University of Southern Queensland

Faculty of Engineering and Surveying

Development of a tool for estimating net emissions of greenhouse gases at farm and sub-catchment level

A dissertation submitted by

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ABSTRACT

Global average temperatures have been steadily on the increase over time, largely due to anthropogenic activities that accelerate the production and accumulation of Greenhouse Gases (GHGs) in the lower atmosphere. Agriculture is a significant contributor of such gases, emitting approximately 20% of Australia's national figures. Research into how to identify and quantify major agricultural sources so as to determine appropriate sequestration measures is vital. This is necessary to enable Australia to realise its Kyoto targets through the first commitment period (2008 - 2012) and beyond.

Increase in concentration of GHGs arises from an imbalance between the rate of input from various sources, and the rate at which they are sequestered by sinks. The major direct emissions are carbon dioxide (CO_2) from fossil fuel combustion, methane (CH_4) emissions from enteric fermentation and nitrous oxide (N_2O) emissions from soils and manures. Indirect GHG emissions arise from, among others, transport of goods, energy use and manufacture of fertiliser.

The main objective of this project is to extend the current GreenGauge model to include a cost component for natural resource management and "carbon tax". The project, therefore, is twofold: one section is as described in the preceding statement and the other involves improving GreenGauge's initial scope. This is achieved through the realization of the objectives outlined below:

- Update and expand the capacity of the existing tool;
- Refine and "localise" the model for the particular local conditions of Queensland;
- Identify areas of sensitivity which can be modified to improve emissions and sinks;
- Use the model to compare and rate the impact of alternative management systems.

A Microsoft Excel spreadsheet is used to intake data relating to agricultural activities. Each workbook is sub-divided into three components: an emissions-estimation component, an economics component and a sensitivity-analysis component. Using NGGI-compliant algorithms, constants and conversion factors, a simple code is produced to output estimates of the GHG quantity per activity. The emissions-estimation segment adopts algorithms defined in the tool GreenGauge. Through the use of carbon-value estimates and further algorithms, costs associated with the input parameter are calculated. The fundamental approach to quantifying costs is such that a net profit is calculated under a ‘current systems’ scope (i.e. net returns - net expenditures). Hypothetical environmental costs are then inducted into the equation to quantify the ‘true’ returns. A new theoretical profit is determined to reflect economic returns weighed against quantifiable costs detrimental to the environment.

The cost model will be applied to evaluate the cost effectiveness and environmental impact of different farming scenarios. Upon full completion (including validation), the cost model should have the capacity to estimate both environmental and economic costs associated with specific farm activities. The end-product is that farmers have at their disposal an easy-to-use guide that allows comparative analysis of their current farming practices and proposed mitigation options.

Keywords: *Cost Model, Greenhouse Gases (GHGs), Sequestration, Mitigation*.

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NOMENCLATURE

The following is a list of the acronyms, initialisms and abbreviations (including chemical symbols and units of measurements) used in this dissertation paper.

Acronyms, Initialisms and Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
AGO	Australian Greenhouse Office
ATSE	Australian Academy of Technological Sciences and Engineering
BMP	Best Management Practice
COMAP	Comprehensive Mitigation Assessment Process (for forestry)
COPATH	Carbon, Pasture, Agriculture, Total, Harvesting
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DPI	Department of Primary Industries
EF(s)	Emission Factor(s)
EPIC	Erosion and Productivity Impact Calculator
GACMO	Greenhouse **Ga**s **C**osting **Mo**del
GDP	Gross Domestic Product
GHG(s)	Greenhouse Gas(es)
GIS	Geographic Information Systems
GWP(s)	Global Warming Potential(s)
IPCC	Intergovernmental Panel on Climate Change
LUCF	Land-Use Change and Forestry
NCAS	National Carbon Accounting System
NGGI	National Greenhouse Gas Inventory
Ppm	Parts per million
QLD	Queensland (The State of)
UNFCCC	United Nations Framework Convention on Climate Change

Chemical Symbols and abbreviations

C	Carbon
C_{eq}	Carbon equivalent
CO_2	Carbon dioxide
CO_{2-eq}	Carbon dioxide equivalent
CO	Carbon monoxide
CFCs	Chlorofluorocarbons
CH_4	Methane
H_2	Hydrogen (gas)
HFCs	Halofluorocarbons
HCFC	Halochlorofluorocarbons
NMHC	Non methane hydrocarbons
NO_x	Nitrous Oxides
N_2	Nitrogen (gas)
N_2O	Nitrous Oxides
O_2	Oxygen (gas)
O_3	Ozone
SO_x	Sulphur Oxides
SF_6	Sulphur hexafluoride

Units and conversions

°C	degree(s) Celsius
g	gram(s)
GJ	gigajoules
ha	hectare(s)
km	kilometer(s)
kW	kilowatt
kWh	kilowatt-hour
L	litres
m	metre(s)
m3	cubic metre(s)
Mt	megatonnes
MWe	megawatt electric
Pg	petagram(s)
t CO_2-e	tonnes of Carbon dioxide equivalent
yr	year

1 hectare = $10^4 m^2$
One cubic metre (m3) equals one thousand litres
One kilowatt hour (kWh) equals 3.6 megajoules (MJ), or 0.0036 gigajoules (GJ)

1 Gigagram (Gg) = 10^9 grams (g)
= 10^6 kilograms (kg)
= 10^3 tonnes (t)
= 1 kilotonne (kt)
= 10^{-3} megatonnes (Mt)

Conversely:
1 gram (g) = 10^{-9} Gg
1kilogram (kg) = 10^{-6} Gg
1 tonne (t) = 10^{-3} Gg
1 kilotonne (kt) = 1 Gg
1 megatonne (Mt) = 1000 Gg

Glossary

Afforestation: 'the act or process of creating forest land where it "historically" did not exist' (Lund 2002).

Anthropogenic: caused or originated from human activity or agency (Commonwealth of Australia 1998a).

Biomass burning: the combustion of any vegetation including but not limited to forests, savanna, temperate grasslands and crop stubble (Commonwealth of Australia 1998a).

Burning efficiency: the fraction of fuel load on a surface that is combusted in a fire (Commonwealth of Australia 1998a).

Business-as-Usual (b.a.u.): a projection that incorporates changes in activity levels and greenhouse gas emission factors, with the exclusion of any effects that are directly attributable to greenhouse policy measures. It is also referred to as 'without measures' and baseline (Australian Greenhouse office, 2005).

Carbon dioxide equivalents ($C0_2$-e): see ***Global Warming Potentials (GWP).***

Conventional Tillage (CT): Conventional tillage systems are characterised by a significant number of tillage operations prior to sowing. Seedbed preparation processes usually involves three or more tillage operations. Tillage implements may differ from those used for reduced tillage practices, resulting in more extensive soil disturbance per tillage operation.

Deforestation: 'the act or process of changing forest land to non-forest land' (Lund 2002).

Direct emissions: emissions produced from sources within the boundaries of an organisation and as a result of that organisation's activities (AGO, 2005).

Dry Matter Content (DMC): the mass of material that exists after vegetation has been dried to an *oven dry* state (Commonwealth of Australia 1998a).

Elemental to molecular mass conversion factor: the factor used to convert estimates of the elemental mass of C or N in a compound to the molecular mass of the compound, for example the conversion of mass of N to mass of N_20 (Commonwealth of Australia 1998a).

Emission factor (EF): the quantity of a greenhouse gas released into the atmosphere per unit of the specified activity (Commonwealth of Australia 1998a).

Enteric fermentation: a digestive process by which plant material consumed by an animal is broken down under anaerobic conditions. A portion of the plant material is fermented to simple fatty acids which then are absorbed into the bloodstream and the gases ($C0_2$ and CH_4) vented by eructation and exhalation by the animal. Enteric fermentation is pronounced in ruminant animals due to the presence of a rumen which provides the primary site for fermentation (Commonwealth of Australia 1998).

Forest: a minimum area of land of 0.05-1.0 hectares with tree crown cover of more than 10-30 percent with trees with the potential to reach a minimum height of 2-5 metres at maturity in situ. Young natural stands and all plantations which have yet to reach a the specified crown density and height are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest (Commonwealth of Australia 2002c).

Fuel load: the mass of material that is readily available for combustion, exclusive of living overstorey biomass (Commonwealth of Australia 1998a).

Global Warming Potential (GWP): the relative warming effect (i.e. cumulative radiative forcing) of a unit mass of a gas when compared to the same mass of CO_2 over a specific period of time. Carbon dioxide equivalents (CO_2-*e)* are calculated by multiplying the mass of each gas by the appropriate GWP. Aggregate emissions are then obtained by summing the emissions of various GHGs.

Greenhouse Gas (GHG): Any gas with the capacity to capture and/or retain infrared radiation in the atmosphere (Watson et al., 1998).

Indirect emissions: emissions generated in the wider economy as a consequence of an organisation's activities (particularly from its demand for goods and services), but which are physically produced by the activities of another organisation (AGO, 2005).

No-Tillage (NT): No tillage or direct drill systems are those in which stubble is retained for the maximum length of time prior to sowing a new crop; weeds are controlled with herbicides and there may be limited or no grazing. Ground disturbance is kept minimal at sowing time and seedbeds are not tilled prior to sowing. Permanent beds, raised beds, controlled traffic and precision agriculture are also grouped under the no-tillage class.

Prescribed burning: the intentional burning of forests to reduce the amount of combustible material present, thereby reducing the risk of wildfires. In Australia this is known as 'fuel reduction burning' (Commonwealth of Australia 1998b).

Reduced Tillage (RT): Tillage systems that minimise soil disturbance while time achieving viable seedbeds for crop growth. Weed/disease control and treatment of crop residues is usually similar to that of no-tillage methods (NT)

Reforestation: 'the act or process of changing previously deforested lands back to forest land (Lund 2002).'

Regrowth: native trees and shrubs that re-establish on land previously cleared for cropping, pasture establishment or forestry plantation purposes (Eldridge *et al.* 2003).

Sources: processes (or places that encompass particular processes) that release greenhouse gases into the atmosphere (Commonwealth of Australia 1998a).

Sinks: processes (or places that encompass particular processes) that remove greenhouse gases from the atmosphere and include chemical transformations in the atmosphere and uptake of the gases from the atmosphere by the underlying land surfaces (Commonwealth of Australia 1998a).

Stubble Incorporation (SI): The use of tillage implements to incorporate remnant plant residue into the soil following harvest; considered (traditionally) useful in returning organic matter to the soil an hence protecting it from erosion. SI can contribute to the transfer of plant pathogens from one crop to another, offers less surface protection than stubble retention and destroys soil structure/porosity (Valzano et al, 2005).

Stubble management: The control of surface residues subsequent to harvesting a crop (Valzano et al, 2005); see Stubble Incorporation (SI) and Stubble Retention (SR).

Stubble Retention (SR): A stubble management practice that involves leaving crop residues at the soil surface (standing or treated i.e. by slashing, bashing, or harvest spreading) that are sometimes grazed prior to sowing a succeeding crop. Stubble retention is used in no-till systems to protect the soil surface from erosion processes, particularly raindrop impact, while retaining carbon at the soil surface (Valzano et al, 2005).

Troposphere: the layer of atmosphere extending about five miles up from the Earth's surface

Vegetation Thickening: a change in carbon per unit area arising from human induced changes in grazing or fire regimes. Vegetation thickening usually involves an increase in the biomass of woody plants (measured as an increase in basal area and height) and often a simultaneous increase in soil carbon and dead plant material. The species of woody plants may be native or exotic. Changes in fire frequency, reduction of browsers and the effects of elevated carbon dioxide may be contributory factors (Commonwealth of Australia 1998b).

CHAPTER 1

INTRODUCTION

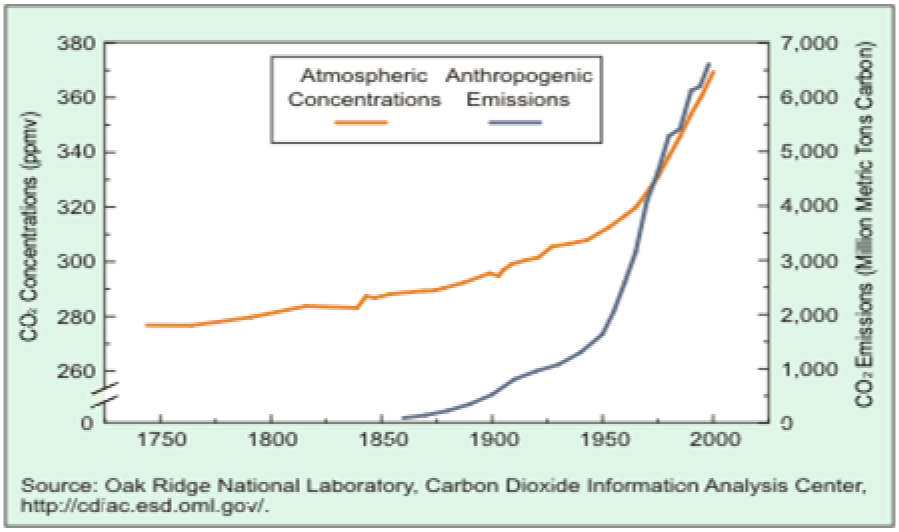
1.1 Project Background

What Are Greenhouse Gases?

Many chemical compounds found in the Earth’s atmosphere act as “greenhouse gases.” These gases allow sunlight to enter the atmosphere freely. When sunlight strikes the Earth’s surface, some of it is reflected back towards space as infrared radiation (heat). Greenhouse gases absorb this infrared radiation and trap the heat in the atmosphere. Over time, the amount of energy sent from the sun to the Earth’s surface should be about the same as the amount of energy radiated back into space, leaving the temperature of the Earth’s surface roughly constant [National Energy Information Center (NEIC), 2004].

Why Are Atmospheric Levels Increasing?

Levels of several important greenhouse gases have increased by about 25 percent since large-scale industrialization began around 150 years ago (Figure 1). During the past 20 years, about three-quarters of human-made carbon dioxide emissions were from burning fossil fuels to meet the energy requirements of industrial processes (NEIC, 2004).



Source: Oak Ridge National Laboratory, Carbon Dioxide Information Analysis Center, http://cdiac.esd.ornl.gov/.

Figure 1: **Trends in Atmospheric Concentrations and Anthropogenic Emissions of Carbon Dioxide (Source: Oak Ridge National Laboratory, 2004)**

Different economic sectors, including agriculture, have varying percentage contributions to net greenhouse gas emissions; in Australia, the energy sector heads these contributions with agriculture second. The latter contributes between 15 and 20% (figure varies in this range between different data sources) of Australia’s net greenhouse gas emissions. It is the dominant source of both methane (67.9%) and nitrous oxide (77.1%). Methane is primarily sourced from enteric fermentation in ruminants, while nitrous oxide is lost from agricultural soils as a result of soil disturbance, nitrogen fertilisers and animal excreta.

The most widely-discussed impact of climate change has been unprecedented temperature hikes. Trends show that global average temperatures have steadily been on the increase over time, largely due to anthropogenic activities that accelerate the production and accumulation of radiatively-selective gases in the lower atmosphere. Climatologists place the figures at approximately 0.6 °C rise in the past 100 years (Figure 2 below), and extrapolations forecast an increase of up to ten times this amount within the next century (see Figure 3).

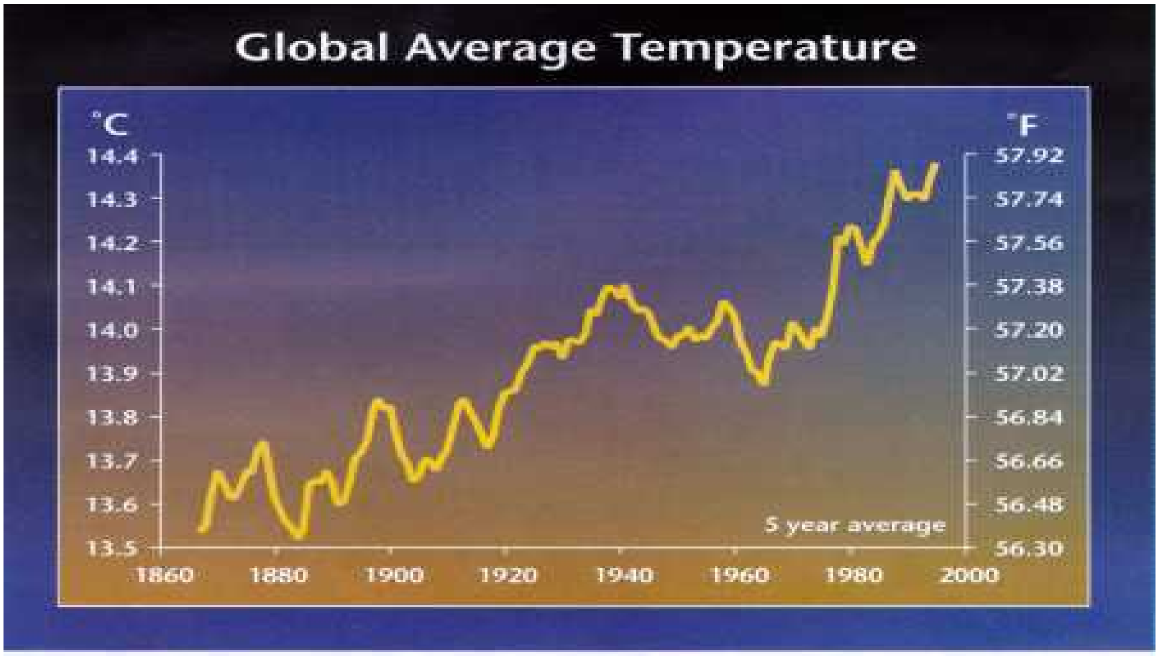


Figure 2: **Global average temperature trends (Image: Australian Greenhouse Office, 2006)**

There are numerous other predicted impacts of global warming and subsequent climate change. Some of these pose an even greater threat than increases in global average temperatures, such as the potential total inundation of large coastal ecosystems by rising sea levels. Bio-diversity, including displacement of entire human populations, would be put at risk in this eventuality.

The agricultural sector is particularly vulnerable to the potential impacts of climate change. These impacts include:

- a reduction in annual average rainfall over much of the Australian continent,
- increases in mean annual temperature and atmospheric carbon dioxide concentrations,
- an increased frequency of extreme weather events such as flooding and drought,
- altered distribution and survival of pests and weeds, which are likely to have a significant impact on agricultural production in some regions, and
- an increased risk of heat stress for intensively housed animals.

These impacts could affect agricultural productivity, sustainability and economic returns. A detailed discussion of the predicted impacts of global warming is undertaken in latter parts of this dissertation.

Using global climate model simulations, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) has projected future climatic conditions in Australia, which include an increase in average annual temperature of 1-6 °C (Figure 3) by 2070 over most of Australia (Australian Greenhouse Office, 2006).

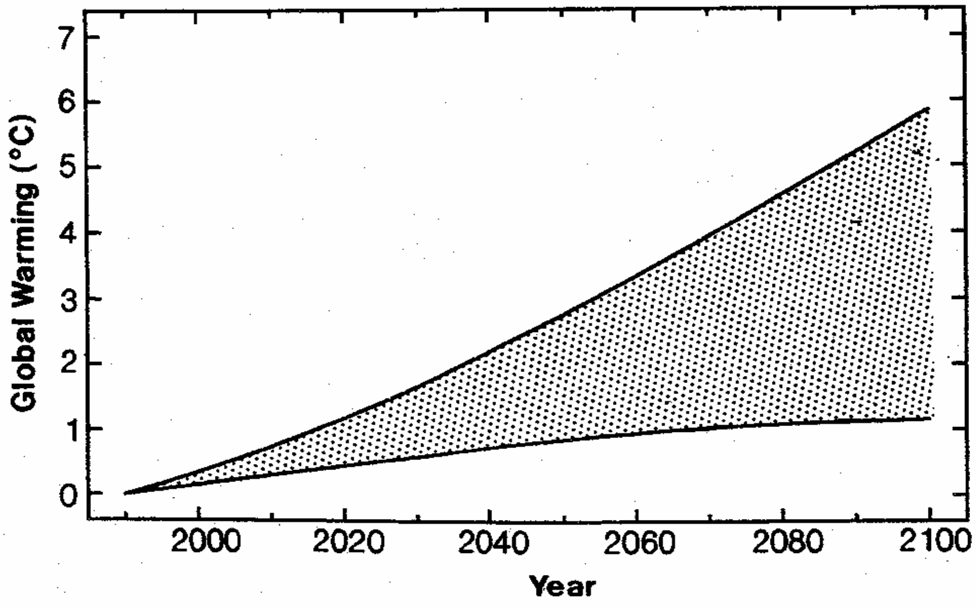


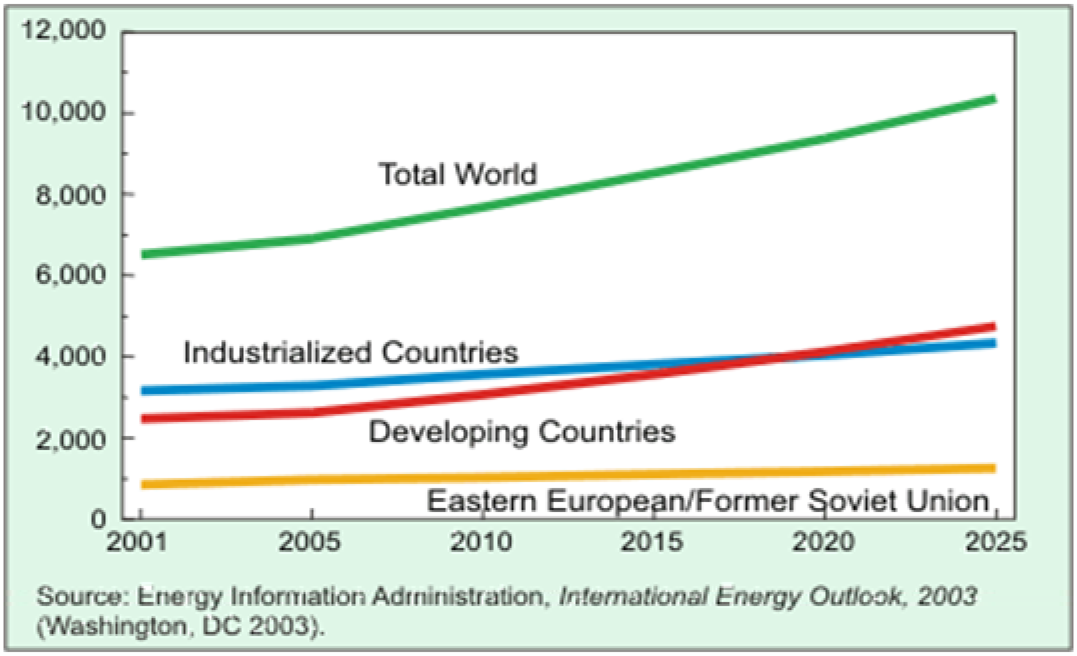
Figure Scenarios of future global warming fall within the shaded region of the map

Figure 3: **Forecast temperature trends shown at their extremes (AGO, 2006)**

The upper boundary in Figure 2 represents a 'business-as-usual' scenario, where no mitigation efforts are made to impede the emission of greenhouse gases and subsequent accumulation in the atmosphere. The lower boundary is reflects the result of a combination of mitigation efforts from all significant stakeholders. Actual temperature fluxes could fall anywhere between these two extremes.

What Is the Prospect for Future Emissions?

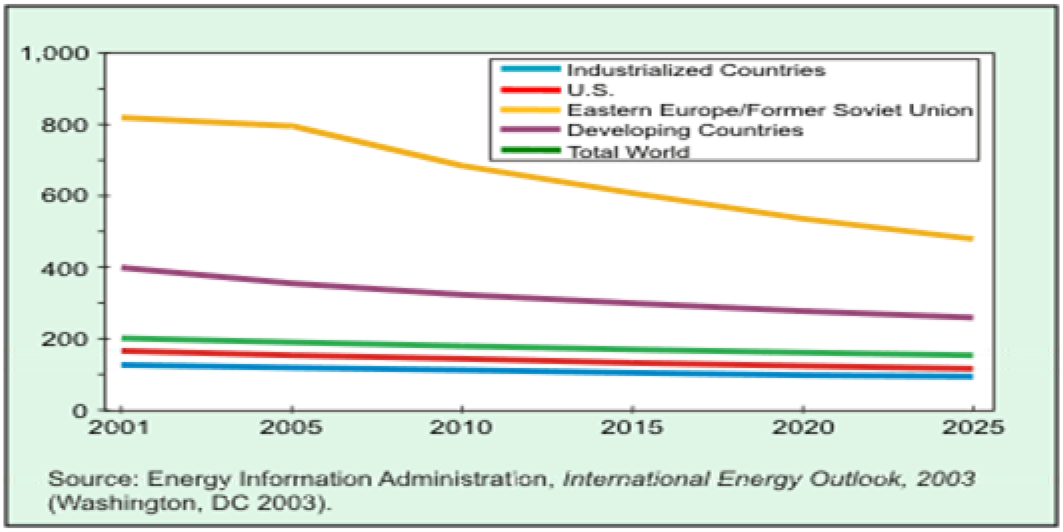
World carbon dioxide emissions are expected to increase by 1.9 percent annually between 2001 and 2025 (Figure 4). Much of the increase in these emissions is expected to occur in the developing world where emerging economies, such as China and India, fuel economic development with fossil energy. Developing countries' emissions are expected to grow above the world average at 2.7 percent annually between 2001 and 2025; and surpass emissions of industrialized countries near 2018 (NEIC, 2004).



Source: Energy Information Administration, *International Energy Outlook, 2003* (Washington, DC 2003).

Figure 4: **World Carbon Dioxide Emissions by Region (Megatonnes of CO_2-e)**

Current data indicates that industrialised nations, of which Australia is a member by virtue of its economic status, spearhead global emissions figures; this trend is tipped to shift in due time when developing countries' energy consumption increases to support growth of their flourishing economies. In 1990, carbon dioxide accounted for 63 per cent of global greenhouse gas emissions; about three quarters (75%) of this total was emitted by developed countries (Davidson, undated). The United States (U.S.) leads global emissions producing about 25% (NEIC, 2004) of the world's total, primarily because its economy is the largest in the world; 85% of their energy need is met through burning fossil fuels. Australia's emissions are significantly lower than the US's, emitting approximately 1-2% of the globe's total. However, due to its small population, Australia has one of the highest per capita emissions (emissions per person) amongst the developed nations. Reduction efforts by Australia alone would not have a marked impact on global emissions; collaboration between countries, irrespective of economic status, is a key requirement for any abatement policies to be effective. Figure 5 shows relative carbon intensities by region relative to the 1997 economic performance indicators (in US $).



Source: Energy Information Administration, *International Energy Outlook, 2003* (Washington, DC 2003).

Figure 5: **Carbon Intensity by Region [Metric tonnes of C-Equivalent per $ Million (1997)]**

Regionally, the CSIRO has projected a decrease in annual average rainfall in Queensland. This, coupled with increased evaporation rates due to (projected) temperature hikes paints a gloomy portrait of any future agricultural establishments. According to the Australian Greenhouse Office (2005), it is possible that Australia is already experiencing the effects of climate change, and further changes are inevitable. Continued drought conditions in several parts of the continent could be attributed to changing rainfall patterns, which in turn is linked to climate change due to enhanced greenhouse capacities. Australia is naturally a dry continent relative to the rest of the globe, receiving about 450 mm of precipitation per annum (Australian Bureau of Meteorology, undated). Any irregularities and/or reduction in precipitation further compound the already stretched water resources.

Increased frequency and intensity of extreme weather occurrences have raised awareness that the onset of global warming and climate change is indeed more than just a theory. Some of these incidents are given in this section, and include:

- increased cyclone/hurricane activity off the US coast in 2005;

- the devastating 2003 European heat wave that claimed thousands of lives and destroyed 30% of crop worth about AU $ 17 – 20 billion;

- recent tropical storm in Innisfail [north Queensland] that destroyed 90 to 100% of crop, causing losses equalling $300 million worth of fruit (Topham, 2006); and

- record high temperatures (the past decade was the hottest since record-keeping started in 1860; 2005-joint hottest of the last 20 years).

Table 1: Evidence of Increasing Temperatures by rank (reference year: 1860)

Rank	Year	Rank	Year	Rank	Year
1	2005	8	1990	15	1994
1	1998	9	1995	16	1983
3	2002	10	1999	17	1996
4	2003	11	2000	18	1944
5	2004	12	1991	19	1989
6	2001	13	1987	20	1993
7	1997	14	1988		

The record heat of 2005 is part of a longer-term warming trend exacerbated by the rise of heat-trapping gases in our atmosphere primarily due to human-intervention in natural cycles. Nineteen of the hottest 20 years on record have occurred since 1980. There are concerns that unprecedented temperature increases would pose a threat to species diversity culminating from glacial meltdowns, sea level rise and possible total inundation of low-altitude habitats/ecosystems. This is a major threat; entire human populations could be forced out of their natural homelands by encroaching tidal waves. Specifically for Australia, this could mean having to shelter environmental refugees from neighbouring Pacific islands and/or providing humanitarian aid at increased frequency to address disasters culminating from climate change.

