Carbon Footprinting for the Kiwifruit Supply Chain

– Report on Methodology and Scoping Study

Final Report

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Landcare Research
Manaaki Whenua

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Summary

Project and Client

The project aims to: develop a sector-specific methodology and use it to calculate an illustrative carbon footprint for kiwifruit produced in New Zealand and exported to Europe; investigate and recommend alternative carbon footprint reduction opportunities; and investigate options for implementation. The work was carried out by Landcare Research in collaboration with AgriLINK, HortResearch, and Massey University. It was undertaken for Zespri International and the Ministry of Agriculture and Forestry, between February and August 2008.

This report focuses on the methodology, and its application to produce an illustrative carbon footprint for kiwifruit produced in New Zealand and consumed in Europe. It is one of three reports produced during this project; the other two are a report on reduction opportunities (Deurer et al. 2008) and a report on implementation (McLaren et al. 2008).

Objectives of Project

To create an agreed methodology, guidance and case studies for measuring GHG emissions in the kiwifruit sector.

To work towards creation of an agreed sector approach to achieving reductions in GHG emissions and, where desired, mitigating remaining unavoidable GHG emissions in the kiwifruit sector – including guidance and case studies.

To work towards development of strategies for the uptake and promotion of the agreed approach across the sector.

Methods

This report addresses the first objective of the project. It describes a scoping study of the kiwifruit supply chain, and gives details of methodological issues that arise when modelling the carbon footprint of this chain. Two approaches to GHG footprinting have been used to inform the discussion: product-focused Life Cycle Assessment (based on ISO 14040 and 14044) and the UK's draft *Publicly Available Specification (PAS) for greenhouse gas (GHG) emission measurement of goods and services* (BSI 2008).

Conclusions

The total GHG emissions released for an illustrative tray of green kiwifruit (3.3 kg kiwifruit) consumed by a consumer in Europe are 5.326 kg CO_2eq. The contributions by the individual stages of the supply chain are: orchard operations 13%, packhouse 10%, New Zealand port operations 1%, shipping 44%, repackaging at Zeebrugge 3%, retail operations 6% and consumer and end-of-life disposal 23%.

Due mainly to higher yields per hectare and a shorter storage time at the coolstore, the gold kiwifruit cultivar 'Hort16A' has slightly lower GHG emissions than green and green organic kiwifruit.

The results are sensitive to variations in orchard practices, shipping distance, distance between overseas port and retailer, and distance between retailer and the consumer's home.

Recommendations

Further data collection and modelling is required to confirm the calculated GHG emissions for: nitrogen fertiliser and compost production and use (see McLaren et al. 2008), coolstore energy use and refrigerant leakage (see McLaren et al. 2008), refrigerated shipping, and changes in soil carbon on orchards.

Introduction

This project aims to develop a sector-specific methodology and use it to calculate an illustrative carbon footprint for kiwifruit produced in New Zealand and exported to Europe. Initial guidance is provided on measurement, management and mitigation (where feasible) of greenhouse gas (GHG) emissions associated with the kiwifruit supply chain; the longer-term purpose is to facilitate the industry to compete in international markets with credibility. This work was carried out by Landcare Research in collaboration with AgriLINK, HortResearch, and Massey University. It was undertaken for Zespri International and the Ministry of Agriculture and Forestry between February and August 2008.

An earlier version of the report was reviewed by an independent Life Cycle Assessment (LCA) expert. His report is reproduced in Appendix 2 along with a list of the subsequent amendments in response to his comments.

Background

Kiwifruit is New Zealand's largest horticultural export, and Zespri International Limited (ZESPRI™) is the largest kiwifruit exporter in the world. Kiwifruit and the associated name ZESPRI™ is an iconic New Zealand brand with a high degree of consumer recognition globally. Emerging supply chain requirements for continued market access to large retail outlets overseas necessitate the kiwifruit industry achieving carbon efficiency across the whole supply chain.

This report describes the kiwifruit supply chain, provides details of methodological issues that arise when modelling the carbon footprint of this chain, and gives the results of a scoping study. Two approaches to GHG footprinting have been used to inform the discussion and scoping study: product-focused Life Cycle Assessment (LCA; based on ISO 14040 and 14044) and the UK's draft *Publicly Available Specification (PAS) for greenhouse gas (GHG) emission measurement of goods and services* (BSI 2008). The relevance of organisation-focused GHG measurement (based on ISO 14064), and assessment as part of the carboNZero programme is considered in the 'Implementation Report' (McLaren et al. 2008).

As it is difficult to discuss methodological issues in isolation from data issues (because they are inextricably linked), the report also provides data for each life cycle stage in the kiwifruit supply chain. However, it should be noted that these data should not be considered representative of the average New Zealand kiwifruit life cycle. The data have been collected from relatively accessible sources solely for the purpose of providing illustrative values.

Three categories of kiwifruit have been studied in this report: green, gold, and organic. In many cases the methodological issues will be identical for the three categories – but any differences are noted within each subsection.

Literature search

Literature on the kiwifruit production process is limited to a couple of industry reports on orchard operations (Barber 2004; Barber & Benge 2006), two on packhouse energy use (Smart Power 2003a, b), and one on packhouse waste (Parker et al. 2008). These reports are a main data sources for this study.

The New Zealand apple industry, on the other hand, has been studied extensively using LCA methodology (Stadig 1997; Milà i Canals et al. 2006, 2007).

Milà i Canals et al. (2006) considered alternative orchard practices in apple production in three orchards and two hypothetical representative orchards in two regions of New Zealand using LCA methodology to identify the opportunities to reduce energy use and other environmental impacts. Their study identified wide variations in fertiliser use for a similar yield, due to soil conditions at specific sites. The energy use by different orchards for the same activity also varied by 40–80%, due mainly to variations in machinery efficiency and irrigation and frost-fighting practices. The climate-change-impact category was found to be dominated by energy and fertiliser use.

In their study of the implications of local supply versus global year-round supply of apples Milà i Canals et al. (2007) concluded that issues in addition to the distance travelled are significant in terms of the environmental impacts. Variation in yield and orchard management practices in different countries, and fruit wastage (as high as 40%) due to lengthy storage times and timing of consumption, were identified as important aspects. Shipping makes the highest contribution to the total primary energy use (up to 42% total) for apples exported from New Zealand, although road transportation between European countries can also make a similar contribution. As an increased quantity has to be transported (to account for wastage), storage at the point of consumption is more energy intensive than storage at the point of origin. This study also highlighted the potential impact of post-retailer stages on the total primary energy use of a product. The study, however, was limited to primary energy use as an indicator of the environmental implications.

Sim et al. (2007) considered the significance of transport in the supply of apples, runner beans and watercress to the UK. The study suggests that the GHG emissions due to transport are significant for imported apples, being 30%, 72%, and 90% of the total emissions for apples from Italy, Chile, and Brazil respectively. However, packing and storage activities in the UK, which use non-renewable electricity, were not included in the study.

Life cycle studies on food items vary in their scope and the system boundaries used. Table 1 is a comparison of life cycle GHG emissions of various food products based on a number of studies.

Table 1 Life cycle GHG emissions of various food products (per kg of product).

Food item	GHG emissions (kg CO_2eq/kg)	Country	Source
Beef (from dairy farm)	14	Sweden	LCA Food 2001
Cheese	8.8	Sweden	Berlin 2002
Semi-skimmed milk	1.0	Sweden	LCA Food 2001
Frozen flatfish fillet	20.9	Denmark	Thrane 2006
Carrot[1]	0.3–0.6	Sweden, Denmark, Netherlands, UK, Italy	Carlsson-Kanyama 1998
Carrot puree	1.5	Sweden	Mattsson 1999
Tomatoes[1]	0.8–5.6	Denmark, Netherlands, Spain, Sweden	Carlsson-Kanyama 1998
Rice[1]	6.4	USA	Carlsson-Kanyama 1998
Bread	0.19–0.4	Sweden	Sundkvist et al. 2001
Cereal-based baby food	2.0	Sweden	Mattsson & Stadig 1999
Potatoes – King Edwards[1]	0.6	UK	Tesco 2008

[1] Transport from retailer to consumer not included.

Goal Definition and Scope

The goal of the kiwifruit carbon footprinting project is to work towards development of sector-specific methodologies and guidance for the measurement, management and (where feasible) mitigation of GHG emissions associated with the kiwifruit product; it is focused on kiwifruit produced in New Zealand and sent to Europe.

There are three specific objectives:

To create an agreed methodology, guidance and case studies for measuring GHG emissions in the kiwifruit sector.

To work towards creation of an agreed sector approach to achieving reductions in GHG emissions and, where desired, mitigating remaining unavoidable GHG emissions in the kiwifruit sector – including guidance and case studies.

To work towards development of strategies for the uptake and promotion of the agreed approach across the sector.

It is recognised that these objectives are unlikely to be fully satisfied in the six months of the current project. Instead, Zespri envisages that two further phases of this work will consolidate the results of the first phase after August 2008.

The wider context for the research is to ensure that the New Zealand horticulture industry can operate in markets with credibility and, where necessary, using internationally recognised, transparent and validated greenhouse gas (GHG) footprinting methodologies for the production and supply of products. Hence, the methodological guidance in the PAS 2050 as well as the ISO 14040 series of LCA standards are considered in this report. This report focuses on guidance for methodology related to GHG measurement along the life cycle of three categories of kiwifruit: green, gold and organic. In general it follows the LCA methodology described in the ISO standards (see Section 4.1) but has also been informed by aspects of the PAS 2050 (see Section 4.2) where there is no clear guidance in the ISO standards.

A potentially important decision concerns whether a consequential or accounting study is considered appropriate. Consequential studies generally address 'what if?' questions, whereas accounting studies describe the current (or past) situation. This study falls into the latter category, and is an awareness-raising study for the New Zealand kiwifruit industry.

Functional unit

Description

The PAS 2050 and ISO 14040 series of LCA standards specify that a functional unit should be defined that describes the unit of analysis for any study. For the kiwifruit industry, it could be either a number of portions of fruit or a specified weight of fruit. For this study, the functional unit is taken as 'a single-layer-tray equivalent quantity of kiwifruit (with a total weight of 3.3 kg) eaten by the consumer'.

