

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

EMISSIONS AND REMOVALS OF GREENHOUSE GASES AT AN INSTITUTION LEVEL:

A Case Study of Massey University Turitea Campus

A thesis presented in partial fulfilment
of the requirements for the degree of

Doctor of Philosophy (PhD)

in

Natural Resource Management



Institute of Natural Resources
Massey University
Palmerston North, New Zealand

Zulfiqar Haider Butt

2009

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 (CO₂), nitrous oxide (N₂O) and methane (CH₄). 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 CO₂ 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 CO₂ equivalents (CO₂e) 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 CO₂e 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 CO₂e 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.

AKNOWLEDGEMENTS

First and foremost I would like to thank my supervisors, Dr. Ian Valentine (Massey University), Dr. Kevin Tate (Landcare Research), and Dr. Surinder Sagar (Landcare Research) for expertly supervising this thesis. I would like to thank them all for their patience, guidance, continuous support and prompt and constructive comments on the manuscripts.

I would also like to extend my special thanks to Professor Russ Tillman (Head of the Institute of Natural Resources) for agreeing to step-in as my chief supervisor after the retirement of Dr. Ian Valentine. I am very much grateful to him for never failing to have time to spend on this thesis in his very busy schedule.

My special thanks are due to Dr. Ashraf Choudhary (member of New Zealand parliament, my first supervisor at Massey), Professor Peter Kemp, and Dr. Manzoor-ul-Haque Awan whose encouragement, guidance, and support were always with me.

Glenys Gilligan, Irene Manley, Denise Stewart, and Denise Brunskill, are the ladies at the Institute, to whom I owe a lots of thanks.

I appreciate and thank for all the support of my friends and fellow postgraduate students at the Institute of Natural Resources, Dr. Baisen Zhang Dr. Tehseen Aslam, Dr. Entine, Dr. Zulkefly Suleman, Bhoj Bahadur Kshatri and in particular Dr.Zaker Hussain who helped me in many ways. My thanks also go to my friends Tahir Mehmood Akhtar, Amsha Nahid, and Tariq Bashir for their invaluable support throughout my stay in New Zealand. I am also grateful to my dearest friend Mujtaba Mughal whose moral support made it easy for me to stay in New Zealand and complete my PhD.

My sincere gratitude to Cheryl Hutchinson (Physical Resources Manager) for providing basic data on energy use and help in finding and introducing me to a number of contact persons in other departments of the University. To

Geoff Warren (Manager - Haurongo farm) for providing special assistance while collecting data on Massey farms, especially the details about tree plantations. To James Millner for providing forestry instruments and guidance for tree measurement, and to Craig Trotter (Landcare Research) for helping in forestry sector calculations.

My huge thanks must go to the following people for helping and providing data on different sectors:

Dennis Clueard of Shell New Zealand, Brent Stanford (Business Manager Massey School of Aviation), Professor Ravi Ravindran (Institute of Food Nutrition and Human Health, Massey University), Erdinc Atalay (Civil Engineer- Manager P.N. City Council's water treatment plant), Lucy Marsden (Massey Archives), Dave Bull and Terry Walker (Massey Grounds Department), Grant Storrier (Massey Insurance Officer), Garth Evans, Rouse Laurence, and Mary Jenkin (Massey AgServices), Steavert Davies, Rick Bud, Rick Bragger, Charlie Shearsby and Terry Hammond of Regional Facilities Management.

I extend my thanks to Jonathan Hannon (coordinator Massey University's Zero Waste Academy), Raymond Joe of Waste Management Limited, and Helena Winiata of fullcircle for their help in waste data collection. To Scott Gulliver (Adviser Climate Change) for his help in calculating emissions from waste. To Neil Warby (Engineering Officer) in Palmerston North city council and Dave Beattie (Manager Massey Traffic) for their help in counting commuting vehicles. To Harry Clark (AgResearch) and Adrian Walcroft (Landcare Research) for their help in emission calculations from farm animals.

During the last few years, the only financial support for my PhD was from Helen E Akers trust, I sincerely send my thanks to all at Helen E Akers trust for helping me in reducing my student loan.

Finally, and most importantly, I would like to give my eternal gratitude to my late parents as I always feel their prayers and support behind me. Special thanks to my elder brother Sabir Pervez Butt and my bhabi (sister-in-law), my younger brother Iftikhar Haider Butt, all my sisters for their prayers and the rest of my family members for always being supportive of my studies and encouraging me to fulfil my dreams. Thank you Asifa (my wife), Toor and Masroor (my sons) for all your support and love without which I would have surely not been able to complete this task.