Concern over the increasing concentration of greenhouse gases cited as the catalysts to global warming is growing. These increased concentrations arise from an imbalance between the rate of input of ***Greenhouse Gases (GHGs)*** from various ***sources***, and the rate at which they are sequestered by ***sinks*** (Bureau of Resource Sciences *et al.* 1994). Agriculture is a significant component in the net emissions figures, both in Australia and internationally. At national level, agriculture contributes approximately 20% of Australia's total, second only to stationary energy sectors of the economy. The major direct emissions are carbon dioxide (CO_2) from fossil fuel combustion [to power machinery], methane (CH_4) emissions from enteric fermentation by ruminant livestock and nitrous oxide (N_2O) emissions from soils and manures. Indirect GHG emissions arise from, among others, transport of goods, energy use and manufacture of fertilisers.

It is imperative, therefore, that the agricultural sector channels substantial effort towards reducing emissions. Agriculture has to pioneer the emissions-reduction campaign as it could be one of the hardest-hit economic sectors due to its heavy reliance on a stable and, to an extent possible, reliable climate. With this is mind, this research project is undertaken to build on research already undertaken to educate stakeholders in agricultural production of the dangers of a changing climate, what alternatives are available and to generate an analytical tool, complete with an economic component, to help promote low-emission production at acceptable levels of return.

1.2 Objectives

Work undertaken in this research project is aimed at extending the capacity of Greengauge, an emissions estimating tool, by incorporating an economic component. The improved model would help farm managers monitor emissions and align future on-farm operations with approaches that are both financially-viable as well as environmentally friendly, as predicted by the model output. The modified model inherits the initial objectives drawn for the original model, listed in the next page:

- To improve the understanding of sources and sinks of the three major greenhouse gases, carbon dioxide ($C0_2$), methane (CH_4) and nitrous oxide (N_20), from the Agricultural sector;

- To provide a disaggregated estimate of net emissions based on a specified set of activities in agriculture, allowing greenhouse gas accounting to be included into investment decision making;

- To provide an aggregate estimate of net emissions for monitoring performance at a regional level and weighing against other natural resource management (NRM) outcomes (Stephenson, 2003).

The main objective of the current project is to extend the existing GreenGauge model to include a cost component for natural resource management and “carbon tax”. Other objectives are outlined below:

- Refine and "localise" the model for the particular local conditions of Queensland;

- Use the model to compare and rate the GHG impact of alternative farming and management systems; and

- Identify areas of sensitivity which can be modified to improve emissions and sinks.

This project relies on published data for all matters relating to emissions calculation and valuation (i.e. conversion to monetary figures). It is important to make a distinction that the overall scope of this project is to develop an analytical tool that promotes understanding of net greenhouse gas emissions associated with agriculture, the economical implications of such emissions on the environment, and likely outcomes of adopting alternative production means. Calculations are designed to provide indicative estimates as a guide to management only, and are not intended to directly target quantifiable emissions abatement that contributes to Australia’s Kyoto target or other international obligations.

CHAPTER 2

GREENHOUSE, GLOBAL WARMING AND CLIMATE CHANGE

2.1 Introduction

Atmospheric Carbon dioxide (CO_2) concentrations have increased from 250 ppm in pre-industrial times to 370 ppm, a 30% increase (ATSE, 2003). The rapid growth of production scales across different industries, agriculture included, is accountable for the majority of this trend. Agricultural production systems (including land clearing) are responsible for over one-third of Australia's national emissions, a proportion much higher than that of any other Organization for Economic Cooperation and Development (OECD) country apart from New Zealand (Australian Greenhouse Office, 2006). As such, the agricultural sector has an important role to play in the national response to reducing Australia's emissions.

Australia contributes about 2% of global greenhouse gas emissions – on its own it cannot make a dent on global emissions. However, this should not lure authorities into a false sense of security whatsoever, or a feeling of complacency that the subject is irrelevant to the country's immediate and future economic agenda. By the same token, stakeholders should not fall victims to the 'tragedy of the commons' phenomenon, whereby self-interest prevails over concern for long-term sustainability of a free-for-all natural resource (in this case, the atmosphere). Despite the low figures with respect to the global outlook, Australia has invested vast resources towards addressing emissions, and this trend should continue for the following reasons:

- To observe the Kyoto (Annex B) recommendations in the first commitment period (2008 – 2010) and beyond;
- To become a major stakeholder in the development of abatement technologies as a means of increasing sinks;
- Possible source of revenue from sale of carbon credits for landowners that involved in farm forestry;
- The impacts of a changing climate will be indiscriminate (i.e. will not be geo-selective); Australia's emissions might be insignificant relative to those of other

regions, but this will not exonerate the region from bearing the brunt of predicted impacts. Logically, Australia has a 1 in 6 probability of being the worst-hit continent (excluding the polar regions).

2.2 Background

2.2.1 The Greenhouse Effect

The biggest misconception about the "greenhouse effect" is that it is an undesirable phenomenon that is directly linked to global warming. On the contrary, the greenhouse effect is necessary to keep the global average temperatures at levels conducive to the survival of many different species, including humans.

High-energy, shortwave (Ultra violet, or UV) radiation emitted from the sun enters the earth's atmosphere and hits the earth's surfaces, both land and sea. Because the solar radiation is of short wavelength, it has a high penetrative capability, and hence a substantial proportion of the earth-bound radiation does penetrate the atmosphere. When such radiation hits the earth's surface, it is reflected and sent back towards the atmosphere. Some of the initial solar energy gets dissipated onto the earth's surface upon impact, and the radiation reflected upwards is of longwave, infra-red nature with poor penetrative power compared to the UV radiation. As a result, some of the upward-bound radiation becomes trapped by blanket of the radiatively-selective greenhouse gases, leading to the phenomenon known as the greenhouse effect. This process is essential to keep the earth's temperature within a habitable range. It is represented by the left half of Figure 6.

2.2.2 The Enhanced Greenhouse Effect

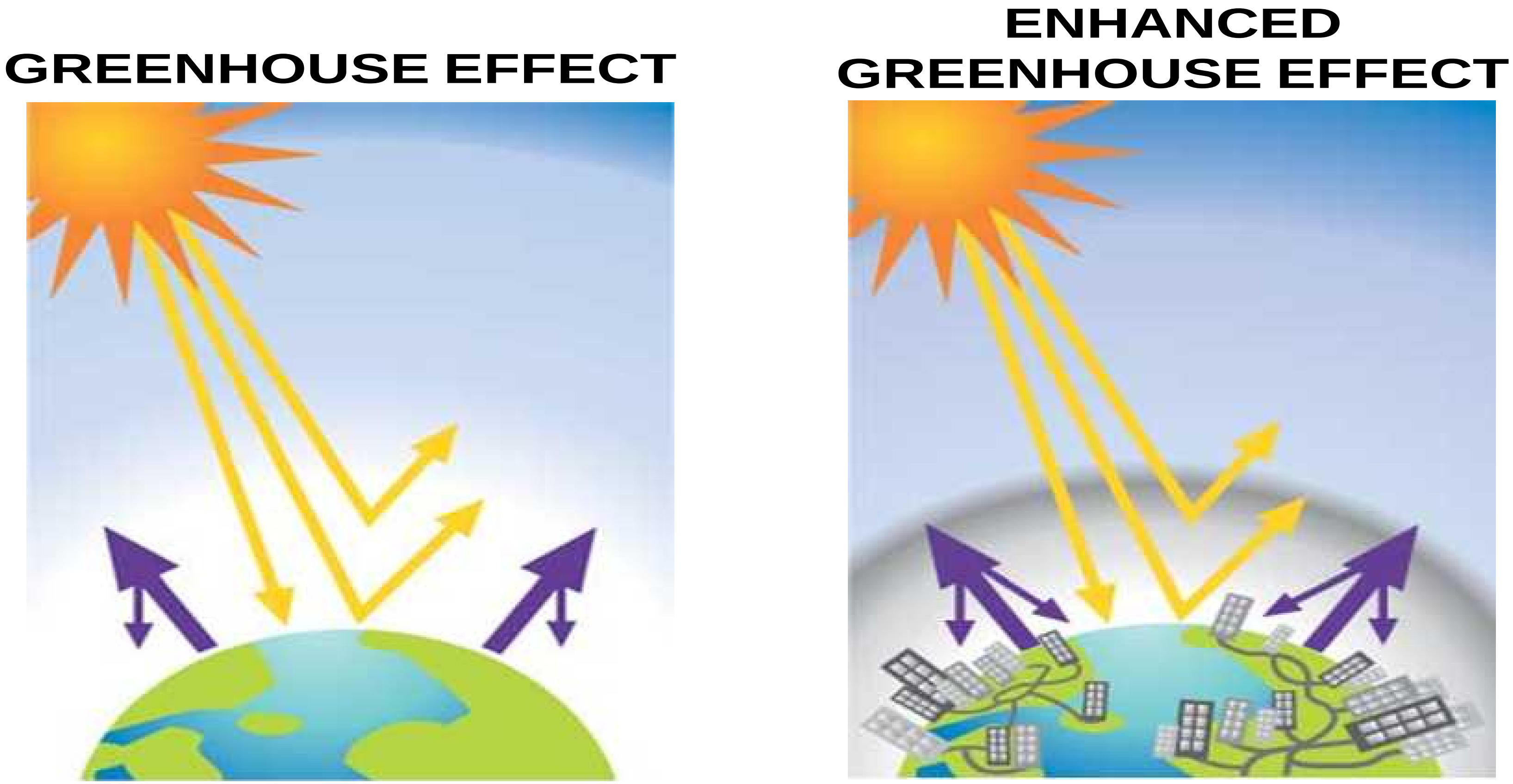
However, due to human intervention, the accumulation of greenhouse gases in the atmosphere is increasing at worrying rates. Depending on the type of gas, the duration for which these gases are retained in the atmosphere varies, but the net effect is that the rate of addition of gases within greenhouse capabilities outweighs the rate of removal, hence a general increase in concentration. As described earlier, solar radiation has a high penetrative ability, and as such, the amount of incoming radiation remains constant. At the other front, however, the increased concentration of greenhouse gases implies more infra-red radiation is being trapped and enclosed within the atmospheric boundaries. This leads to a gradual increase in average temperatures, hence the phenomenon of enhanced greenhouse effect, depicted in the right-half portion of Figure 3.

The capacity of the greenhouse layer to effectively trap heat is determined by:

- type and concentration of Greenhouse Gas,
- duration of existence in the atmosphere, and
- The radiative forcing capacities of the gas

The concept of Global Warming Potential was developed by climatologists to standardize and simplify global warming predictions. GWPs are discussed in detail in section 2.2.3 of this chapter to consolidate the reader’s understanding of the relation between greenhouse gas emissions, the enhanced greenhouse effect, global warming and subsequent climate change.

Figure 6 below gives a diagrammatic summary of the enhanced greenhouse effect:



Source: AGO website

<u>Figure 6</u>: The Enhanced Greenhouse Effect (Source: Australian Greenhouse Office, 2006)

2.2.3 Global Warming Potentials (GWP)

Despite constituting a mere 0.03% of the atmospheric composition, carbon dioxide is being added to the atmosphere in much higher quantities than the other GHGs, and at a much faster rate. Such are the rates of addition that both quantities and radiative capacities of all the other gases are expressed relative to CO_2. In international and national accounting methodologies, greenhouse gas net emissions are recorded in carbon dioxide equivalents ($C0_2$-e). To allow this, the concept of Global Warming Potentials (GWPs) was created to enable a comparison of the total cumulative effect of the various gases over a specified time (Commonwealth of Australia 2002a). A global warming potential is a measure of the warming impact of a particular gas, compared with that of carbon dioxide (Rypinski, 1997).

GWPs take into account how long relevant gases remain in the atmosphere and their relative effectiveness in absorbing outgoing long wave (infrared) radiation. One hundred year time horizons are used by the Inter-Governmental Panel on Climate Change (IPCC) to compare the warming effect of a unit mass of a given greenhouse gas relative to carbon dioxide, with CO_2 assigned a value of 1 and the warming effects of other gases calculated as multiples of this value (Commonwealth of Australia 2002a). Methane and nitrous oxide are considered to be potent greenhouse gases, (Hassall & Associates 2001), as shown by the statistics in the table below. These values are used for calculations in this report. The carbon dioxide equivalent ($C0_2$-e) is calculated simply by multiplying the mass of the emission of the non-carbon dioxide gas by its GWP.

Table 2: Current IPCC recommendation for GWPs (100-year integration)

Greenhouse gas	Global Warming Potential, GWP
Carbon dioxide, $C0_2$	1
Methane, CH_4	31
Nitrous oxide, N_20	310
Halofluorocarbon, HFC 134-a	1,300
Sulphur hexafluoride, SF_6	23,900

The complete list of greenhouse gases and their respective GWPs accounted for under Commonwealth reports is provided as Appendix D.

2.3 Literature Review

Annex A of the Kyoto protocol lists the major greenhouse gases as identified under the United Nations Framework Climate Change on Convention, UNFCC (see Appendix C). Greenhouse gases relevant to this project are carbon dioxide, methane and nitrous oxide. Their distributions across all sectors in the Australian economy are shown in Figure 7. A complete list of these gases is given in Appendix D.

Annex A also identifies the source categories together with their sub-sectors. These are given as the Energy (Fuel combustion and Fugitive emissions from fuels), Industrial Processes, Solvent and other product use, Agriculture and Waste. The sub-systems listed under agriculture are enteric fermentation, manure management, rice cultivation, agricultural soils, prescribed burning of savannas and field burning of agricultural residues. The majority of these sub-systems were used in defining the scope of work to be undertaken in this research project.

2.3.1 Greenhouse Gases: Definitions and Trends

Watson et al (1998) define a greenhouse gas as any gas with the capacity to capture and/or retain infrared radiation in the atmosphere. The major greenhouse gases, both in terms of their quantitative measure (atmospheric concentration) and global warming potential (GWP) are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), water vapour [H_2O (g)] and Halofluorocarbons, or HFCs.

Greenhouse gases have one thing in common: they can trap heat. In other respects, they are very different; they have different sources and sinks; some are part of a natural circulation where human intervention varies in magnitude ($C0_2$, CH4 and N_20), whilst others (CFCs, HFCs) are purely man-made. An effective greenhouse gas:

- sits in a part of the spectrum where most light/heat is transmitted through the atmosphere;

- has a long atmospheric lifetime so that its heating effects persist;

- Is relatively scarce in the atmosphere (Rypinski, 1997).

Appendix B illustrates some of the sinks and sources of these gases. There are contributions made to the enhanced greenhouse effect through complex reactions involving gases such as ozone (O_3), odd nitrogen oxides (NO_x), carbon monoxide (CO), and sulphur gases (SO_x) (Galbally 1992). Various synthetic chemicals such as hydrocarbons also have an impact; however, contributions from these latter examples are considered to be relatively small and are not covered in this report.

Based on concentration, water vapour is the most abundant greenhouse gas. However, human activities have little direct impact on the quantities present in the atmosphere (Commonwealth of Australia 2002a). On the other hand, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_20) quantities are affected by anthropogenic interventions. Carbon dioxide is the most important of the greenhouse gases in Australia with a net share of 73.5% (415.0 Mt) of the total CO_2-*e* emissions, followed by methane which constitutes 21.2% (119.7 Mt CO_2-*e).* The remaining greenhouse gases make up 5.3% (30.0 Mt CO_2-e) of Australia’s greenhouse gas emissions.

2.3.2 Summary of Emissions Figures

Australia’s net greenhouse gas emissions across all sectors totalled 564.7 million tonnes of carbon dioxide equivalent (Mt CO_2-e) in 2004, 2.3% above the 1990 levels. This places Australia well on target to honour the Kyoto-set figure of 8%. In the latest (2004) inventory, agriculture is shown to contribute about 16.5% of the nation’s total emissions (Figure 8). Overall, agricultural emissions increased by 2.2% from 91.1 Mt CO_2-*e* in 1990 (baseline) to 93.1 Mt in 2004. The primary industries’ 39.8% reduction in emissions (Table 4) is largely due to the impacts of declining emissions from forest-cover clearing and increased removals by the forestry industry.

This decline is overshadowed by a rise in emissions from the electricity, gas and water industries (46.7%), services and construction industries (23.3%) and the mining industry (36.5%). Emissions from these other economic sectors are not covered in this research project. Instead, focus is set solely on agriculture and to some extent land use change and forestry (LUCF) sectors.

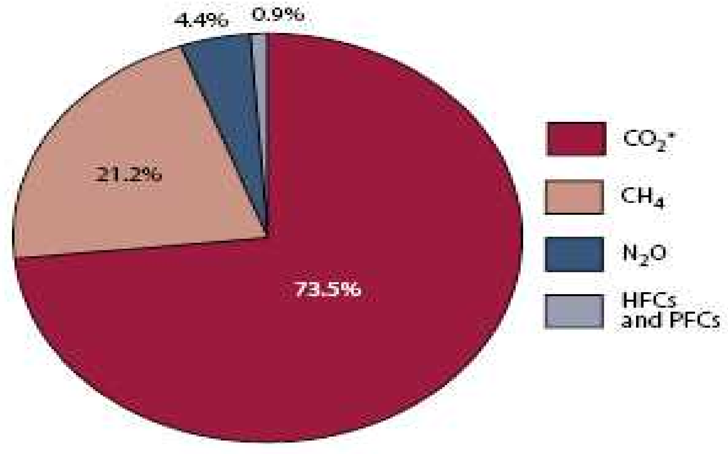
Table 3 below summarises the nation’s total emissions figures for 2004:

Table 3: Australia’s National Greenhouse Gas Inventory for 2004

	Emissions Mt CO_2-e		**% change in emissions**
	1990	**2004**	**1990 - 04**
Australia’s Net Emissions	551.9	564.7	2.3
Energy	**287.5**	**387.2**	**34.7**
Stationary Energy	195.7	279.9	43.0
Transport	61.7	76.2	23.4
Fugitive Emissions	30.0	31.0	3.4
Industrial Processes	**25.3**	**29.8**	**18.0**
Agriculture	**91.1**	**93.1**	**2.2**
Land Use, Land Use Change and Forestry (b)	**128.9**	**35.5**	**-72.5**
Waste	**19.2**	**19.1**	**-0.7**

Source: Australian Greenhouse Office, 2004

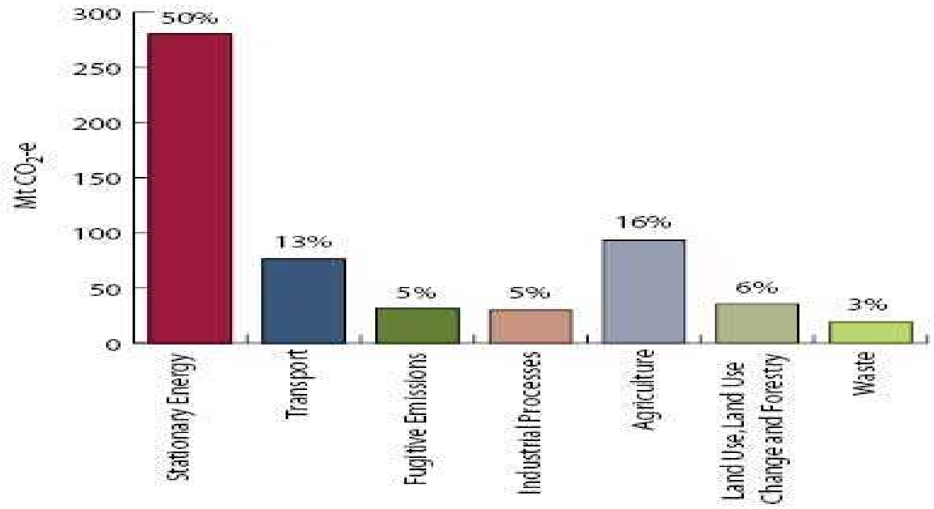
(a) CO_2-e, provides the basis for comparing the warming effect of different GHGs.
(b) 2004 estimate is interim only and will be revised with the next update of the inventory



*Includes confidential N_2O emissions reported as CO_2-e.

Figure 7: **Distribution of total net CO2-e emissions by gas, 2004** (Source: AGO, 2006)

Figure 8 shows emissions’ source categories and their relative values in Australia. Under Annex A (Appendix C) of the Kyoto Protocol, fuel combustion and fugitive emissions from fuels are treated as sub-categories within the energy sector. In turn, energy industries, manufacturing and construction industries, transport and other sectors are listed as subsystems within the fuel combustion category, whilst solid fuels, oil and natural gases are identified as fugitive emissions.



<u>Figure 8:</u> Australia's greenhouse gas emissions by sector in 2004 (AGO, 2006)

Based on the 2004 figures, agriculture contributes about half of the primary industries' total (i.e. 93.1 of the 179.5 Mt CO2-*e*). This is shown in Table 4 below:

<u>Table 4: Australia's Greenhouse Gas Emissions by economic sector 1990, 2004</u> [(b)]

	Emissions Mt CO_2-e		**Change in emissions (%)**
	1990	**2004**	**1990 - 04**
All Sectors	551.9	564.7	2.3
Primary Industries	**256.4**	**179.5**	**-30.0**
Agriculture, Forestry and Fisheries	223.5	134.6	-39.8
Mining	32.9	44.9	36.5
Manufacturing	**65.0**	**70.8**	**8.9**
Electricity, Gas and Water	**138.1**	**202.7**	**46.7**
Services and Construction	**48.7**	**60.0**	**23.3**
Residential	**43.8**	**51.8**	**18.3**

Source: Australian Greenhouse Office, 2006

a) Carbon dioxide equivalent, CO_2-e.

b) Estimated under the Kyoto Protocol reporting provisions.

Individual trends and transitions in emissions for the period 1990 – 2004 between different economic sectors are depicted in Figure 9 below:

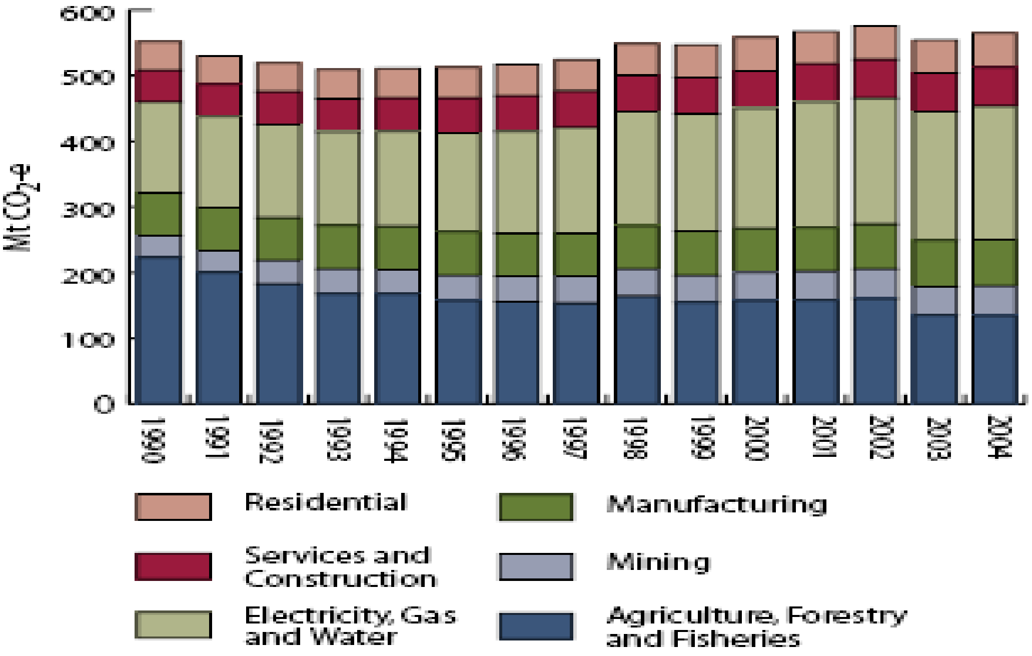


Figure 9: **Emissions trends by sector in the period 1990-2004 (Source: AGO 2006)**

Agricultural Emissions

Methane and Nitrous oxide emissions are produced when living and dead biomass is consumed. Human activities have a significant influence on such emissions. In agriculture, these activities range from soil disturbance, chemical applications, deliberate burning of biomass, flooding (irrigation) to the introduction of (ruminant) livestock. Sources of greenhouse gases in agriculture are:

1. Enteric fermentation in livestock: emissions associated with microbial fermentation during digestion of feed by ruminant livestock;

2. Manure management: emissions from the disintegration of animal wastes while still retained in manure management systems;

3. Rice cultivation: methane emissions from oxygen-deprived (anaerobic) decomposition of plant and other organic material when rice fields are flooded;

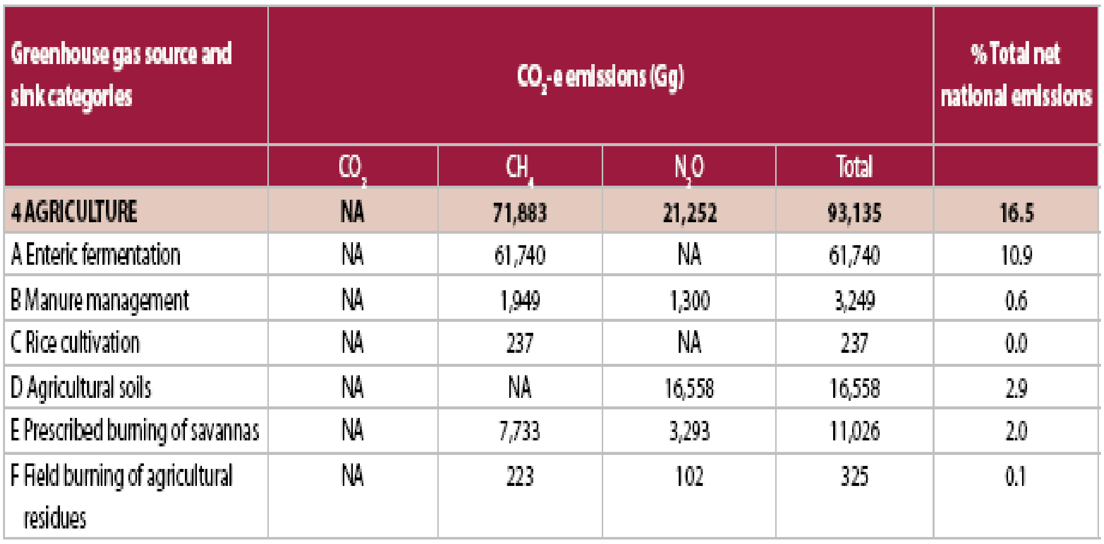
4. Agricultural soils: emissions resulting from the application of fertilisers, crop residues and animal wastes on agricultural lands as well as the use of biological N-fixing crops (legumes) and pastures;

5. Prescribed burning of savannas: emissions associated with the burning of tropical savanna and temperate grasslands for pasture management, fuel reduction and prevention wildfires;

6. Field burning of agricultural residues: emissions from field burning of crop stubble, as well as emissions from burning sugar cane prior to harvest.

Agriculture is the main contributor of methane (60.1%, or 3.4 Mt) and nitrous oxide (86.1%, or 0.069 Mt) emissions (AGO, 2006). Livestock emissions dominate agricultural emissions with a combined total from enteric fermentation and manure management of 65 Mt CO2-*e*. This represents 69.8% of agricultural emissions and 11.5% of the total national figure. The most significant emissions statistics (sources, distribution, etc) from agriculture are summarised in the illustrations below:

Table 5: Distribution of emissions from the agricultural sector by gas



Greenhouse gas source and sink categories	CO_2-e emissions (Gg)				% Total net national emissions
	CO_2	CH_4	N_2O	Total	
4 AGRICULTURE	**NA**	**71,883**	**21,252**	**93,135**	**16.5**
A Enteric fermentation	NA	61,740	NA	61,740	10.9
B Manure management	NA	1,949	1,300	3,249	0.6
C Rice cultivation	NA	237	NA	237	0.0
D Agricultural soils	NA	NA	16,558	16,558	2.9
E Prescribed burning of savannas	NA	7,733	3,293	11,026	2.0
F Field burning of agricultural residues	NA	223	102	325	0.1

Source: **Australian Greenhouse Office, 2006**

The statistics shown in Table 5 above are presented in a slightly different manner in Table 6 below. The slight adjustments were introduced to allow the representation of distribution of emissions (by %) from the sources identified in agricultural production.

