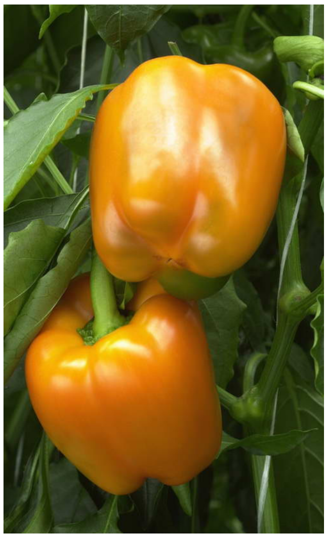
The Carbon Footprint of New Zealand Greenhouse Grown Tomatoes and Capsicums

Life Cycle Assessment



Prepared by

Andrew Barber and

Glenys Pellow

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ACKNOWLEDGEMENTS

This project was jointly funded by MAF Sustainable Farming Fund (SFF) and Horticulture New Zealand's Fresh Tomato Product Group.

The crucial heating data was provided by over 350 greenhouse vegetable growers who responded to the 2004 survey in unprecedented numbers. Such a large response has ensured a sound basis on which to conduct the analysis and prepare the detailed content of this report.

Our thanks are extended to those in the NZ Greenhouse Tomato and Capsicum Industry who have provided data and information enabling this report to be compiled, especially Tony Ivicevich, Hamish Alexander, Michael Gargiulo, Brian Gargiulo, Chris Sinnott, John Ewers, Bryan Hart, Faber Glasshouses, Redpath Greenhouses, Stephen McKinnie Horti Centre, Chris Goodall, Richard Hector, and John White. Special thanks to Ken Robertson (Senior Business Manager, HortNZ) Fresh Tomato Product Group.

LIST OF ABBREVIATIONS

Energy and Power

J	joule	basic unit of energy	Factor
kJ	kilojoule	1,000 joules	E3
MJ	megajoule	1,000,000 joules	E6
W	watt	basic unit of power = 1 joule per second	
kW	kilowatt	1,000 watts	
kWh	kilowatt-hour	3.6 MJ	

Others

ha	hectare	10,000 square metres
kg	kilogram	
t	tonne	1,000 kg
ℓ	litre	
ai	active ingredient	
CO_2	carbon dioxide	
CH_4	methane	
GHG	greenhouse gas	
N_2O	nitrous oxide	
MAF	Ministry of Agriculture and Forestry	
IPCC	International Panel on Climate Change	
MED	Ministry of Economic Development	

Conversions

1 ha = 2.47 acres

1.0 EXECUTIVE SUMMARY

There is growing public concern that carbon dioxide emissions are having a significant detrimental impact on the environment. In particular this has been brought to consumer's attention by various 'Food Miles' campaigns, a constant stream of climate change stories in the media and a desire by some UK supermarkets to label the carbon content of food. The NZ greenhouse tomato and capsicum industries are a mix of domestic and export market producers and have the potential, as producers of high quality high value products, to be directly affected by Food Miles and carbon footprinting requirements.

Accurately determining the NZ greenhouse tomato and capsicum carbon footprints and then gaining insights into how it can be lowered is seen as essential for continued trade.

This project has established the annual average total resource use and greenhouse gas (GHG) emissions or the carbon footprint of New Zealand greenhouse produced tomatoes and capsicums using a life cycle assessment methodology to the point where the fruit arrives at the supermarket. Greenhouse produced crops, unlike most other horticultural products, fruit all year. As such the carbon footprint of any specific tomato may be significantly higher or lower than the annual average figures presented in this report depending on the time of year that it was grown.

While it is essential to capture all resource inputs and emissions from throughout the products supply chain or life cycle, in heated greenhouse operations typically over 85% of the GHG emissions are from the heating source. Table 1 summarise the results for the greenhouse gas emissions of three tomato scenarios a weighted average NZ tomato, and one capsicum scenario. Scenario 1 represents the majority of the tomato industry, an Auckland gas heated glasshouse (most likely using piped hot water); while scenarios 3 and 4 represent the lowest and highest tomato emissions respectively, a double skinned Auckland gas heated plastic house (most likely using ducted heated air) and a coal heated Christchurch glasshouse (most likely using piped hot water). Scenario 6 is an Auckland gas heated glasshouse growing capsicums (most likely using piped hot water).

Table 1: Carbon Footprints Greenhouse Tomato and Capsicum (gCO_2eq/kg marketed fruit)

	Auckland tomato glasshouse using gas	Auckland tomato plastic house using gas	Christchurch tomato glasshouse using coal	Weighted average NZ tomato	Auckland capsicum glasshouse using gas
Scenario	1	3	4	-	6
GH establishment	95	40	95	90	165
Production (excl. heating)	105	105	105	105	175
GH heating	1,860	885	4,475	2,245	3,310
GH waste	35	35	35	35	60
Grading / storage	60	60	60	60	95
Distribution	70	70	70	70	105
Total	**2,225**	**1,190**	**4,840**	**2,610**	**3,910**

The results in Table 1 are based on a tomato yield of 45 kg/m^2 and a capsicum yield of 25 kg/m^2. While there is considerable debate about yield differences between different types of greenhouses, an analysis of yield data found no significant difference either between greenhouse types or location. Given the many variables that impact on yield, not the least of which is management, an industry average was used across all the scenarios tested. There is assumed to be 2% losses in grading and distribution.

Although this project has established an average carbon footprint for NZ greenhouse tomatoes of 2,610 gCO_2eq/kg, this is largely a meaningless number to customers. Even when compared to the carbon footprint of other food it is only one aspect (if the information is available) that consumers may consider when making their purchasing decision amongst more immediate issues of availability, quality and price.

Of more importance than the carbon number itself, is how that number is being lowered. The industry needs to develop stories around the changes that growers are implementing and then be in a position to back this up with evidence that tracks these changes over time.

Clearly greenhouse heating dominates the carbon footprint, so consequently the priority for improvements should focus in this area. Not surprisingly due to the increasing energy costs and some quick payback opportunities for improvement, the industry already has a number of initiatives (MAF SFF 03/158 and 06/057) in place to ensure greenhouse heating and profitability is improved.

2.0 INTRODUCTION

This report presents the methodology and results from a study to establish the resource use inventory for New Zealand greenhouse operations and to determine the carbon footprint of various tomato and capsicum production and distribution scenarios. This project has followed the ISO standards for Life Cycle Assessment that also forms the framework for the PAS 2050 standard (Publicly Available Specification PAS 2050:2008, currently being developed by the British Standards Institute, BSi). The PAS 2050 is being developed specifically for measuring embodied greenhouse gas emissions (GHG) in products and services in response to broad community and industry desires for a consistent method for measuring the embodied GHG emissions of products.

The NZ greenhouse tomato sector produces 94% of its crop for domestic consumption while capsicums are more evenly split with 47% of the crop consumed domestically and the rest exported (Robertson, 2008). Those tomatoes that are exported are predominantly sent to Australia, while most capsicums are exported to Australia and Japan. Both within New Zealand and more so in overseas markets, there is increasing interest in being able to quantify and track trends in a products carbon footprint. This is being done across the products life cycle from the extraction of the minerals that go into its production through the whole supply chain to the products consumption and disposal, or “cradle-to-grave”.

The focus of this work was to establish the first robust and defensible carbon footprint for NZ greenhouse produced tomatoes and capsicums.

The life cycle assessment approach can identify, assess and prioritise environmental impacts (e.g. resource use, GHG emissions, eutrophication, and human health) within and across the business supply chain. Once the model is developed it can also be used to look at the effects of changes at any stage of the cycle or highlight any trade-offs between improvements at one stage in the life cycle, and the consequential impacts at another stage.

3.0 LIFE CYCLE ASSESSMENT (LCA)

3.1 Study Objective

The objective of this study was to use an LCA approach to accurately establish the carbon footprint of NZ greenhouse produced tomatoes and capsicums including modelling a number of different scenarios. These scenarios include the influence of greenhouse type (glass and twin skin plastic), location (Auckland and Christchurch) and fuel type (natural gas and coal) and the heating systems (piped hot water and ducted hot air).