A weighted-average single-layer tray for all green kiwifruit categories weighs 3.615 kg (including the packaging, which itself weighs 0.366 kg), and 3.406 kg for gold kiwifruit (including the same packaging). Each tray may contain from 18 to 36 kiwifruit depending on the size of the kiwifruit (Zespri 2008); for this study, it is assumed a tray contains 33 kiwifruit that each weighs approximately 100 g.

Loss of kiwifruit along the supply chain

The average fruit reject rate at the packhouse is 17% of the total received from the orchard. Seven percent of rejects are recovered and sent to the regional markets (D. Smith, pers. comm., 22 May 2008). Ninety-five percent of the fruit waste is sold to local dairy farms as feedstock and the balance is sent to landfill. The wastage between the repackaging facility at Zeebrugge and the customer (including skins of consumed fruit) is assumed to be 10%[1] (actual data were not available).

Methodological issues

Size of kiwifruit

As kiwifruit come in different sizes, a question arises as to whether the functional unit is better represented by weight or number of fruit. For example, a single-layer tray of large fruit may weigh 3.339 kg and contain 18 fruit whereas a tray of small fruit may weigh 3.644 kg and contain 36 fruit (Zespri, 2008). In other words, the portions of fruit per specified weight of fruit may vary by a factor of two depending on the size of the fruit. This could become an issue if the kiwifruit carbon footprint is compared with that of other fruits; for example, is one apple equivalent to one kiwifruit irrespective of its size, or to one large kiwifruit and two small kiwifruit?

Recommendation:

In this project, a ‘single-layer-tray equivalent’ has been adopted because the industry uses this unit for its internal accounting systems and so it will be particularly meaningful to industry stakeholders (the primary potential audience for this study). However, it should be noted that this is not equivalent to one tray exported from New Zealand because wastage occurs downstream in the supply chain; in fact, 1.23 trays are produced on the orchard for every one tray consumed in either the domestic or overseas markets (see section 5). The results can easily be converted to a specified weight of fruit or number of portions if this is required.

System boundaries

Description

For this study, the system boundaries extend from extraction of raw materials from the ground through to sewage treatment after consumption of kiwifruit. Inclusion of the post-consumption phase of food is logical in an LCA but is often overlooked in LCA food studies. This follows the thinking that, conceptually, all inputs and outputs in the life cycle are relevant for consideration regardless of their physical location or the time period considered in the study. However, as ISO14040 notes (in section 5.2.3), ‘resources need not be expended on the quantification of such inputs and outputs that will not significantly change the overall conclusions of the study’. Therefore, definition of system boundaries is an iterative process and is guided by the process of learning about the product system as the study proceeds. This is reflected in the discussions below about each stage of the kiwifruit life cycle.

[1] A recent British study (WRAP 2008) estimates fruit waste at home to be 26%.

The following inputs to the supply chain are omitted from the analysis due to the lack of readily accessible data:

- Orchard: beehive pollinators – transport and materials; contractors' capital equipment
- Packhouse: bins and pallets, adhesive used for trays, transport of fruit waste to landfill; construction and maintenance of packhouse building and equipment[2]
- Transport: the efficiency gains due to loading, packaging, etc. in transport activities are disregarded as transport is modelled using the weight and distance
- New Zealand port: energy use for handling
- Repackaging facility, Europe: energy use for handling and repackaging, packaging material (although spifes[3] included).

With respect to time boundaries, the yield of kiwifruit can vary widely from year to year; data on average yields per hectare for the four years from 2004/05 to 2007/08 indicate that the yield increased by 15%, 29% and 24% above the lowest average annual yield for green, gold, and green organic kiwifruit respectively in at least one of those years (J. Chamberlain, pers. comm., 17 June 2008). Even if exactly the same production practices occur each year, yields may vary due to weather conditions. Furthermore, some activities occur infrequently (i.e. less than once per year) yet have benefits for crops in subsequent years; examples include application of lime and compost.

Methodological issues

Omission of life cycle stages

The ISO 14040 series of LCA standards do not define specific system boundaries for LCA studies; instead, they recognise that 'the selection of the system boundary shall be consistent with the goal of the study' (ISO14044, section 4.2.3.3.1). However, the PAS 2050 is more prescriptive: it states that product category rules developed in accordance with ISO14025:2006 should be used where they exist. In other situations, all unit processes with GHG emissions should be included within the system boundary when they make a material contribution (more than 1%) to all life cycle GHG emissions (PAS 2050, section 6.1.2). An exception is transport from the retailer to the consumer's home, which is to be excluded from the analysis (PAS 2050, section 6.3).

Recommendation:

Illustrative GHG emissions associated with transport from the retailer to the home are included in this study to demonstrate the relative importance (or not) of this life-cycle stage in the overall kiwifruit life cycle.

Yield variability between years

The ISO 14040 series of standards and PAS 2050 do not provide guidance on accounting for yield variability due to weather conditions.

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[2] A recent study estimated that packhouse construction makes a very small contribution compared with operational GHG emissions (Forgie et al. 2008).

[3] Spifes are half spoon, half knife plastic utensils that are about 10cm (4 inches long). The knife end is used to slice a kiwifruit in half and then the spoon end is used to scoop out the fruit.

Recommendation:

For this awareness-raising study, it is appropriate to focus on the 2007 harvest, although recognising that this year had the lowest yields out of the four years between 2004/05 and 2007/08. However, for carbon labelling of kiwifruit, focusing on one particular year is more questionable and this aspect is discussed further in McLaren et al. (2008).

Variability within a year

Kiwifruit harvested towards the beginning or end of the season may typically be stored for shorter or longer periods of time, and hence have different carbon footprints arising from the variable time spent in a coolstore. Potentially these kiwifruit could be distinguished in the marketplace by the time at which they appear in retail outlets (see PAS 2050 Section 7.10).

Recommendation:

For this awareness-raising study, it is appropriate to use an average storage time to calculate the carbon footprint. However, further consideration should be given to whether it is appropriate to distinguish between kiwifruit that are harvested at different times (following PAS 2050 Section 7.10).

Infrequent activities

Lime and compost may be applied one year (year 1) yet have benefits for several years after application (year 2 onwards). If all the GHG emissions associated with their application are allocated to the harvested crop in year 1, this effectively disadvantages the year 1 harvest and advantages the subsequent harvests.

Recommendation:

Infrequent activities should be identified and their associated GHG emissions allocated across all subsequent harvests until the activity is repeated.

Data quality

Description

Data quality is a critical issue in LCA studies. It includes the following aspects of data: time-related coverage, geographical coverage, type of technology, variability of data values, completeness, representativeness, consistency, reproducibility, sources, and uncertainty (ISO14044, section 4.2.3.6.2).

Methodological issues

Primary and secondary data

The ISO 14040 series of LCA standards recommend that site-specific data (and/or representative averages) should be used where possible (ISO14044, section 4.2.3.6.3) and lists relevant aspects of data quality (ISO14044, section 4.2.3.6.2). The PAS 2050, on the other hand, distinguishes between primary and secondary data: primary data are equivalent to the site-specific data described in ISO14044 and secondary data are typically data taken from sources such as the European Reference Life Cycle Data System (ELCD) (PAS 2050, section 7.4). The PAS 2050 recommends that primary data should be used for all 'processes owned or operated by the organisation implementing the

PAS 2050, or inputs into those processes' (PAS 2050, section 7.3). It further states that 60% of the GHG emissions from the processes that input into the owned processes should have been derived from primary data.

Recommendation:

Primary (i.e. site-specific) data should be used wherever possible in a study to maximise its legitimacy. The implications of the PAS 2050 specification outlined above are discussed in a separate report (McLaren et al. 2008).

Overview of Methods

Life Cycle Assessment according to ISO 14040 series

Life Cycle Assessment (LCA) is a technique for assessing the environmental impacts of products and services along their life cycle from extraction of raw materials through refining, manufacturing, distribution, use, and on to waste management. It is guided by two ISO standards: ISO14040 which provides an overview of LCA, and ISO 14044 which gives more detailed guidance about undertaking an LCA study.

Carbon footprinting of products is equivalent to the assessment of climate change impacts through an LCA.

UK's Publicly Available Specification (PAS) 2050

The "PAS 2050 – Specification for the assessment of the life cycle greenhouse gas emissions of goods and services" is a Publicly Available Specification (PAS) being produced by the British Standards Institution. Currently it is in draft form, and is being developed in response to a perceived need for a consistent method for assessing the life cycle GHG emissions of goods and services. It recognises that organisations may wish to use the method in order to 'provide improved understanding of the GHG emissions arising from their supply chains, and to provide a common basis for the comparison and communication of results arising from the use of PAS 2050' (Introduction, BSI, 2008).

Kiwifruit Life Cycle

Kiwifruit are either export or non-export quality; about 95% of the crop is export quality. For this report, the life cycle of green, gold, and organic kiwifruit produced in New Zealand and shipped to a European port (such as Zeebrugge) then onwards to a European retail outlet has been modelled. Table 2 gives the number of trays of various categories of kiwifruit submitted to export from New Zealand between 2003 and 2007. It can be seen that green kiwifruit are the most common exported fruit category (76% of export crop in 2007), followed by gold kiwifruit (21% of export crop in 2007). Just over half the total exported kiwifruit goes to Europe (53% in 2007, with over half of this going to Spain, Germany and the Netherlands); the second largest market is Japan (17% of total exported kiwifruit in 2007) (A. Mowat, pers. comm., 15 May 2008). Most gold organic fruit, however, is sent to Japan and South East Asia due to the high premium achieved. Lower grades of fruit are either consumed in New Zealand or exported to other parts of the Pacific region or Asia.

Table 2 Number of trays of kiwifruit submitted for export between 2003 and 2007.