TABLE OF CONTENTS

Abstract.....	i
Acknowledgements.....	iii
Table of Contents.....	vi
List of Tables.....	xi
List of Figures.....	xvi
CHAPTER 1: GENERAL INTRODUCTION.....	1
1.1 Background.....	1
1.2 Thesis Objectives.....	5
1.3 Methodology.....	5
1.4 Scope of the Study.....	6
1.4.1 Thesis Structure.....	8
1.5 References.....	10
CHAPTER 2: LITERATURE REVIEW.....	12
2.1 The Greenhouse Effect.....	12
2.2 Greenhouse Gases.....	14
2.2.1 Carbon dioxide.....	16
2.2.2 Methane.....	17
2.2.3 Nitrous oxide.....	19
2.3 Global Warming Potential.....	20
2.4 Mitigation of Greenhouse Gases.....	21
2.4.1 Intergovernmental Panel on Climate Change	21
2.4.2 United Nations Framework Convention on Climate Change.....	22
2.4.2.1 The Kyoto Protocol.....	23
2.4.3 New Zealand Initiatives	24
2.5 Greenhouse Gas Emission Inventories.....	25
2.5.1 Source/Sink Categories.....	26
2.5.1.1 Energy.....	26
2.5.1.1.1 Road transport.....	28
2.5.1.1.2 Air travel.....	28
2.5.1.2 Industrial Processes.....	29
2.5.1.3 Solvent and Other Product Use.....	29
2.5.1.4 Agriculture.....	30
2.5.1.4.1 Greenhouse gas emissions from domestic livestock.....	31
2.5.1.4.2 Greenhouse gas emissions from agricultural soils...	31
2.5.1.4.3 Methane emissions from rice cultivation.....	32
2.5.1.4.4 Greenhouse gas emissions from agricultural burning.	32
2.5.1.5 Land-Use Change and Forestry.....	33
2.5.1.6 Waste.....	34

2.5.1.6.1 Factors influencing CH ₄ generation in SWDSs	35
2.5.2 Uncertainties in GHG Inventories.....	36
2.6 Mitigation.....	37
2.6.1 Carbon Sequestration through Soil, Crop and Forest Management.....	39
2.6.2 Exploitation of Under-utilised Resources.....	39
2.6.3 Erosion Control and Soil Restoration	40
2.6.4 Mitigation of GHG by Forests	40
2.6.5 Waste Management.....	41
2.6.6 Dairy and Livestock.....	42
2.7 Summary and Conclusions.....	43
2.8 References.....	45
CHAPTER 3: ENERGY	55
3.1 Introduction.....	55
3.1.1 Global Emissions from Energy.....	55
3.1.2 Types of Emissions from the Energy Sector.....	56
3.1.3 Emissions from the Energy Sector in New Zealand.....	57
3.2 Methodology.....	58
3.2.1 Electricity and Gas.....	59
3.2.2 Coal.....	61
3.2.3 Vehicles.....	62
3.2.3.1 Commuting Vehicles in 2004	63
3.2.3.1.1 Calculating number of commuting vehicles to the Turitea campus.....	63
3.2.3.1.2 Proportion of petrol and diesel vehicles.....	67
3.2.3.1.3 Average distance travelled by commuting vehicles...	67
3.2.3.1.4 Staff/student ratio for commuting vehicles.....	68
3.2.3.2 Commuting Traffic in 1990.....	69
3.2.3.3 Calculations and Uncertainties.....	70
3.2.4 Aviation.....	72
3.2.4.1 Massey school of aviation in 1990.....	74
3.2.4.2 Staff air travel in 1990.....	75
3.2.5 Estimates of Uncertainty.....	75
3.3 Results.....	77
3.3.1 Emissions from Electricity.....	77
3.3.2 Emissions from Gas.....	77
3.3.3 Emissions from Coal.....	77
3.3.4 Emissions from Vehicles.....	78
3.3.5 Emissions from Aviation.....	81
3.4 Changes in Emissions Between 1990-2004.....	83
3.5 Discussion.....	84
3.6 Conclusions.....	87
3.7 References.....	89