3.2 LCA Approach

Life cycle assessment (LCA) is the examination of a product or services environmental impacts (e.g. resource use, GHG emissions, eutrophication, and human health) through the whole supply chain from the raw materials through production to consumption and disposal, or 'cradle to grave'. Appendix 2 includes details on what an LCA is; why and how one should be undertaken; and the limitations of LCA in the agricultural industry. The approach to be used in conducting an LCA is set out in the ISO Standards 14040 to 14043. As specified in the ISO standards the steps required to carry out an LCA with confidence include:

- Define the purpose and scope,
- Define the system boundary and unit processes to be covered
- Determine functional unit(s) and data categories
- Collect and validate data
- Analyse and interpretation of inventory data, including sensitivity and consistency checks
- Conduct the life cycle impact assessment

3.3 Purpose and Scope

The scope of this LCA is to:

- Establish the resource use inventory for NZ greenhouse tomato and capsicum production, including grading, packing and distribution to the supermarket.
- Evaluate the environmental impact category of greenhouse gas emissions.

3.4 Life Cycle System Boundary

The system boundary defines the processes and input/output components that have been taken into account in the life cycle study. Figure 1 shows a simplified life cycle diagram for tomato and capsicum production that has been used in this study. The dotted line is the system boundary between the environment and the production system.

3.4.1 Components Included Within the System Boundary

As shown in Figure 1, the system defined in this life cycle study includes the impacts associated with:

- Greenhouse establishment. The emissions embodied in the greenhouse capital structure and internal fittings
- The extraction, refinement, formulation, packaging and transport to the grower of fuel, growing media, fertiliser and agrichemicals
- Fuel use on the property. This is predominantly for heating and potentially CO_2 generation, but also includes diesel, petrol and LPG for various activities
- Electricity use in the growing operation, including motorised vents, irrigation, lighting, office administration. Electricity includes fugitive losses in conversion and distribution
- Nitrogen waste disposal through a field irrigation system
- The embodied energy and emissions from capital equipment
- Transport of waste to landfills and composting facilities
- Fuel and electricity use during grading and packing
- Emissions from refrigerants
- Distribution Centre electricity and LPG use
- Transport of fruit between grower, distribution centre and supermarket by truck.

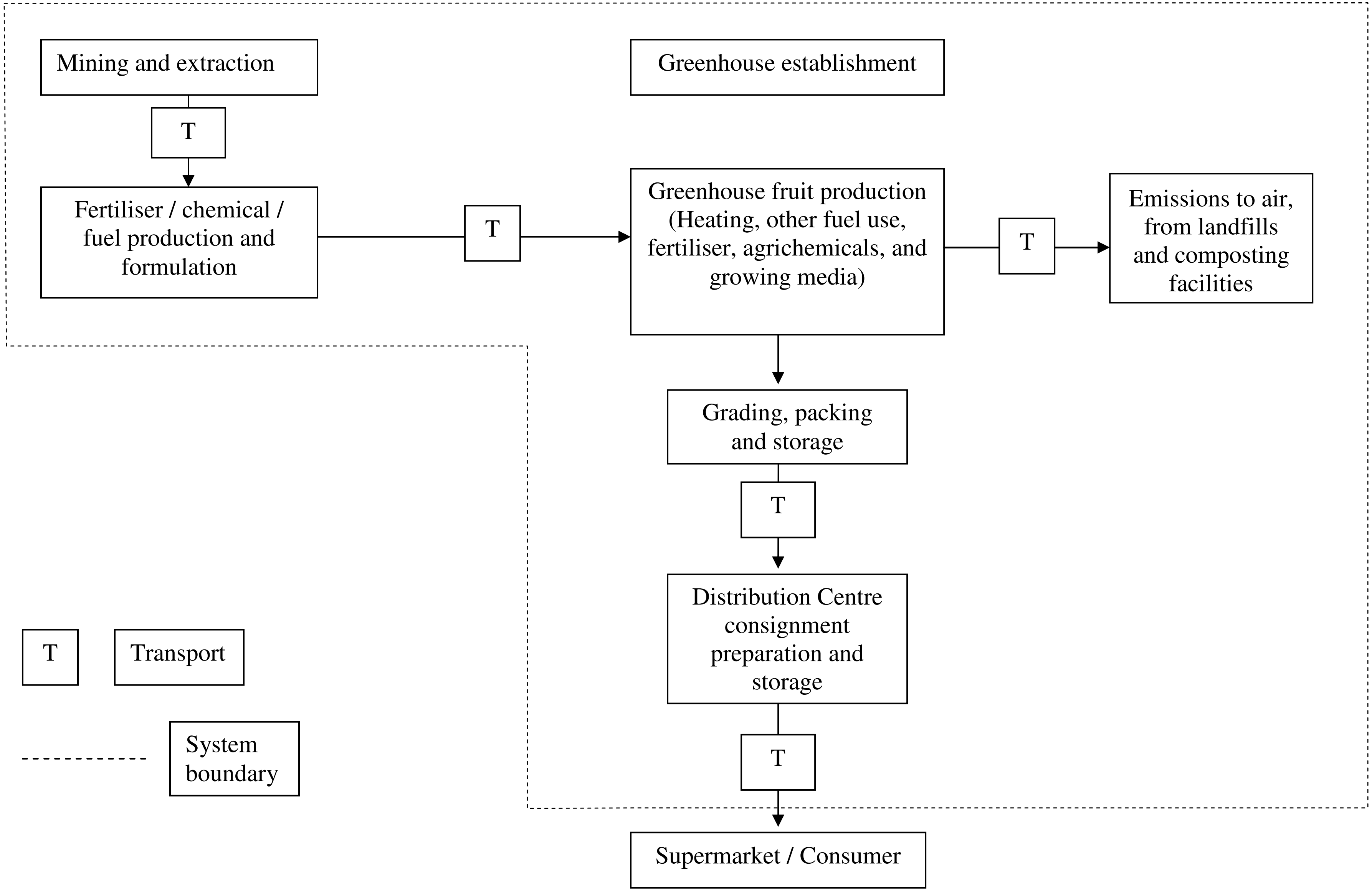
3.4.2 Components Excluded From the System Boundary

The components of the life cycle which have been excluded due to a lack of data are:

- Fruit packaging
- Coconut fibre methane emissions from soaking and retting[1].

[1] retting is the submerging in water of the coconut husk, for up to a year, in order to loosen the fibres; after which time they can be easily removed from the husk

Figure 1: Life Cycle of Greenhouse Fruit Production to the Supermarket



3.5 Functional Unit

The functional unit is a kilogram of fruit arriving at the supermarket.

3.6 Data Categories - Sources

The most significant data was the energy used for greenhouse heating. This was collected from a production and energy use survey of 355 greenhouse vegetable operations in 2004 (Barber and Wharfe, 2004).

The additional greenhouse and packhouse data required for the inventory was collected from product suppliers and growers.

3.7 Allocation of Environmental Impacts to Products

No allocations were needed between products, as there is predominantly only one main product per operation. There was insufficient information to distinguish the heating fuel use based on the crop type within each subcategory of location and greenhouse type.

No distinction was made between domestic and export produce due to the dominance of the domestic crop, particularly in tomatoes. Other horticultural crops may allocate a higher proportion of the environmental impacts to the export crop as the domestic market essentially takes the second grade fruit.

4.0 METHODOLOGY

This project has determined, based on Life Cycle Assessment (LCA) methodology, the total resource use and greenhouse gas emissions or carbon footprint of New Zealand greenhouse tomatoes and capsicums. The life cycle is through to the fruit arriving at the supermarket.

4.1 Tomato and Capsicum Yields

While there is considerable debate about yield differences between different types of greenhouses, an analysis of yield data from the 2004 grower survey (Barber and Wharfe, 2004) found no significant difference either between greenhouse types or location. Given the many variables that impact on yield, not the least of which is management, an industry average was used across all the scenarios tested of 45 kg/m^2 for tomatoes and 25 kg/m^2 for capsicums.