Fruit group	2007	2006	2005	2004	2003
Green	70 639 978 (76%)	59 627 950 (76%)	64 151 000 (79%)	64 017 308 (78%)	50 836 363 (82%)
Organic Green	3 007 918 (3%)	2 384 177 (3%)	2 725 000 (3%)	2 813 889 (3%)	2 376 744 (4%)
Gold	19 504 501 (21%)	16 390 687 (21%)	14 506 000 (18%)	15 352 924 (19%)	8 551 567 (14%)
Organic Gold	278 553 (0.3%)	270 811 (0.3%)	249 000 (0.3%)	251 351 (0.3%)	219 705 (0.4%)
Total (single layer trays)	93 430 950	78 673 625	81 631 000	82 435 471	61 984 379

Source: A. Mowat, pers. comm., 15 April 2008.

Payments for different categories of kiwifruit at the orchard gate for the 2007 season are shown in Table 3.

Table 3 Payments for kiwifruit at the orchard gate (2007).

Fruit group		NZ$/tray
Export quality	Green	3.11
	Organic Green	5.32
	Gold	4.45
Domestic market quality	Green	0.12
	Organic Green	0.79
	Gold (excluding organic)	1.58

Source: S. Gardner, pers. comm., 29 May 2008.

The kiwifruit industry, on average, recruits 1800 seasonal workers from overseas to work in the orchards and packhouses. The air travel of this workforce would have implications for the GHG emissions of kiwifruit production (Table 4), an issue raised by Milà i Canals (2007).

Table 4 Origin of seasonal workers, distance travelled and associated CO_2eq emissions.

Country	Number recruited	Distance travelled by air (km)	Total travel (person.km)	Total CO_2eq emissions[1] (kg)
Vanuatu	632	2300	1 453 140	223 784
Malaysia	364	8400	3 054 240	329 858
Tonga	202	2300	463 680	71 407
Samoa	185	2800	519 120	79 945
Indonesia	157	8800	1 378 080	148 833
Thailand	110	8500	933 300	100 796
Solomon Islands	103	4000	411 120	63 313
Tuvalu	43	2400	103 680	15 967
Total			8 316 360	1 033 901

[1] CO_2 emission factors used for these calculations are shown in Appendix 1: Table A2.
Source: M. Chapman, pers. comm., 16 June 2008.

The majority of workers (79%) are employed in the packhouses, while the balance (21%) work in the orchards. On average, a packhouse worker produces 10 000 trays, while an orchard worker covers an area of 4.5 ha over the season.

Based on the total production of green and gold kiwifruit in the years 2007, seasonal workers add 11.5 g CO_2eq emissions to each tray produced at the packhouse.

The generic kiwifruit life cycle is shown in Figure 1. Each of the life-cycle stages shown in this diagram are described in Sections 6 and 7. Figure 2 shows the flow of kiwifruit along the supply chain from cradle to grave per 100 kiwifruit eaten by an overseas consumer. It can be seen that 134 kiwifruit are produced in the orchard per 109 kiwifruit consumed (including both domestic and overseas consumption) by the customer. In other words, consumption of one kiwifruit is associated with production of 1.23 kiwifruit in New Zealand.

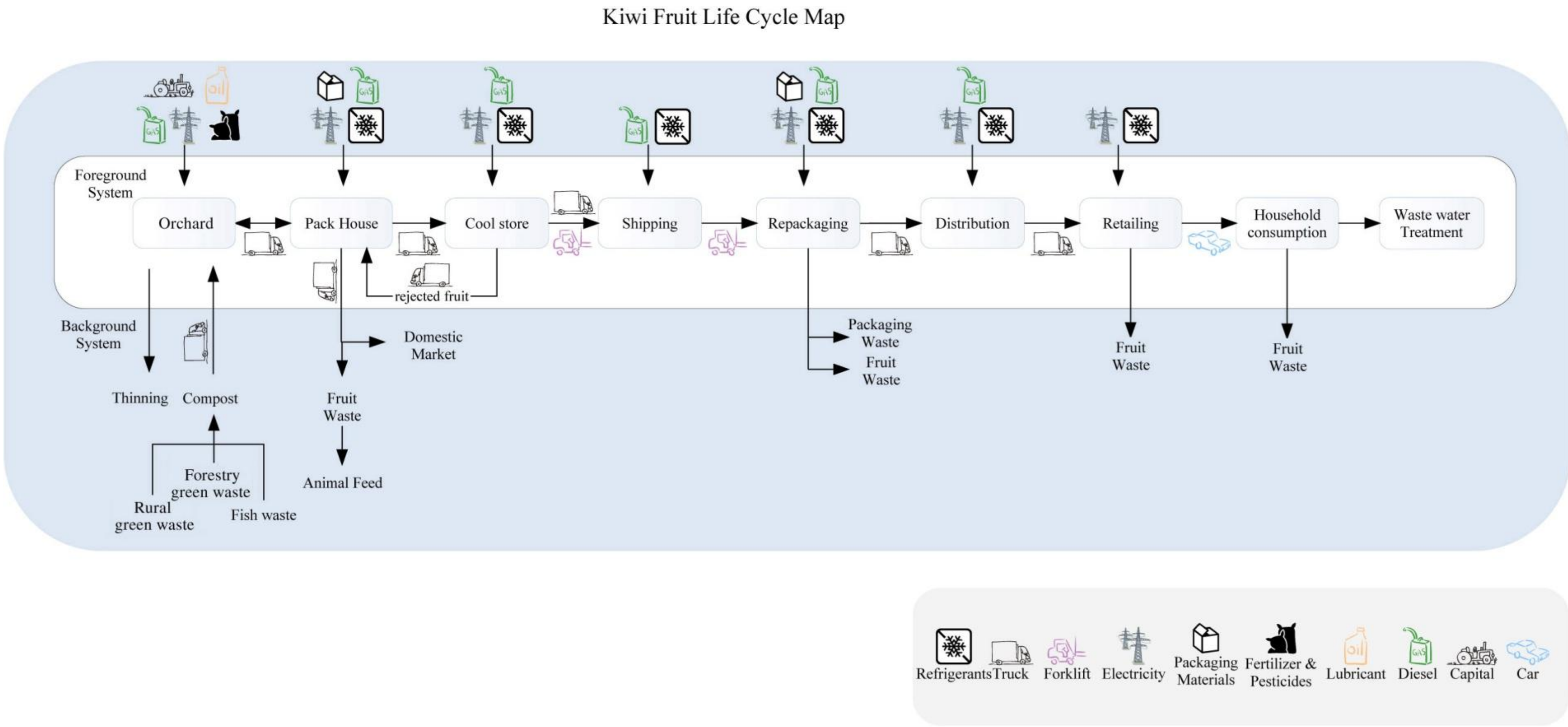

Fig. 1 Generic kiwifruit life cycle.

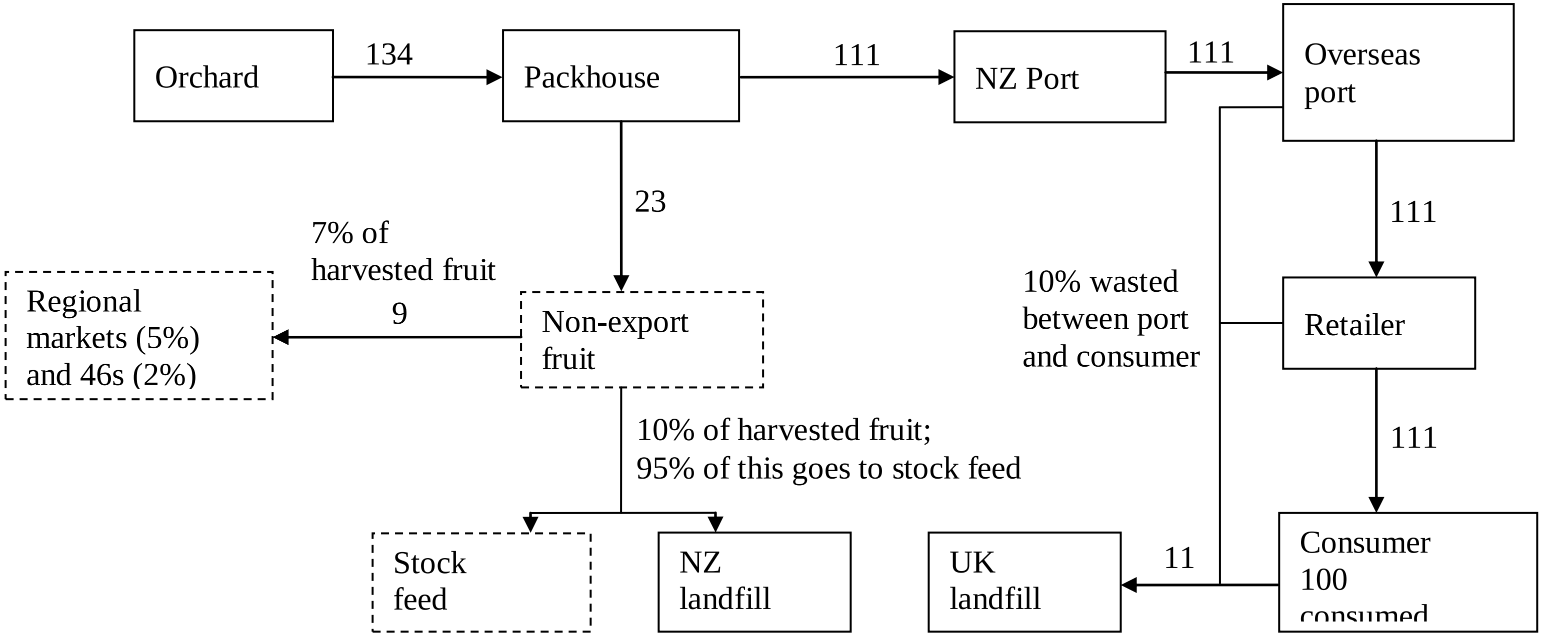

Fig. 2 Kiwifruit flowing along the supply chain from cradle to grave per 100 fruits consumed by the UK consumer.

