Abstract

Greenhouse gases (GHGs) are vital components of the earth’s atmosphere, trapping heat around the earth, maintaining temperatures necessary for human existence. Until the Industrial Revolution, these gases existed in a natural equilibrium with the environment. Since that time, anthropogenic activities such as fossil fuel burning and land clearing have increased the quantity of GHGs, such as carbon dioxide (CO₂) and methane (CH₄), in the earth’s atmosphere. Evidence indicates that global warming is occurring as a result of the additional accumulation of GHGs in the atmosphere.

International response to climate change resulted in the 1997 development of the Kyoto Protocol. If the Protocol is ratified, developed countries will be legally bound to reduce their GHG emissions in accordance with negotiated emission reduction targets. At the beginning of the year 2001, the Protocol was still to be ratified.

With the possibility of future GHG emission restrictions, some Australian companies have started quantifying their GHG emission levels. One such company is Visy Industries, the largest privately owned paper packaging manufacturing company in the world. Visy’s core business is the manufacture of cardboard boxes from recycled paper. As part of its future operations, a kraft pulp and paper mill is presently being built in New South Wales, Australia.

The environmental decision support tool, Life Cycle Assessment (LCA), was used to quantify Visy’s CO₂ and CH₄ emissions across the entire life cycle of the Visy paper recycling and virgin papermaking processes. Commercially defined LCA models were developed for both papermaking processes.

GHG emissions estimated by each model were compared and the effect of different energy sources, technologies and manufacturing processes on CO₂ and CH₄ emissions were assessed. The majority of emissions in the two Visy papermaking models were due to fossil fuel derived energy sources and the decomposition of wood fibre in Solid Waste Disposal Sites (SWDSs). Results were used to propose appropriate GHG reduction strategies and business opportunities.
GHG reduction strategies included increasing the use of renewable energy, reducing the volume of solid waste rejects sent to SWDS, incinerating solid waste rejects with energy recovery and sourcing steam from third party providers. Proposed GHG business opportunities included increasing the production of Greenpower from the pulp and paper mill for sale to the grid.

This thesis is an example of the practical application of current GHG knowledge and LCA methodology that was undertaken in an environment where technical, political and commercial guidelines at both a national and international level were still evolving. Nevertheless, the thesis is not a critical review of LCA methodology.

The LCA support tool was able to quantify CO₂ and CH₄ emissions across the life cycle of the Visy recycling and virgin papermaking processes. The chosen functional unit, the assumptions and exemptions made, and the placement of the system boundaries, were found to be critical to the Visy LCA results.
Acknowledgments

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Ms Julia Lamborn and Dr Graeme Frecker for their guidance and patience during the writing up of this thesis. Their constructive and challenging questions not only made discussions lively and stimulating, but also kept the author continuously focused on the goals of the research. For the rest of her life, the author will forever ask the question ‘what am I trying to say’ whenever pen is put to paper. Discussions over coffee will be greatly missed!

Finally, the author wishes to acknowledge her family, for their patience and total support. A special thank you must go to my husband Philip, for his interest in the research, supplies of endless cups of tea, encouragement and constant reminders that there is life after writing a thesis. Hopefully, he can now start planning weekends away!
Declaration

I hereby declare that this thesis contains no material that has been accepted for the award of any other degree or diploma in any University or College of Advanced Education in Australia or in other countries.

To the best of my knowledge, all material previously published or written by another person has been referenced in the text of the thesis.

The conception of an initial LCA framework for both the Visy paper recycling and virgin processes was a joint collaboration between Energetics Pty. Ltd and me. This collaboration resulted in the production of two Visy internal documents (Energetics Pty Ltd & Wiegard 1998a & 1998b). I was solely responsible for all subsequent research and modelling.

Jean Wiegard

February 2001
# Table of Contents

1. Introduction .................................................................................................................1
   1.2 The Greenhouse Effect ............................................................................................6
   1.3 The Enhanced Greenhouse Effect ...........................................................................7
   1.4 The effect of climate change on the environment ...................................................8
   1.5 The effect of greenhouse gases (GHGs) on climate change ...................................9
      1.5.1 GHG atmospheric lifetimes................................................................................9
      1.5.2 Atmospheric GHG concentrations ...................................................................10
      1.5.3 Global Warming Potential................................................................................13
   1.6 Australia’s National Greenhouse Gas Inventory (NGGI) .....................................15
   1.7 Kyoto Protocol ......................................................................................................19
   1.8 Australia’s response to the Kyoto Protocol ...........................................................23
   1.9 Papermaking processes ..........................................................................................25
      1.9.1 Virgin papermaking process.............................................................................25
      1.9.2 Recycled papermaking process ........................................................................27
   1.10 Reasons for conducting GHG research at Visy: .............................................28
   1.11 Research goals.....................................................................................................29

2. Environmental decision-making support tools..........................................................31
   2.1 Analysis of environmental support tools ...............................................................33
   2.2 Visy LCAs–General overview ..............................................................................43
   2.3 LCA methodology as applied to the Visy papermaking processes .......................43
      2.3.1 Goal and scope .................................................................................................43
      2.3.2 Functional unit and initial system boundaries..................................................46
      2.3.3 Activities included and assumptions used........................................................49
      2.3.4 Selected inputs and outputs ..............................................................................50
      2.3.5 Data considerations ..........................................................................................50
      2.3.6 Quantification of GHGs ...................................................................................54
      2.3.7 Accuracy of data used ......................................................................................59
      2.3.8 LCA evaluation, conclusions and recommendation.........................................60

3. Visy paper recycling LCA model..............................................................................61
   3.1 Stage 1: Quantification of GHG emissions at the paper recycling plants .............62
      3.1.1 Paper recycling plants-GHG emission results..................................................65
      3.1.2 Paper Recycling Plant Studies 1-3 (1996/97 data) ...........................................66
      3.1.3 Comparison between 1996/97 (Study 3) and 1998/99 (Study 4) .....................67
      3.1.4 Emissions by source during 1996/97 & 1998/99 .............................................69
      3.1.5 Summary of findings-paper recycling plants ...................................................73
   3.2 Stage 2: Paper recycling LCA studies ...................................................................73
      3.2.1 Initial system boundaries..................................................................................73
      3.2.2 Paper recycling LCA emission assumptions and exclusions ...........................76
      3.2.3 Visy paper recycling LCA results ....................................................................85
   3.3 Visy paper recycling GHG reduction strategies and business opportunities .......87
      3.3.1 GHG reduction strategies-Visy paper recycling plants....................................88
      3.3.2 GHG reduction strategies-Visy paper recycling process .................................91
Tables

Table 1 GHG atmospheric lifetimes.................................................................10
Table 2 Changes in atmospheric GHG concentrations.....................................10
Table 3 GHG Global Warming Potentials .........................................................15
Table 4 Contribution of specific GHGs to Australia’s emissions 1990-1998.........17
Table 5 1998 CO₂ emissions due to anthropogenic activities ..........................18
Table 6 CH₄ emissions due to anthropogenic activities .....................................18
Table 7 Australia’s response to climate change (1995-1999) ..........................24
Table 8 LCA characteristics ..........................................................................35
Table 9 ISO 14000 series of standards ............................................................37
Table 10 LCA terms as applied to the Visy research .........................................42
Table 11 Unit process activities for each Visy LCA model ...............................47
Table 12 Selected inputs and outputs ..............................................................50
Table 13 Paper recycling plants-carbon mass balance (1996/97) ......................53
Table 14 Paper recycling plants-carbon mass balance (1998/99) ......................54
Table 15 GHG quantification of VP2 in 1998/99 ..............................................56
Table 16 Stationary GHG emission factors ......................................................57
Table 17 Estimated transport energy intensity factors .....................................57
Table 18 Solid and liquid waste factors used in Visy study ..............................58
Table 19 Factors used to quantify GHGs in SWDSs .......................................58
Table 20 Factors used to quantify GHGs ...........................................................59
Table 21 Sensitivity analysis-number of paper cycles ......................................59
Table 22 Example of the contribution of each unit process to total emissions ....60
Table 23 Visy paper recycling data .................................................................61
Table 24 Australia State GHG emissions for electricity and gas (GCO 1997) ....63
Table 25 Stage 1: Paper recycling plant studies .............................................64
Table 26 Results of the 4 paper recycling plant studies ....................................65
Table 27 State CO₂ emission factors for electricity and gas ............................66
Table 28 Consequence of incinerating solid waste ...........................................69
Table 29 Relative emissions by source-1996/97 & 1998/99 ..............................70
Table 30 Features included in the paper recycling LCAs ................................75
Table 31 Recycling sensitivity analyses-Raw Materials Acquisition unit process ....78
Table 32 Recycling sensitivity analyses-Manufacturing unit process ...............81
Table 33 Recycling sensitivity analyses-Post manufacturing unit process ..........82
Table 34 Recycling sensitivity analyses-Disposal unit process ..........................84
Table 35 Paper recycling LCA results ..............................................................85
Table 36 Disposal unit process emissions .......................................................86
Table 37 Paper recycling plants-GHG reduction strategies ..............................88
Table 38 GHG reduction strategies for the Visy paper recycling process ..........91
Table 39 Pulp mill operating parameters .......................................................96
Table 40 Components of the virgin LCA studies ..........................................100
Table 41 Virgin sensitivity analysis-Raw Materials Acquisition .....................102
Table 42 Virgin sensitivity analyses-Manufacturing .......................................103
Table 43 Virgin sensitivity analyses-Post Manufacturing ...............................104
Table 44 Recovered paper: historical data (PPMFA, 1999) ............................105
Table 45 Virgin sensitivity analyses-Disposal ...............................................106
Table 46 Visy virgin LCA results ..................................................................107
Table 47 Fuel CO₂ emission factors (GCO 1997) ...........................................108
Table 48 Summary: Pulp mill-Visy owned and controlled ..............................108
Table 49 Summary: Pulp mill emissions, non-Visy owned and controlled.................109
Table 50 Effect of selling paper out of the Visy system.........................................110
Table 51 Summary: Avoided emissions due to recycling...........................................111
Table 52 Significance of avoidance credits to total emissions.................................112
Table 53 Effect of import replacement ....................................................................113
Table 54 Summary of pulp mill related emissions.................................................113
Table 55 Effect of increased use of biomass at the pulp mill ...................................114
Table 56 Effect of increased wastepaper usage at the pulp mill .........................114
Table 57 Features of recycling LCA Study 4 and virgin LCA Study 3 ......................123
Table 58 Visy virgin and recycling production data.................................................124
Table 59 Visy Recycling and virgin LCA comparison.............................................124
Table 60 Effect of different functional units.............................................................127
Table 61 Application of different functional units to the Visy LCAs.......................129
Table 62 Recycling LCA-Consequence of using different functional units ..........130
Table 63 Virgin LCA-Consequence of using different functional units .................131
Table 64 Recycled LCA-emissions assigned to Australian sourced paper ..........133
Table 65 Virgin LCA-emissions assigned to Australian sourced paper ...............134
Table 66 Consequence of recycling virgin paper....................................................135
Figures

Figure 1 Global Carbon Cycle (IPCC 1994) ................................................................. 4
Figure 2 The Greenhouse and Enhanced Greenhouse Effect (AGO 1999(a)) .............. 7
Figure 3 GHG emissions by sector (excluding landclearing), 1990-1998 ............... 17
Figure 4 Overview of the LCA framework ................................................................. 38
Figure 5 Unit processes defining the boundaries of the LCA studies ..................... 47
Figure 6 Paper recycling LCA ................................................................................. 74
Figure 7 Virgin LCA ............................................................................................... 99
Figure 8 CAMPFor output from a pine plantation ................................................... 120
Appendices

Appendix 1 Summary of major environmental events..................................................147
Appendix 2 Research Plan ..........................................................................................149
Appendix 3 Detailed flowcharts of the Visy paper recycling and virgin processes ...150
Appendix 4 Visy paper recycling and virgin life cycles .............................................152
Appendix 5 Steam calculation.....................................................................................155
Appendix 6 Calculations used to quantify CH₄ emissions in SWDSs .......................156
Abbreviations used throughout this thesis

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>AGO</td>
<td>Australian Greenhouse Office</td>
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<tr>
<td>CAMFor</td>
<td>Carbon Accounting Model for Forests</td>
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<td>CBA</td>
<td>Cost Benefit Analysis</td>
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<td>CERs</td>
<td>Certified Emission Reductions</td>
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<td>CFCs</td>
<td>Chlorofluorocarbons</td>
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<tr>
<td>CNG</td>
<td>Compressed Natural Gas</td>
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<tr>
<td>CO$_2$(e)</td>
<td>Carbon dioxide equivalent</td>
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<tr>
<td>COP</td>
<td>Conference of the Parties</td>
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<td>CSIRO</td>
<td>Commonwealth Scientific and Industrial Research Organization</td>
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<tr>
<td>DOC</td>
<td>Degradable Organic Carbon</td>
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<tr>
<td>DOC$_F$</td>
<td>Dissimilated Degradable Organic Carbon</td>
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<tr>
<td>EIA</td>
<td>Environmental Impact Assessment</td>
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<td>EIS</td>
<td>Environmental Impact Statement</td>
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<td>EMS</td>
<td>Environment Management System</td>
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<td>Environment Protection Agency</td>
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<td>ESAA</td>
<td>Electricity Supply Association of Australia</td>
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<td>FCCC</td>
<td>Framework Convention on Climate Change</td>
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<td>GCO</td>
<td>Greenhouse Challenge Office</td>
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<td>GCV</td>
<td>Gross Calorific Value</td>
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<tr>
<td>GHG</td>
<td>Greenhouse Gas</td>
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<tr>
<td>GWP</td>
<td>Global Warming Potential</td>
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<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<td>LCA</td>
<td>Life Cycle Assessment</td>
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<td>Description</td>
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<tr>
<td>LCI</td>
<td>Life Cycle Inventory</td>
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<td>LCIA</td>
<td>Life Cycle Impact Assessment</td>
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<td>Landfill Gas</td>
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<td>LPG</td>
<td>Liquid Petroleum Gas</td>
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<td>MRF</td>
<td>Material Recovery Facility</td>
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<td>National Greenhouse Strategy</td>
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<td>National Greenhouse Gas Inventory</td>
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<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
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<td>OCC</td>
<td>Old Cardboard Cartons</td>
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<td>RECs</td>
<td>Renewable Energy Certificates</td>
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<td>SETAC</td>
<td>Society of Environmental Toxicology and Chemistry</td>
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<tr>
<td>SWDS</td>
<td>Solid Waste Disposal Site</td>
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<td>t</td>
<td>tonne</td>
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<tr>
<td>TAPPI</td>
<td>Technical Association of the Pulp and Paper Industry</td>
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<tr>
<td>UNEP</td>
<td>United Nations Environment Program</td>
</tr>
<tr>
<td>UNFCC</td>
<td>United Nations Framework Convention on Climate Change</td>
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<tr>
<td>WCED</td>
<td>World Commission on Environment and Development</td>
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<tr>
<td>WCP</td>
<td>World Climate Program</td>
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<tr>
<td>WMO</td>
<td>World Meteorological Organization</td>
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<tr>
<td>WWTP</td>
<td>Waste Water Treatment Plant</td>
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Chapter 1

1. Introduction

Greenhouse gases (GHGs) such as carbon dioxide (CO$_2$), methane (CH$_4$) and nitrous oxide (N$_2$O) are vital components of the earth’s atmosphere. Without these gases, the earth would be in a permanent deep freeze with an average temperature of –18°C (GCO 1997). GHGs act like a blanket, trapping heat around the earth to maintain temperatures necessary for human existence. Until the Industrial Revolution of 1750-1850, these gases existed in a natural equilibrium with the environment.

The Industrial Revolution resulted in the development of technology that enabled fossil fuels such as coal, oil and natural gas to be transformed into more useable forms of energy such as electricity. In conjunction with this technological change, there began an exponential increase in population growth and living standards in the industrialised world. According to Eliasson (2000), electricity will play a leading role in the future improvement of living standards in developing countries. The introduction and use of fossil fuel derived electricity in these countries is likely to increase global greenhouse gas (GHG) emissions even further. However, it is acknowledged that if hydroelectricity or nuclear electricity were used, GHG emissions may not increase.

Since the early 1800's anthropogenic (human induced) activities such as fossil fuel burning, land clearing and agricultural activities have ‘thickened the greenhouse blanket’. As a result, temperatures in the lower atmosphere (troposphere) have risen. Anthropogenic activities have disrupted the natural equilibrium that had previously existed between GHGs and the environment. Without abatement action, GHG emissions from developed countries in 2010 are expected to increase 18% above 1990 levels (UNEP 1999).

In the last 15 years (1986-2001) the world has become increasingly conscious of the possible consequences of climate change (Zillman 2000). According to the Intergovernmental Panel on Climate Change (IPCC), climate models predict that by 2100, mean global temperatures will increase between 1-3.5°C, the mean sea level will
rise 15-95 cm and climatic zones in the mid-latitude regions could shift towards the poles by 150-550 km (UNEP 1999).

The adoption of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCC) in 1997 was a major achievement in the development of an international response to climate change (COP 1997). The Protocol is an international treaty under which developed countries have agreed to limit net GHG emissions. Many countries, including Australia, have indicated intent to reduce emissions by a first signing of the protocol. However, the protocol will not be legally binding until it is ratified. Ratification will only occur when the protocol is signed a second time by at least 55 countries that account for at least 55 per cent of the total 1990 CO₂ emissions of developed countries. At the beginning of the year 2001, this has not occurred. Ratification is unlikely to occur until many of the issues surrounding the articles in the protocol are clarified and resolved.

In 1998, the use of fossil fuel derived energy was responsible for 79.6% of Australia’s net national emissions. The majority of these emissions (56.8%) were derived from stationary energy sources and transport use (15.9%). The remaining emissions were due to agriculture, forestry, landclearing, industrial processes and waste processes (AGO 2000(b)). If ratification of the Protocol occurs, industries using fossil fuels as their primary energy source will be required to play a significant role in helping Australia meet its negotiated emission target.

Australian industry needs to be prepared for the possibility of future GHG emission restrictions. At the present time, there is no legislation in Australia requiring companies to reduce their GHG emission levels. If ratification occurs, this situation is likely to change. Compliance with any GHG restrictions will require commitment and resources. Unless companies are prepared for GHG restrictions in advance of possible ratification, they may find it difficult to minimise their costs of compliance in a short period of time, and capitalise on any commercial opportunities that may occur.

Some Australian companies have quantified their GHG emission levels and developed reduction strategies as part of the Greenhouse Challenge Program (AGO 2000(a)). However, the Greenhouse Challenge Program only quantifies particular aspects of a
Visy Industries (hereafter called ‘Visy’) decided not to participate in the program, as it wanted to determine the GHG effect of its papermaking processes across their entire lifecycle i.e. from ‘cradle to grave’. Visy chose to use the internationally recognised Life Cycle Assessment (LCA) tool to quantify its emissions, and from the results identify GHG reduction strategies and business opportunities.

Visy is the largest privately owned paper packaging manufacturing company in the world, employing in excess of 5,000 people. Visy is a multinational company. Its core business is the manufacture of cardboard boxes from recycled paper. As part of its operations, a kraft pulp and paper mill is presently being built at Tumut in New South Wales, Australia. Pinus radiata plantations in the Tumut region will provide the virgin fibre required for the process. The kraft process uses the chemicals sodium hydroxide and sodium sulphate to produce pulp of the strength required for the production of cardboard boxes.

GHG research began at Visy’s Australian operations in 1997. Visy recognised that it emitted GHGs in the course of its operations, but initially had no knowledge of its emission levels or the potential effect of those emissions on its business. Visy realised that if it was prepared well in advance of any restrictions, it would be in an ideal position to reduce its emissions in the most cost efficient manner, and capitalise on any identified GHG business opportunities. Visy also wanted to pass on to its customers some of the benefits gained by reducing its emissions. To do this, it needed to determine which of its processes emitted GHGs and to quantify its emission levels.

The Visy LCAs were single-issue GHG studies, focused on the two most important GHGs, CO₂ and CH₄. These gases are known to be responsible for more than 90% of all GHG emissions (AGO 2000(b)). Other GHG’s were considered minor in comparison and were excluded from the study (GCO 1997). Visy acknowledged that there might be other environmental consequences resulting from the production of paper that are not covered in this thesis.
1.1 The Carbon Cycle
The carbon cycle is one of many material cycles existing in the earth’s ecosystem. All the carbon atoms in existence circulate and are continually recycled between the atmosphere, hydrosphere, biosphere and geosphere. The carbon cycle involves the storage, release and absorption of enormous quantities of carbon between living organisms and the non-living environment. Natural processes within the cycle keep the carbon fluxes finely balanced.

Figure 1 illustrates how each process in the carbon cycle has an impact on other parts of the cycle (IPCC 1994). The flux of carbon, if known, is shown in gigatonnes of carbon (GtC). The amount of carbon being exchanged in each process determines whether the specific reservoir or sink is increasing or decreasing eg. oceans absorb approximately 1.6 GtC more from the atmosphere than they emit to the atmosphere. In Figure 1, the numbers in brackets denote the overall change in carbon eg. intermediate and deep oceans act as a sink as they accumulate more carbon (1.9 GtC) than they emit.

![Global Carbon Cycle (1992-1997) (in GtC)](image)

Figure 1 Global Carbon Cycle (IPCC 1994)
Within this complex cycle, carbon can be found in different chemical forms eg. carbon dioxide (CO$_2$), carbonate ion (CO$_3^{2-}$), bicarbonate ion (HCO$_3^-$) or carbonic acid (H$_2$CO$_3$). Carbon dioxide is removed from the atmosphere by a number of processes that operate on different time-scales. The biosphere is part of a short-term cycle (less than 100’s of years) within the global carbon cycle. Carbon needed for cell development is principally derived from free CO$_2$ in the atmosphere. In combination with water from the soil, plants incorporate inorganic carbon during photosynthesis into organic carbon in the form of sugars, and then release carbon back into the atmosphere during respiration. In this way, trees act as a storage area or carbon ‘sink’ for atmospheric CO$_2$. When plants die, microorganisms break down the organic material and release carbon back into the environment. Animals gain carbon by feeding on plants and other animals. While the animal is alive, carbon is released through respiration. After death, microorganisms break down the cells releasing carbon back into the atmosphere.

Oceans drive the carbon cycle, with 71% of the world's carbon in the oceans. Oceans make up the short-intermediate cycle within the global cycle. Human activity doesn't alter carbon absorption or emission in the oceans. The form that carbon is present in the oceans is very dependant upon the acidity/alkalinity of the seawater. Where saltwater is slightly alkaline (pH=9), the carbon is predominantly present as H$_2$CO$_3$. Adding more CO$_2$ to saltwater tends to make the water more acidic, converting the carbon into the HCO$_3^-$ form. Excess CO$_2$ is converted by marine biota into coral. Dead phytoplanktons fall to the ocean floor and constitute another carbon sink.

The long-term carbon cycle occurs with carbon interactions with the geosphere where larger reservoirs and smaller fluxes occur. Carbon buried in the sediment of the oceans is in the form of organic and inorganic carbon. Organic carbon from the short-term cycle can eventually end up in the long-term cycle.

The earth’s atmosphere is made up of mainly nitrogen (78%) and oxygen (21%). Naturally occurring GHGs (water vapour, carbon dioxide, methane, nitrous oxide and ozone) make up less than 1% of the gases in the atmosphere. The atmosphere also contains the artificially produced GHGs, chlorofluorocarbons and perfluorocarbons.
Since the Industrial Revolution, anthropogenic activities have altered the atmospheric carbon equilibrium. Almost all-human activity occurs within the troposphere, which extends to an altitude of 10km (NASA 2000). Fossil fuel burning and cement production releases 6.2 GtC into the atmosphere each year. Changing land-use (e.g. deforestation) results in increased emissions of carbon. Once a forest area has been cleared, no photosynthesis occurs to absorb CO₂ from the atmosphere, and increased emissions result from the decay of organic matter and disturbances to the soil as a result of the clearing process. Whilst the natural processes within the carbon cycle can remove some of the anthropogenic CO₂ emissions produced, excessive emissions of carbon can result in a shift or change to the natural equilibrium.

The IPCC believes that there is enough evidence to indicate that there has been a discernible human influence on the global climate. Global mean surface temperatures have increased 0.3-0.6°C since the late 19th century and global sea level has risen 10-25 cm over the past 100 years (IPCC 1995). The effect of human activity on climate change was further reinforced in the IPCC’s Working Group 1 ‘Summary for Policymakers’ document which will be part of the Third Assessment Report due for release in May 2001 (IPCC 2001). The report states that:

“There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities”.

1.2 The Greenhouse Effect

The greenhouse effect is the term used to describe the role some atmospheric gases play in warming the earth’s surface. Although they make up only a very small component of the atmosphere, GHGs are present in sufficient quantities to produce a natural greenhouse effect. Incoming energy from the sun (solar, short-wave radiation) is balanced by the release of heat (near-infrared radiation) back into the atmosphere from the land, oceans and clouds. The net energy (the difference between solar radiation and infrared radiation) is zero, so that temperatures near the earth’s surface remain constant.
Solar radiation reaching the earth’s atmosphere is either reflected back into space (by clouds, aerosols, snow or ice) or absorbed as heat by the earth’s surface. GHGs in the troposphere have the ability to absorb some of this long-wave radiation, preventing its escape into space and re-directing it towards earth. The resulting retention of heat by the troposphere is called the Greenhouse Effect and is shown in Figure 2 (AGO 1999(a)).

![The Greenhouse Effect](image1.png)
![The Enhanced Greenhouse Effect](image2.png)

Figure 2 The Greenhouse and Enhanced Greenhouse Effect (AGO 1999(a)).

1.3 The Enhanced Greenhouse Effect

Human activities have decreased carbon storage areas and increased carbon emissions, creating a large influx of carbon into the atmosphere, resulting in higher temperatures close to the earth’s surface. This effect is known as The Enhanced Greenhouse Effect. Other terms that are often used to describe this effect are ‘climate change’ and ‘global warming’. The term ‘climate change’ has been used in this thesis to describe this effect.
The Enhanced Greenhouse Effect is often expressed in terms of ‘radiative forcing.’ Radiative forcing is a change imposed on the energy balance of the planet that has the potential to alter global temperature. In simplistic terms it is the consequence of a difference between the levels of incoming solar radiation and outgoing infrared radiation.

Every GHG molecule in the troposphere has the ability to intercept some of the outgoing radiation. The degree to which a GHG intercepts the radiation is dependent upon both its physical and chemical composition. When additional GHGs resulting from anthropogenic activities are present in the troposphere, the atmosphere becomes more opaque to outgoing infrared radiation. However, the influx of solar radiation remains the same, as GHGs are almost transparent to this type of radiation. The net energy influx becomes positive instead of zero and causes higher temperatures close to the earth’s surface. Since a ‘thicker GHG blanket’ reduces the energy loss to space, the climate has to change in order to restore the balance between incoming and outgoing energy.

1.4 The effect of climate change on the environment

Climate change poses a very serious threat of change to the earth’s surface ecosystem, as is presently understood. The faster that climate change occurs, the greater is the potential risk of damage, as there is less time for adjustment. The damage caused by climate change will have environmental, social and economic aspects. Significant costs will be incurred in adapting to the changes.

According to the IPCC, the effect of increasing emissions on the Earth’s temperature and the potential consequences are significant. Compared with 1990 data, and assuming that no effort is made to reduce emissions, climate models predict that by 2100 the global mean surface temperature may rise an additional 1.0 to 3.5°C. This change is greater than any climate change experienced in the last 10,000 years and is based on current emissions trends (IPCC 1995).
Possible consequences of climate change include:

Inundation of coastal land

By the year 2100, global sea level is expected to rise a further 15-95 cm, threatening islands and low-lying coastal areas. This is due to the expansion of seawater when heated and the melting of some glacial ice. It has been estimated that a one-metre rise will cause estimated land losses of 6% in the Netherlands, 17.5% in Bangladesh and about 80% in Atoll Majuro in the Marshall Islands (UNEP 1999).

Ecological change, threatening agricultural productivity and the survival of the present natural forests

Extreme rainfall events of higher intensity are predicted with increases in the global averages of evaporation and precipitation. In areas where there is currently snow, precipitation will be as rain, rather than snow. This is likely to increase winter moisture and runoff. In spring, as the snow melts faster, flooding may occur. In summer, increased evaporation will result in lower moisture in the soil and the probability of drought. Increased severity of floods and droughts is likely to threaten the agricultural productivity in some areas of the planet (UNEP 1999).

1.5 The effect of greenhouse gases (GHGs) on climate change

The effect that a particular GHG has on climate change is dependant upon the following factors:

- The atmospheric lifetime of the GHG.
- Changed concentrations of the GHG in the atmosphere.
- Global Warming Potential of each GHG.

1.5.1 GHG atmospheric lifetimes

Due to the length of time particular GHGs remain in the atmosphere, the climate is not able to immediately respond to emission changes. Past and present emissions have already committed the earth to at least some climate change during the 20th century.
Approximate lengths of time that the most significant anthropogenic GHGs remain in the atmosphere are shown in Table 1 (IPCC 1994; Ledley et al. 1999).

<table>
<thead>
<tr>
<th>GHG</th>
<th>GHG lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>50-200 years.</td>
</tr>
<tr>
<td>CH₄</td>
<td>Approximately 10 years</td>
</tr>
<tr>
<td>N₂O</td>
<td>Approximately 130 years</td>
</tr>
<tr>
<td>Chlorofluorocarbons</td>
<td>50-400 years eg. CFC-11 has a lifetime of 55 years</td>
</tr>
<tr>
<td>Hydrofluorocarbons, Perfluorocarbons and SF₆</td>
<td>Extremely long periods of time</td>
</tr>
</tbody>
</table>

Table 1 GHG atmospheric lifetimes

As can be seen, GHGs remain in the atmosphere for varying periods of time eg. the effect of CH₄ is greater in the short term than in the long term. GHG with longer atmospheric lifetimes (eg. Hydrofluorocarbons, Perfluorocarbons and SF₆) will have long-term effects on the climate. The relative importance of particular GHGs in relation to CO₂ depends on the ‘time horizon’ chosen. This is further discussed in Chapter 1, Section 1.5.3.

1.5.2 Atmospheric GHG concentrations

Between the last ice age 9,000 years ago and 1850, atmospheric levels of CO₂ have varied by less than 5% (UNFCC 1993). However, since 1850, anthropogenic activities have significantly increased the atmospheric concentrations of CO₂, CH₄, N₂O and the chlorofluorocarbons, CFC-11 and CFC-12 (Ledley et al. 1999). Changes in GHG concentrations between 1850 and 1997 are shown in Table 2.

<table>
<thead>
<tr>
<th>GHG</th>
<th>CO₂ ppm</th>
<th>CH₄ ppb</th>
<th>N₂O ppb</th>
<th>CFC-11 ppt</th>
<th>CFC-12 ppt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration in 1850</td>
<td>280 ppm</td>
<td>700 ppb</td>
<td>275 ppb</td>
<td>Not present</td>
<td>Not present</td>
</tr>
<tr>
<td>Concentration circa 1990</td>
<td>364 ppm</td>
<td>1721 ppb</td>
<td>312 ppb</td>
<td>CFC-11: 100 ppt in 1975</td>
<td>CFC-12: 200 ppt in 1975</td>
</tr>
</tbody>
</table>

ppm = parts per million, ppb = parts per billion, ppt = parts per trillion

Table 2 Changes in atmospheric GHG concentrations


**Carbon dioxide (CO\(_2\))**

As a result of CO\(_2\) naturally occurring in the atmosphere, the atmosphere is already partially opaque to wavelengths absorbed by CO\(_2\). Since the Industrial Revolution, atmospheric CO\(_2\) concentrations have increased 30% (Ledley et al. 1999), and are responsible for 70% of climate change (AGO 1999(a)). Increased levels are largely due to fossil fuel combustion. The amount of carbon in fuels per unit of energy content varies significantly by fuel type. As coal contains the highest amount of carbon per unit of energy, it emits more GHGs than the other fossil fuels. Compared with coal, petroleum and natural gas have approximately 25% and about 45% less carbon per unit of energy respectively (US EPA 2000). Cement production, deforestation and land-use change have also contributed to increased emissions. Due to its concentration and persistence in the atmosphere, CO\(_2\) is considered the most important indicator of future climate warming (UNFCC 1993).

**Methane (CH\(_4\))**

CH\(_4\) is responsible for 20% of the contribution to climate change. Its concentration in the atmosphere has increased 146% in the past 150 years (Ledley et al. 1999). Methane is produced when organic material containing carbon is broken down under anaerobic conditions. Activities such as rice cultivation, animal husbandry, natural gas and oil extraction, landfill decomposition and the burning of non-fossilised organic material (biomass) are responsible for increased emissions. Methane is broken down in the atmosphere into CO\(_2\).

**Nitrous Oxide (N\(_2\)O)**

N\(_2\)O is produced naturally in soils through microbial action and human activities such as fossil fuel combustion, land-use changes, biomass burning and some industrial processes. N\(_2\)O concentrations in the atmosphere have increased 13% since 1850.
**Chlorofluorocarbons**

Chlorofluorocarbons (eg. CFC-11 and CFC-12) were first manufactured in the 1930’s but were not present in the atmosphere in any appreciable quantity before 1950. Up until the 1990’s, they were widely used as propellants, refrigerants and foaming agents (Ledley et al. 1999). They act as a GHG in the troposphere but also damage the ozone layer in the stratosphere. In 1987, the Montreal Protocol was developed to phase out their use (UNEP 2000). Under this protocol developed countries have not been able to use CFCs since 1996, however, developing countries have until 2010 to phase out their use (Darby 2000). As a result, CFC levels in the atmosphere are only expected to fall slowly (US EPA 1997).

The following gases and aerosols have an indirect effect on climate change. Even though they have no relevance to the Visy’s paper and board manufacturing, they are briefly discussed in order to describe the context of their role in the atmosphere.

**Hydrofluorocarbons, Perfluorocarbons and Sulfur hexafluoride**

Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) will effect future atmospheric emission levels. These synthetic chemicals were introduced as alternatives to the ozone depleting substances, however, along with sulfur hexafluoride (SF₆), they are now recognised as potent GHGs. Although only a small effect has been seen to date, their importance as GHGs is expected to increase substantially by 2010 (NOAA, 2001). HFCs are used in refrigeration, PFCs are a by-product of aluminium smelting and SF₆ is widely used in the insulation of electrical equipment.