4.2 Fuel, Electricity and Refrigerant GHG Emissions

4.2.1 Global Warming Potentials

Global warming potentials (GWP's) are based on the ability of different 'greenhouse' gases to trap heat in the atmosphere and the decay rates, relative to that of carbon dioxide. GWP's provide a means by which different gases radiative impacts (emissions) can be converted to a common measure denominated in carbon or carbon dioxide equivalents.

Carbon dioxide equivalents are the amount of CO_2 by weight emitted into the atmosphere that would produce the same estimated radiative forcing as a given weight of another radiatively active gas. For calculations, the weight of gas measured is multiplied by its estimated GWP.

The GWP's are published by the IPCC. Consistent with the NZ Government reporting commitments this study uses the GWP's from the IPCC's Second Assessment Report (1995), where carbon dioxide is the reference gas with a GWP of 1, and methane is 21 and nitrous oxide 310.

4.2.2 Summary of Fuel and Electricity GHG Emission Coefficients

Table 2 describes the greenhouse gas emissions (CO_2, CH_4, N_2O) of NZ fuels and electricity.

Table 2: Summary of fuel energy and emission factors

Fuel type	Unit	GHG (gCO_2eq/unit)	MED‡ GHG (gCO_2eq/unit)
Diesel	litres	3,108	2,678
Petrol (regular unleaded)	litres	2,735	2,339
Natural Gas	MJ	53.36	52.35
LPG	litres	1,836	1,624
Coal (sub-bituminous)	kg	2,147	2,044
Average Electricity (2006)	kWh	244.1	228.7

‡ Energy Greenhouse Gas Emissions 1990-2006 June 2007. These are not LCA based, but rather in-use emissions. They are included for comparison but have not been used in this report.

4.2.3 Greenhouse Heating

The energy used for heating was sourced from the raw data collected as part of the energy use survey of 355 greenhouse vegetable operations in 2004 (Barber and Wharfe, 2004).

4.2.4 Electricity

Electricity use was determined by averaging the meter readings provided by several growers.

4.2.5 Refrigeration

Refrigeration is used throughout the post harvest chain to ensure that the product reaching the customer is in the best possible condition. The total life cycle emissions of refrigeration includes: in-use energy consumption, unit manufacture and maintenance, and refrigerant losses. Over 95% of the lifetime emissions are from in-use energy consumption (Bateman, 1999 and Sand et al., 1997). Refrigerant manufacture, losses, and unit manufacture contribute 4.5% of the life cycle emissions (Bateman, 1999).

4.2.6 Transport

Diesel used for road cartage is 0.069 ℓ/tonne-km (Barber, 2004), or 3.117 MJe/t-km, which is based on surveyed fuel use by a transport operation. Rail is 1.000 MJe/t-km (Eyre and Michaelis, 1991), and shipping is 0.114 MJe/t-km (Saunders, et al., 2006).

The distance and type of transport shown in Table 3 was used to determine the transport component of overseas sourced material. Shipping distances were taken from the website www.maritimechain.com/ with truck and rail distances from Milà i Canals (2003).

Table 3: Transport Distances of Overseas Inputs

Country of origin	Truck (km)	Rail (km)	Ship (km)
Germany	200	1,500	21,587
Japan	40		8,921
Australia	40		2,359
Sri Lanka	200		11,536

4.3 Fertiliser and Agrichemicals

4.3.1 Fertiliser

Fertiliser use was determined for tomatoes and capsicums grown in recirculation and run-to-waste systems based on grower discussions and the recommendations of John White (R.A.J White Horticultural Consultants) for plant nutrient use in recirculation systems.

Table 4 shows the average energy costs of manufacturing each component (Wells, 2001). These are average figures taken from a range of different fertiliser production methods. The GHG emission for each nutrient component was determined in the study by Barber and Pellow (2008).

Table 4: Energy Requirements to Manufacture Fertiliser Components

Component	Energy Use (MJ/kg)	GHG (kgCO_2eq/kg)
N	65	3.38
P	15	0.96
K	10	0.64
S	5	0.32
Mg	5	0.32
Lime	0.6	0.43

4.3.2 Agrichemicals

The agrichemical use was determined from grower discussions. A "typical" programme was determined, although agrichemical use is extremely variable across the industry. Environmental influences and climatic variations between regions and years, as well as the issues of resistance development and pest presence or absence will influence the agrichemical programme. Where an integrated pest management programme is used, a complete lifecycle inventory would need to be completed on the beneficial and predator production systems, e.g. *Encarsia* formosa, which is beyond the scope of this project.

The agrichemical emissions included production, formulation, packaging and transport. Further methodology details can be found in the kiwifruit industry study by Barber and Benge, 2006.

The largest quantities of chemicals used, and following discussions with growers the most variable, are cleaners or detergents used both inside and outside the greenhouse.

Cleaning chemicals are mixed products that contain different substances that can be generally categorised as tensides or surfactants, builders, bleaches, and auxiliary agents. The average primary energy input into the detergent ingredients studied by Dall'Acqua et al. (1999) determined that of the chemicals studied the average primary energy input into tensides was 66.7 MJ/kg, builders 17.6 MJ/kg and bleaches averaged 25.5 MJ/kg.

While there are many variations on chemical cleaning formulations, we have assumed a formulation of 16% surfactant (tensides), 60% builder and 24% bleaches and enzymes, with a water content of 6% (Glennie et al., 2002). Therefore the primary energy of a cleaning chemical is approximately 25.2 MJ/L.

Apart from the energy required to manufacture the ingredients there is additional energy for product formulation of 20 MJ/L, assumed to be an emulsifiable concentrate, transport from the manufacturing plant in Australia at 0.4 MJ/L, and 2 MJ/L for packaging (Barber and Benge, 2006). Therefore the total primary energy of cleaning chemicals 47.6 MJ/L and at 0.064 $kgCO_2eq/MJ$ GHG emissions are 3.1 $kgCO_2eq/L$.

4.4 Growing Media

Most growers produce their crops in soilless growing media. This includes either pumice or sawdust filled planter bags, meter long slabs of rockwool or coconut fibre blocks, or hydroponic troughs. Very few commercial operations still grow in the soil.

Two growing media were investigated, rockwool and coconut fibre, these being the most commonly used media types.

4.4.1 Rockwool

Rockwool is used for a range of different purposes and consequently a number of studies have been conducted determining the energy and emissions from its manufacture. The majority of the GHG emissions associated with rockwool manufacture are from the initial heating stages where rocks are heated to a temperature of 1,500°C. The total energy use and greenhouse gas emissions for the pre-production, production, delivery and end of life is 16.80 MJ/kg and 1.074

kgCO_2eq/kg (www.rockwool.co.uk/graphics/RW-GB-implementation/datasheets/LCI_Rockwool.pdf)

Rockwool is being sourced from Europe, so transportation to NZ was added (see Transport section)

4.4.2 Coconut Fibre (coir fibre)

The environmental impact of coconut plantations is thought to be small. In addition as the fibre is a by-product it would only be allocated a small proportion of these inputs and emissions. In a bed mattress LCA study (Deliege and Nijdam, no date), only the fibres transportation was taken into account, because the fibre was considered to be both minor as well as a by-product of the coconut tree. However what this study did not consider was that the fibre extraction process has potentially high environmental impacts. The husks are soaked in ponds for 3 to 9 months to make the fibres soft so they can be extracted from the pith much easier. During this time methane gas is released. The coir sector in India is improving the fibre extraction process to make it more environmentally friendly (Banerjee, 2003). As there is no data on the methane emissions from this process only transport from Sri Lanka has been included.

As at 25 February 2008 MAF required all imported coconut fibre to be heat-treated on arrival (MAF, 2008) but there is currently a temporary exemption (requiring registration and conditions on disposal) in place for coconut fibre slabs wrapped in plastic and used in greenhouse crops. Heat treatment or fumigation would add additional emission costs; however it has not been possible to determine how much, although it is thought to be minor.

4.5 Capital

An assessment was made of all the capital inputs required to establish and maintain the growing structure based on information provided by suppliers, growers and internet searches.