CHAPTER 4: WASTE	92
4.1 Introduction.....	92
4.1.1 Waste Generated at Massey University.....	92
4.1.2 Factors Affecting Emissions from MSW Disposal.....	94
4.1.2.1 Waste Composition.....	94
4.1.2.2 Physical Factors.....	94
4.1.3 Global GHG Emissions from Waste.....	95
4.1.4 New Zealand GHG Emissions from the Waste Sector.....	95
4.1.5 Objectives.....	96
4.2 Methodology.....	97
4.2.1 General Inventories for the Waste Sector.....	97
4.2.2 Data Collection.....	97
4.2.3 Estimation of CH ₄ Emissions from Solid Waste Disposal.....	98
4.2.4 Estimation of CO ₂ Emissions Resulting from Solid Waste Disposal.....	100
4.2.5 Estimation of CO ₂ Emissions Resulting from Flaring of Recovered CH ₄	100
4.2.6 Estimation of CH ₄ and N ₂ O Emissions from Wastewater Handling.....	101
4.2.7 Estimation of CH ₄ and N ₂ O Emissions from the Waste Sector in 1990.....	103
4.3 Results.....	105
4.3.1 Total MSW in 2003-04.....	105
4.3.2 Methane Emissions from Solid Waste.....	105
4.3.3 Carbon dioxide from Flaring of CH ₄	106
4.3.4 Nitrous oxide Emission from Wastewater & Human Sewage..	106
4.3.5 Total CO ₂ e Emissions from the Waste Sector.....	106
4.4 Discussion.....	109
4.5 Conclusions.....	113
4.6 References.....	114
 CHAPTER 5: AGRICULTURE	 117
5.1 Introduction.....	117
5.1.1 Global Emissions from the Agricultural Sector.....	118
5.1.2 National Emissions from the Agricultural Sector.....	118
5.1.3 Methane from Enteric Fermentation.....	119
5.1.4 Methane from Manure Management.....	120
5.1.5 Nitrous oxide from Soils.....	121
5.1.6 Nitrous oxide from Manure Management.....	122
5.1.7 Objectives.....	123
5.2 Methods.....	123
5.2.1 General Methodology	123
5.2.2 Data Collection.....	124
5.2.3 Livestock.....	125
5.2.3.1 Calculating CH ₄ from Enteric Fermentation.....	125
5.2.3.2 Calculating CH ₄ from Animal Manure Management.....	128
5.2.3.3 Calculating N ₂ O from Animal Manure Management.....	130

5.2.4 Agricultural Soils.....	130
5.2.4.1 Calculating N ₂ O from Agricultural Soils and Sports Grounds.....	131
5.3 Results.....	135
5.3.1 Emissions from Livestock.....	135
5.3.1.1 Methane Emissions from Enteric Fermentation & Manure Management.....	135
5.3.1.2 Nitrous oxide Emissions from Animal Manure Management.....	138
5.3.2 Emissions from N Addition to Agricultural Soils.....	140
5.3.2.1 Direct N ₂ O Emissions from Excreta Added Directly to the Soil by Grazing Animals.....	144
5.3.2.2 Direct N ₂ O Emissions from Agricultural Soils and Sports Grounds as a Result of Adding N in the form of Synthetic Fertilisers and Animal Waste.....	144
5.3.2.3 Indirect N ₂ O Emissions from N Lost from the Field as NO _x or NH ₃	145
5.3.2.4 Total N ₂ O Emissions from Agricultural Soils and Sports Grounds.....	147
5.3.3 Total Agricultural Emissions in CO ₂ Equivalents.....	147
5.4 Discussion.....	148
5.5 Conclusions.....	151
5.6 References.....	152
CHAPTER 6: LANDUSE CHANGE AND FORESTRY.....	156
6.1 Introduction.....	156
6.1.1 Global Scenario.....	156
6.1.2 National Scenario.....	157
6.1.3 Objectives.....	159
6.2 Methods.....	159
6.2.1 Data Collection.....	166
6.2.1.1 True Area of the Circular Plot and Plot Layout.....	170
6.2.2 Estimation of Annual CO ₂ and Biomass Increase in the Established Plantations.....	171
6.2.3 Estimation of Annual Biomass Increase in Non-Measured Younger Exotic Tree Plantations.....	174
6.2.4 Estimation of C Sequestered by Native Bush.....	177
6.3 Results.....	179
6.3.1 Massey University Forest Estate.....	179
6.3.2 Annual Biomass Increase and CO ₂ Removed by Established Plantations.....	180
6.3.3 Annual Biomass Increase and CO ₂ Removed by Younger Exotic Tree Plantations.....	180
6.3.4 Annual CO ₂ Removed by Non Kyoto Exotic Tree Plantations.....	180
6.3.5 Annual Removal of CO ₂ by Native Bush Plantations.....	180
6.3.6 Total CO ₂ Removed by Forestry Sector at Massey University...	182
6.4 Discussion.....	183