**Water vapour**

Water vapour is responsible for approximately 75% of the natural greenhouse effect (CSIRO 1996). Although its concentration in the atmosphere is not directly affected by human activity, it is important in climate change as it provides a 'positive feedback' effect. As warmer air is capable of holding more moisture, increased temperatures are likely to increase water vapour levels, increasing the enhanced greenhouse effect (UNEP & WMO 1997).
Ozone

O_3 is found in both the tropospheric and stratospheric layers of the atmosphere. Increased atmospheric emissions of GHGs have led to O_3 depletion in the stratosphere and an over abundance in the troposphere. Human activities and in particular fossil fuel burning have greatly increased ozone levels in the troposphere.

Most atmospheric ozone is concentrated in the stratosphere (US EPA 1997). Its presence acts as a shield to protect all life from the sun’s harmful radiation. It does this by absorbing a portion of the radiation from the sun, thereby preventing it reaching the earth’s surface. Anthropogenic activities that have led to increased concentrations of CFCs in the atmosphere have damaged this shield, enabling more and more ultraviolet radiation to reach the earth’s surface (Ministry of Environment, Lands & Parks 1992). The result is a hole in the ozone layer. The development of CFCs is an example of a man-made chemical produced for a different purpose, which has caused a negative effect on atmospheric gases.

Aerosols

Although not a GHG, aerosols have a very big effect on the climate due to the massive quantities that are emitted. These microscopic particles are produced from sulphur dioxide emitted by power stations, smoke from the clearing of forest areas and the burning of crop wastes. Whilst in the atmosphere, they block sunlight and provide a ‘seeding effect’ for the formation of clouds. The effect is a local cooling of the climate, counteracting the climate change (UNEP 1999).

1.5.3 Global Warming Potential

The Global Warming Potential (GWP) of a particular GHG and its effect on climate change is dependent upon the following factors:

- The molecular properties of the gas itself. These properties determine how much infrared radiation the gas will absorb and in what wavelength.
- How much energy the GHG will encounter in these wavelengths.
- How much of the gas is already present in the atmosphere.
The Global Warming Potential (GWP) of a GHG determines its relative contribution to climate change. The GWP of a particular gas is defined as the ratio of the warming (radiative forcing) caused by a substance to the warming caused by a similar mass of CO$_2$, over a specified period of time.

The time period chosen strongly influences the relative importance of each GHG. The IPCC has calculated GWPs for three different time horizons: 20, 100 and 500 years. The 20-year horizon is relevant to short term effects such as changes in weather patterns; the 100-year horizon applies to longer time-scale changes such as sea-level rise; while 500 years represents the longest time scale that can be applied, based on current knowledge (UNFCCC 1993). CH$_4$, which has a short atmospheric lifetime relative to CO$_2$, has a much greater consequence in the 20-year horizon. Conversely, CFCs have very long lifetimes and maintain their effect over longer time periods.

The IPCC chose a time horizon of 100 years and used CO$_2$ as the reference gas against which all other GHGs are compared (IPCC 2000). On this basis, CO$_2$ was allocated a GWP value of one and CH$_4$ was given a value of twenty-one. This means that methane is twenty one times more effective at trapping heat in the atmosphere than CO$_2$. This is due to its molecular structure and the wavelength at which the infrared radiation is absorbed. GWPs used in this thesis were all based on 100-year timelines, in order to be consistent with the IPCC Guidelines (IPCC 2000).

The GWP of each GHG gas was used to convert emissions into ‘carbon dioxide equivalent' (CO$_2$(e)). It was on this basis that the GHG emissions from Visy were quantified. Each emission tonne (t) was multiplied by its GWP, giving t CO$_2$(e). Total emissions were then calculated as the sum of the t CO$_2$(e) of each gas. The GWPs of the most significant GHGs are shown in Table 3.
<table>
<thead>
<tr>
<th>GHG</th>
<th>GWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide CO₂</td>
<td>1</td>
</tr>
<tr>
<td>Methane CH₄</td>
<td>21</td>
</tr>
<tr>
<td>Nitrous Oxide N₂O</td>
<td>310</td>
</tr>
<tr>
<td>Chlorofluorocarbons eg. CCl₂F₂</td>
<td>8,500</td>
</tr>
<tr>
<td>Perfluorocarbons eg. C₂F₆</td>
<td>9,200</td>
</tr>
</tbody>
</table>

Table 3 GHG Global Warming Potentials

1.6 Australia’s National Greenhouse Gas Inventory (NGGI)

The author used the NGGI data to identify those activities that were responsible for high levels of GHG emissions. Gaining this information prior to the start of the Visy GHG research assisted in the identification of activities within the Visy papermaking processes that were likely to cause significant emissions.

Australia produces 1.4% of the world's GHG emissions (Howard 1997). More than 80% of Australia’s exports are GHG intensive, primarily due to the manufacture and export of products such as aluminium, steel and agricultural products (AGO 2000(b)). Fossil fuels provide 94% of Australia’s energy needs (Howard 1997).

Australia has a growing economy and a projected population increase of 30% from 1990 to 2020 (Howard 1997). Without GHG abatement action, Australia's emissions are expected to grow by around 28% during that period. Emissions from the energy sector alone are expected to grow approximately 40% (Howard 1997).

The NGGI is the tool used by the Australian Greenhouse Office (AGO) to determine Australia’s annual GHG emissions, and the contribution that key industry sectors make to those emissions. It is based on international guidelines established by the IPCC. The 1998 NGGI is the latest report on Australia’s GHG emissions (AGO 2000(b)). The inventory only reports on anthropogenic induced GHG emissions, and covers the following sectors:
1. **Stationary Energy**-emissions from electricity generation, energy produced by the manufacturing, construction and industrial sectors and emissions from other sources like domestic heating.

2. **Transport**-emissions from road, rail and domestic air.

3. **Fugitive**-leakage emissions from coal seams and oil and gas production

4. **Industrial Processes**-emissions from processes such as aluminium smelting and cement clinker manufacturer.

5. **Agriculture**-CH$_4$ emissions from livestock, N$_2$O from fertilisation of soils.

6. **Land-Use Change and Forestry**. Emissions in this category include:
   - Forest and grassland conversion–landclearing, including the burning and decay of cleared vegetation and soil disturbance.
   - Changes in forests and other woody biomass stocks–managed forests, plantations and vegetation establishment.
   - CO$_2$ emissions and removals from soils.
   - Emissions from prescribed burning and wildfires.

7. **Waste**-emissions from Solid Waste Disposal Sites (SWDSs), incinerators and wastewater treatment facilities. (In keeping with IPCC terminology, the term SWDSs has been used in this thesis in place of the term landfill.)

The inventory covers the following GHGs:

- Carbon dioxide (CO$_2$)
- Methane (CH$_4$)
- Nitrous Oxide (N$_2$O)
- Perfluorocarbons (PFCs)
- Sulphur hexafluoride (SF$_6$)
- Carbon monoxide (CO)
- Oxides of nitrogen (NOx)
- Non-methane volatile organic compounds (NMVOC)

The GHG consequence of Australia’s heavily dependent fossil fuel, export-based commodity economy during 1990-1998, is shown in Figure 3. GHG emissions in 1990 were 389.8 megatonnes (Mt) of CO$_2$(e) and 455.9 Mt of CO$_2$(e) in 1998. This represents a 16.9% increase in emissions since 1990. The AGO believes the increase is a reflection of Australia’s high population and economic growth (AGO 2000(b)).
Figure 3 GHG emissions by sector (excluding landclearing)$^1$, 1990-1998

Table 4 details the contribution of specific GHGs to Australia’s GHG emissions for 1990 and 1998. Emissions from landclearing have been excluded (AGO 2000(b)).

<table>
<thead>
<tr>
<th>GHG</th>
<th>CO$_2$</th>
<th>CH$_4$</th>
<th>N$_2$O</th>
<th>PFCs*</th>
<th>Total CO$_2$(e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990 Mtonne CO$_2$(e)</td>
<td>250.0</td>
<td>112.9</td>
<td>22.1</td>
<td>4.8</td>
<td>389.8</td>
</tr>
<tr>
<td>1990% of total emissions</td>
<td>64.1%</td>
<td>29.0%</td>
<td>5.7%</td>
<td>1.2%</td>
<td></td>
</tr>
<tr>
<td>1998 Mtonne CO$_2$(e)</td>
<td>312.1</td>
<td>114.9</td>
<td>27.5</td>
<td>1.4</td>
<td>455.9</td>
</tr>
<tr>
<td>1998% of total emissions</td>
<td>68.5%</td>
<td>25.2%</td>
<td>6.0%</td>
<td>0.3%</td>
<td></td>
</tr>
<tr>
<td>Changes Mtonne CO$_2$(e) 1990-1998</td>
<td>62.1</td>
<td>2.0</td>
<td>5.4</td>
<td>-3.4</td>
<td>66.1</td>
</tr>
<tr>
<td>% Change in emissions 1990-1998</td>
<td>24.8%</td>
<td>1.8%</td>
<td>24.3%</td>
<td>-70.6%</td>
<td>16.9%</td>
</tr>
</tbody>
</table>

* 1998 value includes SF$_6$ from Metal Production

Table 4 Contribution of specific GHGs to Australia’s emissions 1990-1998

Table 4 indicates that CO$_2$ and CH$_4$ were responsible for 93% of Australia’s contribution to climate change during 1990-1998. As expected, this is in keeping with global contributions of CO$_2$ and CH$_4$ to climate change (AGO 1999(a)).

$^1$ Land clearing has been accounted for separately from other sectors, due to the high level of uncertainty associated with the estimates and major improvements in methodology and sources of data (AGO 2000(b)).
Carbon dioxide (CO\textsubscript{2})

Table 5 details the main activities that were responsible for CO\textsubscript{2} emissions during 1998 (AGO 2000(b)).

<table>
<thead>
<tr>
<th>Anthropogenic activities</th>
<th>Mtonne CO\textsubscript{2(e)}</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stationary emissions</strong></td>
<td></td>
</tr>
<tr>
<td>Electricity = 168.0 Mtonne CO\textsubscript{2(e)}</td>
<td>255.8</td>
</tr>
<tr>
<td><strong>Transport emissions</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>68.4</td>
</tr>
<tr>
<td><strong>Forestry emissions</strong></td>
<td></td>
</tr>
<tr>
<td>Forestry growth (sink)</td>
<td>-73.4</td>
</tr>
<tr>
<td>Forest harvesting</td>
<td>51.8</td>
</tr>
</tbody>
</table>

Table 5 1998 CO\textsubscript{2} emissions due to anthropogenic activities

Stationary energy emissions, particularly the production of electricity, were responsible for 85% of CO\textsubscript{2} emissions during 1998. Between 1990 and 1998, electricity generation emissions increased 30.6% (AGO 2000(b)). This was due to increased usage of electricity and increased production from brown coal power stations (AGO 2000(b)). Transport emissions accounted for 23% of CO\textsubscript{2} within Australia. Road transport (14.2%) was the largest contributor with cars contributing 9% of national emissions.

Methane (CH\textsubscript{4})

The main activities that contributed to CH\textsubscript{4} emissions in 1998 are shown in Table 6 (AGO 2000(b)).

<table>
<thead>
<tr>
<th>Anthropogenic activities</th>
<th>Mtonne CO\textsubscript{2(e)}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture (mainly from the digestive processes of livestock)</td>
<td>70.3</td>
</tr>
<tr>
<td>Fugitive emissions</td>
<td>25.5</td>
</tr>
</tbody>
</table>

Table 6 CH\textsubscript{4} emissions due to anthropogenic activities

The data indicates that livestock contributed the majority of CH\textsubscript{4} emissions. Fugitive emissions such as losses from oil and gas production and emissions from oil mines,
contributed 22% of CH₄ emissions. Waste emissions contributed 3.4% to national emissions (AGO 2000(b)). Most waste emissions were from solid waste disposal.

The author analysed the results of Australia’s 1990-1998 NGGI at the beginning of the Visy research, in the hope of gaining some indication of which GHGs and activities were likely to be responsible for Visy’s emissions. The author assumed that there was a direct correlation between the NGGI emissions and Visy’s emissions.

Based on the NGGI, the author identified that the use of fossil fuel energy sources during the manufacturing process, the transport and decomposition of waste in SWDSs, were areas of the Visy operations likely to produce significant emissions. Analysis of the data also indicated that the majority of Visy’s emissions were likely to be due to CO₂ and CH₄. Based on the above information, the decision was made to quantify Visy’s GHG emissions in terms of CO₂ and CH₄.

1.7 Kyoto Protocol

Climate change began to be acknowledged internationally following the First World Climate Conference in 1979 (Morrisey 1998). All efforts to globally reduce GHG emissions since that time have culminated in the development of the Kyoto Protocol. Appendix 1 contains a summary of major environmental events that led to the development of the Protocol.

The Kyoto Protocol was developed at the Third Conference of the Parties (COP3) meeting in Japan in 1997 (UNFCCC 2000). Under the Protocol, thirty-eight industrialised nations are required to reduce emissions of CO₂, CH₄, N₂O, HFCs, PFCs and SF₆. Each nation has an individual emission target based on their individual economic circumstances and capabilities. The negotiated target is applicable for the first commitment period of 2008-2012. Assuming all targets are met, emissions in developed countries will fall by greater than 5% compared with 1990 emissions. Australia's negotiated GHG target is to limit annual emissions to 108% of 1990 levels (AGO 1998 (a)).
The Protocol is still to be ratified. If and when this is likely to occur is unknown due to the breakdown in negotiations at COP 6 in November 2000 (UNFCCC 2000). The first commitment period of the Protocol does not require developing countries to make any GHG reduction commitments. With major emitters such as China and India not involved in the Protocol, many countries, including Australia, believe their non-involvement will considerably weaken the reduction benefits from developed countries. The USA has stated it will not ratify the Protocol unless developing countries are involved in the commitment (Taylor 1999).

If ratification does occur, Australia will be required to reduce its emissions in accordance with their negotiated target. As industry contributes significantly to Australia’s emissions (AGO 2000(b)), Visy will probably be required to reduce its emissions as part of that process. The Kyoto Protocol negotiations are closely monitored by Visy.

The Protocol includes three ‘mechanisms’ to help reduce emissions at the lowest cost. They are:

- Clean Development Mechanism.
- Emission Trading scheme.
- Joint Implementation.

In their present form, these mechanisms will allow countries to generate and trade carbon credits without actually reducing their emissions by the set amount (Hordern 2000):

A brief discussion on each of these mechanisms as they presently stand is included in this thesis. However, it should be noted that negotiations have not resolved some of the key Protocol issues that Australia took to the negotiating table at COP6. These issues include the rules for trading mechanisms, the inclusion of sinks, the compliance regime and issues involving developing countries (AGO 2000(c)). Until these and other issues are resolved, the circumstances under which these three mechanisms may operate in the future are unknown.
Understanding these mechanisms and the circumstances under which they may operate is important to Visy, as these mechanisms may become part of Visy’s future environmental strategies.

**Clean Development Mechanism (CDM)**

The CDM involves technology transfer between developed countries and developing countries. Projects must provide real, measurable and long-term benefits related to the mitigation of climate change, and yield emission reductions additional to any that would otherwise occur. The advantage of the CDM program is that developing countries gain the benefit of GHG abatement technology and training, while the developed country receives part of the carbon credits (also known as Certified Emission Reductions (CERs)), created by the project. Developed countries will be able to use the carbon credits created under the CDM to help meet 2008-2012 GHG commitments. Participation is voluntary. It is the only program in the Kyoto Protocol that allows credits to be ‘banked’ prior to 2008.

**Emission trading scheme**

Under article 17 of the Protocol (UNFCCC 2000), developed countries can participate in international and national emission trading schemes in order to meet their Kyoto commitments. Any trading must be in addition to domestic abatement action. Trading is voluntary. Emission trading is seen to be one of the most effective, least cost strategies for reducing emissions (AGO 1999(b)). If a national emission trading scheme were introduced within Australia, it would be established under Commonwealth legislation. The scheme would have to be compatible with the internationally operated trading scheme.

One possible method for operating an emission trading scheme is as follows. Emission permits, issued by the government would provide the holder with the right to emit a specified amount of GHG in a given time period. The permits would represent a tradeable form of Australia’s allocated amount under the Kyoto Protocol (AGO 1999b). Each permit is likely to be equal to a t CO$_2$(e). Under this system, the government is able to control GHG emissions by limiting the number of permits issued
and requiring them to be acquitted (handed back) at the end of a designated period of
time eg. one year.

Companies would be required to hold enough permits to cover their emissions for the
designated period of time. Those companies clever enough to reduce their emissions
below the permitted level, would be in a position to trade their excess permits for profit
using either the national or international emission trading scheme. Visy sees the
ability to reduce emissions and trade excess permits as a potentially very good
business opportunity. If a company’s emissions were higher than the permitted
amount, new permits would have to be purchased from the trading scheme to make up
the shortfall (AGO 1999(b)). The company’s cost of production would be increased.
Such companies have several alternatives:
- Reduce their emissions.
- Increase the price of the product and run the risk of not selling their product.
- Shut down their business.

Current predictions on the price of carbon under emissions trading are in the range of
$US 30 per ton (Horden 2000). Depending upon the result of future negotiations,
carbon credits generated by sink activities could also be traded (AGO 1999(c)).

**Joint Implementation**

Under this mechanism, developed countries are able to invest in projects in other
developed countries to acquire credits to assist in meeting their Kyoto target.
Countries are only able to use credits generated between 2008-2012. Participation is
voluntary. Projects must be approved by the parties involved and must be additional to
what would otherwise occur. Unlike CDM, credits cannot be banked.

Of the three mechanisms, Visy believes that emission trading is the most appropriate
mechanism for their company. With the GHG research identifying reduction strategies
and business opportunities in relation to GHG emissions from its papermaking
processes, Visy believes that it has the knowledge and ability to reduce emissions to
below any future designated levels. Excess carbon credits could then be traded for profit.

Visy sees emission trading as having the potential to generate a win/win situation i.e. a win for the environment and a win for business for the following reasons:

- The system is non-prescriptive and flexible, enabling companies to choose the most appropriate means of reducing emissions.
- As the number of permits would be controlled, there is greater certainty that Kyoto targets would be achieved and GHG emissions will be reduced.
- The cost of the emission trade could introduce appropriate price incentives for developing better abatement and monitoring technologies.
- The costs of administration, revenue collection and control should be minimal.

The research discussed in this thesis was undertaken in order to take advantage of emission trading opportunities. Based on the current state of knowledge, Visy needed to quantify its GHG baseline and then identify appropriate GHG reduction strategies and business opportunities in order to be able to quickly respond if required.

1.8 Australia’s response to the Kyoto Protocol

The production of energy intensive goods was the basis on which Australia negotiated its Kyoto GHG commitments (AGO 1998 (a)). To achieve Australia’s emission target, a reduction in emission levels of greater than 30%, compared to business as usual is required. The Australian Prime Minister (Howard 1997) stated that

“Even stabilising our emissions at 1990 levels would put at risk $68 billion of energy intensive projects and the tens of thousands of potential jobs that go with them.”

With emissions steadily increasing, Australia faces a significant challenge to reduce its emissions in the most cost-efficient manner (Howard 1997).

The Australian Government has accepted the findings of the IPCC that anthropogenic activities have lead to an increase in global warming and has structured its response in
accordance with its potential Kyoto commitments (Howard 1997). For Australia to meet those commitments, large sums of money have been made available by the Australian government for research and development (Howard 1997). The purpose of the research is to:

“Determine the most cost-efficient solutions and generate technological innovation in GHG abatement.”

Table 7 briefly outlines the Australian government’s actions to date in response to climate change.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>ACTION</th>
<th>AIM</th>
</tr>
</thead>
</table>
| 1995 | Greenhouse Challenge Program established | • Joint initiative between the Commonwealth government and Australian industry.  
• The program takes a voluntary and self-regulatory approach to emissions reductions. Improvements are usually in energy and process efficiency. |
| 1997 | Funding of $A180 million provided by the Commonwealth Government over 5 years | ‘Safeguarding the Future’ package:  
• Increase the use of renewable energy.  
• Introduce efficiency standards for fossil fuel energy generation.  
• Energy efficiency measures for buildings and appliances.  
• New fuel efficiency targets for passenger vehicles.  
• Expansion of the Greenhouse Challenge and other partnership programs.  
• Vegetation projects to act as carbon sinks. |
| 1998 | AGO established by the Australian Government | • AGO is responsible for the coordination of domestic climate policy and the delivery of Commonwealth programs. The AGO established the NGGI and uses the results to support strategic policy development. |
| 1998 | National Greenhouse Strategy (NGS) developed by commonwealth, state & territory governments | Strategy objectives include:  
• Energy sector reform.  
• Promotion of renewable energy sources.  
• Improved vehicle fuel efficiency and fuel technologies.  
• Community action to be achieved through local government initiatives, education and awareness. |
| 1999 | $A796 million | ‘Measures for a better Environment’ package:  
• $321 million to the development of renewable energy generation.  
• $75 million for the alternative fuel conversion program.  
• $100 million per year to support greenhouse abatement programs. |

Table 7 Australia’s response to climate change (1995-1999)
1.9 Papermaking processes

The following is a generalised summary of the virgin and recycled papermaking processes, as they occur in Australia. Visy’s processes will be described in Chapters 3 and 4. It should be noted that all stages of each process require the use of some form of energy. Currently, the majority of this energy is fossil fuel based.

1.9.1 Virgin papermaking process

In simplistic terms, the production of paper from new feedstock (eg. wood) involves the following steps:

- Wood preparation and chipping.
- Chemical or mechanical pulping.
- Papermaking process.

Wood is made up of millions of cellulose fibres, bonded together with a glue-like substance called lignin. Different types of wood have different fibre lengths and are classed as either softwoods or hardwoods. Pine logs (softwoods) have long fibres and are used to make packaging products requiring strength. Eucalypt logs (hardwoods) are composed of short fibres that are ideal for the manufacture of printing and writing papers. In order to make paper, the cellulose fibres must first be separated.

Wood preparation and chipping

Logs are delivered from the forest to the pulp mill where they are stripped, washed, debarked and chipped in rotary chippers. From the rotary chippers, conveyor belts are used to transport the wood chips to a final screening unit. Here the chips are screened into the correct size fractions.
Chemical or mechanical pulping

The two most commonly used methods of pulping are the mechanical and chemical processes. Mechanical pulping (where the fibres are separated by physical action) is mainly used with softwoods to manufacture paper for newsprint and magazines.

The kraft process is the most widely used chemical method of pulping. In this process, the woodchips are cooked in large digesters containing caustic soda and sodium sulphate. This action releases the cellulose fibres, which are then screened and washed. The chemicals are then recovered and reused. The cooking liquor from the digestion process is combusted and used throughout the papermaking process.

Once the pulp has been separated from the cooking liquor it can be washed and bleached. Bleaching agents such as chlorine dioxide, ozone and hydrogen peroxide are now being used. The bleaching agent is applied to the pulp and then agitated to allow the bleaching reaction to occur. The pulp is then rinsed with water and the process repeated several times with continued washing and rinsing until a final product of the desired brightness is achieved.

Papermaking process

The pulp is now ready to be processed into paper. The papermaking process consists of the pressing, forming and drying of a large matt of pulp. To make a single ply paper, the mixture is drained over a wire mesh, squeezed and dried, then rolled again for a smooth surface finish before being wound onto large reels. Paperboards are made by combining a series of single sheets while still wet to make a multi layer product. The paper can be sold or further processed. Virgin paper contains approximately 10% moisture. A tonne of virgin paper is termed an Air Dried tonne (ADt).
1.9.2 Recycled papermaking process

The recycled papermaking process involves the following steps:

- Collection of wastepaper.
- Papermaking process.

Collection of wastepaper

Recycling begins with the collection of clean, uncontaminated wastepaper, cardboard, packaging and writing papers. Recycled paper products can be sourced from both within Australia and overseas. These products are either separated at source from the other waste streams and sent directly to paper recycling plants, or if not source separated, sent to a Material Recovery Facility (MRF). At the MRF, the paper is separated from the other waste streams, baled and stored before being sent to the recycling plants.

Papermaking process

At the paper recycling plant, chemicals and water are used at various stages of the papermaking process. Recycled paper is initially disintegrated in a Pulper. The resulting pulp is then passed through screens to remove any contaminants present eg. rubber bands, wire and staples. Pulping releases the cellulose fibres, which vary in length depending upon the number of times the fibre has been recycled. Recycling shortens the length of the fibres, so it is essential that the correct mix of short and long fibres are present to produce a product with the correct strength, colour, moisture resistance and opacity. The fibres are then fed into the paper machine. The process is essentially the same as described in the virgin papermaking process. The product can either be sold or further processed at converting plants into cardboard products. Recycled paper contains approximately 8.25% moisture.
1.10 Visy Industries GHG research

1.10.1 Reasons for conducting GHG research at Visy:

Corporate responsibility

In 1997, with the COP3 meeting about to take place, climate change was emerging as a major global environmental concern. Visy wanted to be very pro-active in this area, and as a good corporate citizen acknowledged that it had a responsibility to reduce GHG emissions as much as possible.

Inadequacy of the Greenhouse Challenge Program

Visy initially investigated being part of the Australian government established Greenhouse Challenge Program (GCO 1997). Under this voluntary program, companies are required to identify their capacity to reduce emissions, develop and implement action plans and monitor and report on performance.

The Program primarily concentrates on the manufacturing component of a process and doesn’t cover all stages of the product’s development and ultimate disposal. As Visy wanted to quantify GHG emissions across the entire lifecycle of the papermaking process, it decided against joining the program.

Assessment of emissions made good business sense

Visy concluded that if ratification of the Kyoto Protocol did occur, Australian industry, as a significant contributor to national emissions would be required to play a role in reducing GHGs. In order to identify the most appropriate reduction strategies, it made good business sense to investigate and quantify its emission levels well in advance of any possible commitment. Visy concluded that by quantifying all stages of the papermaking life cycle, it would be in an ideal position to identify appropriate reduction strategies that would be good for both the environment and its business.
1.11 Research goals

This research had two main objectives:

The primary objective of the research was to determine the GHG effect of the Visy virgin and recycled papermaking processes across their entire lifecycle, from the ‘cradle to grave’. The effect was evaluated in terms of CO₂ and CH₄ emissions. The investigation had to be accomplished in a field that was rapidly evolving in a technical, political and commercial sense.

In order to achieve the primary objective, it was necessary to:

- Quantify and compare CO₂ and CH₄ emissions from the Visy virgin and recycled papermaking processes.
- Determine the consequence of using different forms of energy, technologies and manufacturing processes on CO₂ and CH₄ emissions from the Visy virgin and recycled papermaking processes.

The results would be used to establish a GHG baseline from which appropriate GHG reduction strategies and business opportunities would be identified. The investigation would enable Visy to reduce its GHG emissions in compliance of any future GHG restrictions and position itself to take advantage of any future GHG business opportunities.

The second objective of the research was to choose an environmental decision support tool to use in the research. As part of the research, assessment tests would be established to evaluate and determine whether the chosen methodology was:

- Effective in quantifying CO₂ and CH₄ emissions across the entire lifecycle of the Visy papermaking processes.
- Easy to use in terms of the methodologies involved.
- Able to produce results in a format that was understandable within the pulp and paper industry.
• Flexible enough to cope with change. This would be assessed in terms of whether the methodology was able to quantify emissions in the Visy papermaking processes as a result of changed processes and energy sources.

The Research Plan can be found in Appendix 2
Chapter 2

2. Environmental decision-making support tools

Increased knowledge of the global environment has demonstrated the complexity and interaction between many of the earth’s ecosystems. As global problems such as climate change and ozone depletion increase, it is acknowledged that a more holistic approach is required. Traditional monodisciplinary instruments are no longer appropriate for dealing with complex global issues (Harding 1998).

Environmental decision-making support tools have evolved as a result of increased community awareness of environmental issues and demand for product information covering the life of the product (Greene 1992).

Four environmental support tools were analysed for use in this research. With the exception of LCA, they were chosen because they were well known and often used within Australian industry. Due to its relatively short period of use in Australia (Sonneveld 2000), LCA is the newest support tool and its role and status within the environmental field is still being refined (Udo de Haes 2000).

The support tools chosen for analysis were:

- Environmental Impact Assessment (EIA).
- Risk Management (RM).
- Cost-Benefit Analysis (CBA).
- Life Cycle Assessment (LCA).

In determining the most appropriate support tool, the research required the following characteristics to be present. The characteristics are presented in priority order.
1. **The tool must be capable of quantifying GHG emissions across the full life cycle of the recycling and virgin papermaking processes**

As well as quantifying GHG emissions for the complete life cycle, the tool must be flexible enough to cope with different processes in such a way that the processes can be compared.

2. **Methods used by the tool must be based on recognised standards that are internationally accepted**

As Visy has operations outside Australia, the chosen tool had to be capable of being transferred to overseas operations. It needed to be internationally recognised and creditable.

3. **The tool had to be dynamic and able to cope with change**

Visy needed to use the tool under different operating conditions, different processes and different time periods. The tool needed to be flexible enough to cope with these changes. With a choice of reduction strategies, the tool had to be capable of answering the ‘what if’ questions.

4. **The tool had to provide a framework for decision-making**

The tool needed to be capable of presenting information in a form that was understandable to the decision-makers.

5. **The tool had to be capable of examining the social, economical and technical issues of the papermaking processes**

The author recognised that any proposed GHG reduction strategy could not be implemented without consideration of the social, economical and technical issues surrounding the strategy. Decisions made without considering the above issues may
not be feasible technically, may be too expensive and may not be acceptable to the community.

6. Results needed to be in a format that could be used for other purposes

The information provided needed to be in a format suitable for other purposes, such as eco-labelling claims, trade negotiations, GHG verification claims and company environmental publications.

2.1 Analysis of environmental support tools

LCA, EIA, CBA and Risk Management are all decision-making support tools, the results of which should not be used in isolation. It is acknowledged that there is not one ‘complete’ environmental decision support tool and that often a combination of support tools is required to evaluate the technical, economic and social aspects of a process or strategy.

Based on the analyses of the four support tools, LCA was chosen as the most appropriate support tool for the Visy GHG research. It is acknowledged that in choosing this tool, it might be necessary to use a combination of support tools eg. LCA and CBA. Using such a combination would ensure that the technical, social and economic factors were considered.

LCA is the only one of the four support tools that is capable of quantifying GHG emissions across the full life cycle of the papermaking processes. Of the four support tools, it is the only one to have international as well as Australian/New Zealand recognition. The LCA ISO standards are part of the ISO 14000 environmental series of standards, and as such are recognised worldwide (ISO 1999(a)). Neither EIA nor CBA have standards associated with them, even though they represent long established and professionally accepted processes. Risk Management is backed by Australian/New Zealand (AS/NZ) standards.

Of the four tools, LCA is the most dynamic and flexible. Unlike EIA, which uses a static approach for a single point in time, LCA is flexible enough to account for
changes across different time periods. CBA and Risk Management are not as flexible and are limited in estimating future projections.

All four tools provide a strategic framework for the decision-makers. EIA, CBA and Risk Management are all capable of assessing the social and economic aspects of proposed strategies. LCA is limited in only being able to assess the technical aspects.

Information gained from some of the support tools can be used for other purposes. In addition to its use in the environmental decision-making process, LCA information can be used to verify some activities within a company eg. if Visy wanted to sell carbon credits as part of an emission trading scheme, LCA data would be invaluable as part of the verification process (ISO 1997). Similarly, if Visy wanted to develop a GHG environmental label for its products, LCA information is very valuable, as LCA procedures are part of the Environmental Standards (ISO 2000). All four tools are capable of assisting in the development of environmental standards and regulations.

LCA is a non-mandatory, scientifically based, systems approach for collating and evaluating information on the environmental performance of an activity across its full life cycle, from "cradle to grave." In essence, it is a tool that allows its users to look holistically at a product, process or service. LCA is seen by some as a paradigm through which to think and prioritise (Astrup Jensen et al. 1997). LCA has also been called, ‘Cradle to Grave Analysis’, ‘Eco-balancing’, ‘Materials Flow Analysis’ and ‘Life Cycle Thinking.’

Table 8 contains a brief summary of the main characteristics of LCA.
<table>
<thead>
<tr>
<th>LCA characteristics</th>
<th>Brief explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Based on non-mandatory, international standards</td>
<td>LCA Standards are part of the ISO 14000 Environmental Management Systems series</td>
</tr>
<tr>
<td>Uses a holistic approach</td>
<td>Covers the entire life cycle of the product, process or service</td>
</tr>
<tr>
<td>Has clearly defined system boundaries</td>
<td>The system boundaries define what is included or excluded in the study. All assumptions regarding the position of the boundaries should be clearly stated and justified.</td>
</tr>
<tr>
<td>Uses process models</td>
<td>Process models describe the key elements of the physical systems being investigated and their relationships</td>
</tr>
<tr>
<td>Transparent</td>
<td>Information should be presented in an open, comprehensive and understandable fashion so that the logic of methods used can be readily followed.</td>
</tr>
<tr>
<td>Flexible</td>
<td>Can be used for different purposes eg. at the design stage, across the entire life cycle, to compare different products/processes and environmental labelling</td>
</tr>
<tr>
<td>Takes an iterative, integral approach to the data</td>
<td>Enables the process model to cope with multiple operations and activities eg. resource use, solid and liquid emissions to air, water and soil</td>
</tr>
<tr>
<td>Has a defined functional unit</td>
<td>A reference unit that allows comparisons to be made within the model and between models</td>
</tr>
<tr>
<td>Decision support tool which should not be used in isolation</td>
<td>Provides a strategic framework to support the decision-making process. Quantifies the environmental data, but doesn’t determine the social, environmental or health effects</td>
</tr>
<tr>
<td>Uses both subjective and scientific based decisions</td>
<td>Some LCA phases are very subjective eg. the selection of impact categories and indicators, whereas others have a stronger scientific basis eg. the collection and quantification of specific data.</td>
</tr>
</tbody>
</table>
| 3 different levels of LCA                               | 1. Conceptual  
2. Simplified  
3. Detailed |
| A detailed LCA is composed of 4 distinct phases         | Phase 1 Goal and scope definition  
Phase 2 Life Cycle Inventory Analysis (LCI)  
Phase 3 Life Cycle Impact Assessment (LCIA)  
Phase 4 Interpretation of results |
| Can be very demanding and expensive                     | Often requires a rigorous collection and analysis of data which can be very time consuming and expensive |

Table 8 LCA characteristics
Curran (1999) sees the benefits of using the LCA approach in the following way:

“LCA is a way to be proactive in environmental management by heading off potential problems, as well as benefiting from an improved environmental image”.

Table 9 outlines the current ISO 14000 environmental standards (ISO 1999(a)). In addition to those shown in Table 9, ISO/TR 14047 is also in the process of being developed. This new standard involves the application of the Life Cycle Impact Assessment (LCIA) phase of LCA (Udo de Haes 2000).