The emission factors and product life of the capital inputs is summarised in Table 5.

Table 5: Material GHG Emission Factors

	Unit	Primary Energy MJ/unit	GHG Emissions $kgCO_2eq/unit$	Product Life years
Glass (toughened)	kg	26.4	1.96	20
Glass (4mm)	kg	15.9	1.77	20
Steel	kg	31.3	3.78	50
Aluminium	kg	218.0	9.41	50
Concrete	m^3	12,005	1,939	50
GH plastic film	kg	51.0	3.75	10
Irrigation				
PVC	kg	61.0	4.60	40
Alkathene	kg	51.0	3.75	20
Packaging				
LDPE	kg	51.0	3.75	1
HDPE	kg	51.0	3.65	1
Cardboard	kg	33.4	2.30	1

Alcorn (2003) describes the primary energy and carbon dioxide emissions for NZ building materials, including glass, steel, aluminium, concrete, PVC and low and high-density polyethylene. The carbon dioxide emission factors were increased by between 2% and 6% to account for the methane and nitrous oxide emissions.

Cardboard energy use was determined from the report Environmental Impact of Packaging Materials (Danish EPA, 2001).

4.6 Greenhouse Gas Field Emissions (Synthetic Nitrogen Fertiliser)

Nitrous oxide (N_2O) emissions occur naturally as a result of nitrification and denitrification processes by bacteria. No research was found that had determined the nitrous oxide emissions from the nitrogen fertiliser applied through the fertigation system.

Where a grower is irrigating their captured nutrient discharge onto a surrounding paddock the emissions from the synthetic nitrogen fertiliser component was determined based on the methodology and default emission factors in the NZ Greenhouse Gas Inventory (MED, 2007).

Nitrous oxide comes from both direct and indirect sources. Direct sources include soil emissions from synthetic nitrogen fertiliser applied in the paddock. Indirect sources include the volatilising and leaching of synthetic nitrogen fertiliser. Additional indirect emissions occur from atmospheric deposition in which soils emit ammonia (NH_3) and oxides of nitrogen (NO_x) that react to form nitrous oxide in the atmosphere.

4.7 Post Harvest

The electricity energy used in packing, grading and coolstorage prior to dispatch was provided by a grower from their annual accounts. An adjustment was made to subtract the growing operation, which was included in the accounts, based on electricity use provided by other growers.

As it was not possible to obtain electricity use for a distribution centre, and then allocate a component to tomatoes and capsicums, it was assumed that as most of the energy is used for coolstorage it would be similar to the growers own coolstorage electricity use.

Based on industry discussions it was assumed that there was a 2% fruit loss between the growers reported yield and what arrives at the supermarket.

4.8 Waste Streams

The main waste streams from the growing operation are plant material, plastic, twine, and growing media. Just prior to removing the crop the growing media (rockwool, coconut fibre, pumice, etc) is dried down. The crop is then cut-off at the base and often mulched before being transported to a composting facility or landfill along with the growing media. Some growing media is disposed of as garden mulch.

MfE (2008) has determined a range of landfill emission factors to account for methane emissions from the anaerobic decomposition of organic waste; these are shown in Table 6.

Table 6: Emission Factors for Waste to Landfill ($kgCO_2eq/kg$)

Material	Landfill without gas recovery	Landfill with gas recovery
Garden waste	0.945	0.572
Wood	1.89	1.14
Mixed waste (national average)	0.874	0.529

Source: MfE, 2008

The garden waste emission factor was used for the tomato and capsicum vine waste material. The emission factor for wood was used for the coconut fibre growing media. Rockwool and plastic, being inorganic, have no landfill methane emissions.

The weight of growing media transported 10 km to the composting facility or landfill was 72 tonnes (715 t-km) based on the partially dried media weighing 5 – 6 kg/m with 13,000 m/ha. The plants weighted 15 t/ha, based on there being 15m^3/ha of mulched plants (C. Goodall, pers. comm.).

The disposal of the 2% waste fruit in the postharvest grading and packing has been accounted for and is included in the grading / packing / storage emissions.

5.0 LIFE CYCLE IMPACT ASSESSMENT

Based on a detailed life cycle inventory for greenhouse grown tomatoes and capsicums (see Appendix 1), six scenarios were developed plus a weighted NZ average tomato; these are described in Table 7. Along with the key aspects described in each scenario description it was assumed that the crops were grown in rockwool and they all used a run to waste irrigation system where the discharged water was captured and irrigated onto land.

On average emissions in the fruit production stage to the greenhouse door accounts for 95% of the marketed fruits total greenhouse gas emissions, and ranged between 89% (scenarios 3) and 97% (scenarios 4).

Table 7: Greenhouse Gas Emissions (Carbon Footprint) in Rockwool growing media

	Scenario	GHG Emissions gCO_2eq/kg marketed fruit	
		To the Supermarket	To the GH Door
1	Auckland tomato glasshouse using gas heated piped hot water	2,225	2,095
2	Auckland tomato glasshouse using coal heated piped hot water	3,510	3,380
3	Auckland tomato plastic house using gas	1,190	1,060
4	Christchurch tomato glasshouse using coal heated piped hot water	4,840	4,705
5	Christchurch tomato plastic house using coal heated piped hot water	4,390	4,255
-	Average NZ tomato	2,610	2,475
6	Auckland capsicum glasshouse using gas	3,910	3,710

Based on the grower survey in 2004 it was possible to weight the 5 tomato scenarios described in Table 7 to determine the carbon footprint of the average NZ tomato. Auckland gas heated glasshouses account for over 75% of the NZ profile.

A sensitivity analysis was conducted to test the effect of halving the life of the capital inputs. Given the small contribution to the life cycle emissions from the greenhouse establishment it is not surprising that when this was conducted the emissions increased by between just 1 to 4% for the different scenarios.

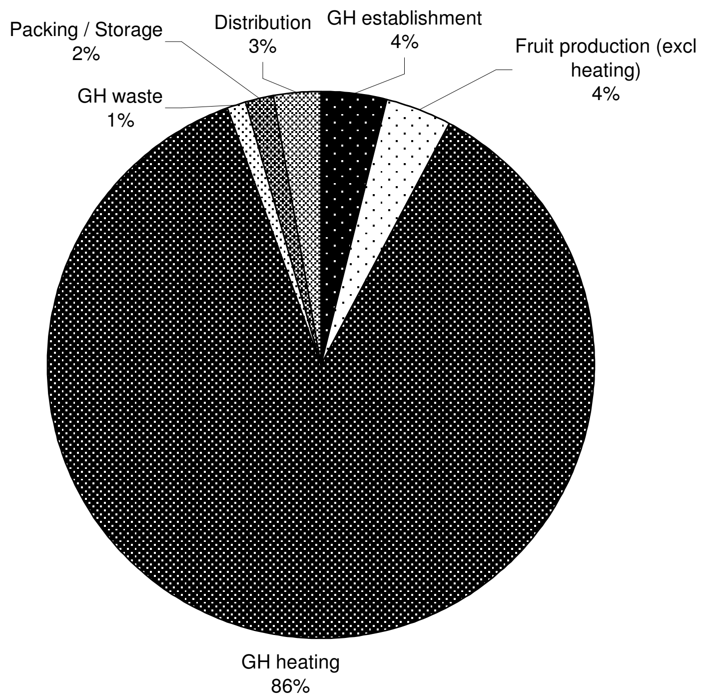
Table 8 shows the contribution of each stage in the production cycle for the four main tomato scenarios, the weighted NZ average tomato and the Auckland capsicum scenario.

Table 8: Carbon Footprints of NZ Greenhouse Tomato and Capsicum (gCO_2eq/kg marketed fruit)

	Auckland tomato glasshouse using gas	Auckland tomato plastic house using gas	Christchurch tomato glasshouse using coal	Weighted average NZ tomato	Auckland capsicum glasshouse using gas
Scenario	1	3	4	-	6
GH establishment	105	40	105	100	185
Production (excl. heating)	105	105	105	105	175
GH heating	1,860	885	4,475	2,245	3,310
GH waste	35	35	35	35	60
Grading / storage	60	60	60	60	95
Distribution	70	70	70	70	105
Total	**2,235**	**1,195**	**4,850**	**2,615**	**3,925**

Figure 2 describes the split of greenhouse gas emissions between the key stages in the average NZ tomatoes life cycle.