Table 6: Distribution of total agricultural emissions by source

Source	Total CO2-e emissions (Gigagrams)	Emissions Distribution (%)	Total net national emissions (%)
Enteric Fermentation	61,470	66.00	10.9
Manure Management	3,249	3.49	0.6
Rice Cultivation	237	0.25	0
Agricultural Soils	16,558	17.78	2.9
Prescribed burning of savannas	11,026	11.84	2
Field burning of residues	325	0.35	0.1
Australian Agriculture	93,135	100	16.5

Source: Australian Greenhouse Office, 2005

A disaggregated distribution of emissions in chart form to help the reader develop better understanding of the distribution of agricultural emissions is shown in Figure 10. Observed variations are due rounding, disaggregation and different inventory periods:

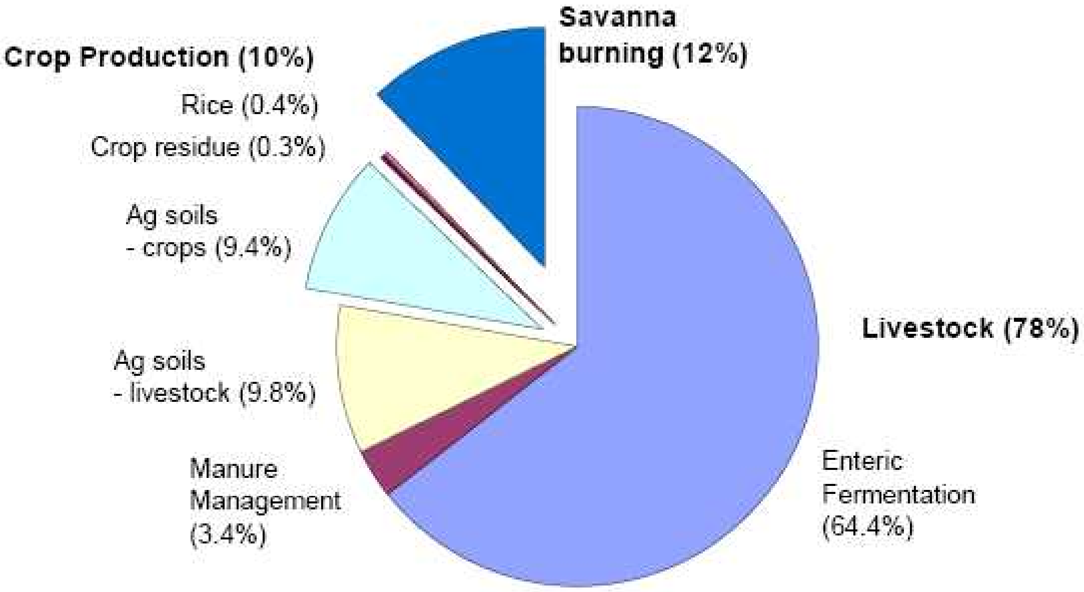


Figure 10: **Distribution of agricultural emissions by source**

Trends in the dominant sub-sectoral emissions (livestock and cropping systems) are shown in figures 11 and 12 [Source: AGO, 2004] below:

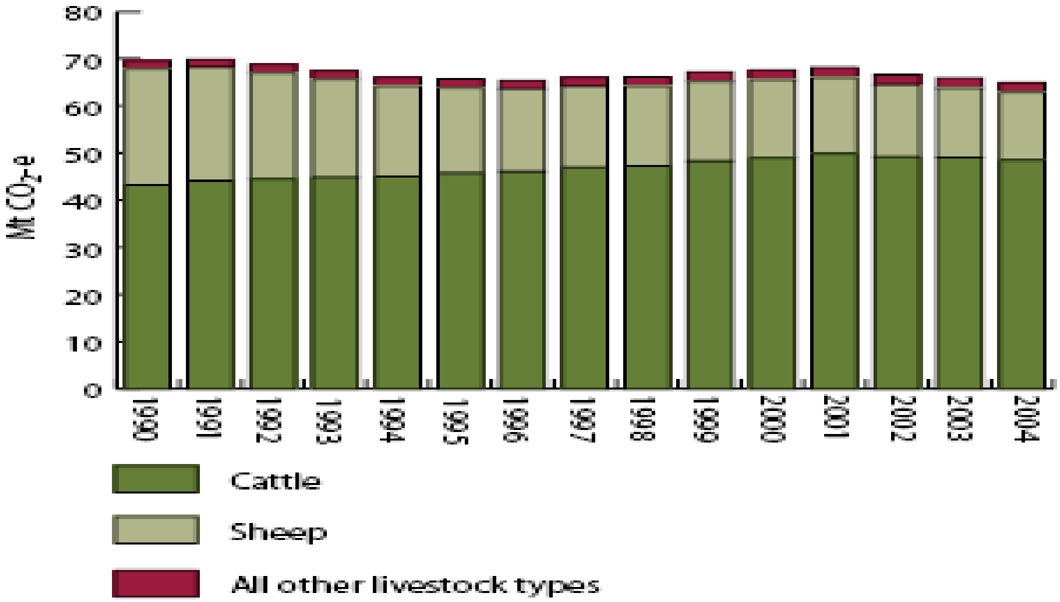


Figure 11: **Trends in CO_2-e emissions from livestock, 1990-2004**

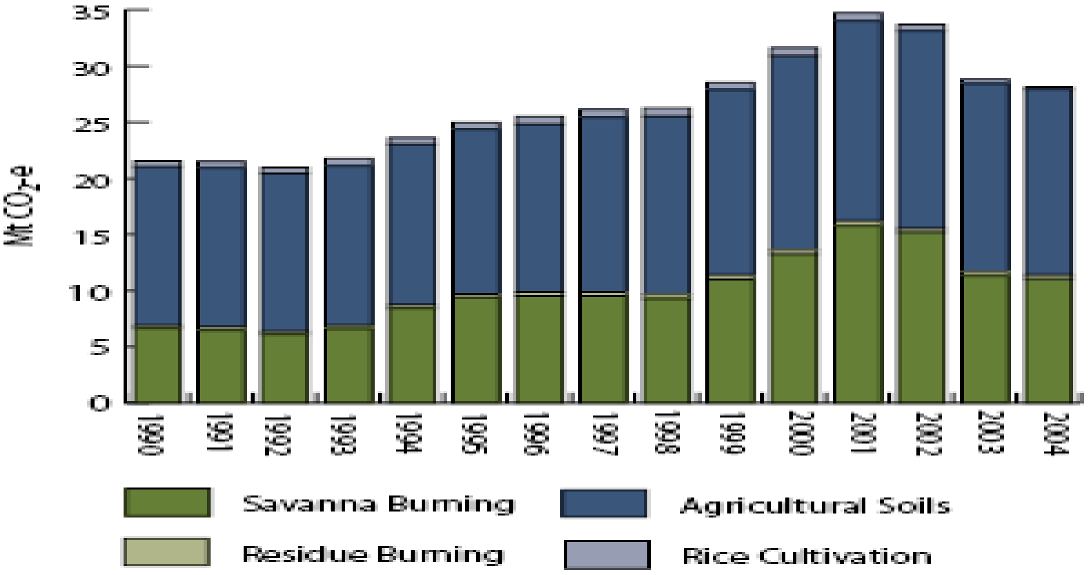


Figure 12: **Trends in CO_2-e emissions from the crop, soil and fire-related sub-sectors**

2.3.3 Predicted Effects of Global Warming

Using global climate model simulations, the CSIRO has projected future climatic conditions in Australia, which include:

- an increase in average annual temperature of 1-6 °C by 2070 over most of Australia
- an increase in the average number of extreme hot days and decrease in the average number of extreme cold days
- a decrease in annual average rainfall in the south-west and in parts of the south-east and in Queensland
- an overall drying trend for Australia due to increased temperatures and evaporation and changes in rainfall
- an increase in maximum wind speed of tropical cyclones of 5-10% in some parts of the globe by 2100 and increase in precipitation rates by 20-30%.

Impacts on agriculture are a key concern to Australia because of this sector's importance to the economy. The sector's vulnerability to climate change due to its high dependence on a steady climate is a major worry. Although agriculture does not lead the sectorial emissions figures, and despite the emissions from individual properties being relatively at acceptable levels, the sheer scale of the industry ensures the contributions by the sector are worth considering. Predicting the impacts of climate change on agriculture is complicated. Some impacts may be positive, such as increased growth and water use efficiency from higher carbon dioxide concentrations, but these could potentially be offset by increased temperatures, reduced rainfall and more frequent extreme events.

Impacts from climate change have the potential to exacerbate other land degradation challenges being faced in Australia such as salinity and soil erosion. Changes to the water balance and water tables can increase salinisation and higher flood flows and drought induced dust storms can result in dramatic soil erosion events (Australian Greenhouse Office, 2006).

2.4 Climate Change and Agriculture

The impacts to Australia's most important agricultural region, the Murray Darling Basin, could include reduced water availability; increases in weeds, pests and diseases; and impacts from changes in carbon dioxide concentrations in the atmosphere (AGO, 2006).

Australian agriculture includes cropping, horticulture, viticulture and grazing. Because of this variety and because agricultural activities are undertaken in many different regions, the impacts of climate change will be diverse (AGO, 2006). The table below summarises some of the likely impacts on different types of agriculture:

Table 7: Potential climate change impacts on selected agricultural sub-sectors

Sub-sector	Some potential impacts from climate change
Cropping	• increased crop water-use efficiency due to higher carbon dioxide concentrations but potentially reduced grain quality • reduced water availability due to both reduced rainfall and increased evaporation • reduced crop yield • changes to world grain trading • increased risk of pests, parasites and pathogens
Horticulture	• changes to frost frequency and severity may cause lower yields and reduced fruit quality • damage from more extreme events such as hail, wind and heavy rain • increased risk of pests and disease • warmer conditions may impact on chilling requirements of some fruit cultivars
Viticulture	• higher ripening temperatures may reduce optimum harvesting times • potential changes to phenology and wine quality • warmer conditions may allow new varieties to be grown in some areas • reduced water supply for irrigated crops • investment impacts due to long investment cycles
Grazing and Livestock	• increased growth from higher carbon dioxide levels but potentially offset by reduced rainfall and higher temperatures • higher temperatures reducing milk yields • decreases in forage quality • increased rainfall variability reducing livestock carrying capacity • heat stress in Northern Australia impacting on productivity and animal welfare • increased risk and rates of salinisation in some areas • increased risk of pests, parasites and pathogens

Source: ***Australian Greenhouse Office, 2006***

CHAPTER 3

DEVELOPING A COST MODEL

3.1 Preparing for a Mitigation Assessment

A mitigation assessment involves analysis of the potential costs and impacts of various technologies and practices that have the capacity to either reduce emissions (abatement) or increase terrestrial storage of carbon (sequestration) [Sathaye and Meyers, 1995]. Two key aims of a mitigation assessment are:

1. To provide policymakers with an evaluation of practices that can both mitigate climate change while contributing to national development objectives; and

2. To identify policies and programs that could enhance their adoption.

An initial assessment should be followed by more detailed evaluation of specific policies or programs designed to encourage implementation of selected practices. Eventhough this research project is a continuation of work undertaken in developing GreenGauge, it is the first phase of a mitigation assessment in that GreenGauge is merely an emissions-estimation tool with no capabilities whatsoever to assess mitigation options. As such, this work is a preliminary effort in this regard; further work will need to be undertaken to align the project with the requirements outlined above. Key factors that ought to be considered when preparing a mitigation assessment are briefly discussed in the following sections.

3.1.1 Defining the Time Frame of the Assessment

Mitigation options usually adopt a long-term strategy for reducing emissions or enhancing carbon sinks. This is largely due to the fact that changes that have the potential to significantly affect emissions in a desired manner take time to adopt and/or implement. This proved to be an impossible obstacle to overcome in the efforts to validate the developed ‘mitigation tool’.

3.1.2 Defining the Scope of the Assessment

A mitigation assessment may span numerous areas and associated sub-systems; these include energy demand and supply, agriculture, land-use change and forestry and waste management. Ideally, an assessment should include analysis of the impact of mitigation options on the macro-economy scale. Slight deviations are made from this norm in this project since this tool is not being developed at national-level scale; it is being developed at farm/sub-catchment level instead.

The scope of this assessment is set such that it investigates variables that are significant to agriculture emissions. Ultimately, the basis of the analysis (i.e. scope) was determined by the target gases (GHGs produced in abundance in Australia, namely methane and nitrous oxide) and the sub-systems identified as the major greenhouse gas sources in agricultural production. Defining the type of output required was critical to selecting the areas where efforts were to be directed.

The scope of the mitigation assessment undertaken in this project includes consideration of activities, policies and management programs that can encourage adoption of mitigation practices. Modelling approaches were kept consistent with data availability. The desired level of output detail was set to a level acceptable for foundation research; hence the analytical methods employed are not highly sophisticated. Approximate estimates of scenarios will be regarded as sufficient, hence a detailed costing model is not necessary (Sathaye and Meyers, 1995).

Figure 13 shows an overview of the mitigation structure assessment, including the scope.

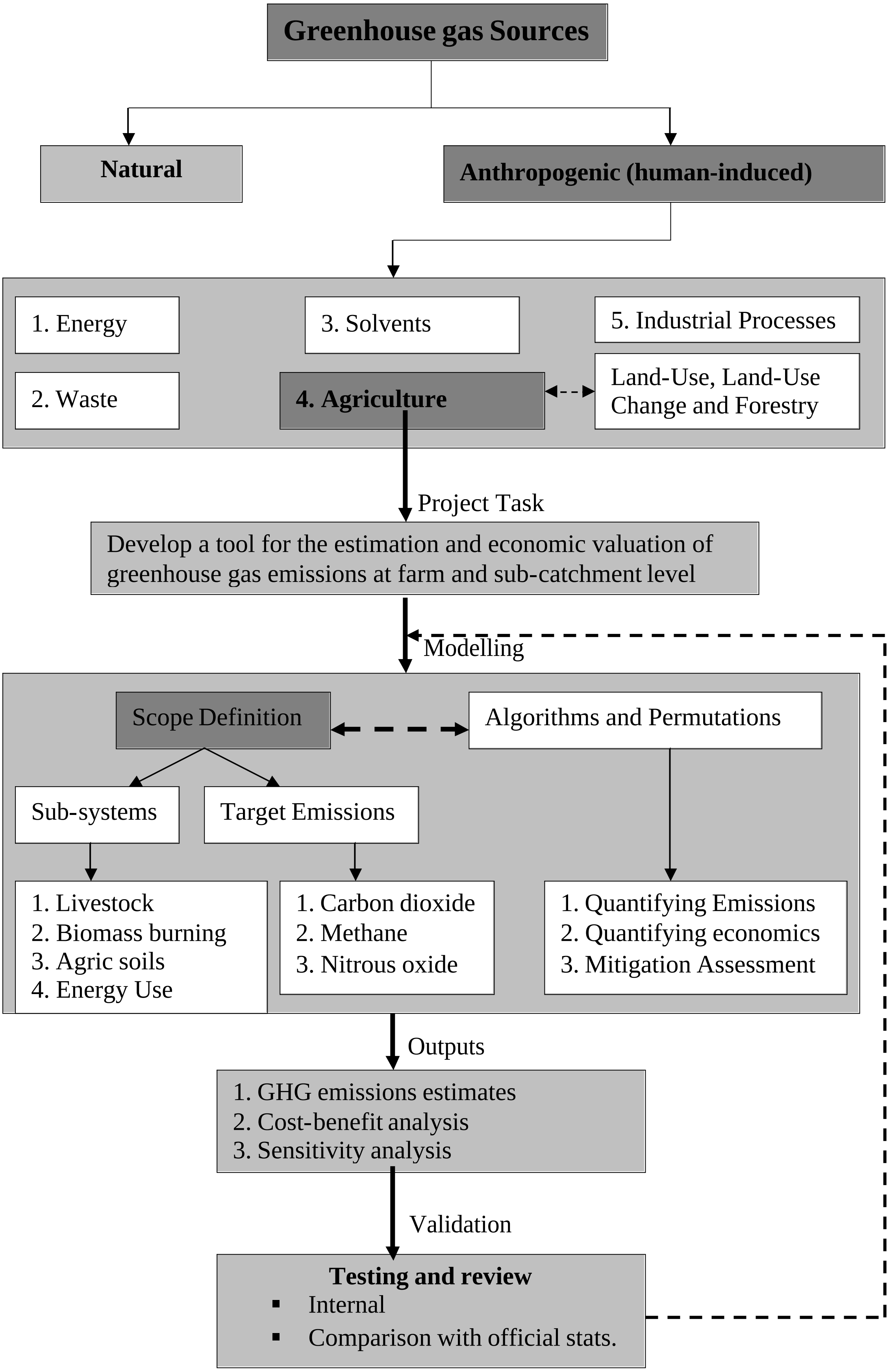


Figure 13: **Project overview defining the scope of the mitigation assessment**

The Greenhouse Gas Protocol (available at *www.ghgprotocol.org*) defines three 'scopes' of emission categories. These are:

- *Scope 1:* covers **direct emissions** (defined in the glossary) from sources within the boundary of an organisation such as fuel combustion. In this research project, the 'organisation' is the farm.

- *Scope 2:* covers **indirect emissions** (see glossary) from the consumption of purchased electricity, heat or steam produced by another organisation. Scope 2 emissions result from the combustion of fuel and do not include emissions associated with the production of fuel.

- *Scope 3:* includes all other **indirect emissions** that are a consequence of an organisation's activities but are not from sources owned or controlled by the organisation.

Scopes 1 and 2 are carefully defined to ensure that two or more organisations do not report the same emissions in the same scope. The bulk of work undertaken in this project is restricted to direct on-farm emissions (i.e. Scope 1). Some on-farm activities such as irrigation are powered by purchased electricity units, hence will be treated as Scope 2 emissions (see Appendix G).

3.2 The Structure of a Mitigation Assessment

The structure of a mitigation assessment varies depending upon its intended goals and defined scope. Once basic details have been outlined, the remainder of the assessment undertakes an evaluation of what might or could occur in the future. The development of future scenarios requires data on activities and sub-systems that emit GHGs as well as those with the potential to sequester carbon. Development of scenarios requires a projection of expected future intensities of each activity. Once options have been for inclusion in the assessment, it is necessary to characterise practices with respect to their costs (e.g., performance, environmental implications, labour and infrastructure requirements). Such practices may include those already available or in use, as well as those that are expected to be available in the future (Sathaye and Meyers, 1995).

3.3 Available Mitigation Analytical Tools

Despite an extensive literature review conducted to identify tools similar in nature and scope to the one this project sought to produce, identical tools specifically built for Australian agriculture were discovered. Sectoral tools were found for the grains and dairy industries, but both models are limited to emissions estimation only, and contain no economic or mitigation components whatsoever. However, concepts and guidelines were obtained from tools in and for countries overseas, mainly Canada and the United States. Table 8 gives examples of some of these tools:

Table 8: Examples of Analytical tools available for mitigation assessments

Topic	Analytical Tools Available
Energy Sector	
Accounting Models	LEAP, STAIR
Optimisation Models	MARKAL, ETO
Iterative Equilibrium Model	ENPEP
Decision Analysis Framework	Analytical Hierarchy Process (AHP)
Non-Energy Sectors	
Forestry	COPATH, COMAP
Agriculture	EPIC, CENTURY
Rangelands	CENTURY
Waste Management	Landfill Gas Model
Energy-Economy Interaction	LBL-CGE, MARKAL-MACRO

Analytical tools found useful in some respects were those under non-energy sector category, especially the ones listed for agriculture and forestry. Analytical methods used largely focus on the estimation of carbon and other GHG flows. The COPATH model has been used for carbon accounting in forestry, while COMAP has been developed for estimating the impacts of mitigation options in the same sector. EPIC and CENTURY are plant/soil simulation models which may be used to simulate carbon cycling dynamics in agricultural ecosystems (Sathaye and Meyers, 1995). Simple spreadsheet models are preferred for assessing methane mitigation options in agriculture, a trend which this research project follows.

Other mitigation assessment tools not listed in the table above include *Overseer* for soil-nutrient simulation (developed in neighbouring New Zealand) and GACMO (Greenhouse Gas Costing Model).

3.4 Criteria for evaluating a model

Cost models provide direct estimates of effort. These models typically have a primary cost factor such as size and a number of secondary adjustment factors or *cost drivers*. Cost drivers are characteristics of the project, process, products, or resources that influence effort. Cost drivers are used to adjust the preliminary estimate provided by the primary cost factor (Fenton, 1997).

A typical cost model is derived using regression analysis on data collected from past projects. Effort is plotted against the primary cost factor for a series of projects. The line of best fit is then calculated among the data points. If the primary cost factor were a perfect predictor of effort, then every point on the graph would lie on the line of best fit. In reality however, there is usually a significant residual error. It is therefore necessary to identify the factors that cause variation between predicted and actual effort. These parameters are added to the model as cost drivers. Boehm (1981) provides the following criteria for evaluating cost models:

1. *Definition* – Has the model clearly defined the costs it is estimating, and the costs it is excluding?

2. *Fidelity* – Are the estimates close to the actual costs expended on the projects?

3. *Objectivity* – Is it hard to adjust the model to obtain any result you want?

4. *Constructiveness* – Can a user tell why the model gives the estimates it does?

5. *Stability* – Do small differences in inputs produce small differences in output cost estimates?

6. *Scope* – Does the model cover the entire range of on-farm activities whose costs you need to estimate?

7. *Ease of Use* – Are the model inputs and options easy to understand and specify?

8. *Prospectiveness* – Does the model avoid the use of information that will not be well known until the project is complete?

The guides outlined above are adopted to dictate the direction of the model.

3.5 Introduction to Model Components

3.5.1 Agricultural Soils: Chemical Applications

It is common practice among farmers to occasionally administer chemicals to their crop depending on soil type (fertility) and crop requirements. Applications include fertilisers (to boost soil fertility and supply more nutrients to crop), pesticides (to control and/or eradicate pests) and herbicides (to control weeds). Of these three, fertiliser application has sufficient economic and GHG emissions significance to warrant detailed investigations.

Agricultural soils, under which fertiliser applications are categorized, constitute 17.8% of total agricultural emissions (16.558 of 93.135 Mt CO_2-e). The concentration of N_2O has increased by 16% since 1750, and are estimated to have increased by almost 30% between 1990 and 2002, due in part to increased cropping acreage and fertiliser application rates (AGO, 2002). Although atmospheric concentration of N_2O is much smaller (314 ppb in 1998) than of CO_2 (365 ppm), its global warming potential is 310 times more effective in a 100-year time horizon. Currently, it contributes about 6% of the overall global warming effect but its contribution from the agricultural sector is about 18%. Of that, almost 80% of N_2O is emitted from Australian agricultural lands, originating from N-fertilisers (32%), soil disturbance (38%), and animal waste (30%).

As outlined in the abstract, the modeling in this project is 3-phased. The first component attempts to quantify greenhouse gas emissions resulting directly from the chemical applications. 'Chemical applications' in this project refers to fertiliser use; other farm chemicals such as herbicides and pesticides are included only partially i.e. only the cost of application (energy used) is included, relative direct emissions are not estimated due to lack of appropriate algorithms in the NGGI workbooks. The key parameters are quantity of fertiliser applied, type (to determine the nitrogen content), preset emission factors and conversion factors. All are fed into an emissions algorithm to output an estimate of the quantity of nitrous oxide released, which then is converted to an equivalent amount of carbon dioxide. Further details on exact calculations are given in Chapter 5.

The second phase attempts to quantify net expenses and gains associated with use of fertilisers to possibly increase yield. A net profit is calculated by evaluating the difference between total returns and total expenditure. Total expenditure sums purchase and application costs. Total returns are effectively revenue collected from sale of yield, and include a *Direct Fertiliser-Use Effect* (DFE) price; the DFE price is the difference between returns when fertiliser is used compared to when it is not. This is crucial to sensitivity analysis: considering the (possible) long-term detriment to the environment, are the returns from using fertilisers worth the practice?

The net profit described above is inconsiderate of the environmental impacts of agricultural production. Therefore a hypothetical costing approach is introduced into this second phase component to quantify environmental implication in economic terms. A rough dollar-value estimate is attached to a set of undesirable consequences of chemical use: a carbon-tax fee for resultant emissions, an estimate charge for pollution of underground water resources (from leaching and deep percolation), a fee for reduction in product quality (assuming impurities are retained in produce due to absorption of trace minerals in the fertiliser) and other socio-environmental impacts.

A new ‘virtual’ profit is now calculated to reflect ‘true’ returns where farmers are held accountable for their environmental underperformances. The virtual profit estimate is calculated by subtracting the total environmental charges from the ‘real’ net profit.

The final phase of the chemical-applications component attempts to investigate the feasibility of possible mitigation options. The effects of reducing the mass of fertiliser applied, use of a different type of fertiliser (with a lower N-content), stubble retention and inclusions of crops with N-fixing capabilities (e.g. legumes) are analysed and new profits (both ‘real’ and ‘virtual’) are weighed against the new (lesser) emissions figures. Effectiveness of the mitigation option is evaluated in terms of an emissions per output value (e.g. total emissions per $ gained in return). Based on a number of combination scenarios, best management practices can be drawn from these estimates. This approach is adopted in the majority of the modeling exercises for the subsystems discussed in the rest of this chapter, with appropriate adjustments where necessary.

3.5.2 Agricultural Soils: Tillage

It is essential at this point to distinguish between different types of tillage practices to eliminate the confusion arising from the terminology and connotations given to soil management regimes in Australia. Tillage operations can be divided into two main groups: conventional and conservational practices. Conventional tillage practices are the ‘traditional’ tillage methods that undertake soil disturbance and a broad level. In contrast, conservational methods aim for negligible disturbance, with practices ranging from zero tillage (direct drill) to reduced (minimal tillage). Crop residue (stubble) may be burnt, grazed or retained in either tillage system. In this report, the terms full tillage (FT) and traditional tillage (TT) are used interchangeably to refer to conventional tillage (CT) methods. Similarly, conservational tillage is referred to as no tillage (NT), zero tillage (ZT), direct drill (DD), reduced tillage (RT) and minimum tillage (MT). Individual definitions and distinctions can be viewed in the glossary.

Management practices that simultaneously improve soil properties and yield are fundamental to maintain high crop production and reduce detrimental impact on the environment. A large proportion of cropping properties in Australia undertake cultivation (tillage) as part of their seed-bed preparation activities. By breaking up soil clods and loosening soil aggregates, more soil mass is exposed to erosion agents such as wind and water. There are GHG emissions as well associated with tillage practices, depending on type and extent. Soil themselves have varying carbon-store capabilities, hence breaking up a soil mass releases this soil-bound carbon into the atmosphere. Besides exposure to eroding agents and releasing carbon, tillage accelerates the rate of mineralisation and conversion of soil nitrogen to nitrous oxide. These emissions might not be quantitatively enormous per property, but the cumulative effect could be significant based on the sheer scale of agricultural production in Australia.

The important variable in the tillage analysis is the type used on the property, whether conventional or conservational. It is difficult to predict significant differences in the GHG emissions for different tillage types, but their environmental impacts could vary considerably. The report therefore seeks to document trends in the economics of different tillage methods (specifically effect on yield), energy use (to calculate associated net GHG emissions) and effects, if any, of reverting from conventional to conservational tillage. This information is essential to overcome the obstacles to the uptake of improved (conservative) tillage practices by farmers and landholders.

While emissions estimates resulting from the cultivation of agricultural soils can not be guaranteed, the use of conservation tillage techniques have been proven to be effective in reducing soil organic carbon losses (Kern and Johnson, 1993). Conservation tillage techniques minimize wind and water erosion, conserve moisture and reduce fuel consumption; such systems could potentially reduce production costs, but require a higher level of farming skill and an increase in the consumption of other farm resources as portrayed by the New South Welsh (NSW) case study given below:

<u>Case Study:</u>

In New South Wales alone, production losses associated with erosion and soil structural design have been reported at around $700 million/year (Roberts and Packer, 2000). Research conducted between two farms, one using conventional tillage and the other conservational, during an above-average rainfall season returned observations favourable to conservational farming. Table 9 compares the production figures:

Table 9: Comparative income and expense analysis of conventional vs. conservational farming

Practice	**Conventional Tillage**	**Conservational Farming**		
Crop	*Wheat*	*Wheat*	*Canola*	*Legume*
Total income ($/ha)	187.85	395.70	423.15	240.00
Total Costs ($/ha)	137.83	277.19	362.27	237.32
Gross Margin ($/ha)	50.02	118.51	60.78	2.68

Source: **Smith, 2001**

For conservation farming, inputs required to achieve yields tabulated above are significantly greater than under conventional farming. For example, eight different herbicides (for weed control) were used under conservational farming at expenditure rates of $99.26/ha compared to $37.22/ha under conventional farming (use of glyphosate and cultivation). Fertiliser use under the conservational system was 300% higher than that under conventional. Obviously, GHG emissions resulting from the increased fertiliser use will be greater for conservational than for conventional tillage, hence in line with the provisions of the costing model, the carbon-tax charges incurred will be higher. Depending on the carbon price ($/ tCO_2-e ha^{-1}) the ‘virtual’ profit could eventually be less for conservational tillage despite other environmental fees being minimised. Through the use of this tool, management has the means to weigh alternative scenarios and optimise activities to attain a ‘best of both worlds’ result.

3.5.3 Electricity Use: Irrigation

The agriculture industry is the major water user in the Australian economy, with estimates showing that agriculture accounted for 67% of water consumption in the period 2000-2001, the bulk of which is used for irrigation purposes. Most irrigated land is located within the confines of the Murray-Darling Basin, which covers parts of NSW, Victoria, Qld and SA.

A substantial amount of energy is expended in operating an irrigation system, from installation to operation and maintenance. Using the Scope 1 section of the

Greenhouse Gas Protocol (see section 3.1.2), a simple algorithm is used to estimate the amount of greenhouse gas emitted as a result of electricity consumption. This amount can be easily obtained from electricity bills. Conversion from a price paid to amount of electricity consumed might be necessary, and is obtained by dividing the total electricity charge (AUD) by the tariff charge ($/kWh). That is:

$$\text{Electricity consumed (kWh)} = \frac{\text{Total electricity charges (\$)}}{\text{Regional tariff charge (\$/kWh)}}$$

Poorly-run schemes compound land degradation issues. Irrigated agriculture contributes significantly to changes in water quality and flow in major river systems due to accumulation of salts, nutrients, sediment and agricultural chemicals. It affects local and regional water tables and alters catchment ecology. The cost component of the Excel model attempts to quantify the financial implications of these environmental impacts of irrigation systems. Alternative (pressurised) irrigation systems have a less pronounced environmental impact compared to conventional surface irrigation (flooding); they commonly use less water but at much higher uniformities. However, a common criticism of pressurised irrigation systems is that they replace water use with energy use. Sensitivity investigations take this and other options into account. Table 10 shows the range of energy use given by different researchers.