The ISO Standards have brought consistency to LCA procedures (ISO 1997). When comparing products or processes, these elements are essential. As Visy wanted to compare the recycling and virgin papermaking processes, the ability of LCA to perform this task was an important consideration.

One of the most important aspects of LCA is the initial development of appropriate process models. These models describe the key elements of the physical systems being investigated and would normally cover the manufacture of a product, from the mining of the raw materials used in production and distribution, through to its use, possible reuse, recycling and disposal.

LCA analyses have international credibility and can be used during trade negotiations, the establishment of Environmental Management Systems (EMS), eco-labelling claims and verification procedures (ISO 1997).
<table>
<thead>
<tr>
<th>Standard</th>
<th>Year of publication</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 14001</td>
<td>1996</td>
<td>Environmental management systems-Specification with guidance for use</td>
</tr>
<tr>
<td>ISO 14004</td>
<td>1996</td>
<td>Environmental management systems-General guidelines on principles, systems and supporting techniques</td>
</tr>
<tr>
<td>ISO 14010</td>
<td>1996</td>
<td>Guidelines for environmental auditing-general principles</td>
</tr>
<tr>
<td>ISO 14011</td>
<td>1996</td>
<td>Guidelines for environmental auditing-audit procedures of environmental management systems</td>
</tr>
<tr>
<td>ISO 14012</td>
<td>1996</td>
<td>Guidelines for environmental auditing-Qualification criteria for environmental auditors</td>
</tr>
<tr>
<td>ISO/WD 14015</td>
<td>To be determined</td>
<td>Environmental assessment of sites and entities</td>
</tr>
<tr>
<td>ISO 14020</td>
<td>2000</td>
<td>Environmental labels and declarations-General principles</td>
</tr>
<tr>
<td>ISO 14021</td>
<td>1999</td>
<td>Environmental labels and declarations-Self-declared environmental claims (Type II environmental labelling)</td>
</tr>
<tr>
<td>ISO 14024</td>
<td>1999</td>
<td>Environmental labels and declarations-Type I environmental labelling – Principles and procedures</td>
</tr>
<tr>
<td>ISO/TR 14025</td>
<td>2000</td>
<td>Environmental labels and declarations-Type III environmental declarations</td>
</tr>
<tr>
<td>ISO 14031</td>
<td>1999</td>
<td>Environmental management-Environmental performance evaluation-Guidelines</td>
</tr>
<tr>
<td>ISO/TR 14032</td>
<td>1999</td>
<td>Environmental management-Environmental performance evaluation-Case studies illustrating the use of ISO 14031</td>
</tr>
<tr>
<td>ISO 14040</td>
<td>1997</td>
<td>Environmental management-Life cycle assessment-Principles and framework</td>
</tr>
<tr>
<td>ISO 14041</td>
<td>1998</td>
<td>Environmental management-Life cycle assessment-Goal and scope definition and inventory analysis</td>
</tr>
<tr>
<td>ISO 14042</td>
<td>2000</td>
<td>Environmental management-Life cycle assessment-Life cycle impact assessment</td>
</tr>
<tr>
<td>ISO 14043</td>
<td>2000</td>
<td>Environmental management-Life cycle assessment-Life cycle Interpretation</td>
</tr>
<tr>
<td>ISO/CD 14048</td>
<td>2000</td>
<td>Environmental management-Life cycle assessment-Life cycle assessment data documentation format</td>
</tr>
<tr>
<td>ISO/TR 14049</td>
<td>2000</td>
<td>Environmental management-Life cycle assessment-Examples for the application of ISO 14041</td>
</tr>
<tr>
<td>ISO 14050</td>
<td>1998</td>
<td>Environmental management-Vocabulary</td>
</tr>
<tr>
<td>ISO/TR 14061</td>
<td>1998</td>
<td>Information to assist forestry organizations in the use of the Environmental management system standards ISO 14001 and ISO 14004</td>
</tr>
<tr>
<td>ISO Guide 64</td>
<td>1997</td>
<td>Guide for the inclusion of environmental aspects in product standards</td>
</tr>
</tbody>
</table>


Table 9 ISO 14000 series of standards
LCA framework

An overview of the LCA framework is shown in Figure 4 (ISO 14040 1997).

Figure 4 Overview of the LCA framework

The LCA framework and those activities where the LCA tool can be applied are shown in the above table. The double arrows between the different phases indicate the interactive nature of LCA eg. if at the impact assessment phase it became obvious that data were missing, the inventory analysis stage would need refining and updating.

LCA levels

There are three (3) levels of LCAs:

- Conceptual.
- Simplified.
- Detailed.

Conceptual or Life Cycle Thinking

This approach is the simplest form of LCA and is more a qualitative discussion to identify stages of the life cycle and/or the potential environmental effects of greatest significance (Christiansen 1997). Some of the activities where conceptual thinking has been applied include (Astrup Jensen et al. 1997):
• Product development.
• Strategic planning.
• As part of the ISO 14021 Standard (ISO 1999(b)): Environmental labels and declarations-Self-declared (Type II Environmental labelling).

**Simplified LCAs**

Simplified LCAs may provide the same or similar results as detailed LCAs, but often have a lower level of reliability. Compared to detailed LCAs, they can be achieved faster and at a lower cost. A simplified LCA covers the whole life cycle but at a superficial level eg. using data imported from similar cases and not project specific (qualitative and/or quantitative), standard modules for transportation or energy production, followed by a simplified assessment. Three stages are involved (Christiansen et al. 1997):

1. Screening: To identify the essential parts of the life cycle, data flow or data gaps.
2. Simplifying: To focus work on the findings obtained in the screening procedure so that the most important parts of the life cycle or data flow are studied.
3. Assessing reliability: To ensure that the simplifying procedure did not significantly reduce the reliability of the overall result.

According to Astrup Jensen (1997), some of the activities where simplified LCAs have been applied include:

- Product Development and improvement.
- Organization marketing.
- Strategic Planning.
- As part of the ISO 14024 Standard (ISO 1999(c)): Environmental labels and declarations-Type I Environmental Labelling Programs.

**Detailed LCAs**

Few detailed studies have been carried out (due to time constraints and expense) and in practice, a simplified form of LCA tailored to the product and the purpose is often used. The detailed LCA procedure was applied to the Visy study.
Some of the activities where detailed LCAs have been applied include (Astrup Jensen et al. 1997):

- Product development.
- Organization marketing.
- As part of the ISO 14025 Standard (ISO 2000): Environmental labels and declarations-Type III environmental declarations

**LCA Phases**

LCAs are composed of 4 phases (ISO 14040 1998).

**Phase 1: Goal and scope definition**

In Phase 1 of a LCA, the following are defined:

- The goal of the study.
- The scope of the study.
- The functional unit.
- The system boundaries.
- Data quality requirements.
- Comparisons between systems.
- Critical review considerations.

**Phase 2: Life Cycle Inventory Analysis (LCI)**

LCI involves the following activities:

- Relevant data is collected.
- Data is related to the appropriate reference flow.
- The system boundaries are refined.
- The procedures that will be used to quantify the data are defined.
- The accuracy of the data is validated.
Phase 3: Life Cycle Impact Assessment (LCIA)

LCIA involves the following:

- Category definition.
- Classification.
- Characterisation.
- Normalisation/weighting.

Phase 4: Interpretation

During the interpretation phase, the following occurs:

- Significant environmental issues are identified.
- The results are evaluated.
- Conclusions and recommendations are made.

Additional information can be found in relevant ISO Standards as shown in Table 9.

Table 10 outlines the meaning of some LCA terms (AS/NZS 2001) that may be confusing to non-LCA practitioners. A brief explanation of how these terms were applied to the Visy LCAs is shown.
<table>
<thead>
<tr>
<th>LCA Term</th>
<th>Meaning of LCA term</th>
<th>Application to the Visy study</th>
</tr>
</thead>
</table>
| **Phase 1**  
Functional Unit | The functional unit provides a reference to which the inputs and outputs are related. The unit enables the LCA results to be compared on a common basis | The Functional Unit chosen was one Air Dried tonne (ADt) of paper manufactured |
| **Phase 2**  
Life Cycle Inventory (LCI) results | Quantified input and output data for a given product system throughout its life cycle | Data was quantified in terms of the GHGs, CO₂ and CH₄ |
| **Phase 3**  
Impact categories | Environmental impacts into which the LCI results are placed. Impact categories used in other studies include human toxicity, acidification and stratospheric ozone depletion | As the study was a single stream study, only the single impact category of Climate Change was chosen |
| **Phase 3**  
Classification (Assignment of LCI results) | Input and output data are allocated to impact categories | All results were allocated to the impact category of Climate Change |
| **Phase 3**  
Characterisation model | The model used to link the LCI results and the category indicator | The model chosen was the IPCC model |
| **Phase 3**  
Category indicator | Quantifiable representation of an impact category | Infrared radiative forcing |
| **Phase 3**  
Characterisation factor | Term derived from the characterisation model and used to convert the LCI results into a common unit | The GWP of each GHG emission to air over a time horizon of 100 years eg. GWP of CO₂ = 1, CH₄ = 21. GWP enabled data to be converted into t CO₂(e)/ t gas emission |
| **Phase 3**  
Indicator result | Aggregation of the common unit | Aggregation of t CO₂(e)/ t gas emission into total t CO₂(e) |
| **Phase 3**  
Normalisation | Relative contribution of the indicator results to a selected reference | Normalisation was treated differently from the ISO Standard. Individual indicator results (t CO₂(e)/ADt) were referenced against the total indicator results (total t CO₂(e)/ADt), as follows:  
\[ \frac{t \text{ CO}_2(e)/ADt \text{ for a single activity} \times 100}{\text{Total } t \text{ CO}_2(e)/ADt \text{ for all activities}} \]  
Results gave an indication of the % contribution of each activity to the LCA |

**Table 10 LCA terms as applied to the Visy research**
2.2 Visy LCAs–General overview

Throughout the investigation, the researcher was aware that the guidelines surrounding the quantification, ownership and potential liability for GHGs were still being resolved. For companies to quantify their GHG baseline and formulate strategies to comply with potential GHG restrictions, they need to be aware of current climate change developments and the ramifications of those developments to their business.

This thesis is an example of the practical application of current GHG knowledge and LCA methodology that evolved in an environment where technical, political and commercial guidelines at both a national and international level were still being developed. The thesis was not intended to be critical review of LCA methodology.

The researcher was aware that where new developments were found to be relevant to the research, they had to be incorporated into the investigation eg. the Federal Government’s passing of the Renewable Energy (Electricity) Act 2000 (AGO 2001(a)). As Visy plan on incorporating a Biomass Cogeneration Plant into its pulp mill development, the ramifications of that Act on the investigation needed to be included in the research.

The chosen functional unit and LCA system boundaries were refined as part of the research. As will be shown, the choice of an appropriate functional unit within a defined LCA system boundary was crucial to the outcome.

2.3 LCA methodology as applied to the Visy papermaking processes

2.3.1 Goal and scope

The reasons for conducting the GHG research were discussed in Chapter 1, Section 1.10. The goals of the research were as stated in Chapter 1, Section 1.11.

Visy intend to use the results of the research whenever they were required. The intended audience for the research include:
Visy staff

The company needed an indication of what its GHG emissions were. Only then could the company implement strategies to reduce its emissions and prepare for the possibility of future emission restrictions.

Local, State and Federal governments

Visy intended to use the results of the research at all government levels eg. the results could be used at the local government level to inform the community of its GHG emissions from its local operations. At the state and federal government levels, the results could be used to support applications for new processes or equipment.

Climate change scientific community

Visy wanted to learn from and share the results of the research with the climate change scientific community. This was accomplished by Visy supporting the author to attend and present at national and international conferences. Visy believed that its LCA study was unique, as the majority of Australian companies had not used the LCA procedure to evaluate their GHG emissions.

Scope

Visy LCA process models were developed for both the paper recycling and virgin paper processes. Detailed flowcharts of both processes can be seen in Appendix 2. No critical review of the Visy LCAs has been conducted to date. It is anticipated that such a review would occur as part of verification procedures for emission trading and environmental labelling claims.

The following is a brief overview of how the LCA framework was applied to the Visy recycled and virgin papermaking processes. The Visy recycled paper LCA studies are discussed at length in Chapter 3, whilst the Visy virgin LCA studies are discussed in Chapter 4.
Visy Recycled papermaking process

The defined Visy recycled papermaking process model involved all stages of the process, from the initial pickup of wastepaper to paper production, corrugated product, use, recycling of the product and ultimate decomposition in SWDSs. A simplified version of the process is shown in Appendix 4, Figures 1 & 3.

The system begins with contractors collecting household recycled material at kerb side collection points and industry sites. Where municipal councils have established paper recycling programs, the separated wastepaper is sent directly to the Visy paper recycling plants. Where no separation occurs, the waste is first sent to a MRF (e.g. Visy recycling plant at Laverton), where it is separated from the rest of the collected waste streams (garden waste, bottles, cans, food etc.), compacted and bailed before being forwarded to the Visy paper recycling plants.

At the paper recycling plants, the fibre is pulped and processed into recycled paper. Following transportation to the Visy converting plants, the paper is converted into cardboard boxes. If required, printed labels are placed on the boxes. Converter waste cardboard is transported back to the paper recycling plants for further processing. Once customers have used the cardboard boxes, they are placed out for collection for further recycling. The model assumes the product is capable of being recycled 4 or 5 times before the fibres become too short for processing. Decomposition of the short fibres occurs in SWDSs.

Visy Virgin papermaking process

The Visy virgin process model includes all activities relevant to the virgin papermaking process. The model follows the fibre from the forest, through the pulp and papermaking process, its conversion into cardboard boxes, product use and disposal into SWDSs. A simplified version of the process is shown in Appendix 4, Figures 2 & 3.
The virgin process model begins in the Pinus radiata plantations. Emissions resulting from the management and milling of the plantations have been included in the model. In conjunction with the virgin fibre, Visy intends to process a small amount of wastepaper at the pulp mill.

It is intended that biomass (in the form of softwood pulp logs, sawmill residues, woodwaste and plant by-products) will be used as the fuel source for the biomass cogeneration plant. According to EIS projections, the biomass plant will supply close to 60% of the energy requirements for the site. Any excess electricity produced from the cogeneration plant will be sold to the grid as Green Power\(^2\) (Nolan-ITU 1998).

Emissions resulting from the conversion, pre-printing and coating operations are included in the model. Transport emissions relevant to Visy and emissions resulting from solid and liquid waste disposal have been included. The original virgin papermaking model assumed that as soon as the cardboard box was used, it was disposed into SWDSs without recycling. This assumption is discussed in detail in Chapter 4.

The sequestration of carbon by the plantation developments was excluded from the virgin model. This was due to the high level of uncertainty associated with the sequestration accounting methods and the allocation of emissions, which are still being negotiated at an international level. Carbon sequestration issues are discussed in Chapter 4.

### 2.3.2 Functional unit and initial system boundaries

As shown in Table 10, the functional unit chosen for both models was one Air Dried tonne (ADt) of paper manufactured. This unit is commonly used within the pulp and paper industry (PPMFA 1999). In the Visy paper recycling process, the paper was manufactured at the paper recycling plants. In the Visy virgin papermaking process, the paper was manufactured at the pulp mill.

\(^2\) Green Power is electricity produced from a renewable energy source.
Initial system boundaries

Each model was composed of the same 6 unit processes, as shown in Figure 5.

![Recycling loop diagram](image)

Figure 5 Unit processes defining the boundaries of the LCA studies

Activities within these unit processes differed from process to process. Table 11 outlines the main activities that occurred within each of the six unit processes.

<table>
<thead>
<tr>
<th>LCA unit process</th>
<th>Paper Recycling LCA activities</th>
<th>Virgin LCA activities</th>
</tr>
</thead>
</table>
| Raw Materials Acquisition | • Import and local transport of wastepaper  
• Transport of sorted wastepaper from consumer to paper recycling plants  
• Transport of unsorted wastepaper from consumer to recycling plants  
• Transport of chemicals to paper recycling plants | • Development and management of pine plantations  
• Transport of biomass fuel, and chemicals to the pulp mill  
• Transport of sorted wastepaper from consumer to paper recycling plants  
• Transport of unsorted wastepaper from consumer to the recycling plants |
| Raw Materials Processing | • Sorting, compacting, baling and storage of wastepaper at the recycling plants  
• Transport of baled wastepaper from recycling plants to paper recycling plants | • Transport of saw plant residues, logs and pulp wood to pulp mill  
• Sorting, compacting, baling and storage of wastepaper at the recycling plants  
• Transport of wastepaper from the paper recycling and MRF plants to the pulp mill |
| Manufacturing | • Production of recycled paper at the paper recycling plants | • Production of paper at the pulp mill |
| Post Manufacturing | • Conversion of recycled paper into cardboard boxes at the converting plants | • Conversion of paper into cardboard boxes at the converting plants |
| Use & Service | • Consumer use of the product | • Consumer use of the product |
| Disposal into SWDSs | • Wood fibre recycled a number of times before ultimately being disposed into SWDSs | • Wastepaper processed assumed to be recycled a number of times before ultimately being disposed into SWDSs  
• Virgin portion used once then disposed into SWDSs |

Table 11 Unit process activities for each Visy LCA model
Defining where to place the initial LCA system boundaries was a subjective and very difficult decision. Visy owned operations were automatically included in the LCA models. This decision was based on the assumption that if GHG restrictions were introduced as part of the Kyoto Protocol, Visy would only be required to control/reduce emissions from its own operations. Those non-Visy owned operations that were part of the papermaking processes that Visy may benefit from commercially were also included.

To be credible, the LCAs had to model the Visy paper recycling and virgin processes as closely as possible. This was particularly important for the virgin model, as there was no opportunity to test the validity of the model. As shown in Tables 13 and 14, a carbon mass balance conducted using 1996/97 and 1998/99 paper recycling data verified the accuracy of the paper recycling model.

The placement of initial system boundaries were based on the following considerations:

1. At the company level, Visy wanted to determine its overall GHG liability. This meant that all Visy owned operations were included in both LCA models. Based on the LCA results, potential business strategies for the company were developed.

2. At the paper recycling plant level, Visy wanted to determine the GHG emissions from each of its paper recycling plants. By quantifying its emissions at this level, the GHG effect of different processes could be evaluated. This information was invaluable when determining GHG reduction strategies and commercial opportunities for the paper recycling plants.

3. GHG emissions across different time periods. By comparing GHG emissions across different time periods (eg. 1996/97 and 1998/99), Visy were able to gain an indication of whether its emissions had changed. To enable this to occur, those activities that varied from year to year that were not critical to the process were placed outside the LCA system boundaries eg. emissions resulting from the export of product once it left the Australian dock to different countries each year.
4. Non-Visy owned operations that were part of the papermaking processes that Visy had some interest in and wanted to determine the GHG effect of, were included in each LCA model eg. the gas cogeneration plant that supplies steam to VP3&6 and transport emissions for Visy operations within Australia. Contractors transport most of Visy’s stock. Visy were aware that according to the NGGI data, road transport was responsible for 14.2% of national emissions in 1998. Including these activities within the LCA boundary meant that their GHG effect could be assessed. If these activities were found to be significant in creating business opportunities to reduce GHG emissions and produce carbon credits that could be traded for profit, then having more than a passing interest in these activities may be a good commercial decision.

5. Non–Visy owned activities that were part of the papermaking processes and which Visy had no interest in were excluded from the LCA models eg. GHG emissions from the sawmills in the virgin model and chemical manufacturing in both models.

6. As one of the goals of the research was to compare GHG emissions from the Visy recycling and virgin processes, it was essential that each process model had comparable system boundaries including unit processes.

2.3.3 Activities included and assumptions used

Activities included in the models have been clearly defined and are discussed in greater detail in Chapter 3 (Recycling LCAs) and Chapter 4 (Virgin LCAs).

Assumptions to the models

Assumptions made in both models are discussed in Chapters 3 and 4. Sensitivity analyses were conducted on those activities where a degree of uncertainty existed. If the sensitivity analysis found the assumption to be significant, the assumption was quantified. If not, the baseline assumption was used in the study.
2.3.4 Selected inputs and outputs

GHG emissions result from energy sources (e.g., electricity and gas usage) and non-energy sources (e.g., production of CH₄ in SWDSs). Identified inputs and outputs relevant to the Visy GHG research, in their appropriate units are shown in Table 12. Data was collected on a yearly basis.

<table>
<thead>
<tr>
<th>INPUT DATA</th>
<th>OUTPUT DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Raw Materials</strong></td>
<td><strong>Production volume</strong></td>
</tr>
<tr>
<td>Local and imported paper (tonnes/year)</td>
<td>tonnes/year (recycling process)</td>
</tr>
<tr>
<td>Woodstock feed (tonnes/year)</td>
<td>ADt/year (virgin process)</td>
</tr>
<tr>
<td>Chemicals used in the papermaking/converting processes (tonnes/year)</td>
<td></td>
</tr>
<tr>
<td>Water (kL/year)</td>
<td></td>
</tr>
</tbody>
</table>

| **Energy consumption data**                     | **Disposal**                                    |
| Electricity (kWh/year)                          | Solid waste (tonnes/year)                       |
| Gas (GJ/year)                                   | Liquid waste (kL/year)                         |
| Renewable biomass (tonnes/year)                 | Decomposition of wood fibre in SWDSs (tonnes/year) |
| Diesel (kL/year)                                |                                                 |
| Steam (tonnes/year)                             |                                                 |
| Coal (tonnes/year)                              |                                                 |
| (LPG) Liquid Petroleum Gas (kg/year)            |                                                 |
| Fugitive emissions³                             |                                                 |

| **Transportation data**                         | **Transportation data**                         |
| Distances in km/year                            | Distances in km/year                            |

Table 12 Selected inputs and outputs

2.3.5 Data considerations

Data collection

The impact category chosen for this study was the environmental category of Climate change. This category was consistent with the stated goals and scope of the study. Relevant data contributing to GWP were allocated to this category.

³ Fugitive emissions from electricity and gas are included in the full-fuel cycle CO₂(e) emission factors (GCO 1997). Fugitive emissions for the remaining energy sources are not included, due to the high level of uncertainty in their estimation (IPCC 1997) and a lack of available data.
Data collection and inventory analyses are very iterative stages of a LCA. One of the most difficult aspects of the procedure was finding people within the pulp and paper industry who were skilled in system thinking. Visy is a very large company and data had to be sourced from a multitude of staff who were specialised in their field but didn’t have the holistic approach that the research required. It took a long time to integrate the many aspects of the papermaking processes in life cycle terms, and then to collect the required data.

No sooner was one LCA completed than additional information was obtained, necessitating an iteration of the LCA with redefined system boundaries. As a result, the author conducted 3 Visy recycling LCA iterations using 1996/97 data. For ease of identification, the iterations have been referred to as Recycling LCA Study 1, Recycling LCA Study 2 and Recycling LCA Study 3. A recycling LCA using 1998/99 data was also conducted, and has been referred to as Recycling LCA Study 4. Site-specific, averaged, and assumed data were used for all Visy recycling LCA’s.

EIS data were used for the proposed unbleached kraft pulp and paper mill (Nolan ITU 1998). As the plant is still in the process of being built, EIS data were taken at face value and no verification of the data could be undertaken. It is acknowledged that the virgin LCAs were heavily dependant upon this data, and that actual operating data may differ from the EIS data. Ideally, a further quantification should be conducted once the plant is operating.

LCA transport distances were both estimated and assumed. Estimated distances were obtained from appropriate maps and other sources (travel agencies, Navy, Internet etc). Where distances could not be accurately estimated, assumptions were made eg. the distance that imported waste travelled from the collection point in the particular country to the closest dock was assumed to be 100 km.

Transport energy intensity data used in both LCA models were based on average MJ/tonne-kilometre of Australian transport for urban and non-urban areas of operation (Apelbaum Consulting Group 1997).
Each Visy paper recycling plant within the Visy paper recycling process operates under its own unique conditions. Comparing the emissions from the different plants gave an indication of the effect that different operating conditions had on the production of GHGs. However, emissions from the paper recycling plants only related to one unit process of the Visy Recycling LCA i.e. the manufacturing unit process, as shown in Figure 5.

In order to quantify emissions from the individual paper recycling plants and the full Visy paper recycling LCA, the analysis was conducted in two stages.

Stage 1 involved the quantification of emissions from each of the individual Visy paper recycling plants. At this stage of the analysis, *data from the Visy paper recycling plants were quantified in terms of t CO₂(e)/t of product manufactured and not as t CO₂(e)/ADt*, for the following reasons:

- Recycled paper contains approximately 8.25% moisture, which is not an Air Dried tonne (ADt).
- It was important that Visy staff were able to understand and interpret the paper recycling plants GHG data. As data within the paper recycling industry is commonly referred to in terms of per tonne of product manufactured, and not as an ADt, all GHG emissions from the Visy paper recycling plants were interpreted in this way prior to their aggregation and incorporation into the Visy LCA.

Stage 2 involved the aggregation and conversion of the Visy paper recycling plant data into ADt. The data were then incorporated into the *manufacturing unit process* of the paper recycling LCA.

Unlike the paper recycling process where data from the paper recycling plants were individually analysed prior to being aggregated and imported into the paper recycling LCA, data from each of the virgin unit processes were placed directly into the LCA.
Data sources

The priority order for data collection was as follows:

1. Site-specific Visy data.
2. Pulp and paper mill EIS data.
3. Data from recognised organizations eg. IPCC, AGO and NGGIC.
4. Specific reference papers and consultants as required.

References to data sources can be found in Tables 16-20.

Validation of data

A carbon mass balance based on actual site flows was conducted on the aggregated paper recycling plant data in order to verify the accuracy of the mass flow data. The assumption was made that 100% of the Visy production was recycled. Based on this assumption, an additional source of recycled paper was required to reach the total recycled input. It was assumed that this fibre was manufactured in a similar manner to the Visy process.

As shown in Table 13, the 1996/97 data indicated an overall carbon mass balance agreement of 97.77%. Results shown in Table 14 indicated an agreement of 98.14% for the 1998/99 data. It is acknowledged that the outstanding 2-3% are in all probability fugitive emissions. These results verified the accuracy of the recycled fibre data used in the LCA models.

<table>
<thead>
<tr>
<th>Carbon Source</th>
<th>Quantities</th>
<th>tonnes Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon In</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imported waste</td>
<td>35,939 tonnes</td>
<td>14,179</td>
</tr>
<tr>
<td>Domestic recycle</td>
<td>622,720 tonnes</td>
<td>245,679</td>
</tr>
<tr>
<td><strong>Total Carbon In</strong></td>
<td><strong>259,858 t Carbon</strong></td>
<td></td>
</tr>
<tr>
<td>Carbon Out</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid waste to SWDSs</td>
<td>106,815 tonnes</td>
<td>12,057</td>
</tr>
<tr>
<td>Solid waste to incineration</td>
<td>Zero</td>
<td></td>
</tr>
<tr>
<td>Liquid waste</td>
<td>2,409,561 kL</td>
<td>3,615</td>
</tr>
<tr>
<td>Production</td>
<td>604,251 tonnes</td>
<td>238,392</td>
</tr>
<tr>
<td><strong>Total Carbon Out</strong></td>
<td><strong>254,064 t Carbon</strong></td>
<td></td>
</tr>
</tbody>
</table>

Table 13 Paper recycling plants-carbon mass balance (1996/97)
### Table 14 Paper recycling plants-carbon mass balance (1998/99)

<table>
<thead>
<tr>
<th>Carbon Source</th>
<th>Quantities</th>
<th>tonnes Carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon In</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imported waste</td>
<td>28,323 tonnes</td>
<td>11,174</td>
</tr>
<tr>
<td>Domestic recycle</td>
<td>673,687 tonnes</td>
<td>265,786</td>
</tr>
<tr>
<td><strong>Total Carbon In</strong></td>
<td></td>
<td><strong>276,960 t Carbon</strong></td>
</tr>
<tr>
<td>Carbon Out</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid waste to SWDSs</td>
<td>100,563 tonnes</td>
<td>13,297</td>
</tr>
<tr>
<td>Solid waste to incineration</td>
<td>12,700 tonnes</td>
<td>1,679</td>
</tr>
<tr>
<td>Liquid waste</td>
<td>2,401,607 kL</td>
<td>1,224</td>
</tr>
<tr>
<td>Production</td>
<td>647,897 tonnes</td>
<td>255,612</td>
</tr>
<tr>
<td><strong>Total Carbon Out</strong></td>
<td></td>
<td><strong>271,811 t Carbon</strong></td>
</tr>
</tbody>
</table>

#### Comparisons between systems

Both Visy LCA models used the same unit processes and functional unit. Similarities and differences between the two LCA models are discussed in Chapter 5.

#### 2.3.6 Quantification of GHGs

GHGs were quantified in accordance with IPCC Guidelines (IPCC 1997). The use of the IPCC model in this research was appropriate, given that the investigation is controlled by commercial goals. The IPCC acts as an interface mechanism between international science and global warming policy, and is internationally known and accepted within the scientific and political community. The IPCC conducts an expert scientific assessment process drawing on global data from international organisations and research programs and provides policy relevant scientific advise to the Framework Convention on Climate Change (FCCC) (Zillman 2000).

All GHG calculations were performed using an Excel spreadsheet. Initial studies used a basic program that was later replaced by a more sophisticated program, specifically designed by the author for Visy. An example of the quantification procedure is given in Table 15. Factors used in the quantification procedure and their sources are shown in Tables 16-20. GWPs were used to determine the radiative forcing of CO₂ and CH₄, in terms of t CO₂ (e). Data were quantified as t CO₂(e)/t paper manufactured. Data
were normalised as shown in Table 10. Normalised results were valuable as they indicated the percentage contribution of each unit process to the overall LCA study.

Consistent with the IPCC Guidelines, biomass used in Visy operations was classed as carbon neutral. This meant that no GHG emissions were attributed to the use of biomass in this thesis. According to the IPCC Guidelines, when biomass is used as an energy source, CO$_2$ is emitted. However, these emissions are balanced by the sequestration of carbon from the atmosphere during sustainable growth (IPCC 1997). CO$_2$ emissions from fossil fuel energy sources are not considered carbon neutral as these energy sources are not sustainable.

**Quantification procedure**

An example of how Visy CO$_2$ and CH$_4$ emissions were quantified from different emission sources is shown in Table 15. 1998/99 data from one of the Victorian Visy paper recycling plants (VP2) were used in this example. As shown, different factors are often used to quantify GHG emissions from different sources.

Results of the paper recycling LCAs are detailed in Chapter 3, while the results of the virgin LCAs are shown in Chapter 4.
### Table 15 GHG quantification of VP2 in 1998/99

<table>
<thead>
<tr>
<th>Emission Source</th>
<th>Quantity used</th>
<th>Distance travelled (km)</th>
<th>Energy content of fuel</th>
<th>CO₂ emission factor</th>
<th>CO₂ emissions (t CO₂(e))</th>
<th>t CO₂(e)/t paper manufactured at VP2</th>
<th>Data normalised as a percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>38,291,862 kWh</td>
<td>10</td>
<td>1.283 kg/kWh 38,291,862 x 1.283</td>
<td>49,128</td>
<td>0.581</td>
<td>1.17</td>
<td>49.7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>= 49,128</td>
<td>= 0.581</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>611,486.2 GJ</td>
<td>58.9 kg/GJ</td>
<td>611,486.2 x 58.9 x 10^5</td>
<td>36,017</td>
<td>0.426</td>
<td>1.17</td>
<td>36.4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>= 36,017</td>
<td>= 0.426</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td>65 kL</td>
<td>38.6 GJ/kL</td>
<td>69.7 kg/GJ 65 x 38.6 x 69.7</td>
<td>175</td>
<td>0.002</td>
<td>1.17</td>
<td>0.2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>= 175</td>
<td>= 0.002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid waste</td>
<td>247,539 kL</td>
<td>5.25 kg CO₂(e)/kg BOD</td>
<td>247,539 x 2,500 x 5.25 x 0.1</td>
<td>324.9</td>
<td>0.004</td>
<td>1.17</td>
<td>0.3%</td>
</tr>
<tr>
<td>(BOD =2,500mg/L)</td>
<td></td>
<td></td>
<td></td>
<td>= 324.9</td>
<td>= 0.004</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport of solid waste from VP2 to SWDS</td>
<td>9,617t</td>
<td>30km</td>
<td>1.48 MJ/tonne-km (Urban) 9,617 x 30 x 1.48 x 96.7</td>
<td>29.8</td>
<td>0.001</td>
<td>1.17</td>
<td>0.1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>= 29.8</td>
<td>=&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VP2 solid waste reject at SWDS</td>
<td>9,617t</td>
<td>1.37(4)</td>
<td>9,617 x 1.37 = 13,205</td>
<td>13.205</td>
<td>0.156</td>
<td>1.17</td>
<td>13.3%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>= 13,205</td>
<td>= 0.156</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. 84,508t = recycled paper manufactured at VP2 in 1998/99
2. 5.25 = 0.25 kg of methane/kg BOD (Default value for the maximum amount of CH₄ from wastewater) x 21 (GWP of CH₄)
3. 0.1 = CH₄ emissions were assumed to be 10% of maximum CH₄ emissions
4. 1.37 = 0.45 (55%=moisture content of waste) x 0.75 (75%=dried waste fibre content) x 0.20 (tCH₄ in SWDSs) x 0.95 (CH4 not captured in SWDS) x 21(GWP for CH₄)
5. 1.17 = total t CO₂(e)/t paper manufactured at VP2 in 1998/99
Factors used to quantify GHGs are shown in Tables 16-20.

