comprehensive estimate of GHG emissions from agricultural soils, the annual amount of N excreted by the farm animals and total fertiliser input in 2004 and 1990 was required. Nitrous oxide emissions from the soils were determined using the IPCC approach in which the amount of N emitted into the atmosphere as N_2O is assumed to be proportional to the amount of N added to the soil in fertiliser or animal excreta. The proportionality constant varies depending on the type of N input and these constants are termed emission

[4]refer xl spreadsheet "agriculture_master.xls, worksheet "Tables5.13-5.13a" in the CD attached.

factors. An emission factor is also assigned to N that is lost from the system and then contributes to indirect N_2O emissions.

Tables 5.3 and 5.4 show the emission factors and fractions of N input used in these calculations. Mostly the default values from IPCC were used except the following two which are New Zealand-specific.

- an emission factor for direct emissions from the animal excreta deposited directly on pasture (pasture, range and paddock system).
- the fraction of N input to soil that is lost through leaching and run-off.

Table 5.3: Fractions of N lost in different systems

Parameter	Value	Fraction of	Additional sources
$Frac_{FUEL}$	0	Livestock N excretion in excrements burned for fuel	Practice does not occur at Massey University
$Frac_{GASF}$	0.1	Total synthetic fertiliser emitted as NO_X or NH_3	IPCC Reference manual Table 4.19
$Frac_{GASM}$	0.2	Total N excretion emitted as NO_X or NH_3	IPCC Reference manual Table 4.19
$Frac_{LEACH}$	0.07	Nitrogen input to soils that is lost through leaching and run-off	Thomas *et al.*(2002)

Source: (MfE 2006)

Table 5.4: Emission factors for agricultural emissions of N_2O

Emission factor	Value	Emission factor for....	Additional sources
EF_1	0.01	Direct emissions from N input to soil	IPCC GPG Table 4.17
EF_2(AL)	0.001	Direct emissions from waste in the anaerobic lagoons AWMS	IPCC GPG Table 4.12
EF_2(PR&P)	0.01	Direct emissions from waste in the pasture range and paddock AWMS	Carran *et al.* (2003), Sherlock *et al.* (2003), Kelliher *et al.* (2003)
EF_2(OTHER)	0.005	Direct emissions from waste in other AWMSs	IPCC GPG Table 4.13
EF_3	0.01	Indirect emissions from volatilising N	IPCC GPG Table 4.18
EF_4	0.025	Indirect emissions from leaching N	IPCC GPG Table 4.18

Source: (MfE 2006)

5.2.4.1 Calculating N_2O Emissions from Agricultural Soils and Sports Grounds

In this section the direct and indirect N_2O emissions from N excreted by grazing animals and synthetic N fertilisers used by AgServices on the Massey University

farms, and synthetic N fertilisers used by the Grounds Department, have been calculated. The emissions calculations were split into the following three sub-categories:

- Direct N_2O emissions from animal production i.e. the pasture range and paddock (PR&P) system
- Indirect N_2O from N lost from the paddock or sports field as NO_x or NH_3
- Direct N_2O emissions from agricultural soils and sports grounds as a result of adding N in the form of synthetic fertilisers and animal manure

The direct soil emissions of N_2O from animal production considered here are those produced from excreta deposited directly onto pasture by grazing animals. Under New Zealand conditions, it is considered that 95% of excreted N from dairy cattle and 100% of the excreted N from sheep, deer and non-dairy cattle is deposited directly onto the paddock during grazing (MfE, 2006). The emission calculations in this section were based on the numbers of the various types of animals in the "PR&P" system. An average N excretion rate for each animal type was multiplied by the number of animals. Then the New Zealand-specific emission factor (EF_{PRP} = 0.01) for direct emissions from N inputs to soil was used (MfE, 2006).

Indirect N_2O emissions were calculated from the total amount of N added to the soil in the form of animal excreta and synthetic fertilisers, multiplied by a combination of country specific and IPCC default emission factors as specified below.

For calculating indirect N_2O emissions from N leaching, the total amount of leached N was calculated by first multiplying the total N input with the New Zealand specific average leaching factor of 0.07 (Thomas *et al.*, 2005). Then the amount of leached N was multiplied by the IPCC default emission factor (0.025).

Similarly, for calculating indirect N_2O emissions due to NH_3 volatilisation, the total amount of volatilised N was calculated by first multiplying the amount of synthetic fertiliser N and animal manure N by the IPCC default volatilisation factors of 0.1

and 0.2 respectively. The amount of volatilised N was then multiplied by the IPCC default N_2O emission factor of 0.01.

Direct N_2O emissions from synthetic fertiliser use and spreading of animal manure on agricultural land were calculated from the net amounts of N added to the soils from these two sources, after making allowance for the proportions of added N that would be lost as NO_X or NH_3. The default IPCC values for the proportions of added N lost as these two gases were 0.1 and 0.2 for synthetic N fertiliser and animal manure respectively. The resulting net N additions to the soil were then multiplied by the default emission factor of 0.01 for direct emissions from N input to soil.

To estimate uncertainties in the total N_2O emissions from agricultural soils and sports grounds, Monte Carlo simulations were run. For the input parameters, the uncertainties were estimated and combined according to the equations and calculations that computed N_2O emissions from animal excretion, from leaching, from volatilization, and from fertiliser placement. These uncertainties were used in the Monte Carlo simulations and contributed to the resulting uncertainty in total N_2O emission. The following uncertainties (MfE, 2005, 2006) were assigned: a non-dairy cattle excretion uncertainty of ±22%; a dairy cattle excretion uncertainty of ±20%; a sheep excretion uncertainty of ±22%; a deer excretion uncertainty of ±22%; a poultry excretion uncertainty of ±22%; a non-dairy cattle population uncertainty of ±1%; a dairy cattle population uncertainty of ±1%; a sheep population uncertainty of ±1%; a deer population uncertainty of ±1%; a poultry population uncertainty of ±1%; a leaching parameter uncertainty of ±28.6%; a volatilization parameter uncertainty of ±33%; and an uncertainty on the amount of synthetic fertiliser used of ±6.6%[5]. These uncertainties are specific to New Zealand data, but are assumed to apply to the Massey farms in the absence of local data.

[5]refer xl worksheet AnalysisAgrisoils.xls, worksheets "livestock," "soils," "calculations," and "PDF" in the CD attached.

In addition, in the Monte Carlo simulation, the following uncertainties were applied to the various agricultural emission factors for N_2O: direct emissions from N input to soil, uncertainty ±79.4% (value calculated by Ministry for the Environment; MfE, 2005, 2006); direct emissions from waste in anaerobic lagoons or in solid waste and drylot or in pasture and paddock, uncertainty ±100% (default uncertainty value; IPCC, 2000); indirect emissions from volatising N, uncertainty±100 % (default uncertainty value; IPCC, 2000); and indirect emissions from leaching N, uncertainty ±100% (default uncertainty value; IPCC, 2000). The IPCC default uncertainty values were used because no New Zealand specific values for the various agricultural emission factors for N_2O emissions were available. The IPCC default uncertainty values (Table 4.13, IPCC 2000) are actually asymmetric, with a range of -50/+100 %. For the Monte Carlo simulation, a symmetric uncertainty of ±100% was used due to the calculation method employed in the simulation. This means that the uncertainties in calculated N_2O emissions will be slightly more conservative than would otherwise be the case.

The overall N_2O emission uncertainty was computed as twice the standard deviation divided by the mean value as generated by the simulation[6].

The uncertainties calculated for CH_4 and N_2O emissions as discussed above were combined with uncertainties on global warming potentials for CH_4 (±20%) and for N_2O (±20%) in the calculation of CO_2e emissions[7].

[6]refer xl spreadsheet AnalysisAgrisoils.xls, worksheet "Summary Report"; and spreadsheet agricultural_master.xls, worksheet "Tables 5.12-5.12a" in the CD attached.
[7]refer xl spreadsheet "agriculture_master.xls, worksheets "Table5.13-5.13a" in the CD attached.

5.3 RESULTS

5.3.1 Emissions from Livestock

5.3.1.1 Methane Emissions from Enteric Fermentation & Manure Management

The total CH_4 emission from enteric fermentation and manure management at Massey University in 2004 was 204±56 Mg. It includes 199 Mg from enteric fermentation and about 5 Mg from manure management (Table 5.5). Similarly the total estimated CH_4 emission from enteric fermentation and manure management in 1990 was 245±70 Mg (Table 5.5a)[8]. All animal classes contributed significantly to these emissions of CH_4 (Fig 5.2).

Monte Carlo simulations estimated that the coefficient of variation for CH_4 emissions from sheep, dairy, and beef animals were approximately 23% for both 1990 and 2004 (Table 5.6). The details are given in the summary report in the file named "AnalysisLiveStock" in the attached CD. MfE (2004) have indicated that the natural variation from one animal to the next is the main reason for this uncertainty and this is borne out in this study in which the uncertainty in emission factors and the uncertainty in energy requirements have the biggest impact on the overall uncertainty in CH_4 emissions (Table 5.7).

[8]refer xl spreadsheet "agriculture_master.xls, worksheets "Table5.3-5.3a" in the CD attached.

Table 5.5: Methane emissions from enteric fermentation and manure management from Massey University farms in 2004.

Livestock type	Number of animals	Emission factor for enteric fermentation (kg CH_4/head/yr)*	Emissions from enteric fermentation (kg/yr)	Emission factor for manure management (kgCH_4/head/yr)*	Emissions from manure management (kg/yr)	Total CH_4 emissions from domestic livestock (Mg/year)
Dairy Cattle	1,076		78,037	0.889	957	79
Non-dairy cattle	1,049		44,323	0.909	954	45
Sheep	10,325		74,248	0.178	1838	76
Deer	116	22.0	2,552	0.369	43	3
Poultry	9,700			0.117	1,135	1
Total			199,160		4,926	204

Table 5.5a: Methane emissions from enteric fermentation and manure management from Massey University farms in 1990

Livestock type	Number of animals	Emission factor for enteric fermentation (kg CH_4/head/yr)*	Emissions from enteric fermentation (kg/yr)	Emission factor for manure management (kgCH_4/head/yr)*	Emissions from manure management (kg/yr)	Total CH_4 emissions from domestic livestock (Mg/year)
Dairy Cattle	825		60,996	0.889	733	62
Non-dairy cattle	1,014		61,481	0.909	922	62
Sheep	14,589		114,825	0.178	2,597	117
Deer	106	22.0	2,332	0.369	39	2
Poultry	9,700			0.117	1,135	1
Total			239,634		5,426	245

*Source : (MfE, 2006)

Table 5.6: Coefficient of variation for CH_4 emissions from sheep, dairy, and beef animals

Livestock category	Year	Enteric CH_4 emissions (Mg/year)		Coefficient of variation
		Mean	St. Deviation	
Dairy	2004	78.03	18.59	0.238
	1990	60.99	14.47	0.237
Beef	2004	44.32	10.49	0.236
	1990	61.48	14.50	0.235
Sheep	2004	74.24	17.58	0.236
	1990	114.82	27.43	0.238

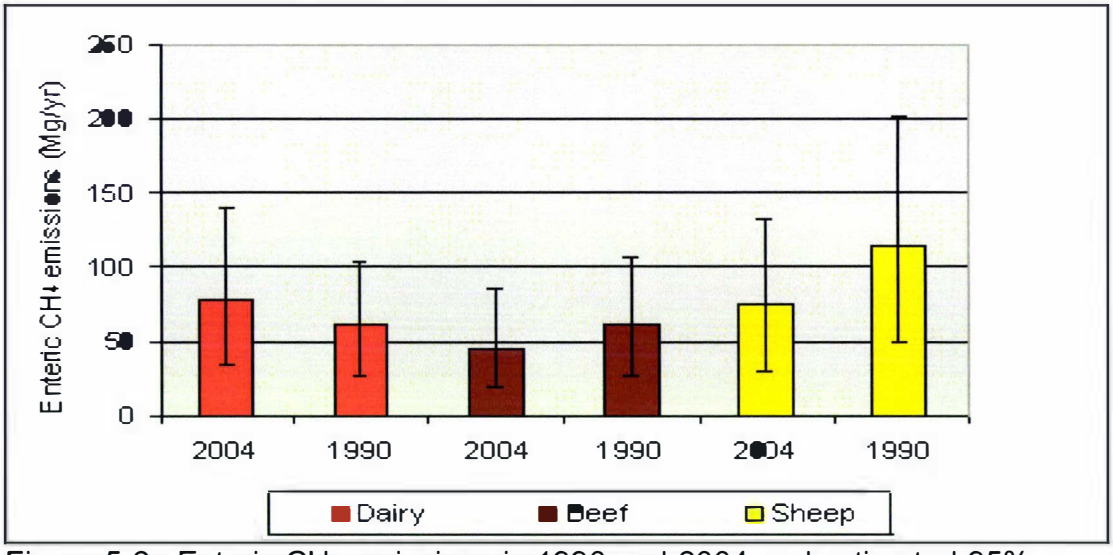

Figure 5.2: Enteric CH_4 emissions in 1990 and 2004 and estimated 95% confidence intervals

Table5.7: Sensitivity ranking for CH_4 emissions from livestock

Rank according to the affects on uncertainty	Name of the factor affecting uncertainty values
1	CH_4 factor uncertainty
2	Energy requirement uncertainty
3	Feed energy uncertainty
4	Population uncertainty

5.3.1.2 Nitrous Oxide Emission from Animal Manure Management

Total N excretion by agricultural animals for the year 2004 in all AWMS was calculated as 363,127 kg (Table 5.8). Similarly, total N excretion for the year 1990 was 383,638 kg (Table 5.8a).

Total N_2O emission in 2004 from this animal manure management was 54±16 kg (Table 5.9). It is important to note that this estimate only includes the N emitted from the storage and/or the treatment of excreted N in the "AL" and "OTHER" AWMS. The N excreted in the "PR&P" system is considered when calculating emissions from agricultural soils. Estimated emissions of N_2O from the same sub-category in 1990 were 52±16 kg (Table 5.9). As described above, an uncertainty of ±30% was applied to the amount of N_2O emitted from animal manure management[9].

According to IPCC (2000), the main factors causing uncertainty in N_2O emissions from manure management are the livestock population, N excretion rates, type of manure management system used, and the emission factors used for manure and manure management systems. Although the detailed livestock characterisation and New Zealand specific N excretion rates were used in calculations, IPCC default emission factors were also used to calculate the direct emissions from the animal waste and these have uncertainties of -50% to +100% (IPCC, 2000; MfE, 2004). Monte Carlo simulations applied to the N_2O emissions from the agricultural soils and sports grounds show that the coefficient of variation for the emissions in this section is 32%[10].

[9] refer xl spreadsheet "agriculture_master.xls, worksheet "Tables5.13-5.13a" in the CD attached.
[10] refer to summary report in file named "Analysis Agrisoils" in the CD attached

Table 5.8: Nitrogen excretion in different AWMSs at Massey University in 2004

Livestock type	Number of animals	N excretion (Nex)	Total annual N excretion by AWMS=AL		Total annual N excretion by AWMS=OTHER		Total annual N excretion by AWMS=PR&P	
		(kg/head/yr)	(%)	(kg N/yr)	(%)	(kg N)	(%)	(kg N)
Dairy cattle	1,076	117	5	6,295			95	119,597
Non-dairy cattle	1,049	72.5		0			100	76,053
Sheep	10,325	14.8		0			100	152,810
Deer	116	22		0			100	2,552
Poultry	9,700	0.6		0	97	5,645	3	175
Total				6,295		5,645		351,187

Table 5.8a: Nitrogen excretion in different AWMSs at Massey University in 1990

Livestock type	Number of animals	N excretion (Nex)	N excretion in AWMS=AL		N excretion in AWMS=OTHER		N excretion in AWMS=PR&P	
		(kg/head/yr)	(%)	(kg N/yr)	(%)	(kg N)	(%)	(kg N)
Dairy cattle	825	117	5	4826			95	91,699
Non-dairy cattle	1,014	72.5		0			100	73,515
Sheep	14,589	14.8		0			100	215,917
Deer	106	22		0			100	2,332
Poultry	9,700	0.6		0	97	5,645	3	175
Total				4,826		5,645		383,638

Source: (MfE, 2006)

Table 5.9: Nitrous oxide emissions from manure management in 1990 and 2004

Animal waste management system (AWMS)	N excretion for each AWMS (Nex(AWMS)) (kg N)		Emission factor for each AWMS (EF_2) (kg N_2O-N/kg N)	Emissions from animal waste (kg N_2O)	
	1990	2004		1990	2004
Anaerobic lagoons	4,826	6,295	0.001	8	10
Other	5,645	5,645	0.005	44	44
Total	10,471	11,940		52	54

The Monte Carlo simulations applied to calculate uncertainty in N_2O emissions show that the various emission factors described in Table 5.4 have the largest effect on the overall uncertainty of the results followed by the amounts of excreta from sheep, dairy cattle and non-dairy cattle (Table 5.10).

Table5.10: Sensitivity ranking for N_2O emission from soils

Rank according to the affects on uncertainty	Name of the factor affecting uncertainty values
1	EF_2 (Direct emissions due to animal waste)
2	EF_3 (Indirect emissions from volatilising N)
3	EF_4 (Indirect emissions from leaching N)
4	EF_1 (Direct emissions from N input to soil)
5	Sheep excreta
6	Dairy cattle excreta
7	Non-dairy cattle excreta
8	$Frac_{GASM}$
9	$Frac_{LEACH}$
10	Synthetic fertiliser
11	Dairy population
12	Sheep population
13	Beef population
14	Deer excretion
15	Deer population
16	Poultry population

5.3.2 Emissions from N addition to Agricultural Soils

In this section estimates are made of the direct and indirect emissions of N_2O from N added to agricultural soils in two ways. First, the N added directly to the soil in excreta from animals while they are grazing is considered, and then in a separate calculation, the N added to the soil in synthetic N fertilisers and animal manure that is spread on the soil after storage and/or treatment in the "AL" and

"OTHER" AWMS. In order to estimate these emissions of N_2O, it was firstly necessary to calculate the total amounts of N added to the soil through both of these pathways.

Total N fertiliser use by AgServices and the grounds department during 2004 was 48,039 kg N (Table 5.11). Total N in the excreta spread on the soil from the "AL" and "OTHER" AWMS was 11,990 (6,295+5,695) kg (Table 5.9). The N deposited directly on soil in excreta from grazing animals amounted to 351,187 kg in 2004 (Table 5.8).

When calculating the N inputs to the soil from synthetic fertiliser and animal manure, it is assumed that 10% of the N added to the soil in synthetic fertiliser and 20% of the N added in animal manure is emitted as NO_x or NH_3 and so is subtracted from the total N applied (MfE, 2006) (Tables 5.12 and 5.13).

Therefore, the total annual N input to the soil in 2004 from these sources was 52,787 kg (i.e. 43,235kg from synthetic fertilisers and 9,552 kg from animal waste). Similarly, the total estimated N input in 1990 was 51,612 kg (Tables 5.12 and 5.13).

Table 5.11: Total Nitrogen fertiliser used by Massey University in 2003-04

Name of Fertiliser	Name of the Farm and Amount of Fertiliser used in Mg							Total fertiliser (Mg)	% of N in fertiliser	Total N kg N/Yr
	Deer Farm	DSU	Dairy 1	Dairy 4	DCRU	Riverside Farm	Grounds department			
Urea	2		20.7	32.8	7	15.8		78.3	45	35,235.0
D.A.P.	2.5		4.85					7.35	21	1,543.5
30%P.Super				18				18	0	0.0
20%P.Super				46				46	0	0.0
Cropmaster 15			37.15			13.5		50.65	15.2	7,698.8
Amon. Sulphate			7.4					7.4	20.5	1,517.0
Selenium Super					4.3			4.3	0	0.0
Varions (Organic)					18			18		0.0
Super Phosphate			25.2		6.6	116		147.8	0	0.0
TURF Fertiliser							8.89	8.89	23	2,044.7
Total N input										48,039.0

Table 5.12: Nitrogen input to agricultural soils, pastures and sports grounds from synthetic fertiliser use in 1990 and 2004

Year	Synthetic fertiliser use (kg N)	One minus the fraction of synthetic fertiliser emitted as NOx or NH_3	N input from synthetic fertiliser use (kg N)
	N_{FERT}	x (1-$Frac_{GASF}$)	F_{SN}
1990	48,039	0.9	43,235
2004	48,039	0.9	43,235

Source: (MfE 2006)

Table 5.13: Total N input to agricultural soils from animal waste in the "AL" and "Other" AWMS in 1990 and 2004

Year	N excretion spread from AWMS (kg N)*	Fraction of N excretion burned for fuel	Fraction of N excretion deposited onto soil during grazing	Fraction of N excretion emitted as Nox or NH_3	N input from animal waste (kg N)
	Nex_{spread}	x (1-($Frac_{FUEL}$	+ $Frac_{GRAZ}$	+ $Frac_{GASM}$))	= FAW
1990	10,471	0		0.2	8,377
2004	11,940	0		0.2	9,552

Source: (MfE 2006)

* Animal waste in all AWMS except pasture range and paddock. $Frac_{GRAZ}$ is not required as waste from grazing livestock is already excluded.

5.3.2.1 Direct N_2O emissions from excreta added directly to the soil by grazing animals.

The calculated direct N_2O emissions for 2004 at Massey University from the excreta deposited directly on soil by grazing animals was 5,519±3,478 kg, and 6,029±3,799 kg of N_2O was emitted from the same source in 1990[11] (Table 5.14).

Table 5.14: Direct N_2O emissions from N deposited directly on soil by grazing animals in 1990 and 2004

Animal waste management system (AWMS)	Annual N excretion for AWMS (Nex AWMS) (kg N)		Emission factor for AWMS (EF_3) (kg N_20-N/kg N)	Total N_2O-N/yr (kg)		Total annual N_2O (N_2O-N*44/28) (kg)	
	1990	2004		1990	2004	1990	2004
PR&P	383,638	351,187	0.01	3,836.38	3,511.87	6,029	5,519

5.3.2.2 Direct N_2O emissions from agricultural soils and sports grounds as a result of adding N in the form of synthetic fertilisers and animal waste

Direct N_2O emissions due to the application of synthetic fertilisers and animal waste in 2004 were 830±438 kg. In this sub-category, 679 kg of emitted N_2O was from synthetic fertilisers and 150 kg was from the addition to the soil of animal waste from the "AL" and "OTHER" AWMS (Table 5.15). This amount was calculated by multiplying the amount of N input in the form of synthetic fertilisers (Table 5.11) and the amount of N in form of animal waste (Table 5.13) with the IPCC default emission factor for direct N_2O emissions from Table 5.4. Emissions from the same sources in 1990 totalled 811±436 kg of N_2O[12] (Table 5.15a).

[11] refer xl spreadsheet "agriculture_master.xls, worksheet "Tables5.8-5.8a" in the CD attached.
[12] refer xl spreadsheet "agriculture_master.xls, worksheet "Tables5.11-5.11a" in the CD attached.

Table 5.15: Direct N_2O emissions from agricultural soils in 2004

Type of N input to soil	Amount of N input to soil (kg N)	Emission factor for direct emissions (EF_1) (kg N_2O-N/kg N)	Direct N_2O-Nemissions (kg)	Direct N_2O emission (kg)
Synthetic fertiliser (FSN)	43,235	0.01	432	679
Animal Waste (FAW)	9,550	0.01	96	150
Total			528	830

Table 5.15a: Direct N_2O emissions from agricultural soils in 1990

Type of N input to soil	Amount of N input to soil (kg N)	Emission factor for direct emissions (EF)* (kg N_2O-N/kg N)	Direct N_2O-N emissions (kg)	Direct N_2O emission (kg)
Synthetic fertiliser (FSN)	43,235	0.01	432	679
Animal Waste (FAW)	8,377	0.01	84	132
Total			516	811

5.3.2.3 Indirect N_2O emissions from N lost from the field as NO_x or NH_3

Total indirect N_2O emissions in 2003-004 were 2,348±1,047 kg[13]. The N_2O emission due to leaching of nitrate was 1,131 kg (Table 5.16), whereas 1,217 kg was emitted due to volatilization of ammonia (Table 5.17). Similarly, indirect N_2O emissions in 1990 amounted to 2,530±1,128 kg, comprising of 1,216 kg from leaching and 1,314 kg from volatilization respectively (Tables 5.16 and 5.17).