Table 10: Comparison of primary energy consumed by irrigation systems (GJ/ha-yr)

Irrigation Technologies	Batty, et al. (1975)	Chen, et al. (1976)	Down, et al. (1986)	Irrigation Training and Research Centre (1996)
Border check	2.0	1.12	1.8 – 7.0	N/A
Centre Pivot	11.1	21.4	6.0 – 14.9	47.6
Drip	8.9	6.8	21.0 – 67.4	46.1

As part of further research and model development in future, the Excel tool could be expanded to assist in decision-making with regards to irrigation activities. Features incorporated would be specifically coded to allow:

- Comparison of irrigation schemes; pressurised-type versus surface irrigation
- Ranking irrigation systems based on environmental performance.

Figure 14 shows relative proportions of common irrigation systems across Australia.

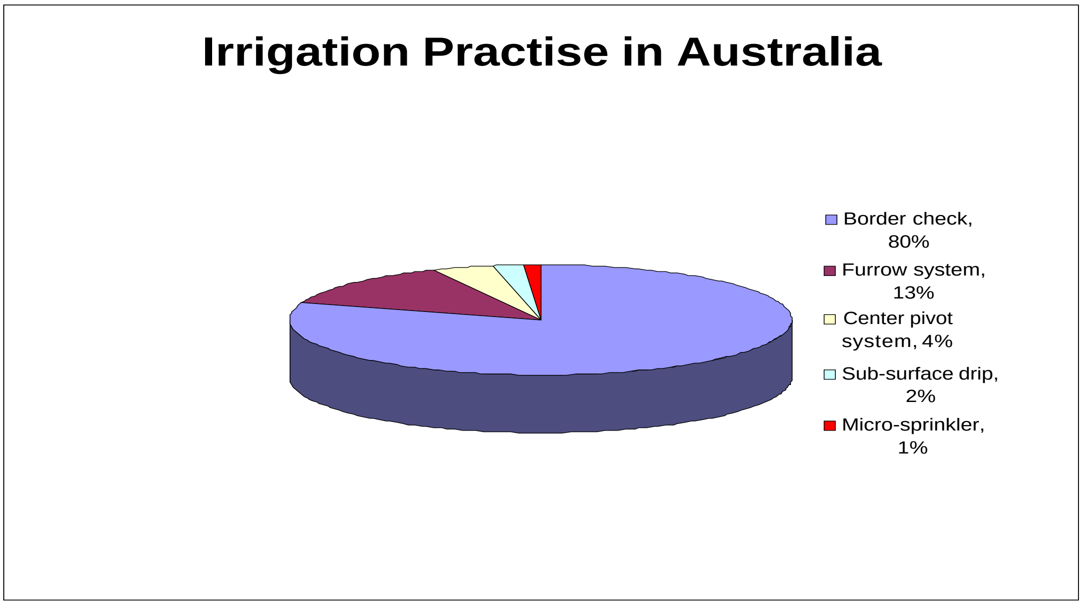


Figure 14: Distribution of irrigation systems in Australia (Source: ANCID 2002)

According to Figure 14 above, the border check system is the broadest-used form of irrigating. Border check consumes between 1 and 7 GJ of electricity per hectare per year (Table 11), with a median value of 4 GJ/ha-yr. In the 2002-03 season, the total area of agricultural land irrigated was 2.378×10^6 hectares, implying the area irrigated using the border check system was approximately 1.9×10^6 hectares, giving a national electricity consumption of 7.61 PJ (petajoules). Combined emissions resulting from this much electricity consumption range between 0.63 and 2.75 Mt CO2-e, depending on the emission factor. Two key assumptions have been introduced in deriving this figure; one is that the bulk of the on-farm electricity consumption is for irrigation purposes and the second is that emissions can be calculated using a median value.

More information on calculating emissions from electricity use and the implications of the assumptions is given in Chapter 5. A summative table of the quantities of energy used at different stages of a lifecycle are given for different irrigation schemes in Table 11. These figures are included to showcase two key variables: the energy consumption for different irrigation technologies as well as the types and distribution of energy forms. In the model, only the *total* figure is used in calculations.

Table 11: Life cycle energy analysis of irrigation systems

Life cycle Energy analysis of Irrigation Technologies			
	GJ/hayr^{-1}		
	Border check	Centre pivot	Sub-surface drip
Initial Embodied Energy	1.4839	4.4235	5.4711
Recurring Embodied Energy	0.0445	0.1106	0.0821
Operational Energy	6.469	10.3759	9.4690
Decommissioning Energy	0.0148	0.3539	0.6565
Total	8.0123	15.2638	15.6786

***Source:* Amaya, 2000**

3.5.4 Fuel Combustion

Fuel use on-farm is largely to power machinery for cultivation, sowing, harvesting, pest and weed management and other activities. Associative emissions algorithms outlined in Chapter 5 evolve around the type of fuel used as well as the **total** amount of fuel expended for different activities (i.e. emissions are not segmented into individual emissions for cultivation, harvesting, etc).

The algorithms outlined in the AGO's *Factors and Methods workbook* (2005) are used to effect some changes into GreenGauge for simpler modelling. The range of fuels is increased to improve usability, while using algorithms that are easier to understand (for the average farmer) and whose logic is easy to interpret. The methodology used in Greengauge to estimate emissions resulting from fuel consumption are based on the energy densities of different fuel types (auto diesel, petrol and biodiesel), the quantity of fuel used and the percentage of fuel oxidised to determine an emission factor. The processes modelled under the fuel consumption subsystem are irrigation and cropping activities (land clearing, soil cultivation [scarifying, tillage, etc], planting, herbicide and fungicide application, and harvesting). An entirely new algorithm that bases emissions from irrigation systems using electricity is introduced into Greengauge as another way of increasing the scope of the tool. Post-harvest activities are not included in calculations.

3.5.5 Livestock Production

Emissions from the livestock industry constitute nearly 70% of agricultural emissions in Australia. The chief sources from this subsystem are enteric fermentation by ruminant (and some non-ruminant) stock and manure management processes. Eventhough livestock production forms the most significant component of agricultural emissions, the focus of this report primarily is on cropping systems. Livestock emissions algorithms are included for completeness of the report, and as help achieve the project objective of updating the livestock component in GreenGauge. The critical cost analysis documented for agricultural soils, vegetation management and energy worksheets are not undertaken for the livestock sub sector. However, the third component of the worksheets (i.e. the sensitivity/mitigation analysis) is undertaken to a satisfactory level.

Enteric Fermentation

Enteric fermentation primarily produces methane, with a total value of 61.5 Mt CO_2-e. This represents 86% of total methane emissions from agricultural production which stand at 71.88 Mt CO_2-e, which in turn implies methane emissions form 77% of agricultural emissions (71.9 of 93.1 Mt CO_2-e). In the rumen a group of microbes called methanogens are responsible for producing methane, utilising surplus hydrogen in the rumen to reduce carbon dioxide and form a new compound, methane. The methane produced is then belched and exhaled by the animal. The relative quantity of gas released per beast (or per property) is dependent on the type and quantity of feed ingested by livestock. Possible emissions-reduction efforts therefore evolve around changing the type of feed used as well as technologies that enhance effective digestion through the use of chemical supplements.

However, methane gas is a high energy source. Escape of this gas represents a significant loss of energy from the production system that can and should be redirected back into production. The key is therefore to provide another mechanism for reducing hydrogen levels in the rumen, otherwise normal digestion will be adversely affected and the energy savings will not be realised in improved production.

Manure Management

Manure management processes emit a total of approximately 3.25 Mt CO_2-e (methane emissions form 1.95 Mt CO_2-e and nitrous oxide the remaining 1.3 Mt CO_2-e). Emissions from this component are largely due to the disintegration of animal wastes while still retained in manure management systems

For this project, calculations for nitrous oxide emissions from animal waste are included under the livestock category to aid logical reporting by landholders and on-ground coordinators. Under the NGGI methodology, the nitrous oxide emissions emanating from deposited livestock wastes (urine and faeces) are considered soil processes and so would be included under that section. To retain some level of conformity to NGGI reporting, the results generated from estimating emissions will be reported as a component of the Agricultural (Cultivated) Soils category, while the actual methodology for estimating these emissions is located under the Livestock category.

3.5.5 Vegetation Management

This category is concerned with the emissions and removals of carbon dioxide as a result of anthropogenic activities that influence sources and sinks. In the original tool (Greengauge), a detailed discussion of emissions and sequestration from forestry was undertaken under the vegetation subsystem. However, the scope of the current project is emissions from consumption of energy resources (fuel and electricity) in agricultural production (mainly cropping systems). Deviation from Greengauge is taken by dissociating the forestry component from agricultural production. It is included in this report only for completeness of the project in line with the mother-model. Focus in this subsystem was set on updating the emission-estimation algorithms where new data was available. A number of activities are of significance including:

- clearing of native vegetation for agricultural use,
- sequestration associated with the accumulation of woody biomass (vegetation thickening),
- regrowth of native vegetation following deforestation, and
- deliberate planting including environmental plantings, windbreaks, and farm forestry (agroforestry).

This subsystem is covered extensively in GreenGauge, both in the Excel model and the supporting documentation; no attempt to re-invent the wheel was entered into. Sub-components included biomass burning and prescribed burning of plant material (agricultural crops are regarded as vegetation in this project). Stubble management practices (see glossary) are included in this project at an introductory (basic) level, and used primarily to investigate mitigation options in tillage systems.

CHAPTER 4

METHODOLOGY

4.1 Summary of Modelling Approach

The project is centrally based on iterative processes, both in the evaluation of technical and logical validity and in generating an understanding of end-user requirements through direct engagement and adaptive responses. Eclecticism is also imposed given that the development of the cost-model crosses technical, functional, cultural and social boundaries, drawing from the fields of mathematics, sociology, ecology, resource management and economics (Stephenson, 2003).

The solution process involved a sequence of development phases commencing with an extensive literature review to acquire intimate knowledge of agricultural sources, sinks, national and state emissions, evaluation of other greenhouse models and other relevant subjects. The methodology adopted is such that a model framework is set up and reviewed internally (by NCEA and/or QMDC). Subsequent models are then constructed based on the feedback and recommendations from the reviewing process. Initial models were designed to a point where personal input from literature research was effectively exhausted and validation required from ‘experts’ with practical acquaintance and experience of technical and logistics matters.

A summary of the major technical activities undertaken in the development phases is given below:

1. **Mapping** and review of records to collect relevant production and land management data from the landholder,

2. **Simulation** of estimated:

    - ➢ net greenhouse emissions associated with their particular composite of farm activities, using *GreenGauge*, and exploring alternative scenarios based on constructed hypotheticals;

    - ➢ net expenditure per farm activity, using the economic cost-model, and investigating the feasibility of alternative farming practices

Due to time restrictions, mapping and data acquisition were carried out using case studies instead of the preferred method of consultation with willing stakeholders for access to farm records. Simulation was conducted with the aid of Microsoft Excel Software package, where constants, variables and other parameters acquired at the mapping stage are fed into the developed simulation model. The algorithms and typical output are outlined in Chapters 5 and 6 respectively.

The general format that will be followed to produce the cost model is depicted in figure 15 (overleaf). The key stages are:

1. Literature review (desktop research);

2. Mapping (compiling production data);

3. Simulation (estimating emissions and associated costs); and,

4. Validation (testing and further[a] review).

(a); review of the initial (framework) model and subsequent modifications.

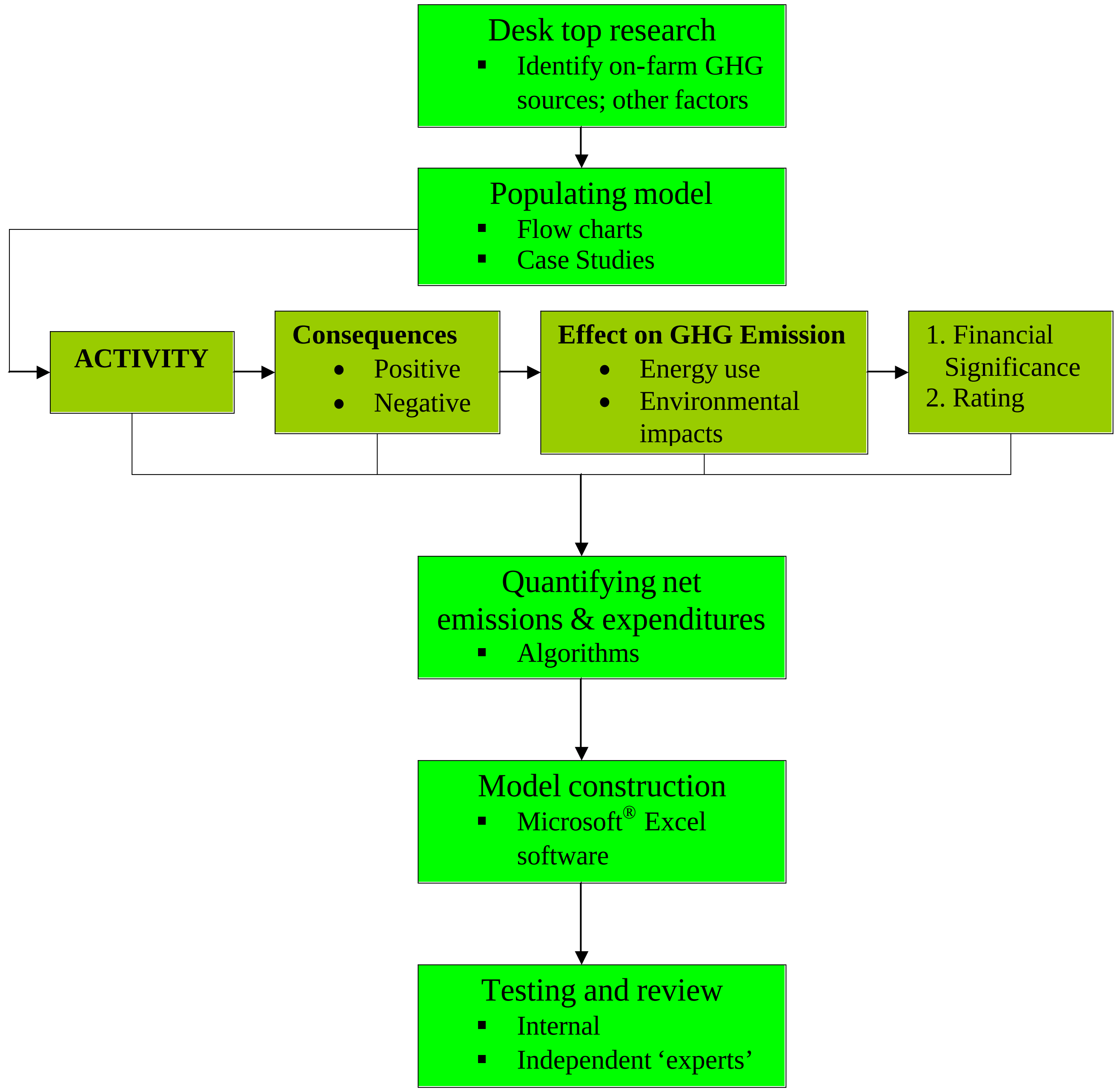


Figure 15: **Outline of the research project methodology**

The subsystems included in the modelling phase of the project are outlined in section 3.5. These are identified by the AGO as the significant sources of emissions in agriculture. The ‘populating model’ stage is further broken down into sub-sectors shown in Figures 16 and 17. Focus in this project is set solely on the primary (direct) sources associated with basic on-farm activities.

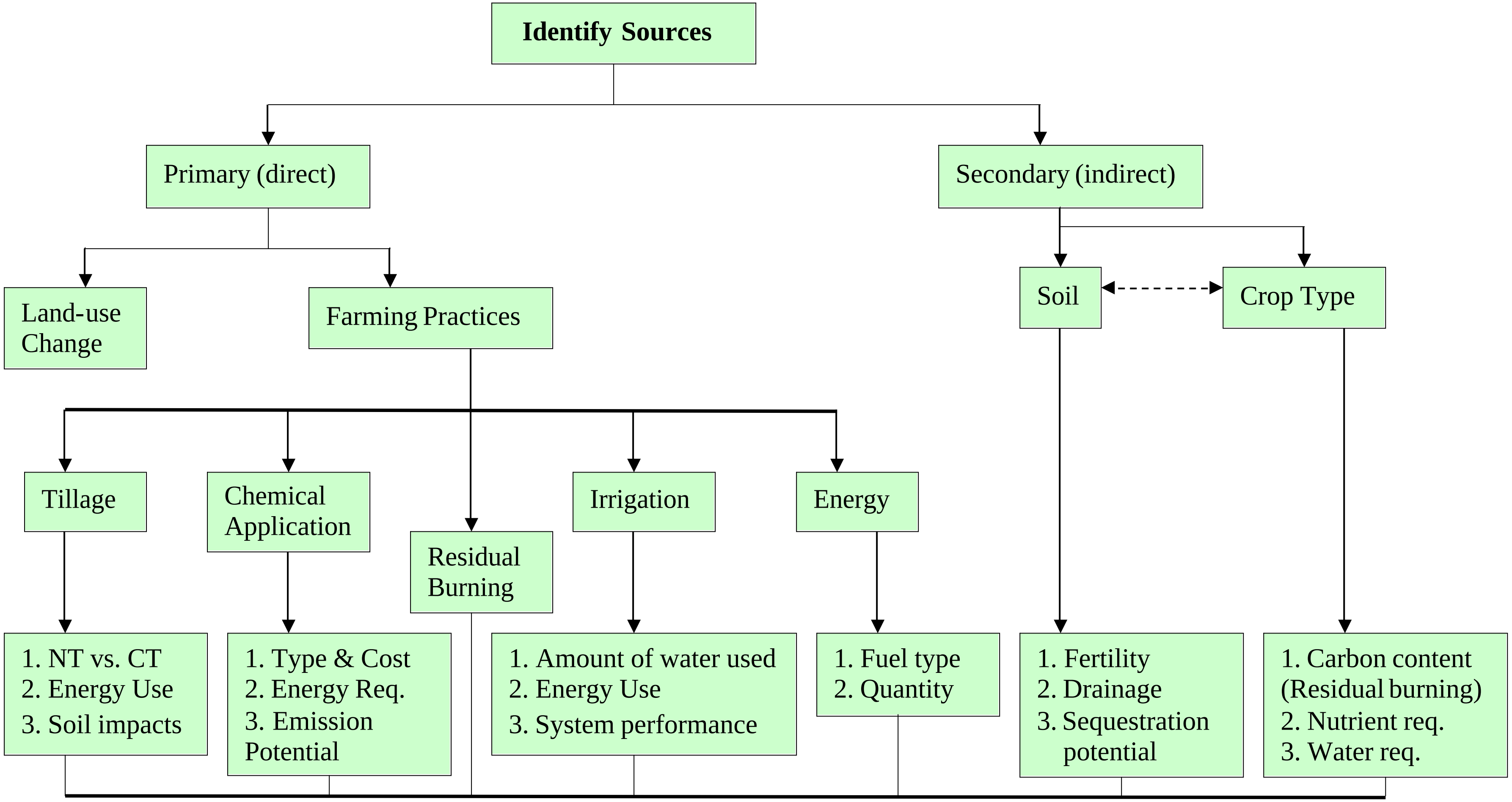


Figure 16: **Classification of model components by emissions source and type**

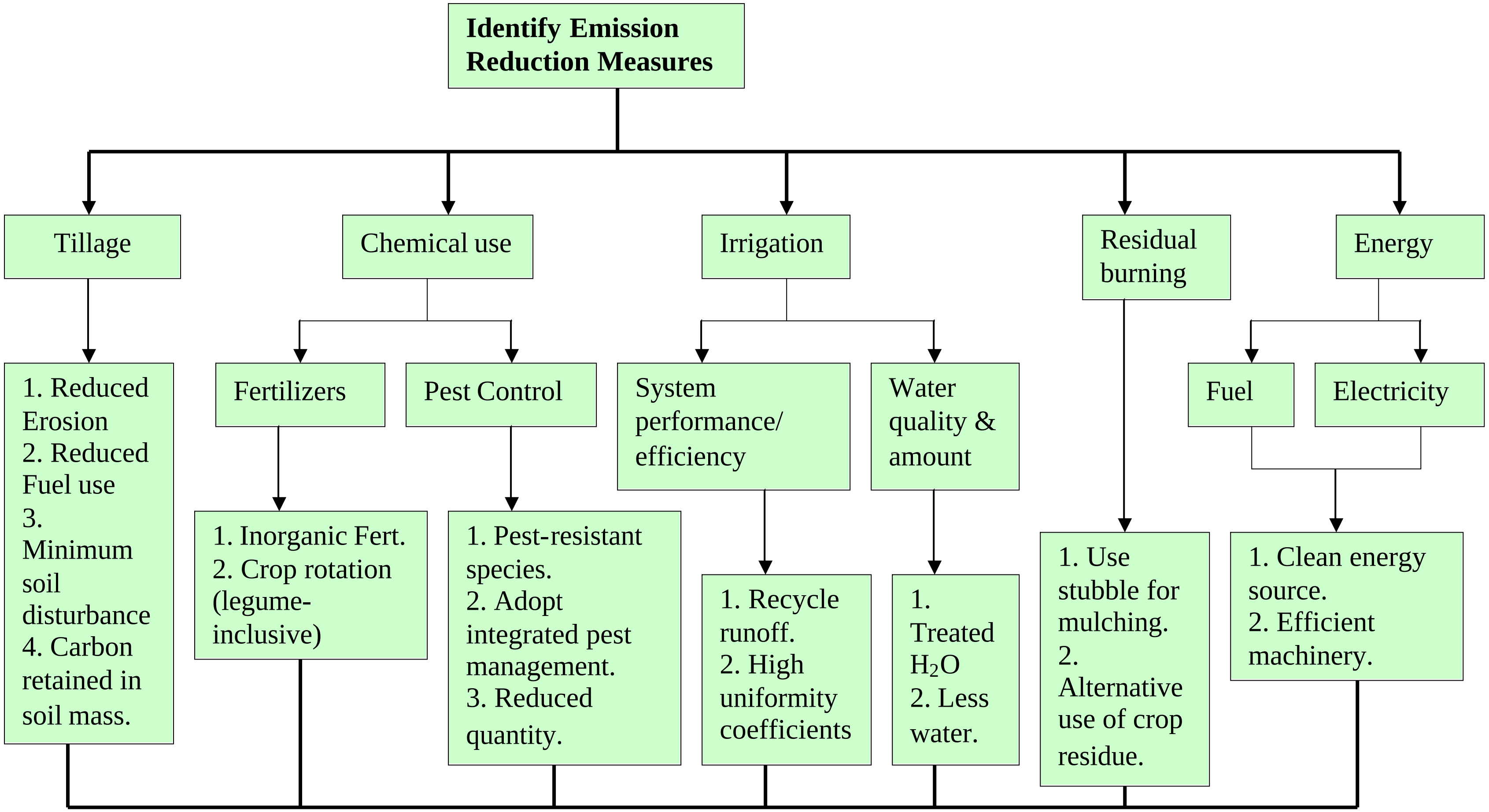


Figure 17: **Summary of emissions-reduction measures**

Construction of the model framework outlined in Chapter 3 (Figure 13) was representative of a top-down modeling approach. In a **top-down** model an overview of the system is formulated, without going into detail for any part of it (for example, anthropogenic sources are given but subsystems responsible for actual emissions are not). Each part of the system is then refined by designing it in more detail; in this case, subsequent parts of the dissertation identify the agricultural subsystems responsible for the sector's emissions (e.g. livestock production, soils, energy). Each new part may then be refined again, defining it in yet more detail until the entire specification is detailed enough to validate the model (distinguishing between manure management and enteric fermentation for livestock, classifying soils emissions into fertiliser use and cultivation, etc). The initial model was designed in this format.

By contrast in **bottom-up** design individual parts of the system are specified in detail. The parts are then linked together to form larger components, which are in turn linked until a complete system is formed. Strategies based on this bottom-up information flow seem necessary and sufficient because they are based on the knowledge of all variables that may affect the elements of the system. This was undertaken in the construction of the end product (i.e. the Excel model).

4.2 Model Framework

The initial model was constructed to allow critical review by key stakeholders and academic 'experts'. The framework was set out to outline the scope of the final model, as well as define in detail the types emissions and range of costs the final product would encompass. This initial work was presented at a WaterTAP's technical session at the National Centre for Engineering in Agriculture (NCEA) headquarters at the University of Southern Queensland as the first step towards validation.

Using the ideas and suggestions from the discussions at the presentation, the initial framework was refined and adjusted to reflect the scope more explicitly. Examples of typical framework templates are shown in Figures 18, 19 and 20 for the agricultural soils (chemical applications), energy use (irrigation) and tillage subsystems respectively. These are presented in a crude manner to accommodate as much detail as possible. Some of the details were discarded during the further development and further development phases towards final modelling, discussed in detail in Chapter 5.

Notation:

- The ‘+’ signs on the cost columns (denoted by $) indicates expenditure (e.g. purchase costs, penalties, e.t.c.);
- The ‘-’ signs indicates a financial gain (e.g. from sale of produce, profits, rebates and other incentives, e.t.c.);
- The ‘±’ sign reflects an uncertainty of the effect of a variable, or the exact magnitude and implications of that variable on other components;
- The ‘x’ values are replaced with numerical values in the cost component of the model. The accuracy of the model output is inextricably dependent upon the accuracy of these x-values.