<table>
<thead>
<tr>
<th>Emission source</th>
<th>Data period</th>
<th>Energy content of fuel</th>
<th>CO₂ emission factor</th>
<th>Reference Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Coal (unwashed)</td>
<td>1993/94, 1994/95</td>
<td>23.0 GJ/t, 23.0 GJ/t</td>
<td>89.4 kg/GJ, 90 kg/GJ</td>
<td>GCO 1997</td>
</tr>
<tr>
<td>Diesel (Non transport)</td>
<td>1993/94, 1994/95</td>
<td>38.6 GJ/kL, 38.6 GJ/kL</td>
<td>74.9 kg/GJ, 69.7 kg/GJ</td>
<td>GCO 1997</td>
</tr>
<tr>
<td>Diesel oil (Automotive)</td>
<td></td>
<td></td>
<td>69.7 g/MJ</td>
<td>NGGIC 1998</td>
</tr>
<tr>
<td>Electricity in NSW #</td>
<td>1993/94, 1994/95</td>
<td></td>
<td>0.92 Kg/kWh, 0.833 Kg/kWh</td>
<td>GCO 1997</td>
</tr>
<tr>
<td>Electricity in Victoria #</td>
<td>1993/94, 1994/95</td>
<td></td>
<td>1.34 Kg/kWh, 1.283 Kg/kWh</td>
<td>GCO 1997</td>
</tr>
<tr>
<td>Electricity in Queensland (Qld) #</td>
<td>1993/94, 1994/95</td>
<td></td>
<td>1.02 Kg/kWh, 0.916 Kg/kWh</td>
<td>GCO 1997</td>
</tr>
<tr>
<td>Electricity # (Australian average)</td>
<td>1993/94, 1994/95</td>
<td></td>
<td>1.0 Kg/kWh, 0.913 Kg/kWh</td>
<td>GCO 1997</td>
</tr>
<tr>
<td>Electricity - aver. for Vic./Qld &amp; NSW #</td>
<td>1993/94, 1994/95</td>
<td></td>
<td>1.09 Kg/kWh, 1.01 Kg/kWh</td>
<td>GCO 1997</td>
</tr>
<tr>
<td>Natural Gas in NSW #</td>
<td>1993/94, 1994/95</td>
<td></td>
<td>63.2 Kg/GJ, 63.2 Kg/GJ</td>
<td>GCO 1997</td>
</tr>
<tr>
<td>Natural Gas in Victoria #</td>
<td>1993/94, 1994/95</td>
<td></td>
<td>58.9 Kg/GJ, 58.9 Kg/GJ</td>
<td>GCO 1997</td>
</tr>
<tr>
<td>Natural Gas in Qld #</td>
<td>1993/94, 1994/95</td>
<td></td>
<td>56.7 Kg/GJ, 56.7 Kg/GJ</td>
<td>GCO 1997</td>
</tr>
<tr>
<td>LPG non-transport</td>
<td>1993/94, 1994/95</td>
<td>49.6 GJ/t</td>
<td>64.7 Kg/GJ, 59.4 Kg/GJ</td>
<td>GCO 1997</td>
</tr>
<tr>
<td>Fuel oil</td>
<td></td>
<td></td>
<td>73.6 g/MJ</td>
<td>NGGIC 1998</td>
</tr>
<tr>
<td>Steam</td>
<td></td>
<td></td>
<td>0.14 kg/kg</td>
<td>Visy Staff</td>
</tr>
</tbody>
</table>

* CO₂(e) emission factors
# Full-fuel cycle emissions

Table 16 Stationary GHG emission factors

<table>
<thead>
<tr>
<th>Emission source</th>
<th>Data period</th>
<th>Estimated energy intensity of transport services (MJ/tonne-km)</th>
<th>Reference Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight Rail Services (mean of government/ non-government systems)</td>
<td>1994/95</td>
<td>0.28</td>
<td>Apelbaum 1997</td>
</tr>
<tr>
<td>International shipping</td>
<td></td>
<td>0.052 MJ/tonne-km</td>
<td>Apelbaum 1997</td>
</tr>
</tbody>
</table>

Table 17 Estimated transport energy intensity factors

---

4 See Appendix 5
5 Fuel emissions (including fugitive emissions) from extraction of the fuel through to the processing, transportation and combustion stage.
### Table 18 Solid and liquid waste factors used in Visy study

<table>
<thead>
<tr>
<th>Emission source</th>
<th>Data period</th>
<th>Factors used in the Visy study</th>
<th>CO$_2$(e) emission factor</th>
<th>Reference Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content of solid waste rejects</td>
<td>65% (96/97) 59% (98/99)</td>
<td></td>
<td></td>
<td>Visy Staff</td>
</tr>
<tr>
<td>Fibre content of solid waste rejects</td>
<td>75%</td>
<td></td>
<td></td>
<td>Visy Staff</td>
</tr>
<tr>
<td>COD levels of liquid effluent</td>
<td>1996/97</td>
<td>VP2, VP3&amp;6, VP4, VP5 = 8,000 mg/L (averaged data) VP8 = 1900 mg/L (site specific data)</td>
<td></td>
<td>Visy Staff</td>
</tr>
<tr>
<td>BOD levels of liquid effluent</td>
<td>1998/99</td>
<td>Site-specific data used</td>
<td></td>
<td>Visy Staff</td>
</tr>
<tr>
<td>Default value for maximum CH$_4$ in liquid effluent</td>
<td>0.25 kg CH$_4$/kg BOD or COD</td>
<td></td>
<td></td>
<td>Environment Australia 1997</td>
</tr>
<tr>
<td>Factor used to determine the amount CO$_2$(e) in liquid effluent</td>
<td></td>
<td></td>
<td>5.25 kg CO$_2$(e)/kg BOD or COD</td>
<td>Author’s research</td>
</tr>
</tbody>
</table>

* The source of these factors can be found in Appendix 5

### Table 19 Factors used to quantify GHGs in SWDSs

<table>
<thead>
<tr>
<th>SWDSs paper emission factors</th>
<th>Factors used*</th>
<th>Reference Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH$_4$ in SWDSs Original value</td>
<td>0.15</td>
<td>GCO 1997</td>
</tr>
<tr>
<td>CH$_4$ in SWDSs Revised value</td>
<td>0.20</td>
<td>IPCC 1997</td>
</tr>
<tr>
<td>CH$_4$ recovered in SWDSs</td>
<td>0.05</td>
<td>IPCC 1997 &amp; author’s research</td>
</tr>
<tr>
<td>CH$_4$ remaining in SWDS</td>
<td>0.15</td>
<td>IPCC 1997 &amp; author’s research</td>
</tr>
</tbody>
</table>

* This factor was obtained by multiplying the default value of the maximum CH$_4$ producing capacity of wastewater (0.25 kg CH$_4$/kg BOD or COD) by 0.1 (10% of maximum CH$_4$) x 21 (GWP of CH$_4$)
<table>
<thead>
<tr>
<th><strong>Emission factors</strong></th>
<th><strong>Factors used</strong></th>
<th><strong>Energy content of fuel</strong></th>
<th><strong>Reference Source</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Imported paper emissions assigned*</td>
<td>0.868 t CO₂(e)/ADt of paper manufactured</td>
<td></td>
<td>Author’s research</td>
</tr>
<tr>
<td>Felling &amp; Splitting of logged timber</td>
<td></td>
<td>165.7 MJ/t</td>
<td>Pickin 1996</td>
</tr>
<tr>
<td>Plantation management</td>
<td></td>
<td>69.77 MJ/t</td>
<td>Pickin 1996</td>
</tr>
<tr>
<td>Moisture content of wastepaper</td>
<td>8.25% (Wet weight)</td>
<td>Visy Staff</td>
<td></td>
</tr>
<tr>
<td>Average carbon content of paper</td>
<td>43% (of dry weight)</td>
<td>Pickin 1996</td>
<td></td>
</tr>
</tbody>
</table>

* Sometimes termed ‘embodied emissions’

**Table 20 Factors used to quantify GHGs**

**2.3.7 Accuracy of data used**

Data used in this research were continually checked to ensure consistency with the stated goals and scope of the Visy LCA studies. Where the accuracy of the assumed data was in doubt, sensitivity analyses were conducted singly on particular inputs, outputs and choice of methods that the author believed had a high degree of uncertainty. All sensitivity analyses have been documented. An example of the sensitivity analyse procedure is shown in Table 21.

<table>
<thead>
<tr>
<th>Number of fibre cycles</th>
<th>Recycled LCA emissions t CO₂(e)/ADt of paper manufactured</th>
<th>% Change in emissions from the baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1.36</td>
<td>+15.3 %</td>
</tr>
<tr>
<td>5</td>
<td>1.18</td>
<td>Baseline</td>
</tr>
<tr>
<td>6</td>
<td>1.06</td>
<td>-10.2 %</td>
</tr>
<tr>
<td>8</td>
<td>0.91</td>
<td>-20.8 %</td>
</tr>
</tbody>
</table>

**Table 21 Sensitivity analysis-number of paper cycles**

Initial paper recycling LCAs assumed that paper was capable of being cycled 5 times (recycled 4 times). A sensitivity analysis was conducted to determine the effect on LCA emissions of using 4-8 fibre cycles, while holding all other conditions and values constant. All sensitivity analyses conducted in this thesis used the assumed value as
the baseline. The assumed value used in the above example was 5 fibre cycles. A change in emissions from the baseline value was then calculated. A result was said to be significant if it caused a change of greater than 5% from the baseline value. Table 21 indicated that the number of fibre cycles used in the recycling LCAs was significant. As a result of the analysis, further research was conducted and the number of fibre cycles was increased to 6 (Cullinan 1991). All subsequent LCAs assumed that paper was capable of being cycled 6 times.

Visy LCA results were not weighted. As the LCA study was a single stream study, it was not necessary to distribute the data across different impact categories. Visy required the data in a form that they could relate to, in both a business and environmental sense. Quantifying data in terms of t CO₂(e)/ADt of paper manufactured was found to be the most appropriate reference. An example of the contribution of each unit process to total GHG emissions is shown in Table 22.

<table>
<thead>
<tr>
<th>Virgin LCA-Study 3 LCA unit processes</th>
<th>t CO₂(e)/ADt of paper manufactured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Material Acquisition</td>
<td>0.08</td>
</tr>
<tr>
<td>Raw Material Processing</td>
<td>0.03</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>0.53</td>
</tr>
<tr>
<td>Post Manufacturing</td>
<td>0.14</td>
</tr>
<tr>
<td>Use and Service</td>
<td>Undetermined–outside LCA boundary</td>
</tr>
<tr>
<td>Disposal</td>
<td>1.08</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1.84</strong></td>
</tr>
</tbody>
</table>

Table 22 Example of the contribution of each unit process to total emissions

2.3.8 LCA evaluation, conclusions and recommendation

Once all relevant GHGs were quantified, the final phase of the LCA procedure was conducted. The results were evaluated; conclusions drawn and recommendations in the form of GHG reduction strategies and business opportunities made. Proposed recommendations for the Visy paper recycling process are discussed in Chapter 3. Chapter 4 contains the proposed recommendations for the Visy virgin papermaking process.
Chapter 3

3. Visy paper recycling LCA model

Four recycling LCA studies are discussed in this chapter. Three iterations using the same 1996/97 data (Recycling LCA Study 1, Recycling LCA Study 2 and Recycling LCA Study 3) were undertaken. These studies were evolving studies, where boundaries and subjective data were constantly refined to accurately model the existing process and reduce the level of subjectivity used. The refinement that occurred in these studies was then applied to the 1998/99 data. Paper recycling LCA Study 4 was the only LCA to use paper recycling process data from 1998/99.

Of the four paper recycling studies, Recycling LCA-Study 4 is the most refined. The progress and refinement of the research from the development of a very basic LCA model to a more transparent model with clearly defined system boundaries will be discussed.

Data relevant to the Visy paper recycling papermaking process is shown in Table 23.

<table>
<thead>
<tr>
<th></th>
<th>Visy paper recycling 1996/97 data</th>
<th>Visy paper recycling 1998/99 data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wastepaper input (Australian sourced)</td>
<td>622,720 tonnes</td>
<td>673,687 tonnes</td>
</tr>
<tr>
<td>Wastepaper input (imported)</td>
<td>59,939 tonnes</td>
<td>53,323 tonnes</td>
</tr>
<tr>
<td>Total wastepaper processed</td>
<td>682,659 tonnes</td>
<td>727,010 tonnes</td>
</tr>
<tr>
<td>Total production from the Visy paper recycling plants. (Contains 8.25% moisture) (Value used in Functional Unit)</td>
<td>604,251 tonnes of paper manufactured</td>
<td>647,897 tonnes of paper manufactured</td>
</tr>
<tr>
<td>Quantity sold to customers</td>
<td>120,850 tonnes</td>
<td>102,796 tonnes</td>
</tr>
<tr>
<td>Quantity sent to Visy converting plants</td>
<td>483,401 tonnes</td>
<td>545,101 tonnes</td>
</tr>
<tr>
<td>Converting products sold to customers</td>
<td>432,644 tonnes</td>
<td>510,240 tonnes</td>
</tr>
</tbody>
</table>

Table 23 Visy paper recycling data
The quantification of CO$_2$ and CH$_4$ emissions for the recycling LCA studies took place in two stages.

**Stage 1** involved the quantification of emissions using site-specific data from each of the paper recycling plants. Results from each paper recycling plant were evaluated and compared. At the completion of Stage 1, the results were aggregated and incorporated into the manufacturing unit process of the LCA.

**Stage 2** involved the quantification of emissions for the complete life cycle of the Visy paper recycling process. Emissions were quantified and grouped into the 6 identified unit processes, as identified in Figure 5. On-site, averaged and assumed data were all used in the LCA studies. Sensitivity analyses were conducted to determine the significance of the use of averaged and assumed data. Results were evaluated and GHG reduction strategies and business opportunities at the paper recycling plant and full LCA level were identified.

### 3.1 Stage 1: Quantification of GHG emissions at the paper recycling plants

CO$_2$ and CH$_4$ emissions from each of the paper recycling plants were individually quantified using on-site data prior to being incorporated into the paper recycling LCAs. Visy believed that many of the reduction strategies were likely to centre around the paper manufacturing process, so an initial analysis of the individual paper recycling plants prior to the analysis of all activities and operations in the papermaking process was warranted.

Visy has six (6) paper recycling plants in Australia. VP2, VP4 and VP5 are all located in Victoria, VP3&6 is located in New South Wales and VP8 is located in Queensland. The location of each plant was an important factor in the quantification of energy emissions, as each state has different CO$_2$(e) emission factors for the production of electricity and gas. These factors are shown in Table 24.
<table>
<thead>
<tr>
<th>Australian State</th>
<th>Electricity CO₂(e) emission factor (1994/95) kg/kWh</th>
<th>Gas CO₂(e) emission factor (1993/94) kg/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSW, ACT</td>
<td>0.833</td>
<td>63.2</td>
</tr>
<tr>
<td>Victoria</td>
<td>1.283</td>
<td>58.9</td>
</tr>
<tr>
<td>Queensland</td>
<td>0.916</td>
<td>56.7</td>
</tr>
<tr>
<td>SA</td>
<td>0.897</td>
<td>57.6</td>
</tr>
<tr>
<td>WA</td>
<td>0.917</td>
<td>62.3</td>
</tr>
<tr>
<td>Tasmania</td>
<td>0.000</td>
<td>54.6</td>
</tr>
<tr>
<td>NT</td>
<td>0.628</td>
<td>59.4</td>
</tr>
</tbody>
</table>

Table 24 Australia State GHG emissions for electricity and gas (GCO 1997)

With a CO₂ emission factor of 1.283 kg/kWh for electricity, Victoria has the highest factor of any Australian state. Victoria uses brown coal which is very carbon intensive, to produce electricity. Tasmania on the other hand, uses the renewable energy source of hydropower to produce its electricity and has been allocated a CO₂ emission factor of 0.000 kg/kWh (GCO 1997). Although hydropower is considered carbon neutral by the IPCC, some scientific discussion has suggested that waterlogged vegetation in the dams emits large quantities of CO₂ and CH₄ (Pearce 1996). The consequences of using different CO₂ emission factors to quantify emissions at the paper recycling plants will be discussed later.

The main differences between the Visy paper recycling plants are as follows:

- VP4 is the only plant to have a de-inking section. The effect of this process on GHG emissions was unknown.
- A cogeneration plant operated at VP3&6 up until July 1997. Since that time, steam has been purchased from a third party operated cogeneration plant located adjacent to the Visy plant.
- VP8 is the only plant that has an up-flow anaerobic digester. The other plants have no means of reducing their BOD/COD levels before discharge.
- Since 1998, VP8 has been burning some of its solid waste rejects in an on-site boiler for energy recovery. This has significantly reduced the amount of solid waste rejects sent to SWDSs. Emissions resulting from incineration are predominantly CO₂. As the fibre content in the waste is from a renewable energy source, emissions are considered to be carbon neutral.
Some Visy paper recycling plants use technologies and processes that are unique to that particular plant (e.g. third party sourced steam at VP3 & 6 and the use of an on-site anaerobic digester at VP8). The GHG effect of using such technologies was included in the sensitivity analyses.

The essential differences between each GHG quantification study at the paper recycling plants are shown in Table 25. Please note that Table 25 only refers to Stage 1 of the Visy paper recycling LCA study.

<table>
<thead>
<tr>
<th>Features of the paper recycling plant studies</th>
<th>Stage 1 Study 1</th>
<th>Stage 1 Study 2</th>
<th>Stage 1 Study 3</th>
<th>Stage 1 Study 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time period that conversion factors were sourced from</td>
<td>1993/94</td>
<td>1993/94</td>
<td>1993/94</td>
<td>1994/95</td>
</tr>
<tr>
<td>Specific State CO₂ emission factors used for electricity and gas calculations</td>
<td>No Averaged data used</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Third party steam provided to VP3&amp;6</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>VP8 started incinerating some of its solid waste rejects</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Methane/carbon molecular weight factor (16/12) included in paper recycling plant solid waste emissions from SWDSs</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Methane capturing/flaring activities at SWDSs included</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 25 Stage 1: Paper recycling plant studies

Each Paper Recycling Plant Study was evaluated in order to:

- Quantify emissions as accurately as possible. This meant that activities used in some of the studies were assessed in terms of their accuracy and significance to the paper recycling process e.g. the use of averaged instead of specific State electricity and gas emission factors.
- Determine the effect that different plant processes and technologies had on GHG emissions e.g. third party supplied steam and incinerating solid waste to avoid SWDS emissions. It was hoped that this information gained from these evaluations would indicate some of the strategies that could be employed to reduce emissions.
3.1.1 Paper recycling plants-GHG emission results

The 4 paper recycling plant studies were evaluated and discussed in the following categories:

1. Studies 1-3 (1996/97 data) were compared. This comparison enabled the effect of using averaged CO2 emission factors instead of state specific factors and the effect of including methane capturing and flaring activities at SWDSs to be evaluated.

2. Study 3 (1996/97) and Study 4 (1998/99) were compared. As shown in Table 25, this comparison gave an indication of the GHG effect of steam supplied to VP3&6 and the consequence of VP8 burning 52% of their solid waste rejects.

3. Emissions by source during the two time periods and the different technologies used within the plants were compared.

The results of the 4 paper recycling plant studies are shown in Table 26. As explained in Section 2.3.5, data from the paper recycling plants were presented as t CO2(e)/t paper manufactured.

<table>
<thead>
<tr>
<th>Paper recycling plant</th>
<th>Study 1 t CO2(e)/t paper manufactured</th>
<th>Study 2 t CO2(e)/t paper manufactured</th>
<th>Study 3 t CO2(e)/t paper manufactured</th>
<th>Study 4 t CO2(e)/t paper manufactured</th>
</tr>
</thead>
<tbody>
<tr>
<td>VP2</td>
<td>1.06</td>
<td>1.17</td>
<td>1.20</td>
<td>1.17</td>
</tr>
<tr>
<td>VP3&amp;6</td>
<td>0.91</td>
<td>0.88</td>
<td>0.91</td>
<td>0.70</td>
</tr>
<tr>
<td>VP4</td>
<td>1.42</td>
<td>1.49</td>
<td>1.56</td>
<td>1.65</td>
</tr>
<tr>
<td>VP5</td>
<td>0.89</td>
<td>1.16</td>
<td>1.19</td>
<td>1.03</td>
</tr>
<tr>
<td>VP8</td>
<td>1.53</td>
<td>1.51</td>
<td>1.56</td>
<td>1.25</td>
</tr>
<tr>
<td>Total emissions (t CO2(e)/year for all paper recycling plants)</td>
<td>700,335</td>
<td>729,082</td>
<td>752,584</td>
<td>702,080</td>
</tr>
</tbody>
</table>

Table 26 Results of the 4 paper recycling plant studies
3.1.2 Paper Recycling Plant Studies 1-3 (1996/97 data)

Consequence of using averaged CO\textsubscript{2} emissions factors for electricity and gas

Study 1 used Australian State averaged CO\textsubscript{2(e)} emission factors for all electricity and gas calculations. Although this made the calculations easier to perform, emissions from energy usage at the individual paper recycling mills in Study 1 were not completely accurate due to variation in these factors. Table 27 highlights the differences.

<table>
<thead>
<tr>
<th>Location of Visy paper recycling plants</th>
<th>State electricity CO\textsubscript{2(e)} factors (kg/kWh)</th>
<th>% Change in emissions from baseline</th>
<th>State gas CO\textsubscript{2(e)} factors (kg/GJ)</th>
<th>% Change in emissions from baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Victoria</td>
<td>1.34</td>
<td>+22.9</td>
<td>58.9</td>
<td>-1.2</td>
</tr>
<tr>
<td>New South Wales</td>
<td>0.92</td>
<td>-15.6</td>
<td>63.2</td>
<td>+6.0</td>
</tr>
<tr>
<td>Queensland</td>
<td>1.02</td>
<td>-6.4</td>
<td>56.7</td>
<td>-4.9</td>
</tr>
<tr>
<td>Average</td>
<td>1.09</td>
<td>Baseline</td>
<td>59.6</td>
<td>Baseline</td>
</tr>
</tbody>
</table>

Table 27 State CO\textsubscript{2} emission factors for electricity and gas

The effect of using State electricity CO\textsubscript{2} emission factors instead of averaged emission factors was significant. Victoria recorded the largest change with a 22.9% increase in emissions. This is due to its use of brown coal. New South Wales recorded a drop in emissions of 15.6%. The use of averaged gas emission factors was not as significant as gas emission factors do not vary as much as electricity. New South Wales produced the only significant result.

As the results were significant to individual plant GHG energy emissions, the decision was made to use State emissions factors for both electricity and gas in Study 2 and all subsequent Studies. Using the correct factors resulted in all Victorian plants (VP2, VP4, VP5) recording higher emissions in Study 2 compared with Study 1. The result was an overall increase in total emissions of 28,747 t CO\textsubscript{2(e)} as seen in Table 26. In terms of energy emissions, the results do indicate that setting up a manufacturing business in Victoria as opposed to the other Australian States will have a higher GHG consequence. Under a regime of GHG restrictions, the type of energy source being used to produce electricity and gas will become increasingly important.
Methane/carbon factor and methane capturing or flaring at SWDSs

Appendix 6 details the equations used to calculate methane emissions from SWDS. These equations take into account the capturing or flaring of CH$_4$ at SWDSs. Solid waste rejects from the paper recycling plants have traditionally been sent to SWDSs. This has resulted in high emissions of CO$_2$(e) due to the production of CH$_4$ under anaerobic conditions.

Studies 1 & 2 assumed that wood fibre in SWDSs decomposed to methane in accordance with Greenhouse Challenge Office (GCO) Methodology (GCO 1997). Methane capturing or flaring activities were not included in these calculations. In addition, the GCO neglected to include the molecular weights of methane and carbon (16/12) in their calculations. This factor is recognised in the IPCC Guidelines and as waste is converted anaerobically into CH$_4$, the factor is a vital part of the equation (IPCC 1997).

The methane/carbon factor and methane capturing and flaring activities at SWDSs were included in Studies 3 & 4. The author noted that the Australian NGGI estimated that the amount of methane capturing and flaring at SWDSs in 1994 and 1995 was zero (AGO 2001(b)). Due to a lack of current data, the author assumed that the number of Australian SWDSs capturing or flaring CH$_4$ was 10%. The addition of these activities to Studies 3 and 4 lead to an increase in emissions from all plants and an overall total increase of 23,502 t CO$_2$(e). As both these activities are part of the papermaking process, they have been included in all subsequent Studies. The effect of these activities in the full Visy paper recycling LCA will be discussed in Stage 2.

3.1.3 Comparison between 1996/97 (Study 3) and 1998/99 (Study 4)

Effect of using third party supplied steam

Gas usage at VP3&6 was very low during 1998/99 as the cogeneration plant adjacent to the site supplied steam to the paper recycling mills. The allocation of emissions under these circumstances is an arbitrary decision made between the relevant companies (GCO 1997).
In order to make a decision, a set of reference conditions were adopted:
(a) All electricity was purchased from the state electricity grid.
(b) 100% of steam was obtained from an on-site natural gas fired boiler operating at 80% efficiency.

Against this reference point, the third party owned and operated cogeneration plant providing steam to VP 3&6 was “avoiding” emissions at VP3&6 equivalent to operating a natural gas fired boiler at 80% efficiency. The plant may therefore seek some “credit” for supplying steam, whilst VP3&6 may be required to accept “responsibility” for some emissions incurred elsewhere.

This position was represented algebraically as shown below (Energetics & Wiegard 1998(a)). This simplified analysis assumed that gas consumption at Visy had fallen to zero from the defined reference point as a result of purchasing steam from the third party cogeneration plant.

\[
\begin{align*}
\text{Visy}_t &= \text{Ve} + \text{Vst} \\
\text{Cogen}_t &= \text{Cogen}_g - \text{Vst} \\
\text{TOTAL}_t &= \text{Ve} + \text{Cogen}_g
\end{align*}
\]

Where:
- \(\text{Visy}_t\) = Visy (VP3&6) total emissions
- \(\text{Ve}\) = Visy (VP3&6) electricity emissions
- \(\text{Vst}\) = Emissions related to Visy (VP3&6) steam use
- \(\text{Cogen}_t\) = Cogeneration plant allocated emissions
- \(\text{Cogen}_g\) = Cogeneration plant emissions due to gas consumption

Provided each party accounted for emissions in the same way, the emissions “allocated” to the steam cancel out. As the third party cogeneration plant was a joint initiative between Visy and the third party, a nominal amount was allocated to the Visy study:

- Visy = emissions equating to 50% of equivalent boiler emissions.
- Third party = emission credit of 50% of equivalent boiler emissions.

Based on the above allocation, 50% of boiler emissions applicable to the steam supplied to Visy were allocated to VP3&6 during 1998/99.
Table 26 indicated VP3&6’s GHG emissions decreased approximately 23% in 1998/99. This was significant, as production increased 15.7% in the same period. The large decrease in emissions was greatly aided by the allocation of steam emissions. If VP3&6 were accountable for 100% of the boiler emissions from the cogeneration plant its total emissions would have increased from 0.7 to 0.85 t CO$_2$(e)/t paper manufactured. This analysis indicated that obtaining steam from a third party did significantly reduce GHG emissions at VP3&6.

**Incineration of solid waste**

In 1998/99, VP8 diverted 52% of their solid wastes from SWDSs to their boiler. This had a large effect on their overall emissions as incineration of waste avoided the production of CH$_4$ at SWDSs. As shown in Table 28, the result was an 11.2 % reduction in total emissions.

<table>
<thead>
<tr>
<th>VP8</th>
<th>t CO$_2$(e)/t paper manufactured</th>
<th>% Change in total emissions from the baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>52% of solid waste rejects incinerated at VP8 in 1998/99</td>
<td>1.25</td>
<td>Baseline</td>
</tr>
<tr>
<td>All solid waste rejects sent to SWDSs</td>
<td>1.39</td>
<td>+11.2%</td>
</tr>
</tbody>
</table>

**Table 28 Consequence of incinerating solid waste**

The results indicated that burning solid waste in the boiler is an effective means of reducing GHG emissions. The CO$_2$ emitted as a result of the combustion process was assumed to be carbon neutral as it is offset by an uptake of carbon during forestry growth (IPCC 1997).

**3.1.4 Emissions by source during 1996/97 & 1998/99**

Relative emissions by source at the paper recycling plants during 1996/97 and 1998/99 can be seen in Table 29. Data from Study 3 and Study 4 were used in this table.
Analysis of the percentage emissions by source from each of the paper recycling plants during 1996/97 and 1998/99 indicated that fossil fuel energy sources were responsible for the majority of CO₂ emissions. These findings are consistent with the NGGI results shown in Table 5. Although this was expected, confirmation of these outcomes was important to Visy. The results increased Visy’s chances of success in gaining government assistance in the establishment of viable papermaking GHG abatement projects, as GHG reductions from any of its projects would be accordance with NGGI findings.

Table 29 indicated that with the exception of VP3&6, all plants indicated similar percentage emissions for electricity during 1996/97 and 1998/99. Differences in VP3&6’s emissions were due to the external sourcing of steam during 1998/99. VP8 used very little gas, as its main energy sources are electricity and coal.

High emissions at VP8 were partially offset by the on-site treatment of effluent in an anaerobic digester. Effluent emissions contributed only 0.22% of the plants total emissions in 1998/99. A sensitivity analysis indicated that in the absence of the digester, effluent emissions at VP8 would have been approximately 1.4%.
Effluent emissions

Table 29 indicated a large variation in effluent emissions between the two time periods. This was due to the method used to calculate these emissions rather than any changes at the paper recycling plants.

Effluent may be treated aerobically or anaerobically, or a combination of both. Aerobic treatment of wood fibre results in emissions of CO$_2$, which were assumed to be carbon neutral as these emissions are offset by an uptake of carbon during forestry growth (IPCC 1997). Anaerobic treatment results in the emission of CH$_4$.

Methods used to quantify GHG emissions from effluent treatment and decomposition on disposal are currently not well defined. Current methods use a default value for Biochemical Oxygen Demand (BOD) or Chemical Oxygen Demand (COD) of 0.25 kg CH$_4$ per kg of BOD or COD (Environment Australia 1997). The use of this default value for both BOD and COD produced large variations in the results. The author expected default values for COD and BOD to be different. The fact that they are not only emphasises the inadequacy of the method used.

Effluent values were quantified according to the following equation:

$$t \text{ CO}_2(e) = k \text{L of effluent x BOD (or COD) in mg/L x 0.25 x 21 x 0.1}$$

$$10^6$$

**Equation 1: Formula used to quantify effluent emissions**

The studies assumed that 10% of the maximum possible methane emissions under 100% anaerobic conditions could occur. This nominal assumption was made to allow for:

- Some uncontrolled anaerobic activity may have taken place.
- Some leakage of methane may have occurred.

A sensitivity analysis determined that if maximum levels of CH$_4$ (i.e. 100%) were included in the calculations, aggregated total emissions from the paper recycling plants
would only increase 4.1%. As this result was less than 5%, it was not significant and the 10% value was used in all subsequent calculations.

The 1996/97 emissions from effluent were quantified using Visy paper recycling plant site-specific COD data. However, BOD data from each of the Visy paper recycling plants were used in the 1998/99 calculations. BOD values varied from 1900mg/L to 4,435 mg/L. The default value for BOD in wastewater in the pulp and paper industry is 4000 mg/L (AGO 1996). The default value was not used, as Visy site-specific data were available.

BOD and COD values in the pulp and paper industry often vary e.g. in 1996/97, the BOD value at VP8 was 1100 mg/L and the COD value was 1900 mg/L. As a result, the use of COD values in Equation 1 lead to higher calculated levels of CH₄ in liquid effluent compared to when the BOD values were used. For the above reasons, GHG emissions from effluent should be regarded with a high degree of caution. Further research is required to determine an equation that is specific for the pulp and paper industry.

**VP4**

Table 26 indicated that VP4 was the only paper recycling plant in 1998/99 to have increased its emissions in terms of t CO₂(e)/t paper manufactured. At the same time, production decreased 12.6%. Table 29 indicated that VP4 had the highest percentage emissions from solid waste rejects disposed into SWDSs. This is thought to be from the de-inking process, as Visy believes this process is very energy intensive. Visy has used information gained from these studies and other environmental decision support tools to determine appropriate strategies to improve the operation of the plant, and thereby reducing its GHG emissions. Further research into the effect of the de-inking process on GHG emissions is required.
3.1.5 Summary of findings-paper recycling plants

The quantification of GHGs at the paper recycling plants in 1996/97 and 1998/99 highlighted the following points:

- Fossil fuels were responsible for the vast majority of emissions at the paper recycling plants.
- Australian States have different CO₂ emission factors for electricity and gas. Some States eg. Victoria uses carbon intensive brown coal to produce electricity, which leads to high GHG emissions.
- Obtaining steam from a third party supplier reduced GHG emissions at VP3&6.
- Burning solid waste rejects for energy recovery did reduce emissions. This action not only avoided CH₄ emissions at SWDSs, but also reduced the amount of fossil fuel required.
- The anaerobic digester at VP8 was shown to reduce effluent emissions.

3.2 Stage 2: Paper recycling LCA studies

Stage 2 involved the quantification of CO₂ and CH₄ emissions for the full life cycle of the Visy paper recycling process. As shown in Figure 5, both process models had the same 6 unit processes. Aggregated data from Stage 1 were converted into the functional unit and then imported into the manufacturing unit process of the LCA.

3.2.1 Initial system boundaries

Unlike Stage 1, which used paper recycling plant site-specific data, it was necessary in the full LCA to occasionally use averaged and assumed data. Assumptions used in each of the unit process and results of sensitivity analyses conducted on those assumptions are discussed in Chapter 3, Section 3.2.2.

Based on the considerations discussed in Chapter 2, initial system boundaries were established for Study 1. Results obtained from sensitivity analyses conducted on the assumed and averaged data were used to redefine the system boundaries. The new system boundaries were used in subsequent studies. Examples of included and excluded emissions in recycling LCA Study 4, are shown in Figure 6. Emissions have been grouped into the 6 unit processes.
Figure 6 Paper recycling LCA

Emissions included & excluded in recycling LCA-Study 4

LCA SYSTEM BOUNDARY

### Raw Materials acquisition
- Assigned emissions
  - Imported wastepaper
- Transport emissions
  - From consumer to paper recycling plant
  - Imported paper from the overseas dock to the Visy paper recycling plants
- Chemicals used at the plants—Australian distances only

### Raw Materials Processing
- Emissions due to sorting, compacting, baling & storage at the recycling plant
- From the recycling plant to the paper recycling plant

### Manufacturing
- Energy emissions
  - All energy usage
- Waste emissions
  - Solid waste
  - Liquid waste
- Transport emissions
  - Solid waste

### Post Manufacture Processing
- Energy emissions
  - All energy usage
- Assigned emissions in imported paper
- Waste emissions
  - Solid & liquid
  - Transport emissions
  - Imported waste from overseas dock to paper recycling plant
  - Paper product to converting plants
  - Chemicals
  - Converting waste to paper recycling plants
  - Converted product to consumer

### Use & Service
- Outside of Visy’s control
- Avoided emissions due to:
  - Recycled paper
  - Transport to disposal

### Disposal
- Transport emissions
  - Consumer to depot
  - Depot to SWDS

### Exclusions
- **Raw Materials Acquisition**
  - Assigned emissions in Australian sourced wastepaper
  - Sourcing of overseas converter waste
  - Overseas transport emissions if chemical manufacturer is off shore
  - Chemical manufacturing

- **Raw Material processing**
  - No exclusions

- **Manufacturing**
  - CH4 emissions from VP8 anaerobic digester
  - Emissions from Visy manufactured paper once it was sold out of the Visy system

- **Post Manufacture Processing**
  - Transport Emissions
  - Collection of imported paper in overseas country
  - Overseas transport emissions if chemical manufacturer is located overseas

- **Use and service**
  - All emissions due to the use of the product

- **Disposal**
  - No exclusions
Features of the 4 paper recycling LCA studies (Stage 2) are shown in Table 30.