[13]refer xl spreadsheet "agriculture_master.xls, worksheet "Tables5.10-5.10a" in the CD attached.

Table 5.16: Indirect N_2O emissions from agricultural soils and sports grounds due to leaching in 1990 and 2004

Year	Synthetic fertiliser applied to soil (NFERT) (kg N)	Total N excreted by livestock (kg N)	Fraction of N that leaches ($Frac_{LEACH}$)	Emission factor (EF_4) (kg N_2O-N/kg leached N)	Indirect N_2O-N (kg)	Total indirect N_2O emissions due to leaching (kg)
1990	48,039	394,109	0.07	0.025	774	1,216
2004	48,039	363,127	0.07	0.025	720	1,131

Table 5.17: Indirect N_2O emissions from agricultural soils and sports grounds due to volatilisation in 1990 and 2004

Year	Synthetic fertiliser applied to soil (NFERT) (kg N/yr)	Fraction of syn.fertiliser N that volatilises ($Frac_{GASF}$)	Amount of syn. N applied to soil that volatilises (kg N/yr)	Total N excreted by livestock (kg N/yr)	Fraction of N excretion that volatilise ($Frac_{GASM}$)	Amount of N excretion that volatilise (kg N/yr)	Emission factor (EF_3) (kg N_2O-N/kg volatilised N)	Total N_2O-N (kg N_2O-N/yr)	Total indirect annual N_2O (kg)
	A	B	C = A x B	D	E	F = D x E	G	H= (C+F) x G	H*44/28
1990	48,039	0.1	4,803.9	394,109	0.2	78,822	0.01	836	1,314
2004	48,039	0.1	4,803.9	363,127	0.2	72,625	0.01	774	1,217

5.3.2.4 Total N_2O Emissions from Agricultural Soils and Sports Grounds

Total N_2O emissions from agricultural soils and sports grounds during 2004 and 1990 at Massey University were 8,697±5,481 kg and 9,370±5,905 respectively (Table 5.18). These values include direct N_2O emissions due to grazing animals, synthetic fertilisers, and indirect N_2O emissions due to volatilization and leaching as explained in Section 5.3.2.1 above[14].

Table 5.18: Total annual N_2O emissions from agricultural soils and sports grounds at Massey University in 1990 and 2004

Source category	N_2O emission (kg)	
	1990	2004
Direct N_2O from excreta deposited on soil by grazing animals	6,029	5,519
Indirect N_2O due to leaching	1,216	1,131
Indirect N_2O due to volatilization	1,314	1,217
Direct N_2O due to application of synthetic fertiliser and animal waste	811	830
Total	9,370	8,697

5.3.3 Total Agricultural Emissions in CO_2 Equivalents

Total GHG emissions in CO_2e from the agricultural sector at Massey University for the year 2004 were 6,999±2,305 Mg (Table 5.19). In contrast, 8,067±2,626 Mg of CO_2e were emitted by the same sector in 1990 (Table 5.19a). The main contributors to emissions in the agricultural sector are animals, whether contributing directly from enteric fermentation or from the addition of animal waste to the soils[15].

[14] refer xl spreadsheet "agriculture_master.xls, worksheet "Tables5.12-5.12a" in the CD attached.
[15] refer xl spreadsheet "agriculture_master.xls, worksheet "Tables5.13-5.13a" in the CD attached.

Table 5.19: Total CO_2e emissions from the agricultural sector at Massey University in 2004 (Mg CO_2/yr)

Category	CH_4(kg)	N_2O(kg)	CO_2e CH_4 (kg)	CO_2e N_2O (kg)	Total CO_2e (Mg)
	U	V	W=U*21	X=Vx310	(W+X)/1000
Enteric fermentation	204,086		4,285,806	16,740	4,303
Manure management		54			
Agricultural soils & sports grounds		8,697		2,696,070	2,696
Total	204,086	8,751	4,285,806	2,712,810	6,999

Table 5.19a: Total CO_2e emissions from the Agricultural sector at Massey University in 1990 (Mg CO_2/yr)

Category	CH_4 (kg)	N_2O (kg)	CO_2e CH_4 (kg)	CO_2e N_2O (kg)	Total CO_2e (Mg)
	U	V	W=U*21	X=Vx310	(W+X)/1000
Enteric fermentation	245,060		5,146,260	16,120	5,162
Manure management		52			
Agricultural soils & sports grounds		9,370		2,904,700	2,905
Total	245,060	9,422	5,146,260	2,920,820	8,067

5.4 DISCUSSION

Enteric fermentation is the major source of emissions in the agricultural sector at Massey University, contributing about 4,182±1171 Mg of CO_2e[16]. This is just over 59% of the total emissions in this sector (Fig. 5.3). Of this, the largest CH_4 emissions are from the dairy animals (Table 5.20).

[16]refer xl spreadsheet "agriculture_master.xls, worksheet "Tables5.3-5.3a" in the CD attached

Table 5.20: Share of individual animal categories in total CH_4 emissions at Massey University in 2004.

Animal category	CH_4 emission (kg)	Contribution to total CH_4 emission (%)
Dairy cattle	78,994	38.7
Non-dairy cattle	45,276	22.2
Sheep	76,086	37.3
Deer	2,595	1.2
Poultry	1,135	0.6

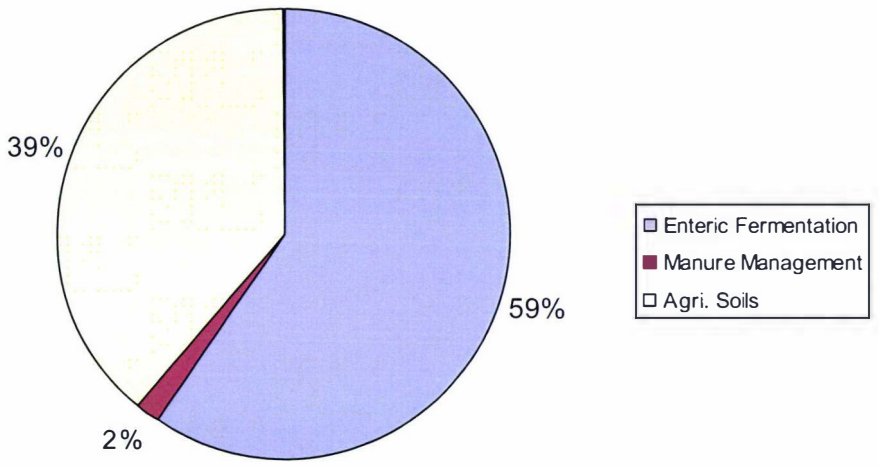

Figure 5.3: Greenhouse gas emissions in CO_2e from different sub-sectors of agriculture at Massey University in 2004

Emissions from the agricultural sector at Massey University are now 13% lower than the 1990 emissions. The major factor responsible for this reduction in emissions was the reduction in the number of sheep on the farms in 2004 (Table 5.1).

There are a number of additional possible sources of error in the data from 1990. The numbers of poultry in 1990 were assumed to be the same as they were in 2004, as there were no data about poultry available prior to 1996 (Table 5.1). It was also assumed that the same amount of N fertiliser was used on the Massey farms in 1990 as in 2004, because no data were available. As there has been a five-fold increase in national N fertiliser use over that time (MfE, 2004), it is very likely that this results in an over-estimate of N fertiliser use on the Massey in 1990, and hence an over-estimate of N_2O emissions in that year.

Most of Massey University's GHG emissions in the agricultural sector were caused by livestock, with the largest contribution coming from enteric fermentation. At present there are no easy ways to eliminate these emissions of CH_4 from enteric fermentation, although it might be possible to achieve some small reductions by improving feed quality and increasing per animal performance at a reduced stocking rate.

There are more opportunities to reduce N_2O emissions. Some options suggested by Oenema *et al*. (1997) included:

- decreasing the number of grazing animals and increasing the per animal productivity
- decreasing the amount of dung and urine added to the pasture through restricted grazing, and
- applying less N fertiliser to the pasture

Manipulating animal diets to reduce N intake can also help reduce N_2O emissions (Kebreab *et al*., 2001). Reductions in N_2O emissions resulting from nitrate leaching are also possible by treating grazed pastures with a nitrification inhibitor (e.g. dicyandiamide (DCD)) (Di and Cameron, 2003). Also proper management of farm effluents can reduce nitrate leaching and N_2O emissions (Cameron and Di, 2004).

As discussed in the section on uncertainty, the biggest influence on the variability of estimates is the uncertainty in emission factors and energy requirements of the animals. Energy requirements are directly related to the live weights of the animals in different categories. Improvements in the quality of data kept by the University farms, such as live weights and animal numbers on a monthly basis, would lead to more accurate estimations. The more detailed data available, the more accurate will be the calculations. Using only the annual animal numbers and average emission factors may limit the accuracy of emissions estimates.

5.5 CONCLUSIONS

- Farm animals are the main contributors of GHG emissions in the agricultural sector at Massey University, and enteric fermentation is the largest source of GHG emissions from this sector.

- The choice of the method used for emission calculations can have a positive or negative effect on the calculated overall GHG emissions, i.e. the emissions can be overestimated by using average national emission factors for certain categories of livestock when the average live weights of animals are lower than the national averages and vice versa.

- The overall uncertainty in the emission results can be reduced by improving the data quality and by developing and using local emission factors.

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CHAPTER 6: LANDUSE CHANGE AND FORESTRY

6.1 INTRODUCTION

Forests can have an important role in the mitigation of climate change and are also important in conservation of biodiversity and soil and water resources (Food and Agricultural Organization (FAO), 2005). Although land use change and land management practices produce considerable amounts of methane (CH_4) and nitrous oxide (N_2O) (Smith & Conen, 2004), carbon dioxide (CO_2) is the most dominant GHG in the land-use change and forestry sector (LUCF) (IPCC, 1997a). Plantation forests can be used to mitigate atmospheric CO_2 by utilising their carbon (C) storage potential (Hollinger *et al.*, 1993). This sector has been a net sink of greenhouse gases (GHGs) for New Zealand from 1990 to the recent inventory reported in 2004 (New Zealand Ministry for the Environment (MfE), 2006).

In addition to the C stored in above-ground vegetation, different land-use practices and forestry operations can alter the amount of C in soil. For example, although deforestation following human settlement in New Zealand has resulted in large vegetation C losses to the atmosphere in the form of CO_2 (MfE, 2006; Scott *et al.*, 2001), establishing pastures for sheep and cattle grazing resulted in a slight increase in mineral soil C (Tate *et al.*, 2002).

6.1.1 Global Scenario

According to the recent forest resource assessment by FAO (2005), forests of the world contain more C than the entire atmosphere. It is estimated that the world's forests store 283 Pg of C in their biomass alone whereas the amount of C in the whole ecosystem (including the soil) is 638 Pg (FAO, 2005).

The total global forest area in 2005 was 3952 million hectares (Mha) representing 30.3% of the total land area and this area has been decreasing at a rate of 0.21% annually since 1990 (FAO, 2005). The net change in the world's forest area in

the period 2000-2005 is estimated at -7.3 Mha per year, down from -8.9 Mha per year in the period 1990-2000 (FAO, 2005). The largest net loss of forests is in Africa and South America, whereas the net area of forests in Europe is expanding. This deforestation is a major source of CO_2-C emissions from the LUCF sector, and it is estimated that the amount of CO_2-C emissions resulting from forest clearance is more than the amount sequestered by the remaining global forest resources (UNFCCC, 2004).

Meeting the increasing demands for industrial timber and fuelwood are two important reasons for deforestation. About 75% of the world's population use wood as their main energy source and it is estimated that 8,700 Tg of dry matter is burnt globally per year (Koppmann *et al.*, 2005). A combined volume of 3,013 Mm^3 of industrial roundwood and fuelwood was removed from the world's forests during 2005 (Koppmann *et al.*, 2005). A third important reason for deforestation is to clear land for agricultural purposes.

6.1.2 National Scenario

New Zealand natural forests consisting mainly of beech, kauri, rimu, taraire and tawa, cover an area of 6.4 Mha. The New Zealand government controls timber extraction from these natural forests through strict legislation, so that New Zealand's timber production from natural forests is less than 0.1% of the total timber production (MfE, 2006).

The overall growing conditions (soil fertility and climate) in New Zealand, are favourable for *Pinus radiata* growth. Approximately 90% of the planted forest area in New Zealand is *Pinus radiata* (MfE, 2006), which is one of the fastest growing commercial trees in the world, and in New Zealand it can grow faster than in any other country (Edgar *et al.*, 1992). Therefore, the average C uptake/ha by the New Zealand plantation estate is higher than estimated uptake rates from other parts of the world (Hollinger *et al.*, 1993; Sedjo, 1989).

According to the MfE, the LUCF sector in New Zealand removed 24,482 Gg of CO_2 equivalents (CO_2e) in 2004, which is 29% above the net removals in 1990 (Fig. 6.1) (MfE, 2006). According to Trotter *et al.* (2005), a further 2.9 ± 0.5 Gg of C/yr (10.6 Gg of CO_2e/year) could potentially be accumulated by planting about 1.45 Mha of marginal pastoral land in New Zealand, which is suitable for indigenous shrubland or forest.

The New Zealand forest plantations were created for the specific purpose of timber supply, but the substantial amount of CO_2 removed by these plantations since 1990 is greater than the emissions that have resulted from the harvesting of both planted and natural forests (MfE, 2006).

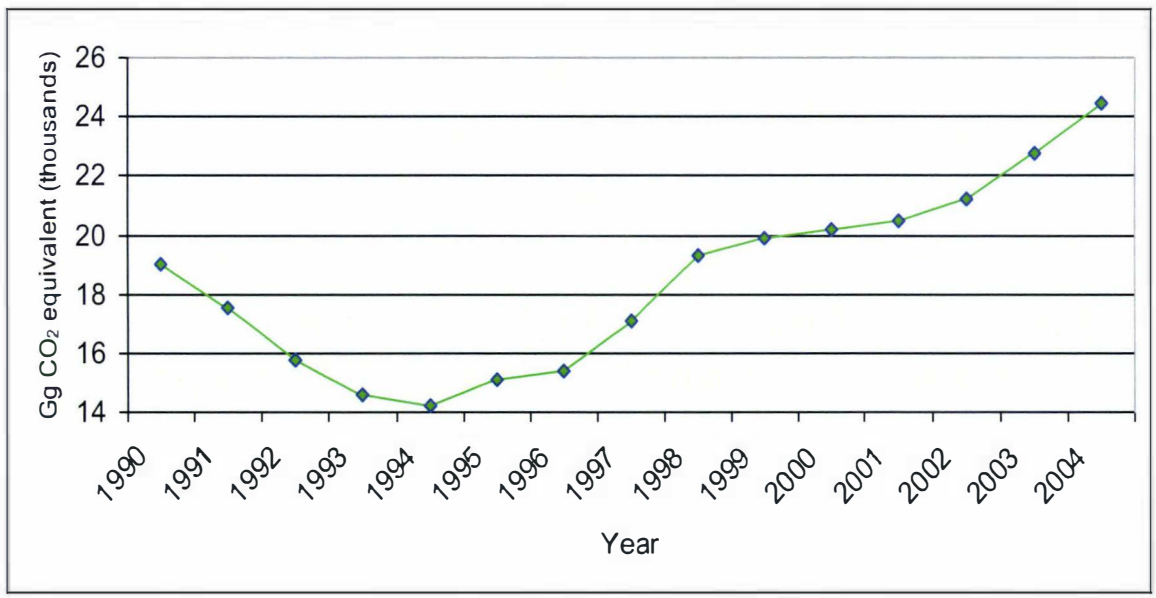

Figure 6.1: Net removals by the LUCF sector in New Zealand from 1990 to 2004
Source: (MfE, 2006)

In New Zealand, the use of land for dairy farming is currently considered more profitable than forestry. Because of this, a substantial area of previously forested land has been converted to dairy farming in recent years. About 9,000 ha of Canterbury forest is reported to be in the process of conversion to pasture and in the central North Island about 30,000 ha are to be converted from trees to dairy farms (Wallace, 2006). As a result, the area under forestry in New Zealand is shrinking. According to Wallace (2006), there was a net reduction of 1000 ha in the forested area of New Zealand in 2005 and this was reportedly the first time in

two decades that more land was taken out of forestry than was planted in trees. This trend has the potential to reduce the country's forest estate even more in the coming years, and this will have a large impact on the national C budget.

6.1.3 Objectives

At present, the forestry sector at Massey University provides the only potential for C sequestration and mitigation of the GHG emissions generated by different sources on the campus and farms of Massey University. Although these forests were planted for commercial and conservation purposes, they still can be used as a tool for C sequestration and mitigation of GHGs – at least in the medium term.

Consequently, the aim of this part of the research project was to assess the forest resource at Massey University so that its contribution to the net annual GHG emissions could be calculated. In this section, forest plantations on all but one of the farms were considered. The exception was Riverside farm, which is leased by Massey University and is owned by the Sydney Campbell Foundation.

6.2 METHODS

Different categories of plantations are identified in this chapter. The net C uptake by each of the identified categories is calculated. Finally, the net C uptake is expressed as CO_2. Possible uncertainties are identified and combined to obtain an overall uncertainty in the total annual CO_2 removed by these plantations.

Generally, the calculations of emissions and removals of CO_2 by the LUCF sector focus on the following three activities (IPCC, 1997b):

- Changes in forest and other woody biomass stock
- Forest and grassland conversion
- Abandonment of managed lands

The IPCC Guidelines for National GHG Inventories (2006) recommend that GHG inventory for the land-use category 'Forest land Remaining Forest land (FF)' involves estimation of changes in C stock from five C pools:

(i) above-ground biomass

(ii) below-ground biomass

(iii) dead wood

(iv) litter and

(v) soil organic matter

as well as emissions of non-CO_2 gases from such pools.

Equation 6.1 is the summary equation, that estimates the annual emissions or removals from FF with respect to changes in C pools (IPCC, 2006):

$$\Delta C_{FF} = (\Delta C_{FF_{LB}} + \Delta C_{FF_{DOM}} + \Delta C_{FF_{Soils}}) \quad \text{.....(6.1)}$$

Where:

ΔC = annual change in C stocks (Mg C yr^{-1})

$\Delta C_{FF_{LB}}$ = annual change in C stocks in living biomass (above- and below-ground biomass) (Mg C yr^{-1})

$\Delta C_{FF_{DOM}}$ = annual change in C stocks in dead organic matter (includes dead wood & litter) (Mg C yr^{-1})

$\Delta C_{FF_{Soils}}$ = annual change in C stocks in soils (Mg C yr^{-1})

CO_2 emissions or removals from FF are generally estimated by calculating and summing the C stock change in all five C pools.

During the inventory year, Massey University did not abandon any managed land; neither was any grassland converted into forest or vice versa. It was assumed that the changes in some of the C pools e.g. dead wood, litter and soil organic C were negligible, and no data were collected for these pools. This is because no cultural operations like thinning and pruning were carried out during 2003-04.

Consequently, calculations are based on the changes in forest and other woody biomass stock only. Also, there is no record of any commercial harvesting during 2004; therefore, in the current inventory, only the removal of CO_2 by plantation forests and native bush at Massey University has been reported, and no emissions from this sector have been considered. Detailed estimates of biomass increase were made for the Kyoto[1] forests only, because only CO_2 removals by the Kyoto forests qualify for discount from the total emission budget.

Massey University did, however, have some forest areas prior to 1990 and these areas still remained in forest in 2004. They are not counted in Kyoto calculations, and because of this, these forests were not measured directly. To obtain an approximate estimate of the likely CO_2 accumulation by these forest areas, it was assumed that the annual increase in biomass per hectare was the same as the average biomass increase in Massey University's Kyoto forests.

To calculate the total amount of CO_2 removed by the Massey University Kyoto forest plantations during one year, the total annual biomass increase in these plantations was required. Firstly, the area of the Kyoto forests was separated from the total planted area at Massey University on the basis of year of planting. All plantings considered here also qualify for the other criteria required for Kyoto forests. The name of plantation, total area and year of planting of all forest plantations at Massey University are shown in Table 6.1. The locations of the different plantation blocks in the various farms around Massey University are shown in Fig. 6.2.

The Kyoto forests at Massey University were divided into the following three categories in order to calculate C sequestration, and different methods were used for each category:

[1] Simply, the Kyoto forests are those planted since 1990 on land not previously in forest (Spittlehouse, 2005). More technically, forests planted since 1990 with a minimum area of land of 0.05-1.0 ha with tree crown cover of more than 10-30 per cent with trees with the potential to reach a minimum height of 2-5 metres at maturity in situ are called Kyoto forests (European Environment Agency(EEA), 2006; UNFCCC, 2002)

- established exotic tree plantations that have already had at least their first pruning done (planted between 1990 and 1998)
- recently planted exotic tree plantations that were still at their original 1,100 trees per ha planting density (planted in 2000 and after), and
- native bush areas

Table 6.1: Massey University forest areas

Farm	Woodlot number	Planted area (ha)	Year of planting	Farm	Woodlot number	Planted area (ha)	Year of planting
Keeble				No.1 Dairy			
	1*	0.4	1980		2	1.7	1995
	2	4.9	1994		4	1	2004
	3*	0.5	1980				
	4	0.75	2002	No.4 Dairy			
	5*	0.5	1995		1	0.5	1994
	6*	0.5	1970		2	1.3	1989
	7*	0.5	1970		3a	3.5	1987
	8*	1	1984		3b	1.7	1994
	9*	0.5	1981		4	3.2	1986
	10*	0.5	1970		5	1	1989
	11	1.7	1992		6	1.2	1989
	12	2.4	1993		7	1	2002
	13	2.3	1993				
	14	1	1981	Haurongo			
	15*	0.75	1970		1	0.6	1980
	16*	0.5	1981		2	2.6	2003
	17*	0.5	1970				
	18a	3	2002	Terrace			
	18b	0.5	2004		1	0.2	2003
	19	6	2004		2	4.6	2002
Tuapaka					3	0.4	2002
	1	14	2002				
	2	6.1	1992	LATU			
	3	10.5	1993		1	4	1980
	4	4.2	1994		2	0.3	1998
	5a	6	1998		3	0.4	1998
	5b	1	1998		4**	1	1993
	6	4	2000		5**	5	2002

* Shelter belts
** Note: all areas shown in this table are *Radiata pine* plantations except woodlot numbers 4 and 5 at the large animal teaching unit (LATU) where Cupressus and Eucalyptus species are planted.