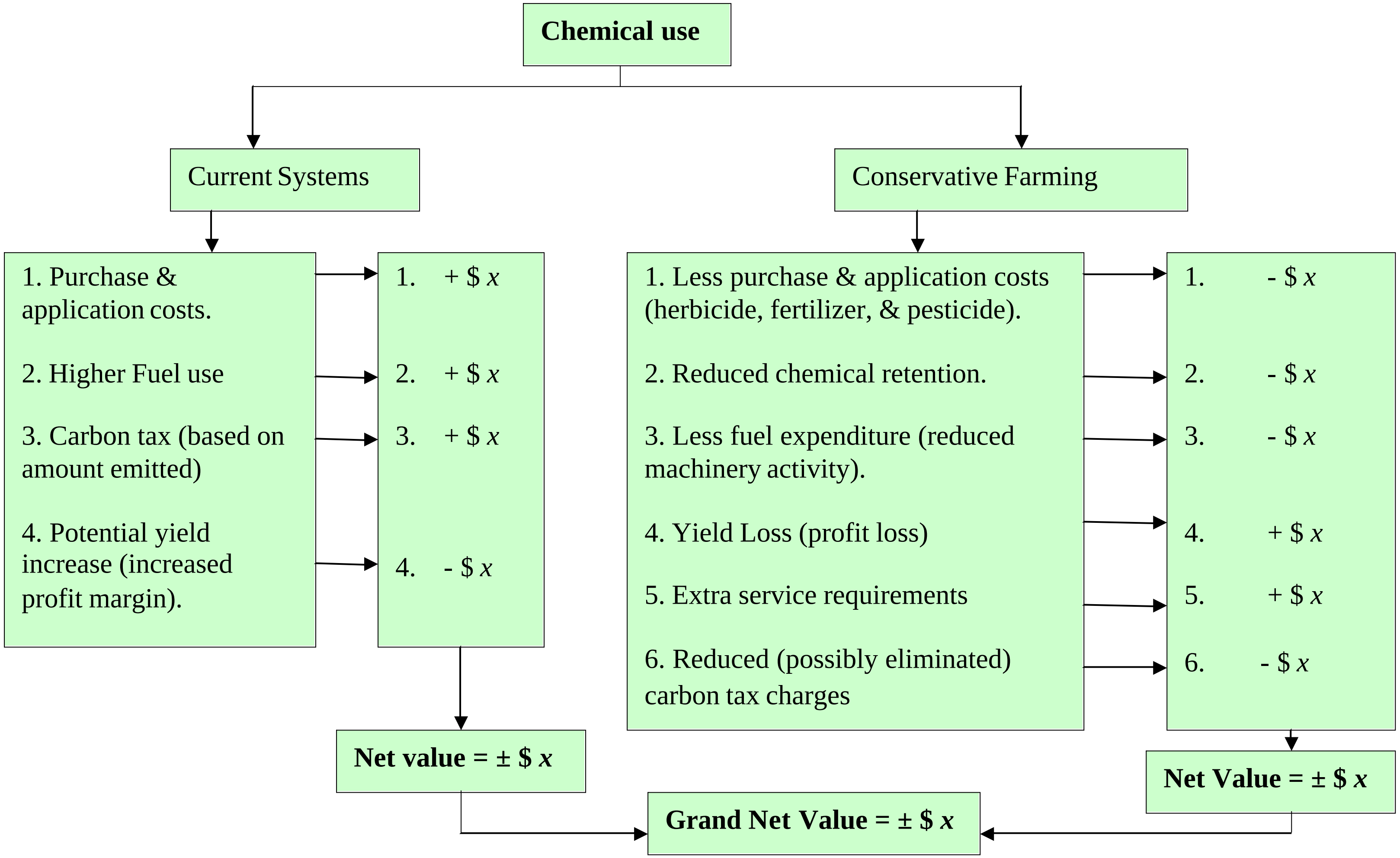


Figure 18: **Typical template for the initial model; chemical use**

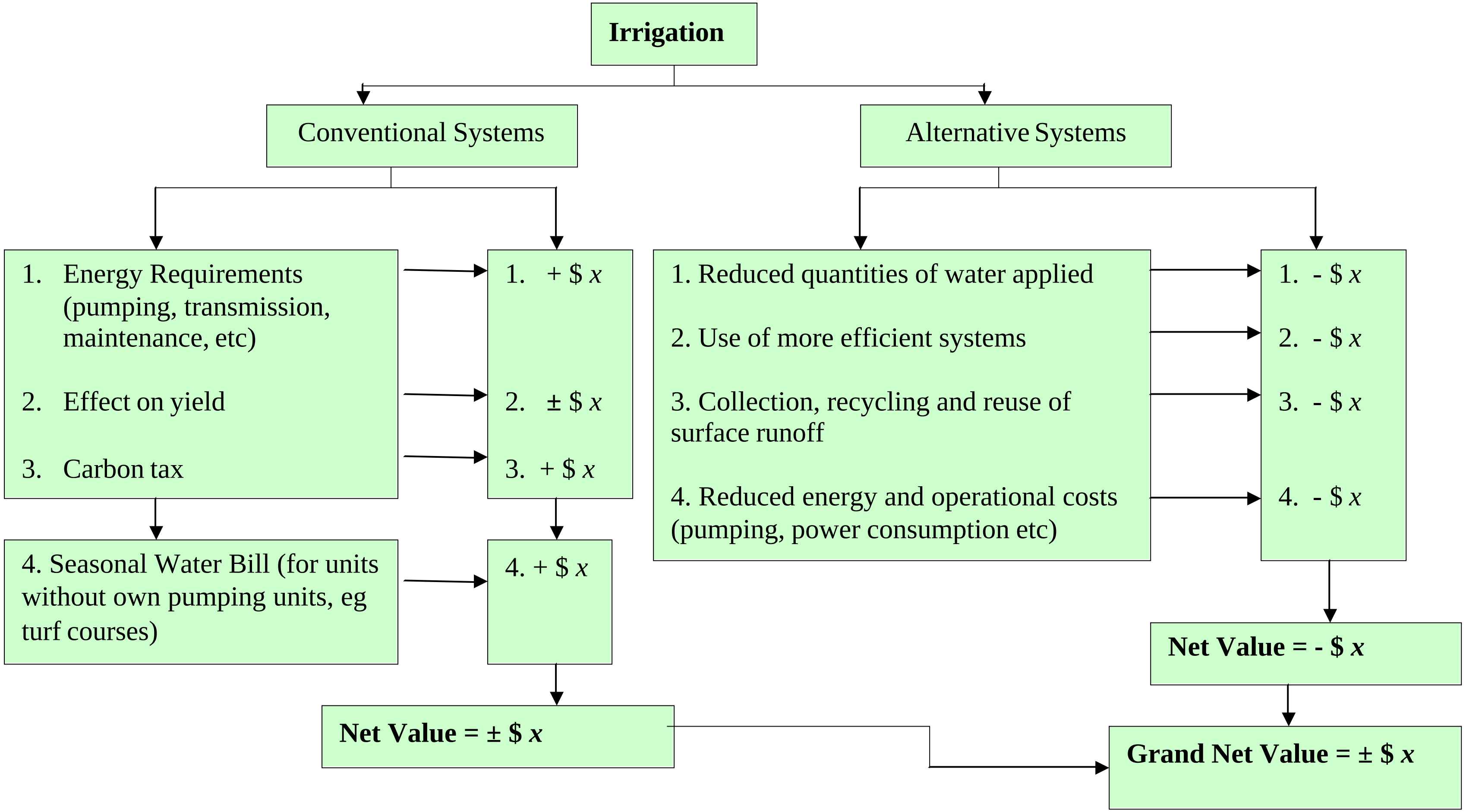


Figure 19: **Typical template for the initial model; Irrigation (energy subsystem)**

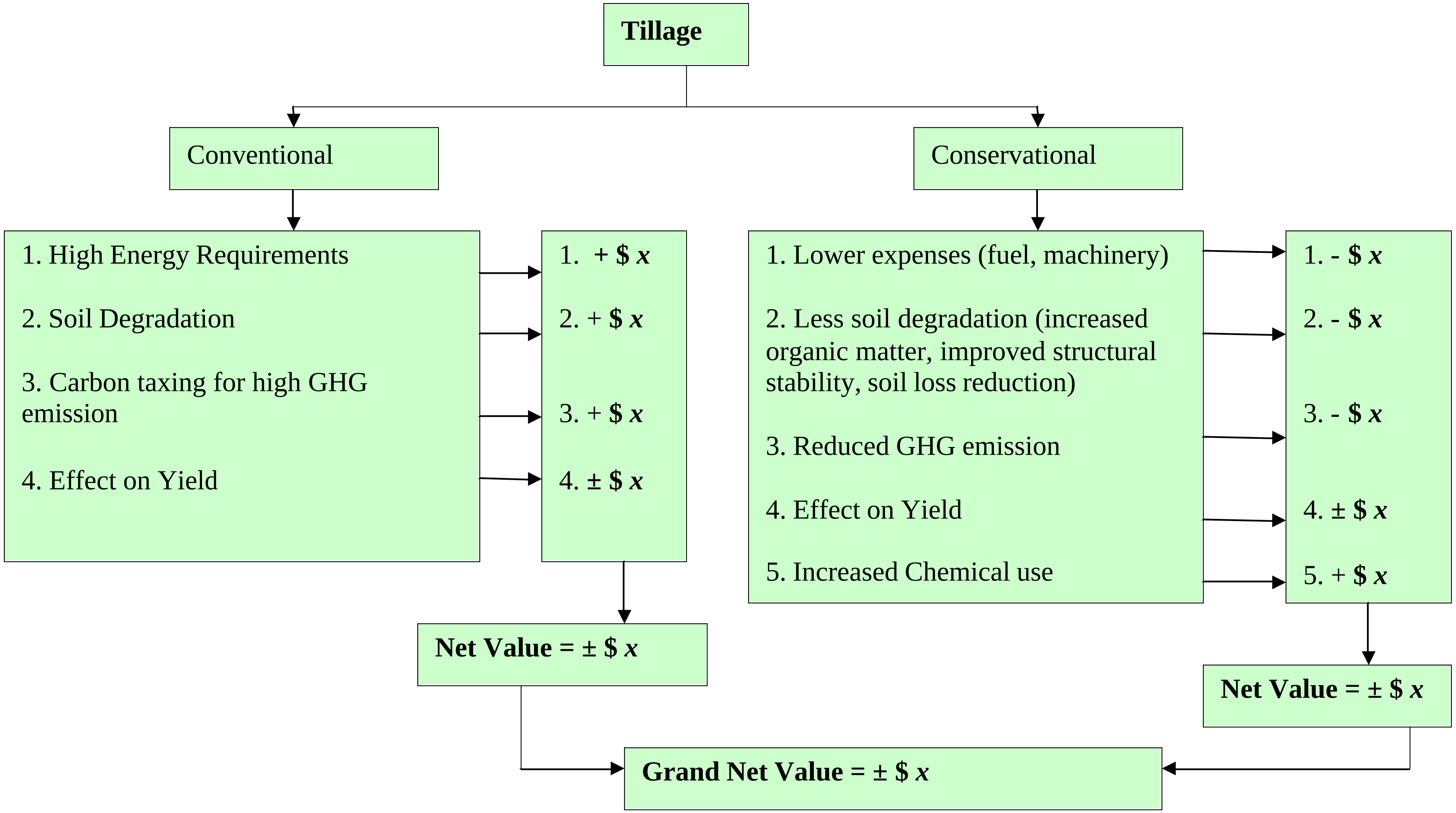


Figure 20: **Typical template for the initial model; Tillage (soils subsystem)**

CHAPTER 5

THE PRODUCT

5.1 A Review of GreenGauge *v. 1.1*

As part of its ongoing commitment to natural resource management in the Queensland Murray Darling Basin, the Queensland Murray Darling Committee Inc. commissioned the construction of a Decision Support System capable of facilitating indicative estimates of greenhouse gases from the land based sectors at property and subcatchment scale. The result was the formulation of the prototype greenhouse gas calculator *GreenGauge v. 1.1:*

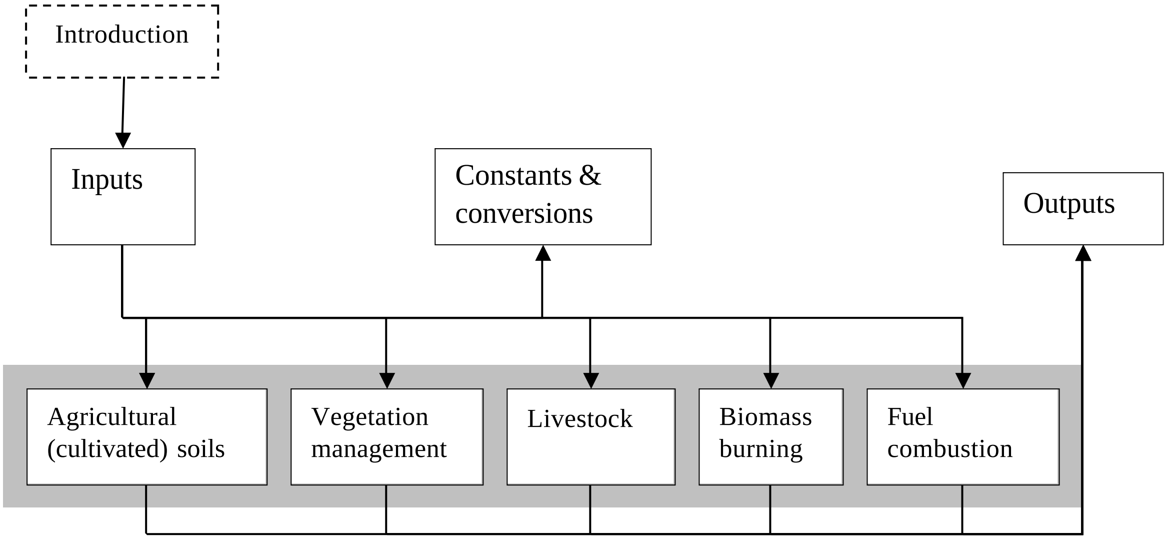


Figure 21: **A diagrammatic representation of *GreenGauge v. 1.1.***

The model was designed to estimate net emissions of the greenhouse gases methane (CH_4), nitrous oxide (N_20) and carbon dioxide ($C0_2$) from a range of activities that align broadly with the Agriculture and Land Use Change & Forestry sectors identified under National Greenhouse Gas Inventory methodologies. Estimates were designed with the intention of being indicative only and to be used as a guide to management and investment decision making, as well as for initiating communication and extension activities.

The model was expected to undergo an evolutionary and adaptive development, hence the current project. Decisions on how the model would evolve in terms of the inclusion and updating of relevant activities and methodologies would be made as new and improved data became available.

The prototype limitations described by its originator (Craig Stephenson, 2003) include inheritance of assumptions due to use of algorithms and methodologies outlined by the NGGI, use of state and regional averages, low confidence in the data used and inconsistencies in accounting methodologies. There were also elements that were conspicuously lacking, paramount among these being the economic and environmental implications of agricultural emissions. Addition of these elements will aid the promotion of this tool as a credible and valid instrument for management, and is a priority for the current research work.

5.2 Computation Worksheets

The product of this project was the development of a simplistic Excel tool that uses individual and unique computation workbooks to estimate greenhouse emissions associated with various basic agricultural processes, subsystem and activities. Emissions algorithms discussed in this chapter are sourced from Greengauge with additions and modifications where applicable, as well as from methodologies outlined by the AGO. The computation worksheets represent each of the subsystems introduced under Section 3.5 and provide the basic workings of the model, including the algorithms used. The sub-modules in this section provide detailed explanation of the rationale, methodology and algorithms used in each of these subsystems, using a series of tables to illustrate the logic behind the calculations.

The methodology involves quantifying emissions for the processes identified as GHG sources. In the construction of Greengauge, explicit corrections were made for natural emissions that would occur from the land in the absence of the land use activity, taking into account Australian conditions such as the generally low N-content of Australian soil. These corrections are inherited in the current project but are not critical to the model outlook. Each worksheet is threefold, containing an emissions estimation component, an economics component and a sensitivity analysis that explores the significance of cited mitigation options. The confidence levels expressed for the greenhouse gas estimates and associated data are proportional to those used in the NGGI workbooks. The GHG estimates produced by this product have a confidence level of Low, meaning that the estimate has an associated uncertainty of greater than 80% of the value of the estimate (Commonwealth of Australia 1998a).

5.2.1 Agricultural Soils

At a staggering 86%, agriculture is the main contributor of the greenhouse gas N_2O in Australia (AGO, 2006). Nitrous oxide (N_2O) emissions from agricultural soils constitute about 18% (16.6 of 93.1 Mt CO_2-e) of total agricultural emissions figures, and 2.9% of Australian emissions. Emissions from soils arise from microbial and chemical transformations that generate nitrous oxide in the soil. These conversions involve inorganic nitrogen compounds in the soil, namely ammonium, nitrate and nitrite (AGO, 2004). These nitrogen compounds can be added to the soil through:

1. application of inorganic fertilisers;
2. mineralisation due to cultivation (tillage) of organic soils;
3. application of animal wastes to pastures;
4. application of crop residues (stubble retention);
5. biological nitrogen fixation (legume-inclusive crop rotation practices);
6. atmospheric nitrogen deposition; and
7. leaching of inorganic nitrogen and subsequent denitrification in rivers and estuaries.

A distinction based on the manner through which nitrogen is added and subsequently lost in soil systems is used to define the scope of the Excel tool. Only the first 4 bullets in the list above are classed as direct emissions with respect to agricultural production; their associated emissions and environmental costs are significant and thus included in the model. Biological nitrogen fixation and nitrogen leaching, from legume crops and chemical use respectively, can be regarded as direct processes in some contexts, but are not included in the model due to lack of sufficient data. Emissions from fertiliser use and cultivation are calculated under soils modules, while application of animal waste and crop residues are included in the livestock (manure management) and vegetation management modules respectively.

Quantifying emissions from Tillage (Cultivated Soils)

The emissions estimation method entails the use of an algorithm that accounts for the area under a particular land use (crops and improved pasture), an emission factor, and a factor to convert the elemental mass of gas to a molecular mass. The emission factor is derived from an emission rate of gas from unfertilized soil associated with the change in land use, minus an emission rate of gas from an undisturbed ecosystem. Emissions are calculated in gigagrams of nitrous oxide per annum (Gg N_2O/yr), reported in gigagrams of carbon dioxide equivalents (Gg CO_2-e) and converted to tonnes of carbon dioxide (t CO_2-e) automatically. This conversion is included for easier comprehension and comparison with other data as most national emissions figures are expressed in either tonnes (t) or megatonnes (Mt) of CO_2-e.

The work table for calculating soil disturbance emissions used in Greengauge is presented in Table 12, shown with a simplified algorithm underneath. The confidence of the estimate is **Low** primarily due to the uncertainty in the emission rate:

Table 12: Methodology for calculating N_20 emissions from agricultural soils: Tillage

***Source:* Commonwealth of Australia 1998a**

Column #	**2**	**3**	**4**	**5**	**6**	**7**
System	**Area (ha) *(A)***	**Emission factor (kgN/ha/yr) *(EF)***	**Conversion factor *(CF)***	**N_20 emissions (GgN_20/yr)**	**$C0_2$ equivalent (Gg $C0_2$-e) *($C0_2$-e)***	**$C0_2$ equivalent (Mt $C0_2$-e) *($C0_2$-e)***
Crop	*x*	0.25	1.57			
Pasture	*x*	0.25	1.57			
Total						

Algorithms: GHG emissions (Gg N_2O/yr)= (A x EF x CF) x 10^{-6}= C5 (i.e. Column 5)
GHG emissions (Gg CO_2-e) = C5 x 310 x Duration (years) = C6
GHG emissions (t CO_2-e) = C6 x 1000

Total emission in gigagrams of $C0_2$-e from Soil Disturbance = $\sum C0_2$-e
Total emission in tonnes of $C0_2$-e from Soil Disturbance = 1000 x $\sum C0_2$-e

Balancing Units:

Note: '*x*' and '*y*' represent unknowns (input and output parameters respectively);

Column 5 (C5) $= \text{'}x_1\text{'}\ \text{ha} \times 0.25\ \frac{\text{kgN}}{\text{ha.yr}} \times 1.57\ \frac{N_2O}{N} \times \frac{1\text{Gg}}{10^6\text{kg}} = \text{'}y_1\text{'}\ \frac{\text{Gg } N_2O}{\text{yr}}$ ( )

Column 6 (C6) $= \text{'}y_1\text{'}\ \frac{\text{Gg } N_2O}{\text{yr}} \times 310\ \frac{CO_2\text{-e}}{N_2O} \times \text{'}x_2\text{'}\ \text{yrs} = \text{'}y_2\text{'}\ \text{Gg } CO_2\text{-e}$ ( )

Column 7 (C7) = $\text{'}y_2\text{'}\ \text{Gg } CO_2\text{-e} \times \frac{1000\text{t}}{\text{Gg}} = \text{'}1000\bullet\ y_2\text{'}\ t\ CO_2\text{-e}$ ( )

Economics Analysis

Estimating costs arising from on-farm activities forms a crucial component of this project. Precisely-defining the range of costs to be included in the model holds the key to the credibility of this Excel tool. Costs are calculated as a profit, and broken down into three types: expenditures, returns and hypothetical environmental penalties.

Ultimately, the cost equation is represented as follows:

$$TP = OP - \sum_{1}^{n} (ECs)$$

Where:

TP = 'True Profit' (also referred to as 'virtual' profit);

OP = Original Profit (the actual profit from sale of produce)
= Total Returns (TR) – Total Expenses (TE)
= Total Returns (TR) – [Purchase Costs (PC) + Activity Costs (AC)];

$\sum_{1}^{n}$ (ECs) = Sum of a combination of Environmental Charges (ranging from 1 to n)

= Carbon Tax + Erosion Contribution + Structural Damage + Other Charges

$\sum_{1}^{n} (ECs) = CT + EC + SD + OC$

Expressed more explicitly, the cost equation can be written as:

Total Profit, $TP = [TR - (PC - AC)] - \sum (CT + EC + SD + OC)$

Purchase costs refer to the total amount spent to acquire tillage equipment (draught power, tillage tools, etc); activity costs entail expenditure on fuel, energy, human and other resources used during the course of the cultivation procedures. Environmental costs are set out to represent penalties, but in certain instances they could be rewards (e.g. for projects undertaking farm forestry; these are included in the OC parameter). Carbon tax fees will in future be determined by a carbon market if and when it comes into existence. For analysis purposes, this parameter is varied within a reasonable range based on information acquired during literature reviews. The cells EE and SD have been left blank in the workbook until further research into the range of values suitable to encourage uptake of less harmful farming practices is undertaken. Other charges could cover costs from compaction (due to weight of tillage machinery), breach of critical depth and for ‘green’ farms, rewards (subsidies, rebates, etc).

The value of TP is included to reflect the impacts of agricultural production on the environment in hypothetical financial terms. In present-day operations, the only profit that matters is that which sits in the bank account (i.e. the OP); little or no thought is spared for environmental welfare and land sustainability. By developing a tool that quantifies the environmental costs in monetary terms it is hoped farmers can reflect on the true nature of their activities and invest in better farming systems; for policymakers, the ideas carried in this sub-component can be used to set performance standards and discourage recklessness by imposing fines on underperforming establishments. In the rare occurrence that Σ (ECs)>OP (negative TP), or where the OP is significantly reduced for any property, users are encouraged to exploit the mitigation options described in this report.

Mitigation Analysis

The third component in the tillage worksheet attempts to analyse possible mitigation measures and quantify likely responses, both on emissions and farm economics. The loss of carbon pools from agricultural soils is mainly through enhanced mineralisation of organic matter as well as increased erosion activity, both linked to cultivation/tillage practices. Much of the soil organic carbon (SOC) is lost through erosion, by water or wind. For example, Lee et al. (1993) estimated that 35% of SOC loss in the US' corn belt is by water erosion. Possible mitigation options include the use of conservation tillage techniques (see glossary). In some cases, conservative tillage practices not only reduce the loss of organic carbon from soils, they enhance accumulation of SOC (Kern and Johnson, 1993). Complimentary environmental gains of conservative tillage include a reduction in wind and water erosion, prolonged moisture retention within soils and lesser emissions from reduced fuel consumption.

Quantifying emissions from Chemical (Fertiliser) Applications

Estimating emissions from fertiliser use is presented in a dual format; one is as outlined in GreenGauge where estimates are based on the type and quantity of fertiliser used, the other uses equivalent masses and production system algorithms adopted from published AGO methodologies for the agricultural sector.

In Australia, synthetic nitrogen fertilisers are applied to a wide range of crops and pastures. The bulk of these applications are for relatively low yielding rainfed cereal crops, whose maximum recommended maximum application rates are 80 kg/ha N; and to a lesser extent sown pastures (intensive grazing systems) with maximum application rates of 40 kg/ha N. More intensive cropping systems, cotton, sugar cane, irrigated summer crops and horticultural crops have higher fertiliser application rates ranging up to 300 kg/ha N.

Recent experimental work on the application of fertilisers to different crop types has shown large variations from the IPCC default emission factor of 1.25% across all different classes of crop and pasture systems, both locally and internationally. Deviations in the EF value are bound to exist for different regions as well and different cropping systems. Variations could be influenced by such factors as soil moisture contents, physical soil properties (drainage, porosity, etc) and chemical characteristics (denitrification potential, N-content in situ, etc). It has now become more apparent that emission factors often increase with the nitrogen application rate; high emission factors occur when application rates and timing produce soil nitrate concentration much higher than what the crop requires.

As pointed out in preceding sections, greenhouse gas emissions from the use of fertilisers are reported using two approaches; the first used is that adopted from AGO methodologies. This approach assigns EF values to various on-farm processes likely to include the use of fertilisers, and through the use of a simple algorithm estimates resultant emissions based on an average mass equivalent applied. Processes covered under this estimation technique are listed in Table 13 together with their respective emission factors. The mass of fertiliser applied to soil is calculated as:

$$\boxed{\mathbf{M = TM \times FN}}$$

Where:

M = mass of fertiliser applied to production system averaged over 3 years (Gg N)
TM = total mass of fertiliser applied over three years (Gg N); and
FN = Fraction of N applied to production system (refer to Appendix I).

Table 13: Nitrous oxide emission factors for fertiliser use by Production Systems

Production System	**Emission Factor (Gg N_2O-N/Gg N)**
Irrigated Pasture	0.004
Irrigated Crop	0.021
Non-irrigated pasture	0.004
Non-irrigated crop	0.003
Sugar cane	0.0125
Cotton	0.005
Horticulture Vegetable crop	0.021

Source: AGO, 2004

Annual nitrous oxide production from the addition of synthetic fertilisers is calculated using the equation:

$$\mathbf{E = M \times EF \times C_g}$$

Where:

E = annual nitrous oxide emissions from fertiliser use (Gg N_2O);

M = mass of fertiliser applied to production system averaged over three years (GgN); obtained from the equation on previous page (i.e. M = TM × FN);

EF = emission factor obtained from **Table 13** above (Gg N_2O-N/Gg N applied); and

C_g = factor to convert elemental mass of N_2O to molecular mass = 44/28 (or 1.57).

Estimating greenhouse emissions from the use of fertilisers uses entirely algorithms in GreenGauge to the one outlined above. Instead of production systems, the GreenGauge algorithm estimates nitrous oxide emissions based on the unique nitrogen content of different fertiliser types. The method accounts for the nitrogen content of a range of commonly used fertilisers, the mass used of each fertiliser type, an emission factor which acts as a loss coefficient for the fertilisers used, and a factor to convert the elemental mass of gas to a molecular mass. The data relating to the nitrogen content of fertilisers was obtained from a study on greenhouse emissions from the grains industry (Department of Primary Industries, Vic. 2003). Emissions are calculated in gigagrams of nitrous oxide (Gg N_2O) and automatic conversions to gigagrams of carbon dioxide equivalent (Gg $C0_2$-e) and tonnes of carbon equivalents ($tC0_2$-e) undertaken; this is an effort to standardise the results, as most state and national statistics are reported in this format.

The work table for calculating emissions using the Greengauge methodology is presented in Table 14. The confidence of the estimate is considered to be Low primarily due to the uncertainty in the emission rate.

Table 14: GreenGauge Methodology for calculating N_20 emissions from Fertiliser application

Source: Commonwealth of Australia 1998a; Department of Primary Industries, Victoria, 2003

Column #	**2**	**3**	**4**	**5**	**6**	**7**	**8**
x_1	x_2	x_3	x_4	x_5	x_6	y_1	y_2
Fertiliser type	**N content (%)** ***(N)***	**Mass used (kg/ha)** ***(M)***	**Area applied (ha)** ***(A)***	**Emission factor (%)** ***(EF)***	**Conversion factor** ***(CF)***	**N_20 emissions (GgN_20)**	**$C0_2$ equivalent (Gg $C0_2$-e)** ***($C0_2$-e)***
MAP	10			1.0	1.57		
DAP	17.5			1.0	1.57		
Urea	46			1.0	1.57		
Ammonium nitrate	16			1.0	1.57		
Ammonium sulphate	21			1.0	1.57		
Agras No.1	17.5			1.0	1.57		
Agras No.2	12			1.0	1.57		
Total							

Algorithm:

GHG Emissions (Gg N_2O) = $(0.01N \times M \times A \times 0.01EF \times CF) \times 10^{-6} = y_1$

GHG Emissions (Gg CO_2-e) = $y_1 \times 310 = y_2$; 310 is the GWP for N_2O

GHG Emissions (t CO_2-e) = $1000 \times y_2$

Total emission of CO_2-e from Fertiliser application = C 0 $_2$-e (in Gg, t or both)

Economic Analysis

As in the soil disturbance component, costs are calculated as a profit, and broken down into three types: expenditures, returns and hypothetical environmental penalties. The major changes are in the individual terms that constitute ECs; since there are greenhouse gas emissions associated with fertiliser use, the carbon tax charge remains; however, the carbon price varies between emissions estimated using the two different approaches. Combined with an inefficient irrigation system, the transport of unused N-compounds pollutes water quality in open water reserves, shallow aquifers and underground reserves. Addition of ‘foreign’ chemicals into soil systems disturbs the soil’s natural balance and potentially leads to long-term structural instabilities.

The OC is again introduced to give flexibility in the model for any environmental impacts not accounted for in the current tool.

The true profit assumes the same logic as before, given by the function:

$$TP = OP - \sum_{1}^{n} (ECs)$$

TP and OP retain the same definitions as in the tillage subsystem. Total expenses (TE) incorporate direct costs for purchase of fertilisers. Activity costs (AC) cover the fuel requirements for carrying out applications, other forms of energy consumed, human and other resources involved in this process. Emissions from fuel use are estimated under Fuel combustion in subsequent segments of this report.

$\sum_{1}^{n} (ECs)$ = Sum of a combination of Environmental Charges (ranging from 1 to n)

= Carbon Tax + Water Pollution + Structural Effects + Other Charges

$$\sum_{1}^{n} (ECs) = CT + WP + SE + OC$$

Expressed more explicitly, the cost equation can be written as:

$$\text{Total Profit, } TP = [TR - (PC + AC)] - \sum (CT + WP + SE + OC)$$

The cells for WP and SE adopt crude estimates to help produce an output. Further research into their monetary values ought to be undertaken for this model to reach its full potential. Such research would to quantify the range of values suitable for these parameters would help encourage the uptake of less harmful farming practices by painting a vivid picture of what agricultural production affects environmental balances and threatens long-term productivity.

Mitigation Analysis

The third component in the chemical applications worksheet outlines possible mitigation measures and attempts to quantify likely responses, both on emissions and farm economics. Although the factors that affect nitrous oxide emissions from fertiliser application are not fully understood, there are several nitrogen management techniques known to be effective in combating net N_2O emissions. The key to guaranteed lesser emissions is to reduce the input rates/quantities. Sathaye and Meyers (1995) list the following as possible mitigation options:

- Test soils to determine appropriate levels of nitrogen deficiency;
- Establish yield goals based on site and crop characteristics;
- Adhere to recommended maximum application rates; exceed only if absolutely necessary;
- Adopt logical application timing (equivalent to irrigation scheduling);
- Use nitrifying and denitrifying inhibitors;
- Implement irrigation water management techniques;
- Use winter cover crops for removal of residual N.

Placing application deeper in the soil horizons, testing for pH, and selection of N fertiliser formulation relative to yield, leaching and runoff potential are also known to have a desirable effect in retarding the rate of conversion of N-based compounds to potent nitrous oxide emissions.

5.2.2 Vegetation Management

As pointed out in earlier sections of this report, the vegetation subsystem has been discussed extensively in Greengauge. The level of detail was judged to be more than satisfactory, exceeding the scope of current of the current research project. It is difficult to quantify the financial implications of one vegetation management practice over another. An example is stubble management practices; whether burning offers more benefits, both to the environment and in yield returns, as opposed to stubble retention/incorporation. Currently, there is no operating carbon trading scheme in Australia, thus complicating efforts to quantify the economics of agroforestry. To satisfy the requirements of the project, an emissions component is documented in this report, sourced from documents published in support of Greengauge. Some results from other published material relating to vegetation management practices are also summarised; these tend to overlap with tillage activities. Readers are advised to be aware of this fact and make a distinction between the two. Reproduction of the methodologies used in Greengauge to estimate emissions from vegetation management can be found in Appendix J.

Mitigation Analysis

Mitigation options that could be adopted to reduce greenhouse gas emissions from this subsystem and/or increase carbon sequestration in agricultural vegetation, wood products and other forms of vegetation may be classified into two basic types: one type involves expanding the carbon pools in vegetation (including the land supporting it), and the other focuses on maintaining existing pools of carbon (i.e. minimising their conversion to gaseous carbon).