6.5 Conclusions.....	187
6.6 References.....	188
CHAPTER 7: GENERAL DISCUSSION AND CONCLUSIONS.....	191
7.1 Summary of Results.....	191
7.1.1 Emission Values and Uncertainties for 1990 and 2004.....	191
7.1.1.1 Breakdown by Sector.....	191
7.1.1.2 Breakdown by Sub-Sector.....	192
7.1.2 Differences in Emissions between 1990 and 2004.....	194
7.1.2.1 Total Emissions and Breakdown by Sector.....	194
7.1.2.2 Total Emissions Breakdown by Sub-Sector.....	195
7.1.3 Uncertainties on 2004 Data: Sensitivity Analysis and Sources of Large Uncertainties.....	197
7.1.3.1 Uncertainty Sensitivity Analysis (2004 Data).....	197
7.1.3.1.1 Sector effects on gross and net total emission uncertainties.....	197
7.1.3.1.2 Sub- sector effects on sector emission uncertainties...	198
7.1.3.1.3 Individual parameter effects on sub-sector emission uncertainties.....	199
7.1.3.2 Sources of the Greatest Uncertainties (2004 Data) and Their Potential for Reduction.....	201
7.2 General Discussion.....	203
7.2.1 Energy Sector.....	205
7.2.1.1 Electricity and Gas.....	205
7.2.1.2 Road Transport.....	207
7.2.1.2.1 Commuting traffic.....	208
7.2.1.2.2 Fuel used by Massey University owned vehicles...	209
7.2.1.3 Aviation.....	212
7.2.1.4 Air Travel by International Students.....	212
7.2.2 Agricultural Sector.....	213
7.2.3 Waste Sector.....	214
7.2.4 Forestry Sector.....	216
7.3 Strategy to Reduce Emissions.....	217
7.4 Suggestions for Future Inventories.....	218
7.5 Conclusions.....	220
7.6 References.....	222
ANNEXURES.....	224

LIST OF TABLES

Chapter-2 Literature Review

Table 2.1:	Global atmospheric concentration of important GHGs and changes in concentration.....	15
Table 2.2:	Carbon dioxide emission per unit of energy for various fossil fuels.....	17
Table 2.3:	Global annual CH ₄ emission from different human activities.....	18
Table 2.4:	Methane emission factors per unit of energy for fossil fuels.....	18
Table 2.5:	Global sources and emissions of N ₂ O.....	19
Table 2.6:	Global warming potential of some GHGs.....	21

Chapter-3 Energy Sector

Table 3.1:	One-week vehicle counts at the Main Drive entrance during 2003-04.....	65
Table 3.2:	Number of counts per week to the Turitea campus during four week-long survey periods in 2003-04.....	65
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.....	66
Table 3.4:	Calculated weekly vehicle counts and return trips assuming vehicle counts on the Main Drive are 61.5% of the total vehicle counts to and from the campus.....	66
Table 3.5:	Return trips per week and total annual return trips calculated according to the activities occurring on campus.....	66
Table 3.6:	Number of petrol and diesel vehicles in selected car parks and on the whole campus.....	67
Table 3.7:	Estimation of average distances travelled by Massey University students and staff; and the proportion of diesel vehicles.....	68
Table 3.8:	Total number of persons and % of staff at the Turitea campus of Massey University.....	69
Table 3.9:	Total number of return trips by commuting vehicles in 1990.....	70
Table 3.10:	Emission factors for different categories of fuel.....	70
Table 3.11:	Average fuel used (g) per available seat kilometre (ASK)..	73
Table 3.12:	General methods of uncertainties calculation.....	76

Table 3.13:	Quantity of coal used by Massey University in 1990 and CO ₂ emissions.....	77
Table 3.14:	Total CO ₂ e emissions due to commuting vehicles in 2004.	79
Table 3.14a:	Total CO ₂ e emissions due to commuting vehicles in 1990.	79
Table 3.15:	Fuel consumed on Massey farms during 2003-04.....	80
Table 3.16:	Carbon dioxide equivalent emissions from different categories of vehicles in 2004.....	80
Table 3.17:	Greenhouse gas emissions due to Massey University-owned vehicles in 1990.....	81
Table 3.18:	Total CO ₂ e emissions due to Massey University staff air travel in 2004.....	82
Table 3.19:	AvGas used by aircraft from the Massey University School of Aviation in 2004 and the resulting CO ₂ e emissions.....	82
Table 3.20:	Changes in CO ₂ e emissions from different categories in the energy sector between 1990 and 2004.....	83
Table 3.21:	Per capita GHG emissions from energy sector in 1990 and 2004.....	86