<table>
<thead>
<tr>
<th>Differences between the paper recycling LCA studies</th>
<th>Stage 2 LCA-Study 1</th>
<th>Stage 2 LCA-Study 2</th>
<th>Stage 2 LCA-Study 3</th>
<th>Stage 2 LCA-Study 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time period that conversion factors were sourced from</td>
<td>1993/94</td>
<td>1993/94</td>
<td>1993/94</td>
<td>1994/95</td>
</tr>
<tr>
<td>Converter waste returned to paper plant</td>
<td>No - Disposed into SWDSs</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Exporting/archiving included in LCA</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>All chemical transport emissions included</td>
<td>Yes</td>
<td>Yes</td>
<td>Australian distances only</td>
<td>Australian distances only</td>
</tr>
<tr>
<td>All transport emissions for imported wastepaper included in LCA</td>
<td>Yes</td>
<td>Yes</td>
<td>Overseas emissions excluded</td>
<td>Overseas emissions excluded</td>
</tr>
<tr>
<td>Number of times wastepaper was cycled</td>
<td>5</td>
<td>5</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Effluent CH₄ was 10% of maximum CH₄</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Avoidance credit claimed</td>
<td>80%</td>
<td>80%</td>
<td>83.3%</td>
<td>83.3%</td>
</tr>
<tr>
<td>CH₄ capturing /flaring at SWDSs included</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 30 Features included in the paper recycling LCAs

Table 30 demonstrates that the LCA model used throughout the 4 studies is essentially the same i.e. the processes are the same, but some parameters have changed in value.

The essential differences between these 4 studies were as follows:

- Studies 1-3 used 1996/97 data. Study 4 used 1998/99 data.
- Study 1 assumed paper from the paper recycling plants was not sold outside of Visy operations.
- Studies 3 & 4 assumed that paper was capable of being cycled 6 times before disposal. As a result of this assumption, the avoidance credit claim increased from 80% (Studies 1 & 2) to 83.3%.
- The effect of methane capturing and flaring at SWDSs was included in Studies 3 & 4.
3.2.2 Paper recycling LCA emission assumptions and exclusions

Raw Materials Acquisition unit process-assumptions and exclusions

The results of the sensitivity analyses conducted on assumptions used in the Raw Materials Acquisition unit process are shown in Table 31.

All 6 paper recycling plants are situated in the outer suburbs of Melbourne, Sydney and Brisbane. Based on the assumption that the diameter of these cites is about 50 km, the distance from the collection point to the paper recycling plant or recycling plant was assumed to be 20 km. A sensitivity analysis was conducted to determine the effect on LCA emissions of increasing the transport distance to 100 km. Estimated energy intensities as stated in Table 17 were used in the analysis. Increasing the transport distance was found to be not significant. As a result of the analysis, the value of 20 km was used in all recycling LCAs.

Imported wastepaper was originally assumed to be converter waste in the form of Old Cardboard Cartons (OCC). Emissions assigned were calculated as the sum of the first four unit processes of the Visy virgin process i.e. acquisition, pre-processing, manufacturing and converting emissions. As shown in Table 20, the calculated value for emissions assigned to imported wastepaper used in all paper recycling LCAs was 0.87 t CO₂(e)/ADt. This value was calculated using data from the Visy pulp mill’s EIS. A sensitivity analysis was conducted to determine the effect on GHG emissions if only half of the imported waste was OCC and the rest was paper. Under these conditions, the imported paper would not go through the converting process and the emissions assigned would equal 0.75 t CO₂(e)/ADt. Using the value of 0.75 instead of 0.87 reduced emissions by only 0.64%. As the result was not significant, the value of 0.87 t CO₂(e)/ADt was used for all emissions assigned in imported paper and OCC.

It was assumed that imported paper was sourced from different areas within different countries and transported to the closest dock. The distance from the collection point to the closest dock was arbitrarily assumed to be 100 km. Due to the non-availability of country specific data, Australian data for the estimated energy intensity of articulated trucks and CO₂ emission factor for automotive diesel oil were used to quantify
transport emissions over the assumed distance. It is acknowledged that this assumption may not be correct. The result of the sensitivity analysis conducted at the end of Study 3 indicated that the inclusion of transport emissions within the overseas country was not significant to the LCA. As a result, the system boundaries were redefined in Study 4 to exclude these emissions.

Emissions resulting from the manufacture of chemicals used in the paper recycling process were excluded from the LCA as Visy considered these emissions to be the responsibility of the chemical manufacturer.

Studies 1 and 2 included transport emissions related to overseas chemical production. At the end of Study 2, a sensitivity analysis determined that excluding these emissions would result in an emission decrease of only -0.02%. As a result of the analysis, the system boundaries were redefined to exclude these emissions from further studies. Further investigations determined that chemicals are stored in central storage areas in Australia prior to delivery, regardless of whether they were manufactured in Australia or overseas. Studies 3 and 4 included transport emissions from the chemical storage area to the paper recycling plant. As chemicals are often sourced from different countries in any given year, refining the system boundaries to include only Australian emissions relevant to chemical transport meant that different Visy recycling LCAs could be readily compared.

Australia has a very open looped recycling system due to the importation of large quantities of paper. In 1998/99, Australia imported 1.3 million tonne of paper (PPMFA 1999). As a consequence of this open looped system, any one tonne of paper sourced within Australia is likely to be composed of different types and mixes of paper. Emissions assigned to Australian sourced wastepaper were not included in the recycling LCA model, due to the inability to accurately estimate the level of emissions.

In hindsight, the author acknowledges that excluding these emissions in the recycling LCAs did not benefit the credibility of the recycling LCA Studies. Chapter 5, Section 5.4, discusses the GHG consequence of including emissions assigned to different mixes of Australian sourced wastepaper.
Table 31 Recycling sensitivity analyses—Raw Materials Acquisition unit process

<table>
<thead>
<tr>
<th>Assumptions used in the paper recycling LCAs</th>
<th>% Change in emissions from the baseline</th>
<th>Degree of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australian wastepaper: The distance from the paper collection point to the paper recycling plant or recycling plant was assumed to be 20 km</td>
<td>30 km = +0.06% 50 km = +0.19% 100 km = +0.50%</td>
<td>Not significant</td>
</tr>
<tr>
<td>The emission assigned value for imported paper was assumed to be 0.75 instead of the 0.87 baseline value</td>
<td>-0.64%</td>
<td>Not significant</td>
</tr>
<tr>
<td>Imported wastepaper: The transport distance from the overseas collection point to the closest dock was assumed to be 100 km</td>
<td>0 km = -0.06% 200 km = +0.06% 300 km = +0.12%</td>
<td>Not significant</td>
</tr>
<tr>
<td>Overseas chemical transport emissions included in the LCA</td>
<td>If excluded = -0.02%</td>
<td>Not significant</td>
</tr>
</tbody>
</table>

Raw Materials Processing unit process—assumptions and exclusions

The Visy paper recycling process uses 100% recycled paper. Approximately 11-12% of the fibre input is lost during production. Visy source additional wastepaper locally and internationally. It was assumed that this ‘non-Visy’ manufactured wastepaper was produced using the same manufacturing process as the Visy process.

Emissions resulting from the sorting of waste at the Visy recycling plants were not significant and were not included in the paper recycling LCAs. This conclusion was based on actual operating data obtained by the author from the Visy Recycling Plant at Laverton in Victoria. Of the 50,000t of mixed waste that was sent to the Laverton plant in 1998/99, 21% of the mixed waste was paper or paper product. The author calculated the total GHG emissions at the Laverton plant for 1998/99 to be 120 t CO₂(e). Of this amount, paper could be said to account for 25 t CO₂. Assuming that all Visy recycling plants operate in a similar fashion, the sorting operation at the recycling plants would only contribute 0.01% to total LCA emissions.

The LCA assumed that GHG emissions during storage were zero due to the relatively short storage period. According to Visy records, paper and cardboard are stored at the paper recycling plants and recycling plants on average 2 months, prior to processing. The maximum storage period is 6 months. Visy have observed no fibre deterioration during that time. The length of time required for the decomposition of paper and the
release GHGs in these storage areas would vary depending upon many factors, including the conditions of storage (exposure to sunlight, rain etc), moisture content, oxygen level etc.

**Manufacturing unit process-assumptions and exclusions**

The results of the sensitivity analyses conducted on assumptions used in the Raw Materials Acquisition unit process are shown in Table 32.

Transport emissions resulting from the delivery of chemicals to individual paper recycling plants were not obtained. The transport of chemicals to VP3&6 were assumed to be typical of all Visy paper recycling plants and were used instead of site specific data. These quantities were linearly scaled up to the total production rate. The sensitivity analysis indicated that even a 100% increase in the value of the data used did not produce a significant result. As a result of the analysis, the original assumption was included in the LCA.

Due to a lack of information at the time, Study 1 assumed that all paper manufactured from the paper recycling plants was transported to the converting plants for further processing i.e. none was sold outside of Visy. Visy records indicate that a total 20% of the amount manufactured was sold outside the Visy system. This was corrected in all subsequent LCAs.

The moisture content of the solid waste rejects collected from the paper recycling plants prior to disposal into SWDSs was often very high, and varied from one paper recycling plant to another. The amount of moisture in the solid waste rejects was dependant upon:

- The presence of a compactor to squeeze out some of the moisture prior to the rejects being sent to the SWDS.
- Whether the solid waste rejects at the paper recycling plants were exposed to the elements prior to disposal.
Visy recorded the quantity of solid waste rejects transported from the paper recycling plants and deposited into SWDSs. These data were used to quantify the GHG emissions emitted in the SWDS due to the presence of fibre in the rejects. In order to do this, the moisture content and composition of the rejects needed to be accounted for in the calculations.

The average moisture content of solid waste produced at the paper recycling plants in 1996/97 was assumed to be 65%. In 1996/97, this value was used in all solid waste emission calculations from the paper recycling plants. The sensitivity analysis indicated that moisture content of greater than 45% was not significant. Moisture tests conducted at the individual paper recycling plants in 1998/99 were used in Study 4. Of these tests, the lowest value was 45% at VP5.

Similarly, tests conducted by the Visy Group Research and Development Manager determined that dry solid waste rejects from the paper recycling plants contained on average, 75% fibre, 23% plastic and 2% sand. These values were incorporated into the solid waste GHG calculations.

CH$_4$ emissions from effluent discharged from the paper recycling and converting plants were arbitrarily assumed to be 10% of maximum CH$_4$ emissions under 100% anaerobic conditions. The sensitivity analysis determined that assumptions of 0-50% of maximum CH$_4$ emissions did not have a significant effect on total LCA emissions. Based on the above results, the level of methane in liquid effluent was kept at 10% for all subsequent studies.

Methane generated by the anaerobic digester at VP8 was assumed to be captured, flared and fully combusted. Emissions of CO$_2$ from the combustion of methane were not included in the inventory as these emissions are considered to be offset by an equivalent uptake due to regrowth in the forest from which the original biomass in the wastewater was derived (IPCC 1997). The energy from the flaring is not presently captured and used by VP8.
Visy paper is sold to many different places throughout the world. In determining where to place the boundary line for paper sold out of Visy operations, the following factors were taken into consideration:

- GHG emissions from the time of sale were assumed to be the responsibility of the buyer and not Visy.
- Emissions resulting from sold paper are likely to vary from buyer to buyer due to differing transport emissions, different uses and different methods of disposal.
- Visy wanted to compare paper recycling LCAs from different years. This meant that if the Visy manufactured paper were sold to different countries in different years, emissions were likely to vary greatly, making comparisons difficult.

Based on the above considerations, it was decided to exclude all emissions of Visy paper that was sold out of Visy operations, from the time of sale.

<table>
<thead>
<tr>
<th>Manufacturing unit process</th>
<th>Assumptions used in the paper recycling LCAs</th>
<th>% Change in emissions from the baseline</th>
<th>Degree of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport emissions from the delivery of chemicals to VP3&amp;6 were assumed to represent all paper recycling plants.</td>
<td>10% increase = +&lt;0.01% 20% increase = + 0.01% 50% increase = + 0.02% 100% increase = +0.04%</td>
<td>Not significant</td>
<td></td>
</tr>
<tr>
<td>% Moisture in solid waste rejects from the paper recycling plants (1996/97 data) was assumed to be 65%</td>
<td>75% moisture = -4.6% 55% moisture = +3.8% 45% moisture = +7.6%</td>
<td>Significant at 40% or lower</td>
<td></td>
</tr>
<tr>
<td>Methane emissions from effluent were assumed to be 10% of maximum methane production under anaerobic conditions</td>
<td>0 % CH₄ = -0.56 % 20% CH₄ = +0.56 % 50% CH₄ = +2.79 %</td>
<td>Not significant</td>
<td></td>
</tr>
</tbody>
</table>

Table 32 Recycling sensitivity analyses-Manufacturing unit process

Post Manufacturing unit process-assumptions and exclusions

The results of the sensitivity analyses conducted on assumptions used in the Raw Materials Processing unit process are shown in Table 33.

Imported wastepaper sent directly to the converting plants was assumed to be converter waste, as indicated in Chapter 3, Section 3.2.2.

Visy Board Coolaroo is a medium sized converting plant. It was assumed that this plant was a “typical Visy converting plant” with average energy, chemical consumption and waste generation per unit of production. Due to a lack of data from
each of the many Visy converting plants, site-specific data for energy, chemical and waste generation per tonne of product from the Coolaroo Visy board plant were linearly scaled up to the total production rate from all Visy converting plants.

Data from the Coolaroo Visy Board converting plant were used in all LCAs. It is acknowledged that this assumption does not take into account the different energy, chemical consumption and waste generation rates for Visy small box plants, short run plants and display plants.

The sensitivity analysis indicated that the value of all of the baseline data used from Visy Board Coolaroo, needed to increase by greater than 20% for the effect to be significant. Based on the results of the sensitivity analysis, it is acknowledged that the use of this data to represent all converting plants may not be accurate. This is an area identified for future research.

Transport distances from the paper recycling plants to the converting plants were based on production rates and distances. The data was then converted into a weighted average before being used in the assessment. As the sensitivity analysis determined that a 100% increase in the data was not significant, the weighted data were used in all LCAs.

<table>
<thead>
<tr>
<th>Post Manufacturing unit process Assumptions used in the paper recycling LCAs</th>
<th>% Change in emissions from the baseline</th>
<th>Degree of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data from Visy Board Coolaroo. The analysis looked at the effect of different data values from the baseline</td>
<td>10% decrease = -2.46% 10% increase = +2.46% 20% increase = +4.9% 50% increase = +12.2%</td>
<td>Significant when the data values were &gt;20% above the baseline</td>
</tr>
<tr>
<td>Average travel distances used for transporting paper from the paper recycling plants to converting plants. The analysis looked at the effect of different travel distances from the baseline</td>
<td>10% increase = +0.19% 50% increase = +0.96% 100% increase = +2.02%</td>
<td>Not significant</td>
</tr>
</tbody>
</table>

Table 33 Recycling sensitivity analyses-Post manufacturing unit process
Use and service unit process-assumptions and exclusions

Use and service emissions are undetermined as they are not within the control of Visy and were therefore placed outside the LCA system boundary.

Disposal unit process-assumptions and exclusions

The results of the sensitivity analyses conducted on assumptions used in the disposal unit process are shown in Table 34.

Paper is made up of cellulose fibres of varying lengths. The ability to recycle paper is dependent upon the fibre length. Each time paper is recycled; the fibre length shortens until it becomes too short for further processing. It is then disposed of in SWDSs.

Virgin paper contains longer fibres than recycled paper and consequently can be recycled more times. However, determining the number of times paper can be recycled in Australia is a very difficult task. Due to the large quantities of paper imports and the age of the cellulose fibres, each tonne of paper has a unique composition (Johnston 1993; Ferguson & Johnston 1998; Gottsching 1999). The sensitivity analysis indicated that the number of times paper was recycled was significant to the LCA.

Initial recycling LCAs (Studies 1 & 2) assumed that wood fibre in wastepaper was cycled 5 times, recycled 4 times (PRISM, 1997). Further research indicated that this value was more likely to be 6. Cullinan suggested that a ‘single-age’ sheet under laboratory testing conditions might be capable of being recycled 10 times (Cullinan 1991). In reality, he believes that the number of recycles may be closer to 5-7. It was on this basis that 6 cycles were used in Studies 3 & 4. This aspect of the LCA is identified as requiring further research.

CH\textsubscript{4} emissions at SWDSs

The effect of methane capturing and flaring at SWDSs was included in LCA Studies 3 & 4. Due to a lack of data, the author assumed that the number of Australian SWDSs
capturing or flaring CH\textsubscript{4} was 10%. Results from the sensitivity analysis conducted on this assumption indicated that a value between 10% and 40% was not significant to the LCA. Based on this knowledge, the 10% value was used in all subsequent studies. Although not significant, these activities are occurring and so were incorporated into all subsequent LCAs.

**Avoided emissions**

Recycling reduces the amount of wood fibre disposed in SWDSs and the quantity of virgin paper required to be manufactured at any one time. As a result, there are reduced GHG emissions and a GHG credit for those ‘avoided emissions’. The value of these avoided emissions is dependent upon the number of times the wastepaper was recycled.

Initial LCAs assumed that the average number of fibre cycles was 5 i.e. fibre was capable of being recycled 4 times. Based on this assumption, the GHG benefit gained from recycling was calculated to be 80% (4/5) of the maximum emissions that would have occurred at SWDSs, in the absence of recycling. Where 6 cycles were assumed, an avoidance credit of 83.3% (5/6) of total emissions that would have occurred in the absence of recycling was calculated. A sensitivity analysis found that excluding avoidance credits in the LCA, increased total emissions by 328%.

<table>
<thead>
<tr>
<th>Disposal unit process</th>
<th>Assumptions used in the paper recycling LCAs</th>
<th>% Change in LCA emissions from the baseline</th>
<th>Degree of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wastepaper was cycled 5 times</td>
<td>4 cycles = +15.3% 6 cycles = -10.2% 8 cycles = -20.8%</td>
<td>Significant</td>
<td></td>
</tr>
<tr>
<td>Methane capturing/flaring activities at SWDSs included in solid waste reject emissions</td>
<td>Not included = Baseline Included = +3.39%</td>
<td>Not significant</td>
<td></td>
</tr>
<tr>
<td>10% of Australian SWDSs capture/flare CH\textsubscript{4}</td>
<td>20% = 1.23% 40% = 3.69%</td>
<td>Not significant</td>
<td></td>
</tr>
<tr>
<td>Avoidance credits not claimed</td>
<td>+328%</td>
<td>Significant</td>
<td></td>
</tr>
</tbody>
</table>

*Table 34 Recycling sensitivity analyses-Disposal unit process*
### 3.2.3 Visy paper recycling LCA results

The results of the 4 paper recycling LCAs are shown in Table 35.

<table>
<thead>
<tr>
<th>LCA unit operation</th>
<th>Paper recycling LCA Study 1</th>
<th>Paper recycling LCA Study 2</th>
<th>Paper recycling LCA Study 3</th>
<th>Paper recycling LCA Study 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t CO₂(e)/ADt of paper manufactured</td>
<td>t CO₂(e)/ADt of paper manufactured</td>
<td>t CO₂(e)/ADt of paper manufactured</td>
<td>t CO₂(e)/ADt of paper manufactured</td>
</tr>
<tr>
<td>Raw Materials Acquisition</td>
<td>+0.10</td>
<td>+0.06</td>
<td>+0.06</td>
<td>+0.04</td>
</tr>
<tr>
<td>Raw Materials Processing</td>
<td>+0.00</td>
<td>+0.00</td>
<td>+0.00</td>
<td>+0.00</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>+1.14</td>
<td>+1.18</td>
<td>+1.22</td>
<td>+1.06</td>
</tr>
<tr>
<td>Post Manufacturing</td>
<td>+0.25</td>
<td>+0.28</td>
<td>+0.28</td>
<td>+0.27</td>
</tr>
<tr>
<td>Use and Service</td>
<td>Undetermined – outside LCA boundary</td>
<td>Undetermined – outside LCA boundary</td>
<td>Undetermined – outside LCA boundary</td>
<td>Undetermined – outside LCA boundary</td>
</tr>
<tr>
<td>Disposal</td>
<td>+0.31</td>
<td>-0.35</td>
<td>-0.26</td>
<td>-0.25</td>
</tr>
<tr>
<td>TOTAL</td>
<td>-1.79</td>
<td>+1.18</td>
<td>+1.30</td>
<td>+1.13</td>
</tr>
</tbody>
</table>

NB: Figures may not completely add up, due to rounding

### Table 35 Paper recycling LCA results

The majority of emissions in each of the recycling LCAs occurred in the manufacturing, post manufacturing and disposal unit processes. The results verified Visy’s original thought that the majority of GHG emissions were emitted in the Manufacturing unit process. Post manufacturing emissions were similar in all LCAs. The greatest discrepancies occurred in the manufacturing and disposal unit processes.

Emissions in the raw materials acquisition unit process were highest in Study 1 due to the model assuming all the imported paper went to the paper recycling plants. As a result, all the emissions assigned in Study 1 were accounted for in this unit process, lowering the post manufacturing emissions.

As indicated in Stage 1, emissions in the manufacturing unit process varied due to the use of averaged rather than State CO₂ emission factors for electricity and gas, and the incorporation of the methane/carbon factor and methane capturing or flaring activities at SWDSs.
Emissions in the disposal unit process were due to:

- Transport of paper products to SWDSs.
- Disposal at SWDS.
- Recycling avoidance credits.
- Transport avoidance credits.

Emissions in the disposal unit process were a balance between the fibres that decomposed in SWDSs following disposal (when they became too short for further recycling) that emitted CH\textsubscript{4} (shown as + emissions), and the emissions that were ‘avoided’ (i.e. didn’t occur), due to recycling (shown as – emissions).

Table 36 indicates that with the exception of Study 1, all other LCA recycling studies had negative emissions in the disposal unit process.

<table>
<thead>
<tr>
<th>Paper recycling LCA disposal unit process emissions</th>
<th>Paper recycling LCA Study 1 t CO\textsubscript{2}/ADt of paper manufactured</th>
<th>Paper recycling LCA Study 2 t CO\textsubscript{2}/ADt of paper manufactured</th>
<th>Paper recycling LCA Study 3 t CO\textsubscript{2}/ADt of paper manufactured</th>
<th>Paper recycling LCA Study 4 t CO\textsubscript{2}/ADt of paper manufactured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disposal emissions*</td>
<td>+3.18</td>
<td>+2.52</td>
<td>+3.17</td>
<td>+3.48</td>
</tr>
<tr>
<td>Avoided emissions**</td>
<td>-2.87</td>
<td>-2.87</td>
<td>-3.43</td>
<td>-3.73\textsuperscript{7}</td>
</tr>
<tr>
<td>Total</td>
<td>+0.31</td>
<td>-0.35</td>
<td>-0.26</td>
<td>-0.25</td>
</tr>
</tbody>
</table>

* Emissions due to the transport of paper products to disposal, and emissions at SWDS (once the fibres became too short for further recycling)

** Emissions avoided due to recycling and avoided transport emissions to SWDSs

Table 36 Disposal unit process emissions

Study 1 has a positive value in the disposal unit process for the following reasons:

- Study 1 assumed that all paper manufactured at the paper recycling plants was assumed to go to the Visy converting plants i.e. no paper was sold out of the Visy

\textsuperscript{7} Eg. of calculation for avoidance credits using data from Paper Recycling LCA Study 4.

726,919t (total tonnes of wastepaper processed at Visy paper recycling in 1998/99) x 4.07 (Appendix 6) x 0.833 (5 recycles) = -2,464,480 t CO\textsubscript{2}(e)/660,495ADt paper manufactured (total production for 1998/99) = -3.73 t CO\textsubscript{2}(e)/ADt paper manufactured.

Avoided transport emissions were –0.004 t CO\textsubscript{2}(e)/ADt paper manufactured.
operations. This assumption meant that the total production for the year, after being recycled a number of times, was disposed into SWDSs. This resulted in high emissions of CH₄. Studies 2, 3 and 4 had lower emissions on disposal, as the sold paper was not sent to the Visy converting plants. This meant that within the LCA model, less fibre was transported to SWDSs.

- Avoidance credits are based on the amount of recycled fibre used in the recycling process and the number of times that paper was recycled. This amount of paper used was a fixed amount (682,659t for Studies 1, 2 & 3) and was not dependant upon the amount of paper sold outside of Visy. As a result, the emissions on disposal in Study 1 were too high to be offset by the avoidance credits. The avoidance credits did offset the emissions in Studies 2, 3 and 4, resulting in negative emissions.

**Transport emissions**

Emissions due to the transport of Visy stock within the LCA, contributed 2.6% (Recycling LCA-Study 3) and 3.1% (Recycling LCA-Study 4) to total emissions. As these emissions were very low, from a GHG perspective Visy would not be warranted in gaining ownership of these activities.

**3.3 Visy paper recycling GHG reduction strategies and business opportunities**

GHG reduction strategies and business opportunities were identified from the Visy paper recycling LCA Studies. It must be remembered that these recommendations are only applicable to GHGs. Other environmental decision support tools (eg. CBA, Risk Management) should be employed to evaluate all aspects of the strategy before a final decision is made. Proposed GHG reduction strategies and business opportunities for the Visy paper recycling process have been grouped as follows:

1. Reduction strategies relevant to the existing Visy paper recycling plants (Stage 1).
2. Reduction strategies relevant to the Visy paper recycling process (Stage 2).
3.3.1 GHG reduction strategies-Visy paper recycling plants

Table 37 details the emission savings (in terms of t CO₂(e)/t paper manufactured) that can be made at the paper recycling plants if the proposed reduction strategies were implemented. The time frame over which the benefit is likely to occur and the degree of control that Visy has over the strategy have been identified.

<table>
<thead>
<tr>
<th>GHG reduction strategies for the Visy paper recycling plants</th>
<th>Potential emissions savings t CO₂(e)/t paper manufactured</th>
<th>Time frame over which the benefit occurs*</th>
<th>Degree of Visy control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase energy efficiency of the paper recycling plants by 10%</td>
<td>0.10</td>
<td>Short-term</td>
<td>High</td>
</tr>
<tr>
<td>Composting all solid waste rejects from the paper recycling plants</td>
<td>0.19</td>
<td>Short-term</td>
<td>High</td>
</tr>
<tr>
<td>Incinerate 50% of solid waste rejects from the paper recycling plants</td>
<td>0.49</td>
<td>Short-term</td>
<td>High</td>
</tr>
<tr>
<td>Establish cogeneration on site at VP2, VP4 and VP5</td>
<td>0.97</td>
<td>Short-term</td>
<td>High</td>
</tr>
<tr>
<td>Sourcing steam from third party providers</td>
<td>0.20</td>
<td>Short-term</td>
<td>High</td>
</tr>
</tbody>
</table>

* Time Scale  
  Short-term = 1-10 years  
  Long term =10-100 years

Table 37 Paper recycling plants-GHG reduction strategies

GHG emissions at the paper recycling plants can be reduced by:

- Increasing the energy efficiency at the existing paper recycling plants.
- Reducing the amount of solid waste sent to SWDSs.
- Establishing cogeneration plants on site at the paper recycling plants
- Sourcing steam from third party providers.

Increasing the energy efficiency at the paper recycling plants

Table 37 indicates that a 10% energy efficiency improvement at the paper recycling plants resulted in potential emission savings of 0.10 t CO₂(e)/t paper manufactured.
Identified energy efficiency improvements relevant to the paper recycling plants included:

- Reduced steam waste.
- Improvements to boiler and steam systems.
- Improved operation of vacuum pumps.
- Improved control of air compressors.
- Improved control of agitators.
- Improved lighting.
- Use of high efficiency motors.
- Reduced machine down time.
- Reduced paper breakage.
- Implementation of on-line energy monitoring.

The above list is by no means exhaustive, but indicates some likely areas that would benefit from further investigation (Energetics & Wiegard 1998(a)).

Reduce the amount of solid waste rejects sent to SWDSs.

Table 29 indicated that VP8’s solid waste GHG emissions in 1996/97 accounted for 15% of its total GHG emissions. In 1998/99, this value was reduced to 10%, due to the incineration of 52% of its solid waste. The reduction in emission proportion was due to the waste not being sent to SWDSs and thus not being emitted as CH₄ under anaerobic conditions.

Options to reduce emissions from solid waste rejects include the following:

- Composting the waste.
- Incinerating the waste.

Composting waste

The analysis assumed that the decomposition of solid waste (in the form of wood fibre) by composting would result in no net emissions of CO₂. The assumption was based on the degradation process occurring aerobically. Under these conditions, emissions are considered to be carbon neutral as the waste originated from a renewable source (IPCC
1997). As detailed in Table 37, composting all solid waste rejects from the paper recycling plants would result in emission savings of 0.19 t CO2/t paper manufactured.

**Incineration**

Incineration of solid waste instead of composting would provide a two-fold benefit:

- Emissions resulting from incineration are predominantly CO2. As the fibre content in the waste is from a renewable energy source, emissions are considered to be carbon neutral. CH4 emissions at SWDSs are avoided.
- The energy content of the waste resulting from incineration can be partially recovered and used as an energy source in the paper recycling plants, reducing the consumption of (and hence emissions from) fossil fuels.

As indicated in Table 37, if all the paper recycling plants incinerated 50% of their solid waste rejects, the result would be a reduction in emissions of 0.49 t CO2(e)/t paper manufactured. In addition, the benefits of recovered energy and less fossil fuel usage would also lead to further reduction in emissions.

**Cogeneration and Steam Purchase**

Two issues have been considered.

- The consequence of operating cogeneration plants at VP2, VP4 and VP5.
- Sourcing steam from a third party provider.

**The consequence of operating cogeneration plants at VP2, VP4 and VP5**

Prior to 1997, VP3&6 had an on-site cogeneration plant. As shown in Table 37, if the same electricity/gas emissions intensity used prior to 1997 were applied to VP2, VP4 and VP5, the aggregated consequence of establishing cogeneration plants at these plants would be a potential emission saving of 0.97t CO2(e)/t paper manufactured.
Sourcing steam from a third party provider

As shown in Table 37, the consequence of sourcing steam from a third party provider was a saving of 0.20 t CO$_2$(e)/t paper manufactured. This calculation assumed each party would be liable for 50% of the boiler emissions.

3.3.2 GHG reduction strategies-Visy paper recycling process

Table 38 details Visy GHG reduction strategies for the paper recycling process.

<table>
<thead>
<tr>
<th>Visy GHG reduction strategies for the paper recycling process</th>
<th>Potential emissions savings</th>
<th>Time frame over which the benefit occurs*</th>
<th>Degree of Visy control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sell off ‘high emission processes’</td>
<td>Dependant upon what was sold</td>
<td>Short term</td>
<td>High</td>
</tr>
<tr>
<td>Recycle more paper</td>
<td>Very dependant upon the size of the Australian paper recycling market and Visy’s share within it</td>
<td>Short to long-term</td>
<td>Medium to high</td>
</tr>
<tr>
<td>Purchase Greenpower for existing paper recycling and converting plants</td>
<td>0.69 t CO$_2$(e)/ADt of paper manufactured</td>
<td>Short term</td>
<td>High</td>
</tr>
<tr>
<td>Manufacture in areas where electricity produces less emissions</td>
<td>0.30 t CO$_2$(e)/ADt of paper manufactured</td>
<td>Short-long term</td>
<td>High</td>
</tr>
<tr>
<td>Import wastepaper for recycling</td>
<td>Unknown</td>
<td>Short-long term</td>
<td>High</td>
</tr>
<tr>
<td>Recover landfill gas</td>
<td>3.48 t CO$_2$(e)/ADt of paper manufactured</td>
<td>Short-long term</td>
<td>Low</td>
</tr>
</tbody>
</table>

* Time Scale  
  Short-term = 1-10 years  
  Long term = 10-100 years

Table 38 GHG reduction strategies for the Visy paper recycling process

Based on the outcomes of the paper recycling LCAs, the following opportunities have been identified:

- Sell off ‘high emission’ processes.
- Recycle more paper.
- Purchase Greenpower for existing paper recycling and converting plants.
• Manufacture recycled paper in areas where low-emission electricity can be sourced.
• Import recycled wastepaper.
• Recover landfill gas (LFG).

**Sell off ‘high emission’ processes**

If Visy were to sell those parts of the recycled papermaking process known to generate high emissions of GHGs, they would no longer be liable for those emissions.

**Recycle more paper**

Recycling more paper will reduce the demand for virgin paper. As a result, emissions due to the production and manufacture of virgin fibre will be reduced. This option involves increasing the total Australian recycled paper market by stimulating demand and/or installing additional production capacity by:

• Building a new paper recycling plant that emitted fewer GHGs per tonne of paper manufactured.
• Increasing production capacity by expansion of existing paper recycling plants.
• Reducing waste and increasing production output of the existing paper recycling plants.

Under the Visy paper recycling LCA model, all of the above options would generate additional avoidance credits. Under the Kyoto Protocol, these credits may be able to be used to expand production or traded for profit.

**Purchase Greenpower for existing paper recycling and converting plants**

The production of “Greenpower” is considered to be GHG neutral. Companies in some Australian States (e.g. New South Wales and Victoria) can now elect to purchase a percentage or all of their electricity in this form. The use of Greenpower substantially reduces GHG emissions. Table 38 indicates that if Greenpower were purchased for all of the paper recycling plants and converting plants, GHG emissions would decrease 0.69 t CO₂(e)/ADt of paper manufactured.
Manufacture recycled paper in areas of low-emission electricity

GHG emissions associated with the production of electricity vary from State to State. Locating plants in Australian States that produce electricity with high GHG emissions will result in higher emissions. As shown in Table 16, electricity produced in New South Wales emits fewer emissions than electricity produced in Victoria. If a Victorian paper recycling plant (eg. VP2) were relocated to New South Wales, the GHG effect would be a reduction from 1.2 t CO$_2$(e)/ADt of paper manufactured to 0.9 t CO$_2$(e)/ADt of paper manufactured.

Import recycled wastepaper

Visy annually imports wastepaper to support their paper recycling operations. Paper produced at the Tumut pulp and paper mill is expected to replace the amount currently being imported. Continuing to import wastepaper after ratification of the Kyoto Protocol may still be a sound strategy. Depending upon the nature of any framework developed, there may be a potential for international credit to be gained by importing wastepaper. Until the rules are established, no quantification on the number and value of credits can be given.