Expanding Carbon Sinks

Specific mitigation options, documented by Sathaye and Meyers (1995), that can be implemented to increase carbon quantities stored in vegetation are given below, with brief descriptions of each option provided:

- Afforestation: planting forests on bare land, with biomass density commensurate to the targets of the project;

- Reforestation: replanting and/or natural regeneration of deforested areas;

- Enhanced Regeneration: increasing the biomass density of existing degraded and under-stocked forests;

- Agroforestry:
  - intercropping for the purpose of producing agricultural and forest products
  - boundary and contour planting for wind and soil protection, as well as for providing agricultural and wood products

Maintaining Existing Stocks

Although this mitigation option may be effective may be an effective way of reducing carbon emissions, it is difficult to implement since the alternative use of land upon which the carbon is stored is often more valuable to local inhabitants than vegetation expansion efforts (Sathaye and Meyers, 1995). Specific options include vegetation protection and conservation (e.g. measures to improve wildfire protection and uncoordinated biomass/residual burning), increased efficiency in vegetation management and bio-energy initiatives. Mitigation options related to bio-energy will reduce the use of biomass, hence retaining carbon stocks within the vegetation.

5.2.3 Livestock Production (Animal Husbandry)

Greenhouse gas emissions from livestock production are the sum of the enteric fermentation and manure management subsystems. Enteric fermentation emissions were 61.74 Mt CO2-e (entirely methane) while manure management emissions were part methane (1.95 Mt CO_2-e) and part nitrous oxide (1.3 Mt CO_2-e). Livestock emissions were 65.0 Mt CO_2-e in 2004 (AGO, 2005), which represents 69.8% of the agriculture sector’s emissions and 11% of net national emissions. According to the latest greenhouse gas inventory, methane (CH_4) emissions constitute 21.2% of the greenhouse gases released by different sectors in the Australian economy (AGO, 2004). Agriculture is the main contributor of methane in Australia at 60.1% (3.5 Mt of CH_4 or 71.9 Mt CO_2-e).

Eventhough emissions from livestock production represent the bulk of agricultural emissions, this research project is more focused on cropping systems. Livestock emission algorithms are included for completeness of the report, and as part of the objectives, to update the livestock component in GreenGauge. The critical cost analysis documented for agricultural soils and energy worksheets are not undertaken for the livestock (and vegetation management) subsystems. However, a mitigation analysis was carried out by identifying the areas of sensitivity that could lead to a reduction in emissions from this component, and the impediments to widespread uptake discussed.

Quantifying Emissions from Livestock Production

The methodology for quantifying emissions from the livestock industry focuses on the two processes identified as the primary sources of greenhouse gases in the sector namely enteric fermentation (CH_4) and manure treatment systems (N_2O). Carbon dioxide produced by livestock during respiration is not estimated. To present the logic in a clearer, precise manner emissions documented in this report span the cattle (dairy and beef) only. More detail on emissions from other major livestock types (sheep and pigs) can be found in the Greengauge report by Stephenson (2003) and AGO workbooks. Passing discussions on how to quantify emissions from other ruminants (goats, deer and buffalo), quasi-ruminants (camels and alpacas) and non-ruminants (horses, donkeys, emus, ostriches and a range of poultry) are included. Emissions from enteric fermentation and animal waste are calculated separately.

Enteric Fermentation (CH_4 emissions)

The proportion of feed intake that is converted into methane depends on factors such as the animal characteristics, type and quantity of feed ingested. Each livestock category has fixed methane conversion rates given under the IPCC (2000) approach. This report uses methodologies developed in Australia and adjustments reflective of the heterogeneity of feed types available in Australia. The methodology developed by Blaxter and Clapperton (1965) is recognised by the AGO as the most appropriate for estimating methane emissions from pasture-fed beef cattle as it reflects the effect of feed quality on emissions. It was developed to represent animals fed on diets used in the United Kingdom, but the digestibility of feeds studied is deemed within the ranges found in temperate Australia. The major limitation of their equations is that they fail to reflect the breeds and feed types used in tropical/sub-tropical parts of Australia. To address this deficiency, the approach developed by Kurihara et al. (1999) is used to estimate emissions from beef cattle in tropical areas. The Blaxter and Clapperton approach uses a gross energy intake estimate to calculate the proportion of this energy that is converted into methane based on digestibility and feed intake factors. The figure for methane can then be expressed on an equivalent mass basis, using the conversion factor of 55.22 MJ/kg CH_4 (Brouwer, 1965). The Kurihara et al. (1965) approach equates daily methane production to dry matter intake.

A country-specific method based on research in Australia was developed by Minson and McDonald (1987) to estimate feed intake relative to liveweight and liveweight gain of cattle. Previous emissions estimation techniques used in the AGO workbooks used intake estimates based on work undertaken in the northern hemisphere which were inappropriate for Australia. Data for both tropical and temperate feeds is entailed in this approach.

The feed intakes of dairy cattle are considerable higher than those of non-lactating cattle. The approach to model the increased energy requirements necessary for high milk production rates compiles average daily milk production per head of lactating cows for each state and uses relationships derived by the Standing Committee on Agriculture to calculate these needs. A modification of the Minson and McDonald (1987) equation is introduced to represent the additional intake for milk production to calculate total intake given by:

$$\mathbf{I = (1.185 + 0.00454W - 0.0000026W^2 + 0.315LWG)^2 \times MR + MI}$$

Where: I = total intake (kg dry matter/head/day)

W = weight in kg (Appendix L1)

LWG = liveweight gain in kg/day (Appendix L2)

MR = increase in metabolic rate when producing milk; 1.1 for milking and house cows and 1 for all other classes (SCA, 1990)

MI = additional intake for milk production

The additional intake required for milk production (MI kg dry matter/head/day) is obtained using the equation:

$$\mathbf{MI = MP \times NE/k/q/18.4}$$

Where: MP = milk production (kg/head/day) form Dairy Australia State Statistics

NE = 3.054 MJ net energy/kg milk (SCA 1990)

k = efficiency of use of metabolizable energy for milk production = 0.60

q = diet metabolizability related to digestibility of dry matter (DMD)

= 0.00795 DMD – 0.0014 where DMD is expressed as a percentage (Minson and McDonald, 1987).

The next step in quantifying methane emissions from dairy cattle is to determine the gross energy intake (GEI), which essentially is the total intake (I, defined in previous equations) converted into energy terms using a gross energy content of 18.4 MJ/kg (SCA, 1990) (i.e. GEI = I ×18.4). The animal intake relative to that needed for maintenance, L, is obtained by dividing total intake by maintenance intake (i.e. intake of non-lactating animal with liveweight gain set to zero).

$$\mathbf{L = I / (1.185 + 0.00454W - 0.0000026W^2 + (0.315\times0))^2}$$

The percentage of the gross energy intake (GEI) that is yielded as methane (Y) is given by Blaxter and Clapperton (1965) as:

$$\mathbf{Y = 1.3 + 0.112DMD + (2.37 - 0.050DMD)\ L}$$

Where: DMD = digestibility of feed (expressed as a %); see Appendix L3

L = intake relative to that needed for maintenance

Finally, the total daily production of methane (M in kg CH_4/head/day) is evaluated as:

$$\mathbf{M = Y / 100 \times GEI / F}$$

Where: $F = 55.22$ MJ/kg CH_4 (Brouwer, 1965).

Further analysis can be undertaken by calculating annual methane production (in Gg) for all classes of dairy cattle across all states using equations given in this section and the algorithm:

$$\mathbf{E = \Sigma_{\ i=1,\,3\text{-}7}\ \Sigma_{\ j}\ (365 \times N_{ij} \times M_{ij}) \times 10^{-6} + \Sigma_{\,i=2}\Sigma_{\,j}\Sigma_{\,k}\ (91.25 \times N_{ijk} \times M_{ijk}) \times 10^{-6}}$$

Where: N = numbers of dairy cattle in each class for each state an season

M = methane production (kg/head/day) obtained using the previous equation

Descriptions of the subscripts use in the above equation are given in the table below:

Table 15: Symbols used in algorithms used for dairy cattle (AGO, 2004)

State (i)	**Dairy Cattle Classes (age) (j)**	**Season[b] (k)**
i = 1 NSW and ACT	j = 1 Milking cows[a]	k = 1 Spring
i = 2 Tasmania	j = 2 Heifers > 1 year	k = 2 Summer
i = 3 Western Australia	j = 3 Heifers < 1 year	k = 3 Autumn
i = 4 South Australia	j = 4 House cows Milk and Dry	k = 4 Winter
i = 5 Victoria	j = 5 Bulls > 1 year	
i = 6 Queensland	j = 6 Bulls < 1 year	
i = 7 Northern Territory		

a: Includes cows used for milk production but not currently lactating

b. This category to Tasmania only. Data was not available to support disaggregation of the other states.

Although the methodology outlined above (adopted from AGO Workbooks) provides a more accurate estimate of methane emissions than Greengauge, it is a laborious process and requires multiple data sets. It should be used only when medium to high accuracy (i.e. through adjusted intake values) is required. The methodology developed for Greengauge suffices for lower accuracy estimates. It uses simple and straight forward algorithms easier to understand. Its methodology is outlined below:

Table 16: Greengauge Methodology for calculating CH_4 emissions from Enteric Fermentation

Column#	2	3	4	5	6
Livestock population characterisation	**Number of animals** ***(N)***	**Inventory period (days)** ***(IP)***	**Emission factor* (kg CH_4/head/day)** ***(EF)***	**CH_4 Emission (Gg CH_4/y)**	**$C0_2$ equivalent (Gg $C0_2$-e)** ***($C0_2$-e)***
Non-dairy cattle					
Bulls>1			0.236		
Bulls <1			0.093		
Steers <1			0.090		
Cows 1-2			0.147		
Cows >2			0.163		
Cows <1			0.090		
Steers >1			0.173		
Dairy cattle					
Milking Cows			0.3406		
Heifers >1			0.1697		
Heifers <1			0,112		
Dairy Bulls >1			0.214		
Dairy Bulls <1			0.135		
Sheep					
Rams			0.016		
Whethers			0.014		
Breeding Ewes			0.016		
Other Ewes			0.013		
Lambs/Hoggets			0.0075		
Pigs					
Boars			0.00448		
Sows			0.00537		
Gilts			0.00448		
Others			0.00268		
Total					

Source: Adapted from Commonwealth of Australia 1998

Algorithm:

(N x IP x EF) x 10^{-6} x 21 (GWP)

Total sequestration in gigagrams of $C0_2$-e for Enteric Fermentation = $C0_2$-e

To estimate emissions from beef cattle using the Minson and McDonald (1987) methodology, some modifications are necessary in a few of the factors required for the different calculation stages. The processes are about 95% identical, thus considering the complexity encountered in conveying the dairy approach, it is left to readers to access this information available in the AGO publication *'Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks: Agriculture'* (2004).

To estimate methane emissions for other types of livestock a simple algorithm that ties emissions factors to different livestock to output quantity (in Gigagrams) of gas released per property. A similar algorithm can be applied to estimate emissions at state and national level:

$$\text{Methane Emissions (Gg } CH_4\text{/year)} = N \times M \times 10^{-6}$$

Where: N = number of specific livestock reared in the property, and

M = methane emission factor (kg/head/year) obtained from the table below:

Table 17: 'Other livestock'–enteric fermentation emission factors (kg CH_4/head/yr)

State	Livestock Type								
	Goats	Horses	Deer	Buffalo	Donkeys/ Mules	Emus/ Ostriches	Alpacas	Camels	Poultry
NSW/ACT	5	18	10.7	55	10	5	10	46	NE
TASMANIA	5	18	10.7	55	10	5	10	46	NE
W.A.	5	18	10.7	55	10	5	10	46	NE
S.A.	5	18	10.7	55	10	5	10	46	NE
VICTORIA	5	18	10.7	55	10	5	10	46	NE
QLD	5	18	10.7	55	10	5	10	46	NE
N.T.	5	18	10.7	55	10	5	10	46	NE

Source: AGO, 2004

Note: NE means 'Not Estimated' under material published to date

Emissions from Animal Wastes

Emissions from management of animal waste are primarily methane and nitrous oxide type. Experts suggest that methane emissions from range-kept livestock (e.g. free-range beef cattle, sheep, goats, etc) are likely to be negligible; this is in recognition of high temperature, high solar radiation and low humidity effects which speed up the drying of manure. Nitrous oxide emissions can be of considerable quantities depending on the waste holding system and duration of waste management.

Nitrogen is a fundamental nutrient for livestock production and performance. Animals acquire their intake through consumption of forage and feeds provided on the property. However, only a proportion of the nitrogen ingested is used productively for growth and other tissue-generation processes; the rest is excreted or passed on in milk. A mass balance approach is used to estimate the amount of nitrogen released based on amounts consumed. This is given by the equation:

$$N_{\text{output}} = N_{\text{input}} - N_{\text{storage}}$$

The UNFCCC reports nitrous oxide emissions based on the different manure management systems rather than on the basis of livestock kept. Emission factors associated with the different manure management systems are tabulated below:

Table 18: Emissions Factors (EFs) associated with manure management systems

Manure Management Systems (MMS)	Emission Factor[a] (kg N_2O-N/kg N excreted)
MMS = 1 Anaerobic Lagoon	0.001
MMS = 2 Liquid Systems	0.001
MMS = 3 Daily Spread	0[b]
MMS = 4 Solid storage and dry lot	0.02
MMS = 5 Digester	0.001
MMS = 6 Poultry manure with bedding	0.02
MMS = 7 Poultry manure w/o bedding	0.005
MMS = 8 Pasture range and paddock	0[b]

Source: AGO, 2004

a. IPCC (1997, 2000) figure

b. there are no direct emissions from these sources.

As in the enteric fermentation analysis, the approach to estimate emissions from manure management systems outlined by the AGO is presented with particular focus on dairy cattle. This process starts with the calculation of volatile solids (VS, the organic fraction of manure vulnerable to conversion to methane), using the equation:

$$\mathbf{VS = I \times (1 - DMD) \times (1 - A)}$$

Where: I = dry matter intake calculated under enteric fermentation emissions,
DMD = Dry matter digestibility expressed as a fraction (Appendix L3), and
A = ash content expressed as a fraction (assumed to be 8% of faecal DM).

Daily methane emission by each animal can then be calculated as:

$$\mathbf{M = VS \times Bo \times MCF \times \rho}$$

Where: B_o = emissions potential = 0.24 m^3/kg VS (IPCC 1997)

MCF = integrated methane conversion factor; based on proportion of different manure management regimes (Appendix L4) and MCF values for ‘warm’ QLD and NT regions as well as MCF values for temperate regions for all other states (Appendix L5)

ρ = density of methane = 0.662 kg/ m^3

Annual methane production (Gg) from dairy cattle manure for a given property is obtained as:

$$\mathbf{E = 365 \times N \times M \times 10^{-6}} \ldots \text{[days × herds × kg/ (herds × day) × Gg/kg = Gg]}$$

Where: N = total number of cattle in each class and season (for Tasmania, use 91.25 instead of 365 i.e. number of days in each season)
M = methane production obtained from the previous equation (in kg/head/day)

Again this is a tedious and data-intensive approach for estimating emissions compared to the approach used in Greengauge given by Table 19 below:

Table 19: Greengauge Methodology for calculating N_20 emissions from Animal Waste

Column#	2	3	4	5	6	7	8
Livestock Population Characterisation	**Number of animals *(N)***	**Inventory period (days) *(IP)***	**Waste Deposited (gN/h/day) *(W)***	**Emission factor (%) *(EF)***	**Conversion factor *(CF)***	**N_20 emissions (GgN_20/yr)**	**$C0_2$ equivalent (Gg $C0_2$-e) *($C0_2$-e)***
Non-dairy cattle							
Bulls >1			40.22	1.25	1.57		
Bulls <1			47.47	1.25	1.57		
Steers <1			45.85	1.25	1.57		
Cows 1-2			88.582	1.25	1.57		
Cows>2			95.039	1.25	1.57		
Cows <1			45.85	1.25	1.57		
Steers >1			100.6	1.25	1.57		
Dairy cattle							
Milking Cows			362.585	1.25	1.57		
Heifers >1			155.84	1.25	1.57		
Heifers <1			94.552	1.25	1.57		
Dairy Bulls >1			202.67	1.25	1.57		
Dairy Bulls <1			111.696	1.25	1.57		
Sheep							
Rams			9.136	1.25	1.57		
Whethers			7.6864	1.25	1.57		
Breeding Ewes			8.864	1.25	1.57		
Other Ewes			7.104	1.25	1.57		
Lambs/Hoggets			2.912	1.25	1.57		
Pigs							
Boars			33.15	1.25	1.57		
Sows			37.2	1.25	1.57		
Gilts			39.65	1.25	1.57		
Others			19.8	1.25	1.57		
Total							

Source: Adapted from Commonwealth of Australia 1998a

Algorithm:

(Column *N* x *IP* x *W* x *EF* x *CF*) x 10^{-9} x 310 (GWP)

Total sequestration in gigagrams of $C0_2$-e for Animal Waste = ***$C0_2$-e***

The equations used to estimate nitrous oxide emissions are not given in this report; their mathematical complexity exceeds the scope of this project. The algorithm given above is sufficient to provide a crude estimate of emissions based on the type of livestock waste being investigated. Since nitrous oxide emissions from manure management are significant, a detailed discussion of available mitigation options is documented, together with likely constraints to their uptake.

Mitigation Analysis

Options for reducing emissions from enteric fermentation must be consistent with animal management practices, feed resources market conditions and economic development priorities (Sathaye and Meyers, 1995), and should be in line with country-specific scenarios. Research has shown that proper veterinary care, sanitation, ventilation (in enclosures), nutrition and animal comfort provide the basis for improving production efficiency and reducing methane emissions. Focusing on these simple but essential management practices could well provide the best opportunity for improving efficiency. Sathaye and Meyers (1995) suggest a variety of techniques aimed at improving animal productivity and reducing methane emissions:

1. Improved nutrition through mechanical and chemical feed processing: Poor-quality feeds increase methane emissions per amount ingested. Improved feeds on the other hand enhance animal performance, including weight gain, milk production and reproductive performance. Put simply, using high-quality livestock feeds reduces emissions while increasing returns. Feed digestibility (FD) is a key variable; assuming a FD factor of 5%, methane emissions per unit product produced could be lowered by 25% for higher quality feeds.

2. Improved nutrition through strategic supplementation: By modifying the manner in which the rumen functions methane emissions per feed intake could be reduced. Providing additional microbial and/or by-pass protein enhances animal performance in a similar fashion as improving the fed quality, leading to reduced methane emissions. Improved rumen function may reduce emissions by up to 10% (Sathaye and Meyers, 1995). Emissions per unit product may be reduced by 25 to 75% due to substantial increase in animal productivity (Leng, 1991).

3. Use of Production Enhancing Agents: Bovine somatotropin and anabolic steroid implants are two such agents commercially available in the market. Many other agents are under development.

4. Improving Production using Genetics: Continued genetic improvements of poor performing breeds to maximum potential could increase animal productivity, reducing methane emissions in the process.

5. Improving Efficiency through Reproduction Techniques: Increasing the reproductive efficiency of ruminant animals reared solely for production of offspring could yield a reduction in methane emissions.

The technical applicability of these emission reduction options can be found in Appendix K.

Options for reducing emissions in manure management systems target recovery of methane produced from anaerobic decomposition of animal excreta in facilities such as lagoons and liquid/slurry storage facilities (pits and tanks). Methane recovered can then be combusted and used as an energy source. Methane recovery technologies have been shown to reduce emissions by up to 80% (USEPA, 1993a). Three main approaches have been identified by Sathaye and Meyers (1995):

1. Covered Lagoons: treat and store manure, using of water to wash out solids in manure. Technology and capital requirements are relatively low. The main constraint to implementation in Australia is the high water requirements.

2. Small-scale digesters: designed to enhance anaerobic decomposition of organic material and optimise methane production and capture. These typically require small amounts of manure and are relatively easy to manufacture. Small scale digesters would be suitable for small to medium (or semi-confined) farms in northern parts of Queensland as they operate best under temperate and tropical climate.

3. Large-scale digesters: designed in the same way, and for the same purpose as small-scale digester, only with a bigger capacity. These technologies are best suited for large livestock operation which handle manure in liquid form (more than 90% fluid) or slurry (10 – 20% solids). Their major impediment to implementation is the capital requirement because they are more complex to build and operate.

Other possible mitigation options for handling methane emissions from manure management include aerobic treatment and composting. The three techniques defined above focus on anaerobic treatment with the goal of production and capture of methane for use as an energy source. An alternative practice is to inhibit emissions altogether by improving air circulation in retention facilities, which enhances aerobic decomposition of animal waste at low emission rates. Composting is a good alternative for managing manure because the compost can be used as a valuable fertiliser. Obstacles to uptake of these options include possible adverse effects on groundwater resources and unwanted runoff.

5.2.4 Fuel Combustion

The method adopted in Greengauge provides a disaggregated estimate of emissions of greenhouse gases from fuel combustion using constants derived from a study conducted by the grains industry (Department of Primary Industries, Vic. 2003) associated with the following activities:

- Land clearing
- Soil cultivation
- Planting
- Irrigation, and
- Harvesting

The original Greengauge tool has capabilities to quantify emissions for each of these activities using simplified algorithms based on the type. An alternative way to calculate bulk fuel use emissions (i.e. no distinction between activities) can be obtained using the equation:

$$\text{GHG Emissions (t CO2-e)} = Q\ (\text{kL}) \times EF$$

OR

$$\text{GHG Emissions (t CO2-e)} = Q\ (\text{GJ}) \times EF/1000$$

Where:
Q = quantity of fuel used in kL or GJ (sourced from inventory, supplier invoices or production records);
EF is the relevant emission factor obtained from Appendix H.

Another modification that can be introduced to the original Greengauge tool is to quantify indirect emissions resulting from consumption of purchased electricity to run irrigation systems: The algorithms is similar to the one(s) for fuel use, and are given by:

$$\text{GHG Emissions (t CO2-e)} = Q \times EF/1000$$

Where:
Q (Activity) is the electricity consumed by the reporting property expressed in kWh;
EF = relevant emission factor expressed in kg CO_2-e/kWh in columns A, C and E in Appendix G2 for Queensland properties (G1 for all other states).

Q can also be expressed in GJ instead of kWh; for unit consistency, use the emission factors listed under columns B, D and F (expressed in kg CO_2-e/GJ) provided in the same appendices.

5.2.5 Other Agricultural Subsystems

No modifications or updating was carried for the remaining agricultural subsystems, namely biomass burning and prescribed burning of savannas (and crop residues). This was mainly due to limited time resources, lack of updated methodologies at the time the literature review phase elapsed (for this project) and the difficulty to quantify the economics associated with the two activities.

For purposes of estimating emissions from these subsystems, readers are advised to use the methodologies outlined in the first instalment of this project i.e. Greengauge *v.1.1* by Stephenson (2003). Future research and development work on the evolution of this tool should focus some substantial effort towards addressing this limitation.

5.3 Intended Use

This emissions-calculation and valuation tool is to be used strictly a crude means of assessing agricultural production’ performance with respect to greenhouse gas emissions and other environmental issues. Its intended purpose is for use as an estimating tool and not as a validated product that can be employed in targeting emissions.

Users are advised that the accuracy level in the developed Excel tool is LOW, and that the decisions they draw from use of this model are entirely their own and in no manner influenced by the output from the model. This condition holds until the model development is completed and validated by experts in the emissions-reduction field. For further information refer to the ‘*Limitations of Use’* page at the beginning of this report.

5.4 Assumptions and Limitations

One of the major limitations in this tool is its heavy reliance on published data. Estimates for both emissions and activity costs could be at either extreme (grossly under or over-estimated) relative to actual scenarios.

Due to the large pool of information sources accessed, there might be inconsistencies in the emissions statistics reported. An example of this is the exact value of agricultural emissions relative to national figures. Some sources place this as low as 16% whilst some place it at just under 20%. This affects the overall technical reliability of the data used and outputs obtained.

Another serious issue encountered in the development of this tool was the ever-present danger of double reporting. This is likely in situations where subsystems overlap. A classical reflection of this is the emissions resulting from manure handling systems. According to the NGGI, these should rightfully be estimated under agricultural soils; if a distinction is not made in the scope, then these will be accounted for under the livestock sector, rendering the net estimates inaccurate. Fuel consumption posed the same dilemma in the cost accounting component, largely due to the sheer number of constituents that require the use of fuel. If utmost care is not observed, purchase costs could be overestimated 5-fold, depending on the number of activities documented under fuel consuming processes.

Due to limited resources and time restrictions, the third element intended to investigate the effects of the suggested mitigation options was underdeveloped. This severely limits the capabilities of the tool to boost farmer confidence in adopting conservative practices, and should be one of the major focuses on any future work on this tool.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Effected Additions and Alterations to GreenGauge

The original version of Green Gauge is a technically-sound tool that conforms to the basic emissions-estimation guidelines set out in national workbooks. However, it has a limited scope and has few, if any, interface features to enhance its usability, improve manoeuvring with ease within the model and increase comprehension of logic applied in the model. Hence efforts were directed towards addressing these issues and a new and improved, user-friendly product was developed.

The majority of the literature review exercise was focused on obtaining as much of the newly-published emissions data relevant to the existing tool. Adjustment and updating of key parameters were effected where appropriate.

The limitation of a narrow model scope was partially addressed by introducing more algorithms to accommodate broader investigation of different scenarios. For example, where the original Greengauge model restricted estimating emissions from fertiliser use solely by nitrogen content, the additional features allow farmers to calculate emissions based on a particular production system (e.g. irrigation of pastures, sugarcane plantations, vegetable production, etc). Simple but valid algorithms are used so as to help end-users easily comprehend their implications. This gives the model more flexibility and hence a wider audience, which subsequently helps achieve the project aim of educating stakeholders on the subject of greenhouse gas emissions.

Perhaps the most significant addition to the existing tool is the incorporation of a cost component that attempts to quantify, in financial terms, the impacts of individual on-farm activities on the environment. This is an essential ingredient in removing obstacles to a widespread adoption of conservative farming practices that are friendlier to the environment compared to conventional (traditional) methods. If the model undergoes further development and gets validated by relevant authorities, the task of weighing the pros and cons of one practice versus another would be made easier. The cost-estimation tool can be used by policymakers to set up performance standards and determine appropriate penalties for under-performers. The combination of quantifying environmental impacts in dollar terms and literally giving farmers an opportunity to maintain ‘honourable’ profits by indulging in cleaner production defines the level of innovative technical work undertaken in the development of the Excel spreadsheets.

6.2 Project Achievements

The development of the emissions estimation and valuation tool, which is in its final stages of development including validation, is in line with achieving the goals set for this project. It is hoped that the level of detail conveyed in this report is sufficient to provide users with a firm idea of what the tool entails. In other areas, a satisfactory level of success in meeting the set objectives was attained. In line with the project specification, the following requirements were met:

1. The importance of the subject of greenhouse gases, global warming and subsequently climate change were discussed, with detailed analysis of the predicted impacts of continued emissions to human life, biodiversity, geology and most significantly Australian culture; brief discussion of impacts on Australia’s most important agricultural region, the Murray-Darling Basin, was undertaken;
2. Emissions data was compiled in a logical fashion, using tables and charts, to help the intended users comprehend the scale and distribution of emissions from agricultural production;
3. Current research on the subject of greenhouse emissions, including work undertaken in developing Greengauge, was reviewed; lack of validation of the original tool, and the accompanying uncertainty into the accuracy of the tool, were identified as the major impediments for practical implementation of the tool;
4. The original model was refined by updating emissions factors where new data was discovered; its capacity was expanded to include some on-farm activities that were omitted in the initial modelling; in some spreadsheets, further methodologies for estimating emissions were introduced to broaden the scope;

efforts were directed towards obtaining data and methodologies suitable for local Queensland conditions. Methods and emission factors for Queensland are included in the appendix;

5. Areas of sensitivity which can be modified to reduce emissions were identified for the livestock (enteric fermentation and manure management), soils (fertiliser use and cultivation) and vegetation management subsystems; impediments to their uptake were also discussed.

6. In the (underdeveloped) sensitivity component, the model can be used to compare the greenhouse gas impact of alternative farming and management systems; and

7. The original model was extended to include a cost component that incorporates a ‘carbon tax’ into the impact of emissions on natural resources.

6.3 Outline of Future Research

1. The cost-estimation techniques employed in the Microsoft Excel tool developed are basic functions that grossly lack technical and/or economics genius. Since this component constitutes the major technical work in the evolution of Greengauge, the next phase of development should focus on substantiating the costing techniques through the use of proper economics algorithms.

2. The scope of the modelling approach was restricted to cropping systems. As a result, an unbalanced tool was developed. To address this asymmetry, further research should focus on livestock production and other significant agricultural subsystems.

3. Another modification that could be introduced in future research is to document the amount of greenhouse gas captured by various sinks. In the development of the Excel tool focus was set solely on quantifying emissions, with little consideration for processes that remove this carbon from the atmosphere. Net emissions are a more reliable way of measuring the true nature of greenhouse performance; quantifying the

fraction of greenhouse gas removed from the air is a requirement for finding net emissions, hence the need to develop a sink component in the tool.

4. Further development of the mitigation (sensitivity) component in the Excel tool is also essential, especially the technical aspects. Upon full completion, this component should be able to recommend possible mitigation options as a standard output feature.