Note: Dashed lines represent activities not included in the study. Values are rounded up or down and so may not exactly match up with other values along the supply chain. 46s are very small fruit so a tray holds 46 fruits.

Kiwifruit Life Cycle Stages: Orchard Production

There are 3077 registered kiwifruit orchards in New Zealand: 79% of the orchard area is in green kiwifruit; 17% in gold kiwifruit; and the remaining 4% in green organic kiwifruit. In the 2006/07 season green-kiwifruit orchards produced on average 6275 tray equivalents (TE[4]) per hectare and the higher producing gold orchards averaged 8390 TE/ha. Green organic fruit averaged 5199 TE/ha. Over three-quarters of the crop is grown in the Bay of Plenty, with the rest grown from Northland to the top of the South Island.

The orchard production information used in this report is based on two studies: Barber (2004), a survey covering the 2002/03 season, and Barber & Benge (2006), a survey covering the 2003/04 season. The combined database includes 32 green, 17 gold and 12 green organic orchards. Sections 6.1 to 6.6 demonstrate that there is great variability in operations and related GHG emissions between orchards.

Appendix 1 gives a summary of the secondary data sources used in the analysis.

Orchard operations – fuel and electricity

Description

Direct energy use comprises diesel, petrol, oil and electricity use, and includes fuel purchased by the orchardist and that used by contractors. Orchardists are not able to distinguish in their aggregated fuel accounts how much fuel is used for each operation. However, Table 5 is an estimate of how much fuel is used in each operation. This was calculated as follows:

- *Fuel use for mowing*: based on using a 50-hp tractor at 8 km/h and being 80% efficient. The number of passes was based on once a month between November and March and once every two months for the rest of the year.

- *Spraying*: based on a 50-hp tractor travelling at 4.4 km/h and being 50% efficient to account for additional travel time during turning and refilling. The number of passes was determined from an analysis of the spray diaries. No significant difference was found between the number of passes for the different orchard types, including green organic orchards.

- *Shelter trimming and mulching*: assumed to use 180- and 130-hp tractors respectively and the work rates were calculated from the survey data.

- *Fertiliser spreading*: involves a base application in August, usually by a contractor, followed by 1 or 2 side applications often with a tractor-mounted spreader. Spreading was also based on a 50-hp tractor travelling at 4.4 km/h and being 80% efficient.

[4] A tray equivalent is a unit of volume measurement based on a single-layer tray of kiwifruit. See Section 3.1 – Description.

- *General orchard activities*: 50 L per year for activities such as moving materials around, pulling trailers at harvest time, inspecting the orchard etc.

Table 5 Generalised fuel use by kiwifruit orchard operations (green, gold, green organic).

Orchard operations	Fuel use (L/h)	Work rate (h/ha)	No. of passes per season	Total fuel use (L/ha)
Mowing	10.3	1.1	8.5	95
Spraying	10.3	0.7	6.6	50
Shelter trimming	27.9	2.0	1.0	55
Mulching	39.0	2.2	1.0	85
Fertiliser spreading	10.3	0.6	2.5	15
General use around the orchard				50
Total in-orchard use				350

Source: Additional analysis based on Barber (2004) and Barber & Benge (2006).

Data

Fuel use was determined from grower surveys where the orchardist provided an estimate of their annual fuel use either in litres or in dollars. Generally, this information is not accurately recorded by orchardists and where the fuel use in dollars is recorded for the orchard it can be an aggregated figure covering a range of company activities. Not all the activities are conducted by the orchardist; where contractors were used, their fuel consumption was estimated based on the activity and either how long it took or how much area they covered (see Table 5). Orchard fuel and electricity use by orchard type is shown in Table 6 (per hectare) and Table 7 (per 1000 trays).

One of the potentially large variables is the use of helicopters for frost protection. This can make a significant difference to the overall carbon footprint for the orchard (Barber & Benge 2006). Gold orchards are more likely to need frost protection; however, the use of helicopters, already rare, is decreasing further as frost-prone orchards establish overhead irrigation systems that can also double as vine irrigation in summer (S. Scarrow, Fruition Horticulture, Tauranga, pers. comm., May 2008). Helicopter fuel use varies by size of the helicopter, with Barber and Benge (2006) assuming 120 L/h based on a range of helicopter specifications. This figure is also between that specified as default factors in Forsyth et al. (2008) of 87 L/h for small helicopters (840 kg maximum take-off weight) and 152 L/h for large helicopters (1050 kg maximum take-off weight). In the sample of 37 orchardists surveyed by Barber and Benge (2006), two had used helicopters for frost protection; one for just one hour, the other for 24 hours. At a GHG emission rate of 2608 g CO_2eq per litre (Barber 2008), total emissions for operating a helicopter for 24 hours will add 7510 kg CO_2eq to the orchard's carbon footprint. In this particular orchard's case, helicopter emissions will be 2835 kg CO_2eq per hectare, or a 68% increase to 6992 kg CO_2eq per hectare for the average gold orchard. On a per-tray basis emissions would be 306 kg CO_2eq per 1000 trays, boosting total emissions by 65% to 778 kg CO_2eq per 1000 trays for the average gold orchard.

The minimum and maximum figures represent the lowest and highest total greenhouse gas emitting orchards on a per hectare and per tray basis. As these orchards have been selected based on their total greenhouse gas emissions, some of the individual inputs will not have the highest or lowest surveyed GHG emissions. In some cases the maximum figure may be below the average simply because that orchard, while having the highest GHG emissions overall, had low emissions for a particular input. For the same reason, in some cases the minimum figure is higher than the average or even the maximum for an individual input.

Table 6 Orchard fuel and electricity use by orchard type (per hectare).

	Orchard type	Units per hectare	Average	95% confidence interval	Minimum	Maximum
Fuel (diesel equivalent)	Green	L	463	85	194	886
	Gold	L	404	128	126	827
	Green organic	L	322	51	102	372
Elec. irrigated	Green	kWh	2022	1417	–	–
	Gold	kWh	3054	4139	–	–
Elec. unirrigated	Green	kWh	146	119	–	–
	Gold	kWh	240	192	–	–
Elec. all surveyed orchards[1]	Green	kWh	849	613	0	9375
	Gold	kWh	1030	773	0	0
	Green organic	kWh	711	528	0	463

Source: Barber (2004) and Barber & Benge (2006).

[1] Weighted irrigated and unirrigated orchard average.

Table 7 Orchard fuel and electricity use by orchard type (per 1000 export trays).

	Orchard type	Units per 1000 trays	Average	95% confidence interval	Minimum	Maximum
Fuel (diesel equivalent)	Green	L	68	14	25	152
	Gold	L	46	15	1	99
	Green organic	L	64	16	47	108
Elec. irrigated	Green	kWh	297	183	–	–
	Gold	kWh	287	325	–	–
Elec. unirrigated	Green	kWh	17	14	–	–
	Gold	kWh	25	20	–	–
Elec. all surveyed orchards	Green	kWh	122	83	125	260
	Gold	kWh	105	68	0	169
	Green organic	kWh	146	131	216	0

Source: Barber (2004) and Barber & Benge (2006).

Please note that this table shows fuel and electricity use per 1000 trays packed for the export market at the packhouse rather than 1000 theoretical trays leaving the orchard.

Methodological issues

Total fuel use on-orchard versus use per operation

It will be noted that the estimation of fuel use based on individual operations (350 L/ha; Table 5) is well below the fuel use actually recorded by orchardists for green and gold kiwifruit (average 463 L and 404 L respectively; Table 6). This is explained by orchards also including business travel in their surveyed fuel use records (personal travel was excluded), and site variation (see below), including tractor size, number of passes etc.

Recommendation:

Actual fuel use recorded by orchardists should be used when available.

Variability between orchards

As shown in Table 6, the variability in total fuel use (diesel-equivalent litres) between orchards was not as significant as may be expected, particularly for the green orchards, which now have a combined database of 32 orchards. The variability measured by the 95% confidence interval was 463 ± 85 L/ha, or 18% of the mean. There were some significant outliers, a minimum of 57 L/ha and a maximum of 1008 L/ha, but these individual orchards would need to be revisited to understand why they are outliers.

There is a significant difference between electricity use on an irrigated versus unirrigated orchard. This has been reported separately and a weighted average of 25% used for the average figure in Tables 7 and 8. There are no quantitative industry data on the number of orchards that irrigate; however, it is estimated that approximately 20–25% of the orchards are irrigated and these are very unevenly distributed around the country (B. Parker, Fruition Horticulture, Tauranga, pers. comm., 2006). There is only a small percentage of orchards in the Bay of Plenty that irrigate once the vines are established. There were insufficient data to distinguish between irrigated and unirrigated green organic orchards so the average survey result has been used.

There is much variability in the use of electricity, with the 95% confidence interval being ±70% of the mean in the irrigated and ±81% on the unirrigated green orchards. Electricity use per hectare on the green irrigated orchards varied between 284 and 9375 kWh/ha. The unirrigated orchards varied between zero and 887 kWh/ha.

Recommendation:

The large differences observed between some orchards in use of fuel indicate that individual orchardists' practices may significantly affect the on-orchard carbon footprint for kiwifruit. Whether this range is communicated to an external audience depends on the purpose of the study, and is addressed in McLaren et al. (2008). In this study, the relative importance of the variability is discussed in section 8.2.

Fertiliser, lime and compost production and use

Description

All orchards use a combination of synthetic and mineral fertilisers plus compost. The main nutrient elements are nitrogen (N), phosphorus (P), potassium (K), sulphur (S), and magnesium (Mg).

Data

Table 8 shows the average energy costs of manufacturing each fertiliser component (Wells 2001). These are average figures taken from a range of different fertiliser production methods. Wells (2001) determined the carbon dioxide emissions for P, K, S and Mg based on the average carbon dioxide emissions of 0.06 kg CO_2 per megajoule of embodied primary energy. Consequently, the GHG emissions for these nutrients were increased to 0.064 $kgCO_2eq/MJ_{primary}$ to account for the small quantity of methane and nitrous oxide that is released when the various types of fuels are used during fertiliser manufacture. The emission of nitrous oxide after fertiliser application is accounted for in Section 6.6 Field Emissions of Nitrous Oxide.