Figure 2: Distribution of GHG Emissions for the Average NZ GH Tomato



An alternative scenario was also developed based on using a coconut fibre growing media rather than rockwool; this affects the growing media's production, transport and waste disposal emissions. If the substrate was coconut fibre, fruit production emissions (excluding heating) would decrease by 22% for tomatoes and 39% for capsicums. This is due to coconut fibre being less energy intensive to produce and being transported approximately half the distance compared to rockwool (note the emissions from the production of coconut fibre have not been determined, see Section 4.3.2 Coconut Fibre for further details). There are also emissions from disposing of the organic coconut fibre at the landfill, while rockwool, being inorganic has no landfill emissions. However as fruit production (excluding heating) and waste disposal are only very small components in the life cycle, the overall change in emissions from using coconut fibre would be an increase of just 0.6% for the NZ average tomato and a 1.2% increase for capsicums (Table 9).

Table 9: Greenhouse Gas Emissions – Coconut Fibre Growing Media

	Scenario	**GHG Emissions gCO_2eq/kg fruit**	
		Rockwool	Coconut fibre
-	Average NZ tomato	2,615	2,630
6	Auckland capsicum glasshouse using gas heated piped hot water	3,925	3,970

6.0 CONCLUSIONS

This project has established the carbon footprint of NZ greenhouse produced tomatoes and capsicums for a range of different scenarios from gas heated Auckland plastic houses through to coal fired glasshouses in Christchurch.

The carbon footprint of greenhouse produced fruit to the “farm gate” is larger than any other horticultural crop, although the profiles are likely to start converging when the system boundary is extended to include postharvest emissions. Where greenhouse production has large emissions due to heating, as the fruit is picked and consumed within a couple of weeks they have a small refrigeration requirement and negligible losses. Other fruit that can be stored for long periods of time and slowly released onto the market while having lower production emissions have an ever-increasing postharvest carbon footprint.

Although this project has established a carbon footprint for NZ greenhouse tomatoes of 2,610 gCO_2eq/kg, this is largely a meaningless number. Is this a good or poor carbon footprint? Would 2.6 $kgCO_2/kg$ be a much better result? Even when compared to the carbon footprint of other food items it is only one aspect (if the information is available) that consumers may consider when making their purchasing decision. A customer is also not going to choose an onion over a greenhouse tomato because the latter has a higher carbon footprint. Even a more realistic choice between an outdoor and indoor grown tomato is more likely to be decided based on availability, apart from imported Australian tomatoes for a short period it is often indoor tomatoes or nothing, quality and price.

Of more importance than the carbon number itself, is how that number is being lowered. Even then, unlike the production line for an appliance, there is seasonal variability that can distort the progress that is being made. Despite this seasonal variability the industry needs to develop stories around the changes that growers are implementing and then be in a position to back this up with evidence that tracks these changes over time.

Unlike many other horticultural sectors the carbon footprint of a greenhouse grown fruit is dominated by an input that also represents a significant production cost. Consequently the drivers for improved profitability will also have a large impact on the carbon footprint. Energy costs in other sectors are typically less than 5% of cash expenditure, and so while improved energy efficiency is a nice goal in greenhouse horticulture it is an imperative to staying in business.

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APPENDIX 1

A1.1 Greenhouse Tomato and Capsicum Resource use Inventory and Greenhouse Gas Emissions

	GHG emissions source and activity	Comments and assumptions	Resource use per hectare	Units	Total GHG emissions (kg CO_2eq/ha)
A	**Greenhouse**				
1	Establishing the Greenhouse				
a	Glasshouse Construction Material	1 ha production house			
i	Steel	structural steel including starter plate, frame, nuts & bolts	138,889	kg	10,501
ii	Toughened Glass	14kg/sq m. Used by 16% of NZ industry, often in new houses.	140,000	kg	18,291
iii	4mm Glass	14kg/sq m. Most commonly used glass	140,000	kg	16,545
iv	Annual glass replacement	0.5% of total glass	700	kg	83
v	Concrete	nib 50m^3 /ha; piles 62.5 m^3/ha; path 48 m^3/ha	161	m^3	6,224
vi	Aluminium	structural aluminium	22,500	kg	4,232
b	Plastic house Construction Material				
i	Steel	structural steel including starter plate, frame, nuts & bolts	75,000	kg	5,671
ii	Plastic	0.36 kg/m^2, twin skin plastic	3,600	kg	2,698
iii	Concrete	concrete piles - m^3	60	m^3	2,327
iv	Aluminium	structural aluminium			

	GHG emissions source and activity	Comments and assumptions	Resource use per hectare	Units	Total GHG emissions (kg CO_2eq/ha)
A	Greenhouse				
1	Establishing the Greenhouse				
c	Internal Fit-out				
i	Hot water pipes				
	Heating header pipes	125mm & 100mm tubing - 350m total	2,738	kg	259
	Row pipes	45mm tubing - 13,000m	42,916	kg	4,056
	Transportation	From Glenbrook to Auckland, 60km	45,653	kg	587
		From Glenbrook to Christchurch, 960km	45,653	kg	9,400
ii	Boiler	1.3 MW/ha; 3 tonne boiler	3,000	kg	394
iii	Buffer tank	Will be minor, further investigation required			
iv	Irrigation pipe	65mm mainline PVC - 100m	340	kg	39
		50mm submain PVC - 56m	66	kg	8
		16mm lateral line alkathene - 6,000m	1,574	kg	295
v	Gear motors etc		1,625	kg	123
vi	Vehicles	One tractor and a ute	3,300	kg	1,241
vii	Implements	4 scissor platforms / ha	1,400	kg	526

	GHG emissions source and activity	Comments and assumptions	Resource use per hectare	Units	Total GHG emissions (kg CO_2eq/ha)
A	**Greenhouse**				
2	Fruit Production				
a	Fuel for Heating				
	Glasshouse				
i	Natural gas	Auckland	1,350	MJ/m^2	814,007
ii	Coal	Auckland	64	kg/m^2	1,375,013
		Christchurch	91	kg/m^2	1,955,574
	Double Skin Plastic house				
iii	Natural gas	Auckland	640	MJ/m^2	385,900
iv	Coal	Auckland	30	kg/m^2	651,858
		Christchurch	83	kg/m^2	1,782,424
b	Other Fuel				
iv	Electricity	lights, office, motors	24,000	kWh	5,859
ii	Diesel / Petrol	for vehicles	500	litres	1,554
c	Fertiliser				
i	Embodied carbon / transportation	**tomato** run-to-waste: 3,700 kgN; 700 kgP; 6,100 kgK; 2,100 kgS; 875 kgMg	see assumptions		18,034
		tomato recirculation: 1,600 kgN; 420 kgP; 2,870 kgK; 675 kgS; 340 kgMg			7,973
		capsicum run-to-waste 2,515 kgN; 460 kgP; 3,070 kgK; 690 kgS; 500kgMg			11,288
		capsicum recirculation 1,065 kgN; 275 kgP; 1430 kgK; 215 kgS; 190kgMg			4,909

	GHG emissions source and activity	Comments and assumptions	Resource use per hectare	Units	Total GHG emissions (kg CO_2eq/ha)
A	Greenhouse				
2	Fruit Production				
c	Fertiliser				
ii	Field emissions	**Tomato**, captured N in the drainage is irrigated onto land	1,200	kgN/ha	6,766
		Capsicum, captured N in the drainage is irrigated onto land	840	kgN/ha	4,735
		No drainage on the recirculation systems	0	kgN/ha	0
c	Pesticides	Pesticide programme for crop :			
i	Manufacture / transportation				
		Tomato fungicides	7	kg/ha or L/ha	40
		Tomato insecticides	1	kg/ha or L/ha	4
		Tomato house soap & cleaners	575	kg/ha or L/ha	1,754
		Capsicum fungicides	0	kg/ha or L/ha	0
		Capsicum insecticides	22	kg/ha or L/ha	125
		Capsicum house soap & cleaners	100	kg/ha or L/ha	305
ii	Application	Included in total fuel usage			
d	Growing Media and Plant Support				
i	Plastic bags	Production for **tomatoes,** 4 plants/bag, 1 gm/bag	6	kg	22
		Transport, Asia, Ship - 11,536 km, Cartage 200 km	70	t-km	1
		Production for **Capsicums,** 6 plants/bag, 1 gm/bag	10	kg	37
		Transport, Asia, Ship - 11,536 km, Cartage 200 km	117	t-km	1