5. An auxiliary feature that could be included in future work is an automatic star-rating mechanism to measure the performance of individual farms relative to some benchmark. Rating can be based on total property emissions, type of farming/management practice, crop type, sequestration efforts, and other performance measures.

6. Continued validation efforts should be undertaken in any manner possible. This could include:

- Internal review by NCEA and University of Southern Queensland staff;
- Review by interested parties and stakeholders (QMDC, landholders, farmers);
- Independent external review by individual ‘expert’ advisors;
- Statistical analysis through case studies case studies;
- Comparison of output with similar products; and
- Workshop review through specialist bodies such as the now defunct Cooperative Research Centre for Greenhouse Gas Accounting.

6.4 Summary and Recommendations

General Comments

Agriculture is a significant contributor of greenhouse gases in Australia. More input from all stakeholders (individual farmers, farming communities, landholders, state/federal government and affiliate agencies, e.t.c.) is necessary if environmental welfare and sustainability are to prevail in agricultural production. Based on findings from literature review, improving fertiliser use efficiency, possibly through better timing of applications, might be one way of reducing nitrous oxide emissions. Other management practices that could achieve the same goal focus on fertiliser types (avoiding nitrate nitrogen sources, adhering to stipulated fertiliser application rates, using controlled-release fertilisers and using fertilisers coated with a nitrification inhibitor) and soil/crop management (reduction in fallow period, change in tillage practice, plant breeding, stubble treatment and minimising soil compaction and waterlogging).

Methane emissions can be targeted through improved management practices by increasing animal productivity to reduce enteric fermentation emissions and by anaerobically decomposing animal wastes and capturing resulting emissions for use as an energy source. Nitrous oxide emissions can be reduced by uptake of conservation tillage practices and informed use of nitrogen-based chemicals. The major impediment to the implementation of mitigation options is uncertainty of the risks associated with switching from ‘traditional’ to alternative farming practice. Other constraints are capital input requirements and resources needed to successfully implement available options.

Summary of Results from Literature Reviews

Agricultural emissions in 2004 were reported at 93.135 Mt CO_2-e, showing an increase of 2.3% from the baseline (1990) total. This represented a 17% share of the nation’s total. Taking into account existing measures, emissions from the sector are projected to continue rising and approach 99 Mt CO_2-e by 2010 and 105 Mt CO_2-e by

2020, reflecting a rise from the 1990 levels of 5 and 10% respectively (AGO, 2005). These projected emissions would comprise business as usual emissions which in the absence of mitigation measures would rise 6% (99.2 Mt CO_2-e) over the 1990 levels in 2010 and by 13% (105.3 Mt CO_2-e) in 2020. A combination of measures from the industry would see a reduction in emissions by 0.6 Mt CO_2-e in 2010 and 1.1 Mt CO_2-e in 2020 (AGO, 2005). The latest (2005) projections use updated information and hence differ from previous (2003 and 2004) projections due to revised livestock and cropping projections, revised emissions factors and improved 'savanna burning' projections. Under these new projections, 'with measures' emissions are projected to be 6.1 Mt CO_2-e lower in 2010. Other changes in the 2010 agricultural emissions include:

- a 4.8 Mt CO_2-e decrease in livestock emissions,
- a 0.7 Mt CO_2-e decrease in emissions from cropping systems, and
- updated emission factors, to be consistent with the current NGGI increased 2010 emissions by under 0.1 Mt CO_2-e (AGO, 2005).

Recommendations

In order for ideas developed in this project to evolve into a useful/practical tool, validation by greenhouse experts is required. This will only be possible if further research is undertaken to improve the understanding of processes that can be targeted to reduce emissions. Due to time restrictions, the prototype was not validated; this step requires not only critique by experts, but more importantly the backing of statistical output from the model with real-life production figures. It is only then that the level of accuracy can be established, and specific modifications introduced in the tool to complete the validation process.

The most significant recommendation is that the state and federal government, through environmental authorities and/or agencies, generate a set of practical performance standards, enforceable by law, for agriculture (and other economic sectors outside the scope of this project) to adhere to as a way to combat greenhouse gas emissions and slow the advent of global warming (climate change). It is paramount that consultations with parties likely to be affected by any such legislative measures be entered into, and education used to exhaustion level before penalties can be imposed on those that disregard protocol. Based on output literature research as well as the developed Excel tool, a high cost of carbon is the most effective way of enforcing changes in practice; potential loss of profit can be incentive enough to instigate cleaner production. The extent and/or severity of penalties for poor performance remains the responsibility of relevant environmental authority.

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APPENDIX

APPENDIX A: PROJECT SPECIFICATION

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project

FOR:	Calvin SEKHESA
TOPIC:	Development of a tool for estimating and costing the emission of greenhouse gasses at farm and sub-catchment level
SUPERVISOR:	Dr Guangnan Chen
SPONSORSHIP:	NCEA, QMDC
PROJECT AIM:	The aim of this project is to further develop a decision-support tool to manage greenhouse gas emissions at the farm and sub-catchments level, and to promote practical and cultural changes.

PROGRAMME:

1. Discuss the importance of the issue.
2. Review the current research and impediments for practical implementation of the tool.
3. Update and expand the capacity of the existing tool
4. Refine and "localise" the model for the particular local conditions of Queensland.
5. Use the model to compare and rate the greenhouse gas impact of alternative farming and management systems.
6. Identify areas of sensitivity which can be modified to improve emissions and sinks.
7. Extend the model to include the cost model for natural resource management and "carbon tax".

As time permits:

1. Carry out a model sensitivity study to develop a practical guideline for the farmers and landholders.
2. Develop a system of certification and farmer incentives policies.
3. Conduct field trials of the above tool.

AGREED

________________(Student), _______________(Supervisor)

___/___/___ ___/___/___ ___/___/___

APPENDIX B: Accounting for Carbon Flows in Agriculture

Table 20: Terrestrial Sources and Sinks of Major Greenhouse Gases

Carbon Dioxide ($C0_2$)	
Sink	***Source***
Trees and woody vegetation (Afforestation, reforestation, vegetation thickening, regrowth)	Deforestation
Surface plant litter	Fossil fuel burning
Soil Organic Matter (SOM)	Biomass burning
Improved pastures	
Methane (CH_4)	
Sink	***Source***
Atmospheric: o Reaction with OH^- (hydroxyl) radicals to produce $C0_2$ & water;	Enteric fermentation (ruminant animals)
Soil: o Activity of methane oxidizing bacteria (methanotrophs); o semi-arid temperate grasslands represent significant sink	Animal wastes
	Biomass burning (fuelwood, agricultural burning, forest fires)
Nitrous Oxide (N_20)	
Sink	***Source***
Stratospheric loss: o N_20 destroyed in reaction with atomic oxygen (0_2), forming nitric oxide (N0). o N0 involved in oxidation of CH_4 and carbon monoxide (C0);	Soils: o Denitrification (some loss of N_20 to atmosphere); o Nitrification (N_20 is a terminal product in conversion of CH^4 to nitrate N; prominent under conditions of medium to high pH and aerobic conditions. It will tend to dominate in low nitrate (unfertilized) soils such as those found in many Australian grazing systems (Bureau of Resources Sciences *et al*. 1994)
Soils play minor role as sink: o Denitrification (N_20 converted to N_2, promoted by anaerobic conditions and by organic substances that promote growth of soil organisms)	Nitrogen fertilizers
Plants during growth phase	Plants: o During senescence and decay; o Legume pastures
	Animal wastes
	Biomass burning

Source: Adapted from Bureau of Resource Sciences, ANU & ABARE, 1994.

APPENDIX C: The Kyoto Protocol to the United Nations Framework Convention on Climate Change

ANNEX A: Greenhouse gases and their sectorial sources

Greenhouse gases

Carbon dioxide
Methane
Nitrous Oxide
Hydrofluorocarbons
Perfluorocarbons
Sulphur hexafluoride

Sectors/source categories

- Energy
  - Fuel Combustion
    - Energy Industries
    - Manufacturing industries and construction
    - Transport
    - Other Sectors
  - Fugitive emissions from fuel
    - Solid fuels
    - Oil and natural gas
    - Other

- Industrial Processes
  - Mineral products
  - Chemical industry
  - Metal production
  - Other Production
  - Production of halocarbons and Sulphur hexafluoride
  - Consumption of halocarbons and Sulphur hexafluoride
  - Other

- Solvent and other products

- Agriculture
  - Enteric Fermentation
  - Manure management
  - Rice Cultivation
  - Agricultural soils
  - Prescribed burning of savannas
  - Field burning of agricultural residues
  - Other

- Waste
  - Solid waste disposal on land
  - Wastewater handling
  - Waste incineration
  - Other

Table 21: ANNEX B: Complete List of signatories and their assigned emission limitations

Party	Quantified emission limitation or reduction commitment (% of base year or period)
Australia	108
Austria	92
Belgium	92
Bulgaria*	92
Canada	94
Croatia*	95
Czech Republic*	92
Denmark	92
Estonia*	92
European Community	92
Finland	92
France	92
Germany	92
Greece	92
Hungary*	94
Iceland	110
Ireland	92
Italy	92
Japan	94
Latvia*	92
Liechtenstein	92
Lithuania*	92
Luxembourg	92
Monaco	92
Netherlands	92
New Zealand	100
Norway	101
Poland*	94
Portugal	92
Romania*	92
Russian Federation*	100
Slovakia*	92
Slovenia*	92
Spain	92
Sweden	92
Switzerland	92
Ukraine*	100
United Kingdom of Great Britain & Northern Ireland	92
United States of America	93

* Countries that are undergoing the process of transition to a market economy

APPENDIX D: Global Warming Potential (GWP) of Greenhouse Gases

Species	**Chemical Formula**	**Lifetime and reference**	**Global Warming Potentials, GWPs**		
			[Time Horizon]		
			20 years	**100 years**	**500 years**
CO_2	**CO_2**	**Bern Model**	**1**	**1**	**1**
HFC-23	CHF_3	264	9100	11700	9800
HFC-32	CH_2F_2	5.6	2100	650	200
HFC-41	CH_3F	3.7	490	150	45
HFC-43-10mee	$C_5H_2F_{10}$	17.1	3000	1300	400
HFC-125	C_2HF_5	32.6	4600	2800	920
HFC-134	$C_2H_2F_4$	10.6	2900	1000	310
HFC-134a	CH_2FCF_3	14.6	3400	1300	420
HFC-152a	$C_2H_4F_2$	1.5	460	140	42
HFC-143	$C_2H_3F_3$	3.8	1000	300	94
HFC-143a	$C_2H_3F_3$	48.3	5000	3800	1400
HFC-227ea	C_3HF_7	36.5	4300	2900	950
HFC-236fa	$C_3H_2F_6$	209	5100	6300	4700
HFC-245ca	$C_3H_3F_5$	6.6	1800	560	170
Chloroform	$CHCl_3$	0.51	14	4	1
Methylene chloride	CH_2Cl_2	0.46	31	9	3
Sulphur hexafluoride	SF_6	3200	16300	23900	34900
Perfluoromethane	CF_4	50000	4400	6500	10000
Perfluoroethane	C_2F_6	10000	6200	9200	14000
Perfluoropropane	C_3F_8	2600	4000	7000	10100
Perfluorobutane	C_4F_{10}	2600	4800	7000	10100
Perfluoropentane	C_5F_{12}	4100	5100	7500	11000
Perfluorohexane	C_6F_{14}	3200	5000	7400	10700
Perfluorocyclobutane	$c\text{-}C_4F_8$	3200	6000	8700	12700
Methane	**CH_4**	**12.2±3**	**56**	**21**	**6.5**
Nitrous Oxide	**N_2O**	**120**	**280**	**310**	**170**
Trifluoroiodomethane	CF_3l	<0.005	<3	<1	<1

Source: Commonwealth of Australia, 1998

Notes:

1. Global Warming Potentials (GWPs) provide a means of estimating the relative radiative effects of the various greenhouse gases. The GWP index is defined as the cumulative radiative forcing between the present, and some chosen later time 'horizon' caused by a unit mass of gas emitted now, expressed relative to some reference gas [CO2 is used here]. The future global warming commitment of a greenhouse gas over the reference time horizon is the appropriate GWP multiplied by the amount of gas emitted.

2. The time horizons of the GWP values in the table are 20, 100 and 500 years. A 100-year horizon is often used for policy purposes.

3. The typical uncertainty associated with GWP values is ±35%, not including the uncertainty in the carbon dioxide reference. GWP values and their estimated uncertainties are intended to reflect global averages only, and do not account for regional effects.

4. The GWP concept is currently inapplicable to gases and aerosols that are unevenly distributed in the atmosphere, as is the case for tropospheric ozone and aerosols and their precursors.

5. The GWP for CH4 includes indirect effects of tropospheric ozone production & stratospheric water vapour production.

APPENDIX E1: METRIC PREFIXES

Abbreviation	**Prefix**	**Symbol**
10^{15} (10^6 x 10^9)	Peta (thousand trillion; million billion)	P
10^{12} (10^3 x 10^9)	Tera (trillion; thousand billion)	T
10^9	Giga (billion)	G
10^6	Mega (million)	M
10^3	kilo (thousand)	k
10^2	hecto	h
10^1	deca	da
10^0	- (e.g. gram)	g
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	µ
10^{-9}	nano	n
10^{-12}	Pico	p

APPENDIX E2: UNIT EQUIVALENCES

10^{15} grams (Petagram)	Gigatonne (Gt)
10^{12} grams(Teragram)	Megatonne (Mt)
10^9 grams (Gigagrams)	kilotonnes (kt) (10^3 tonnes)
10^6 (million grams)	1 tonne
kg/GJ (10^3 g/ 10^9 J)	Gg/PJ (10^9 g/ 10^{15} J)
Mg/PJ (10^6 g/ 10^{15} J)	g/GJ (10^0g/10^9 J)

Illustration: 423, 000 Gg is equivalent to 423, 000 kt and 423 Mt

APPENDIX E3: ENERGY AND POWER UNITS

Unit of Energy: Joule
Unit of power (rate of energy usage): Watt

Conversion Factors		
1 Watt	= 1 Joule/Second	
3600 Watt-seconds	= 1 Watt-hour (3600 seconds in one hour)	
1 Watt-hour	= 3600 Joules	
1000 Watt-hours	= 1 kilowatt hour (kWh)	
1 kWh	= 3.6 x 106 Joules = 3.6 MJ	
1 kWh	= 3.6 x 10-3 GJ	
1 GJ	= 278 kWh	
1 PJ	278 x 106 kWh = 278GWh	
(A) For conversion from First unit to second	**(B) Multiply quantity in first unit by conversion factor**	**(C) To calculate quantity in second unit**
kWh to J	kWh x 3.6 x 106	Joules
J to kWh	J x 1/(3.6 10-6)	kWh
kWh to MJ	kWh x 3.6	MJ
MJ to kWh	MJ x 0.278	kWh
kWh to GJ	kWh x 3.6 x 10-6	GJ
GJ to kWh	GJ x 278	kWh
kWh to PJ	kWh x 3.6 x 10-9	PJ
PJ to kWh	PJ x 278 x 106	kWh

Source: AGO, 2005

APPENDIX F1: NATURAL GAS EMISSION FACTORS FOR STATES AND TERRITORIES

Emissions Algorithm: GHG Emissions (t CO_2-e) = Q × EF/1000

Where: Q is the quantity of natural gas consumed and expressed in GJ; sourced from supplier invoices/meters, and

EF is the relevant emission factor as given in the table below:

	Smaller User < 100,000 GJ per annum			**Large User > 100,000 GJ per annum**		
State	EF for scope 1 (direct/point source EF for combustion emissions)	EF for scope 3 (indirect EF for fuel extraction emissions)	Full Fuel Cycle EF (Scope 1 EF + Scope 3 EF)	EF for scope 1 (direct/point source EF for combustion emissions)	EF for scope 3 (indirect EF for fuel extraction emissions)	Full Fuel Cycle EF (= EF for scope 1 + EF for Scope 3)
	A	**B**	**C**	**D**	**E**	**F**
	kg CO_2-e/GJ	**kg CO_2-e/GJ**	**kg CO_2-e/GJ**	**kg CO_2-e/GJ**	**kg CO_2-e/GJ**	**kg CO_2-e/GJ**
NSW & ACT	51.7	19.5	71.3	51.7	16.2	68.0
VIC	51.9	11.7	63.6	51.9	11.5	63.4
QLD	52.6	16.1	68.8	52.6	11.6	64.2
SA	51.7	22.0	73.8	51.7	19.4	71.2
WA	52.7	8.1	60.7	52.7	7.4	60.0
TAS	NA	NA	NA	NA	NA	NA
NT	52.0	1.6	53.6	52.0	1.4	53.5

Source: AGO, 2005

Notes:

1. These time series are provided for information. The emissions factors are based on the latest information available in the 2004 National Greenhouse Gas Inventory.
2. Data are from George Wilkenfeld and associates: values for 1990, 1995, 1999 and 2002 are actual calculated values; others are interpolations or extrapolations. These are revised emission factors, different to those published in past editions of emissions estimation workbooks.
3. Data are for financial years ending in June

Example: Calculation of emissions Generated from Natural Gas Consumption

Q: A Queensland business uses 125,000 GJ of natural gas per annum. Its GHG emissions are calculated as follows:

Scope 1 GHG Emissions = Q x EF / 1000 = 125,000 x 52.6 / 1000 = 6,575 t CO_2-e

Scope 3 GHG Emissions = Q x EF / 1000 = 125,000 x 11.6 / 1000 = 1,450 t CO_2-e

F2: NATURAL GAS EMISSION FACTORS FOR QUEENSLAND

Emissions Algorithm: GHG Emissions (t CO_2-e) = Q × EF/1000

Where: Q is the quantity of natural gas consumed and expressed in GJ; sourced from supplier invoices/meters, and

EF is the relevant emission factor as given in the table below:

	Smaller User < 100,000 GJ per annum			**Large User > 100,000 GJ per annum**		
F.Y.	EF for scope 1 (direct/point source EF for combustion emissions)	EF for scope 3 (indirect EF for fuel extraction emissions)	Full Fuel Cycle EF (Scope 1 EF + Scope 3 EF)	EF for scope 1 (direct/point source EF for combustion emissions)	EF for scope 3 (indirect EF for fuel extraction emissions)	Full Fuel Cycle EF (= EF for scope 1 + EF for Scope 3)
	A	**B**	**C**	**D**	**E**	**F**
	kg CO_2-e/GJ	**kg CO_2-e/GJ**	**kg CO_2-e/GJ**	**kg CO_2-e/GJ**	**kg CO_2-e/GJ**	**kg CO_2-e/GJ**
	QUEENSLAND					
1990	51.2	13.9	65.1	51.2	12.0	63.2
1991	51.2	14.4	65.6	51.2	12.2	63.4
1992	51.3	14.8	66.1	51.3	12.3	63.6
1993	51.3	15.3	66.6	51.3	12.4	63.7
1994	51.4	15.7	67.1	51.4	12.6	63.9
1995	51.4	16.2	67.6	51.4	12.7	64.1
1996	51.9	17.5	69.4	51.9	12.9	64.7
1997	52.3	18.9	71.2	52.3	13.1	65.4
1998	52.7	20.3	73.0	52.7	13.3	66.0
1999	53.1	21.7	74.8	53.1	13.5	66.6
2000	53.0	19.8	72.8	53.0	12.8	65.8
2001	52.8	18.0	70.8	52.8	12.2	65.0
2002	52.6	16.1	68.8	52.6	11.6	64.2
2003^p	52.6	16.1	68.8	52.6	11.6	64.2
2004^p	52.6	16.1	68.8	52.6	11.6	64.2
2005^p	52.6	16.1	68.8	52.6	11.6	64.2

Source: AGO Factors and Methodology, 2005

Notes:

1. These time series are provided for information. The emissions factors are based on the latest information available in the 2004 NGGI;
2. Data are from George Wilkenfeld and associates: values for 1990, 1995, 1999 and 2002 are actual calculated values; others are interpolations or extrapolations. These are revised emission factors, different to those published in past editions of emissions estimation workbooks;
3. Data are for financial years ending in June;
4. FY stands for financial; ‘p’ denotes AGO provisional estimates based on the ABARE Fuel and Electricity Survey

APPENDIX G1: ELECTRICITY EMISSION FACTORS FOR END-USERS: STATES & TERRITORIES, 1990-2005

Emissions Algorithm:

GHG Emissions (t CO2-e) = Q × EF/1000

Where: Q (Activity) is the electricity consumed by the reporting organisation expressed in kWh; and
EF is the relevant emission factor expressed in kg CO2-e/kWh (Columns A, C and E):

OR

GHG Emissions (t CO2-e) = Q × EF/1000

Where: Q (Activity) is the electricity consumed expressed in GJ; and
EF is the relevant emission factor expressed in kg CO2-e/GJ (Columns B, D & F)

State	**EF for Scope 2** Direct/point source EF for combustion emissions		**EFs for Scope 3** Indirect EF for Fuel extraction & line loss (T&D) emissions		**Full Fuel Cycle EF** (= EF for scope 1 + EF for scope 3)	
	A	**B**	**C**	**D**	**E**	**F**
	kg CO_2-e/kWh[a]	**kg CO_2-e/GJ**[ab]	**kg CO_2-e/kWh**[a]	**kg CO_2-e/GJ**[ab]	**kg CO_2-e/kWh**[a]	**kg CO_2-e/GJ**[ab]
NSW & ACT	0.835	232	0.150	42	0.985	274
VIC	1.229	361	0.168	47	1.467	407
QLD	1.03	286	0.125	35	1.155	321
SA	0.836	232	0.171	48	1.007	280
WA	0.862	239	0.130	36	0.992	276
TAS	0.030	8.3	0.001	0.4	0.031	8.7
NT	0.711	198	0.103	29	0.814	226

Source: AGO, 2005

Notes: This data is for use by consumers and not Transmission and Distribution (T&D) network operators.
a. The emission factors should be applied to the amount of electricity actually consumed (i.e. the amount shown on the electricity bill).
b. kg CO_2-e/GJ is the same as kt CO_2-e/PJ and Gg CO_2-e/PJ.

Illustration:

A company in Queensland consumes 150,000 kWh of purchased electricity from the grid;

Scope 2 GHG emissions (t CO_2) = (150,000 x 1.03) / 1000 = 154.5 tonnes

Scope 3 GHG Emissions (t CO_2) = (150,000 x 0.125) / 1000 = 18.75 tonnes

APPENDIX G2: ELECTRICITY EMISSION FACTORS FOR END-USERS IN QUEENSLAND, 1990 – 2005

Emissions Algorithm:

$$\text{GHG Emissions (t } CO_2\text{-e)} = Q \times EF/1000$$

Where: Q (Activity) is the electricity consumed by the reporting organisation expressed in kWh; and
EF is the relevant emission factor expressed in kg CO_2-e/kWh in the table:

OR

$$\text{GHG Emissions (t } CO_2\text{-e)} = Q \times EF/1000$$

Where: Q (Activity) is the electricity consumed expressed in GJ; and
EF is the relevant emission factor expressed in kg CO_2-e/GJ in the table shown:

Financial Year	**EF for Scope 2** Direct/point source EF for combustion emissions		**EFs for Scope 3** Indirect EF for Fuel extraction & line loss (T&D) emissions		**Full Fuel Cycle EF** (= EF for scope 1 + EF for scope 3)	
	A	**B**	**C**	**D**	**E**	**F**
	kg CO_2-e/kWh	**kg CO_2-e/GJ**	**kg CO_2-e/kWh**	**kg CO_2-e/GJ**	**kg CO_2-e/kWh**	**kg CO_2-e/GJ**
	QUEENSLAND					
1990	0.905	251	0.124	34	1.029	286
1991	0.907	252	0.123	34	1.031	286
1992	0.910	253	0.123	34	1.033	287
1993	0.912	253	0.123	34	1.035	287
1994	0.914	254	0.122	34	1.036	288
1995	0.916	255	0.122	34	1.038	288
1996	0.929	258	0.130	36	1.059	294
1997	0.942	262	0.137	38	1.079	300
1998	0.955	265	0.145	40	1.100	306
1999	0.968	269	0.153	42	1.121	311
2000	0.973	270	0.146	41	1.119	311
2001	0.979	272	0.139	39	1.118	310
2002	0.984	273	0.132	37	1.116	310
2003	0.990	275	0.125	35	1.115	310
2004p	1.048	291	0.125	35	1.173	326
2005p	1.030	286	0.125	35	1.155	321

Source: AGO, 2005

Notes:

1. These time series are provided for information. The emissions factors are based on the latest information available in the 2004 NGGI.
2. Data for 1990-2003 are from George Wilkenfeld and associates: values for 1990, 1995, 1999 and 2003 are actual calculated values; others are interpolations or extrapolations. These are revised emission factors, different to those published in past editions of emissions estimation workbooks.
3. Data are for financial years ending in June
4. ‘p’ indicates AGO provisional estimates for 2004 and 2005 based on the ABARE Fuel and Electricity Survey, NEMMCO, Western Australian Government and Western Power Data.

APPENDIX H: Fuel Combustion Emission Factors

Emissions Algorithm: GHG emissions (t CO_2-e) = Q (kL) × EF

OR

GHG emissions (t CO_2-e) = Q (GJ) × EF/1000

Where: Q is the Quantity of fuel in thousands of litres or GJ (sourced from inventory, supplier or production records); and
EF is the relevant emission factor sourced from the table below:

Fuel	**Energy Content**	**EF for Scope 1** (direct/point source EF for combustion emissions)		**EF for Scope 3** (indirect EF for fuel extraction emissions)		**Full fuel cycle EF** (= EF for Scope 1 + EF for Scope 3)	
	A	**B**	**C**	**D**	**E**	**F**	**G**
	GJ/kL	**kg CO_2-e / GJ**	**t CO_2-e / kL**	**kg CO_2-e / GJ**	**t CO_2-e / kL**	**kg CO_2-e / GJ**	**t CO_2-e / kL**
Automotive gasoline (petrol)	34.2	73.5	2.5	7.8	0.27	81.2	2.8
Automotive diesel oil (diesel)	38.6	70.5	2.7	7.8	0.30	78.2	3.0
Aviation gasoline	33.1	69.5	2.3	7.8	0.26	77.2	2.6
Aviation turbine	36.8	70.4	2.6	7.8	0.29	78.1	2.9
Industrial diesel fuel	39.6	70.5	2.8	7.8	0.31	78.2	3.1
Fuel Oil	40.8	74.3	3.0	7.8	0.32	82.0	3.3
LPG	25.7	60.5	1.6	7.8	0.20	68.3	1.8
	GJ/ m^2	**kg CO_2-e / GJ**	**t CO_2-e / m^2**	**kg CO_2-e / GJ**	**t CO_2-e / m^2**	**kg CO_2-e / GJ**	**t CO_2-e / m^2**
Natural gas* (LDV)	0.0395	57.2	0.0023	11.4	0.00045	68.6	0.0027
Natural gas* (HDV)	0.0395	53.8	0.0021	11.4	0.00045	65.2	0.0026
Biofuels*	–	–	–	–	–	–	–

Source: ago, 2005

Notes:
a. The emission factors for natural gas engines are indicative only. From AGO experience with the Alternative Fuels Conversion Programme, the AGO has discovered that many natural gas engines, whether dual fuel or dedicated, emit significant amounts of unburnt fuel to the atmosphere. This level of methane is dependent on a range of factors and varies from system to system. An accurate emissions factor therefore requires measurement of atleast CO_2 and CH_4 for each engine type.
b. LDV stands for Light Duty Vehicle, e.g. forklifts, and HDV stands for Heavy Duty Vehicle, e.g. buses. Farm machinery is classed as LDV for this project.
c. Biofuel (biodiesel, ethanol blends) emissions vary according to the feedstock used.

Example: Calculation of emissions generated from transport fuels consumed

A Queensland freight company consumes 2500 kL of petrol and 4000 kL automotive diesel (transport) per annum. The Scope 1 direct GHG emissions are calculated as follows:

GHG Emissions (t CO_2-e) = Q (kL) x EF (t CO_2-e / kL)
Petrol Scope 1 GHG Emissions = 2500 x 2.5 = 6,250 t CO_2-e
Diesel Scope 1 GHG Emissions = 4000 x 2.7 = 10,800 t CO_2-e
Total Scope 1 emissions = 6,250 + 10,800 = 17,050 t CO_2-e

APPENDIX I: Fraction of Fertiliser N Applied to each Production System

	NSW	NT	QLD	SA	TAS	VIC	WA		
							1990-1995	1996-2002	2003+
Irrigated Pasture	0.03515	0.02079	0.01932	0.01840	0.09361	0.17074	0.00305	0.00187	0.00182
Irrigated Crops	0.08916	0.02560	0.02868	0.00929	0.10052	0.02756	0.00218	0.00133	0.00129
Non-irrigated pasture	0.39740	0.03543	0.01901	0.60105	0.55850	0.44539	0.69458	0.70109	0.70196
Non-irrigated crops	0.23771	0.00000	0.00447	0.27820	0.01836	0.24182	0.27294	0.27550	0.27584
Sugar cane	0.01771		0.62038					0.00297	0.00288
Cotton	0.18601		0.23151					0.00054	
Horticultural Vegetable Crops	0.03685	0.91818	0.07633	0.09306	0.22901	0.11449	0.02726	0.01670	0.01621

Source: Australian Greenhouse Office, 2004

APPENDIX J: Estimating Emissions from Vegetation Management Using Greengauge Methodologies

This segment of the appendix is a reproduction of work conducted in the construction of the original version of Greengauge. The information has no direct significance to the current project as little modifications were introduced to this subsystem; it is included for completeness of the report.