The total average energy use associated with production and transport of compost was estimated at 0.3 MJ/kg by Barber and Benge (2006, p. 13) based on diesel used in production of compost. It was assumed that the material for composting came from waste streams and so the energy for the raw material input was zero (which is in line with the PAS 2050 section 6.2.9). While there is a large range of different composts and production methods, due to their small contribution to the overall analysis and the limited information available, all composts were assumed to have this same energy requirement.

Commercial compost (made using urban waste) has to be transported 50 km on average. Some growers make compost using their own materials, but base materials such as pine bark and chicken litter may be purchased and transported to the orchard (C. Pretorius, pers. comm., 21 May 2008).

Table 8 Energy requirements and GHG emissions due to manufacture of fertiliser components.

	Wells 2001		EcoInvent 2.01, 2007
Component	Energy use (MJ/kg)	GHG (kg CO_2eq/kg component)	GHG (kg CO_2eq/kg component)
N	65	3.38	Most values between 2.8 (ammonium sulphate) and 6.0 (urea ammonium nitrate)
P	15	0.96	Varies between 1.3 (ammonium nitrate phosphate) and 2.7 (single superphosphate) as P_2O_5 i.e. 0.6–1.2 per kg P
K	10	0.64	Varies between 0.44 (potassium chloride) and 1.27 (potassium sulphate)
S	5	0.32	
Mg	5	0.32	
Lime	0.6	0.43	0.0116
Compost	0.3	0.02	0.882

Tables 9 and 10 give total quantities of fertilisers used for each of the three categories of kiwifruit. Fertiliser use data were collected in orchard surveys and are reported in the different nutrient components. Of all the orchard inputs the fertiliser elements N, P, K and S were generally the least variable between orchards. There was greater variation in the quantity of lime and compost applied.

Table 9 Quantities of fertilisers used for kiwifruit (per hectare).

	Orchard type	Average kg/ha	95% confidence interval	Minimum	Maximum
	Green	129	17	108	108
Nitrogen	Gold	126	36	0	144
	Green organic	0	–	0	0
	Green	27	9	55	0
Phosphorus	Gold	31	13	0	10
	Green organic	16	13	0	0
	Green	215	32	263	0
Potassium	Gold	189	56	40	172
	Green organic	101	34	96	0
	Green	90	21	44	0
Sulphur	Gold	91	32	17	75
	Green organic	50	17	41	0
	Green	48	16	21	32
Magnesium	Gold	52	19	0	11
	Green organic	13	9	0	41
	Green	423	295	313	0
Lime	Gold	522	353	0	0
	Green organic	43	57	250	0
	Green	1588	1037	0	0
Compost	Gold	1176	811	400	0
	Green organic	6469	3750	8000	24 000

Source: Barber (2004) and Barber & Benge (2006).

Table 10 Quantities of fertilisers used for kiwifruit (per 1000 export trays).

	Orchard type	Average weight (kg) per 1000 trays	95% confidence interval	Minimum	Maximum
	Green	19	3	6	28
Nitrogen	Gold	15	5	17	19
	Green organic	0	0	0	0
	Green	4	1	4	12
Phosphorus	Gold	3	1	8	8
	Green organic	3	2	0	0
	Green	31	6	8	33
Potassium	Gold	23	7	21	22
	Green organic	21	9	12	45
	Green	13	4	3	14
Sulphur	Gold	11	4	15	9
	Green organic	11	5	8	31
	Green	7	2	0	3
Magnesium	Gold	6	2	8	2
	Green organic	3	2	5	11
	Green	72	55	0	692
Lime	Gold	69	47	0	446
	Green organic	13	20	40	0
	Green	245	156	0	0
Compost	Gold	142	104	0	446
	Green organic	1195	661	0	181

Source: Barber (2004) and Barber & Benge (2006).

Please note that this table shows fertiliser inputs per 1000 trays packed for the export market at the packhouse rather than 1000 theoretical trays leaving the orchard.

Methodological issues

Variability between orchards

The least variable fertiliser input was found to be nitrogen application on green orchards. The variability measured by the 95% confidence interval was 129 ± 17 kgN/ha, or 13% of the mean. Nitrogen applications on gold orchards were more variable (126 ± 36 kgN/ha, or 29% of the mean). This may be a combination of gold orchard fertiliser practices being inherently more variable and a smaller sample size (32 green orchards and 17 gold). Organic green orchards do not apply synthetic nitrogen. There was a considerable amount of variation in the application of the other nutrients and compost as shown by the 95% confidence intervals in Table 9.

For all the fertiliser inputs, one or more orchards applied zero units of an individual nutrient. Not applying nitrogen in a conventional orchard is very unusual. Overall, excluding the orchard that did not apply nitrogen makes very little difference to the average, given the size of the database, with a slight increase for green from 129 to 133 kgN/ha plus a reduction in the variability (the 95% CI becomes ±15 kgN/ha). Likewise, excluding the one gold orchard that recorded zero nitrogen use increases the overall average from 126 to 134 kgN/ha.

Recommendation:

For this study, the influence of variability in fertiliser input is investigated using sensitivity analysis.

Application of fertiliser and lime with benefits over several years

This methodological issue has been discussed in section 3.2.

Recommendation:

As the data used in this study are based on a number of orchards, it is assumed that infrequent applications on individual orchards are averaged out by using data for a number of orchards. However, for the carbon footprint of a specific orchard it would be necessary to consider a longer time period than one year to account for infrequent applications as recommended in section 3.2.

Carbon sequestration in soils

Although it is being investigated as one of the possible mitigation techniques, this has been excluded from the analysis (following PAS 2050 section 5.5). However, see section 6.7 for a discussion of the possible contribution of changes in soil carbon to the carbon footprint.

Agrichemicals production and use

Description

All conventional orchards apply agrichemicals such as insecticides (including oil used in organic orchards), fungicides, herbicides and biological control agents. The largest quantity of agrichemical used on green and gold orchards is hydrogen cyanamide (H_2NCN), which promotes budbreak in deciduous crops. The most commonly known trade name is Hi-Cane®.

Data

Tables 11 and 12 give the quantities of agrichemicals used for the green, gold and green organic categories of kiwifruit. These data were derived from each orchard's spray diary.

Table 11 Quantities of agrichemicals used on kiwifruit orchards (per hectare).

	Orchard type	Average kg ai/ha	95% confidence interval	Minimum	Maximum
Herbicide	Green	0.4	0.2	0.0	2.2
	Gold	1.0	0.5	0.2	7.4
	Green organic	0.0	0.0	0.0	0.0
Fungicide inorganic	Green	0.2	0.3	0.0	0.0
	Gold	1.5	1.4	0.0	0.0
	Green organic	0.0	0.0	0.0	0.0
Fungicide synthetic	Green	0.7	0.6	9.5	0.8
	Gold	0.2	0.1	0.0	0.5
	Green organic	0.0	0.0	0.0	0.0
Insecticide – general	Green	2.9	1.4	3.1	1.7
	Gold	2.0	0.7	3.0	0.1
	Green organic	0.0	0.0	0.0	0.0
Insecticide – oil	Green	0.4	0.7	0.0	0.0
	Gold	0.0	0.0	0.0	0.0
	Green organic	71.5	25.0	27.3	67.5
Hydrogen cyanamide	Green	14.5	4.1	0.0	18.7
	Gold	14.3	5.6	0.0	6.6
	Green organic	0.0	0.0	0.0	0.0
Biological control agents	Green	0.2	0.2	0.0	0.0
	Gold	0.4	0.2	1.0	0.3
	Green organic	7.9	10.6	0.7	1.5
Other	Green	0.5	0.7	10.0	0.0
	Gold	0.4	0.4	0.0	0.8
	Green organic	0.9	1.7	0.4	0.0

Source: Barber (2004) and Barber & Benge (2006).

Table 12 Quantities of agrichemicals used on kiwifruit orchards (per 1000 export trays).

	Orchard type	Average kg ai/1000 trays	95% confidence interval	Minimum	Maximum
Herbicide	Green	0.06	0.03	0.0	0.2
	Gold	0.10	0.04	0.2	0.2
	Green organic	0.00	0.00	0.0	0.0
Fungicide inorganic	Green	0.03	0.05	0.0	0.0
	Gold	0.13	0.13	0.0	0.0
	Green organic	0.00	0.00	0.0	0.0
Fungicide synthetic	Green	0.10	0.08	0.0	0.0
	Gold	0.02	0.01	0.0	0.0
	Green organic	0.00	0.00	0.0	0.0
Insecticide – general	Green	0.43	0.21	0.0	0.9
	Gold	0.23	0.08	0.1	0.5
	Green organic	0.00	0.00	0.0	0.0
Insecticide – oil	Green	0.06	0.12	0.0	0.0
	Gold	0.00	0.00	0.0	0.0
	Green organic	14.55	6.54	10.0	41.4
Hydrogen cyanamide	Green	1.97	0.55	0.2	3.6
	Gold	1.42	0.54	0.0	2.4
	Green organic	0.00	0.00	0.0	0.0
Biological control agents	Green	0.03	0.02	0.0	0.0
	Gold	0.05	0.03	0.1	0.0
	Green organic	1.15	1.35	0.3	0.2
Other	Green	0.07	0.10	0.0	0.0
	Gold	0.03	0.03	0.0	0.0
	Green organic	0.13	0.22	0.0	0.0

Source: Barber (2004) and Barber & Benge (2006).

Please note that this table shows agrichemicals use per 1000 trays packed for the export market at the packhouse rather than 1000 theoretical trays leaving the orchard.

The manufacturing energy of a specific product was obtained from Green (1987) or, where this was not available, averages for the chemical classes were used as shown in Table 13. The values were calculated based on the following data:

- The biological control agent default of 77 MJ/kg ai was based on *Bacillus thuringiensis* in Milà i Canals (2003).