	GHG emissions source and activity	Comments and assumptions	Resource use per hectare	Units	Total GHG emissions (kg CO_2eq/ha)
A	Greenhouse				
2	Fruit Production				
d	Growing Media and Plant Support				
ii	Coconut fibre	Production for **tomatoes** kg/ha – further analysis required	9,000	kg	
		Transport, Sri Lanka, Ship 11,536 km, Cartage 200km	105,624	t-km	1,199
		Production for c**apsicums,** kg/ha - further analysis required	15,000	kg	
		Transport, Sri Lanka, Ship 11,536 km, Cartage 200km	176,040	t-km	1,998
iii	Rockwool	Production for **tomatoes**	8,100	kg	8,699
		Transportation from EU; 200km truck; 1,500km rail; 21,587km ship	188,625	t-km	2,552
		Production for **capsicums**	13,500	kg	14,499
		Transportation from EU; 200km truck; 1,500km rail; 21,587km ship	314,375	t-km	4,253
iv	Twine	Tomatoes, 14m/plant	229	kg	857
		Transportation, Australia ship 2,349km, truck 40km	546	t-km	6
		Capsicums, 4 m/plant	160	kg	599
		Transportation, Aust ship 2,349km, truck 40km	382	t-km	4
v	Bobbins	Assumed to be minor component – further investigation required			

	GHG emissions source and activity	Comments and assumptions	Resource use per hectare	Units	Total GHG emissions (kg CO2eq/ha)
A	Greenhouse				
3	Waste Disposal				
a	Plastic Bags	**Tomatoes** : goes to a landfill	6	kg	0
		transportation - 10km	0	t-km	0
		Capsicums : goes to a landfill	10	kg	0
		transportation - 10km	0	t-km	0
b	Growing Media	Goes to landfill / composting	72	t	
		transportation - 10km	715	t-km	153
		Coconut fibre - **Tomatoes** -1.5kg/bag & 6,250 bags / ha	9	t	17,719
		Coconut fibre - **Capsicums** 1.5kg/bag & 10,000 bags / ha	15	t	28,350
		Rockwool - **Tomatoes** 1.35kg/bag & 6,250 bags / ha - emissions considered to be minor	8	t	0
		Rockwool - **Capsicums** 1.35kg/bag & 6,250 bags / ha - emissions considered to be minor	8	t	0
c	Plants	**Tomato** plant to landfill, 15m^3/ha	15	t	14,175
		transportation - 10km	150	t-km	32
		Capsicum plant to landfill, 15m^3/ha	15	t	14,175
		transportation - 10km	150	t-km	32

	GHG emissions source and activity	Comments and assumptions	Resource use per hectare	Units	Total GHG emissions (kg CO_2eq/ha)
B	Grading / Packing / Storage				
a	Transportation	Zero, packhouse is part of growing operation	0		0
i	LPG	For forkhoists	50	litres	92
b	Electricity	lighting, grading and coolstorage	72,000	kWh	17,576
c	Refrigerant	annual and end of life losses			830
d	Packaging				
i	Reusable plastic boxes	Minor, life expectancy of 10 years and reused 8 times/yr			
ii	Wooden pallets	Minor, life expectancy of 5 years and reused 8 times/yr			
iii	Transportation	Reusable boxes and pallets - further investigation required			
iv	Sterilisation	Of reusable boxes - further investigation required			
v	Prepacks	Speciality market - further investigation required			
vi	Shrink wrapping	Assumed to be 12m wrap / pallet; 1,646 pallets / ha - further investigation required			
e	Disposal of Fruit	**Tomatoes** go to landfill, 2%	9	t	
		transportation - 10km	89	t-km	19
		Capsicums goes to landfill, 2%	5	t	
		transportation - 10km	50	t-km	11

	GHG emissions source and activity	Comments and assumptions	Resource use per hectare	units	Total GHG emissions (kg CO_2eq/ha)
C	Distribution				
a	Transportation - tomatoes	By road to Distribution Centre - 30km	437	t	2,812
		Distribution Centre to Supermarket within 100km	437	t	9,374
		Distribution Centre to Supermarket within 500km	437	t	46,870
	Transportation - capsicums	By road to Distribution Centre - 30km	246	t	1,583
		Distribution Centre to Supermarket within 100km	246	t	5,276
		Distribution Centre to Supermarket within 500km	246	t	26,378
b	Distribution Centre				
i	Electricity	Lighting, administration and coolstorage, no data so assumed to be the same as the grading / packing and storage stage	72,000	kWh	17,576
ii	Refrigerant	Annual and end of life losses, 4.5% of in-use electricity full life cycle emissions			830
iii	LPG	Forklifts	50	litres	92
iv	Shrink wrapping, strapping & clips	Assumed to be minor, no data, further investigation required			
v	Disposal of packaging	Assumed to be minor, no data, further investigation required			

Production	Comments and assumptions	Tomato kg/ha	Capsicum kg/ha
Greenhouse marketable yield	Average based on 2004 grower survey	446,000	251,000
Distribution Centre yield	2% loss	437,080	245,980

APPENDIX 2

A2.1 Life Cycle Assessment - Overview

This is an extract from the earlier report by Barber and Pellow (2006) 'Life Cycle Assessment: New Zealand Merino Industry Merino Wool Total Energy Use and Carbon Dioxide Emissions' (www.merinoinc.co.nz). It provides a description and overview of LCA methodology.

A2.2 What is Life Cycle Assessment?

The examination of a product or services life cycle started in response to increased consumer and government environmental awareness. The science emerged from studies that were conducted to determine a product's total energy use. These studies not only examined the direct or consumer energy that it took to manufacture a product but also took into account the energy to manufacture and deliver all inputs such as chemicals, fertilisers, and capital equipment.

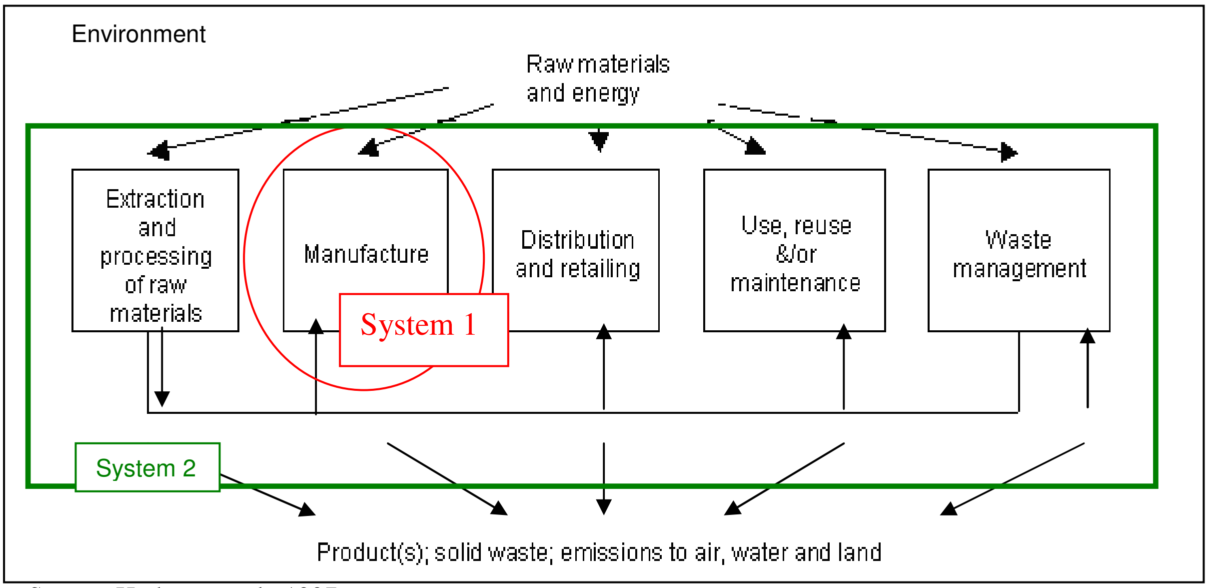
Life cycle studies were an extension of these and became vital to support the development of eco-labelling schemes and to quantify environmental claims.