Chapter-4 Waste

Table 4.1:	Total waste collected from the project area during the last 4 years.....	105
Table: 4.2:	Methane and CO ₂ e emissions from solid waste from the Turitea campus of Massey University	108
Table 4.3:	Annual N ₂ O emissions from human sewage from Massey University.....	108
Table 4.4:	Total CO ₂ e emissions from waste sector at Massey University in 1990 & 2004.....	109
Table 4.5:	Weight of MSW produced at Massey University in 1990 and 2004 and resulting GHG emissions.....	110

Chapter-5 Agriculture

Table 5.1:	Animal numbers on Massey University farms from 1990 to 2004.....	125
Table 5.2:	Population model used to calculate enteric CH ₄ emissions from beef animals at Massey in 2004.....	129
Table 5.3:	Fraction of N lost in different systems	131
Table 5.4:	Emission factors for agricultural emissions of N ₂ O.....	131

Table 5.5:	Methane emissions from enteric fermentation and manure management from Massey farms in 2004.....	136
Table 5.5a:	Methane emissions from enteric fermentation and manure management from Massey farms in 1990.....	136
Table 5.6:	Coefficient of variation for CH ₄ emissions from sheep, dairy, and beef animals.....	137
Table 5.7:	Sensitivity ranking for CH ₄ emission from livestock.....	137
Table 5.8:	Nitrogen excretion in different AWMSs at Massey University in 2004.....	139
Table 5.8a	Nitrogen excretion in different AWMSs at Massey University in 1990.....	139
Table 5.9:	Nitrous oxide emissions from manure management in 1990 and 2004.....	140
Table 5.10:	Sensitivity ranking for N ₂ O emission from soils	140
Table 5.11:	Total Nitrogen fertiliser used by Massey University in 2003-04.....	142
Table 5.12:	Nitrogen input to agricultural soils, pastures and sports grounds from synthetic fertiliser use in 1990 and 2004...	143
Table 5.13:	Total N input to agricultural soils from animal waste in the "AL" and "Other" AWMS in 1990 and 2004.....	143
Table 5.14:	Direct N ₂ O emissions from N deposited directly on soil by grazing animals in 1990 and 2004.....	144
Table 5.15:	Direct N ₂ O emissions from agricultural soils at Massey University in 2004.....	145
Table 5.15a:	Direct N ₂ O emissions from agricultural soils at Massey University in 1990.....	145
Table 5.16:	Indirect N ₂ O emissions from agricultural soils and sports grounds due to leaching in 1990 and 2004.....	146
Table 5.17:	Indirect N ₂ O emissions from agricultural soils and sports grounds due to volatilisation in 1990 and 2004.....	146
Table 5.18:	Total annual N ₂ O emissions from agricultural soils and sports grounds at Massey University in 1990 and 2004...	147
Table 5.19:	Total CO ₂ e emissions from the agricultural sector at Massey University in 2004 (Mg CO ₂ /yr).....	148
Table 5.19a:	Total CO ₂ e emissions from the Agriculture sector at Massey University in 1990 (Mg CO ₂ /yr).....	148
Table 5.20:	Share of individual animal categories in total CH ₄ emissions at Massey University in 2004.....	149

Chapter-6 Land-use Change & Forestry

Table 6.1:	Massey University forest areas.....	163
Table 6.2:	Number and distribution of sampling plots established on different Massey farms.....	167
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.....	172
Table 6.4:	Young/non-measured Kyoto forest plantations at Massey University	175
Table 6.5:	Average above-ground biomass/tree in established plantations.....	175
Table 6.6:	Estimated average above-ground biomass/tree and annual biomass increment in young plantations.....	176
Table 6.7:	Area under different categories of plantation in 2004.....	179
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.....	181
Table 6.9:	Above-ground biomass, total biomass per tree and per ha in the younger Kyoto plantations.....	182
Table 6.10:	The weight of CO _{2e} removed by the younger Kyoto plantations in the 2004-5 year.....	182
Table 6.11:	Annual CO ₂ removed by the native bush at Massey University.....	182
Table 6.12:	Estimated annual CO ₂ removed by all categories of plantations at Massey University.....	183