- The energy required for formulating the agrichemicals into their final product from the pure active ingredient is dependent on the type of formulation. The three most common types of formulation are emulsifiable concentrates, wettable powders and granules. These have embodied energy contents per tonne of agrichemical of 20, 30 and 15 MJ/kg respectively (Green 1987). The energy in packaging requires 2 MJ/kg (Green 1987).
- Transport is generally a small energy cost when compared with the total embodied energy in a product. Transport adds between 0.2 and 4.6 MJ/kg depending on whether it is being produced in Germany or New Zealand. If the product's origin was not known, the default origin for the chemical type was used (as shown in Table 13).
- Barber and Benge (2006) described hydrogen cyanamide production in detail and determined the manufacturing energy was 72 MJ/L ai.
- Wells (2001) used a carbon dioxide emission factor for agrichemicals of 0.060 kg CO_2/MJ. GHG emissions are estimated to be 0.064 kg CO_2eq/MJ to account for the methane and nitrous oxide in the fuel mix.

Table 13 Default manufacturing energy and country of origin for agrichemicals.

	Manufacture MJ/kg ai	Country of origin
Fungicide	97	Germany
Fungicide – inorganic (Cu and S)	5	New Zealand
Herbicide, general	203	Australia
Herbicide (glyphosate)	437	Australia
Insecticide	185	Australia
Plant growth regulator	87	Germany
Biological control agent	77	Australia/Germany
Oil	9	Australia
Other	10	Australia

The distance and type of transport is shown in Table 14 for each country of origin. Shipping distances were taken from the website www.maritimechain.com/ with truck and rail distances from Milà i Canals (2003). The energy used for truck cartage is 3.0 MJ/t-km, rail 1.0 MJ/t-km (Eyre & Michaelis 1991) and shipping is 0.11 MJ/t-km (Saunders et al. 2006).

Table 14 Transport of agrichemicals.

Country of origin	Truck (km)	Rail (km)	Ship (km)	MJ/kg of agrichemical
Germany	200	1500	21 587	4.6
Japan	40		8921	1.1
Australia	40		2359	0.4
NZ	20		1100	0.2

Machinery production and maintenance

Description

Kiwifruit orchard machinery and its associated embodied energy and GHG emissions during material sourcing, manufacture, transport and maintenance tend to be a larger component in the life cycle of kiwifruit than in many other horticultural products. This is due to orchards requiring at least one tractor, and invariably two or three, plus a full complement of implements that is used in a relatively small area (the average orchard size is approximately 8 ha). In addition to the machinery, there is a growing support system and sometimes an irrigation system (see Section 6.5).

Data

An inventory of machinery, implements, growing support structures, and irrigation system components was collected in orchard surveys (Barber 2004; Barber & Benge 2006). Table 15 gives the aggregated weight of all the vehicles and implements owned and used on an orchard, divided by the orchard's canopy area (averaged values). Note that these values do not account for the expected lifetime of the machinery.

Table 15 Aggregated orchard vehicle and implement weights – excluding contractors' operations (per hectare).

	Orchard type	Average kg/ha	95% confidence interval	Minimum	Maximum
Vehicle	Green	978	249	202	1517
	Gold	1184	597	820	6880
	Green organic	1480	533	599	700
Implements	Green	389	87	163	638
	Gold	632	456	401	5600
	Green organic	838	182	368	744

Source: Barber (2004) and Barber & Benge (2006).

Tables 16 gives the aggregated weight of all the vehicles and implements owned and used on an orchard, divided by the equipment's working life (Table 17) and orchard production.

Table 16 Aggregated orchard vehicle and implement weights by production (per 1000 export trays).

	Orchard type	Average kg/1000 trays	95% confidence interval	Minimum	Maximum
Vehicle	Green	9.3	2.7	9.1	22.0
	Gold	8.2	3.4	0.5	14.3
	Green organic	21.9	16.9	8.4	65.8
Implements	Green	2.8	0.7	1.1	3.8
	Gold	2.6	1.7	0.2	5.5
	Green organic	8.7	4.1	5.5	19.5

Source: Barber (2004) and Barber & Benge (2006).

Please note that this table shows vehicle and implement use per 1000 trays packed for the export market at the packhouse rather than 1000 theoretical trays leaving the orchard.

Table 17 gives the energy associated with machinery. The embodied energy of vehicles and implements is 64.6 MJ/kg and 50.3 MJ/kg respectively. This is based on a simplification of the approach used by Audsley et al. (1997) and incorporates New Zealand data for steel and rubber. All vehicles are assumed to contain 95% steel and 5% rubber; while implements are 100% steel (Audsley et al. 1997). In New Zealand the production of steel requires 31.3 MJ/kg (Alcorn 2003) and rubber 110 MJ/kg (Alcorn 1996). Energy consumption for manufacturing and the percentage attributed to repairs was the average of three machine categories and two implement categories given by Audsley et al. (1997). Note that the estimate of vehicle working life is conservative; in most cases tractors are sold on to other businesses at the end of their useful working life in the orchard.

Table 17 Energy used and GHG emissions in machinery manufacture and maintenance.

Machinery type	Energy used to produce materials (MJ/kg)	Energy consumption for manufacture (MJ/kg)	Energy consumption for repairs (%)	Total energy (MJ/kg)	GHG emissions (kg CO_2eq/ kg)	Working life (years)
Vehicle	35.2	14.0	31.3	64.6	5.64	15
Implement	31.3	8.0	28.0	50.3	4.91	20

A contractor's capital equipment contribution has not been included in this analysis due to lack of data. Generally, however, the overall contribution is considered to be relatively low due to their high equipment utilisation compared with a piece of equipment that is dedicated to a single orchard. However, some surveyed orchards recorded zero machinery use because all operations were conducted by a contractor.

Infrastructure: growing support, irrigation and buildings

Description

Kiwifruit is predominantly grown on an overhead pergola system. During the industry's early establishment a t-bar system was popular, but all new orchards use pergolas and most t-bars have been converted over to pergolas because of the higher yields that can be achieved.

Approximately 25% of orchards irrigate on a regular basis, but many more use irrigation during vine establishment. The surveyed orchards (Barber 2004; Barber & Benge 2006) provided information on all irrigation components.

Most orchards have predominantly steel sheds for housing equipment and to provide facilities for workers.

Data

The data in Table 18 give the total area of orchard buildings divided by the canopy area along with the aggregated quantity of support structures and irrigation systems broken down into their components (steel, wood, PVC and polyethylene), again divided by the canopy area.

Table 19 shows the same detail as in Table 18, but this time divided by the working life and annual orchard production, to provide an annual area and weight of each capital component per 1000 trays.

Table 18 Orchard buildings, support structures and irrigation system quantities (per hectare).

	Orchard type	Average m^2/ha or kg/ha	95% confidence interval	Minimum	Maximum
Buildings	Green	47	20	69	24
	Gold	21	12	41	0
	Green organic	50	24	36	29
Steel	Green	1661	548	532	559
	Gold	2408	980	4899	385
	Green organic	1348	870	998	1925
Wood	Green	15 629	1944	21 777	15 426
	Gold	14 671	3695	11 414	15 663
	Green organic	16 854	2307	30 724	39 181
PVC	Green	63	35	0	133
	Gold	80	44	0	371
	Green organic	21	18	20	0
PE	Green	119	38	252	245
	Gold	119	47	0	314
	Green organic	77	51	60	0

Source: Barber (2004) and Barber & Benge (2006).

Table 19 Orchard buildings, support structures and irrigation system quantities (per 1000 export trays).

	Orchard type	Average m^2 or kg/1000 trays	95% confidence interval	Minimum	Maximum
	Green	0.3	0.1	0.7	0.3
Buildings	Gold	0.1	0.1	0.0	0.7
	Green Organic	0.6	0.5	0.3	1.6
	Green	6.5	2.1	0.7	23.4
Steel	Gold	7.1	2.9	1.6	15.2
	Green Organic	6.5	10.6	14.5	8.3
	Green	72.7	8.5	39.8	76.3
Wood	Gold	58.0	15.6	67.7	49.5
	Green Organic	122.6	122.2	46.6	202.8
	Green	0.3	0.1	0.4	0.2
PVC	Gold	0.2	0.1	0.0	0.1
	Green Organic	0.1	0.0	0.0	0.7
	Green	0.9	0.3	0.5	1.1
PE	Gold	0.7	0.3	0.0	0.7
	Green Organic	0.9	1.8	0.0	3.4

Source: Barber (2004) and Barber & Benge (2006).

Please note that this table shows orchard buildings, supports and irrigation systems per 1000 trays packed for the export market at the packhouse rather than 1000 theoretical trays leaving the orchard.

To determine the capital energy embodied in the growing structure it was broken down into its components: posts, 4×1 rough-sawn laminated wood, Agbeam, and wire. Relevant data are shown in Table 20.

The energy embodied in an irrigation system was calculated from the quantity of PVC and polyethylene pipe (Table 20). The energy values were determined by Alcorn (2003) together with carbon dioxide emissions which were then adjusted to account for the methane and nitrous oxide emissions in the fuels (see Barber 2008).

Table 20 Embodied energy, GHG emissions and working life of buildings, support structures and irrigation systems.

Machinery type	Energy in materials (MJ/kg)	Total energy (MJ)	GHG emissions (kg CO_2eq)	Working life (years)	Data source
Building	–	124 (per m²)	12.4 (per m²)	20	Barber & Pellow 2008
Steel wire	31.3	1.2 (per metre)	3.79	30	
Steel Agbeam	31.3	56 (per metre)	3.79	50	
Timber posts	2.8	56 (per post)	0.19	30	
PVC	60.9		4.6	40	
LDPE	51.0		3.7	20	
MDPE	51.0		3.7	30	

Field emissions of nitrous oxide

Description

In most soils, an increase in available nitrogen enhances nitrification and denitrification rates which then increase the production of N_2O. The following nitrogen sources are included in the methodology for estimating direct N_2O emissions from soils:

- Synthetic N fertilisers.
- Organic N applied as fertilisers (e.g. compost).
- N in crop residues (above-ground).

Compost has further N_2O emissions during the production process.