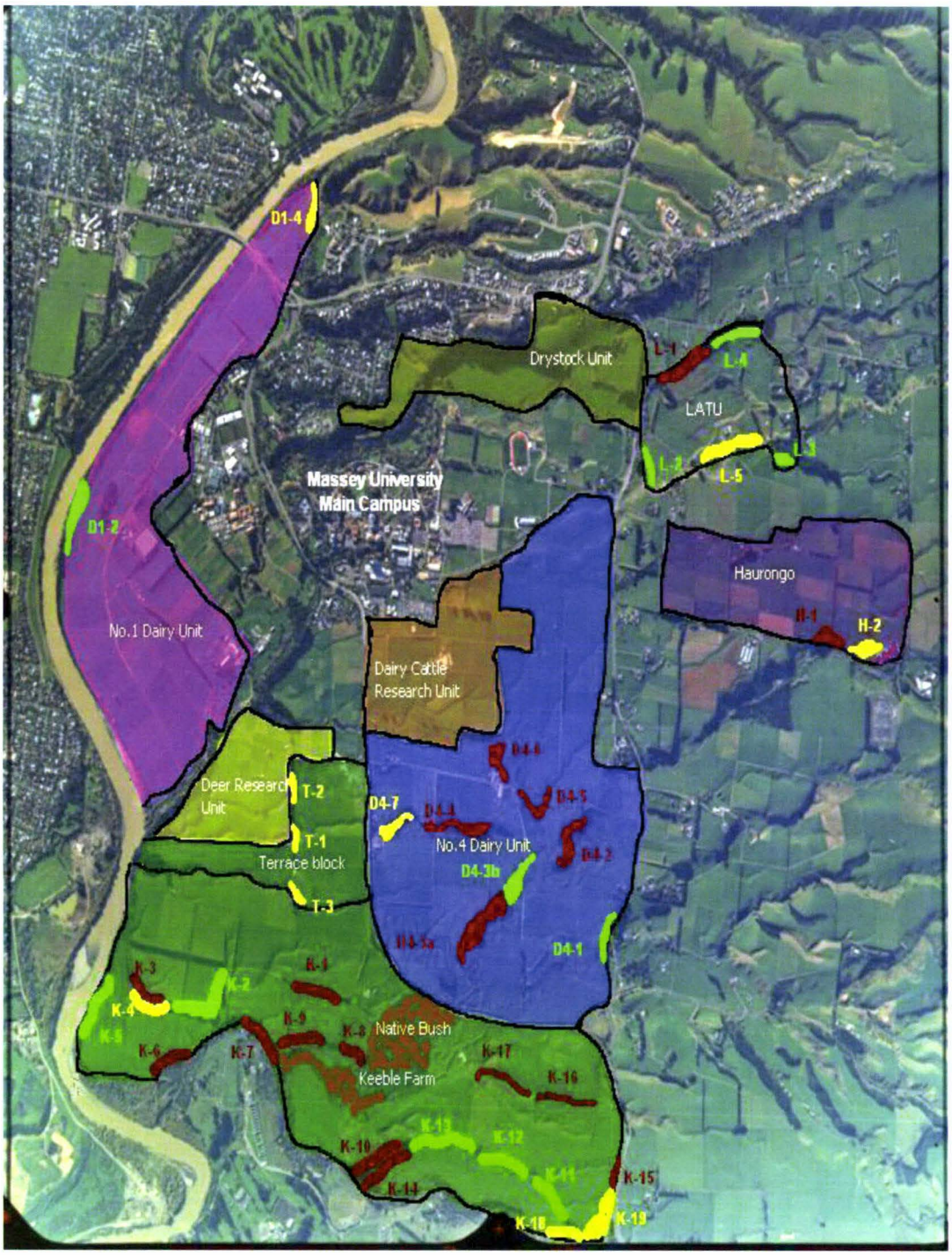

Figure 6.2: An aerial photograph showing location of different farms around Massey University Main campus.

Note: Tuapaka farm is located about 10km east of Palmerston North and not shown in this photo
All measured Kyoto plantations are shown in bright green colour
All non-measured younger Kyoto plantations are shown in yellow colour
All non-Kyoto plantations are shown in dark red colour
Native bush in Keeble farm is shown in light brown colour

The New Zealand Ministry for the Environment uses both the above- and below-ground biomass components (including the forest floor) to estimate the CO_2 removals and emissions (MfE, 2004). The two forest models used by MfE to estimate C removals by planted forests are:

- C-Change and
- Forestry Oriented Linear Programming Interpreter (FOLPI)

According to MfE, the above two models account for emissions generated from both the removal of stem wood C through harvesting and the emissions of non-stem wood C left on site over an extended period following harvesting.

As access to these models was not possible, the following allometric model for calculating total above-ground biomass (AGM_{tot}) was used:

$$AGM_{tot} = \beta_o + \beta_1 DBH^2 H^{0.5} \quad \text{..... 6.2}$$

Where

DBH = stem diameter at breast height (cm)

H = tree height (m)

β_o and β_1 are model parameters estimated to have values of

-21.2984 and 0.0870 respectively.

Equation 6.2 was developed by John Moore (Forest Research-Christchurch) based on the data collected from 458 individual *Radiata pine* trees ranging from 7 to 15 years in age at five different locations in New Zealand (J. Moore, personal communication).

Moore's equation gives the above-ground biomass only. In order to calculate the total biomass accumulated by the Massey University plantations, biomass of the root system or the below-ground biomass was also required. Measurement of root system biomass in a forest is a difficult process (Sanford & Cuevas, 1996). Cairns *et al.* (1997) collected and analysed the data from six continents and twenty five countries to determine a reliable relationship to estimate root biomass for forests. Their overall average value for below-ground biomass was 26% of

above-ground biomass with most values between 20 and 30%. The values for the pine/conifer trees were usually around 25%. About 95% of the exotic tree plantations at Massey University are pine trees, therefore a value of 25% for below-ground biomass for these plantations was selected. This value has also been used by Woollons *et al.* (2005) when estimating the errors associated with the calculation of C in Kyoto forests in New Zealand.

An alternative approach to calculate the below-ground biomass recognises that the root-shoot ratio of temperate conifers varies with age and above-ground biomass. IPCC (2006) default values suggest that conifers with an above-ground biomass <50 Mg/ha have an average root-shoot ratio of 0.46 (0.21-1.06), with an above-ground biomass between 50 and 150 Mg/ha the root shoot ratio is 0.32 (0.24 - 0.50) and with an above-ground biomass >150 Mg/ha the ratio is 0.23 (0.12 - 0.49). Therefore, total biomass in these plantations can be calculated by the following two methods:

a) By considering the below-ground biomass as 25% of the above-ground biomass
b) By using the values of below-ground biomass differentiated according to age as suggested by IPCC

Although method "a" has been used in this study, method "b" was also used to estimate the total biomass to see the difference between the two methods. The estimated biomass in the exotic plantations was then converted into the weight of C using a default value of 0.5 (IPCC, 1997b; MfE, 2006).

6.2.1 Data Collection

Twenty five permanent sample plots were established in different plantation blocks (Table 6.2). Each sample plot contained approximately 20 trees, and the size of the plots varied depending on the tree density. A plot area of 0.03 ha was selected in the plantations where the number of stems/ha was high (e.g. 900 trees/ha in the Tuapaka farm blocks 5a and 5b). A larger sample plot area of

0.06 ha was selected for the plantations that had been thinned to the final stocking rate and where the number of stems/ha was low (e.g. 250 trees/ha in the Keeble farm block 11).

Sample plots were visited twice during the course of this study (i.e. 2004 and 2005), with a one year interval between visits. Total biomass in all plantations was calculated, and the difference in total biomass between the initial and final measurements was considered the total annual increase in biomass.

The circular plot method was used for the sample plots because circular plots have the lowest perimeter-to-area ratio of any plot shape. This reduces the possibility of boundary errors when deciding whether a tree should be included or excluded (Millner, 2003). This method also avoids the possibility of bias due to the orientation of the plot with respect to planting rows.

Table 6.2: Number and distribution of sampling plots established on different Massey farms

Farm	Paddock number	Planted area (ha)	No. of plots
Keeble			
	2	4.9	2
	11	1.7	2
	12	2.4	2
	13	2.3	2
Tuapaka			
	2	6.1	2
	3	10.5	3
	4	4.2	2
	5a,b	7	3
No.1 dairy			
	2	1.7	2
No.4 dairy			
	1	0.5	1
	3b	1.7	2
LATU			
	2	0.3	1
	3	0.4	1
Total		43.7	25

The heights and diameters of all the trees in all the sampling plots were measured. The diameters were measured at breast height (DBH). All the trees in

all of the sampling plots were numbered and marked at DBH to avoid any mistakes in measurements (Fig. 6.3). In New Zealand, breast height is defined as being the point that is 1.4 meters above firm ground on the uphill side of the stem. A Vertex III-360 system from HAGLÖF of Sweden was used to measure the tree heights and distances from the centre of the sampling plot to the individual trees. The system includes a Vertex III hypsometer, a T3 transponder, an adapter and a monopod staff. The Vertex III is an ultrasonic measuring system and gives accurate readings in dense vegetation and difficult surroundings (HAGLÖF, 2004). Slope measurements were made with a Suunto clinometer and the diameters were measured with a diameter tape. A summary of DBH and height of trees measured in all 25 sampling plots in 2004 is given in Fig. 6.4 and 6.5.

Figure 6.3: Measurement of tree diameter at breast height (DBH) at Tuapaka

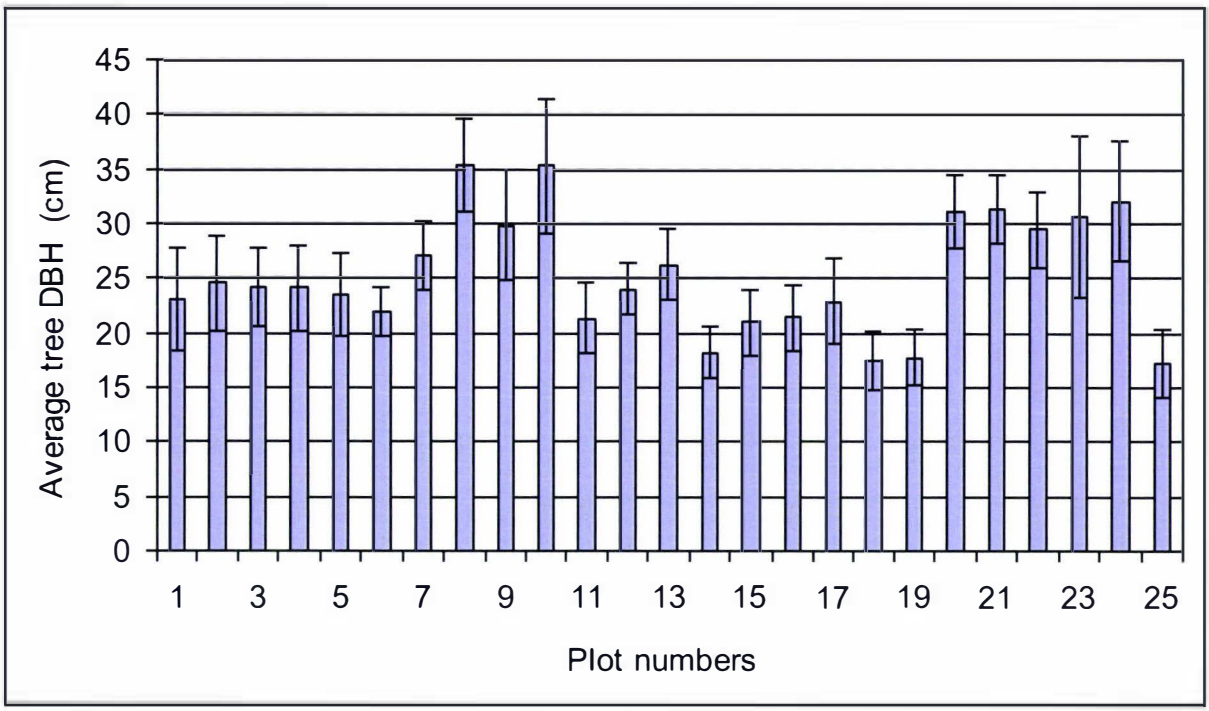

Figure 6.4: Average tree DBH measured in individual sampling plots in 2004. Bars indicate standard deviations

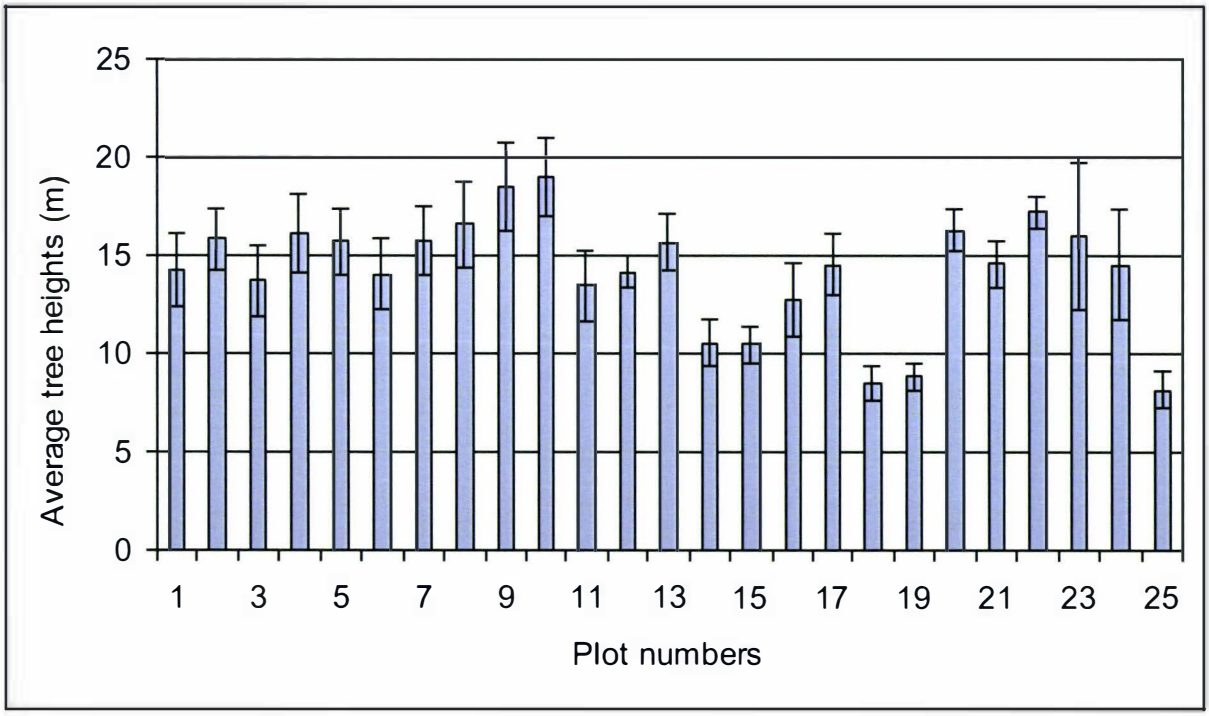

Figure 6.5: Average tree heights in individual sampling plots in 2004. Bars indicate standard deviations

6.2.1.1 True Area of the Circular Plot and Plot Layout

In order to measure the true area of a circular plot, it should be on a horizontal plane. However, the average slope in the sampling plots varied from 3° to 36°. Therefore, a true circle in the horizontal plane, regardless of any variations in topography, needed to be established. That was done by putting all measured distances on a horizontal plane basis, by correcting each measurement for slope (Millner, 2003). Before marking the boundary of the circular plots, the average slope in each plot was calculated from two slope measurements – one taken on the uphill side of the plot and the other on the downhill side. This average slope was then used to calculate the diameter of the circular plot. To lay out a circle on a slope, one should allow for the effects of the average slope by dividing the radius by the square root of the cosine of the slope angle along the line of maximum slope running through the plot centre. A circle laid out on a sloping plane surface will project the shape of an ellipse on the horizontal plane, if the slope is B, then the diameter (D) of the ellipse running in the direction of the slope will be DCosB, while the diameter across the slope will be d, and the true area can be calculated by the formula for the area of an ellipse.

$A = \pi \times r_1 \times r_2 / 10000$

$A = \pi \times r \times r \times Cosb / 10000$ 6.3

Where

A = area (ha)

r_1 = half of the shortest diameter of the ellipse (m)

r_2 = half of the longest diameter of the ellipse in (m)

r = radius of the circle laid out on a plane sloping at angle b°

Conversely, the radius of a circle laid out on a plane sloping at angle B° which projects a plot of area A on the horizontal will be:

$$r = \sqrt{(A \times 10000 / \pi \times CosB)} \quad \text{.....6.4}$$

For example, a 0.06 ha plot has a horizontal radius of 13.81 m, but if we want to lay the same plot on a 25° sloping ground, it will have a radius of 14.50 m,

i.e.$\left(\frac{13.81}{\sqrt{(Cos25^0}}\right)$

Source: (Millner, 2003)

In order to lay out a plot, the centre point was marked after determining the site randomly. Then the radius of the circular plot was calculated with the help of Eq. 6.4. Some of the trees were clearly inside the plot and others clearly outside. For the few that were uncertain, the trees which were more than half inside the circle were included. This assessment was re-checked by measuring the distance with the Vertex III hypsometer and T3 transponder by placing the monopod staff with the transponder T3 and adapter at the centre of the plot and taking the hypsometer to all the uncertain trees one by one.

6.2.2 Estimation of Annual CO_2 and Biomass Increase in the Established Plantations

Equation 6.2 was used to calculate the above-ground biomass of individual trees in each sampling plot in the established plantations. This information was then used to calculate the total above-ground biomass in each plantation. This procedure is demonstrated (Table 6.3) for the plantation in block 3 of the large animal-teaching unit (LATU) at Massey University, and the information for all the other plantation blocks is included in the attached CD in the folders named "AllometricAnalysis & AllometricRound2".

Table 6.3: Calculation of above-ground biomass for individual trees in the sampling block in the "LATU block 3" plantation, and the calculation of the total biomass in the plantation.

β_0	β_1	DBH	DBH^2	H	$H^{0.5}$	AGM tot (kg)
-21.2984	0.087	20.0	400.00	9.6	3.10	86.5
-21.2984	0.087	17.9	320.41	8.7	2.95	60.9
-21.2984	0.087	23.2	538.24	10.5	3.24	130.4
-21.2984	0.087	23.9	571.21	11.1	3.33	144.3
-21.2984	0.087	19.2	368.64	11.4	3.38	87.0
-21.2984	0.087	21.4	457.96	11.5	3.39	113.8
-21.2984	0.087	19.1	364.81	8.7	2.95	72.3
-21.2984	0.087	15.4	235.62	9.0	3.00	40.2
-21.2984	0.087	28.5	812.25	11.3	3.36	216.2
-21.2984	0.087	22.4	501.76	10.7	3.27	121.5
-21.2984	0.087	16.7	278.89	10.9	3.30	58.8
-21.2984	0.087	26.3	689.06	11.9	3.45	185.5
-21.2984	0.087	16.4	268.96	9.3	3.05	50.1
-21.2984	0.087	22.6	510.76	11.0	3.32	126.1
-21.2984	0.087	23.5	552.25	11.3	3.36	140.2
-21.2984	0.087	20.4	416.16	10.0	3.16	93.2
-21.2984	0.087	20.7	426.42	9.4	3.07	92.4
-21.2984	0.087	20.2	408.04	11.0	3.32	96.4
-21.2984	0.087	20.8	432.64	10.5	3.24	100.7
-21.2984	0.087	19.9	396.01	10.3	3.21	89.3
-21.2984	0.087	21.6	466.56	10.2	3.19	108.3
-21.2984	0.087	21.3	453.69	11.6	3.41	113.1
No. of trees in the sampling plot						22
Area of the sampling plot (ha)						0.03
Trees per ha (no. of trees in the plot / area of the plot)						733
Ave. AGM/tree (total AGM / no. of trees)						106
Above-ground biomass/ha (no. trees per ha / Ave. AGM per tree)						77,579
Area of woodlot (ha)						0.40
Total above-ground biomass in woodlot (kg) (biomass/ha x area of the woodlot)						31,032

Once the total above-ground biomass had been calculated, total biomass was calculated by adding a value equivalent to 25% of the above-ground biomass to account for the below-ground biomass (Cairns *et al.*, 1997; Woollons *et al.*, 2005). The annual biomass increase was then calculated by subtracting the calculated values of total biomass in the first year from the calculated biomass values of the second year. The IPCC default value of 0.5 was used to convert the total estimated biomass into C has been used (IPCC, 1997b; MfE, 2006). Finally the amount of CO_2 removed was calculated by multiplying the amount of C by 44/12.

A large part of the uncertainty in the estimates of CO_2 uptake may be associated with the allometric model (Eq. 6.2) used to calculate the above-ground biomass of

the individual trees. The site quality and the resulting tree conformation may be different on the Massey University farms from those in the plantations where Eq. 6.2 was developed and this could introduce a systematic error into the relationship between tree height, DBH and above-ground biomass. However, the extent of any such difference in site parameters is unknown. To account for this, a ±10% uncertainty was assigned to the values of β_0 and β_1 in the allometric model. A ±10% uncertainty in β_0 and β_1 would result in an uncertainty of ±3.2% in the calculated value of the average above-ground biomass per tree (106 kg) for block 3 of the LATU. The corresponding uncertainty in above-ground biomass would be ±5.7% for ±20% uncertainties in β_0 and β_1 and ±2.2 % for ±5 % uncertainties in β_0 and β_1.

Uncertainties of ±1 cm on the measured value of DBH and of ±0.1 m on the measured value of the tree height were also used, representing the minimum unit of measurement in the equipment used. Other uncertainties included an uncertainty of ±5% in each of the sample plot areas and an uncertainty of ±5% in the areas of the woodlots. IPCC (2006) cites reported uncertainties for estimation of the forest area in the order of 3% for industrialized countries, and the slightly higher uncertainties (5%) used in this study were to make sure that the possible uncertainties were not underestimated. A similar uncertainty of ±5% in the number of trees per hectare was assigned. All the uncertainties were propagated through the various stages of the calculations[2].

For the annual (2005-2004) change in the amount of biomass, the uncertainty was calculated by combining the uncertainties resulting from the subtraction of the 2004 biomass value from the 2005 biomass value. It is quite likely that this approach will overestimate the uncertainty in the annual biomass increase because several of the uncertainties in the parameters used to calculate the biomass are likely to be systematic rather than random, and will apply equally to the biomass estimates in each of the two years. A good example is the uncertainty associated with using the allometric equation (Eq. 6.2). The

[2]refer xl spreadsheet "forestry_master.xls, worksheets "2004" and "2005" in the CD attached.

uncertainty in the annual biomass increase was then applied to estimates of annual C increase and of the amount of CO_2 removed[3].

6.2.3 Estimation of Annual Biomass Increase in Non-Measured Younger Exotic Tree Plantations

Almost half of the total Kyoto forest plantations at Massey University were less than 5 years old. Table 6.4 shows the name, area and year of planting of these younger plantations. Locations of these plantations in different farms are marked in yellow in Fig. 6.2.

The trees in these plantations were too small to meaningfully measure height and DBH. Therefore, the average above-ground biomass per tree in these younger plantations was calculated using data collected from the permanent sample plots established in measured older plantations. The ages of already-measured plantations were 6, 7, 10, 11, 12, and 13 years.

An average above-ground biomass/tree was calculated by adding all available biomass/tree values of the same age and dividing by the number of plots of that particular age. Table 6.5 shows the average above-ground biomass/tree in 6, 7,10,11,12, and 13-year old plantations. Details are given in Annex 6.1.

[3]refer xl spreadsheet "forestry_master.xls, worksheets "2005-2004change" and "Table 6.7" in the CD attached.

Table 6.4: Young/non-measured Kyoto forest plantations at Massey University

Farm	Woodlot/paddock number	Area of plantation (ha)	Year of planting
Keeble			
	4	0.75	2002
	18a	3	2002
	18b	0.5	2004
	19	6	2004
Tuapaka			
	1	14	2002
	6	4	2000
No.1 Dairy			
	4	1	2004
No.4 Dairy			
	7	1	2002
Haurongo			
	2	2.6	2003
Terrace			
	1	0.2	2003
	2	4.6	2002
	3	0.4	2002
LATU			
	5	5	2002
Total area		43.05	

Table 6.5: Average above-ground biomass/tree in established plantations

Age of plantation (years)	Average above-ground biomass/tree (kg)
6	71.5
7	103.6
10	173.7
11	241.5
12	345.4
13	449.1

The average above-ground biomass/tree for 1, 2, 3, 4, and 5-year old plantations was then estimated by assuming that there was no biomass at time zero and fitting a curve (that was constrained to pass through the origin) to the data in Table 6.5 (Fig 6.6). A quadratic equation ($y = 2.3x^2$, where y = biomass/tree (kg) and x = age (year)) fitted the data closely and enabled estimates to be made of biomass per tree for years 1 to 5 (Fig. 6.6). Although technically, this approach uses a regression curve to make predictions outside the range of measured values, the fact that it can reasonably be assumed that there is no biomass at time zero, provides some assurance that any errors associated with this approach will be small.