Deforestation

Fluxes of CO_2 associated with forest clearing are dependent on a number of processes. These processes include:

- burning of biomass,
- regrowth of vegetation following clearing (original forest class and/or crops/pastures),
- delayed emissions from decay, and
- delayed emissions from belowground carbon release (soil and roots)

The general methodology used involved quantifying the source/sink potential for each process listed above to allow calculation of net emissions for the deforestation category. Default data is sourced either directly or adapted from the NGGI, including disaggregated parameters and data on land clearing to State level (Commonwealth of Australia 1998b, p.11). In developing this component of Greengauge *v.1.1*, the following forest classes were used:

- Tropical and temperate closed forest,
- Open forest, and
- Woodland and scrub

Biomass burning (CO_2 emissions)

The method recognized that an area affected by a clearing activity may not necessarily be completely cleared, therefore a correction was formulated for this occurrence. It was assumed that biomass may remain on-site or be removed for various purposes. Material taken off-site was eliminated from calculations due to the complexities of determining factors such as the quantity of carbon stored in wood products. An on-site default figure for the amount of biomass burnt was supplied based on Queensland averages found in the NGGI. The method accounted for biomass per unit area of each forest class before clearing, with a correction for carbon content and combustion efficiency. The work table for used for calculating emissions as presented in Table 21, with a simplified algorithm provided. Emissions are reported in gigagrams of carbon equivalents (CO_2-e).

Table 22: Methodology for calculating $C0_2$ emissions from burning biomass on-site following deforestation

Source: Adapted from Commonwealth of Australia 1998b

Column #	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Forest Class	**Area affected (ha)** ***(A)***	**Proportion cleared (%)** ***(PC)***	**Proportion of aboveground biomass burnt (On site) (%)** ***(PB)***	**Aboveground biomass per unit area for each forest class before clearing (t dm/ha)** ***(AB_{fc})***	**Carbon content of biomass before clearing** ***(CC)***	**Combustion efficiency (On site)** ***(CE)***	**Carbon release (t C/ha)**	**$C0_2$ emission (Gg $C0_2$)** ***($C0_2$-e)***
Tropical and temperate closed forests			0.9	188	0.5	0.9		
Dense woodland and open forests			0.9	72	0.5	0.9		
Open woodland & scrub			0.9	41	0.5	0.9 1		
Total								

Algorithm: (A x [PC/100] x [PB/100] x AB_{fc} x CC x CE) x 10^{-3} x 3.66

Total emission in gigagrams of $C0_2$-e from Deforestation: Burning = *$C0_2$-e*

Regrowth (CO_2 sequestration)

The method assumed that following initial land clearing a certain amount of sequestration occurs through regrowth of crops/pastures and woody vegetation. This sequestration potential is accounted for in Tables 23 & 24, with a simple algorithm immediately following. It was stressed that for crops/pastures an estimate of biomass is only calculated for the initial inventory year following clearing. According to Stephenson (2003), this was an unrealistic assumption given the flux associated with these systems. Nonetheless, in the interests of simplicity it was assumed that a seasonal flux of CO_2, through harvesting and planting of crops, achieves some degree of equilibrium. In the case of woody vegetation, the biomass of the relevant forest class was assumed to increment linearly up to an arbitrary period of 25 years, at which point it is considered to be a carbon pool and exempt from further calculations. Emissions are reported in gigagrams of carbon equivalents (CO_2-e).

Table 23: Methodology for calculating $C0_2$ sequestration from regrowth of crops/grasses following deforestation

Source: Adapted from Commonwealth of Australia 1998b

Column #	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Forest Type	**Area affected (h)** ***(A)***	**Proportion cleared (%)** ***(PC)***	**Biomass per unit area of crops or grasses after clearing (t dm/ha)** ***(B_{cg})***	**Carbon content of crops or grasses after clearing** ***(CC_{cg})***	**Proportion of area cleared going to crops or grasses (%)** ***(PC_{cg})***	**Mass of carbon taken up by regrowth (t C/y)**	**Mass of $C0_2$ taken up (Gg $C0_2$/y)** ***($C0_2$-e)***
All forest classes			10.3	0.42			
TOTAL							

Table 24: Methodology for calculating CO_2 sequestration from regrowth of forest classes following deforestation

Source: Adapted from Commonwealth of Australia 1998b

Column #	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Forest Type	**Area affected (h)** ***(A)***	**Proportion cleared (%)** ***(PC)***	**Time elapsed since cleared** ***(T)***	**Biomass per unit area after regrowth of each forest class (t dm/ha) (per year over 25 years)** ***(B_{fc})***	**Carbon content of the biomass after regrowth of forest class** ***(CC_{fc})***	**Proportion of area cleared going to forest class regrowth (%)** ***(PC_{fc})***	**Mass of carbon taken up by regrowth (t C/y)**	**Mass of $C0_2$ taken up (Gg $C0_2$/y)** ***($C0_2$-e)***
Tropical & temperate closed forest				7.52	0.5			
Dense woodland & open forests				2.88	0.5			
Open woodland & scrub				1.64	0.5			
TOTAL								

Algorithm:

{***Table 23*** (*A* x [*PC*/100] x [PC_{cg} /100] x B_{cg} x CC_{cg})) + ***Table 24*** (*A* x [*PC*/100] x [*T* x B_{fc}] x [PC_{fc} /100] x CC_{fc})} x 10^{-3} x 3.66

Total sequestration in gigagrams of CO_2-e from Deforestation: Regrowth = (*CO_2-e* ***Table 23***) + (*CO_2-e* ***Table 24***)

Delayed emissions from decay (CO_2 emissions)

Following burning of on site biomass, a proportion which is not combusted remains on the ground as slash where it decays slowly. Table 25 provides the methodology designed to account for this delayed emission. Although the time taken for decay is highly variable, a default of 10 years has been suggested for Queensland (Commonwealth of Australia 1998b, p.11). Therefore, the estimated emission is assumed to be released to the atmosphere over that 10 year period. Emissions are reported in gigagrams of carbon equivalents (CO_2-e).

Table 25: Methodology for calculating $C0_2$ delayed emissions from decay following deforestation

Source: Adapted from Commonwealth of Australia 1998b

Column #	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Forest class	**Area affected (ha)** ***(A)***	**Proportion cleared (%)** ***(PC)***	**Area cleared (ha)** ***(AC)***	**Proportion of biomass burnt (on site) (%)** ***(PBB)***	**Biomass for forest class before clearing (t dm/ha)** **(B_{fc})**	**Carbon content of biomass before clearing** ***(CC)***	**Carbon emissions t C/yr**	**$C0_2$ emission (Gg $C0_2$/y)** **$(C0_2\text{-}e)$**
Tropical & temperate closed forest				0.9	188	0.5		
Dense woodland & open forests				0.9	72	0.5		
Open woodland & scrub				0.9	41	0.5		
TOTAL								

Algorithm:

$\{\{AC - (A \times [PC/100] \times [PBB/100])\} \times B_{fc} \times CC\} \times 10^{-3} \times 3.66$

Total emissions in gigagrams of $C0_2$-e from delayed emissions from decay = $CO_2\text{-}e$

Delayed $C0_2$ emissions from belowground carbon release (Soil and roots)

Delayed emissions are also released from belowground soil and roots. The method estimates the soil carbon content of an area before clearing, and then subtracts the soil carbon reached in ‘steady state’ after clearing to arrive at a net emission. This ‘steady state’ is assumed to increase linearly over a 20 year period (Commonwealth of Australia 1998b). Similarly, the root carbon content of an area before clearing is estimated and then corrected for the root carbon content of regrowth (crops/pastures & woody vegetation). The root carbon content of original forest class regrowth is assumed to increase linearly over a period of 25 years. The work tables for calculating emissions are presented in Tables 26 & 27, with a simplified algorithm immediately following. Emissions are reported in gigagrams of carbon equivalents (CO_2-e).

Table 26: Methodology for calculating delayed $C0_2$ emissions from soil following deforestation

Column #	2	3	4	5	6	7
Forest class	**Area cleared (ha) *(A)***	**Time elapsed relevant to soil carbon decay (up to 20 yr max.) *(T_{scd})***	**Soil carbon content before clearing (t C/ha) *(SCC)***	**Soil carbon content reached in 'steady state' after clearing (t C/ha/y) *(SCC_{ss})***	**Carbon emissions t C/ha**	**$C0_2$ emission (Gg $C0_2$/y) *($C0_2$-e)***
Tropical & temperate closed forest			120	4.2		
Dense woodland & open forests			85	2.975		
Open woodland & scrub			70	2.45		
TOTAL						

Table 27: Methodology for calculating $C0_2$ delayed emissions from root decay following deforestation

Column #	2	3	4	5	6	7	8	9	10
Forest class	**Area cleared *(A)***	**Time elapsed since clearing (up to 25 y max) *(T)***	**Area of regrowth (crops/pastures) (ha) *(AR_{cp})***	**Area of regrowth (woody veg) (ha) *(AR_{wv})***	**Root carbon content before clearing (t C/ha) *(RCC)***	**Root carbon content of regrowth - crops & pastures (t C/ha) *(RCC_{cp})***	**Root carbon content of regrowth - woody veg (per year over 25 years)) (t C/ha) *(RCC_{wv})***	**Carbon emissions t C/ha**	**$C0_2$ emission (Gg $C0_2$/y) *($C0_2$-e)***
Tropical & temperate closed forest					28.25	2.1	1.13		
Dense woodland & open forests					10	2.1	0.4		
Open woodland & scrub					5.25	2.1	0.21		
TOTAL									

Source: Adapted from Commonwealth of Australia 1998b

Algorithm: {{**Table 26** (A x SCC) – (A x T_{scd} x SCC_{ss})} +{**Table 27** (A x RCC) – [RCC_{cp} x AR_{cp}) + ((RCC_{wv} x T) x AR_{wv})]} x 10^{-3} x 3.66

Total emissions in gigagrams of C02-e for Deforestation: Delayed emissions from belowground carbon release (soil and roots) = $C0_2$-e ***(Table 26)*** + $C0_2$-e ***(Table 27)***

The total estimated net emission from deforestation is therefore:

{ $C0_2$-e ***(Table 22)*** + $C0_2$-e ***(Table 25)*** + ($C0_2$-e ***(Table 26 + Table 27)***)} **– (** $C0_2$-e ***(Table 23 + Table24)***)

Vegetation Thickening ($C0_2$ sequestration)

It has been suggested that Queensland is the most important region in terms of the total area affected by vegetation thickening (Commonwealth of Australia 1998b). Analysing the area affected is complicated by the fact that many areas have been previously cleared and there can be confusion as to what is considered regrowth. The default figure for average increment in basal area provided in Table 28 is derived from data collected in the Fitzroy Basin, Queensland as part of the TRAPS data set and augmented by figures obtained from the Queensland Forest Service (Commonwealth of Australia 1998b, p.66). The figures arrived at were 0.24m^2/ha/y and 0.12m^2/ha/y respectively. These figures were averaged to arrive at an incremental value of 0.18m^2/ha/y for the purposes of this study.

Table 28: Methodology for calculating $C0_2$ sequestration from Vegetation thickening

Column #	**2**	**3**	**4**	**5**	**6**
Area affected (ha) ***(A)***	**Time elapsed since affected (up to 25 y max.)** ***(T)***	**Average increment in basal area (m^2/ha/yr)** ***(BA)***	**Conversion from basal area to dry matter biomass (including root dry matter to one metre depth in soil) (t DM/ m^2)** ***(BADM)***	**Carbon content of biomass** ***(CC)***	**Mass of $C0_2$ taken up (Gg $C0_2$/yr)**
		0.18	4.7	0.5	

Algorithm: (A x [T x BA] x $BADM$ x CC) x 10^{-3} x 3.66 (Gg CO_2-e)

Source: Adapted from Commonwealth of Australia 1998b

Regrowth ($C0_2$ sequestration)

Regrowth has been included as a distinct sub-category of Vegetation Management to account for NRM activities that are enhancing this process but are not included in accounting under regrowth following forest clearing occurring since 1990. As described under *Deforestation: Regrowth*, the biomass of the relevant forest class is assumed to increment linearly up to an arbitrary period of twenty five years, at which point it is considered to be a carbon pool and exempt from further calculations (Commonwealth of Australia 1999b). The work table for calculating emissions is presented in Tables 29, with a simplified algorithm immediately following. Emissions are reported in gigagrams of carbon equivalents ($C0_2$-e). For this study, a base year of 1990 is suggested for recording data on regrowth.

Table 29: Methodology for calculating $C0_2$ sequestration from Regrowth

Source: Adapted from Commonwealth of Australia 1998b

Column#	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Forest Type	**Area affected (h)** ***(A)***	**Proportion cleared (%)** ***(PC)***	**Time elapsed since cleared** ***(T)***	**Biomass per unit area after regrowth of each forest class (t dm/ha/y over 25 years)** ***(B_{fc})***	**Carbon content of biomass after regrowth of forest class** ***(CC_{fc})***	**Mass of carbon taken up by regrowth (t C/y)**	**Mass of $C0_2$ taken up (Gg $C0_2$/y)** ***($C0_2$-e)***
Tropical & temperate closed forest				7.52	0.5		
Dense woodland & open forests				2.88	0.5		
Open woodland & scrub				1.64	0.5		
TOTAL							

Algorithm: (A x [PC/100] x [T x B_{fc}] x CC_{fc}) x 10^{-3} x 3.66

Total sequestration in gigagrams of $C0_2$-e from Regrowth = *$C0_2$-e*

Direct planting ($C0_2$ sequestration)

For the purposes of this study, direct plantings include:

- Environmental plantings
- Windbreaks/Shelterbelts
- Small scale Farm forestry/Agroforestry ventures

Due to the scale and objectives of the study, plantation estates that required detailed accounting and any plantings being established for carbon credits were considered beyond the scope of the project and more detailed estimates should be obtained through the suggestions already made.

To simplify use, categories for sequestration potential were reduced to High (>700mm rainfall zone), Medium (500-700mm rainfall zone), and Low (<500mm rainfall zone). If a site is irrigated it is taken as having high sequestration potential. Carbon sequestered in above and belowground biomass of trees and tree litter and woody debris on the forest floor were included, but soil carbon was not. The methodology did not take into account losses on harvest and estimates can only be made up to that point. It is assumed that in most cases after harvesting, the site will be replanted and a new cycle of sequestration will be initiated.

Users are required to settle on the sequestration potential of the area in question, determine the expected planting year, estimate the number of hectares of forest of each age, and determine the age of the trees in the year of the inventory. A correction can be made for the proportion of the planting surviving. To simplify use the pattern of carbon sequestration over time was treated as linear by dividing aggregate figures by the appropriate age class for that planting. The effect of this is that in calculating sequestration for any period less than the actual age of the planting there will be varying degrees of inaccuracy. This inaccuracy was viewed as acceptable for the purposes of the project. If greater accuracy is required it will be necessary to establish the age of the planting at the start of the desired period and at the end of the period, determine the quantity of CO_2-e at each of these two ages and manually calculate the difference between these quantities.

Appendix K: Applicability of Enteric Fermentation Emissions Reduction Options to Animal Management Systems (USEPA, 1993b)

	% of Animals (% of Emissions)	**Feed Processing**	**Improved Nutrition**	**Production-Enhancing Agents**	**Genetic Improvement**	**Improved Reproduction**
Intensive Dairy: Non grazing	10 – 15 % of animals (20 – 25 % of emissions)	Processed feeds used monthly	Balanced rations used routinely	Candidate for additional implementation (e.g. bST)	Strong programs in place in main dairy countries	Strong programs in place in main dairy countries
Intensive Dairy: Grazing		(NA)	Candidate for targeted supplementation in selected areas	Candidate for additional implementation (e.g. bST)	Strong programs in place in main dairy countries	Strong programs in place in main dairy countries
Extensive Commercial Ranching	35 – 40 % of animals (40 – 45 % of emissions)	(NA)	Possible candidate for targeted supplementation in selected areas	Candidate for additional implementation	Candidate for additional implementation	(NA)
Non-Extensive Commercial Ranching		(NA)	Candidate for targeted supplementation in selected areas; candidate for defaunation	Currently used routinely	Candidate for additional implementation	Possible candidate for targeted implementation in cases with adequate access to animals
Feedlot Production	1 – 2 % of animals (2–4% of emissions)	Processed feeds used routinely	Balanced rations used routinely	Currently used routinely where allowed	(NA)	(NA)
Small-scale Dairy and Draft	15-20 % of animals (10-15% of emissions)	Candidate for additional implementation	Candidate for using molasses-urea blocks (MUB) & bypass protein feeds (BPF)	(NA)	Candidate for additional implementation	(NA)

APPENDIX L: Dairy Cattle

L1: Dairy Cattle; Liveweight (kg)

State	Milking Cows	Heifers>1	Heifers<1	House Cows; Milk and Dry	Dairy Bulls>1	Dairy Bulls<1
NSW/ACT	550	425	240	450	650	300
TASMANIA	500	350	220	400	600	250
W.A.	550	350	180	450	550	250
S.A.	550	450	260	500	500	350
VICTORIA	550	450	250	450	600	250
QUEENSLAND	580	400	150	500	650	200
N.T.	500	350	220	400	550	250

L2: Dairy Cattle; liveweight gain (kg/day)

State	Milking Cows	Heifers>1	Heifers<1	House Cows; Milk and Dry	Dairy Bulls>1	Dairy Bulls<1
NSW/ACT	0.04	0.6	0.6	0.04	0.2	0.9
TASMANIA	0.04	0.5	0.8	0.04	0.1	1
W.A.	0.06	0.8	0.8	0.06	0.1	1
S.A.	0.06	0.5	0.8	0.06	0.1	1
VICTORIA	0.04	0.5	0.6	0.04	0.1	1
QUEENSLAND	0.06	0.7	0.7	0.06	0.1	0.7
N.T.	0.06	0.5	0.8	0.06	0.1	1

L3: Dairy Cattle: dry matter digestibility of feed intake (%)

State	Milking Cows	Heifers>1	Heifers<1	House Cows; Milk and Dry	Dairy Bulls>1	Dairy Bulls<1
NSW/ACT	75	75	75	75	75	75
TASMANIA						
Spring	75	75	75	75	75	75
Summer	65	65	65	65	65	65
Autumn	65	65	65	65	65	65
Winter	75	75	75	75	75	75
W.A.	75	75	75	75	75	75
S.A.	75	75	75	75	75	75
VICTORIA	78	78	78	78	78	78
QUEENSLAND	70	65	65	60	65	65
N.T.	75	75	75	75	75	75

Source: **AGO, 2004**

Appendix L: Dairy Cattle (continued)

L4: Dairy Cattle: Allocation of waste to manure management systems

State	**Milking Cows**				**Other Dairy Cattle**
	Lagoon (%)	**Liquid/slurry (%)**	**Daily Spread (%)**	**Voided at Pasture (%)**	**Voided at Pasture (%)**
NSW/ACT	6.0	0.5	1.5	92.0	100
TASMANIA	6.0	0.5	1.5	92.0	100
W.A.	2.0	0.0	6.0	92.0	100
S.A.	10.0	0.5	1.0	88.5	100
VICTORIA	6.0	0.5	1.5	92.0	100
QLD	3.0	0.0	7.0	90.0	100
N.T.	3.0	0.0	7.0	90.0	100

L5: Dairy Cattle: Methane Conversion Factors (MCFs)

State	**Manure Management System MCF**					**Integrated MCF**
	Lagoon (%)	**Liquid/slurry (%)**	**Voided at Pasture (%)**	**Daily Spread (%)**	**Milking Cows (%)**	**Other Dairy Cattle (%)**
NSW/ACT	90	35	1.0	0.5	6.50	1.0
TASMANIA	90	35	1.0	0.5	6.50	1.0
W.A.	90	35	1.0	0.5	2.75	1.0
S.A.	90	35	1.0	0.5	10.07	1.0
VICTORIA	90	35	1.0	0.5	6.50	1.0
QLD	90	65	2.0	1.0	4.57	2.0
N.T.	90	65	2.0	1.0	4.57	2.0

APPENDIX M: Estimating Emissions from Fuel Combustion Using Greengauge Methodologies

This segment of the appendix is a reproduction of work conducted in the construction of the original version of Greengauge.

Land Clearing ($C0_2$, CH_4 & N_20)

The work table for calculating emissions is presented in Table 30, with a simplified algorithm immediately following. Emissions are reported in gigagrams of carbon equivalents ($C0_2$-e).

Table 30: Methodology for calculating CH_4, N_20 & $C0_2$ emissions from Fuel combustion: Land clearing

Source: Adapted from Department of Primary Industries, Vic. 2003

Column#	2	3	4	5	6	7	8	9
Fuel Type	**Ghg**	**Fuel consumed (litres) *(F)***	**Energy density (Mj/L) *(ED)***	**Energy consumption (Mj)**	**Oxidised (%) *(O)***	**Emission factor (g/Mj) *(EF)***	**Emission (Gg)**	**$C0_2$ equivalent (Gg $C0_2$-e) *($C0_2$-e)***
Auto diesel	$C0_2$		38.6		0.99	69.7		
	CH_4					0.01		
	N_20					0.002		
	Sub Total							
Petrol	$C0_2$		34.2		0.99	66.0		
	CH_4					0.38		
	N_20					0.0009		
	Sub Total							
LPG	$C0_2$		25.7		0.99	59.4		
	CH_4					0.022		
	N_20					0.001		
	Sub Total							
Biodiesel	$C0_2$		36.284		0.99	40.426		
	CH_4					0.003714		
	N_20					0.001622		
	Sub Total							
Total								

Algorithm:

(F x ED x O x EF) x 10^{-9} x GWP

Total emissions in gigagrams of $C0_2$-e for Fuel combustion: Land clearing = *$C0_2$-e*

(Sub totals)

Soil Cultivation ($C0_2$, CH_4 & N_20)

The work table for calculating emissions is presented in Table 31, with a simplified algorithm immediately following. Emissions are reported in gigagrams of carbon equivalents ($C0_2$-e).

Table 31: Methodology for calculating CH_4, N_20 & $C0_2$ emissions from Fuel combustion: Soil cultivation

Source: Adapted from Department of Primary Industries, Vic. 2003

Column#	**2**	**3**	**4**
Management	**Area (hectares)** ***(A)***	**Fuel consumption (litres/ha)** ***(FC)***	**Fuel consumed (litres)**
Scarifying			
Tillage			
Fertiliser Application			
Total			

Column#	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Fuel Type	**Ghg**	**Energy density (Mj/L)** ***(ED)***	**Energy consumption (Mj)**	**Oxidised (%)** ***(O)***	**Emission factor (g/Mj)** ***(EF)***	**Emission (Gg)**	**$C0_2$ equivalent (Gg $C0_2$-e)** ***($C0_2$-e)***
Auto diesel	$C0_2$	38.6		0.99	69.7		
	CH_4				0.01		
	N_20				0.002		
	Sub Total						
Petrol	$C0_2$	34.2		0.99	66.0		
	CH_4				0.38		
	N_20				0.0009		
	Sub Total						
LPG	$C0_2$	25.7		0.99	59.4		
	CH_4				0.022		
	N_20				0.001		
	Sub Total						
Biodiesel	$C0_2$	36.284		0.99	40.426		
	CH_4				0.003714		
	N_20				0.001622		
	Sub Total						
	TOTAL						

Algorithm:

$\{(A \text{ x } FC) \text{ x } ED \text{ x } O \text{ x } EF\} \text{ x } 10^{-9} \text{ x GWP}$

Total emissions in gigagrams of $C0_2$-e for Fuel combustion: Soil cultivation = *$C0_2$-**e*** (Sub totals)

Planting ($C0_2$, CH_4 & N_20)

The work table for calculating emissions is presented in Table 32, with a simplified algorithm immediately following. Emissions are reported in gigagrams of carbon equivalents ($C0_2$-e).

Table 32: Methodology for calculating CH_4, N_20 & $C0_2$ emissions from Fuel combustion: Planting

Source: Adapted from Department of Primary Industries, Vic. 2003

Column#	**2**	**3**	**4**
Management	**Area (hectares)** ***(A)***	**Fuel consumption (litres/ha)** ***(FC)***	**Fuel consumed**
Planting			
Herbicide Application			
Total			

Column#	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Fuel Type	**Ghg**	**Energy density (Mj/L)** ***(ED)***	**Energy consumption (Mj)**	**Oxidised (%)** ***(O)***	**Emission factor (g/Mj)** ***(EF)***	**Emission (Gg)**	**$C0_2$ equivalent (Gg $C0_2$-e)** ***($C0_2$-e)***
Auto diesel	$C0_2$	38.6		0.99	69.7		
	CH_4				0.01		
	N_20				0.002		
	Sub Total						
Petrol	$C0_2$	34.2		0.99	66.0		
	CH_4				0.38		
	N_20				0.0009		
	Sub Total						
LPG	$C0_2$	25.7		0.99	59.4		
	CH_4				0.022		
	N_20				0.001		
	Sub Total						
Biodiesel	$C0_2$	36.284		0.99	40.426		
	CH_4				0.003714		
	N_20				0.001622		
	Sub Total						
	TOTAL						

Algorithm:

{(*A* x *FC*) x *ED* x *O* x *EF*} x 10^{-9} x GWP

Total emissions in gigagrams of $C0_2$-e for Fuel combustion: Planting = *$C0_2$-e* (Sub totals)

Irrigation (Fuel use) ($C0_2$, CH_4 & N_20)

The work table for calculating emissions is presented in Table 33, with a simplified algorithm immediately following. Emissions are reported in gigagrams of carbon equivalents ($C0_2$-e).

Table 33: Methodology for calculating CH_4, N_20 & $C0_2$ emissions from Fuel combustion: Irrigation (Fuel use)

Source: Adapted from Department of Primary Industries, Vic. 2003

Column#	2	3	4	5	6	7	8	9
Fuel Type	**Ghg**	**Fuel consumed (litres) *(FC)***	**Energy density (Mj/L) *(ED)***	**Energy consumption (Mj)**	**Oxidised (%) *(O)***	**Emission factor (g/Mj) *(EF)***	**Emission (Gg)**	**$C0_2$ equivalent (Gg $C0_2$-e) *($C0_2$-e)***
Auto diesel	$C0_2$		38.6		0.99	69.7		
	CH_4					0.01		
	N_20					0.002		
	Sub Total							
Petrol	$C0_2$		34.2		0.99	66.0		
	CH_4					0.38		
	N_20					0.0009		
	Sub Total							
LPG	$C0_2$		25.7		0.99	59.4		
	CH_4					0.022		
	N_20					0.001		
	Sub Total							
Biodiesel	$C0_2$		36.284		0.99	40.426		
	CH_4					0.003714		
	N_20					0.001622		
	Sub Total							
	TOTAL							

Algorithm:

(FC x ED x O x EF) x 10^{-9} x GWP

Total emissions in gigagrams of $C0_2$-e for Fuel combustion: Irrigation = *$C0_2$-e* (sub totals)

Irrigation (Electricity use) (CO_2)

Electricity consumption is converted from kilowatt hours (kWh) to Gigajoules (GJ) and multiplied by an emission factor to arrive at an emission for CO_2. The work table for calculating emissions is presented in Table 34.

Table 34: Methodology for calculating $C0_2$ emissions from Fuel combustion: Irrigation (Electricity use)

Source: Adapted from Department of Primary Industries, Vic. 2003

Column#	**2**	**3**	**4**	**5**
Energy Type	**Energy consumption (kWh)** ***(EC)***	**Emission factor (kg $C0_2$/GJ)** ***(EF)***	**Emission (kg $C0_2$)**	**$C0_2$ equivalent (Gg $C0_2$-e)** ***($C0_2$-e)***
Electricity		275.2		

Algorithm: (*EC* x 0.0036) x *EF* x 10^{-6} x 3.66

Harvesting ($C0_2$, CH_4 & N_20)

The work table for calculating emissions is presented in Table 35, with a simplified algorithm immediately following. Emissions are reported in gigagrams of carbon equivalents ($C0_2$-e).

Table 35: Methodology for calculating CH_4, N_20 & $C0_2$ emissions from Fuel combustion: Harvesting

Source: Adapted from Department of Primary Industries, Vic. 2003

Column#	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Fuel Type	**Ghg**	**Fuel consumed (litres)** ***(FC)***	**Energy density (Mj/L)** ***(ED)***	**Energy consumption (Mj)**	**Oxidised (%)** ***(O)***	**Emission factor (g/Mj)** ***(EF)***	**Emission (Gg)**	**$C0_2$ equivalent (Gg $C0_2$-e)** ***($C0_2$-e)***
Auto diesel	$C0_2$		38.6		0.99	69.7		
	CH_4					0.01		
	N_20					0.002		
	Sub Total							
Petrol	$C0_2$		34.2		0.99	66.0		
	CH_4					0.38		
	N_20					0.0009		
	Sub Total							
LPG	$C0_2$		25.7		0.99	59.4		
	CH_4					0.022		
	N_20					0.001		
	Sub Total							
Bio diesel	$C0_2$		36.284		0.99	40.426		
	CH_4					0.003714		
	N_20					0.001622		
	Sub Total							
	TOTAL							

Algorithm:
(*FC* x *ED* x *O* x *EF*) x 10^{-9} x GWP

Total emissions in gigagrams of $C0_2$-e for Fuel combustion: Harvesting = *$C0_2$-e* (Sub totals)