Recover LFG

GHG emissions resulting from the decomposition of paper in SWDSs were found to be very significant to the paper recycling process. Table 38 indicates that disposing paper into SWDSs released 3.48 t CO$_2$(e)/ADt of paper manufactured. There are three major benefits associated with the recovery and combustion of gases at SWDSs:

- GHGs released into the atmosphere from SWDSs are significantly reduced.
- Energy produced from the captured gases (Greenpower) is considered carbon neutral. Greenpower can be sold into the grid or utilised during the paper recycling process.
- The use of Greenpower displaces energy derived from fossil fuels, further reducing emissions.

In 1997, the Australian government announced that retailers and major wholesale purchasers of electricity would be required by 2010 to source an additional 2% of their
electricity from renewable sources. The relevant Act, passed by Federal Parliament in December 2000, is known as the Renewable Energy (Electricity) Act 2000 (AGO 2001(a)). The aim of the Act is to encourage the additional production of electricity from renewable sources.

This Act has the potential to make Greenpower valuable from two points of view:

- It can be used to reduce companies GHG emissions.
- Its monetary value will increase as retailers and major wholesale purchasers of electricity will need to comply with the Act.
Chapter 4

4. Visy virgin LCA model

The progress and refinement of the Visy virgin LCA model is discussed in this Chapter. Three virgin LCA studies are discussed.

The virgin LCA model covers the GHG emissions from the forestry development through to papermaking, converting, use and disposal. The development of a pulp and paper mill at Tumut is central to the virgin model. Data relevant to Stage 1 of the pulp mill development were included in the LCA studies. Studies 1 and 2 were iterations of data taken from the mill’s EIS (Nolan-ITU 1998). Study 3 used revised Visy data.

The pulp mill complex will include a wood yard, wastewater recycling plant, pulp mill, biomass cogeneration plant, paper machine and water recycling irrigation system. The scope of the development has been detailed in the mill’s EIS (Nolan-ITU 1998). As the mill is in the process of being built, the Visy virgin LCAs are design models. A LCA conducted using actual operating data has been identified as an area for future research.

According to the EIS, operating hours of the mill will be 24 hrs/day, and at least 350 days per year. As shown in Table 39, Stage 1 of the development will have an initial capacity of 300,000 tonne of paper per year, of which 54,000 tonne will be sold outside of Visy operations. The remainder will be sent to Visy converting plants for further processing. Production from the pulp mill is expected to replace currently imported paper and kraft waste.

Feedstock for the pulp mill will be softwood pulp logs, sawmill residues and wastepaper. Pulp logs and sawmill residues will be sourced from State Forests and private plantations in the Tumut region. Electricity and LPG will supply 40% of the pulp mill’s energy requirements. The remaining 60% will be supplied by carbon neutral biomass fuel. Under a Visy-State Forest Agreement (Nolan-ITU 1998), 30,000 hectares of additional softwood plantations within a 100 km radius of Tumut must be
established over a ten-year period. The agreement requires that Visy plant 10,000 hectares and State Forests plant the remaining 20,000 hectares. Provided these plantations are managed sustainably and in perpetuity, they have the potential to create substantial carbon sinks.

Some wastepaper will be processed with the virgin fibre at the pulp mill. Wastepaper will be sourced from Victoria, New South Wales, South Australia and Queensland. Visy intends to develop recycling plans for most of the miscellaneous solid waste produced from the mill (Nolan–ITU 1998).

In March 2000, Visy revised its operating parameters for Stage 1 of the pulp mill development. The main differences between the EIS data and the revised data that are relevant to GHG emissions are shown in Table 39. The most significant changes can be seen in the annual production level, the wastepaper demand, the amount of product sold and the quantity of paper sent to the converting plants.

<table>
<thead>
<tr>
<th>Operating parameters for Stage 1 of the Tumut pulp &amp; paper mill development</th>
<th>Virgin LCA Studies 1 &amp; 2 (EIS data)</th>
<th>Virgin LCA Study 3 (Revised data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual production</td>
<td>300,000 tonne</td>
<td>242,000 tonne</td>
</tr>
<tr>
<td>(Value used in Functional Unit)</td>
<td></td>
<td>(Value used in Functional Unit)</td>
</tr>
<tr>
<td>Wastepaper input</td>
<td>80,500 tonne/year</td>
<td>60,000 tonne/year</td>
</tr>
<tr>
<td>Grid electricity</td>
<td>102,000 MWhr</td>
<td>109,000 MWhr</td>
</tr>
<tr>
<td>LPG demand</td>
<td>950,000 GJ</td>
<td>500,000 GJ</td>
</tr>
<tr>
<td>Quantity of annual production to be sold outside of Visy operations</td>
<td>54,000 tonne/year</td>
<td>126,972 tonne/year</td>
</tr>
<tr>
<td>Quantity of annual production sent to Visy converting plants</td>
<td>246,000 tonne/year</td>
<td>115,028 tonne/year</td>
</tr>
<tr>
<td>Quantity of cardboard product from Visy converting plants</td>
<td>220,170 tonne/year</td>
<td>102,925 tonne/year</td>
</tr>
</tbody>
</table>

Table 39 Pulp mill operating parameters

4.1 Visy Virgin LCA studies

GHG emissions for the three virgin LCA studies were quantified in the following groupings:

- GHG emissions across the entire life cycle of the virgin papermaking process.
- GHG emissions from the pulp mill.
• GHG consequence of processing recycled fibre together with virgin fibre at the pulp mill.
• GHG implications of paper and kraft waste import replacement.

(a) GHG emissions for the full life cycle of the virgin papermaking process

In order to identify GHG reduction strategies and business opportunities for the Visy virgin papermaking process, it was first necessary to establish a GHG baseline for the full life cycle. A GHG comparison was then made between the Visy recycling and virgin processes. The results of the comparison are discussed in Chapter 5.

(b) GHG emissions from the pulp mill

Visy believed that the majority of GHG emissions from the virgin papermaking process would be emitted from the pulp mill at Tumut. The use of renewable energy and its effect on total GHG emissions was of particular interest. GHG emissions from the pulp mill were further categorised into Visy owned and controlled activities or non-Visy owned and controlled activities.

(c) Consequence of processing recycled fibre together with virgin fibre at the pulp mill.

Recycling paper lessens the production of CH₄ at SWDSs and reduces the demand for virgin paper. It was recognised that processing recycled paper together with virgin fibre would enable a claim to be made for avoidance credits. In order to determine the GHG significance of using recycled paper, it was necessary to quantify the avoided emissions.

(d) GHG implications of paper and kraft waste import replacement

According to Visy records, approximately 55,000 tonne/year of paper and kraft waste is annually imported to support Visy’s paper recycling process. Replacing imported paper and kraft waste with Visy domestically produced paper will have an effect on
total GHG emissions generated by Visy and in particular by the Visy paper recycling process.

4.2 Initial system boundaries

Figure 5 detailed the unit processes used in the Visy virgin process model. The aim of the Visy virgin LCA model was to develop a model that closely reflected the projected process. Initial system boundaries included all activities under Visy’s control, and activities not owned by Visy but essential to the virgin papermaking process.

Where actual data could not be obtained, assumptions were made. These assumptions related to:

- Measurements eg. distance travelled.
- Processes and relationships eg. it was assumed that data from the Visy Board Coolaroo converting plant was representative of all Visy converting operations.

Sensitivity analyses were conducted on assumptions at the completion of each virgin LCA study. The chosen assumption was deemed the baseline value from which the degree of significance was determined. If the assumptions were found to be significant, they were incorporated into the next LCA study and the system boundaries adjusted accordingly. Where an assumption was found not to be significant, the baseline value was used.

The sensitivity analyses were based on single variable changes. Although not within the scope of this thesis, the effect of multiple variables to identify best and worse case scenarios was identified as a future area of study.

An example of emissions included and excluded in Virgin Study 3 is shown in Figure 7. Emissions have been grouped into the 6 defined unit processes.
Figure 7 Virgin LCA

Emissions included & excluded in the virgin LCA-Study3

<table>
<thead>
<tr>
<th>LCA SYSTEM BOUNDARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Manufacture</td>
</tr>
<tr>
<td>Processing</td>
</tr>
<tr>
<td>Raw materials acquisition</td>
</tr>
<tr>
<td>Machinery fuel emissions</td>
</tr>
<tr>
<td>• Plantation management</td>
</tr>
<tr>
<td>• Milling</td>
</tr>
<tr>
<td>Transport emissions</td>
</tr>
<tr>
<td>• Biomass fuel to pulp mill</td>
</tr>
<tr>
<td>• Recycled paper from consumer to recycling plant</td>
</tr>
<tr>
<td>• Chemicals to pulp mill</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Exclusions

Raw Materials Acquisition
- Wastepaper allocated emissions
- Carbon sequestration, seedlings growth emissions
- Emissions from living trees, decay of organic matter, harvesting & naturally occurring processes eg. fires
- Transport of seedlings to plantation, sawlogs to the sawmills
- Chemical manufacture

Exclusions Raw material processing
- Saw mill operations

Exclusions Manufacturing
- Emissions from Visy manufactured paper once it was sold out of the Visy system
- Biomass plant emissions (Carbon neutral)

Exclusions Post Manufacture Processing
- Transport
- Overseas emissions if chemical manufacturer was located overseas

Exclusions Use & service
- Emissions due to the use of the product

Exclusions Disposal
- No exclusions

Outside of Visy’s control
- Emissions at SWDSs
- CH₄ capturing /flaring at SWDSs
- Transport emissions
- Consumer to depot
- Depot to disposal
- Avoided emissions
- Recycled paper
- Transport to disposal
Relevant features of each Visy virgin LCA study are shown in Table 40.

<table>
<thead>
<tr>
<th>Aspects of each virgin LCA study</th>
<th>LCA-Study 1</th>
<th>LCA-Study 2</th>
<th>LCA-Study 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data used</td>
<td>EIS</td>
<td>EIS</td>
<td>Revised data</td>
</tr>
<tr>
<td>Time period CO₂ conversion factors were sourced from</td>
<td>1993/94</td>
<td>1993/94</td>
<td>1994/95</td>
</tr>
<tr>
<td>Converter waste returned to paper plant</td>
<td>No - Disposed into SWDSs</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>All chemical transport emissions included</td>
<td>Australian distances only</td>
<td>Australian distances only</td>
<td>Australian distances only</td>
</tr>
<tr>
<td>Number of times recycled paper was cycled</td>
<td>5</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Effluent CH₄ was 10% of maximum CH₄</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Avoidance claim</td>
<td>80%</td>
<td>83.3%</td>
<td>83.3%</td>
</tr>
<tr>
<td>Methane factor (16/12) included in emissions from SWDSs</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Methane capturing/flaring at SWDSs included in all calculations</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 40 Components of the virgin LCA studies

The essential differences between these studies were as follows:

- LCA interactions (Studies 1 & 2) used data obtained from the pulp mill EIS. Study 3 used Visy revised data.
- Study 1 assumed that converter waste went directly to SWDSs. Further investigations found this assumption to be incorrect. Studies 2 and 3 better reflected the actual papermaking process and transported the waste back to the paper recycling plants for further processing.
- Study 1 assumed that recycled paper processed with the virgin fibre was capable of being cycled 5 times before disposal. Studies 2 and 3 assumed that the paper was cycled 6 times.
- Study 1 did not take into account the CH₄/C factor and the effect of CH₄ capturing or flaring at SWDSs. These factors were included in Studies 2 and 3.
4.3 Assumptions and emission exclusions

The following section details the assumptions made and emissions excluded within each of the virgin LCA unit processes.

**Raw Materials Acquisition unit process-assumptions and exclusions**

Emissions assigned to wastepaper collected within Australia were excluded from the virgin model. The consequence of this assumption is discussed in detail in Chapter 5.

Emissions resulting from fuel usage during the growth of the Pinus radiata seedlings, transportation and planting of seedlings were excluded from the virgin model. Under a GHG restriction regime, these emissions are likely to be the responsibility of the nursery owners and transport contractor. Visy has no interest in being involved in plantation seedling development, so emissions from this aspect of the life cycle were of no relevance to them.

Carbon sequestration and any emissions resulting from the development of forestry carbon sinks, harvesting and naturally occurring activities (eg. forestry fires due to lightning strikes) were not included within the virgin LCA system boundary. Many of the rules and quantification methods governing these sinks and emission activities are still to be internationally resolved as part of the Kyoto Protocol negotiations (IPCC/OECD/IEA 1998). The author concluded that including these activities within the virgin model at this time may distort the results of the LCA and would not add to the model’s credibility. Once the rules and methods have been negotiated, these activities could be included in the virgin model. The GHG implications of the forestry developments that are part of the Tumut pulp mill development are briefly discussed at the end of this Chapter.

Emissions associated with sawmill operations and chemical manufacturing, were excluded from the virgin LCAs as these operations are not owned by Visy. Emissions resulting from these activities were considered the responsibility of the sawmill operators and chemical manufacturers. Based on the above decision, emissions resulting from the following activities were excluded from the LCA:
• Transport of saw logs to the sawmills.
• Manufacture of chemicals used in the pulp mill.

The LCA assumed that all transport to and from the pulp mill was contracted out. As a result, transport emissions within the virgin papermaking life cycle were placed in the non-Visy owned group as shown in Table 49.

The assumption for the distance from the wastepaper collection point to the recycling plant used in the recycling LCA model was also used in the virgin model i.e. the distance was arbitrarily assumed to be 20 km. As seen in Table 41, the sensitivity analysis indicated that the distance chosen was not significant to the LCA emissions. The assumed distance of 20 km was used in the virgin LCA model.

<table>
<thead>
<tr>
<th>Unit 1-Raw Materials Acquisition Assumptions used in the virgin LCAs</th>
<th>% Change in LCA emissions from the baseline</th>
<th>Degree of significance</th>
</tr>
</thead>
</table>
| Australian wastepaper: The distance from the collection point to the paper recycling plant or recycling plant was assumed to be 20 km | 30 km = +0.01%  
50 km = +0.03%  
100 km = +0.08% | Not significant |

Table 41 Virgin sensitivity analysis-Raw Materials Acquisition

**Raw Materials Processing unit process-assumptions and exclusions**

Visy will obtain sawmill residues from the sawmill for use in its biomass cogeneration plant. Emissions resulting from the production of these residues have been attributed to the sawmill owners.

Emissions due to the sorting and storage of recycled paper at the recycling plants were assumed to be zero (Chapter 3, Section 3.2.2).

**Manufacturing unit process-assumptions and exclusions**

The results of sensitivity analyses conducted on assumptions used in the manufacturing unit process can be seen in Table 42.
Under IPCC Guidelines, CO₂ emissions from sustainably produced biomass are offset by an equivalent uptake of CO₂ in the forest from which the original biomass was derived (IPCC 1997). Based on the above understanding, the inventory has recorded the following activities as carbon neutral:

- Emissions resulting from the use of sawmill residues in the biomass cogeneration plant.
- Emissions from the combustion of de-watered sludge in the power boilers.
- Emissions from purge lime mud from the Recausticising plant, purge fly ash from the Recovery Boiler and tall oil (fuel) from the Lime Kiln.

The four stages of the Wastewater Treatment Plant (WWTP) Process (cooling, activated sludge, clarification and sludge dewatering) were assumed to operate aerobically and generate minimum levels of methane. Effluent discharged from the WWTP will be treated on site and used for irrigation. The COD levels on leaving the WWTP are projected to be <100 mg/L (Nolan-ITU 1998). A sensitivity analysis determined that COD levels as high as 2000 mg/L did not have a significant effect on total GHG emissions. The value of <100 mg/L was used in the virgin LCA studies.

Flyash produced from the boiler will be processed into soil improvement products. An electrostatic precipitator operating at 99.5% efficiency will capture boiler particulates (Nolan-ITU 1998).

CH₄ emissions from effluent were assumed to be 10% of maximum possible emissions, under full anaerobic conditions. The sensitivity analysis determined that if maximum CH₄ emissions were used in the LCA, the result would be not significant. The assumed value was used in the LCA.

<table>
<thead>
<tr>
<th>Unit 3-Manufacturing Assumptions used in the virgin LCAs</th>
<th>% Change in LCA emissions from the baseline</th>
<th>Degree of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD &lt;100 mg/L on leaving WWTP</td>
<td>COD of 500 = +&lt;0.01%</td>
<td>Not significant</td>
</tr>
<tr>
<td></td>
<td>COD of 1000 = +&lt;0.01%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>COD of 2000 = +&lt;0.01%</td>
<td></td>
</tr>
<tr>
<td>Overseas transport emissions for sold product included in Study 1</td>
<td>If excluded = -0.10%</td>
<td>Not significant</td>
</tr>
<tr>
<td>Effluent CH₄ was assumed to be 10% of maximum CH₄ levels</td>
<td>If maximum CH₄ = +1.39%</td>
<td>Not significant</td>
</tr>
</tbody>
</table>

Table 42 Virgin sensitivity analyses-Manufacturing
Post Manufacturing unit process-assumptions and emission exclusions

The results of sensitivity analyses conducted on assumptions used in the post manufacturing unit process can be seen in Table 43.

Operating data from Visy Board Coolaroo were linearly scaled up to the total production rate, as was done in the recycling LCAs (Chapter 3, Section 3.2.2). It is acknowledged that scaling up data in this way introduced a degree of uncertainty in the Post Manufacturing emissions, however a sensitivity analysis indicated that a 70% increase in data values was required before the effect became significant to the LCA emissions.

The distance from the converting plant to the consumer was arbitrarily chosen as 20 km. This distance was based on the same assumption used for the paper recycling plants (Chapter 3, Section 3.2.2). Distances of as much as 100 km were not significant to the LCA. The distance of 20 km was used in the LCA.

<table>
<thead>
<tr>
<th>Unit 4-Post Manufacturing Assumptions used in the virgin LCAs</th>
<th>% Change in LCA emissions from the baseline</th>
<th>Degree of significance</th>
</tr>
</thead>
</table>
| Data from Visy Board Coolaroo was scaled up to reflect all converting plant operations. The analysis looked at the consequence of changed data values | 10% decrease = -0.73%  
20% increase = + 1.46%  
50% increase = +3.65%  
75% increase = +5.48% | Significant only above approx. 70% |
| Transport distance from the converting plant to the consumer was 20 km | 30 km = +0.02%  
50 km = +0.07%  
100 km = +0.19% | Not significant |

Table 43 Virgin sensitivity analyses-Post Manufacturing

Use and service unit process - assumptions and emission exclusions

GHG emissions from the use of converted paper products were undetermined as they were assumed to be outside the system boundary (Chapter 3, Section 3.2.2).
Disposal unit process-assumptions and emission exclusions

The results of sensitivity analyses conducted on assumptions used in the disposal unit process can be seen in Table 45.

The Visy model assumed that only the recycled proportion of the paper feedstock processed at the pulp mill was further recycled. The virgin component, once used, was disposed into SWDSs. This assumption was based on the following information:

- There are no new recycling operations planned in conjunction with the development of the virgin pulp mill.
- Assuming all paper recycling plants are running at maximum capacity, the quantity of paper being recycled in Australia is unlikely to increase.
- As shown in Table 44, Australian statistics (PPMFA 1999) indicate that there has been little change in the recovery and utilisation rates of wastepaper in the last few years.

The recovery rate is defined as the total wastepaper collected in Australia as a percentage of the total apparent consumption. The utilisation rate is defined as the total recovered paper used in domestic production as a percentage of the total domestic production of paper (PPMFA 1999).

<table>
<thead>
<tr>
<th>Year</th>
<th>Recovery Rate %</th>
<th>Utilisation Rate %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998/9</td>
<td>50.9</td>
<td>60.5</td>
</tr>
<tr>
<td>1997/8</td>
<td>47.8</td>
<td>57.6</td>
</tr>
<tr>
<td>1996/7</td>
<td>48.6</td>
<td>61.5</td>
</tr>
</tbody>
</table>

Table 44 Recovered paper: historical data (PPMFA, 1999)

It is acknowledged that the above assumption may not necessarily be correct, particularly if the recovery and utilisation rates increase. Different scenarios (no recycling versus recycling and the effect of different recycling cycles on the Visy virgin papermaking process) are evaluated in Chapter 5.
Virgin Study 1 assumed that the recycled paper processed at the pulp mill was capable of being cycled 5 times. Further research by the author indicated that the number of cycles was more likely to be 6. The effect on total LCA emissions of varying the number of recycled paper fibre cycles from 4 to 8 was found to be not significant to total GHG emissions. This was due to the proportionally small amount of recycled paper used in the virgin model. Although not significant, the number of fibre cycles was increased to 6 and used in all subsequent virgin LCA studies, to reflect the research conducted and to keep the model compatible with the recycling LCA model.

The distance from the consumer collection point to the depot and then onto the SWDS was arbitrarily chosen to be 40 km. A sensitivity analysis indicated that the distance chosen was not significant to total GHG emissions.

Like the Recycling LCA Study 1, Virgin LCA Study 1 did not account for the methane/carbon molecular factor (16/12), or methane capturing or flaring at SWDSs. A sensitivity analysis conducted on virgin LCA Study 1 indicated that the inclusion of these factors into the LCA had a significant effect on LCA emissions. As a result of the sensitivity analysis, the LCA system boundaries in Studies 2 and 3 were redefined to include these activities.

<table>
<thead>
<tr>
<th>Unit 6-Disposal Assumptions used in the virgin LCAs</th>
<th>% Change in LCA emissions from the baseline</th>
<th>Degree of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study 1 assumed that the number of times recycled paper was cycled was 5</td>
<td>4 cycles = +1.54% 6 cycles = -0.98% 8 cycles = -2.28%</td>
<td>Not significant</td>
</tr>
<tr>
<td>The distance from the consumer to disposal was assumed to be 40 km</td>
<td>60 km = +0.05% 120 km = +0.19% 200 km = +0.38%</td>
<td>Not significant</td>
</tr>
<tr>
<td>Study 1 did not include the CH₄/C factor and CH₄ capturing/flaring activities at SWDSs</td>
<td>If included = +24.1%</td>
<td>Significant</td>
</tr>
</tbody>
</table>

Table 45 Virgin sensitivity analyses-Disposal
4.4 Visy Virgin LCA results

Life cycle emissions for the 3 LCA studies are shown in Table 46.

<table>
<thead>
<tr>
<th>LCA virgin unit process</th>
<th>Study 1 t CO2(e)/ADt of paper manufactured</th>
<th>Study 2 t CO2(e)/ADt of paper manufactured</th>
<th>Study 3 t CO2(e)/ADt of paper manufactured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Materials Acquisition</td>
<td>+0.07</td>
<td>+0.07</td>
<td>+0.08</td>
</tr>
<tr>
<td>Raw Materials Processing</td>
<td>+0.04</td>
<td>+0.03</td>
<td>+0.02</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>+0.52</td>
<td>+0.52</td>
<td>+0.52</td>
</tr>
<tr>
<td>Post Manufacture</td>
<td>+0.24</td>
<td>+0.25</td>
<td>+0.13</td>
</tr>
<tr>
<td>Use and Service</td>
<td>Undetermined–outside LCA boundary</td>
<td>Undetermined–outside LCA boundary</td>
<td>Undetermined–outside LCA boundary</td>
</tr>
<tr>
<td>Disposal</td>
<td>+1.96</td>
<td>+2.40</td>
<td>+1.08</td>
</tr>
<tr>
<td><strong>Total emissions</strong></td>
<td><strong>+2.83</strong></td>
<td><strong>+3.27</strong></td>
<td><strong>+1.83</strong></td>
</tr>
</tbody>
</table>

Table 46 Visy virgin LCA results

The unit processes that produced the greatest level of emissions in all three virgin LCA studies were the manufacturing, post manufacturing and disposal stages.

The majority of emissions were due to:
- The use of fossil fuels at the pulp mill and converting plants. The GHG consequence of using fossil fuels was significantly reduced by the use of biomass as a fuel source at the pulp mill.
- The quantity of paper sold. Based on the defined system boundaries, the less paper that was sold, the more that was sent to the converting plants and ultimately disposed of into SWDSs.

Factors contributing to reduced emissions in Study 3

When the LCA emissions for the three studies were compared, revised data used in Study 3 produced fewer emissions than the previous two studies. Reduced emissions were very evident in the Post Manufacturing and Disposal stages of Study 3. These reductions were due to more paper being sold outside of the defined LCA system boundary leaving less paper to be processed at the converting plants and ultimately
disposed of. The result was significantly lower emissions at the Post Manufacturing and Disposal stages.

The use of the most recent (1994/95) CO₂ emission factors in Study 3 also contributed to the reduction in emissions. Table 47 details the significance of the different factors used.

<table>
<thead>
<tr>
<th>Fuel CO₂ emission factors</th>
<th>Sourced from 1993/94</th>
<th>Sourced from 1994/95</th>
<th>% Change from 1993/94 data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automotive diesel oil</td>
<td>74.9 g/MJ</td>
<td>69.7 g/MJ</td>
<td>-6.94</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>78.8 g/MJ</td>
<td>73.6 g/MJ</td>
<td>-6.60</td>
</tr>
</tbody>
</table>

Table 47 Fuel CO₂ emission factors (GCO 1997)

4.5 GHG emissions for the proposed pulp mill

4.5.1 Emissions due to Visy owned activities

Emissions due to Visy owned activities are shown in Table 48.

<table>
<thead>
<tr>
<th>Source</th>
<th>Study 1 t CO₂(e)/ADt of paper manufactured</th>
<th>Study 2 t CO₂(e)/ADt of paper manufactured</th>
<th>Study 3 t CO₂(e)/ADt of paper manufactured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass Fuel (operation of power and recovery boilers)</td>
<td>+0.00</td>
<td>+0.00</td>
<td>+0.00</td>
</tr>
<tr>
<td>Wastepaper sorting, baling and compacting at recycling plants</td>
<td>&lt;+0.01</td>
<td>+0.00</td>
<td>&lt;+0.00</td>
</tr>
<tr>
<td>Electricity imported from NSW grid</td>
<td>+0.30</td>
<td>+0.30</td>
<td>+0.37</td>
</tr>
<tr>
<td>LPG</td>
<td>+0.20</td>
<td>+0.20</td>
<td>+0.13</td>
</tr>
<tr>
<td>Solid wastes to SWDSs</td>
<td>&lt;+0.01</td>
<td>&lt;+0.01</td>
<td>&lt;+0.01</td>
</tr>
<tr>
<td>Effluent</td>
<td>&lt;+0.01</td>
<td>&lt;+0.01</td>
<td>&lt;+0.01</td>
</tr>
<tr>
<td>TOTAL</td>
<td>&lt;+0.53</td>
<td>&lt;+0.52</td>
<td>&lt;+0.52</td>
</tr>
</tbody>
</table>

Table 48 Summary: Pulp mill-Visy owned and controlled

Table 48 indicates that fossil fuels, in the form of grid supplied electricity and LPG will be responsible for approximately 99% of GHG emissions being emitted from Visy owned and controlled activities at the pulp mill. Electricity and LPG will supply 40% of the pulp mill’s energy requirements. The remaining 60% will be supplied by carbon neutral biomass fuel (Nolan-ITU 1998). Compared to the use of grid supplied
electricity, the use of renewable energy in the form of biomass, will result in GHG emission savings of approximately 0.76 t CO₂(e)/ADt of paper manufactured.

4.5.2 Emissions due to non-Visy owned activities

Table 49 details emissions due to activities directly supporting the operation of the pulp mill but not owned by Visy.

<table>
<thead>
<tr>
<th>Emission Source</th>
<th>Study 1 t CO₂(e)/ADt of paper manufactured</th>
<th>Study 2 t CO₂(e)/ADt of paper manufactured</th>
<th>Study 3 t CO₂(e)/ADt of paper manufactured</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Plantation activities</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forestry management</td>
<td>+0.02</td>
<td>+0.02</td>
<td>+0.02</td>
</tr>
<tr>
<td>Milling of logged timber</td>
<td>+0.02</td>
<td>+0.02</td>
<td>+0.02</td>
</tr>
<tr>
<td><strong>Total plantation</strong></td>
<td>+0.04</td>
<td>+0.04</td>
<td>+0.04</td>
</tr>
<tr>
<td><strong>Transport emissions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulp logs</td>
<td>+0.01</td>
<td>&lt;+0.01</td>
<td>&lt;+0.01</td>
</tr>
<tr>
<td>Sawmill Residues</td>
<td>+0.01</td>
<td>+0.02</td>
<td>+0.01</td>
</tr>
<tr>
<td>Biomass fuel</td>
<td>Included above</td>
<td>Included above</td>
<td>+0.01</td>
</tr>
<tr>
<td>Chemicals to pulp mill</td>
<td>&lt;+0.01</td>
<td>&lt;+0.01</td>
<td>+0.01</td>
</tr>
<tr>
<td>Recycled paper to pulp mill</td>
<td>+0.01</td>
<td>+0.01</td>
<td>+0.01</td>
</tr>
<tr>
<td>Solid waste, recyclables</td>
<td>&lt;+0.01</td>
<td>&lt;+0.01</td>
<td>&lt;+0.01</td>
</tr>
<tr>
<td>By-products</td>
<td>&lt;+0.01</td>
<td>&lt;+0.01</td>
<td>&lt;+0.01</td>
</tr>
<tr>
<td>Paper to converting plants</td>
<td>+0.05</td>
<td>+0.05</td>
<td>+0.02</td>
</tr>
<tr>
<td><strong>Total transport</strong></td>
<td>+0.11</td>
<td>&lt;+0.12</td>
<td>+0.09</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>&lt;+0.15</td>
<td>&lt;+0.16</td>
<td>&lt;+0.13</td>
</tr>
</tbody>
</table>

Table 49 Summary: Pulp mill emissions, non-Visy owned and controlled

The majority of emissions from non-Visy owned activities were from plantation activities and the transport of manufactured paper to the converting plants. *Plantation Activities* refers to the machinery fuel emissions used in the management of the forest and emissions involved in the felling and splitting of pulpwood. Energy used to fell sawlogs was considered the responsibility of the sawmill operators and was not included in the above table. Contractor transport emissions have been included.

Manufactured paper remaining within the Visy system boundaries (i.e. paper not sold) will be sent to Visy converting plants for further processing. As transport emissions are based on MJ/tonne-km, tonnage of paper and distance travelled to the converting plants will determine the level of emissions. Transport emissions in Study 3 were
lower than Study 2 due to less paper being transported to the converting plants, as shown in Table 39.

Table 50 details the results of two sensitivity analyses that examined the consequence on GHG emissions of selling different quantities of the manufactured paper outside of the Visy system. All three studies assumed a total production of 241,972t. Any paper that was not sold was sent to the converting plants for further processing. Virgin Study 3 total LCA emissions were used as the baseline. The percentage change in emissions in the two sensitivity studies was calculated from the baseline.

<table>
<thead>
<tr>
<th>Virgin LCAs</th>
<th>Fate of paper manufactured</th>
<th>% Change in emissions from the baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virgin LCA, Study 3</td>
<td>126,972 tonne sold, 115,000 tonne to converter plants</td>
<td>Baseline study</td>
</tr>
<tr>
<td>Virgin Sensitivity Study 1</td>
<td>106,972 tonne sold, 135,000 tonne to converter plants</td>
<td>+19.56%</td>
</tr>
<tr>
<td>Virgin Sensitivity Study 2</td>
<td>All manufactured paper to converting plants</td>
<td>+122.8%</td>
</tr>
</tbody>
</table>

Table 50 Effect of selling paper out of the Visy system

The analysis indicated that the quantity of paper sold had a very large effect on LCA emissions as less paper was transported and processed at the converting plants. These analyses clearly demonstrate the importance of LCAs being transparent and having clearly defined system boundaries.

4.5.3 Effect of using recycled fibre at the pulp mill

The following data assumed that in the absence of recycling, wastepaper would be transported to SWDSs where it would emit GHGs. Studies 1 and 2 assumed 80,500 tonne of wastepaper would be processed at the pulp mill (Nolan-ITU 1998). As indicated in Table 39, revised data used in Study 3 used a value of 60,000 tonne.
Table 51 details the avoided emissions claimed in each of the virgin LCAs.

<table>
<thead>
<tr>
<th>Emission Source</th>
<th>Study 1 t CO₂(e)/ADt of paper manufactured</th>
<th>Study 2 t CO₂(e)/ADt of paper manufactured</th>
<th>Study 3 t CO₂(e)/ADt of paper manufactured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoided emissions at SWDSs</td>
<td>-0.69</td>
<td>-0.91</td>
<td>-0.84</td>
</tr>
<tr>
<td>Avoided transport emissions</td>
<td>&lt;-0.01</td>
<td>&lt;-0.01</td>
<td>&lt;-0.01</td>
</tr>
<tr>
<td>Total avoided emissions</td>
<td>&lt;-0.70</td>
<td>&lt;-0.92</td>
<td>&lt;-0.85</td>
</tr>
</tbody>
</table>

**Table 51 Summary: Avoided emissions due to recycling**

According to the Visy virgin LCA model, avoided emissions were only applicable to the proportion of recycled paper processed at the pulp mill. The size of the avoidance credit was dependent upon the following factors:

- The quantity of wastepaper processed.
- The number of times the paper was recycled.
- The method used to calculate emissions at SWDSs.
- Travel distance from the collection point to SWDS.

Study 1 did not include the methane/carbon molecular factor (16/12) in the emissions calculations and assumed the wastepaper was cycled 5 times. As a result, avoided emissions in Study 1 were lower compared to the other two LCA studies. Studies 2 and 3 did include the methane factor and claimed 83.3% of emissions, as those studies assumed paper was cycled 6 times before the fibres became too short for further processing. Avoided emissions in Study 3 were lower than Study 2 as the revised data assumed that less recycled paper would be processed at the mill. As indicated in Table 50, avoided transport emissions had very little effect on total avoided emissions.

Table 52 details the effect that claimed avoidance emissions had on the virgin LCA model.
<table>
<thead>
<tr>
<th>Virgin LCA</th>
<th>Disposal emissions t CO$_2$(e)/ADt of paper manufactured</th>
<th>Avoidance credits claimed t CO$_2$(e)/ADt of paper manufactured</th>
<th>% Change in emissions if avoidance credits were excluded from the LCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study 1</td>
<td>2.65</td>
<td>-0.69</td>
<td>+24.2%</td>
</tr>
<tr>
<td>Study 2</td>
<td>3.31</td>
<td>-0.91</td>
<td>+27.7%</td>
</tr>
<tr>
<td>Study 3</td>
<td>1.92</td>
<td>-0.84</td>
<td>+45.6%</td>
</tr>
</tbody>
</table>

Table 52 Significance of avoidance credits to total emissions

The consequence of excluding avoidance credits from the LCA was found to be significant in all three studies. The effect seen in Study 3 was significantly higher than previous studies due to the following:

- Data used in Study 3 indicated that more manufactured paper was sold compared to Studies 2 and 3. This meant that less paper was further processed and ultimately disposed into SWDSs. The result was lower CH$_4$ emissions from SWDSs.
- Avoidance credits are dependent upon the amount of wastepaper fed into the process. The credits claimed in Study 3 were only slightly lower than Studies 1 and 2 due to 60,000 tonne being used instead of 80,500 tonne.