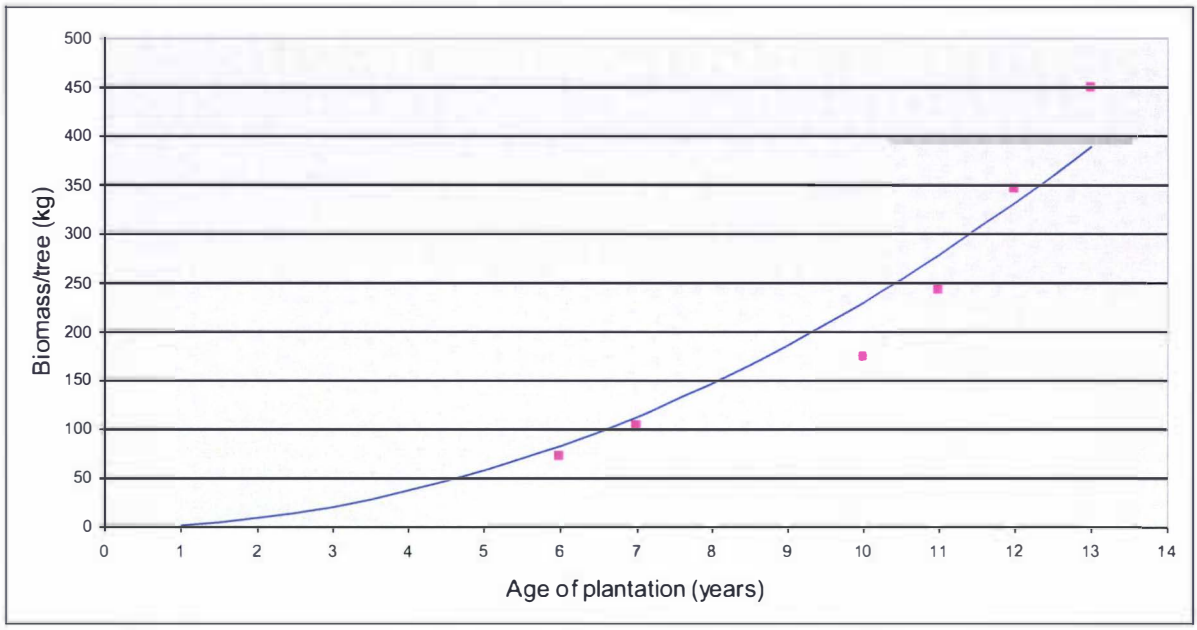

Figure 6.6 Relationship between tree age and above-ground biomass

Table 6.6 shows the estimated above-ground biomass/tree in 1-5 year old trees (estimated from Fig. 6.6). The annual biomass increment is also shown in the same Table.

Table 6.6: Estimated average above-ground biomass/tree and annual biomass increment in young plantations

Age of plantation (years)	Estimated average above-ground biomass/tree (kg)	Estimated annual biomass increment/ tree (kg)*
1	2.3	2.3
2	9.2	6.9
3	20.7	11.5
4	36.8	16.1
5	57.5	20.7

*The differences in biomass from one year to the other were assumed to be the annual biomass increment.

Total above-ground biomass/ha in these younger plantations was calculated by assuming that the tree density was 1,100 stems/ha (Geoff Warren, personal communication). Total biomass was then calculated by adding another 25% to the above-ground biomass (Cairns *et al.*, 1997) to account for root biomass.

Annual biomass increase in these young plantations was also estimated by using the alternative method "b" explained in Section 6.2 (details in Annex 6.2).

For the young plantations, an uncertainty of ±10% was used for the above-ground biomass. This 10% uncertainty is approximately twice the calculated uncertainty for the measured established plantations, and reflects the possible additional uncertainty associated with the regression analysis[4].

6.2.4 Estimation of C Sequestered by Native Bush

Besides exotic tree plantations on Massey University farms, there is also a bush reserve on Keeble farm of approximately 14.2 ha (shown in light brown colour in Fig.6.2), and several areas of native bush species covering an area of about 8 ha (Dave Bull, personal communication) scattered over the Turitea campus. The one on Albany drive is shown in Fig. 6.7. Besides all five lowland podocarp species (kahikatea, rimu, totara, matai and miro), these areas also contain manuka (*Leptospermum scoparium)*, kanuka (*Kunzea ericoides*) and many other seed plants and ferns.

Figure 6.7: Native bush area along Albany drive at Massey University

The areas of native bush on the campus are considered to be "Kyoto forests" because they were established after 1990, whereas the native bush reserve at the Keeble farm does not qualify because it was planted before 1990.

[4] refer xl spreadsheet "forestry_master.xls, worksheet "non-meas-kyoto" in the CD attached.

Although it is possible to develop allometric equations relating above and below-ground biomass to diameter at breast height for some of the native shrub species (Scott *et al*., 2000), the process cannot be recommended for a small scale study because it requires destructive sampling of different age classes. Analysis carried out by Trotter *et al.* (2005) on data from five different sites in New Zealand to assess the potential for manuka and kanuka (the most common shrubland species in New Zealand) to sequester atmospheric CO_2, showed that mean net C accumulation rates for these species are in the range of 1.9 to 2.5 Mg of C/ha/yr. Because the native bush plantations at Massey University are not purely manuka and kanuka, a conservative figure of 1.5 Mg of C/ha/yr has been used to calculate the amount of C accumulated by these native bush plantations at Massey University (Craig Trotter, personal communication).

An uncertainty of ±15% was assigned to the annual amount of CO_2 sequestered by native Kyoto plantations[5]. This value was assigned on the basis that the calculated uncertainty for the annual amount of CO_2 removed by the established Kyoto plantations was ±15%.

[5]refer xl spreadsheet "forestry_master.xls, worksheet "native-Kyoto" in the CD attached.

6.3 RESULTS

6.3.1 Massey University Forest Estate

The Massey University forest estate currently stands at 109.7 ha. About 95% of the woodlot area at Massey University is planted in *Pinus radiata*. Other species include Cupressus, Eucalyptus and some native bush. These are even-aged stands, and the silvicultural practices used in all the blocks are the same. Kyoto plantations at Massey University occupy 88.25 ha (Fig. 6.8) and of this, 87.75 ha is in block plantations, with shelter belts occupying only 0.5 ha (Table 6.7).

Table 6.7: Area under different categories of plantation in 2004

Category	Area (ha)
Total planted area	109.7
Kyoto plantations	88.25
Area in block plantation(Kyoto)	87.75
Area in shelter belts (Kyoto)	0.5

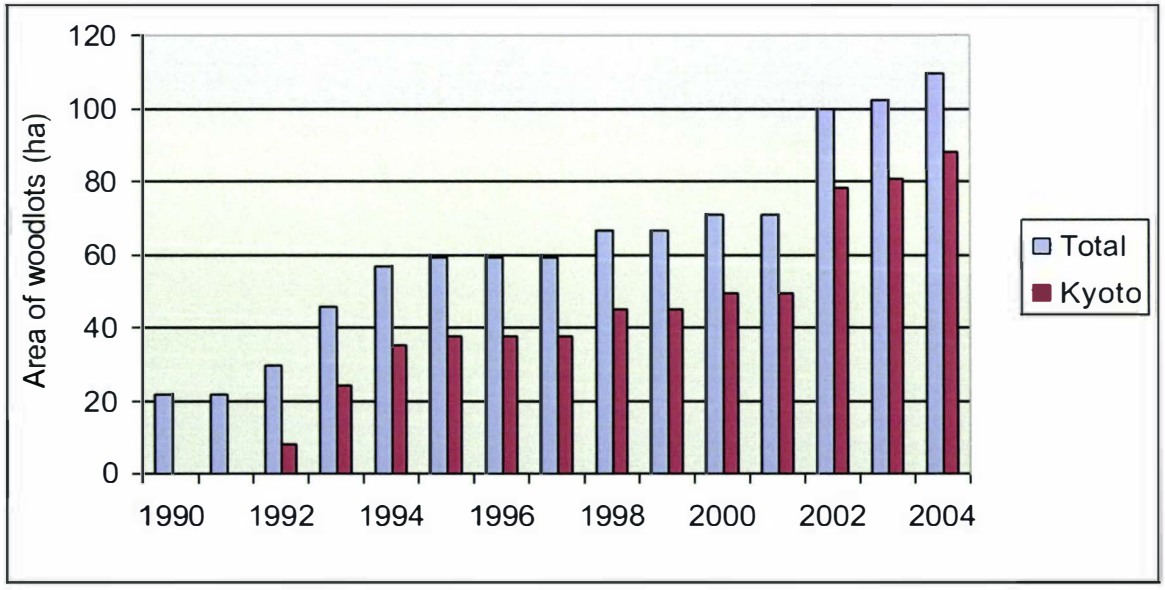

Figure 6.8: Total Massey University forest area and the area of Kyoto forests from 1990 to 2004

6.3.2 Annual Biomass Increase and CO_2 Removed by Established Plantations

The total estimated annual increase in biomass in the established tree plantations (Kyoto plantations) at Massey University was 1,590 Mg (Table 6.8). This corresponds to a total CO_2 removal of 2,915 ± 429 Mg (Table 6.7)[6]. Calculation of annual biomass increase by method "b" (described in Section 6.2) underestimates the amount of CO_2 removed by these plantations (Table 6.7).

6.3.3 Annual Biomass Increase and CO_2 Removed by Younger Exotic Tree Plantations

The annual increase in biomass in the young plantations was approximately 619 Mg, corresponding to a removal of CO_2 of 1,135±91 Mg (Tables 6.9 and 6.10, and Annex 6.4). Although there are comparable areas of established and young plantations, the CO_2 removed by the young forests is only 43% of that removed by the older, established trees.

6.3.4 Annual CO_2 Removed by Non Kyoto Exotic Tree Plantations

The annual amount of CO_2 removed by 21.45 ha of non-Kyoto exotic tree plantations at Massey University was estimated as 983 Mg. Although it is a considerable amount of sequestered CO_2, this amount cannot be discounted from the annual GHG emissions when considering obligations under the Kyoto Protocol.

6.3.5 Annual Removal of CO_2 by Native Bush Plantations

The estimated annual amount of CO_2 removed by native bush that qualifies as Kyoto forests was 44±7 Mg. Another 78 Mg of CO_2 was estimated to be removed by the non-Kyoto native bush (Table 6.11). Therefore the total amount of CO_2 removed by the native bush plantations was 122±18 Mg.

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[6] refer xl spreadsheet "forestry_master.xls, worksheets "2005-2004change" in the CD attached.

Table 6.8: Above-ground and below-ground biomass, annual biomass increase and annual CO_2 removed by the established Kyoto plantations at Massey University

Farm	Area under plantation (ha)	Total Above ground biomass in 2004 (Mg)	Total Below-ground biomass in 2004 (method "a")* (Mg)	Total Above ground biomass in 2005 (Mg)	Total Below-ground biomass in 2005 (method "a")* (Mg)	Total biomass 2004 (method "a")* (kg)	Total biomass 2005 (method "a")* (kg)	Annual increase in biomass (method "a")* (Mg)	Annual increase in C (method "a")* (Mg)	Total CO_2 removed by (method "a") (Mg)	Total CO_2 removed by (method "b") (Mg)*
	A	B	C=(B x 0.25)	D	E=(D x 0.25)	F=B+C	G=D+E	H=G-F	I=Hx0.5	J=Ix44/12	
Dairy 1	1.7	267	67	328	82	334	410	75	38	138	
Dairy 4	2.2	327	82	411	103	409	514	105	53	193	
LATU	1.7	152	38	202	51	189	253	63	32	116	
Keeble	11.8	1112	278	1,448	362	1,390	1,810	421	210	771	
Tuapaka	27.8	2,980	745	3,721	930	3,725	4,651	925	463	1,697	
Total	45.2	4,838	1,209	6,110	1,527	6,047	7,637	1,590	795	2,915	2,558

*Details of methods "a" and "b" are given in Section 6.2 and Annex 6

Table 6.9: Above-ground biomass, total biomass per tree and per ha in the younger Kyoto plantations

Age of plantation (years)	Average aboveground biomass/tree (kg)*	Above ground biomass/hectare (Mg)	Total biomass/hectare (Mg)
	A	B= (Ax1100**)/1000	T=B+(Bx0.25)
5	57.5	63.25	79
4	36.8	40.48	51
3	20.7	22.77	28
2	9.2	10.12	13
1	2.3	2.53	3

*Values from Table 6.6
**number of trees planted/ha

Table 6.10: The weight of CO_2e removed by the younger Kyoto plantations in the 2004-5 year.

Farm	Area under plantation (ha)	Total biomass increase (Mg)	Total C in the plantation (Mg)	Total CO_2 removed (method "a")* (Mg)	Total CO_2 removed (method "b")* (Mg)
Dairy 1	1	3	2	6	
Dairy 4	1	16	8	29	
LATU	5	79	40	145	
Keebles	10.25	80	40	147	
Haurongo	2.6	25	13	46	
Terrace block	5.2	81	41	149	
Tuapaka	18	335	168	614	
TOTAL	43.05	619	310	1,135	1,260

* Details of methods "a" and "b" are given in Section 6.2 and Annex 6.2
Note: Annual biomass increases in individual blocks of these younger plantations are shown in Annex 6.4

Table 6.11: Annual CO_2 removed by the native bush at Massey University

Category of native bush plantation	Area (ha)	C/year/ha (Mg)	Total annual C (Mg)	Total annual CO_2 removed (Mg)
Non-Kyoto	14.2	1.5	21	78
Kyoto	8	1.5	12	44
Total	22.2		33	122

6.3.6 Total CO_2 Removed by the Forestry Sector at Massey University

The total estimated annual amount of CO_2 removed by the forestry sector at Massey University was 5,155±567 Mg[7] (Table 6.12). Of this total, the estimated

[7] Refer xl spreadsheet "forestry_master.xls, worksheet "totals" in the CD attached.

annual amount of CO_2 removed by the Kyoto eligible plantations at Massey University was 4,094±439 Mg[8]. Most of this CO_2 was taken up by the established forests (Fig.6.9).

Table 6.12: Estimated annual CO_2 removed by all categories of plantations at Massey University

Category of plantation	Area under plantation (ha)	Annual CO_2 removed (Mg)
Exotic-Measured Kyoto	45.2	2,915
Exotic-non-measurable Kyoto	43.05	1,135
Exotic-non-measured, non-Kyoto	21.45	983
Native bush Kyoto	8	44
Native bush non-Kyoto	14.2	78
Total	131.9	5,155

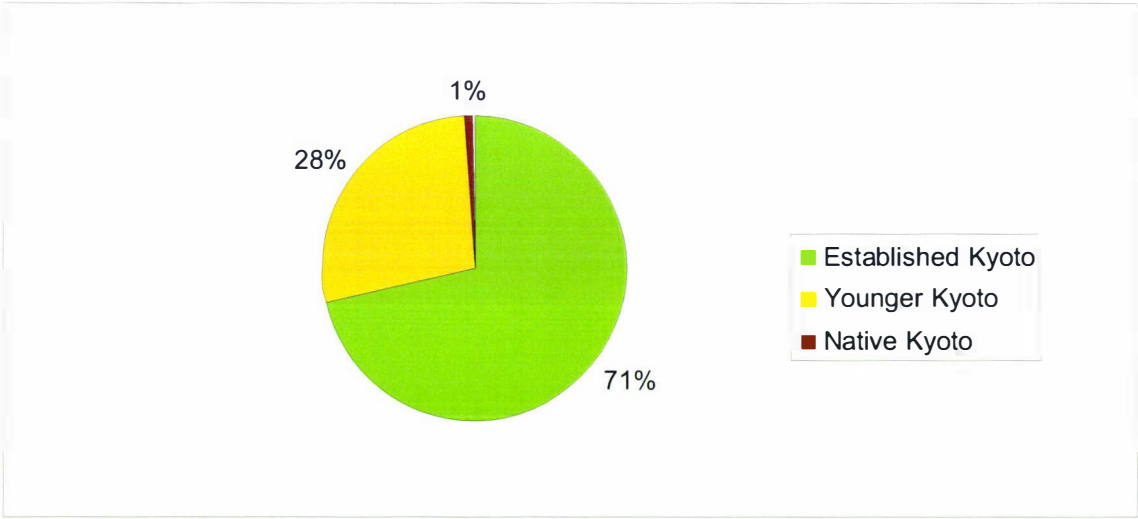

Figure 6.9: Relative contributions of the different categories of forests to the total "Kyoto recognised" CO_2 removal

6.4 DISCUSSION

Massey University has 109.7 ha of planted forests that have the potential to emit or remove CO_2. About 80.5% (88.25 ha) of the total Massey University exotic

[8] Refer xlspreadsheet "forestry_master.xls, worksheet "totals" in the CD attached.

tree plantations qualify as Kyoto forests. Because the total planted area at Massey University was unchanged during the inventory period (i.e. there was no harvesting/felling/extraction of trees during this period), only the estimated changes in biomass were used to calculate the amount of CO_2 removed by these forest plantations.

At present, the annual capacity for C uptake by the Massey University Kyoto forest plantations is approximately 1,105±120 Mg without harvest (Tables 6.8 and 6.10). An additional 12 Mg of C is sequestered by the Kyoto native bush plantations annually. Therefore the total discountable CO_2 removal from this sector is 4,094±439 Mg. Only 1% (44 Mg) of the total removals in this sector was from the native bush plantations while the rest (4,050 Mg) is removed by the exotic tree plantations (Fig. 6.9).

This estimate (4,050 Mg) of CO_2 removed by the exotic tree plantations was made using method "a" (Section 6.2) that assumes that the below-ground biomass is 25% of the above-ground biomass. If the alternative method "b" described in Section 6.2, (which assumes that the ratio of below–ground to above-ground biomass varies with tree age), was used the corresponding estimate was 3,818 Mg of CO_2. This is an almost 6% decrease in estimated CO_2 removals by the exotic tree plantations at Massey University.

There are a number of input components that can affect the overall precision of the final estimates of CO_2 mitigation by forest plantations. There are two major types of errors: those associated with measurement, and those associated with the model used to calculate the biomass. Some of the values used in calculations – e.g. the assumption that below-ground biomass is 25% of above-ground biomass - do not have readily available estimates of precision. IPCC (2006) has suggested that expert judgement can be used for estimating uncertainty in emission factors or direct emission measurements when empirical data are lacking. This is the case here.

To estimate annual biomass growth the standing biomass in each of the two years was measured and the difference calculated. Subtracting two large

numbers to give a smaller number can lead to substantial errors. However, much of the uncertainty associated with the estimates of biomass at a site are specific to that site. For example, the extent to which the conformation of the trees corresponds with the average conformation in the allometric model. Any deviations from the average conformation assumed by the model will be the same for both years of measurement, and thus not all of the uncertainty associated with the absolute estimate of biomass will apply to the estimates of annual biomass increase.

At the moment, forestry is the only sector that can be used as a tool by Massey University to mitigate the GHG emissions from other sectors. The area of exotic tree plantations at Massey University has increased from 21.45 ha to 109.7 ha since 1990, i.e. it has increased by 411%, and it is intended to increase it to 150 ha over the next few years (Warren, 2004).

Although the 21.45 ha of *Radiata pine* plantations (Table 6.1) that were present in 1990 did not qualify for Kyoto forests, it is estimated that about 268 Mg of C was sequestered by those plantations during the measurement year. This estimate was made on the basis of the average C uptake/ha (12.5 Mg/ha) calculated from all the plantation blocks considered as Kyoto plantations at Massey University (average of Tables 6.8 and 6.10).

At present, there is no harvesting operation planned for the Massey University forest plantations. The first possible harvesting operation will be after 3-7 years (Warren, 2004), and after that it is proposed that 5-6 ha of forests will be harvested annually. This removal will add approximately 229-275 Mg of CO_2e to the Massey University annual GHG emissions budget.

Currently the forestry sector at Massey University is capable of mitigating about 15.4% of the total 26,646 Mg of CO_2 emitted due to the energy, waste and agriculture sectors. This is more than would be required to reduce the total current CO_2 emissions to a level equal to the 1990 emissions of 25,163 Mg. New land will need to be planted continually to increase the overall mitigation percentage in the coming years. This will especially be the case after the start of

harvesting operations when more and more area will be required for planting to mitigate the additional amount of CO_2 resulting from the harvesting operations as well.

6.5 CONCLUSIONS

- The Kyoto eligible plantation forests and the native bush plantations at Massey University stored 1117 Mg of C in 2003-04.

- Massey University did not plant exotic forest trees and native bush species to offset their C emissions. They were planted to diversify and utilize marginal land, but most of these plantations qualify as Kyoto plantations and can be used as a bonus for C sequestration.

- Planting new land and especially establishing long rotation species on the University farms will ensure the continuation of the C sequestration process. Without continued plantings, the net annual capacity of C uptake by the forest plantations will decline. This will especially be the case once felling operations commence. If this additional planting does not take place the volume of wood removed through extraction will be more than the total annual biomass increase in these plantations. This would cause the net C balance due to the forestry sector at Massey University to become negative in the future, unless replanting occurs.

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CHAPTER 7: GENERAL DISCUSSION AND CONCLUSIONS

7.1 SUMMARY OF RESULTS

7.1.1 Emission Values and Uncertainties for 1990 and 2004

7.1.1.1 Breakdown by Sector

The net GHG emissions measured from Massey University in 2004 were 22,602±2,710 Mg CO_2e (Table 7.1).[1] The three major sectors (energy, agriculture, and waste) emitted a gross amount of 26,696±2,674 Mg CO_2e. The forestry sector in 2004 removed 4,094±439 Mg CO_2e of GHG - equivalent to 15.4% of the total gross emissions. The largest emissions came from the energy sector which contributed 19,064±1,324 Mg CO_2e (71.4% of gross emissions). The agricultural sector emitted 6,999±2,305 Mg CO_2e (26.2% of gross emissions) and the waste sector was responsible for only 633±290 Mg CO_2e (2.4% of gross emissions) (Table 7.1).

Table 7.1: Emissions and removals of GHG at Massey University in 2004

Sector	Greenhouse gas emissions (CO_2e Mg/yr)	Uncertainty for emission value (CO_2e Mg/yr)	Relative uncertainty for emission value (CO_2e Mg/yr)	% of total gross GHG emissions
Energy	19,064	1,324	0.07	71.4
Waste	633	290	0.46	2.4
Agriculture	6,999	2,305	0.33	26.2
Total gross	26,696	2,674	0.10	
Forestry	-4,094	439	0.11	15.4
Total net	22,602	2,710	0.12	

The gross and net GHG emissions in 1990 were 24,736±2,948 Mg of CO_2e. The net and gross values of GHG emissions in 1990 were equal (from a Kyoto Protocol standpoint) because at that stage forestry was not considered an active

[1] For all emission value and uncertainty summaries and analyses in Section 7.1, in addition to the tables presented and referred to in the text, please refer to xl spreadsheets "Total_master.xls", "energy_master.xls", "waste_master.xls", "agriculture_master.xls", and "forestry_master.xls" in the CD attached.

sector (Table 7.2). The energy sector emitted 15,531±1,288 Mg CO_2e (62.8%), the agricultural sector 8,067±2,626 Mg CO_2e (32.6%) and waste 1,138±363 Mg CO_2e (4.6%).

Table 7.2: Emissions and removals of GHG at Massey University in 1990

Sector	Greenhouse gas emissions (CO_2e Mg/yr)	Uncertainty for emission value (CO_2e Mg/yr)	Relative uncertainty for emission value (CO_2eMg/yr)	% of total gross GHG emissions
Energy	15,531	1,288	0.08	62.8
Waste	1,138	363	0.32	4.6
Agriculture	8,067	2,626	0.33	32.6
Total gross	24,736	2,948	0.12	
Forestry	0			0.0
Total net	24,736	2,948	0.12	

7.1.1.2 Breakdown by Sub-Sector

In 2004, commuting vehicles, enteric fermentation, and gas burnt for energy were the three largest GHG-emitting sub-sectors out of the 16 analyzed in this study (Table 7.3). Emissions from waste were small in 2004. In 1990, the greatest emitting sub-sectors were enteric fermentation, coal burnt for energy, and commuting vehicles (Table 7.4). Staff air travel and emissions from agricultural soils and sports grounds also featured highly in both 2004 (ranks 5 and 6, respectively) and 1990 (ranks 6 and 4, respectively).