Chapter-7 General Discussion and Conclusions

Table 7.1:	Emissions and removals of GHG at Massey University in 2004	191
Table 7.2:	Emissions and removals of GHG at Massey University in 1990	192
Table 7.3:	Emissions and removals of GHG from different sub-sectors in 2004, at Massey University ranked from greatest to least.....	193
Table 7.4:	Emissions and removals of GHG from different sub-sectors in 1990, at Massey University ranked from greatest to least.....	193
Table 7.5:	Differences in GHG emissions and removals from different sectors at Massey University between 1990 and 2004.....	195

Table 7.6:	Differences in GHG emissions and removals from different sub-sectors at Massey University between 1990 and 2004.....	196
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.....	198
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.....	198
Table 7.9:	Sensitivity analysis for uncertainties in the “Vehicles Commuting” sub-sector emission estimates arising from uncertainties in individual parameters.....	199
Table 7.10:	Sensitivity analysis for uncertainties in “MSW” sub-sector emission values arising from uncertainties in individual parameters.....	200
Table 7.11:	Comparison of National and Massey University’s per capita GHG emissions (Mg CO ₂ e/yr) from different sectors in 2004.....	204
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.....	211
Table 7.13:	Strategies for improvement.....	218

LIST OF FIGURES

Chapter-1 General Introduction

- Figure 1.1: An aerial photograph showing Massey University's main campus and adjacent farms.....7
- Figure 1.2: Structure of the thesis.....9

Chapter-2 Literature Review

- Figure 2.1: The greenhouse effect.....13
- Figure 2.2: Rising global temperatures from 1860 – 2000..... 14
- Figure 2.3: Proportion of different sectors in global GHG emissions in 2004.....16

Chapter-3 Energy

- Figure 3.1: World CO₂ emissions due to primary energy use by sector, from 1971-200156
- Figure 3.2: Greenhouse gas emissions from the energy sector in New Zealand from 1990 to 2004..... 58
- Figure 3.3: MetroCount vehicle counter installed at the Massey main entrance.....64
- Figure 3.4: Emissions from different categories in the energy sector at Massey University in 2003-2004.....84

Chapter-4 Waste

- Figure 4.1: Recycling bins at Massey University for source separation of waste material93
- Figure 4.2: Greenhouse gas emissions from the waste sector in New Zealand from 1990 to 2004.....96
- 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 2003/04103
- Figure 4.4: Gas flare station at Awapuni landfill107
- Figure 4.5: Methane collection system installed at Awapuni landfill.....107
- Figure 4.6: Average monthly amount of recycling material from Massey University from 2002-03 to 2005-06111

Figure 4.7:	Net annual CH ₄ emissions (Mg) from Massey University waste from 2000-01 to 2003-04	112
-------------	--	-----

Chapter-5 Agriculture

Figure 5.1:	Total national agricultural sector emissions from 1990 to 2004	119
Figure 5.2:	Enteric CH ₄ emissions in 1990 and 2004 and estimated 95% confidence interval.....	137
Figure 5.3:	GHG emissions in CO ₂ e from different sub-sectors of agriculture at Massey University in 2004.....	149

Chapter-6 Land-use Change & Forestry

Figure 6.1:	Net removals by LUCF sector in New Zealand from 1990 to 2004	158
Figure 6.2:	An aerial photograph showing location of different farms around Massey University Main campus.	164
Figure 6.3:	Measurement of tree diameter at breast height (DBH) at Tuapaka	168
Figure 6.4:	Average tree DBH measured in individual sampling plots in 2004.....	169
Figure 6.5:	Average tree heights measured in individual sampling plots in 2004.....	169
Figure 6.6:	Relationship between tree age and above-ground biomass... ..	176
Figure 6.7:	Native bush area along Albany drive at Massey University.....	177
Figure 6.8:	Total Massey University forest area and the area of Kyoto forests from 1990 to 2004.....	179
Figure 6.9:	Relative contribution of the different categories of forest to the total "Kyoto recognised" CO ₂ removal	183

Chapter-7 General Discussion and Conclusion

Figure 7.1:	Comparison of GHG emissions (Mg CO ₂ e) in 1990 and 2004	195
Figure 7.2:	GHG emissions at Massey University in 2004, from different categories in the energy sector.....	206
Figure 7.3:	Solid waste produced at Massey University /head/yr	215