A number of different terms have been used to describe LCAs. One of the first terms used was Life Cycle Analysis, although this has largely been replaced by Life Cycle Inventory (LCI) and Life Cycle Assessment (LCA) that better describe the two-stage process of data collection and then interpretation of that data.

Linked with environmental concerns is the question of sustainable production. A whole production approach needs to be adopted that not only includes the production process itself but also raw materials, total energy use, environmental impacts throughout the supply chain, and how the final product is used, disposed of or recycled. Consideration of these components has lead to the concept of 'cradle to grave' assessments of environmental impacts (Cowell, 1999).

This concept is illustrated in Figure 3. The conventional approach to environmental assessment only considered the processing system, as illustrated by System 1. However, to assess sustainability it is necessary to consider the raw materials and product disposal, as shown by System 2. This creates the 'cradle to grave' analysis for environmental impacts of a product or service under analysis (Cowell, 1999). A product system is characterised by its function and includes unit processes, elementary flows, product flows across the system boundaries (either into or out of the system) and intermediate product flows within the system (AS/NZS ISO 14041:1999). The life cycle of a product is all the activities utilised in extraction of raw materials, design and formulation, production, processing, packaging, transportation, use and disposal of a product (European Environment Agency, 1997).

Figure 3: Generic Flow Diagram for Life Cycle Thinking and LCA



Source: Hodgson et al., 1997

Undertaking a Life Cycle Assessment involves a number of steps, which are outlined in the International Standards – ISO 14040:1998, 14041:1999, 14042:2001 and 14043:2001.

The functional unit of analysis is service driven so different systems providing the same service may be able to be compared (Cowell, 1999). However the limitation of LCAs noted below needs to be considered when making such comparisons.

A2.3 Why undertake a Life Cycle Assessment?

Both nationally and internationally, businesses discuss sustainable development of products and customers demand efficiency with which energy is used, raw materials utilised and waste minimised (European Environment Agency, 1997). This is part of a process through which responsible businesses look for ways to improve the eco-efficiency of products or services throughout their life cycle. Undertaking a life cycle assessment is a method used to address these responsibilities.

Narayanaswamy et al. (2004) consider LCA to be an environmental management tool that aims to decrease input costs and improve profitability with a reduction in environmental stress. An LCA can demonstrate a company's commitment to environmental management and can be used to identify, assess and prioritise environmental impacts within and across the business supply and demand chains. It should also highlight any trade-offs between improvements at one stage, and increased impacts at another stage (Cowell, 1999), and the process encourages multi-criteria assessment, thereby reducing the chance of single-issue based decision making (Cowell, 1999).

LCAs focus managers' attention on those parts of the product lifecycle that have the greatest contribution to environmental impacts. Having identified these hot spots it is possible for the industry or company to then prioritise which functions it will focus on to improve its environmental performance (Cowell, 1999). A well-executed LCA study can increase confidence in decision making around environmental management.

As an example of this, Arla Foods, a Scandinavian dairy manufacturer (Larsson, 2003), used the results of an LCA to provide answers to customers on environmental questions, and to set targets for reducing milk losses within their production system. It also gave them a benchmark measure to avoid increasing the environmental impact of their packaging.

A LCA can also give companies the opportunity to substantiate claims of a "clean and green" image. They can also complement and strengthen the implementation of other environmental programmes such as the Australian Environmental Management Standard. In summary, a well researched LCA together with appropriate decision making tools and models can lead to better environmental outcomes (Narayanaswamy et al., 2004).

A2.4 What is Involved in a Life Cycle Assessment?

To have confidence in the data collected and results of an LCA study, the ISO Standards 14040 to 14043 should be followed. This involves a number of steps as outlined below.

<u>Defining the Goal and Scope</u>
The planning stage of a LCA involves defining the purpose or goal of the study, the scope, the data quality goals and determining the functional unit. The product, process or activity is described and the system identified.

The goal should state the intended application of the LCA study, the reasons for undertaking the study and who the study is being undertaken for (AS/NZS ISO 14041:1999). The scope defines the boundaries of the study and these define the unit processes that are included in the system study. AS/NZS ISO 14041:1999 recommends that inputs and outputs at the boundaries are elementary flows; however, this may demand a study that is unachievable due to the depth of data collection that would be required.

The criteria used to set the system boundaries must be chosen with care to ensure that the goal of the study is achieved and the results can be used with confidence. In setting the goal therefore it is necessary to determine which unit processes are included and the level of detail to which each is studied. It is not necessary to quantify inputs and outputs that will not significantly change the overall conclusions of the study. Decisions have to be made regarding which environmental emissions will be studied and in what detail. If life cycle stages, processes or inputs/outputs are omitted these decisions must be stated and justified. The system needs to be described in such detail that another practitioner could duplicate the inventory analysis.

The LCA study is an interactive technique and as such during the collection of information and data it may become obvious that the scope requires alteration to meet the study goal or even that the goal requires revising if unforeseen limitations or constraints arise or additional information is obtained. Where such a situation arises, it is necessary to document the changes and the justification for these.

Data categories

This is the stage to determine what data is to be collected and the environmental categories that will be examined. Data may be sourced from a mixture of measured data from the production site and calculated or estimated from published sources.

Functional Unit

AS/NZS ISO 14041:1999 requires that the LCA scope includes a clear statement on the product's functions (performance characteristics). The functional unit defines and quantifies the identified functions and is to be consistent with the goal and scope of the study. The functional unit is measurable allowing it to be a reference to which input and output data can be normalised in a mathematical sense. Also the volume of product required to fulfil the function can be quantified and is referred to as the reference flow. The reference flow allows calculation of the inputs and outputs of the system and comparisons to be made between systems providing that the same function, functional unit and reference flow is used.

The functional unit allows comparison of data between similar stages. Also the environmental inputs/outputs should be partitioned and assigned to co-products in a multi-product system using either a mass or dollar value percentage between the co-products (Narayanaswamy et al., 2004).

Life Cycle Inventory Analysis

This stage requires identification and quantification of energy, water, materials and land use, and environmental release data such as air emissions, solid waste emissions, water discharge etc during each life cycle stage (Narayanaswamy et al., 2004).

Data should be collected from specific sites (or representative averages) for the processes that contribute the majority of the mass and energy flows in the system being studied. The data collected needs to be validated and related to the unit processes and functional unit. The data can then be aggregated and if required the system boundaries refined (AS/NZS ISO 14041:1999).

Interpretation of the Life Cycle Inventory Analysis

The interpretation phase is for analysing the results including the identification of significant issues and explanation of limitations. An analysis of the results should consider the completeness of the data and include sensitivity and consistency checks. The sensitivity check analyses the reliability of final results and conclusions by determining whether they are affected by uncertainties in any of the data, allocation methods or calculation of category indicator results.

The consistency check also determines whether the assumptions made, methods used, and data, are consistent with the defined goal and scope. The interpretation draws conclusions and provides recommendations based on the findings of the LCA. It also provides a readily understandable, complete and consistent presentation of the LCA study in conjunction with the goal and scope of the study (AS/NZS ISO 14043:2001).

Life Cycle Impact Assessment
In this stage, estimates are made of the likely human and ecological effects of material consumption, natural resource use and environmental releases that have been estimated during the inventory analysis (Narayanaswamy et al., 2004).