Table 7.3: Emissions and removals of GHG from different sub-sectors in 2004, at Massey University ranked from greatest to least

Rank	Sub-sector	emission/removal (CO_2e Mg/yr)
1	Vehicle commuting	6,854
2	Enteric fermentation	4,286
3	Gas	3,884
4	Forest (established)	-2,915
5	Staff air travel	2,698
6	Agricultural soils & sports grounds	2,696
7	Electricity	2,547
8	Aviation school	2,330
9	Forest (younger)	-1,134
10	Vehicles Massey	751
11	MSW	391
12	Human sewage	136
13	CH_4 flaring	106
14	Forest (native)	-44
15	Manure management	17
16	Coal	0.0

Table 7.4: Emissions and removals of GHG from different sub-sectors in 1990, at Massey University ranked from greatest to least

Rank	Sub-sector	emission/removal (CO_2e Mg/yr)
1	Enteric fermentation	5,146
2	Coal	5,047
3	Vehicle commuting	5,045
4	Agricultural soils & sports grounds	2,905
5	Electricity	1,853
6	Staff air travel	1,735
7	Gas	1,366
8	MSW	1,035
9	Vehicles Massey	264
10	Aviation school	222
11	Human sewage	103
12	Manure management	16.1
13	Forest (established)	0.0
14	Forest (younger)	0.0
15	Forest (native)	0.0

7.1.2 Differences in Emissions between 1990 and 2004

7.1.2.1 Total Emissions and Breakdown by Sector

The annual gross emissions of GHG at Massey University in 2004 were 1,960±3,980 Mg CO_2e (7.9%) higher than the emissions in 1990 (Table 7.5). The estimated uncertainty in this apparent increase in GHG emissions is very large because two large numbers have been subtracted to leave a small difference. The actual uncertainty associated with the difference in emissions between 2004 and 1990 is likely to be much smaller than that indicated because many of the assumptions in the estimates of the annual emissions (e.g. the GWP of the various GHGs) will apply equally to the data from both years. The similarity in the gross emission values for the two years is due to the decreases in emissions from waste and agricultural sources being offset by the increase in energy-sourced emissions (Fig. 7.1; Table 7.5). Similarly, although the value for net GHG emissions in 2004 is 8.6% less than the value in 1990, the uncertainty in the difference is greater than the difference itself.

For the different sectors, the greatest change in emissions since 1990 was recorded in the energy sector (Fig. 7.1), which increased by 22.7% (Table 7.5). In contrast, the emissions from the agricultural and waste sectors have decreased by 13.2% and 44.4% respectively (Table 7.5). However, there are large uncertainties in the estimates of changes in GHG emission from these sectors between 1990 and 2004 (Tables 7.1 and 7.2).

Table 7.5: Differences in GHG emissions and removals from different sectors at Massey University between 1990 and 2004

Sector	Greenhouse gas emissions in 1990 (CO_2e Mg/yr)	Greenhouse gas emissions in 2004 (CO_2e Mg/yr)	2004-1990 difference (CO_2e Mg/yr)	% change (relative to 1990 values) in GHG emissions 1990 to 2004
Energy	15,531 ± 1,288	19,064 ± 1,324	3,533 ± 1,847	22.7
Waste	1,138 ± 363	633 ± 290	-505 ± 465	-44.4
Agriculture	8,067 ± 2,626	6,999 ± 2,305	-1,068 ± 3,494	-13.2
Total gross	24,736 ± 2,948	26,696 ± 2,674	1,960 ± 3,980	7.9
Forestry	0	-4,094 ± 439	-4,094 ± 439	
Total net	24,736 ± 2,948	22,602 ± 2,710	-2,134 ± 4,004	-8.6

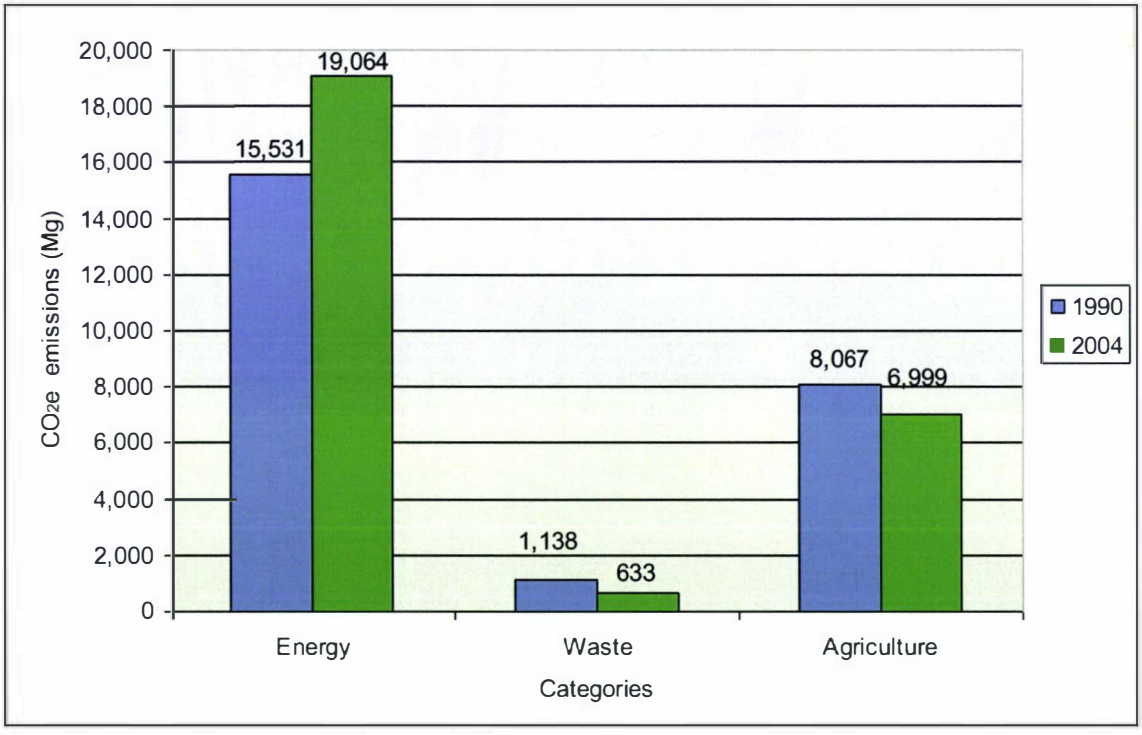

Figure 7.1: Comparison of GHG emissions (Mg CO_2e) in 1990 and 2004

7.1.2.2. Total Emissions Breakdown by Sub-Sector

There were significant differences in GHG emissions between 1990 and 2004 in all the sub-sectors in the energy sector (Table 7.6). In the waste sector, GHG emissions from the MSW sub-sector decreased by 62.2%. In the agricultural

sector, emissions from both the enteric fermentation and agricultural soils and sports grounds sub-sectors decreased between 1990 and 2004, although when the uncertainties from 1990 and 2004 estimates are combined, the 2004 and 1990 emissions are not significantly different (Table 7.6). No forestry sub-sectors were active in 1990 and therefore all show increases in GHG removal from 1990 to 2004.

Table 7.6: Differences in GHG emissions and removals from different sub-sectors at Massey University between 1990 and 2004

Sub-sector	Greenhouse gas emissions in 1990 (CO_2e Mg/yr)	Greenhouse gas emissions in 2004 (CO_2e Mg/yr)	2004-1990 difference (CO_2e Mg/yr)	% change in GHG emissions 1990-2004
Electricity	1,853 ± 207	2,547 ± 285	694 ± 352	37.5
Gas	1,366 ± 68	3,884 ± 194	2,518 ± 206	184.3
Coal	5,047 ± 252	0.0	-5,047 ± 252	
Staff air travel	1,735 ± 312	2,698 ± 402	963 ± 509	55.5
Aviation school	222 ± 27	2,330 ± 164	2,108 ± 166	950.0
Vehicles commuting	5,045 ± 1,204	6,854 ± 1,200	1,809 ± 1700	35.9
Vehicles Massey	264 ± 26	751 ± 75	487 ± 79	184.5
MSW	1,035 ± 362	391 ± 286	-644 ± 461	-62.2
Human sewage	103 ± 30	136 ± 40	33 ± 50	32.0
CH_4 flaring	0.0	106 ± 28	106 ± 28	
Enteric fermentation	5,146 ± 1,791	4,286 ± 1,462	-860 ± 2312	-16.7
Manure management	16 ± 6	17 ± 6	1 ± 8	6.2
Agricultural soils & sports grounds	2,905 ± 1,920	2,696 ± 1,782	-209 ± 2,620	-7.2
Forest (measured)	0.0	2,915 ± 429	2,915 ± 429	
Forest (younger)	0.0	1,134 ± 91	1,134 ± 91	
Forest (native)	0.0	44 ± 7	44 ± 7	

7.1.3 Uncertainties in 2004 Data: Sensitivity Analysis and Sources of Large Uncertainties

7.1.3.1 Uncertainty Sensitivity Analysis (2004 Data)

Table 7.1 presents the 2004 GHG emissions for each sector and their absolute and relative uncertainties. The uncertainties in the gross and net totals are derived from the uncertainties in the emissions from the various sectors, which in turn are derived from the uncertainties in the values of the various parameters used in calculating the sub-sector emissions. This section presents a sensitivity analysis of the contributing parameters for each sector and sub-sector, in order to identify which parameter uncertainties are contributing most to the uncertainties at four levels of calculation: total, sector, sub-sector, and lower (individual parameter) levels. For each analysis, the relative uncertainties used or generated in the actual emission calculations of the study are halved, and the effect of halving on higher-level uncertainties is then identified.

7.1.3.1.1 Sector effects on gross and net total emission uncertainties

The major influence on the size of the uncertainties in estimates of gross and net total emissions is from the agricultural sector (Table 7.7). This is because of the large emissions from agriculture and the high relative uncertainty associated with this estimate (Table 7.1). Halving the uncertainty associated with the estimate of GHG emissions from agriculture reduces the uncertainty in the net total emissions from 10% to 7% and the uncertainties in the gross emissions from 12% to 8%. The other three sectors have much smaller effects on the size of the uncertainties in the estimates of the net and gross emissions.

Table 7.7: Effect of halving the uncertainties in estimates of emissions from individual sectors on the uncertainties in the final estimates of total gross and net GHG emissions

Sector Relative Uncertainty (halved uncertainty)	Effect of halving on Gross GHG Emission Value Uncertainty	Effect of halving on Net GHG Emission Value Relative Uncertainty
Energy 7 % (to 3.5 %)	10 % to 9 %.	12 % to 11 %
Waste 46 % (to 23 %)	10 % to 10 %	12 % to 12 %
Agriculture 33 % (to 16.5 %)	10 % to 7 %	12 % to 8 %
Forestry	NA	12 % to 12 %

7.1.3.1.2 Sub- sector effects on sector emission uncertainties

Some sub-sectors have larger influences on sector emission uncertainties than others (Table 7.8). The most influential sub-sectors are commuting vehicles, MSW, enteric fermentation, agricultural soils and sports grounds, and established forests.

Table 7.8: Effect of halving the uncertainties in estimates of GHG emissions from sub-sectors on the uncertainties in the final estimates of sector emissions

Sub-sector Relative Uncertainty (halved uncertainty)	Sector	Effect of halving on Sector GHG Emission Relative Uncertainty
Electricity 11 % (to 5.5 %)	Energy	7 % to 7 %
Gas 5 % (to 2.5 %)	Energy	7 % to 7 %
Staff air travel 15 % (to 7 %)	Energy	7 % to 7 %
Aviation school 7 % (to 3.5 %)	Energy	7 % to 7 %
Commuting vehicles 18 % (to 9 %)	Energy	7 % to 4 %
Massey vehicles 10 % (to 5 %)	Energy	7 % to 7 %
MSW 73 % (to 36.5 %)	Waste	46 % to 24 %
Human sewage 29 % (to 14.5 %)	Waste	46 % to 46%
CH_4 flaring 26 % (to 13 %)	Waste	46% to 46 %
Enteric fermentation 34 % (to 17 %)	Agriculture	33 % to 28 %
Manure management 36 % (to 18 %)	Agriculture	33 % to 33 %
Ag soils & sports grounds 66 % (to 33 %)	Agriculture	33 % to 24 %
Forest (measured) 15 % (to 7.5 %)	Forestry	11 % to 6 %
Forest (younger) 8 % (to 4 %)	Forestry	11 % to 11 %
Forest (native) 15 % (to 7.5 %)	Forestry	11 % to 11 %

7.1.3.1.3 Individual parameter effects on sub-sector emission uncertainties

Individual parameter effects are analysed only for those sub-sectors in Table 7.8 that have a significant impact on the uncertainties of the relevant sectors when their uncertainty is halved. These sub-sectors are: commuting vehicles (Table 7.9), MSW (Table 7.10), enteric fermentation (Table 5.7), agricultural soils & sports grounds (Table 5.10), and forest (established) (refer xl spreadsheet "forestry_master.xls" in the CD attached).

For commuting vehicles, most individual parameters have little effect on the overall uncertainty (Table 7.9). The main effect is provided by the estimated number of trips by students in petrol vehicles, the uncertainty of which, when halved, reduces the commuting vehicle sub-sector emission uncertainty from 18% to 13%. The uncertainty in the fuel efficiency of vehicles has a lesser effect (Table 7.9).

Table 7.9: Sensitivity analysis for uncertainties in the "Vehicles Commuting" sub-sector emission estimates arising from uncertainties in individual parameters

Individual Parameter Relative Uncertainty (halved uncertainty)	Effect of halving on Sub-sector GHG Emission Relative Uncertainty
No. diesel trips by students 20 % (to 10 %)	18 % to 17 %
No. diesel trips by staff 20 % (to 10 %)	18 % to 18 %
No. petrol trips by students 20 % (to 10 %)	18 % to 13 %
No. petrol trips by staff 20 % (to 10 %)	18 % to 17 %
Distance per trip by students 7 % (to 3.5 %)	18 % to 17 %
Distance per trip by staff 13 % (to 6.5 %)	18 % to 17 %
Fuel efficiency of diesel and petrol vehicles 10 % (to 5 %)	18 % to 16 %
Fuel combustion emission factor CO2 5 % (to 2.5 %)	18 % to 17 %
Fuel combustion emission factor CH_4 50 % (to 25 %)	18 % to 18 %
Fuel combustion emission factor N_20 50 % (to 25 %)	18 % to 18 %
GWP value for CH_4 20 % (to 10 %)	18 % to 18 %
GWP value for N_2O 20 % (to 10 %)	18 % to 18 %

For the waste sub-sector "MSW", the major contributors to the 73% uncertainty in the estimate of MSW emissions are the uncertainty in CH_4 generation potential

(L_o), the quantity of waste collected and the waste volume-to-weight conversion factor, which when halved from its 10% value to 5% reduces the 73% uncertainty to 67% (Table 7.10). Another major effect is the way in which uncertainties are propagated in the calculation of waste emissions; this is discussed in Section 7.1.3.2 (next section).

Table 7.10: Sensitivity analysis for uncertainties in "MSW" sub-sector emission values arising from uncertainties in individual parameters

Individual Parameter Relative Uncertainty (halved uncertainty)	Effect of halving on Sub-sector GHG Emission Relative Uncertainty
Total waste collected 10 % (to 5 %)	73 % to 67%
Waste volume-to-weight conversion factor 10 % (to 5 %)	73 % to 67 %
Methane generation potential Lo 10 % (to 5 %)	73 % to 67 %
Methane recovery efficiency 20 % (to 10 %)	73% to 66%
Oxidisation factor 10 % (to 5 %)	73 % to 73 %
GWP value for CH_4 20 % (to 10 %)	73 % to 72 %

For the enteric fermentation (Table 5.7) and agricultural soils & sports grounds sub-sectors, the major influences (Table 5.10) on uncertainties in emission estimates are derived from parameters input into the relevant Monte Carlo simulations (Chapter 5). The biggest influence on the enteric fermentation emission uncertainty arises from the CH_4 conversion factor uncertainty (Table 5.7), which was ±52% (Section 5.2.3.1). Uncertainty in the value of EF_2 (direct emissions due to animal waste) is a major influence on the size of the uncertainty in the agricultural soils and sports grounds emission estimate (Table 5.10). The uncertainty in EF_2 is in turn partly a function of the animal excretion uncertainties of ±22% (Section 5.2.4.1).

For forestry, the relative uncertainty of 15% in the established trees sub-sector is largely attributable to the subtraction involved in the calculation of annual biomass change. In the calculation, absolute uncertainties from large values of estimated biomass for 2005 and 2004 are combined and applied to the relatively small difference between those two years' biomass values, leading to a higher relative

uncertainty (refer to xl spreadsheet "forestry_master.xls", worksheet "2005-2004 change" in the attached CD).

7.1.3.2 Sources of the Greatest Uncertainties (2004 Data) and Their Potential for Reduction

The overall absolute uncertainties from the energy sector are large, whereas the waste and agricultural sectors have by far the highest relative uncertainties (32-46%) associated with their emission values (Tables 7.1 and 7.2), compared with those for the energy sector (7-8%). Large relative uncertainties are not as important as large absolute uncertainties. Waste may have a large relative uncertainty but it is only a small contributor to the GHG profile for Massey and improving the accuracy of the waste GHG emission will not greatly improve the overall accuracy of the total Massey GHG emission. Therefore, efforts to reduce uncertainties should be concentrated in the energy sector. In the sub-sectors, the most influential uncertainties are those associated with commuting vehicles, MSW, enteric fermentation, agricultural soils & sports grounds, and forest (established). Aspects of these uncertainties are discussed below.

The relative uncertainty of 18% in the commuting vehicles GHG emission estimate is influenced most by the uncertainty in the number of trips made in petrol vehicles by students (Table 7.9). Reducing that uncertainty from 20% to 10 % reduces the sub-sector uncertainty from 18% to 13%. Given the large amount of effort that was made in this study to measure the number of trips (as detailed in Chapter 3), the size of this uncertainty is unlikely to be able to be substantially reduced in any future investigation of energy use by commuting vehicles.

The large relative uncertainty for the waste emission value (46%) in 2004 (Table 7.1) is due to uncertainties in several parameters in the equations used to calculate emissions, as identified in the uncertainty sensitivity analysis. The large relative uncertainty is due to the very large uncertainty in the estimate of emissions from MSW (391 ± 286 Mg CO_2e; 73% relative uncertainty). This large uncertainty is partly due to the 10% uncertainty applied to the waste volume-to-weight conversion factor (Table 7.10). This 10% uncertainty in the conversion

factor was an assumed uncertainty and was chosen to be fairly large in order to not underestimate the variation in possible values. This conversion factor uncertainty could be reduced substantially in the future by a detailed analysis of waste composition and volume-weight relationships for different waste types, which was not performed in this study.

The high MSW emission uncertainty is also partly due to how the MSW emission estimate was calculated and uncertainties propagated in that calculation. Between 1990 and 2004 a CH_4 recovery system was installed at the landfill. The amount of CH_4 emitted in 2004 was therefore calculated as the difference between the amount of CH_4 generated and the amount recovered. The recovery efficiency is thought to be approximately 65% which means that the final amount of CH_4 emitted is small compared to both the amount of CH_4 produced and the amount recovered. As the estimates of both CH_4 production and recovery have sizable uncertainties associated with them, subtraction of these two values to give a final net CH_4 emission results in a very large (73%) relative uncertainty. The size of the uncertainty in net CH_4 emissions is unlikely to be able to be reduced in future waste GHG inventories, given that the amount of recovered CH_4 is likely to remain similar or improve due to improving CH_4 recovery technologies.

The biggest influence on the enteric fermentation emission uncertainty is the CH_4 conversion factor uncertainty. It is not known whether uncertainties in animal excretion factors can be reduced in order to reduce the uncertainty on N_2O emissions related to agricultural soils and sports grounds. Regarding the established forestry sub-sector, it is unlikely that the 15% relative uncertainty can be reduced, because the major effect on the uncertainty arises through calculation of annual change in biomass by subtraction, as explained above.

It is interesting to note that although there are some uncertainties that Massey can do something to improve, (e.g. uncertainty in annual animal numbers, uncertainty in the annual amount of energy used) some other uncertainties, such as uncertainty in the CH_4 conversion factor and the uncertainty in GWP values are beyond Massey University's control.

7.2 GENERAL DISCUSSION

Generally speaking, the concept of a GHG inventory at an institutional level is young and still in its developmental stage. Consequently, there are some widespread variations in the quality and approach used for inventories by universities, governments and the corporate sector. This makes it very difficult to compare the inventories of different institutions. Over time it is hoped that GHG inventories will become more uniform in quality and approach, and this will help cross-institutional comparisons.

Few attempts have yet been made at an institutional level to determine the aggregated net emissions of the major GHGs, although a few universities have started taking an interest in this field. Examples are Harvard University's Green Campus Initiative (HGCI), Tufts Climate Initiative (TCI), Tulane University (TU) and the University of North Carolina (UNC). It is however, difficult to compare the emissions of one university with the emissions of another university because these universities are often very different.

A considerable proportion of the emissions from Massey University comes from the agricultural sector, whereas the other Universities with GHG inventories (e.g. Harvard University, Tulane University and the University of North Carolina) do not have this sector at all. Therefore any comparison of emissions among these universities must take these differences into account.

Considering the total number of full time equivalent students and staff at Massey University Turitea campus and the net emissions in 2004, the estimated per capita emission in CO_2e was 1.4 Mg/yr. The only available per capita emission figures for a university are from the University of North Carolina which has 9 Mg/year of CO_2e emissions (UNC, 2006). The reasons for this big difference in per capita emissions are not known because full details of North Carolina University's GHG inventory are not available. However, in the case of Harvard University, approximately 90% of the GHG emissions are directly related to heating, cooling and powering of buildings, whereas at Massey University this

category contributed only 24% of the total GHG emissions in 2004. The need to heat buildings in winter and cool in summer in the more extreme continental climate of North America may account for the higher per capita GHG emissions from North American universities.

The changes in emissions over time also differ between universities. Gross GHG emissions at the Turitea campus only increased by 7.9% between 1990 and 2004, whereas at Harvard University there has been an overall increase of 35% since 1992 (HGCI, 2006). An increase in building area, an increase in intensive laboratory research, and the sources and efficiency of energy production are the reasons given for this large increase (HGCI, 2006).

Estimated total net per capita GHG emissions from New Zealand in 2004 were 12.3 Mg CO_2e/yr (Table 7.11) and the gross per capita GHG emissions were 18.3 Mg/yr of CO_2e . The net per capita emissions at Massey University were 1.4 Mg/yr (Table 7.11) and the gross per capita emissions on the Massey campus amounted to 1.7 Mg/yr of CO_2e. This was 10.8% of the national figure.

Table 7.11: Comparison of National and Massey University's per capita GHG emissions (Mg CO_2e/yr) from different sectors in 2004

Source Sector	Per capita emissions in 2004 (Mg CO_2e /yr)*	
	National	Massey
Energy	7.8	1.2
Industrial Process	1.0	
Solvent and other product use	<0.5	
Agriculture	9.1	0.4
Landuse change and forestry	-6.0	-0.3
Waste	0.5	<0.5
Net	12.3	1.4

*Based on projected New Zealand population in 2004 (Statistics NZ, 2006), and number of full time equivalent students and staff at the Turitea campus of Massey University in 2004.

Of course, it would be expected that the per capita emissions from an institution such as a university would be less than the national average, because most of the staff and students do not spend all their time on the campus. However, if it is assumed that staff and students spend about 25% of their year either at or travelling to and from Massey University, it is apparent that the University does

not contribute in a disproportionate way to the national average GHG emissions. Inspection of Table 7.11 suggests that the major differences between the national and the university per capita emissions are in the Energy and Agricultural sectors. The national per capita energy consumption is boosted by a number of energy intensive industries, which Massey does not have. Also Palmerston North is a small city, which means that commuting times for Massey students and staff are short compared to large cities, such as Auckland.

It is interesting to note that although Massey has a number of farms associated with the campus, the per capita GHG emissions of University staff that can be attributed to agriculture are considerably smaller than the contribution of agriculture to the national per capita GHG emissions (Table 7.11). This is because the ratios of Massey University's population to the number of dairy animals and sheep are 1:0.07 and 1:0.6 respectively, whereas the national ratios are 1:1.27 for dairy animals and 1:9.7 for sheep (based on the New Zealand population (StatisticsNZ, 2006) and the number of farm animals in New Zealand in 2004 (Ministry for the Environment (MfE) , 2006)).