Data

The quantities of synthetic nitrogen fertiliser and compost are shown in Tables 9 and 10.

Methodological issues

Soil emissions from synthetic N fertiliser

Nitrous oxide emissions from the application of synthetic nitrogen fertiliser were determined based on the methodology and default emission factors in the NZ Greenhouse Gas Inventory (MED 2007). The content and format of the NZ GHG Inventory is prescribed by the Intergovernmental Panel on Climate Change.

Nitrous oxide comes from both direct and indirect sources. Direct sources include soil emissions from synthetic nitrogen fertiliser applied in the orchard. 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. Nitrous oxide emissions from soils can be estimated (in kg CO_2eq) by summing the various emission components in Equations 1, 2 and 3 below.

Direct soil emissions (SE_{DIRECT}) = kgN applied × (1−$Frac_{GASF}$) × EF_1 × 44/28 × GWP_{N_2O} (1)

Indirect soil emissions ($SE_{INDIRECT}$) = kgN applied × $Frac_{GASF}$ × EF_4 × 44/28 × GWP_{N_2O} (2)

Indirect leaching soil emissions (SE_{LEACH})
= kgN applied × (1−$Frac_{GASF}$) × $Frac_{LEACH}$ × EF_5 × 44/28 × GWP_{N_2O} (3)

Total SE = SE_{DIRECT} + $SE_{INDIRECT}$ + SE_{LEACH}

Table 21 defines the different terms in these equations and gives their default values.

Table 21 Relevant factors for use in evaluating nitrous oxide emissions from soil.

	Description	Default value
GWP_{N2O}	Global warming potential of nitrous oxide (IPCC, 2001)	296
EF_1	Emission factor for direct emissions from N input to soil	0.01
EF_4	Emission factor for indirect emissions from volatising nitrogen	0.01
EF_5	Emission factor for indirect emissions from leaching nitrogen	0.025
$Frac_{GASF}$	Fraction of synthetic N fertiliser emitted as NO_x or NH_3	0.1
$Frac_{LEACH}$	N input to soil that is lost through leaching and run-off	0.07

Soil emissions from compost

These emissions are determined using Equation 4:

Direct soil emissions ($SE_{COMPOST}$) = kgN × EF_1 × 44/28 × GWP_{N_2O} (4)

The kilograms of nitrogen in the compost is determined using Equation 5:

Compost nitrogen = kg compost × % dry matter × % nitrogen (5)

In the absence of measured values for the percentage of dry matter (DM) in compost, plus the likely large range, a value of 75% was used (based on typical values such as 85% DM in cereals and 48% DM in silage).

The fraction of nitrogen was taken to be 0.015, being the IPCC default fraction of nitrogen in non-N-fixing crops.

In addition to the field emissions for compost, one source suggests that 0.5% of the initial nitrogen of the compost material is lost as gaseous N_2O during composting (Beck-Friis et al. 2001). This was added to the field emissions from compost.

Soil emissions from leaf litter and shoots

Based on a trial of gold kiwifruit, some 60–80 kgN per hectare is accumulated in shoots and leaves of the current season's growth, which is largely returned to the soil as leaf litter and winter prunings (Green et al. 2007). A figure of 70 kgN/ha has been used for all kiwifruit, although this requires further investigation as it is likely to overestimate the quantity of nitrogen in green kiwifruit. Equation 4 was then used to determine nitrous oxide emissions during decomposition.

Other aspects: establishment of orchards

Description

Kiwifruit orchards are established over a period of 3–5 years and then produce fruit for 60 years or more.

Data

Box 1 gives the results of a modelling exercise to determine the GHG emissions associated with establishing a new orchard from pasture over 17 years.

Methodological issues

Establishment of kiwifruit orchard

Theoretically this establishment period should be included in the carbon footprint of the kiwifruit.

Recommendation:

Depending on the inputs during establishment of kiwifruit orchards, this phase could be relevant to the carbon footprint for the orchard operations (from a life-cycle perspective). It is suggested as a topic for future research.

Loss of soil carbon associated with land use change to orchard

Box 1 indicates that the loss of soil carbon and related nitrous oxide emissions associated with establishing a new orchard can be significant.

Recommendation:

Further research is needed to establish an appropriate modelling approach for this aspect, taking account of the total expected lifetime of the orchard and alternative land uses (see discussion in Milà i Canals et al., 2007b).

Box 1. Modelling exercise to estimate GHG emissions associated with establishment of a new kiwifruit orchard.

The first phase in the LCA of a kiwifruit is the establishment of a new orchard. If this happens after 1st January 2008 and constitutes a direct land-use change, then the GHG released as a consequence of land-use change have to be considered according to the IPCC methodology (e.g. 0–0.3 m depth) over the next 20 years (PAS section 5.6).

Contribution to GHG footprint

Due to a lack of data we modelled the worst case scenario with respect to a possible soil organic carbon (SOC) loss following establishment of a new orchard from pasture. This would account for the loss of SOC following the change of a pastoral system into a kiwifruit orchard. We used the HortResearch SPASMO (Soil Plant Atmosphere Model) model to predict the change in soil carbon stocks in 0-0.3 m depth over time (1990–2008) when a permanent pasture was turned into a kiwifruit orchard (Fig. 1). We used a soil and climate record representative of the main kiwifruit production area in New Zealand around Te Puke. Under a "bare orchard floor scenario", the decline would be 1.98 kg/m^2 equalling 19.8 t/ha soil carbon in 0–0.3 m depth over 17 years. If pasture were used as a cover crop in the alleys ("50% cover crop scenario"), the decline would be just 0.76 kg/m^2, equalling 7.6 t/ha soil carbon in 0–0.3 m depth over 17 years. If the entire orchard floor were covered by pasture ("100% cover crop scenario"), we found a carbon would increase of about 0.47 kg/m^2 equalling 4.7 t/ha soil carbon in 0–0.3 m depth over 17 years.

These modelled numbers are quite large; however, they are of the same order of magnitude that we have measured in an apple orchard (Deurer et al. 2008). In an integrated orchard (equivalent to the 50% cover crop scenario) in Hawke's Bay we estimated a loss of 11 ± 7 t/ha of soil carbon in 0–0.3 m depth over 12 years when compared to a permanent pasture reference.

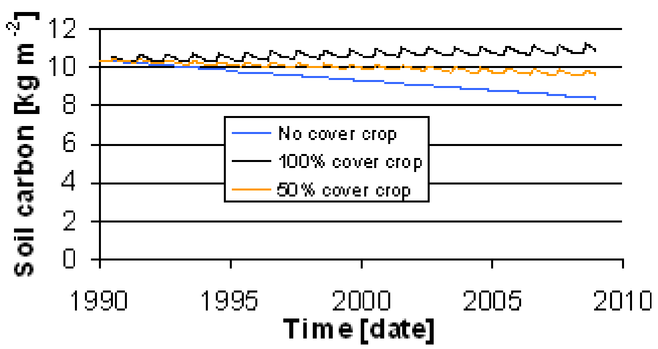

Fig. B1. Modelled change of soil carbon stocks in the soil of an example kiwifruit orchard with different orchard floor management practices. We used existing records of the climate and soils around Te Puke. The previous land use (before 1990) was permanent pasture. Note that we used permanent pasture as a cover crop.

For the no-cover crop scenario this would be equivalent to the following annual SOC losses and CO_{2e} per TE of kiwifruit:

1.98 kg SOC m^{-2} in 17 years equals on average a loss of 116 g C m^{-2} year^{-1} and simultaneously a loss of 9.7 g N m^{-2} year^{-1}. For the N loss we assumed a C:N ratio of 12.

For the conversion of N_2O to CO_{2e} we used a GWP of 298

We assumed a yield of 0.84 TE m^{-2} for Gold and of 0.63 TE m^{-2} for green, and 0.52 TE m^{-2} for green organic

The SOC loss per TE leads then to 130.10 g C TE^{-1} and 11.51 g N TE^{-1} for gold, 184.13 g C TE^{-1} and 15.34 g N TE^{-1} for green, and 223.08 g C TE^{-1} and 18.6 g N TE^{-1} for organic green.

Kiwifruit Life Cycle Stages: Post-Orchard

Transport to packhouse

Description

The kiwifruit are transported by unrefrigerated trucks (tautliners) to packhouses in bins. There were 82 registered kiwifruit packhouses for the 2008 harvest. Some packhouses are located within the orchard; however, at the other extreme there is a packhouse located in Nelson that processes some of the kiwifruit grown in Tauranga (I. Mearns, pers. comm., 19 June 2008).

Data

Data on transport and packaging are given in Table 22.

Table 22 Details of packaging and transport from orchard to packhouse.

Type of data	Item	Relevant data	Source of data
Packaging for orchard-to-packhouse stage	Wooden crates (bins) to transport kiwifruit from orchard to packhouse	Each wooden bin weighs 40 kg with 5–10% being replaced each year; one bin contains 260 kg of fruit	Parker et al. 2008; Zespri. pers. comm.
Transport	Transport from orchard to packhouse	Average distance of 15–20 km from orchard to packhouse; 60 bins transported per truck (40-t trucks); trucks bring the empty bins on the return journey	I. Mearns, pers. comm., 19 June 2008
		Maximum distance: 300 km	
		Minimum distance: 0 km (packhouse within the orchard)	

Packhouse and coolstore

Description

The kiwifruit are cured (i.e. left standing) for about two days (sometimes with an initial short cooling) and then hand-sorted into different grades of fruit. A few packhouses have optical sorting systems, but the fruit is still checked manually in these systems. Each fruit is then labelled and sorted by weight before being packed by individual packers.

Ninety-five percent of fruit shipped overseas is Class I; some Class II and III fruit has to be exported depending on the demand. Four percent of green and 2% of gold kiwifruit goes to Australia. Only non-export-quality fruit is sold on the New Zealand domestic market – 1% of green and 2% of gold kiwifruit.