Table 52 indicated that the consequence of excluding avoidance credits in Visy virgin Study 3 led to a 45.6% increase in total LCA emissions.

4.5.4 Emissions avoided by import replacement

Once the pulp mill is operating, Visy will no longer import wastepaper for their recycling paper operations, as the paper produced from the pulp mill will completely replace the imported amount. Table 53 indicates that the effect of import replacement was the same in all three LCA studies.
Table 53 Effect of import replacement

<table>
<thead>
<tr>
<th>Emission Source</th>
<th>Visy virgin LCA Study 1</th>
<th>Visy virgin LCA Study 2</th>
<th>Visy virgin LCA Study 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t CO₂(e)/ADt of paper manufactured</td>
<td>t CO₂(e)/ADt of paper manufactured</td>
<td>t CO₂(e)/ADt of paper manufactured</td>
</tr>
<tr>
<td>Transport emissions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land transport within overseas country</td>
<td>&lt;-0.01</td>
<td>&lt;-0.01</td>
<td>&lt;-0.01</td>
</tr>
<tr>
<td>Shipping to Australia</td>
<td>&lt;-0.01</td>
<td>&lt;-0.01</td>
<td>&lt;-0.01</td>
</tr>
<tr>
<td>Land transport within Australia</td>
<td>&lt;-0.01</td>
<td>&lt;-0.01</td>
<td>&lt;-0.01</td>
</tr>
<tr>
<td>TOTAL</td>
<td>&lt;-0.03</td>
<td>&lt;-0.03</td>
<td>&lt;-0.03</td>
</tr>
</tbody>
</table>

Table 54 Summary of pulp mill related emissions

<table>
<thead>
<tr>
<th></th>
<th>Visy virgin LCA Study 1</th>
<th>Visy virgin LCA Study 2</th>
<th>Visy virgin LCA Study 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t CO₂(e)/ADt of paper manufactured</td>
<td>t CO₂(e)/ADt of paper manufactured</td>
<td>t CO₂(e)/ADt of paper manufactured</td>
</tr>
<tr>
<td>Pulp mill: Visy controlled</td>
<td>&lt;+0.53</td>
<td>&lt;+0.52</td>
<td>&lt;+0.52</td>
</tr>
<tr>
<td>Pulp mill: Non-Visy controlled</td>
<td>&lt;+0.15</td>
<td>&lt;+0.16</td>
<td>&lt;+0.13</td>
</tr>
<tr>
<td>Emissions avoided by the use of wastepaper</td>
<td>&lt;-0.70</td>
<td>&lt;-0.92</td>
<td>&lt;-0.85</td>
</tr>
<tr>
<td>Emissions avoided by import replacement</td>
<td>&lt;-0.03</td>
<td>&lt;-0.03</td>
<td>&lt;-0.03</td>
</tr>
<tr>
<td>Total emissions for the 4 groupings</td>
<td>&lt;-0.05</td>
<td>&lt;-0.27</td>
<td>&lt;-0.23</td>
</tr>
</tbody>
</table>

It can be seen that GHG emissions resulting from the Visy controlled and non-Visy controlled pulp mill operations are offset by avoided emissions and import replacement. Based on the above criteria, the results indicate that the development of the pulp mill can be achieved with a net reduction in GHG emissions. In terms of any future GHG restrictions, Visy saw the pulp mill development as a very good business strategy.
4.6 Visy Virgin GHG reduction strategies and opportunities

Virgin papermaking process GHG reduction strategies and business opportunities were identified from the virgin LCA Studies. The identified reduction strategies and business opportunities were as follows:

- Increase the use of renewable energy as a fuel source.
- Increase the proportion of recycled fibre processed at the pulp mill.
- Produce Green Power at the pulp mill and sell it to the grid.

Increase the use of renewable energy as a fuel source

The use of renewable energy as a fuel source to displace carbon intensive fossil fuels has been shown to significantly reduce GHG emissions. Table 55 indicates that if biomass provided 80% of the energy source at the pulp mill instead of the projected 60%, LCA emissions would decrease 28%.

<table>
<thead>
<tr>
<th>Virgin LCA Study 3</th>
<th>% Change in emissions from the baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>60% energy sourced from biomass</td>
<td>Baseline</td>
</tr>
<tr>
<td>80% energy sourced from biomass</td>
<td>-28.3%</td>
</tr>
</tbody>
</table>

Table 55 Effect of increased use of biomass at the pulp mill

This result justifies further investigation in the use of renewable energy at other Visy operations.

Increase the proportion of recycled fibre processed at the pulp mill

Table 56 highlights the consequence of using more than the projected input of wastepaper at the pulp mill.

<table>
<thead>
<tr>
<th>Wastepaper processed at the pulp mill</th>
<th>% Change in LCA emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>60,000 t</td>
<td>Baseline</td>
</tr>
<tr>
<td>80,000 t</td>
<td>-14.7%</td>
</tr>
<tr>
<td>90,000 t</td>
<td>-22.3%</td>
</tr>
</tbody>
</table>

Table 56 Effect of increased wastepaper usage at the pulp mill
The sensitivity analysis demonstrated that processing larger quantities of wastepaper at the pulp mill resulted in significantly reduced emissions. These emissions were reduced due to the claim for avoided credits resulting from recycling the paper. Recycling paper ‘avoids’ GHG emissions at SWDSs and a claim was made based on paper being recycled 5 times.

However, a decision to increase the percentage of wastepaper in the virgin process would need to be thoroughly investigated prior to implementation. Shorter fibres in the paper manufactured may restrict the type of product produced and the number of times the product could be further processed.

**Produce Green Power and sell to the grid**

Compared to the conventional use of fossil fuel derived electricity, the virgin LCAs identified that the use of renewable energy (in the form of biomass) as the major fuel source at the pulp mill will result in GHG emission savings of approximately 0.76 t CO₂(e)/ADt of paper manufactured.

In addition to significant GHG emission savings at the pulp mill, a very good business opportunity exists if Visy proceed with their plans to produce and sell excess Greenpower to the electricity grid. As a producer of renewable energy under the Renewable Energy (Electricity) Act 2000 (AGO 2001(a)), Visy will be in a position to sell both its Greenpower and Renewable Energy Certificates (RECs) at premium prices.

The Renewable Energy (Electricity) Act 2000 supports the implementation of the mandatory renewable energy target. Under the Act, liable parties (wholesale energy purchasers) will have to purchase increasing amounts of electricity generated from renewable energy sources from 1 April 2001.

Any accredited renewable electricity generation or displacement project in commercial operation on or after 1 January 1997 will be eligible to earn RECs. To meet their obligations, liable parties will be required to acquire RECs from accredited renewable energy generators. Each REC will equal 1 MWh of electricity generated from
renewables and will be traded through a separate market from the physical energy market (AGO 2001(a)).

4.7 Plantation carbon sinks

Visy is aware that with the possible ratification of the Kyoto Protocol, Australia would be legally bound to reduce GHG emissions. One of the ways Visy may be able to contribute to its own and Australia’s GHG emission reduction would be to develop ‘carbon sinks’ as part of the Visy-State Forest Agreement (Nolan-ITU 1998). However, the issues surrounding carbon sinks are complex and full of uncertainties. As of early 2001, international discussions to resolve these issues were still occurring.

Through a process known as photosynthesis, green plants sequester carbon from the atmosphere. This results in a carbon ‘store’ or ‘sink’. Depending upon the outcome of the negotiations, a company with ownership rights to the sequestered carbon may be able to use the carbon to either offset emissions from their operations, or under Article 17 of the Kyoto Protocol (COP 1997), trade the sequestered carbon nationally or internationally as part of an emission trading scheme.

Trading of carbon credits outside the Kyoto Protocol is already occurring. According to Hordern, credits worth $US50 million were traded worldwide in 1999. This value was estimated to increase to $US200 billion by the end of the decade (Hordern 2000).

Countries around the world have expressed different views in regard to the Kyoto Protocol sink negotiations (AGO 2000d). Some countries believe sinks should not be part of the Protocol, as they believe countries able to establish large sinks could use them to meet all of their Kyoto obligations. Their reasoning is that in the event of this happening, these countries would not have to reduce their consumption of fossil fuels and develop new technologies to reduce emissions. Some countries have also expressed concerns over the measurement uncertainties of sinks and the reliability of the results.

The Australian government does not share these views. Australia strongly believes that sinks should be part of the Protocol and has acknowledged that sinks would only
one of many measures that would need to be implemented in order to meet its Kyoto
commitments (AGO 2000d)

Under Article 3.3 of the Kyoto Protocol, land use change and forestry activities that
are eligible to be included in the Protocol are restricted to afforestation, reforestation
and deforestation activities (COP 1997). However, the precise definition of these and
other activities is still being negotiated internationally. Based on Australia’s current
interpretation of Article 3.3 of the Protocol, Visy’s pine plantations would be eligible
to be defined as ‘Kyoto Forests’(AGO 2000d).

Assuming this to be the case, Visy would be required to account for changes in its
carbon stocks in these pine plantations between 2008 and 2012. To accomplish this,
the quantification of relevant carbon pools such as above ground biomass, litter and
woody debris, below ground biomass, soil carbon and harvested materials is required.

At the present time, there is a lack of accepted, validated carbon accounting systems
for forestry developments. In addition, there is a still a high degree of uncertainty
associated with estimating the size of a carbon sink (AGO 2000d).

The rate at which carbon is sequestered depends upon many variables such as:

- Location of the plantation.
- Soil condition.
- Climate.
- Land use prior to plantation development.
- Species grown.
- Rate of growth of the plantation.
- Plantation management system.
- Plantation age.

In addition to the above uncertainties, the responsibility for emissions from harvested
wood products is still unresolved. Relevant methodologies for determining the
harvested wood emissions need to be in accordance with the 1996 IPCC Revised Inventory Guidelines (IPCC 1997).

Harvested wood products can be considered under Article 3.3 or 3.4 of the Protocol. If considered under Article 3.3, the producing country is responsible for wood product emissions at harvest. This applies to products used domestically and exported. Under the same Guidelines, countries are not required to report emissions associated with imported wood products that are consumed domestically.

The IPCC Guidelines provide 2 alternative accounting options. The difference between the two options is that the Option 2 accounts for emissions when they occur and not at the time of harvest. According to the AGO (AGO 2000d), Option 1 is the more likely to be applied.

**Option 1:**
Assumes wood products break down immediately and emissions occur at the time of harvest.

**Option 2:**
Assumes wood product emissions are delayed and occur when the product decays at the end of its life. This approach requires tracking the fate of wood products once they leave the Kyoto Forest. Wood used in construction is considered to be involved in long-term storage (up to 50 years), while paper is considered short-term storage (up to 3 years). The AGO believes that there is insufficient information available at this stage to undertake Option 2.

Due to the difficulties with placing wood products under Article 3.3, the AGO believes that some countries may decide to account for their wood products under Article 3.4. According to the AGO, wood products placed under Article 3.4 would still to be tracked within the domestic economy, but the task would be much simpler (AGO 2000d).

Other approaches that have been considered by the UNFCC in regard to harvested wood products are the Stock Change Approach, the Production Approach and the
Atmospheric Flow Approach. There are problems in adopting any of these approaches as they do not take into account all of the requirements of the Protocol (AGO 2000d).

According to Article 5.1 of the Protocol, countries must have a national accounting system in place by 2007. The AGO first issued the Greenhouse Challenge Sinks Workbook in 1998 (AGO 1998(b)), to provide assistance in quantifying carbon stocks in forest vegetation and soils. Since that time the AGO has developed the National Carbon Accounting System to help reduce the uncertainties associated with measuring and verifying emissions and sequestrations.

CAMFor (Carbon Accounting Model for Forests) is the system proposed by the AGO for calculating carbon flows associated with a stand of trees, including the wood products and the various components within the stand. CAMFor is not a forest management model.

The author requested Dr John Turner of Forsci Pty Ltd to conduct a carbon analysis of the proposed Visy pine plantations, using the CAMFor model (Turner 2000). As the Visy plantations are yet to be established, Turner used data for radiata pine from an area adjacent to the planned plantations. It should be noted that the analysis conducted contained a large number of variables, but without actual Visy data, it provided the best information available. Using the CAMFor model, outputs from two rotations (each lasting 30 years) of a pine plantation are shown in Figure 8.

Results indicated that the tree carbon mass accumulated as the plantation developed. This produced a carbon credit. However, the accumulation of carbon declined at the time of thinning and at the end of the rotation, when all of the standing carbon was removed. It should be noted that according to the model, soil carbon mass declined throughout the life of the rotation. Turner concluded that based on the data used in the model, there would be no net carbon accumulation at the end of the rotation (Turner 2000). The model does not include the ownership and accountability of the harvested carbon.
Figure 8 CAMPFor output from a pine plantation

Turner described CAMPFor in the following manner

‘CAMPFor is a complex, non-user friendly system for tracking carbon in forests. Many of the required constants essentially have to be developed by trial and error, which then requires a sound database to validate if the inputs are correct. It would be difficult to use CAMPFor at an extensive estate level for routine assessment and other systems would need to be place to maintain the required data sets and to undertake statistical analyses. The system is not suitable for analysing alternatives or ‘what if’ to evaluate planning alternatives’

If the above comments are correct, the use of this model may introduce added costs and more uncertainties into the calculation and verification of carbon sequestration.

Under the Kyoto Protocol, only carbon sequestered during the commitment period (2008-2012) will be claimable. This means that the plantations would have to be very carefully managed to ensure maximum sequestration during this period of time. If mismanaged, a plantation development over the commitment period or over the course
of its life may end up producing emissions rather than acting as a sink (AGO 2000d, Turner 2000).

Based on the current uncertainty regarding a reliable methodology to quantify carbon sources and appropriate accounting methods, any decisions made by Visy at this time in regard to forestry development for carbon credits should be made with a great deal of caution.
Chapter 5

5. Visy recycling and virgin LCA comparison

Two principal assessments have been made:

1. A comparison between the outcomes of the Visy recycling and virgin LCA models.
2. The consequences of including emissions assigned to Australian sourced wastepaper and modifying the assumption that virgin paper in the Visy virgin process was not recycled.

5.1 Comparison between the two Visy papermaking processes

One of the goals of the research was to compare the Visy recycling and virgin papermaking LCAs. The LCA studies used for this comparison were Visy recycling LCA Study 4 and Visy virgin LCA Study 3. These two studies most accurately represented the Visy papermaking processes because they were the culmination of the investigation program.

Assumptions common to both processes

In comparing the Visy virgin and recycling LCA models, 4 assumptions were made:

1. The converting process used in both papermaking models was the same process. It was assumed that the same quantity of energy and raw materials per tonne of product was consumed.
2. Emissions from the following activities were assumed to be zero:
   - Storage of recycled paper at the pulp mill and paper recycling plants.
   - Separation of wastepaper from other waste streams.
3. Both models assumed that recycled paper was capable of being cycled 6 times before the fibres became too short to enable further recycling.
4. The ultimate fate of paper products was assumed to be disposal into SWDSs and decomposition into CH₄ in accordance with IPCC Guidelines (IPCC 1997).
Emissions included and excluded in each study have been shown in Figures 6 and 7. Table 57 highlights the similarities and differences between the two studies.

<table>
<thead>
<tr>
<th>Aspects of the LCA studies</th>
<th>Paper Recycling LCA-Study 4</th>
<th>Virgin LCA Study 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time period the conversion factors were sourced from</td>
<td>1994/95</td>
<td>1994/95</td>
</tr>
<tr>
<td>Emissions assigned to imported wastepaper included</td>
<td>YES</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>Emissions assigned to Australian sourced wastepaper included</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>Chemical transport emissions included</td>
<td>Australian distances only</td>
<td>Australian distances only</td>
</tr>
<tr>
<td>Number of times wastepaper was cycled</td>
<td>6</td>
<td>6*</td>
</tr>
<tr>
<td>Number of times virgin fibre was cycled</td>
<td>NA</td>
<td>1</td>
</tr>
<tr>
<td>Effluent CH₄ was assumed to be 10% of maximum CH₄ levels</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Avoidance credits claimed due to recycling</td>
<td>YES</td>
<td>Only applied to the recycled paper component (60,000 tonnes)</td>
</tr>
<tr>
<td>CH₄ capturing or flaring at SWDSs included</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

* Visy intend to process 60,000 tonnes of wastepaper at the pulp mill

**Table 57 Features of recycling LCA Study 4 and virgin LCA Study 3**

**Similarities between the two studies were as follows:**

- Australian transport distances for all activities relevant to the papermaking processes were included in both models.
- Neither model accounted for emissions assigned to Australian sourced wastepaper i.e. GHG emissions due to the production of paper and cardboard, prior to its entry into the Visy process.

**The most notable differences between the two studies were as follows:**

- It was assumed that virgin paper manufactured at the pulp mill was not recycled.
- Each model differed in the quantity of manufactured paper that was sent out of the Visy system. The recycling model sold 15.9% of its production, while the virgin model sold 52.5%.
- Renewable energy was used to supply 60% of the energy requirements of the pulp mill. In contrast, the recycling process was heavily dependent upon fossil fuel for its energy source.
- The recycling process began at the kerbside collection point. The virgin process began with the growth of the pine plantations. Seedling growth emissions and the transport of the seedlings to the plantation were not included in the virgin model.

Data relevant to paper production at Visy is shown in Table 58.

<table>
<thead>
<tr>
<th>Aspects of the Visy LCA studies</th>
<th>Paper Recycling LCA Study 4</th>
<th>Virgin LCA Study 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity of Visy paper manufactured (ADt)</td>
<td>660,495</td>
<td>242,000</td>
</tr>
<tr>
<td>Quantity of Visy paper sold out of the Visy system (ADt)</td>
<td>104,794 (15.9% of total production)</td>
<td>126,972 (52.5% of total production)</td>
</tr>
<tr>
<td>Quantity of Visy paper sent to Visy converting plants (ADt)</td>
<td>555,701</td>
<td>115,028</td>
</tr>
<tr>
<td>Visy manufactured cardboard product sold to customers (ADt)</td>
<td>520,161</td>
<td>102,925</td>
</tr>
</tbody>
</table>

Table 58 Visy virgin and recycling production data

5.2 Results of the LCA comparison

The results of the comparison between the Visy papermaking LCAs are shown in Table 59.

<table>
<thead>
<tr>
<th>Visy LCA unit processes</th>
<th>Visy Recycling LCA Study 4 t CO₂(e)/ADt of paper manufactured</th>
<th>Visy Virgin LCA Study 3 t CO₂(e)/ADt of paper manufactured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Materials Acquisition</td>
<td>+0.04</td>
<td>+0.08</td>
</tr>
<tr>
<td>Raw Materials Processing</td>
<td>+0.00</td>
<td>+0.02</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>+1.06</td>
<td>+0.52</td>
</tr>
<tr>
<td>Post Manufacture</td>
<td>+0.27</td>
<td>+0.13</td>
</tr>
<tr>
<td>Use and Service</td>
<td>Undetermined-outside the LCA boundary</td>
<td>Undetermined-outside the LCA boundary</td>
</tr>
<tr>
<td>Disposal</td>
<td>-0.25</td>
<td>+1.08</td>
</tr>
<tr>
<td>Total</td>
<td>+1.13</td>
<td>+1.83</td>
</tr>
</tbody>
</table>

Table 59 Visy Recycling and virgin LCA comparison

When total emissions per unit of production from each model were compared, the virgin model emitted 61% more GHG emissions than the recycling model. In order to
understand the specific differences between the two models, the unit processes in each model were examined. The greatest differences were found to be in the manufacturing and disposal unit processes.

**Raw Materials Acquisition-unit process**

Compared with the recycling model, the virgin model emitted twice as much GHG in this unit process. Emissions in the virgin model were due to forestry management activities (preparation of the harvest area for regeneration, thinning of trees and application of fertilisers and pesticides) and planting (harvesting of trees and clearing of the harvest area). Emissions that occurred in the recycling LCA were associated with the transport of wastepaper and emissions assigned to imported paper.

**Raw Materials Processing-unit process**

Emissions in the virgin model were due to the transport of raw materials to the pulp mill. These raw materials included sawmill residues, logs, pulpwood and recycled paper.

In the recycling model, the majority of wastepaper was separated from the other waste streams prior to collection and transported directly to the paper recycling plants i.e. very little processing was required. Where wastepaper was not separated at source, GHG emissions due to sorting, compacting and baling at the recycling plants were found to be insignificant.

**Manufacturing-unit process**

Table 59 highlighted the consequences of:

- Using fossil fuel energy sources during manufacturing.
- Disposing solid waste rejects from the manufacturing stage of the papermaking process into SWDSs. Both the paper recycling plants and pulp mill produced solid waste rejects.

The recycling model emitted 100% more GHG emissions than the virgin model, primarily due to the extensive use of fossil fuel during manufacturing. Lower emissions in the virgin model were due to the use of renewable energy as the major fuel source at the pulp mill.
In addition to the use of fossil fuel, Table 29 indicated that GHG emissions from solid waste rejects from the paper recycling plants accounted for approximately 14% of total manufacturing emissions in the paper recycling model. This was due to the majority of these rejects being sent to SWDSs where under anaerobic conditions they emitted CH$_4$. As CH$_4$ has a GWP of 21, its effect on total emissions ($t$ CO$_2$($e$)) is 21 times that of CO$_2$. In contrast, solid waste emissions in the virgin model contributed only 0.05% of manufacturing emissions. Lower emissions were due to the diversion of solid waste rejects from SWDSs into other products out of the Visy system (Nolan-ITU 1998).

**Post Manufacture Processing and Disposal-unit processes**

Paper manufactured at the Visy paper recycling plants was either sold out of the Visy system or sent to Visy converting plants for further processing. Table 58 indicated that the virgin model sold 52.5% of its manufactured paper out of the Visy system, and sent the remaining 47.5% to the Visy converting plants. In the paper recycling model, only 15.9% of manufactured paper from the Visy paper recycling plants was sold out of the Visy system. The remaining 84.1% was sent to the Visy converting plants for further processing.

The magnitude of post manufacturing and disposal emissions in both Visy LCA models was dependent upon the proportion of manufactured paper sent to the converting plants i.e. the quantity of Visy manufactured paper that was further processed within the Visy system. The chosen functional unit used in both Visy LCA models was *one ADt of paper manufactured*.

The use of this functional unit implied that all of the manufactured paper was sent to the Visy converting plants for further processing i.e. the quantity of paper sold out of the Visy system was not taken into account. The research indicated that the chosen functional unit was useful for the *Visy papermaking process* but was not as useful once the manufactured paper was either sold out of the Visy system or sent to the Visy converting plants. A more useful functional unit that accounted for the *production of cardboard products* at the converting plants was required.
Table 60 demonstrates the consequence of using a different functional unit in the post manufacturing and disposal unit processes of both LCAs. The alternative functional unit was based on the production of Visy cardboard products from the Visy converting plants. To illustrate this point, emissions from electricity usage at the Visy converting plants and the decomposition of wood fibre in SWDSs (when the fibres become too short for further recycling) have been used. Production data were sourced from Table 58. Values obtained using the original functional unit were used as the baseline.

<table>
<thead>
<tr>
<th>Visy LCA model</th>
<th>t CO(_2) (e)/ADt of paper manufactured (Original functional unit)</th>
<th>t CO(_2) (e)/ADt of cardboard product manufactured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visy Recycling LCA Study 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emissions due to electricity usage at the Visy converting plants</td>
<td>0.14</td>
<td>0.18</td>
</tr>
<tr>
<td>Emissions from the decomposition of Visy paper products in SWDSs</td>
<td>3.48</td>
<td>4.42</td>
</tr>
<tr>
<td>Visy Virgin LCA Study 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emissions due to electricity usage at the Visy converting plants</td>
<td>0.07</td>
<td>0.17</td>
</tr>
<tr>
<td>Emissions from the decomposition of Visy paper products in SWDSs</td>
<td>1.71</td>
<td>4.07</td>
</tr>
</tbody>
</table>

**Table 60 Effect of different functional units**

When a different functional unit (t CO\(_2\) (e)/ADt of cardboard product manufactured) was used with the same quantity of emitted GHGs, the apparent assessment outcomes are expressed differently. Variations from the baseline were due to the following:

1. The quantity of Visy manufactured paper sold out of the Visy system.
2. The alternative functional unit used the quantity of cardboard product manufactured, instead of the quantity of paper manufactured originally used.
3. One tonne of cardboard is not the same as one tonne of paper.

These points are best illustrated in Virgin LCA Study 3. Emissions due to electricity usage at the Visy converting plants were 0.07 t CO\(_2\) (e)/ADt of paper manufactured. If the alternative functional unit was applied to the same data, the result was 0.17 t CO\(_2\) (e)/ADt of cardboard product manufactured ie. a 135% increase from the baseline.
value. The alternative functional unit took into account the 52.5% of the Visy manufactured paper that was sold out of the Visy system, which resulted in less Visy cardboard product being manufactured. Variations from the baseline values in the recycling LCA were not as large due to less Visy manufactured paper (15.9%) being sold out of the Visy system. As a result, a greater proportion of cardboard product was manufactured in the paper recycling LCA compared to the virgin LCA.

As the Visy LCA models were commercially defined, it became apparent that functional units that reflected the production of Visy paper and cardboard products were more meaningful to the Visy papermaking processes.

5.3 Effect of using different functional units on both LCA models

The original functional unit used in both the Visy virgin and paper recycling LCA models was one ADt of paper manufactured. This functional unit was used in all six unit processes in both the Visy virgin and recycling LCA models and implied that paper was the only product manufactured by Visy.

The use of the original functional unit gave a ‘rough approximation’ of how emissions were allocated within the Visy paper and cardboard making processes. However, by choosing to use functional units that acknowledged both Visy products, it was possible to quantity GHG emissions across the full Visy paper and cardboard making processes in a more meaningful way.

Two separate companies within Visy are responsible for the manufacture of paper and cardboard. Visy Paper manufactures paper, whereas Visy Board manufactures cardboard. By using functional units that separately quantified the GHG effect of the two Visy manufactured products, Visy were able to determine the GHG effect of the Visy Paper and Visy Board operations. This was a more useful outcome than the ‘overall’ GHG effect of the Visy process obtained with the original functional unit.
The alternative functional units were defined as follows:

**Functional Unit 1:**
*One ADt of paper manufactured*

This is the same functional unit as the *original* functional unit, however, its use was restricted to the *first three unit processes* of the LCA i.e. up until the paper was manufactured at the paper recycling plants (in the case of the recycling LCAs) or pulp mill (virgin LCAs).

**Functional Unit 2:**
*One ADt of cardboard product manufactured*

Functional Unit 2 was the functional unit that reflected the quantity of cardboard product manufactured at the Visy converting plants. Its use was restricted to the *final three unit processes* of the LCA. As Functional Unit 2 used Visy manufactured paper, assigned emissions generated by the first three LCA unit processes were included in the post manufacturing unit process.

Table 61 details the unit processes within the Visy virgin and recycling LCA models where each functional unit was applied.

<table>
<thead>
<tr>
<th>LCA Unit Process</th>
<th>Original Functional Unit One ADt paper manufactured</th>
<th>Functional Unit 1 One ADt paper manufactured</th>
<th>Functional Unit 2 One ADt cardboard product manufactured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Materials Acquisition</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Raw Materials Processing</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Post Manufacturing</td>
<td>•</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Consumer Use &amp; Service</td>
<td>•</td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Disposal</td>
<td>•</td>
<td></td>
<td>•</td>
</tr>
</tbody>
</table>

• Unit processes where the functional unit was applied

**Table 61 Application of different functional units to the Visy LCAs**
In the Visy recycling LCA, emissions assigned to Visy paper used to manufacture Visy cardboard were 0.93 t CO₂(e)/ADt of paper manufactured. This value represented 84.1% (proportion of manufactured recycled paper sent to Visy converting plants) of total emissions in the first three unit processes of the Visy recycling LCA Study 4.

Emissions assigned to the production of cardboard in the Visy virgin LCA were 0.29 t CO₂(e)/ADt of paper manufactured. This value represented 47.5% (proportion of manufactured virgin paper sent to Visy converting plants) of total emissions in the first three unit processes of Visy virgin LCA Study 3.

The consequences of using the alternative functional units on Visy recycling LCA Study 4 and Visy virgin LCA Study 3 are shown in Tables 62 and 63.

<table>
<thead>
<tr>
<th>Visy paper recycling LCA Study 4</th>
<th>Functional Unit 1</th>
<th>Functional Unit 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t CO₂(e)/ADt paper manufactured</td>
<td>t CO₂(e)/ADt cardboard product manufactured</td>
</tr>
<tr>
<td>Raw Materials Acquisition</td>
<td>+0.04</td>
<td>NA</td>
</tr>
<tr>
<td>Raw Materials Processing</td>
<td>+0.00</td>
<td>NA</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>+1.06</td>
<td>NA</td>
</tr>
<tr>
<td>Post Manufacturing</td>
<td>NA</td>
<td>+1.26</td>
</tr>
<tr>
<td>Disposal</td>
<td>NA</td>
<td>-0.31</td>
</tr>
<tr>
<td>TOTAL</td>
<td>+1.10</td>
<td>+0.95</td>
</tr>
</tbody>
</table>

NA= Not Applicable

**Table 62 Recycling LCA-Consequence of using different functional units**

In this comparative assessment, the GHG consequences of Visy manufacturing recycled paper and cardboard products were separately quantified. Table 62 indicates that the GHG consequence of Visy manufacturing recycled paper was 1.10 t CO₂(e)/ADt paper manufactured. Similarly, the GHG consequence of Visy manufacturing cardboard products from its recycled paper was 0.95 t CO₂(e)/ADt cardboard product manufactured.
Table 63 Virgin LCA-Consequence of using different functional units

Table 63 indicates that the GHG consequence of Visy manufacturing paper from virgin fibre was 0.62 t CO\(_2\)(e)/ADt paper manufactured. The GHG consequence of Visy manufacturing cardboard products from its manufactured virgin paper was 3.14 t CO\(_2\)(e)/ADt cardboard product manufactured.

The alternative functional units were not used in the initial Visy LCA studies for the following reasons:

The initial part of the research involved defining the carbon flow and creating the LCA models for the Visy paper and cardboard making processes. The Visy LCA studies were evolving studies. LCA models that accurately represented the Visy paper and cardboard processes needed to be developed before the effect of different functional units, system boundaries etc. could be evaluated.

The initial LCA studies (Visy recycling and virgin Studies 1 & 2) were very basic studies. Once more was learnt about the Visy processes and the flow of carbon could be accurately tracked, the more detailed LCA studies (Visy recycling LCA Study 4 and Visy virgin Study-3) that better represented the actual processes were developed.

The effect of using a functional unit that was based on the quantity of Visy manufactured paper was initially considered a suitable reference against which inputs and outputs of the Visy processes could be assigned to. It was only during the
evaluation stage of the latter studies that the consequence of using different functional units that represented both Visy products evolved.

5.4 Emissions assigned to Australian sourced wastepaper

At the present time Visy does not buy GHG emissions in its raw materials eg. Australian sourced wastepaper. Any future decision to include or exclude these assigned emissions has the potential to heavily affect Visy’s GHG baseline.

If ratification of the Kyoto Protocol occurs, it is likely that rules will be established in regard to GHG liabilities and system boundaries. These boundaries could be:

- Country boundaries where emissions assigned to imported and exported paper are taken into account.
- Company boundaries eg. Visy-owned operations.
- Both of the above.

Emissions associated with Australian sourced wastepaper were not assigned in either the Visy recycling or virgin LCA models, as the allocation of these emissions was complicated by the many different types, quality and mixes of paper available.

In the following scenarios, particular mixes of wastepaper were assumed. These scenarios are realistic as different proportions of once used virgin, OCC and recycled paper are regularly combined at the paper recycling plants in order to achieve the correct strength and grade of paper. Visy Recycling LCA Study 4 and Visy virgin LCA Study 3 were used in the following evaluations.

Scenario 1

No emissions were assigned to Australian sourced wastepaper. Values obtained in scenario 1 were used as a baseline.
**Scenario 2**

A 50% once used virgin and 50% recycled mix of Australian sourced wastepaper was assumed. Based on this assumption, an allocation of 0.86 t CO₂(e)/ADt of paper manufactured was made. This value was the average of the first three unit processes of the Visy recycling (1.10 t CO₂(e)/ADt of paper manufactured) and virgin models (0.62 t CO₂(e)/ADt of paper manufactured), as shown in Table 62 and Table 63.

**Scenario 3**

A mix of 75% once used virgin and 25% recycled Australian sourced wastepaper was assumed. Based on this assumption, emissions of 0.68 t CO₂(e)/ADt of paper manufactured were assigned to Australian sourced wastepaper. Relevant data were obtained from Table 62 and Table 63.

The consequences of incorporating emissions assigned to Australian sourced wastepaper in Visy recycled LCA Study 4, are shown in Table 64.

<table>
<thead>
<tr>
<th>Visy paper recycling LCA Study 4</th>
<th>Functional Unit 1</th>
<th>% Change from baseline</th>
<th>Functional Unit 2</th>
<th>% Change from baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t CO₂(e)/ADt paper manufactured</td>
<td></td>
<td>t CO₂(e)/ADt cardboard product manufactured</td>
<td></td>
</tr>
<tr>
<td>Scenario 1</td>
<td>+1.10 Baseline</td>
<td></td>
<td>+0.95 Baseline</td>
<td></td>
</tr>
<tr>
<td>Scenario 2</td>
<td>+1.98 +80%</td>
<td></td>
<td>+1.81 +90%</td>
<td></td>
</tr>
<tr>
<td>Scenario 3</td>
<td>+1.79 +63%</td>
<td></td>
<td>+1.63 +72%</td>
<td></td>
</tr>
</tbody>
</table>

Scenario 1: Emissions assigned to Australian sourced paper-not included  
Scenario 2: Emissions (50/50 mix) assigned to Australian sourced wastepaper were included  
Scenario 3: Emissions (75/25 mix) assigned to Australian sourced wastepaper were included

**Table 64 Recycled LCA-emissions assigned to Australian sourced paper**

Table 64 indicates that incorporating GHG emissions assigned to Australian sourced wastepaper in the Visy paper recycling LCA, did affect the overall result. This was expected as the Visy paper recycling process uses 100% recycled paper. Incorporating these emissions lead to a 63%-80% increase in the t CO₂(e)/ADt paper manufactured, and a 72%-90% increase in the t CO₂(e)/ADt cardboard product manufactured.