7.2.1 Energy Sector

The energy sector is responsible for most of the GHG emissions at Massey University. In 2004 the GHG emissions due to this sector were 19,064±1,324 Mg CO_2e, and this sector had the largest increase (22.7%) in GHG emissions between 1990 and 2004 (Table 7.5). Within the energy sector, electricity and gas contributed 33% of GHG emissions, road transport 41% and aviation 26% (Fig. 7.2).

7.2.1.1 Electricity and gas

Turitea campus of Massey University has been identified as one of New Zealand's 300 largest energy users (Energy Efficiency and Conservation Authority (EECA), 2006). The calculated emissions from electricity for 2004 were based on the number of units of electricity consumed and a national emission

factor. The combined consumption of electricity and gas measured in kWh for 2004 was almost double that of 1990 (Sections 3.3.1 and 3.3.2). This was partially balanced by a decrease in coal use. However, the per capita energy consumption in buildings dropped by 21% from 10,402 MJ/head to 8,212 MJ/head.

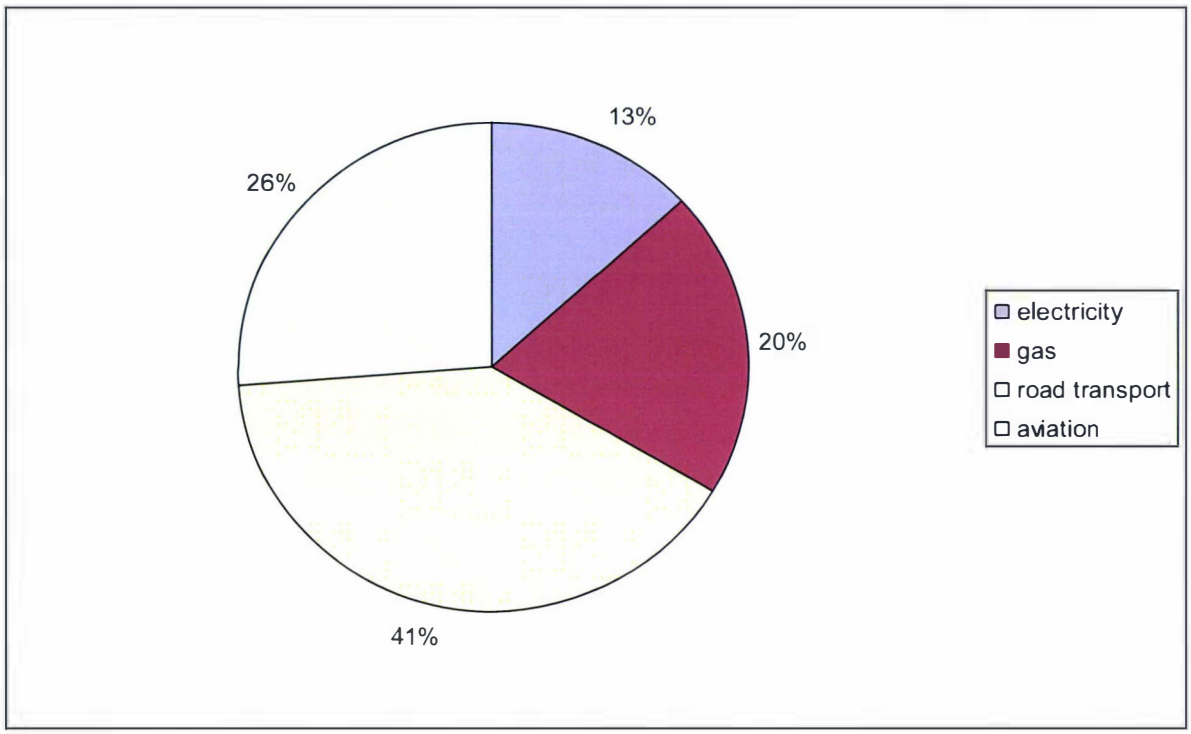

Figure 7.2: GHG emissions at Massey University in 2004, from different categories in the energy sector

There are probably two reasons behind this decrease in per capita energy consumption. Firstly, Massey University's population at the Turitea campus (full time equivalent students and staff) had increased from 11,953 in 1990 to 16,238 in 2004. The facilities that were used by a lesser number of people in 1990 are now shared by more people. Secondly, there has been an improvement in the efficiency of heating with the shift from a coal powered boiler plant to natural gas heating.

A possible option to reduce energy consumption and therefore GHG emissions in this sector is to implement active energy management programmes. The Faculty

of Applied Science in Queen's University of Canada has introduced a smart lighting system that allows light and power usage to be monitored by a database which can reduce the electricity consumption by up to half (http://appsci.queensu.ca/). The illumination in different offices and rooms can be changed with the help of this system using dimmable ballasts which helps in adjusting the light according to individual comfort. The annual power consumption of dimmable ballasts can be up to 50% less than traditional ballasts. The installed motion sensors automatically turn the lights off when a room is empty. This not only significantly increases the life span of the ballasts but also saves a considerable amount of energy. A 50% reduction in electricity consumption at Massey University could reduce the overall GHG emissions by up to 5%.

Another option to reduce electricity consumption and CO_2 emissions from electricity is to control standby power consumption[2]. The National Appliance and Equipment Energy Efficiency Committee of the Australian government (NAEEEC) reported that in 2002, standby power consumed 2.8% of the total electricity consumption in New Zealand as compared to 2.9% by Australia and 1% by Canada (NAEEEC, 2002). Although the exact consumption of standby power at Massey University is not known, if the New Zealand national average (2.8%) is assumed, this would equate to 459,677 kWh of electricity is being used for standby power annually. This would generate about 71 Mg GHG in CO_2e per year from Massey University.

7.2.1.2 Road transport

The main contribution to GHG emissions from the energy sector at Massey University is road transport, which contributes 41% of the total emissions from this sector (Fig. 7.2). This sub-sector includes emissions from commuting traffic and from the fuel consumed by the vehicles owned by Massey University.

[2] Standby power is the energy used by an appliance while plugged in but not performing its central function.

7.2.1.2.1 Commuting traffic

Commuting vehicles were responsible for 90% of the total GHG emissions from vehicles at Massey University in 2004 (Table 3.15) and contributed about 25% of the total gross GHG emissions from the campus. Estimated GHG emissions from commuting traffic in 2004 were 36% greater than the comparable estimate for 1990. Clearly therefore, this is an important area and may provide a number of opportunities for Massey University to reduce its GHG footprint.

Massey University has already made significant progress in this area with the launch of a "free" bus service in February 2005. It is estimated that the free bus service has reduced annual CO_2 emissions from commuting vehicles by more than 11% (Massey, 2006). This would be equivalent to a reduction of 15 Mg/week. This has reduced the total gross GHG emissions from Massey University by approximately 3%.

Motivating more students to use bicycles could reduce the traffic pressure on the campus. Although no documentary record of the numbers of staff and students cycling to the campus in 1990 could be found, anecdotal evidence from some long-serving staff members suggested that the use of bicycles in 1990 was many times greater than in 2004. A helpful initiative could be to support the Green Bike Trust of Palmerston North, which loans out free bikes to Massey University students.

Car pooling can also be an option to reduce the pressure of commuting vehicles on campus. Among the 385 students and staff members interviewed during the traffic survey in September 2004, less than 5% were members of a car pool. Special education and liaison programmes and incentives are needed to motivate students and staff towards car pooling. Governments in some parts of the world are pursuing initiatives to motivate their public towards car pooling for a number of community and environmental benefits. A website following the example of eRideShare.com (http://www.erideshare.com/) could be established by Massey University to assist students and staff members to share cars. eRideShare.com is a free service for connecting commuters and travellers in America and Canada.

7.2.1.2.2 Fuel used by Massey University owned vehicles

Greenhouse gas emissions from the fuel used by Massey owned vehicles have apparently increased by more than 100% since 1990. The University vehicles used 57,552 litres of diesel and 237,284 litres of petrol during 2003-04 (Table 3.15). This resulted in overall GHG emissions of 751 Mg of CO_2e. In contrast, the total petrol and diesel consumed by the university vehicles in 1990 was 57,836 and 42,385 litres respectively (Annex 3.3), and this resulted in an emission of 264 Mg of CO_2e.

However, comparisons between 1990 and 2004 are complicated by a change in Massey University's vehicle policy. In 1990 most work-related staff vehicle use was in cars rented from a commercial rental firm (FLEETWISE, 2000). Massey University did own some vehicles in 1990, but these were mainly for use on farms or other special purposes. It was possible to obtain records of the fuel used by these Massey-owned vehicles in 1990, but it was not possible to obtain records of the rental car use. By 2004, Massey University had moved to a policy of leasing its own fleet of vehicles, and it was much easier to obtain records of fuel use. This does, however, mean that estimates of GHG emissions from vehicle use in 1990 were significantly under-estimated.

The emissions due to the fuel purchased by Massey University through the BP fuel card for the fleet of leased cars made up 78% of the total GHG emissions from purchased fuel in 2004, and almost 8% of the total emissions from road transport (Table 3.16). The equivalent emissions could not be included in the inventory for 1990 and this gives an idea of the scale of the likely underestimation of emissions in 1990.

To reduce the emissions in this category the University will need to reduce the fuel used in its vehicles. A possible option for this is to use more efficient vehicles. Hybrid cars, which use a small petrol engine and an electric motor, have higher fuel economy and their CO_2 emissions per kilometre travelled are lower than those of non-hybrids. Most of the vehicles owned by Massey University are petrol vehicles and more than 50% of the vehicles in the fleet have

an engine capacity of 1.8 litres. Replacing all Massey University's fleet vehicles (i.e. the vehicles using fuel through BP fuel cards) with the 1.5 litre hybrid vehicles could reduce the CO_2 emissions by up to 56% (Table 7.12). In this analysis the total distance travelled by the petrol and diesel vehicles in the current leased fleet was calculated from the total amount of fuel used and then the amount of fuel required to cover the same distance by the hybrid vehicles was calculated.

This scenario of using hybrid vehicles instead of the current fleet could potentially save Massey University around NZ$183,000 annually in fuel costs, provided the number of vehicles remains the same and the market prices of fuel (i.e. petrol @ $1.51/lit and diesel @ $1.07/lit) remain the same as when this analysis was completed. However, the lease cost of hybrid vehicles is likely to be considerably higher than for standard vehicles and this may reduce or eliminate the savings from decreased fuel use. The reduction in GHG emissions would, however, still remain.

Table 7.12: Comparison of fuel used and GHG emissions from the current fleet of leased vehicles at Massey University and predicted fuel used and GHG emissions from a fleet of the same total number of hybrid vehicles that are driven for the same distance. (Assuming fuel efficiencies of 12 km/litre and 10 km/litre for diesel and petrol vehicles in the current leased fleet and 22.7 km/litre for hybrid vehicles)[1]

Type of vehicles	Fuel consumed (l)		CO_2 emissions (kg)		N_2O emissions (kg)		CH_4 emissions (kg)		Total $CO_2e.$ (kg)	Fuel saving (lit)	
	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol		Diesel	Petrol
Standard	25,034	208,826	70,094.4	501,182.9	3	22	12	429	588,095		
Hybrid		105,228		252,546.2		11		216	260,441	2,5034	103,598

[1] Toyota N.Z. Customer Dialogue Centre, personal communication

7.2.1.3 Aviation

As discussed in Chapter 3, this sub-category included emissions from the aircraft belonging to the Massey School of Aviation's and from staff air travel. Because, there was no record of the fuel consumed by Massey School of Aviation aircraft in 1990, emissions for 1990 were calculated by assuming fuel consumed per year per aircraft was same as in 2004.

The GHG emissions from staff air travel in 2004 were 2,698 Mg of CO_2e. Emissions in this category were about 55% higher than 1990, but this estimated increase is purely dependent on the number of full time equivalent staff members in 1990 and 2004. As discussed in Chapter 3, no record could be found of air travel by Massey University staff in 1990. The emissions due to this category in 1990 were therefore assumed to be similar per FTE staff member in 1990 as in 2004.

These assumptions are likely to have overestimated the emissions in 1990 because greater internationalisation of the University over the last 15 years has probably resulted in more international travel for staff in 2004 than 1990. Also, a greater number of students in the Massey school of aviation might have increased the flying hours of each aircraft in 2004. No information was collected on how much of this air travel involved staff travelling to other Massey University campuses. Investment in improved electronic linkages between the campuses could possibly reduce travel for that reason.

7.2.1.4 Air Travel by international students

International students from more than 90 countries come to Massey University. The details of air travel by these international students were not available and therefore emissions from air travel by international students are not included in this inventory.

The estimated GHG emissions from an average return air trip between Palmerston North and Beijing are 2.2 Mg of CO_2e[4]. This is a much higher figure than the emissions caused by a student's daily commute to the campus in one year[5], which is about 0.5 Mg. Given the importance of air travel in total GHG emissions, it is suggested that Massey University should take the initiative through its International Students Office (ISO) of collecting data on international students' air travel and to include these emissions in future inventories.

Total number of international students at Massey University in 2004 was 6,216 (Massey University, 2005). If we assume that 50% of the international students visited their home countries in 2004, travelling an average distance equal to the distance between Palmerston North and Beijing total GHG emissions due to international students' air travel would be 6,838 Mg CO_2e. This is greater than the amount of GHG mitigated by the forestry sector at Massey in 2004, and is nearly equal to the total emissions from the agricultural sector. This makes the international students' air travel an important component of the University's GHG inventory.

7.2.2 Agricultural Sector

The agricultural sector contributes 26.2% of Massey University's total GHG emissions (Table 7.1). This sector is the second largest emitter and includes the emissions from enteric fermentation, manure management and agricultural soils and sports grounds. Emissions due to the energy used on the farms (i.e. electricity, diesel and petrol) are included in the energy sector (see Chapter 3).

There has been a considerable change in the agricultural emissions at Massey University since 1990. They have decreased from 8,067 Mg to 6,999 Mg (Table 7.5) - a decrease of more than 13%. The agricultural emissions at Massey University are mainly dependent on the number of animals kept on the farms.

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[4] This emission is based on air travel distance between Palmerton North and Beijing (Airtimetable.Com, 2006), and has been calculated by using the same method used for emission calculation from staff air travel (see Chapter 3 - section 3.2.4).

[5] This emission value is based on the average daily commute (14 km per return trip) by a student during the year, assuming a student attends the university in all working days (i.e.140 days according to Massey University's calendar), excluding summer vacations, term and study breaks.

The number of dairy and non-dairy (beef) animals has not changed significantly over the years, but the number of sheep on the Massey University farms has decreased by 29% since 1990.

The greatest contribution to GHG emissions from the agricultural sector was from enteric fermentation. Emissions due to chemical fertilisers were very low (9% of the total emissions from the agricultural sector). Therefore, any attempt to reduce GHG emissions from this sector will require attention to the management of animals on the different farms.

Increase in per animal production is a way to reduce the CH_4 emissions from ruminants on a "whole farm" basis (deKlein *et al.*, 2002). Although the production efficiency of the dairy cows at Massey University farms is already higher than the New Zealand national average (4,376 litres of milk/cow/year as compared to 3,660 litres/cow/year at national level (MfE, 2006)), it can still be improved further.

Other management practices, such as the substitution of cereal silage for fertiliser N-boosted pasture (deKlein *et al.* 2002), or the use of feed additives such as monensin (Vugt *et al.*, 2005) may have the potential to reduce agricultural GHG emissions. It is important however, when evaluating such management practices that a full GHG inventory of the whole production system is carried out as some practices (e.g. the purchase of supplementary feed grown off-farm) may simply transfer the GHG emissions to another farming property. Massey University may wish to take a lead in developing and demonstrating farming systems that have low GHG emissions per unit of production.

7.2.3 Waste Sector

The waste sector at Massey University produced 633±281 Mg of GHG in CO_2e in 2004 (Table 4.4). This is only 2.4% of the gross GHG emissions from the campus. There appears to have been a net reduction of about 44% in emissions in this sector since 1990. But this reduction is only an estimate because accurate data on waste production in 1990 were not available. It is interesting to note that

most of the estimated reduction in GHG emissions from waste originates from the major improvement in the gas collection system in the landfill operated by the Palmerston North City Council which has mitigated about 65% of the gross CH_4 produced at the solid waste disposal site in 2004 (Table 4.2).

The CH_4 generation potential (L_o) used in these calculations is based on the NZ national solid waste composition and volume with data taken from the published results of the NZ Solid Waste Analysis Protocol (MfE, 2002). A proper waste audit of Massey University waste is required to obtain the university-specific value of CH_4 generation potential. This will help in calculating more accurate emissions from the waste sector.

Although the available data from the campus shows a reduction in the waste produced per head from 2000-01 to 2003-04 (Fig.7.3), there is still considerable scope for further reducing the volumes of waste. A potential to increase the recycling rate for the kitchen/cafeteria and concourse areas respectively by 88% and 84% was identified by Mason (2001). An analysis of the quantity of waste collected from these areas since 2001 shows no apparent reduction in the waste quantity. The amount of general waste from the campus can also be further reduced by implementing proper recycling procedures.

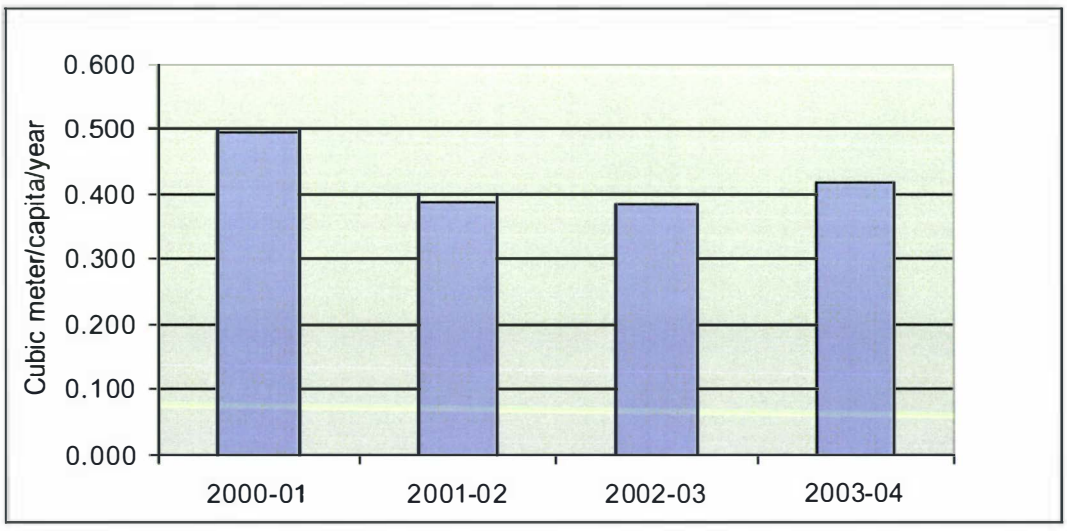

Figure 7.3: Solid waste produced at Massey University /head/yr

To facilitate improvements in this area the company dealing with the solid waste should be required to provide monthly figures of waste collected expressed both by volume and weight along with their invoice.

7.2.4 Forestry Sector

The forestry sector at Massey University removed about 4,094±439 Mg of CO_2 in 2004 (Table 7.1). Although the basic purpose of these plantations was not C sequestration, they can still be used to help Massey University reduce its net CO_2e emissions.

At the time of inventory in 2004, there was 109.7 hectares of forest owned by Massey University, of which 88.25 hectares had been planted since 1990. In the next 10 years it is expected that the forest estate will expand to cover 150 ha of land on the University farms (Geoff Warren, personal communication). This means that during the first commitment period of the Kyoto protocol, the University will have enough forests to mitigate the extra GHG emissions and keep the net emissions at a level equal to or lower than the level of 1990, provided there are no felling operations in these plantations and the energy requirements of the campus do not increase at an extraordinary rate.

As the farm forests reach maturity it is estimated that harvesting and replanting operations will take place on an area of 5-6 ha every year (Warren, 2004). This will add GHG emissions to the University's annual inventory and the total area in forests will need to increase by the same amount (5-6 ha each year) to maintain the same level of GHG mitigation. An alternative approach may be to establish plantations of trees with longer rotations and to establish plantations of native trees because they can retain high levels of C biomass under a wide range of environmental conditions (Hall, 2001).

7.3 STRATEGY TO REDUCE EMISSIONS

New Zealand ratified the Kyoto protocol on 19 December 2002, and the protocol entered into force on 16 February 2005. According to Section 1, Article 3 of the Kyoto protocol, the countries that have ratified the protocol are bound to ensure that their aggregate anthropogenic CO_2e emissions of GHGs do not exceed their assigned amounts, with a view to reducing their overall emissions of such gases by at least 5% below 1990 levels in the first commitment period 2008 to 2012 (UNFCCC, 2003). Otherwise they will have to take responsibility for any emissions above this level if they cannot meet their target.

In order to avoid any possible penalties imposed by the government or local authorities, Massey University should set its own targets for reducing GHG emissions in the future, like Tuft University which has decided to bring its GHG emissions 7% below 1990 levels by the year 2012 (Gloria, 2001).

As Fig. 7.1 shows, the maximum emissions are from the energy sector. This sector is also important in terms of increased emissions since 1990. Therefore, concentrated efforts are required to deal with this sector. The strategies to reduce the overall GHG emissions at Massey University require some technical innovations and a change in behaviour of the staff and students. The suggested points that can potentially improve this situation are summarised in Table 7.13.

A better understanding and awareness of environmental issues such as energy, waste management techniques, and the role of forestry can be provided by training. Campus level training programmes for students and staff could be arranged. Staff dealing with particular sectors should specifically be targeted and made aware of the amount of emissions from that sector and its contribution to the overall emissions from the university. Quotas for different energy uses can be allocated to different departments to encourage competition in reducing GHG emissions.

Table 7.13: Strategies for improvement

Sector	Technical Innovation	Behavioural Change
Electricity & Gas	• Building technology • Micro power generation	• Energy awareness • Publish energy budget
Commuting Vehicles		• Car pooling • Public transport
Campus Vehicles	• Hybrid vehicles- long distance • Electric vehicles- on campus	
Air Travel		• Use of electronic media • Charge carbon tax
Agriculture	• Improved feed quality	• Energy awareness
Waste	• Methane generators	• Recycling
Forestry	• Native trees	

7.4 SUGGESTIONS FOR FUTURE INVENTORIES

The following steps are suggested to improve the inventory of overall GHG emissions at Massey University:

- Creating this inventory of GHG emissions from Massey University has been hampered by the difficulty in obtaining accurate information/data. The main reason for this difficulty was the fragmented information recorded with differing methods and in varying places. It is therefore suggested that Massey University should establish a central office for collecting data related to GHG emissions from all sectors. Centralised control and management of data will increase the efficiency and accuracy of the estimates.

- Massey University should select a minimum number of suppliers for fuel, electricity and gas to avoid difficulties caused by differing recording methods. Alternatively, the university needs to consider a better system for recording information. A great deal of difficulty and delay was faced while collecting data on Massey University staff air travel. It is suggested that all staff members should book their domestic and international travel through the same travel agent, and the travel agent should be bound to supply all the travel itineraries showing nautical miles to be travelled in each journey.

The travel agent should be required to provide this information with the invoice to the University.

- To increase the accuracy of emission estimates, postgraduate students should be encouraged to carry out small projects to calculate emissions from the wide variety of sources on the campus. Farm managers should be asked to adopt a uniform system of recording animal data.

- A detailed waste audit is also required to calculate the percentage of different waste categories in the total waste stream. It will also help in calculating the specific value for the CH_4 generation potential for Massey University waste.

- Lastly, permanent sampling plots should be established in all the forest plantations at Massey University. Trees in those plots should be measured at least on a bi-annual basis to calculate the increased biomass in these plantations which is necessary to calculate the amount of C sequestered by these plantations.

7.5 CONCLUSIONS

- Most GHG emissions at Massey University are from the energy sector - therefore efforts are required to reduce/control emissions from this sector.