The assessment phase provides a system wide perspective of environmental and resource issues for product systems. This allows for the inventory analysis results to be allocated to impact categories and an indicator result to be calculated. The indicator results give information on the environmental issues associated with the inputs and outputs of the system (AS/NZS ISO 14042:2001).

A2.5 Limitations of a Life Cycle Assessment and Applicability of LCA Studies to the Agricultural Industry

Data Variability
Dalgaard et al. (2003) commented that often data for agricultural LCAs were often from a limited number of farms and therefore did not adequately account for the large variation in resource use by farmers and the environmental impact between farms within a sector.

A detailed LCA study of New Zealand Braeburn apple production (Milà i Canals et al., 2003) showed that there can be 30 – 50% variation in energy use between orchardists undertaking the same field operation due to differences in management technique, systems and physical site conditions. This highlights the considerable influence on inputs, outputs and emissions that orchardists' and farmers' individual management techniques exert.

The quality of data collected will have significant impacts on the accuracy of the LCA. Gaps in data collection or differences in allocation and aggregation procedures can limit the quality of results (Milà i Canals, 2003; AS/NZS ISO 14042:2001).

Site Dependency
LCA methodology has been developed for industrial sites contained within a building and therefore is often site-independent, whereas agriculture production integrates with the wider environment. An agricultural operation is located on a particular parcel of land and as a result is heavily influenced by the specific land attributes, and related climatic and environmental factors. In contrast, an industrial system can often be located in any location and even any country.

As a result a LCA of polyester manufactured in the USA could be compared to Asian manufactured polyester utilising the same environmental impacts with confidence. In contrast, agricultural operations vary significantly between different locations and hence the results of the different life cycle inventory analyses will most likely be significantly different (Milà i Canals, 2003).

Beaufoy's (2001) study of olive farming in the European Union confirmed that there are significant variations between agricultural production locations especially in physical and biological conditions of the site; grove characteristics, production systems and technology usage; and the socio-economic situation of the production unit.

In another analysis, Cowell and Clift (1997) discussed that site dependency aspects can have more influence on LCA results than activity dependent aspects. Krewitt et al. (2001) also concluded that site dependent data has a significant influence, especially in the impact categories of human health, acidification, eutrophication and man-made environment. However, Milà i Canals (2003) notes that there is some disagreement in the scientific community on the impact of site dependency.

Whatever the impact category, site dependency leads to limitations in the ability to consider all environmental impacts associated with agricultural production. This is due largely to the difficulty in assessing an input or output in isolation within the agricultural environment.

<u>System Boundaries</u>

Another difference between industrial and agricultural systems is the ability to define system boundaries. Industrial systems can often easily define their boundaries as the walls of the factory, whereas in an agricultural system there are aspects that occur outside of the system boundary but which impact inside, for example pollinating insect activity (Milà i Canals, 2003) and neighbour's farming activities.

Although ideally LCAs should be 'cradle to grave' analyses, due to time, financial and data limitations, especially in agricultural systems where disposal of the product and lifetime usage is not part of the study, they are often a 'cradle to gate' analysis.

The LCA modelling system must be chosen with care to account for any knock-on effects of activities under analysis. This knock-on effect was considered by Milà i Canals (2003) in relation to activities that have occurred prior to the study period and continued to influence it after. Examples were residual nutrients from previous fertiliser applications, and the question of how to view the soil. Given that soil is a living system, only some aspects will be considered as part of a LCA study. These factors influence the way in which allocations of inputs are dealt with (Milà i Canals, 2003).

Additionally, Cowell (1999) and Milà i Canals (2003) raised the issue of time boundaries. In a complete 'cradle to grave' agricultural LCA study this can be very relevant as activities in the past affect actual productivity, for example, full crop rotations and whole tree life cycles. Therefore, for an agricultural system, studying the system for the full lifetime of animals can be important to accurately analyse environmental impacts.

<u>Other Impacts</u>

LCAs are time consuming and expensive to undertake if primary data is to be gathered and results interpreted to provide meaningful information. However they do provide insight into the environmental impact of various processes in a production chain (De Boar, et al., 2003).

Undertaking a full LCA will give the greatest information to assist in decision-making but could lead to an overload of data in addition to considerable expense and time implications. To deal with these pragmatic issues, a simplified LCA is often undertaken with a clearly defined scope (European Environment Agency, 1997).

In addition to the above, LCAs are a relatively new field of environmental standard, especially in the agricultural industry. As a result it has not yet been shown whether results are repeatable. Also, Milà i Canals (2003) identified that the LCA methodology has not determined conclusively how to allocate emissions of renewable carbon and carbon fixation by plants.

System Knowledge

Detailed knowledge of a system and the interactions between elements within it influences the accuracy of a life cycle assessment. As stated by Milà i Canals (2003), humans have designed industrial processing systems and the functions are well understood, while in contrast agricultural systems are natural ecosystems which have been modified as a means to achieve an economically viable occupation. In these systems, our knowledge of the complexities and interactions between elements is limited, and the biological processes embedded within agricultural ecosystems are complex and can be unpredictable.

Allocation Issue

When undertaking an agricultural life cycle inventory analysis, allocation is often a problem that must be addressed. Many agricultural systems are multi-functional and produce multiple products; therefore the inputs and outputs need to be somehow apportioned between the various products. By comparison industrial systems either produce one product or if multiple products are produced there is usually a clear physical or economic relationship that easily separates the allocation of inputs and impacts (Milà i Canals, 2003).

Data Uncertainty Analysis

Milà i Canals (2003) study of apples discussed the impact of uncertainties they found in the data collected and the impact on their results. In this particular study the uncertainties were large, therefore limiting their confidence in the results. Particular issues surrounded pesticide biodegradation half-lives, volatilisation values, machinery lifetime, and emissions from tractors. They identified the need to collect specific information on machinery use in LCA studies including how machines are used on farms as the energy required to manufacture and service machinery accounted for 7 – 15% of total energy consumption. They also found a need to reduce model uncertainty for nitrate leaching, pesticide leaching, and the retention of heavy metals from fertilisers and pesticides in soils.

Assessing Impact on the Environment

It is important to note that the Life Cycle Inventory Analysis is looking at the inputs and outputs of the system and not their impact on the environment (AS/NZS ISO 14041:1999). Therefore, care needs to be taken in drawing conclusions on the impacts to the environment. This reiterates the importance of a precise scope for the LCA, as the scoping phase assists in defining the limitations of the study and the data collected. The scope also defines which environmental impacts will be studied (AS/NZS ISO 14042:2001) in the Life Cycle Impact Assessment.

There are also a number of environmental impacts that are not assessed easily using an LCA, such as land use, soil quality, biodiversity, and animal welfare and these can potentially have major impacts on the production system (Milà i Canals, 2003).

Comparison between products

Whole industry LCAs consider the activities occurring at a number of sites, however each site will vary in its impact on the environment. LCAs are more suited to comparison between two identical sites rather than across an industry. Milà i Canals (2003) also noted a lack of consistency and standardisation of methodology between different projects for agricultural environmental analysis, leading to difficulties in transferability and relevance under differing conditions. As a result, caution therefore needs to be exercised when comparing agricultural systems with different sets of indicators. For an accurate comparison between two different products, the same environmental impacts must be selected, and the same methodology and functional unit used (AS/NZS ISO 14042:2001).

AS/NZS ISO 14042:2001 recommends analysing the results of an LCA for sensitivity. This measures the influence that changes to inputs/outputs have on the indicator results, and uncertainty that determines the statistical variability in data sets, when a comparison between two products is required. It may be necessary to undertake other studies to provide full information on environmental impacts when making comparative statements. The undertaking of sensitivity and uncertainty analysis so as to compare two products is only possible when you have a complete set of raw data for each product.

The European Environmental Agency (1997) recommends that LCAs are not used to claim a product or service is environmentally friendly or superior to another. It is possible to claim that using a specified set of criteria one product is better than another in certain aspects of its performance. However if making such claims it is very important not to over-claim, that accurate data and unbiased information is used, and the assessment has been peer reviewed.

A2.6 References

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