The consequence of including GHG emissions assigned to Australian sourced wastepaper in Visy virgin LCA Study 3 is shown in Table 65.
Table 65 Virgin LCA-emissions assigned to Australian sourced paper

Incorporating emissions assigned to Australian sourced paper into Visy virgin LCA Study 3 did not have as large an effect as that seen in Visy recycling LCA Study 4. The inclusion of these emissions lead to a 26%-34% increase in the t CO$_2$e/ADt paper manufactured, and a 12.7%-15.9% increase in the t CO$_2$e/ADt cardboard product manufactured. The effect is significantly less than that seen in the Visy recycling LCA-Study 4, as only 60,000 tonne of recycled paper will be processed at the pulp mill.

5.5 Assume some virgin fibre was recycled

The virgin LCA model assumed that virgin paper manufactured at the pulp mill was not recycled. This assumption was based on the fact that there are no new recycling operations planned in conjunction with the development of the pulp mill, and as indicated in Table 44, there has been little change in the recovery and utilisation rates of wastepaper in Australia. As a consequence of additional virgin fibre being available, there will be a market place adjustment. This may lead to a decrease in the quantity of wastepaper imported or decreased recycling operations. Production of virgin paper at the pulp mill means that Visy will no longer import wastepaper to support its paper recycling operations.

It is acknowledged that the Visy virgin LCA model did assume that the 60,000 tonnes of wastepaper to be processed at the mill was recycled. The following scenarios were evaluated within Visy virgin LCA-Study 3.
Scenario 4
Scenario 4 was the baseline study. No recycling from either the recycled or virgin fibre occurred in this scenario.

Scenario 5
Scenario 5 assumed that 48,323 tonnes of paper manufactured at the pulp mill was recycled. This quantity is equivalent to the quantity of paper annually imported by Visy to support its paper recycling operations and represents 42% of the pulp mill production that will be sent to the Visy converting plants. The scenario assumed that virgin paper was cycled 6 times and an avoidance credit claim for 5/6ths of emissions that would have occurred at SWDSs was made.

Scenario 6
Scenario 6 assumed that 102,925 ADt of virgin paper was recycled 4 times. This is the projected quantity of cardboard product to be manufactured from Visy virgin paper in the Visy converting plants. A lower number of cycles were chosen, to account for increased quantities of virgin paper in the market place. Avoidance credits of 4/5ths of emissions that would have occurred at SWDSs in the absence of recycling were claimed. Results of the above scenarios are shown in Table 66.

<table>
<thead>
<tr>
<th>Visy virgin LCA Study 3</th>
<th>Functional Unit 1</th>
<th>Functional Unit 2</th>
<th>% Change from baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t CO2(e)/ADt paper manufactured</td>
<td>t CO2(e)/ADt cardboard product manufactured</td>
<td></td>
</tr>
<tr>
<td>Scenario 4</td>
<td>NA</td>
<td>+5.12</td>
<td>Baseline</td>
</tr>
<tr>
<td>Scenario 5</td>
<td>NA</td>
<td>+3.53</td>
<td>-31%</td>
</tr>
<tr>
<td>Scenario 6</td>
<td>NA</td>
<td>+1.86</td>
<td>-64%</td>
</tr>
</tbody>
</table>

Scenario 4: Assume no recycling
Scenario 5: Assume 48,323 ADt was recycled 5 times
Scenario 6: Assume 102,925 ADt was recycled 4 times
NA=Not Applicable

Table 66 Consequence of recycling virgin paper

Table 66 verified that recycling a proportion of the manufactured virgin paper reduced emissions. As expected, the more fibre that was recycled (scenario 6), the lower the emissions.

Based on the results of the above assessments, conclusions and recommendations for further research were made and are outlined in Chapters 6 & 7.
Chapter 6

6. Conclusions

The developed Visy recycled and virgin LCA models represented the Visy papermaking processes and were used in a commercial context. The goals of the Visy research were all achieved. The research outlined in this thesis has established Visy’s GHG baseline for its existing recycled papermaking process, and it’s proposed virgin papermaking process.

Using the Visy LCA models, the GHG effect of Visy’s paper (Visy Paper) and cardboard manufacturing (Visy Board) operations was determined. Visy is now in an informed position to react quickly in the event of any future GHG emission regulation/control.

6.1 Visy papermaking processes - GHG emissions

Using LCA methodology, CO$_2$ and CH$_4$ emissions were quantified for both the Visy recycling and virgin papermaking processes. LCA models were developed for each papermaking process. The majority of emissions in both LCA models occurred in the manufacturing, post manufacturing and disposal unit processes. Fossil fuel energy sources were responsible for the majority of these emissions. Transport emissions in both models were found to be responsible for only 3-5% of total LCA emissions.

6.1.1 Visy recycling papermaking process

The following conclusions were made for the Visy recycled papermaking process.

The location of Visy’s Australian paper recycling and converting plants had a large effect on electricity and gas GHG emissions

Australian States were found to have different CO$_2$(e) emission factors for electricity and gas. The magnitude of the emission factors was dependent upon the fossil fuel source used. Table 24 indicates that Victoria had the highest CO$_2$(e) emission factor for electricity and New South Wales has the highest CO$_2$(e) emission factor for gas.
Compared to the other Australian States, electricity usage in Victoria and gas usage in New South Wales lead to comparatively higher GHG emissions.

**Increased energy efficiency reduced GHG emissions**

Table 37 identified that by increasing the energy efficiency at the paper recycling plants, less energy was required to manufacture the same volume of product. When less fossil fuel energy is used, GHG emissions are reduced.

**Cogeneration plants**

Table 37 identified that cogeneration technology would significantly reduce GHG emissions. The combined production of heat and electricity from natural gas produces significantly fewer emissions compared to coal fired power stations. Table 37 identified that introducing cogeneration technology to more Visy paper recycling plants would lead to emission savings of 0.97 t CO$_2$(e)/t paper manufactured.

**Third party provided steam was effective in reducing GHG emissions**

In 1998/99, sourcing steam from a third party provider significantly reduced emissions at VP3&6. This was due to the cogeneration technology used and the assumed liability for only 50% of boiler GHG emissions at the cogeneration plant. Results indicated that even if Visy were accountable for all of the boiler emissions from the cogeneration plant, its total emissions would still be lower when compared with emissions from the use of less efficient technologies. Table 37 indicated that sourcing steam from third party providers reduced Visy’s GHG liability by 0.20 t CO$_2$(e)/t paper manufactured.

**Burning solid waste rejects from the paper recycling plants**

Using solid waste rejects from the paper recycling plants as fuel reduced CH$_4$ emissions at SWDSs. The incineration of solid waste rejects was found to reduce VP8’s GHG emissions at SWDS by 11.2%. In addition to avoided CH$_4$ emissions the energy recovered in the incineration process reduced the quantity of fossil fuel required for the manufacturing process.
Anaerobic digesters

Under anaerobic conditions, high levels of degradable carbon in effluent increase the potential to form CH₄. Anaerobic digesters act by reducing the BOD levels of effluent. Although Table 29 indicated that the anaerobic digester at VP8 was effective in reducing effluent BOD levels, its effect was not large. Results indicated a reduction of only 1.4%.

6.1.2 Visy virgin papermaking process

Results indicated that fossil fuel usage was responsible for the majority of emissions at the pulp mill

Table 48 demonstrates that electricity sourced from the grid was responsible for 71% of GHG emissions at the pulp mill.

Replacing fossil fuel with carbon neutral fuel significantly reduced emissions

The use of biomass in the Biomass Cogeneration Plant was found to significantly reduce GHG emissions at the pulp mill, as sustainably produced renewable energy sources are classified as ‘carbon neutral’ according to IPCC Guidelines (IPCC 1997). Analysis of the pulp mill data indicated that replacing fossil fuel with a sustainably produced renewable energy source reduced emissions by 0.76 t CO₂(e)/ADt.

6.1.3 Value of Greenpower

Under the Renewable Energy (Electricity) Act 2000 (AGO 2001(a)), any excess renewable energy produced at the pulp mill and sold to the grid as Greenpower was identified as potentially a very valuable resource. The introduction of the Act has increased the price and demand for Greenpower. Two streams of opportunity were identified:

- The power itself, which will assist electricity companies to meet their renewable energy obligations under the Act.
- The RECs that will be sold at a price determined by market forces.
6.1.4 Ownership of plantation carbon rights

There are many uncertainties associated with the development of a carbon sink. If international negotiations enable sequestered carbon credits to be traded as part of an emission trading regime, and the wood harvested emissions are transferred to the buyer of the wood product, the ownership of plantation carbon rights may be a good business opportunity.

It is essential that the plantations be sustainably managed in order to maximise the carbon accumulation in the plantation at any one time (particularly during 2008-2012) and claim the carbon neutral status of the feedstock for the Biomass plant.

Whether Visy should proceed with gaining the carbon rights to their forestry development is very much dependant upon current international negotiations. Some concerns have been raised in regard to the AGO preferred carbon accounting model (CAMFor), as companies using the model may find that it increases plantation costs, is inflexible and difficult to use.

6.2 LCA models

The research found that the LCA tool was capable of quantifying and comparing GHG emissions in respect of CO₂ and CH₄ at Visy Industries. Developing process models with common structure enabled a comparison to be more easily made between the two Visy papermaking processes.

The flexible and dynamic nature of LCA enables the methodology to be used under different operating conditions. As shown in Table 29, the same LCA model was able to determine the GHG consequences of using different proportions of energy and different energy sources.

Information gained from the LCAs could be presented in the appropriate language and life experience of the pulp and paper industry. Visy staff are experienced in evaluating data in terms of production levels, so the presentation of GHG emissions in terms of
t CO$_2$(e)/ADt of paper manufactured or t CO$_2$(e)/ADt of cardboard product manufactured, presented no difficulties to Visy staff. The GHG liability of the two Visy operations, Visy Paper and Visy Board was also presented.

The construction of the Visy LCA models were very time consuming and expensive. One of the greatest difficulties encountered, were the barriers that exist within Visy that tended to inhibit system thinking. This organisational problem is common within industry and occurs where people are trained to concentrate on specific aspects of an organization. The author was aware that fragmentation could occur which would make it difficult to view a process holistically. Vital process steps could be overlooked. This occurred in the Visy paper recycling LCA studies 1 & 2, necessitating more data collection and further refinement of the LCA system boundaries.

The collection of data was very time consuming for both the author and Visy staff. Data were difficult to assemble in a timely manner, as a relevant reporting procedure did not exist at Visy at the time.

The following issues were found to have a very large effect on the Visy LCA models:

1. The choice of an appropriate functional unit.
2. Placement of the LCA system boundaries.
3. Emissions assigned to locally sourced wastepaper.
4. Recycling of Visy virgin paper.
5. Avoidance credits claimed as a result of recycling.
6. GHG liability associated with purchased product.

1. The choice of an appropriate functional unit

Three different functional units were tested in the Visy LCA models. Each functional unit produced different LCA results. One the three functional units tested, Functional Unit 1 and Functional Unit 2 were found to be the most meaningful to Visy, as these functional units separately defined the GHG consequence of the two processes.
2. Placement of the LCA system boundaries

According to the Visy LCA models, Visy manufactured paper taken out of the Visy system was deemed to be outside the LCA system boundary. Designing the Visy LCA models in this way enabled GHG emissions that were directly attributable to the production of Visy paper and cardboard to be readily quantified. Emissions that occurred after the paper was removed from the Visy system were considered to be the responsibility of the purchaser.

3. Emissions assigned to Australian sourced wastepaper

As shown in Table 64, the greatest effect of incorporating emissions assigned to Australian sourced wastepaper was seen in the Visy recycling LCA model. When a mix of 50% once used virgin and 50% recycled paper was incorporated into the study, the baseline value changed.

4. Recycling Visy virgin paper

Recycling virgin paper reduced emissions. Table 66 indicated that if 48,323 ADt of virgin paper manufactured at the pulp mill were recycled 5 times, emissions decreased 31% from a baseline that assumed no recycling. When 102,925 ADt of virgin paper were recycled 4 times, emissions decreased 64% from the baseline.

5. Avoidance credits

Results shown in Table 36 indicated that the inclusion of avoidance credits in the Visy recycled LCA model had a significant effect on total LCA emissions. Table 51 indicated a smaller effect in the Visy virgin LCAs, as only a small quantity of wastepaper will be processed at the pulp mill. The higher the number of times paper was assumed to be recycled, the larger the avoidance credit claimed. These results demonstrated the importance of knowing the number of times paper is actually recycled in Australia, rather than the number of times paper is capable of being recycled.
6. **GHG liability associated with purchased product**

The Visy LCAs included emissions assigned to imported wastepaper, including OCC. These emissions were calculated as the sum of the first four unit processes of the Visy virgin process i.e. acquisition, pre-processing, manufacturing and converting emissions. As shown in Table 20, the calculated value for emissions assigned to imported wastepaper used in all paper recycling LCAs was 0.87 t CO₂(e)/ADt. Excluding these emissions resulted in a 6% reduction in total paper recycling LCA emissions.
Chapter 7

7. Recommendations

GHG research recommendations are discussed in the following categories:

1. Business and political.
2. Technical.

7.1 Business and political

Recognition of avoidance credits

At a government level, Visy should actively pursue recognition for avoidance credits. Avoidance credits acknowledge the benefits of recycling. These credits are openly accepted within the GHG national and international scientific community, but to date, the Australian government has given no indication that they will allow such credits to be included in a company’s emission baseline. Formal recognition of avoidance credits is vital if Visy wish to reduce its emissions to below a designated level and trade emission credits.

Resolution regarding the GHG liability for assigned emissions

The author acknowledges that greater consistency in the treatment of emissions assigned to paper/paper products would have led to more reliable results. However, the responsibility for GHG emissions assigned to paper products is still to be resolved at both a national and international level. This meant that the decision to include or exclude emissions assigned in the Visy LCAs was a subjective decision.

Where emissions assigned to imported paper were included in the LCA model, the emissions have been ‘charged in Australia’. However, emissions assigned to paper sold out of the Visy system were not included in the original model. For consistency, it stands to reason that if Visy takes the GHG responsibility for imported paper then buyers of Visy products should take a similar responsibility for paper that is no longer owned by Visy. The alternative would be to completely disregard all emissions
assigned to all paper products. Visy should be actively involved in discussions to ensure that an appropriate system boundary is established that is fair to all parties.

**Elimination/reduction of fossil fuel usage**

From a GHG perspective, Visy should make every effort to eliminate the use of fossil fuel as its main energy source and switch to renewable energy sources. Such a decision would substantially reduce GHG emissions.

**Produce Greenpower**

Visy should investigate further opportunities to capitalise on the opportunities that have become available under the Renewable Energy (Electricity) Act 2000. Increased Greenpower sold to the grid in compliance with this Act has the potential to create a very large revenue flow for Visy.

**Develop strategies regarding plantation carbon sink development**

Until international negotiations have been resolved, no firm decisions should be made in regard to the development of plantation carbon sinks. As of early 2001, the inclusion or exclusion of plantation carbon sinks within the Kyoto Protocol was still to be resolved. In addition to the above, too many uncertainties still exist in many areas of carbon sequestration eg. the quantification and verification of plantation carbon sinks and the ownership of carbon and GHG emissions at harvest.

Visy should continue to develop strategies but not act on these strategies until international negotiations have been resolved. With strategies prepared, Visy would be in an ideal position to influence the policy makers. From a commercial perspective, Visy should do all they can to prepare and influence the outcome of these issues.

**Data collection**

The research has highlighted the need for Visy to implement a procedure that ensures that Visy specific data is readily available. The data should be presented in the
required format, such as a common database. Such a database would significantly reduce the time and cost of data collection.

**Further investigation is required to determine:**

- The number of times different types and grades of paper are recycled in Australia. This information will greatly assist the verification of avoidance credits.
- The GHG consequence of the Visy de-inking process at VP4. If this process is found to emit high levels of emissions and GHG restrictions come into force, Visy will need to introduce strategies to reduce these emissions. Determining the effect of this process on GHG emissions before possible GHG restrictions will give Visy time to determine suitable reduction strategies.
- Emissions resulting from the growth and transport of seedlings from the nursery to the plantation. Quantifying these emissions will enable Visy to determine the consequence of these activities in the Visy virgin model.
- A suitable method for calculating GHG emissions in effluent. Quantifying effluent emissions will give a better indication of actual emissions from the various Visy processes.

**7.2 Technical**

The reliability of the LCA outcomes would be improved by the following recommendations.

**Need for accurate data**

The effect of subjective decisions should always be assessed by sensitivity analyses. Every effort should be made to eliminate as many subjective decisions as possible. Where actual data is not available, Australian generic data should be used, as data from other countries is not appropriate for Australian conditions (Sutton 2000).
Multiple assumptions

Only single assumptions were investigated in this research. Quantifying the effect of multiple assumptions would give an indication of the best and worst case outer limits of emissions.

Choice of Functional Unit

The chosen functional unit should be reviewed for suitability each time the LCA system boundaries are redefined. The unit must be applicable to the process being investigated and understood by the relevant industry.

LCA procedure and system training

The following LCA recommendations are directed to both industry and LCA practitioners. For LCA to be effectively used as a decision support tool, people need to be trained in the LCA procedure and system thinking. Perhaps the best way to achieve these objectives is through LCA short courses and workshops. In addition to short courses and workshops, the author is aware that some universities such as Curtin, Sydney, RMIT, Queensland and Western Sydney have LCA modules in their undergraduate courses.
### 8. Appendices

**Appendix 1 Summary of major environmental events**

**Summary of major environmental events that culminated in the development of the Kyoto Protocol**

<table>
<thead>
<tr>
<th>YEAR</th>
<th>EVENT</th>
<th>ACTIONS</th>
<th>RESPONSIBILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td>First World Climate Conference</td>
<td>• The Conference called on the world’s governments to:</td>
<td>World governments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>‘Foresee and prevent potential man-made changes in climate that might be adverse to the well being of humanity’</td>
<td>WMO, UNEP &amp; ICSU</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• WCP established</td>
<td></td>
</tr>
<tr>
<td>Late 1980's &amp; early 1990's</td>
<td>Intergovernmental conferences on climate change</td>
<td>• Addressed scientific and policy issues and called for global action.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Focused international attention on climate change</td>
<td></td>
</tr>
<tr>
<td>1988</td>
<td></td>
<td>• IPCC established</td>
<td>UNEP &amp; WMO</td>
</tr>
<tr>
<td>1990</td>
<td>Second World Climate Conference</td>
<td>• The conference called for a framework treaty on climate change</td>
<td>World governments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• IPCC First Assessment Report released</td>
<td>IPCC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• INC/FCCC developed in readiness for Rio 'Earth Summit' Conference</td>
<td>United Nations General Assembly</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Rio Declaration</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Agenda 21</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Convention on Biological Diversity and Forest Principals</td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>COP-1 meeting</td>
<td>• INC was dissolved and replaced by COP</td>
<td>World governments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The 'Berlin Mandate' was adopted. The mandate required commitments to be made for the post 2000 period</td>
<td>IPCC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• IPCC Second Assessment Report was released. It stated that 'the balance of evidence suggests that there is a discernable human influence on global climate’</td>
<td></td>
</tr>
<tr>
<td>YEAR</td>
<td>EVENT</td>
<td>ACTIONS</td>
<td>RESPONSIBILITY</td>
</tr>
<tr>
<td>------</td>
<td>-------</td>
<td>---------</td>
<td>----------------</td>
</tr>
</tbody>
</table>
| 1996 | COP-2 meeting | The following activities were reviewed:  
- Reports from COP1  
- Berlin Mandate  
- Development and transfer of technologies  
- IPCC Second Assessment Report | World governments |
| 1997 | COP-3 meeting | Kyoto Protocol  
Each country was allocated an emission target based on 1990 emissions  
3 mechanisms were proposed  
- Clean Development Mechanism  
- Emission Trading  
- Joint Implementation | World governments |
| 1998 | COP-4 meeting | A two-year Plan of Action was adopted.  
Deadlines were set for finalising the outstanding details of the Kyoto Protocol | World governments |
| 1999 | COP-5 meeting | Progress made on Kyoto Protocol issues:  
- Accelerating the negotiation process  
- Kyoto mechanisms  
- Land Use, Land Use Change and Forestry  
- Compliance | World governments |
| 2000 | COP-6 meeting | No resolution on Kyoto mechanisms that could be used to reduce emissions. Ratification of the Kyoto Protocol did not occur | World governments |

WCP = World Climate Program,  
WMO = World Meteorological Organization  
UNEP = United Nations Environment Program,  
ICSU = International Council of Scientific Unions  
IPCC = Intergovernmental Panel on Climate Change  
INC/FCCC = Intergovernmental Negotiating Committee for a Framework Convention on Climate Change  
COP = Conference of the Parties
Appendix 2 Research Plan

The research plan, which included regular liaising and reporting to Visy staff during all phases of the research was as follows:

- Gain knowledge of the papermaking processes and in particular the Visy papermaking processes by researching and asking Visy staff countless questions.
- Extensively review information regarding:
  - GHGs and their quantification.
  - National and international GHG guidelines.
  - Different environmental support tools that could be used.
- Keep informed in regard to current developments in GHG research and methodologies by extensive networking and attending seminars and conferences.
- Collect all relevant data i.e. Visy on-site specific data, national and international data.
- Evaluate and determine the environmental support tool to be used.
- Define the Visy virgin and recycled papermaking system boundaries.
- Use the international (eg. IPCC) and national (eg. AGO) Guidelines to quantify the data in terms of CO₂ and CH₄ emissions for both papermaking processes.
- Develop a specific, flexible unique computer program to enable quick and easy quantification of CO₂ and CH₄ emissions.
- Compare the two Visy papermaking processes in terms of CO₂ and CH₄ emissions.
- Determine the effect of different forms of energy, technologies and manufacturing processes on CO₂ and CH₄ emissions.
- Determine the GHG effect of Visy’s virgin and recycled papermaking processes.
- Use the results to identify and propose Visy specific GHG reduction strategies and business opportunities.
- Evaluate the appropriateness of the chosen methodology.
Appendix 3 Detailed flowcharts of the Visy paper recycling and virgin processes
Appendix 4 Visy paper recycling and virgin life cycles

Figure 1 Visy Paper Recycling Life Cycle
Appendix 4

Figure 2 Visy Virgin Papermaking Life Cycle

Virgin paper life cycle showing energy and greenhouse gas flows
Appendix 4

Figure 3 Visy Virgin and Recycling Paper Life Cycle
Appendix 5 Steam calculation

CO₂ emitted from a natural gas fired package boiler

Mr. Rob Ironside provided this information in 1999 when he was working for Visy Industries.

Assumptions used:
1. Boiler efficiency = 79%
2. Fuel GCV = 49,780 kJ/kg
3. Carbon content of gas = 0.7145 kg C/kg gas

1. Heat to steam:
Enthalpy of saturated steam at 18.5 bar absolute = 2,795.5 kJ/kg steam
Less the enthalpy of incoming feedwater at 168°C saturated = 710.4 kJ/kg steam
Heat to steam = 2,085.10 kJ/kg steam

2. Heat from gas = (heat to steam)/(boiler efficiency):
2,085.10/79*100 = 2,639.37 kJ/kg steam

3. Gas flow rate = (Heat from gas)/(GCV of fuel)
2,639.37/49,780 = 0.05302 kg gas/kg steam

4. One mole of carbon produces one mole of CO₂ =0.7145 kg C/kg gas which is equivalent to 0.0595 moles C/kg gas
Therefore 0.7145 kg C produces 0.0595 moles CO₂/kg gas
0.0595 moles CO₂/kg gas equates to 0.0595 *(12.011+31.999)=2.62 kg CO₂/kg gas

5. CO₂ emitted per unit of steam = (CO₂ emitted per kg gas)*(kg gas required to generate a kg of steam)
CO₂ emitted per unit of steam = 2.62* 0.053
= 0.1388 kg CO₂/kg steam
Appendix 6 Calculations used to quantify CH₄ emissions in SWDSs

Calculations used to quantify CH₄ capturing and flaring activities in SWDSs

The default methodology used for calculating CH₄ emissions in SWDSs in the IPCC Guidelines (IPCC 1997) used a mass balance approach. This approach uses the Degradable Organic Carbon (DOC) content of the solid waste and the Fraction of dissimilated DOC (DOCₖ) to determine the amount of CH₄ generated by the waste. The GCO adopted the same approach, and recommended the following method for estimating total emissions from SWDSs (GCO 1997).

A6 Equation 1

t CO₂(e) emissions from SWDSs = tonne of paper sent to SWDSs x 3.234

Where 3.234 = 0.4 x 0.77 x 0.5 x 21

0.4 = the fraction of degradable organic carbon (DOC). This is a measure of the quantity of carbon in the waste that degrades to CH₄.
0.77 = the fraction of dissimilated degradable organic carbon. This factor represents the fraction of degradable carbon that is released in landfill gas. The IPCC report states that the value of 0.77 is currently under review (IPCC 1997). As the IPCC have not included these changes in the current Guidelines, the original recommended values have been used in this thesis.
0.5 = conversion factor. This factor represents the fraction of methane in landfill gas.
21 = GWP for methane.

Equation 1 was used in Studies 1 and 2.

The GCO neglected to include a carbon to methane factor of 16/12 (molecular weights of methane and carbon) in Equation 1. This factor is part of the IPCC Guidelines (IPCC 1997). Once the CH₄ factor was incorporated, the equation became:

A6 Equation 2

t CO₂(e) emissions from SWDSs = tonne of paper sent to SWDSs x 4.3
Where \( 4.3 = 0.4 \times 0.77 \times 0.5 \times 21 \times 1.33 \)

In terms of methane, the equation became:

**A6 Equation 3**

\[ t_{CH_4} \text{ in SWDSs} = \text{tonne of paper sent to SWDSs} \times 0.2048 \]

These equations do not account for methane capturing or flaring at SWDSs. Research conducted on this aspect of the LCA produced Equations 4-7. Due to a lack of data, IPCC default values have been used throughout the equations (IPCC 1997).

**A6 Equation 4**

\[ t_{CH_4} \text{ recovered} = t_{CH_4} \text{ in SWDS} \times 0.054 \]

Where:
\[ 0.054 = 0.10 \times 0.6 \times 0.9 \]

0.1 = Due to a lack of data, the author has assumed that the number of Australian SWDSs capturing or flaring \( CH_4 \) is 10%. A sensitivity analysis was conducted on this assumption. The analysis indicated that even a value of 40% was not significant to the LCA. Based on this knowledge, the 10% value was used in all subsequent studies.

0.60 = is the assumption used for the efficiency of the SWDS gas collection.

SCS-Wetherill Environmental supplied this information.

0.9 = is the methane correction factor. This factor accounts for the methane generation potential of the site. The author has used the average of the IPCC default values for managed/unmanaged SWDSs (IPCC 1997).

**A6 Equation 5**

\[ t_{CH_4} \text{ remaining in SWDS} = t_{CH_4} \text{ in SWDS} - t_{CH_4} \text{ recovered} \]

**A6 Equation 6**

\[ t_{CO_2(e)} \text{ in SWDS} = t_{CH_4} \text{ remaining in SWDS} \times (1-0X) \times 21 \]
(1-OX) = Oxidation factor (IPCC default value is 0). This factor represents the oxidation of methane by microbes in the soil layer (IPCC 1997).

Combining Equations 3-6 resulted in Equation 7, which was used in recycling LCA Studies 3 and 4.

A6 Equation 7

\[ t\text{ CO}_2(e) \text{ remaining in SWDS} = \text{ paper sent to SWDSs} \times 0.2048 \times 0.946 \times 21 \]

Which became:

\[ t\text{ CO}_2(e) \text{ remaining in SWDS} = \text{ tonne of paper sent to SWDSs} \times 4.07 \]
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10. Publications

The author has published the following publications:


11. Glossary

**Aerobic Decomposition**

The microbial breakdown of a molecule into a simpler form in the presence of oxygen. The primary product of aerobic decomposition is CO$_2$.

**Air Dry (AD)**

The term applied to any pulp or paper sample whose moisture content in equilibrium with the surrounding atmospheric conditions.

**Anaerobic Decomposition**

The microbial breakdown of a molecule into simpler molecules or atoms in the absence of oxygen. The primary product of anaerobic decomposition is CH$_4$.

**Anthropogenic**

Anything caused or created by human activity.

**Emissions assigned**

GHG emissions emitted as a result of the production of a product. This term is often called ‘embodied emissions’

**Assimilated carbon**

Assimilated carbon is carbon that is released as a result of waste breakdown. This carbon forms part of the cellular material in microorganisms.

**Avoidance credits**

Carbon credits claimed as a result of an activity that avoided the production of GHG emissions. These emissions would have occurred in the absence of that activity. In the context of this thesis, the term has been used to describe the credits that have been claimed as a result of recycling. Recycling paper avoids the production of CH$_4$ in
SWDSs. The size of the credit is dependent upon the number of times paper is recycled.

**Biochemical Oxygen Demand (BOD)**

BOD is used as a measure of the amount of oxygen that would be consumed if all the organics in one litre of water were oxidised by bacteria and protozoa.

**Biomass**

Non-fossilised organic material both above ground and below ground, living and dead, eg. trees, crops, grasses, tree litter, roots etc. When burned for energy purposes, these materials are referred to as biomass fuels.

**Biosphere**

The biosphere is made up of the earth’s animals, plants and soil.

**Carbon credit**

This is the opposite of carbon emission, and occurs when CO₂ is removed from the atmosphere and stored.

**Carbon Offset**

The consequence of emitting a tonne of CO₂ is negated by avoiding the release of a tonne of CO₂ elsewhere, or absorbing a tonne of CO₂ from the air that would normally have remained in the atmosphere.

**Carbon Sequestration**

Carbon is absorbed or removed from the atmosphere and stored in a terrestrial or oceanic reservoir eg. plantation development where carbon is removed from the atmosphere through the process of photosynthesis.
**Carbon-dioxide equivalent (CO2(e))**

CO2(e) is a measure of the warming effect of GHGs relative to CO2. It is calculated by multiplying the actual mass of emissions of the GHG by its appropriate GWP eg. multiplying methane emissions by 21 will convert them into CO2(e).

**Chemical Oxygen Demand (COD)**

Chemical oxygen demand is a measure of the amount of oxygen required to chemically oxidise organic matter in a sample.

**Converting Process**

The manufacture of products by processes applied after the normal paper manufacturing process eg. waxing, gumming, off-machine coating, printing, bag manufacture, envelope manufacture, box and container manufacture.

**Degradable Organic Carbon (DOC)**

The DOC is the amount of carbon in waste that degrades to CH4. Its value is dependent on the composition of the waste. The IPCC has allocated paper a DOC value of 40%.

**Default values**

‘Best bet’ values used instead of actual measurements.

**Dissimilated Degradable Organic Carbon (DOCf)**

That portion of carbon that is broken down to form CO2 and CH4. Dissimilated DOC is the actual amount of carbon that is released as landfill gas.

**Emission Coefficient**

The amount of emission resulting from the combustion of a unit of fuel. The emission coefficient is also called the emission factor.
Environment

The biophysical, social, economic and political dimensions of our surroundings.

Environmental Impact Assessment (EIA)

EIA can be either a formal or informal process used to evaluate the possible environmental risks or effects of a particular activity.

Environmental Impact Statement (EIS)

A document that is part of the EIA process. The document includes a description of the proposed activity, possible environmental effects, alternatives to the activity, and mitigation measures to be adopted.

Environmentally sound decisions

Environmental strategies that maintain and promote sustainability.

Fuel Cycle

The set of sequential processes or stages involved in the utilisation of fuel, including extraction, transformation, transportation, and combustion. GHG emissions generally occur at each stage of the fuel cycle.

Fossil Fuel

Combustible fuels (and products manufactured from them) that have formed from organic matter within the earth’s crust over geological time scales.

Global Warming Potential (GWP)

The instantaneous radiative forcing that results from the addition of 1 kilogram of a gas to the atmosphere, relative to 1 kilogram of CO₂.

Greenpower

Power produced from a renewable energy source.
**Kraft Pulp**

Pulp made by the alkaline process of cooking fibrous material (wood chips) in a digester under steam pressure with a liquor containing sodium hydroxide and sodium sulphate. Resultant pulp can be bleached or unbleached and is noted for its strength of fibre.

**Life Cycle**

Consecutive and interlinked stages of a product system, from the raw material acquisition or generation of natural resources to the final disposal (ISO 14040 1997).

**Non-renewable energy**

These are finite resources, which are not renewable eg. fossil fuels such as coal, oil and gas.

**Paper Manufacture**

The processing of pulp into paper.

**Photosynthesis**

The conversion of sunlight energy into chemical energy. The process is carried out in green plants and involves the conversion of carbon dioxide and water into carbohydrates and oxygen. Sunlight is the energy source used to drive the process.

**Process flow diagram**

Chart containing labelled boxes connected by lines with directional arrows to illustrate the unit processes or sub-system included in the product system and the interrelationships between those unit processes.

**Pulp**

Fibrous material, generally of natural vegetable origin, made ready for use in further manufacturing processes.
**Wastepaper Recovery Rate**

The total wastepaper collected as a percentage of the total apparent consumption of paper.

**Recycling**

The return of a used material for manufacture into new products of the same general type eg. the repulping and manufacture of paper out of wastepaper.

**Recycled fibre**

Fibre reclaimed from pre-consumer or post-consumer wastepaper.

**Renewable energy**

Any source of energy that can be used without depleting its reserves eg. sunlight, wind, wave, biomass and hydro energy. Biomass refers to any recently produced organic matter. If the organic matter was produced sustainably then it is considered to be a renewable energy resource.

**Respiration**

The process where oxygen and food is converted into energy. All livings things respire, from simple plants to complex animals.

**Sensitivity analysis**

A procedure whereby results are analysed to determine whether a small change will cause a significant effect.

**Solid Waste Disposal Site (SWDS)**

This refers to land disposal of solid waste. In Australia these sites are commonly called ‘landfills’. The use of the term SWDS is more in keeping with IPCC Guidelines.
System boundary

Interface between a product system and the environment or other product systems.

Tool

An instrument used to conduct a specific activity. Complex environmental decisions may require a range of complementary tools eg. LCA and CBA.

Unit process

The smallest portion of a product system.

Wastepaper Utilisation Rate

The total recovered paper used in domestic production as a percentage of the total domestic production of paper.

Virgin Fibre

Fibre made from new feedstock.

Wastepaper

In the context of this thesis, the term wastepaper was used to cover all paper that was no longer virgin. This included recycled paper, OCC, kraft waste and once dried pulp.
Visy Recycled Papermaking process model

Visy Virgin Papermaking process model

Note that most recycled paper by-passes the recycling plants and goes directly to the paper recycling plants.