- Commuting vehicles form the largest single sub-sector and produce about 25% of the total gross GHG emissions from the University.

- The gross GHG emissions have increased by about 7.9% since 1990, but the net emissions from the campus and Massey farms are 8.6% below the 1990 baseline value. This is attributed to tree plantations, better waste management practices and a reduction in per capita energy consumption.

- It is possible to reduce annual GHG emissions still further through technical innovation, improved management and efficient use of resources.

- The uncertainty associated with the inventory can be reduced to some extent by better record keeping within the University, but much of the uncertainty is currently associated with parameters that need to be sourced from IPCC and national inventories. It can be expected that the uncertainties associated with these parameters will decrease over time as more research is carried out.

- The establishment of forest plantations provides a key channel for the University to communicate its environmental performance and its commitment to the principles of sustainability.

- Massey University is committed to the principles of environmental responsibility and sustainable resource management at local, national and international levels. This inventory can be helpful in preparing any future environmental plans and fulfilling the objectives set by Massey University in its environmental mission statement. The university can also develop a system of environmental management accountability, and be prepared for

compliance with any possible environmental and safety regulations which the central Government or the local authorities may introduce in future.

- The final outcome of the GHG emissions inventory is not only affected by the policies of an individual institute. The policies of other agencies and organizations working in the area can also make a big difference. For example, as discussed in Chapter 4, emissions from Massey University's waste were considerably reduced in 2004 due to the gas collection system installed by the Palmerston North City Council at its waste disposal facility. Also, the free bus service supported in part by the local regional council (Horizons Regional Council) is also helping in reducing emissions from the commuting traffic to Massey University. Similarly, if the electricity supply company is generating electricity with wind power, it can play an important role in reducing the levels of GHG emissions.

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Massey Vehicle List

Institute of Technology & Engineering

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2122	10LWO	MASSEY FERG. TRACTOR	TRACTOR	83	D	
2122	P8067	MASSEY FERG. TRACTOR	TRACTOR	93	D	4070

Institute of Natural Resources

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2125	RX6511	TOYOTA HILUX 2.8 UTILITY	UTE	93	D	2779
2125	-	WESTWOOD MOWER	MOWER	88	P	
2125	RA834	TOYOTA HILUX D/CAB	UTE	91	D	2400
2125	89SHH	SUZUKI MOTORCYCLE	QUAD	91	P	250
2125	35SWE	SUZUKI QUAD MOTORCYCLE	QUAD	94	P	250
2125	78SYG	SUZUKI QUAD MOTORCYCLE	QUAD	93	P	250
2125	RT7359	TOYOTA MINIBUS	MINIBUS	93	P	2400
2125	-	KUBOTA TRACTOR	TRACTOR	91	D	
2125	PE3261	TOYOTA HIACE	VAN	90	P	2430
2125	TU1142	TOYOTA CAMRY	S/WAGON	95	P	2164
2125	YY9359	TOYOTA HILUX 2.7P UTILITY	UTE	00	P	2694
2125	ZI9007	TOYOTA HILUX D/C UTE	UTE	00	D	2986
2125	37UMT	SUZUKI MOTORCYCLE	QUAD	01	P	250
2125	AEE906	TOYOTA HILUX UTE	UTE	01	D	2986

Institute of Veterinary, Animal & Biomedical Sciences

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2126	-	KOMATSU FORKLIFT	FORKLIFT		P	
2126	78TOM	SUZUKI MOTORCYCLE	QUAD	89	P	250
2126	YC5135	TOYOTA HIACE MINIBUS	MINIBUS	99	P	2438
2126	YC5134	TOYOTA HIACE MINIBUS	MINIBUS	99	P	2438
2126	UA6059	MITSUBISHI L200 4WD	UTE	96	D	2500

School of People, Environment & Planning

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2545	UE4081	FORD TRANSIT	MINIBUS	96	D	2500

Veterinary Clinic & Teaching Hospital

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2693	77KTL	FORD TRACTOR				
2693	4SXR	KAWASAKI MOTORCYCLE	QUAD	94	P	300
2693	-	KAWASAKI MOTORCYCLE	QUAD	96	P	300
2693	WM8355	HOLDEN RODEO UTILITY	UTE	97	D	2771
2693	AME602	HOLDEN RODEO 4WD	UTE	02	D	3000
2693	WX5940	HOLDEN RODEO UTILITY	UTE	98	D	2800

2693	WY1262	HOLDEN RODEO UTILITY	UTE	98	D	2800
2693	XU6290	HOLDEN RODEO UTILITY	UTE	99	P	3165
2693	87ULF	SUZUKI MOTORCYCLE	QUAD	01	P	250
2693	AAQ417	TOYOTA CAMRY WAGON	S/WAGON	01	P	2200
2693	ZM1205	TOYOTA HIACE MINIBUS	MINIBUS	00	P	2438
2693	87ULF	SUZUKI MOTORCYCLE	QUAD	01	P	250
2693	ALG760	MITSUBISHI L200 TRITON	UTE	02	D	2835
2693	AAQ417	TOYOTA CAMRY WAGON	S/WAGON	01	P	2200

Information Technology Services

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
9309	PT3810	TOYOTA CORONA WAGON	S/WAGON	91	P	1998
9309	WL9713	TOYOTA HIACE MINIBUS	MINIBUS	97	P	2438

Regional Facilities Management

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2326	19SBB	HONDA MOTORCYCLE	CYCLE	90	P	80
2326	RN3037	SUZUKI CARRY VAN	VAN	92	P	970
2326	XL6586	MAZDA E2000 VAN	VAN	98	P	2000
2326	XM3081	FORD ECONOVAN	VAN	98	P	1998
2326	WE5736	MITSUBISHI L300 4X4	VAN	97	P	2351
2326	XX4636	FORD ECONOVAN	VAN	99	P	1998
2326	YF1425	MAZDA E2000 VAN	VAN	99	P	1998
2326	ABG347	MITSUBISHI L300 VAN	VAN	01	P	2351
2326	ABG348	MITSUBISHI L300 VAN	VAN	01	P	2351
2326	ARP486	MITSUBISHI L300 VAN	VAN	02	P	2400
2326	SD9443	TOYOTA MINIBUS	MINIBUS	93	P	2438
2326	SJ6849	MITSUBISHI L300 VAN	VAN	94	P	2351
2326	UN2316	FORD TRANSIT VAN	VAN	96	D	2500
2326	WO1301	FORD ECONOVAN	VAN	97	P	1998
2326	WW1963	ISUZU TRUCK	TRUCK	98	D	4334
2326	AQE939	HOLDEN CALAIS	CAR	02	P	5700

Grounds

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2329	791ET	MASSEY FERG. TRACTOR	TRACTOR	63	P	2187
2329	833OA	MASSEY FERG. TRACTOR	TRACTOR	66	P	2100
2329	922OA	MASSEY FERG. TRACTOR	TRACTOR	66	P	2500
2329	F4495	MASSEY FERG. TRACTOR	TRACTOR	90	D	3860
2329	-	TORO MOWER	MOWER	02	D	
2329	-	RANSOME MOWER	MOWER	91		
2329	-	WALKER MOWER	MOWER	94		
2329	-	RANSOMES MOWER	MOWER	95		
2329	WE2654	JOHN DEERE GATOR	TRACTOR	97	P	617
2329	39TZU	JOHN DEERE GATOR	TRACTOR	99	D	
2329	-	WALKER LAWNMOWER	MOWER	88		
2329	-	POWER PONY	MOWER	88		
2329	26PDY	POWER PONY	MOWER	85	P	656
2329	-	RANSOMES MOWER	MOWER	89	P	

2329	27DWE	FORD TRACTOR	TRACTOR	76		
2329	-	TORO MOWER	MOWER	91	D	

Physical Resources

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
1324	47TIK	HONDA MOTORCYCLE	QUAD	96	P	300
1324	WF9478	FORD ECONOVAN	VAN	97	P	1998
1324	WY5787	TOYOTA HIACE VAN	VAN	98	P	2438

Regional Facilities Management - Central Store

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
6633	JT4316	DATSUN FORKLIFT	FORKLIFT	80	P	

Printery

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
9637	-	KOMATSU FORKLIFT				
9637	AAC777	SUZUKI VAN	VAN	01	P	1300

Institute for Professional Development & Educational Research

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
1663		HONDA JAZZ	RV	02	P	1300
1663		HONDA JAZZ	RV	02	P	1300
1663	BQU291	HONDA JAZZ	RV	03	P	1300

Animal Health Services Centre

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2690	SQ7498	NISSAN NAVARA	UTE	87	D	2289
2690	WG1786	HYUNDAI WAGON	S/WAGON	97	P	1600
2690	XM1963	TOYOTA HILUX UTILITY	UTE	98	D	2800
2690	YL7338	TOYOTA HILUX UTILITY	UTE	99	D	2986
2690	99UCD	HONDA MOTORCYCLE	QUAD	99	P	300
2690	97SNR	ISEKI TRACTOR	TRACTOR	80	D	1500
2690	RX6738	TOYOTA HILUX UTILITY	UTE	93	D	2779

Poultry Research Unit

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2694	ER8978	COMMER TRUCK	TRUCK	64	P	2266
2694	-	GRAVELLY TRACTOR	TRACTOR	73		
2694	-	POWER PONY	MOWER	79	P	

Feed Processing Unit

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2695	-	UNIVERSAL TRACTOR	TRACTOR	80		

School of Aviation

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2790	RR2325	TOYOTA HIACE MINIBUS	MINIBUS			
2790	-	TRACTOR	TRACTOR		P	

AFS Catering

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
AFS	TE9396	SUZUKI VAN	VAN	95	P	970
AFS	OG4403	SUZUKI VAN	VAN	89	P	1000
AFS	SO4589	SUZUKI VAN	VAN	94	P	1994

Recreation & Sports Centre

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2798	WD6583	TOYOTA HIACE (1991)	VAN	97	P	2779

Fleet Management

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2336	ASG955	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASR188	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASC953	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASC115	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASC111	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASG941	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASR185	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASG949	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASC112	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASG948	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASC114	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASC106	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASG944	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASG950	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASG946	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASC110	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASG952	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASR194	TOYOTA CAMRY WAGON	S/WAGON	02	P	

2336	ASR193	TOYOTA CAMRY WAGON	S/WAGON	02	P	
2336	ASR189	TOYOTA CAMRY WAGON	S/WAGON	02	P	
2336	ASR236	TOYOTA HIACE MINIBUS	MINIBUS	02	P	
2336	ASG945	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASG947	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASR182	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASG957	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASG960	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASC107	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASC108	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASC109	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASC116	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASC104	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASC113	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASR186	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASG951	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASC119	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASC118	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASG942	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASG954	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASG943	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASR184	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASC120	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ASC105	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	APA351	MITSUBISHI L300 VAN	VAN	02	P	
2336	ASR226	TOYOTA CAMRY WAGON	S/WAGON	02	P	
2336	AQW201	TOYOTA HILUX D/C UTE	UTE	02	P	
2336	ASR191	TOYOTA CAMRY WAGON	S/WAGON	02	P	
2336	ASR195	TOYOTA CAMRY WAGON	S/WAGON	02	P	
2336	ASR190	TOYOTA CAMRY WAGON	S/WAGON	02	P	
2336	ASR192	TOYOTA CAMRY WAGON	S/WAGON	02	P	
2336	ASR198	TOYOTA COROLLA WAGON	S/WAGON	02	P	
2336	AST271	TOYOTA COROLLA WAGON	S/WAGON	02	P	
2336	ASR181	TOYOTA COROLLA WAGON	S/WAGON	02	P	

2336	ASG956	TOYOTA COROLLA WAGON	S/WAGON	02	P	
2336	ASR183	TOYOTA COROLLA WAGON	S/WAGON	02	P	
2336	ASG958	TOYOTA COROLLA WAGON	S/WAGON	02	P	
2336	ASR187	TOYOTA CAMRY SEDAN	CAR	02	P	
2336	ZU5219	MAZDA 626 SEDAN	CAR	02	P	
2336	AST262	TOYOTA COROLLA WAGON	S/WAGON	02	P	
2336	ASG959	TOYOTA COROLLA WAGON	S/WAGON	02	P	
2336	ASG117	TOYOTA COROLLA WAGON	S/WAGON	02	P	
2336	ASR199	TOYOTA COROLLA WAGON	S/WAGON	02	P	
2336	AST270	TOYOTA COROLLA WAGON	S/WAGON	02	P	
2336	ATH805	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ATH806	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ATH807	TOYOTA COROLLA HATCH	HATCH	02	P	
2336	ATH810	TOYOTA COROLLA WAGON	S/WAGON	02	P	
2336	ATH811	TOYOTA COROLLA WAGON	S/WAGON	02	P	

Agricultural Services

Sheep & Beef Keebles

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2910	45KSU	FORD TRACTOR	TRACTOR	82	D	3294
2910	11RPM	SUZUKI MOTORCYCLE	CYCLE	88	P	125
2910	20SNS	YAMAHA MOTORCYCLE	QUAD	92	P	250
2910	TI8504	MITSUBISHI L200 UTILITY	UTE	95	P	1997
2910	38UCA	HONDA MOTORCYCLE	QUAD	99	P	300
2910	82UHI	YAMAHA QUAD BIKE	QUAD	00	P	400
2910	72UQW	SUZUKI MOTORCYCLE	CYCLE	02	P	125
2910	66UMQ	YAMAHA MOTORCYCLE	QUAD	01	P	400
2910	67UMQ	YAMAHA MOTORCYCLE	QUAD	01	P	400

Dairy Cattle Unit

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2932	60PPG	FORD TRACTOR	TRACTOR	87	D	
2932	81UHI	YAMAHA QUAD BIKE	QUAD	00	P	400

No. 4 Dairy Farm

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2930	7SCR	SUZUKI MOTORCYCLE	CYCLE	90	P	125
2930	54SNQ	JOHN DEERE TRACTOR	TRACTOR	91	D	2250

2930	RL1968	TOYOTA HILUX	UTE	92	P	1812
2930	55SNQ	HONDA MOTORCYCLE	CYCLE	92	P	125
2930	84SZL	SUZUKI MOTORCYCLE	CYCLE	94	P	125
2930	5SXR	SUZUKI MOTORCYCLE	CYCLE	94	P	125
2930	54TMH	SUZUKI MOTORCYCLE	CYCLE	96	P	125
2930	53TMH	SUZUKI MOTORCYCLE	CYCLE	96	P	125
2930	98UCD	JOHN DEERE TRACTOR	TRACTOR	99	D	4530
2930	13UIF	JOHN DEERE TRACTOR	TRACTOR	00	D	4500
2930	26UIS	SUZUKI MOTORCYCLE	CYCLE	00	P	125

Tuapaka Farm

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2912	33USN	YAMAHA MOTORCYCLE	QUAD	02	P	660
2912	AEB704	FORD COURIER UTE	UTE	01	D	2499

Pasture & Crop Research Unit

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2958	1MJK	KUBOTA TRACTOR	TRACTOR	83	D	2598
2958	62PKK	YAMAHA MOTORCYCLE				

Dry Stock Unit

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2954	525QT	MASSEY FERG. TRACTOR	TRACTOR	71	D	2490
2954	RX6697	FORD COURIER				

Riverside Farm

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2918	TA3354	TOYOTA HILUX UTILITY	UTE	94	D	2800
2918	41TIA	JOHN DEERE TRACTOR	TRACTOR	97	D	3900
2918	34USN	YAMAHA MOTORCYCLE	QUAD	02	P	660
2918	61USP	YAMAHA MOTORCYCLE	QUAD	02	P	660
2918	-	ALLIS CHAL. BULLDOZER	BULLDOZER	78		
2918	ADK558	FORD COURIER UTE	UTE	01	D	2745

Drainage Extension Service

UNIT	REG NO	DESCRIPTION	TYPE	YEAR	FUEL	CC
2979	SX1016	NISSAN NAVARA 4WD	UTE	89	D	2289
2979	-	SAME BULLDOZER	BULLDOZER'88		D	
2979	NY212	TOYOTA HILUX	UTE	88	D	2446
2979	-	VERTI-DRAIN		90		
2979	-	BARTH DRNG. MACHINE		94		
2979	91TLM	JOHN DEERE TRACTOR	TRACTOR	96	D	3920
2979	77TOM	JCB TRACTOR	TRACTOR	97	D	3999
2979	WM1083	TOYOTA HILUX	UTE	97	D	2779
2979	AEB439	FORD FALCON UTE	UTE	01	P	4984

Fuel purchased by Massey vehicles through BP fuel card

	Time Period	Fuel Used in litres	
		Diesel	Petrol
1	29June03 to 29July03	1813.58	14521.69
2	30July03 to 27Aug03	1900.7	19414.27
3	28Aug03 to 28Sep03	1851.9	20731.5
4	29Sep03 to 29Oct03	2095.82	17949.47
5	30Oct03 to 26Nov03	2015.83	17495.25
6	27Nov03 to 27Dec03	1845.24	14387.8
7	28Dec03 to 28Jan04	962.59	8325.28
8	29Jan04 to 25Feb04	1499.16	13957.85
9	26Feb04 to 29Mar04	2669.92	20356.22
10	30Mar04 to 28Apr04	2882.71	17172.52
11	29Apr04 to 29May04	2871.68	22456.95
12	30May04 to 28June04	2624.57	22057.44
	Total	25033.7	208826.2

Fuel supplied by Shell New Zealand in 1990

Department	Type of fuel	Quantity (lit)	Supply date
MASSEY DRAINAGE EXTN UNIT	SHELL DIESOLINE	1040	6/12/1990
MASSEY PLANT PHYSIOLOGY D	SHELL DIESOLINE	295	6/12/1990
MASSEY AGRONOMY DEPT	SHELL DIESOLINE	1800	6/12/1990
KEEBLES FARM *MA	SHELL DIESOLINE	600	6/12/1990
MASSEY SHEEP & BEEF	SHELL DIESOLINE	380	14/12/1990
MASSEY N03 DAIRY UNIT	SHELL DIESOLINE	400	21/12/1990
MASSEY FRUIT CROPS UNIT	SHELL DIESOLINE	200	6/12/1990
MASSEY FRUIT CROPS UNIT	SHELL DIESOLINE	210	8/11/1990
KEEBLES FARM *MA	SHELL DIESOLINE	700	8/11/1990
MASSEY AGRONOMY DEPT	SHELL DIESOLINE	3073	8/11/1990
MASSEY VETERINARY CLINIC	SHELL DIESOLINE	270	1/11/1990
MASSEY DRAINAGE EXTN UNIT	SHELL DIESOLINE	1160	8/11/1990
MASSEY N01 DAIRY UNIT	SHELL DIESOLINE	406	20/11/1990
MASSEY PLANT PHYSIOLOGY D	SHELL DIESOLINE	235	15/10/1990
MASSEY N03 DAIRY UNIT	SHELL DIESOLINE	250	15/10/1990
MASSEY AGRONOMY DEPT	SHELL DIESOLINE	3200	10/10/1990
MASSEY DRAINAGE EXTN UNIT	SHELL DIESOLINE	1700	10/10/1990
KEEBLES FARM *MA	SHELL DIESOLINE	1800	15/10/1990
MASSEY FRUIT CROPS UNIT	SHELL DIESOLINE	210	15/10/1990
MASSEY SHEEP & BEEF	SHELL DIESOLINE	400	21/09/1990
MASSEY FRUIT CROPS UNIT	SHELL DIESOLINE	400	21/09/1990
MASSEY FEED PROCESSING UN	SHELL DIESOLINE	500	25/09/1990
MASSEY FRUIT CROPS UNIT	SHELL DIESOLINE	140	8/08/1990
MASSEY N01 DAIRY UNIT	SHELL DIESOLINE	350	30/08/1990
MASSEY DRAINAGE EXTN UNIT	SHELL DIESOLINE	125	8/08/1990
MASSEY SHEEP & BEEF	SHELL DIESOLINE	220	25/07/1990
MASSEY PLANT PHYSIOLOGY D	SHELL DIESOLINE	165	12/07/1990
MASSEY N01 DAIRY UNIT	SHELL DIESOLINE	394	6/07/1990
MASSEY AGRONOMY DEPT	SHELL DIESOLINE	700	12/07/1990
KEEBLES FARM *MA	SHELL DIESOLINE	500	12/07/1990
MASSEY FRUIT CROPS UNIT	SHELL DIESOLINE	85	12/07/1990
MASSEY DRAINAGE EXTN UNIT	SHELL DIESOLINE	720	12/07/1990
MASSEY AGRONOMY DEPT	SHELL DIESOLINE	615	25/01/1990
KEEBLES FARM *MA	SHELL DIESOLINE	1170	16/01/1990
MASSEY N01 DAIRY UNIT	SHELL DIESOLINE	390	7/01/1990
MASSEY FRUIT CROPS UNIT	SHELL DIESOLINE	240	7/01/1990
MASSEY DRAINAGE EXTN UNIT	SHELL DIESOLINE	900	16/01/1990
MASSEY PLANT PHYSIOLOGY D	SHELL DIESOLINE	532	7/01/1990
MASSEY SHEEP & BEEF	SHELL DIESOLINE	400	23/02/1990
MASSEY N03 DAIRY UNIT	SHELL DIESOLINE	250	23/02/1990
MASSEY AGRONOMY DEPT	SHELL DIESOLINE	900	23/02/1990
KEEBLES FARM *MA	SHELL DIESOLINE	560	23/02/1990
MASSEY DRAINAGE EXTN UNIT	SHELL DIESOLINE	1700	23/02/1990
MASSEY AGRONOMY DEPT	SHELL DIESOLINE	900	22/03/1990
MASSEY FRUIT CROPS UNIT	SHELL DIESOLINE	440	22/03/1990
MASSEY PLANT PHYSIOLOGY D	SHELL DIESOLINE	340	22/03/1990
KEEBLES FARM *MA	SHELL DIESOLINE	240	22/03/1990
MASSEY AGRONOMY DEPT	SHELL DIESOLINE	1149	13/03/1990
MASSEY SHEEP & BEEF	SHELL DIESOLINE	285	18/04/1990

MASSEY FRUIT CROPS UNIT	SHELL DIESOLINE	130	18/04/1990
MASSEY N01 DAIRY UNIT	SHELL DIESOLINE	280	18/04/1990
MASSEY DRAINAGE EXTN UNIT	SHELL DIESOLINE	1900	18/04/1990
MASSEY AGRONOMY DEPT	SHELL DIESOLINE	1200	18/04/1990
KEEBLES FARM *MA	SHELL DIESOLINE	915	18/04/1990
MASSEY N03 DAIRY UNIT	SHELL DIESOLINE	300	18/04/1990
MASSEY AGRONOMY DEPT	SHELL DIESOLINE	-1149	4/04/1990
MASSEY VETERINARY CLINIC	SHELL DIESOLINE	453	29/05/1990
MASSEY FRUIT CROPS UNIT	SHELL DIESOLINE	150	16/05/1990
MASSEY DRAINAGE EXTN UNIT	SHELL DIESOLINE	800	16/05/1990
MASSEY AGRONOMY DEPT	SHELL DIESOLINE	700	16/05/1990
KEEBLES FARM *MA	SHELL DIESOLINE	400	16/05/1990
MASSEY PLANT PHYSIOLOGY D	SHELL DIESOLINE	150	16/05/1990
MASSEY AGRICULTURE ENGINE	SHELL DIESOLINE	157	21/06/1990
KEEBLES FARM *MA	SHELL DIESOLINE	445	11/06/1990
MASSEY DRAINAGE EXTN UNIT	SHELL DIESOLINE	600	11/06/1990
MASSEY AGRONOMY DEPT	SHELL DIESOLINE	700	11/06/1990
MASSEY FRUIT CROPS UNIT	SHELL DIESOLINE	190	11/06/1990
MASSEY UNIVERSITY TUAPAKA	SHELL DIESOLINE	200	26/06/1990
MASSEY N03 DAIRY UNIT	SHELL DIESOLINE	225	26/06/1990
MASSEY UNIVERSITY TUAPAKA	SUPERSHELL MOTOR SPT	200	27/12/1990
MASSEY UNIVERSITY W/S GEN	SUPERSHELL MOTOR SPT	3000	17/12/1990
MASSEY UNIVERSITY W/S GEN	SUPERSHELL MOTOR SPT	2200	30/11/1990
MASSEY UNIVERSITY W/S GEN	SUPERSHELL MOTOR SPT	1600	31/12/1990
MASSEY UNIVERSITY W/S GEN	SUPERSHELL MOTOR SPT	2950	13/11/1990
MASSEY UNIVERSITY W/S GEN	SUPERSHELL MOTOR SPT	2000	3/10/1990
MASSEY UNIVERSITY W/S GEN	SUPERSHELL MOTOR SPT	3669	25/10/1990
MASSEY UNIVERSITY W/S GEN	SUPERSHELL MOTOR SPT	2000	19/09/1990
MASSEY UNIVERSITY W/S GEN	SUPERSHELL MOTOR SPT	2000	5/09/1990
MASSEY UNIVERSITY W/S GEN	SUPERSHELL MOTOR SPT	2000	23/08/1990
MASSEY UNIVERSITY W/S GEN	SUPERSHELL MOTOR SPT	2000	8/08/1990
MASSEY UNIVERSITY W/S GEN	SUPERSHELL MOTOR SPT	1700	11/07/1990
MASSEY UNIVERSITY W/S GEN	SUPERSHELL MOTOR SPT	2400	25/07/1990
MASSEY UNIVERSITY CENTRAL	SUPERSHELL MOTOR SPT	3576	25/01/1990
MASSEY UNIVERSITY TUAPAKA	SUPERSHELL MOTOR SPT	315	22/01/1990
MASSEY UNIVERSITY CENTRAL	SUPERSHELL MOTOR SPT	3400	15/02/1990
MASSEY UNIVERSITY CENTRAL	SUPERSHELL MOTOR SPT	3200	22/03/1990
MASSEY UNIVERSITY CENTRAL	SUPERSHELL MOTOR SPT	505	21/03/1990
MASSEY UNIVERSITY TUAPAKA	SUPERSHELL MOTOR SPT	600	27/03/1990
MASSEY UNIVERSITY CENTRAL	SUPERSHELL MOTOR SPT	3400	2/03/1990
MASSEY UNIVERSITY CENTRAL	SUPERSHELL MOTOR SPT	2800	4/04/1990
MASSEY UNIVERSITY W/S GEN	SUPERSHELL MOTOR SPT	2135	18/04/1990
MASSEY UNIVERSITY W/S GEN	SUPERSHELL MOTOR SPT	1700	27/04/1990
MASSEY UNIVERSITY W/S GEN	SUPERSHELL MOTOR SPT	2266	30/05/1990
MASSEY UNIVERSITY W/S GEN	SUPERSHELL MOTOR SPT	2000	14/05/1990
MASSEY UNIVERSITY W/S GEN	SUPERSHELL MOTOR SPT	2300	27/06/1990
MASSEY UNIVERSITY W/S GEN	SUPERSHELL MOTOR SPT	1900	13/06/1990
MASSEY UNIV * CENT MTCE S	SHELL LITE	20	24/01/1990

Total Beef 2003-04

	Breeding					Slaughter Animals					
	Cows	Females	Females	Females	Bulls	Heifers		Steers		Bulls	
		<1 year	1-2 Years	2-3 Years		0-1 Year	1-2 Years	0-1 Year	1-2 Years	0-1 Year	1-2 Years
July	313	0	0	0	10	64	0	59	94	324	155
Aug	292	0	0	0	10	64	0	59	94	286	135
Sept	286	0	0	0	10	64	0	58	94	285	135
Oct	283	0	0	0	10	64	0	58	94	285	135
Nov	276	0	0	0	10	64	0	58	93	285	129
Dec	276	0	0	0	10	64	0	58	93	285	72
Jan	276	0	0	0	9	64	0	58	56	283	72
Feb	276	0	0	0	9	64	0	58	56	227	7
Mar	276	0	0	0	9	64	0	58	56	398	109
Apr	276	0	0	0	9	58	0	102	10	398	107
May	253	0	0	0	9	92	77	102	14	398	106
Jun	253	0	0	0	7	92	77	102	14	398	106

Total Dairy 2003-04

	Milking cows & heifers	Growing females 1-2 years old	Bulls	Growing females <1
July	868	252	21	17
Aug	860	249	11	62
Sep	836	247	17	68
Oct	834	245	14	59
Nov	820	220	18	59
Dec	819	216	18	59
Jan	818	214	16	59
Feb	813	214	16	59
Mar	770	181	14	77
Apr	770	181	14	100
May	743	181	14	101
Jun	734	181	14	147

Total Sheep 2003-04

	Rams	Ewes-breeding	Ewes dry	Two tooth breeding	Two tooth dry	Ewes hoggets breeding	Ewes hoggets dry	Ram hoggets	Wether hoggets	Wethers	Lambs
Jul	165	5949		1976		2352		262			0
Aug	177	5861		1909		2262		279			79
Sep	173	5778		1903		2191		217			1649
Oct	173	5702		1898		2177		202			7148
Nov	173	5678		1893		2131		202			7409
Dec	177	5374		1919		2129		200			6277
Jan	183	6860		1978		2058		194			3532
Feb	194	6251		2002		2056		192			2296
Mar	193	5673		2001		1906		188			1748
Apr	198	5700		1982		1881		231			1104
May	262	5832		2140		2267		230			305
Jun	212	5597		1974		2238		253			51

Deer- 2003-04

	Hinds			Stags			
	Breeding	<1yr	1-2yr	<1yr	1-2yr	2-3yr	Mixed age breeding
Jul	79	39	7	33			6
Aug	92	39	7	33			5
Sep	82	39	7	33			5
Oct	82	39	7	33			5
Nov	81	0	27	7			5
Dec	80	0	27	7			5
Jan	87	0	20	6			6
Feb	87	0	20	6			6
Mar	87	0	19	6			6
Apr	87	0	19	6			6
May	106	0	0	6			6
Jun	104	0	0	6			6

Total Beef 1989-90

	Breeding					Slaughter Animals					
	Cows	Females	Females	Females	Bulls	Heifers		Steers		Bulls	
		<1 year	1-2 Years	2-3 Years		0-1 Year	1-2 Years	0-1 Year	1-2 Years	0-1 Year	1-2 Years
July	0	0	0	0	0	44	41	21	0	648	310
Aug	0	0	0	0	0	0	0	21	0	580	309
Sept	0	0	0	0	0	0	0	21	0	578	307
Oct	0	0	0	0	0	0	0	21	0	505	794
Nov	0	0	0	0	0	0	0	21	0	842	865
Dec	50	0	0	0	0	0	0	30	1	724	798
Jan	50	0	0	0	0	0	0	10	1	827	718
Feb	50	0	0	0	0	0	0	10	1	914	350
Mar	50	0	0	0	0	0	0	10	1	934	212
Apr	50	0	0	0	0	0	0	10	1	953	282
May	50	0	0	0	0	0	0	10	1	600	309
Jun	50	0	0	0	0	0	101	10	1	675	177

Total Dairy 1989-90

	Milking cows & heifers	Growing females 1-2 years old	Bulls	Growing females <1
July	709	35	4	130
Aug	704	35	4	130
Sep	771	39	3	158
Oct	705	39	16	158
Nov	705	39	16	158
Dec	685	39	16	158
Jan	670	39	17	158
Feb	691	39	17	158
Mar	636	79	4	136
Apr	603	59	4	136
May	606	145	4	68
Jun	602	145	10	68

Total Sheep 1989-90

	Rams	Ewes-breeding	Ewes dry	Two tooth breeding	Two tooth dry	Ewes hoggets breeding	Ewes hoggets dry	Ram hoggets	Wether hoggets	Wethers	Lambs
Jul	185	9689		2180		3055		667			0
Aug	147	8980		1897		3205		319			0
Sep	147	8980		1897		3205		319			13161
Oct	147	8980		1897		3205		319			13030
Nov	147	8980		1897		3205		319			12899
Dec	147	8980		1897		3234		319			12770
Jan	185	8980		2119		2981		305			12643
Feb	185	8980		2119		2981		305			12516
Mar	185	8980		2119		2981		305			19
Apr	185	8980		2119		2981		305			19
May	185	8980		2119		2981		305			19
Jun	185	8980		2119		2981		305			19

Deer- 1989-90

	Hinds			Stags			
	Breeding	<1yr	1-2yr	<1yr	1-2yr	2-3yr	Mixed age breeding
Jul	57	19		25	14		
Aug	57	19		25	14		
Sep	57	19		25	14		
Oct	57	19		25	14		
Nov	54	19		22	14		
Dec	54	19		22	14		
Jan	54	18		22	12		
Feb	54	18		22	12		
Mar	54	18		22	12		
Apr	54	18		22	12		
May	54	18		22	12		
Jun	54	18		22	12		

@RISK Summary Report

General Information

Workbook Name	Massey Beef 1990.xls
Number of Simulations	1
Number of Iterations	5000
Number of Inputs	4
Number of Outputs	2
Sampling Type	Latin Hypercube
Simulation Start Time	3/9/06 13:28:51
Simulation Stop Time	3/9/06 13:28:55
Simulation Duration	0:00:04
Random Seed	400727380

Output and Input Summary Statistics

Output Name	**Worksheet**	**Simulation#**	**Minimum**	**Maximum**	**Mean**	**Std Dev**
Intake producing CH4	**Intake & CH4**	**1**	2313.490479	4005.558594	3074.993362	228.7658817
Total methane	**Intake & CH4**	**1**	26.2162323	106.6405792	61.48132702	14.50417803
Input Name	**Worksheet**	**Simulation#**	**Minimum**	**Maximum**	**Mean**	**Std Dev**
Population uncertainty	**Methane uncertainties**	**1**	0.981857896	1.01837647	0.999999865	0.004999365
Energy requirement uncertainty	**Methane uncertainties**	**1**	0.817803144	1.204211712	1.00000564	0.050002875
Feed energy uncertainty	**Methane uncertainties**	**1**	0.813810468	1.179399371	0.999999217	0.049993429
Methane factor uncertainty	**Methane uncertainties**	**1**	0.500508964	1.499381065	1.000000826	0.224378683

@RISK Summary Report

General Information

Workbook Name	Massey Beef 2004.xls
Number of Simulations	1
Number of Iterations	5000
Number of Inputs	4
Number of Outputs	2
Sampling Type	Latin Hypercube
Simulation Start Time	3/6/06 9:52:35
Simulation Stop Time	3/6/06 9:52:38
Simulation Duration	0:00:03
Random Seed	420154180

Output and Input Summary Statistics

Output Name	Worksheet	Simulation#	Minimum	Maximum	Mean	Std Dev
Intake producing CH4	**Intake & CH4**	**1**	1631.018066	2932.507568	2215.971344	164.5678095
Total methane	**Intake & CH4**	**1**	18.76374245	84.75872803	44.32284464	10.49988369
Input Name	**Worksheet**	**Simulation#**	**Minimum**	**Maximum**	**Mean**	**Std Dev**
Population uncertainty	**Methane uncertainties**	**1**	0.980343401	1.018522739	0.999999739	0.005000509
Energy requirement uncertainty	**Methane uncertainties**	**1**	0.786491454	1.179230928	0.999992967	0.050020502
Feed energy uncertainty	**Methane uncertainties**	**1**	0.81056881	1.191178441	1.000000229	0.050002229
Methane factor uncertainty	**Methane uncertainties**	**1**	0.500739574	1.49939847	0.999999195	0.224377094

@RISK Summary Report

General Information

Workbook Name	Massey Dairy 1990.xls
Number of Simulations	1
Number of Iterations	5000
Number of Inputs	4
Number of Outputs	2
Sampling Type	Latin Hypercube
Simulation Start Time	3/9/06 13:31:30
Simulation Stop Time	3/9/06 13:31:33
Simulation Duration	0:00:03
Random Seed	971961936

Output and Input Summary Statistics

Output Name	Worksheet	Simulation#	Minimum	Maximum	Mean	Std Dev
Total intake	TOTAL METHANE	1	2118.775391	3620.427002	2822.801435	199.1364819
Total methane	TOTAL METHANE	1	27.17238617	104.2003403	60.99591377	14.47382377
Input Name	**Worksheet**	**Simulation#**	**Minimum**	**Maximum**	**Mean**	**Std Dev**
Population uncertainty	METHANE UNCERTAINTIES	1	0.982152939	1.018877983	1.000000188	0.00500013
Energy requirement uncertainty	METHANE UNCERTAINTIES	1	0.822698236	1.18210268	1.000001782	0.049990123
Feed energy uncertainty	METHANE UNCERTAINTIES	1	0.816666007	1.179367304	0.999999108	0.049991854
Methane factor uncertainty	METHANE UNCERTAINTIES	1	0.500623465	1.499840379	1.000000149	0.224375849

@RISK Summary Report

General Information

Workbook Name	Massey Dairy 2004.xls
Number of Simulations	1
Number of Iterations	5000
Number of Inputs	4
Number of Outputs	2
Sampling Type	Latin Hypercube
Simulation Start Time	3/6/06 10:02:31
Simulation Stop Time	3/6/06 10:02:34
Simulation Duration	0:00:03
Random Seed	404740959

Output and Input Summary Statistics

Output Name	Worksheet	Simulation#	Minimum	Maximum	Mean	Std Dev
Total intake	TOTAL METHANE	1	2699.264648	4856.937988	3610.397633	253.891175
Total methane	TOTAL METHANE	1	34.49252319	139.432663	78.0372077	18.59949772
Input Name	**Worksheet**	**Simulation#**	**Minimum**	**Maximum**	**Mean**	**Std Dev**
Population uncertainty	METHANE UNCERTAINTIES	1	0.981592536	1.017834544	0.999999856	0.004999188
Energy requirement uncertainty	METHANE UNCERTAINTIES	1	0.820603192	1.191659212	1.000002672	0.050002049
Feed energy uncertainty	METHANE UNCERTAINTIES	1	0.81866622	1.19028151	1.000003645	0.049997968
Methane factor uncertainty	METHANE UNCERTAINTIES	1	0.500094116	1.499975801	0.999999906	0.224373213

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General Information

Workbook Name	Massey Sheep 1990.xls
Number of Simulations	1
Number of Iterations	5000
Number of Inputs	4
Number of Outputs	2
Sampling Type	Latin Hypercube
Simulation Start Time	3/9/06 13:32:36
Simulation Stop Time	3/9/06 13:32:41
Simulation Duration	0:00:05
Random Seed	1208346185

Output and Input Summary Statistics

Output Name	Worksheet	Simulation#	Minimum	Maximum	Mean	Std Dev
TOTAL / Total	Total intake & methane	1	4384.632324	7261.118652	5694.830151	407.809688
TOTAL / Total	Total intake & methane	1	49.4995842	201.314743	114.8251913	27.43300415
Input Name	**Worksheet**	**Simulation#**	**Minimum**	**Maximum**	**Mean**	**Std Dev**
Population uncertainty	Methane uncertainties	1	0.981487274	1.01900959	1.000000108	0.005000095
Energy requirement uncertainty	Methane uncertainties	1	0.822756231	1.222957015	1.00001008	0.050023086
Feed energy uncertainty	Methane uncertainties	1	0.804836512	1.179463506	0.999996676	0.050003102
Methane factor uncertainty	Methane uncertainties	1	0.500771821	1.499281645	1.000001229	0.224372636

@RISK Summary Report

General Information

Workbook Name	Massey Sheep 2004.xls
Number of Simulations	1
Number of Iterations	5000
Number of Inputs	4
Number of Outputs	2
Sampling Type	Latin Hypercube
Simulation Start Time	3/9/06 13:33:09
Simulation Stop Time	3/9/06 13:33:13
Simulation Duration	0:00:04
Random Seed	1323808828

Output and Input Summary Statistics

Output Name	Worksheet	Simulation#	Minimum	Maximum	Mean	Std Dev
TOTAL / Total	**Total intake & methane**	**1**	2825.93457	4797.071777	3696.297138	263.2175367
TOTAL / Total	**Total intake & methane**	**1**	30.739851	132.2084808	74.24816399	17.58366279
Input Name	**Worksheet**	**Simulation#**	**Minimum**	**Maximum**	**Mean**	**Std Dev**
Population uncertainty	**Methane uncertainties**	**1**	0.982283592	1.017870903	0.999999869	0.004998123
Energy requirement uncertainty	**Methane uncertainties**	**1**	0.797994614	1.178552508	0.999995557	0.050008211
Feed energy uncertainty	**Methane uncertainties**	**1**	0.78498584	1.177349925	0.999993494	0.050017259
Methane factor uncertainty	**Methane uncertainties**	**1**	0.500426352	1.499719501	0.999999483	0.224376703

Aboveground biomass per tree measured in different sample plots at Massey University

Farm	Block	Plot/average aboveground biomass per tree			Age
		1	2	3	
Dairy 1	B2	162.31	195.78		10
	B2	201.95	236.61		11
Dairy4	3b	167.44	191.29		10
	B1	172.8			10
	3b	212.98	239.95		11
	B1	214.06			11
Keebles	B13	141.72	128.75		11
	B12	238.82	426.33		11
	B11	323.7	470.8		12
	B2	168.74	221.03		10
	B13	170.74	179.95		12
	B12	314.4	537.85		12
	B11	415.13	589.55		13
	B2	231.76	295.87		11
LATU	B2	74.01			6
	B3	105.79			6
	B2	104.64			7
	B3	149.63			7
Tuapaka	B4	124.03	159.75		10
	5ab	59.05	62.58	56.33	6
	B3	323.82	310.37	298.18	11
	B2	334.85	332.29		12
	B4	167.8	194.62		11
	5ab	88.86	92.89	81.96	7
	B3	377.72	381.22	375.94	12
	B2	401.36	390.45		13

The average aboveground biomass per tree in different aged plantations at Massey University*

6Year	7Year	10Year	11Year	12Year	13Year
71.55	103.60	173.69	241.47	345.41	449.12

* These values are derived by adding all same age aboveground biomass values and dividing it by the total number of plots in that particular age

Estimation of annual biomass increase and CO_2 sequestered by non-measurable Kyoto plantations using IPCC default root-shoot ratio for biomass

Farm	Block	Area	Year of planting	Above-ground biomass in 2005 (kg)	Above-ground biomass/ha in 2005 (Mg)	Root-shoot ration	Total biomass in 2005 (Mg)	Above-ground biomass in 2004 (kg)	Above-ground biomass/ha in 2004 (Mg)	Root-shoot ratio	Total biomass in 2004 (Mg)	Annual increase in total biomass (Mg)
Dairy 1	4	1	2004	2530	3	0.46	4	0	0	0.46	0	4
Dairy 4	7	1	2002	22770	23	0.46	33	10120	10	0.46	15	18
LATU	5	5	2002	113850	23	0.46	166	50600	10	0.46	74	92
Keebles	4	0.75	2002	17078	23	0.46	25	7590	10	0.46	11	14
	18a	3	2002	68310	23	0.46	100	30360	10	0.46	44	55
	18b	0.5	2004	1265	3	0.46	2	0	0	0.46	0	2
	19	6	2004	15180	3	0.46	22	0	0	0.46	0	22
Tuapaka	1	14	2002	318780	23	0.46	465	141680	10	0.46	207	259
	6	4	2000	253000	63	0.32	334	161920	40	0.46	236	98
Haurongo	2	2.6	2003	26312	10	0.46	38	6578	3	0.46	10	29
Terrace block	1	0.2	2003	2024	10	0.46	3	506	3	0.46	1	2
	2	4.6	2002	104742	23	0.46	153	46552	10	0.46	68	85
	3	0.4	2002	9108	23	0.46	13	4048	10	0.46	6	7
TOTAL		43.05					1359			0.46	672	687

All these plantation blocks are assumed at initial stocking i.e. 1100 stems/ha

Above-ground biomass for a particular plantation block in each year is calculated by multiplying the area of plantation with the amount of average above-ground biomass/tree at that particular age (Table 6.2-1 below) and then multiplying it by number of trees/ha i.e. 1100

Total biomass in calculated by adding below-ground biomass according to IPCC default values i.e. 0.46 for above-ground biomass of less than 50Mg/h and 0.32 for above-ground biomass between 50-150 Mg/ha

Table 6.2-1

Tree age	Ave. above ground biomass/tree (kg)
5	57.5
4	36.8
3	20.7
2	9.2
1	2.3

	Total annual biomass increase		=	687 Mg
Total C accumulated			=	344 Mg
Total CO_2 sequestered			=	1260 Mg

Estimation of annual biomass increase and CO_2 sequestered by established Kyoto plantations using IPCC default root-shoot ratio for biomass

Farm	Block	Area	Above-ground biomass in 2005 (Mg)	Above-ground biomass/ha in 2005 (Mg)	IPCC root-shoot ratio	Total biomass 2005 (Mg)	Above-ground biomass in 2004 (Mg)	Above-ground biomass/ha in 2004 (Mg)	IPCC root-shoot ratio	Total biomass 2004 (Mg)	Annual increase in biomass (Mg)
Dairy 1	2	1.7	328	193	0.23	403	267	157	0.23	329	74
Dairy4	3b	1.7	312	183	0.23	384	247	145	0.32	326	58
	1	0.5	99	198	0.23	122	80	160	0.23	98	23
Keebles	13	2.3	278	121	0.32	367	215	93	0.32	284	83
	12	2.4	304	127	0.32	401	237	99	0.32	312	89
	11	1.7	249	146	0.32	328	196	116	0.32	259	69
	2	4.9	521	106	0.32	688	385	79	0.32	508	179
	5	0.5	96	193	0.23	119	79	157	0.23	97	22
LATU	2	0.3	35	115	0.32	46	24	81	0.32	32	13
	3	0.4	44	110	0.32	58	31	78	0.32	41	17
	4	1.0	124	124	0.32	163	96	96	0.32	127	37
Tuapaka	4	4.2	414	99	0.32	547	327	78	0.32	431	115
	5ab	7.0	553	79	0.32	731	373	53	0.32	493	238
	3	10.5	1821	173	0.23	2240	1492	142	0.32	1970	270
	2	6.1	932	153	0.23	1146	788	129	0.32	1040	107
TOTAL		45.2	6110			7742	4838			6347	1395

Total annual biomass increase	=	1395 Mg
Total C accumulated	=	698 Mg
Total CO_2 sequestered	=	2558 Mg

Total annual biomass increment in younger plantations

Farm	Block	Area	Year of planting	Age of plantation in Jul 05	Age of plantation in Jul 04	Above-ground biomass in 2005 (kg)	Above-ground biomass in 2004 (kg)	Annual increase in above-ground biomass (Mg)	Total annual biomass increase (Mg)
Dairy 1	4	1	2004	1	0	2530	0	3	3
Dairy 4	7	1	2002	3	2	22770	10120	13	16
LATU	5	5	2002	3	2	113850	50600	63	79
Keebles	4	0.75	2002	3	2	17078	7590	9	12
	18a	3	2002	3	2	68310	30360	38	47
	18b	0.5	2004	1	0	1265	0	1	2
	19	6	2004	1	0	15180	0	15	19
Tuapaka	1	14	2002	3	2	318780	141680	177	221
	6	4	2000	5	4	253000	161920	91	114
Haurongo	2	2.6	2003	2	1	26312	6578	20	25
Terrace block	1	0.2	2003	2	1	2024	506	2	2
	2	4.6	2002	3	2	104742	46552	58	73
	3	0.4	2002	3	2	9108	4048	5	6
TOTAL		43.05				954949	459954	495	619

All these plantation blocks are assumed at initial stocking i.e. 1100 stems/ha
Above-ground biomass for a particular plantation block in each year is calculated by multiplying the area of plantation with the amount of average above-ground biomass/tree at that particular age (from Table 6.4-1) and then multiplying it by number of trees/ha i.e. 1100
Total biomass in calculated by adding 25% to the above-ground biomass

Table: 6.4-1

Age	Average above-ground biomass/tree
5	57.5
4	36.8
3	20.7
2	9.2
1	2.3