There are many types of packaging used for kiwifruit. Modular bulk 10-kg boxes, which contain on average 2.8 tray-equivalents of fruit, are used for fruit exported to Europe, while single-layer trays are used for export to Japan. The single-layer trays each consist of a cardboard box plus a plastic sleeve. The trays are then packed onto pallets, corner pieces are added, and the pallets are wrapped with plastic strapping. The pallets are stored in the cool store for varying amounts of time (24 hours for early harvest fruit and 24–26 weeks on average depending on the demand and onshore fruit volumes); and then checked (about 20% of the first pack) before onward transport; degraded fruit (20–40% of the checked volume) is removed and trays are repacked as necessary (H. Gardner, pers. comm., 17 July 2008). These degraded fruit are part of the total 10% fruit wastage at the packhouse stage (see section 3.1).

Waste fruit is mainly (95%) sent to farmers for stockfeed; this supplements feedstock and sometimes replaces palm kernel as a feed additive (C. Pretorius, pers. comm., 21 May 2008). A very small amount of kiwifruit is sent for processing (mostly gold kiwifruit), and the remainder is sent to landfill.

Forklifts are used to move kiwifruit around. LPG (liquefied petroleum gas) forklifts are used for transport in the open air and electric ones for transport in the packhouse/coolstore.

The commonly used (70–80%) refrigerant in the coolstore is HFC-404A. Small amounts (5%) of HFC-134a are also used, while the balance mainly is HCFC-22. A typical coolstore with a 100 000-tray capacity could require a refrigerant charge of 200 kg per year. However, refrigerant leakage rates can be highly variable between coolstores due to differences in design and maintenance practices (D. Cleland, pers. comm., 8 June 2008). Also, infrequent unintended events can cause a complete recharge of refrigerant.

According to two reports on energy use for packhouse and coolstore activities, electricity use is dominated by the energy for refrigeration, which accounts for 72–82% of the total (Smart Power Ltd 2003a & b). Average electricity use for packhouse activities calculated based on these published data (Smart Power 2003a, b) ranges from 1.0–8.6 kWh/tray. However, the quoted throughput of kiwifruit in these reports is wrong. The electricity use was recalculated based on the total quantity of fruit submitted to Zespri by the two packhouses considered in the above reports for export in that year. The data used are as shown in Table 23; the average of these two values was used in this study.

The total number of trays processed in any given year at the packhouse, however, is generally higher than the number submitted to Zespri for export. The data used for electricity use in the study are therefore conservative estimates.

Table 23 Total electricity use for packhouse activities in 2003.

Name of packhouse	Number of TE submitted	Annual energy use (kWh)	Total energy use (kWh/TE)	Energy use for refrigeration (kWh/TE)
Aerocool	1 696 000 (~ 6000 pallets)	1 000 000	0.590	0.483 (82% of total)
Birleys	1 482 000 (~ 5250 pallets)	437 000	0.295	0.212 (72% of total)

Source: adapted from SmartPower 2003a, b.

Data

The details of packaging materials, energy, refrigeration and packhouse activities are shown in Table 24.

Table 24 Details of packaging, energy use and waste quantities at packhouse.

Type of data	Item	Relevant data	Source of data
Packaging at packhouse	Plastic sleeve	0.0164–0.02196 kg plastic per tray (PET)	Adapted from Parker et al. 2008
	Plastic liner	0.00713 kg plastic liner per tray (HDPE)	
	Adhesive for tray	4–10 g/tray	
	Single-layer tray	0.2 kg (cardboard)	
	Wooden pallet	20 kg (wood); each pallet has 174 trays packed on it weighing an average 727 kg	Zespri 2008
	Corner pieces	18.39 g solid fibre cardboard per tray	J. Chamberlain, pers. comm. 17 April 2008
	Strapping	0.18 m PP strapping per tray	Adapted from Parker et al. 2008
Other ancillary items (excl. packaging)	Refrigerants in coolstore	leakage rate 0.1486 g/tray (HCFC 22)	Packhouse A, pers. comm., 16 June 2008
Energy	Electricity use in packhouse/coolstore	0.295–0.590 kWh/tray 72–82% of the electricity use is for refrigeration	Zespri, pers. comm. 17 June 2008 and D. Cleland, 18 June 2008; Smart Power 2003a, b

Fuel	LPG for forklifts	1.39 g/tray	Packhouse A, pers. comm., 16 June 2008
Waste	Waste at packhouse	Waste fruit[5] 10% (95% of waste fruit is used as cattle feed) Cardboard 2% Wood 5–10% Plastic 1%	D. Smith, pers. comm. 22 May 2008 Parker et al. 2008
Storage times	Coolstore	Green kiwifruit: average 3 months in coolstore Gold kiwifruit: average 6 weeks in coolstore Organic kiwifruit: average 3 months in coolstore Note: fruit picked between March and mid-April are shipped directly to the wharf with no (or very short) cooling periods	S. Kay, Satara pers. comm., April 2008; G. Arrowsmith, Zespri pers. comm., 8 May 2008

Methodological issues

Allocation of upstream GHG emissions between different grades of fruit

It may be questioned whether the GHG emissions associated with kiwifruit production should be allocated in different proportions to the different fruit grades, given that production of export-quality kiwifruit is the main purpose of kiwifruit production. According to the ISO 1404 series of LCA standards, 'decisions within an LCA are preferably based on natural science' (ISO 14040, section 4.1.8.2), and a hierarchy of approaches should be followed in situations where allocation becomes an issue (ISO14044 section 4.3.4.2). The preferred approach is system expansion; according to this approach, the co-products (i.e. non-export quality fruit) are accounted for by quantifying the alternative products that are displaced in the marketplace by this non-export quality fruit – and subtracting their GHG emissions from the modelled system. If we assume that these displaced products have GHG emissions equivalent to production of kiwifruit, effectively we allocate the GHG emissions from kiwifruit production on a mass basis between the different grades of fruit. Where system expansion is not possible, ISO14044 (section 4.3.4.2) recommends 'the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them' (ISO 14044, section 4.3.4.2). In this study, this can be interpreted as allocating the GHG emissions associated with kiwifruit production on a mass basis between the different grades of fruit. This is the approach used, for example, by Milà i Canals et al. (2007, section 6.2, p. 34). However, the PAS 2050 recommends that economic allocation should be used (PAS 2050, section 8.1).

[5] 10% of total fruit entering the packhouse is wasted.

Recommendation:

System expansion should be used as it is the preferred approach in ISO14044; it has been used in this study (however, the assumption used in the study means that this is equivalent to allocation on a mass basis between different grades of fruit). Sensitivity analysis should be used to evaluate the impact of alternative allocation approaches on the results (following ISO 14044, section 4.3.4.1).

Accounting for fruit sent for stockfeed

According to ISO 14044 (section 4.3.4.2), system expansion is the preferred approach when allocation is an issue. For kiwifruit sent for stockfeed, this means accounting for any displaced stockfeed as an avoided environmental burden. However, according to the PAS 2050, economic allocation should be used in this situation (PAS 2050, section 8.1), i.e. the GHG emissions associated with kiwifruit production are allocated to the different grades of fruit and the kiwifruit going to stockfeed in proportion to their economic values. Farmers pay $0–10 per tonne for waste kiwifruit (Parker et al. 2008).

Recommendation:

Waste kiwifruit is regarded as an optional supplement to animal feedstocks, and so it is assumed that it does not replace any alternative feedstocks in this study. Therefore no GHG emissions are associated with its production.

Variability in storage times

According to the PAS 2050, where products are identifiable by source or time period, the GHG emissions should reflect the specific source or time period (PAS 2050, section 7.10). This implies that kiwifruit sold at different times of the year may have different carbon labels due to variable storage requirements (and consequent GHG emissions). However, a recent case study of tomatoes using the PAS 2050 method did not define a carbon label due to uncertainties about how to model seasonal sourcing changes (Tesco 2008, p. 8).

Recommendation:

For this study, average storage times are used and the relative importance of variable storage length is investigated at sensitivity analysis.

Transport from packhouse/coolstore to port

Description

The pallets are transported by 40-t trucks (without refrigeration) from the packhouse or coolstore to port, and the trucks return empty (Table 25).

Data

The details of transport from packhouse to New Zealand port and energy use at the port are shown in Table 25.

Table 25 Details of transport and energy use at New Zealand port.

Type of data	Item	Relevant data	Source of data
Transport	Transport from coolstore to port	45.5-t truck transports 24 pallets; average distance is 40 km one-way and trucks return empty.	I. Mearns, pers. comm.
Energy	Electricity use	0.012 kWh/tray	I. Mearns, pers. comm., 19 June 2008

Shipping

Description

For the European market, about 90% of the fruit is shipped in pallets in REFA bulk ships (i.e. stored below deck) to Zeebrugge; the remainder is transported in containers on deck.

Data

GHG emissions were calculated using an emission factor for reefer ships in Wild (2008); Box 2 provides an alternative calculation based on alternative fuel consumption data.

Methodological issues

Variability in fuel use data for shipping

There appear to be large differences between different data sources for fuel use and GHG emissions associated with shipping.

Recommendation:

This is a topic for further research attention.

Box 2. Carbon footprint of shipping activity based on kiwifruit industry data.

Activity Data:
Distance from Tauranga in New Zealand to Zeebrugge in Belgium is 20 675 km
Distance from Tauranga in New Zealand to Yokohama in Japan is 9141 km

Weight of a pallet with 174 trays of fruit is 727 kg.

To Europe one ship carries 5250 pallets; ship consumes 50 t marine diesel per day (including auxiliary power for cooling), and the ship brings miscellaneous items from Europe.

To Japan one ship carries 2900–3000 pallets; ship consumes 26 t of marine diesel per day.

Time taken to travel to Europe is 26 days and to Japan 12 days. Vessels bring cars and bananas from Japan) on the return trip.

- (Source: R. Dillimore, pers. comm., 12 June 2008)

Contribution to GHG footprint:
The actual fuel use for kiwifruit transport to Europe and Japan can be calculated as follows:

- Total fuel use by the ship to travel 20 675 km from Tauranga to Zeebrugge in Belgium is 1300 t of marine diesel. The ship carries 5250 pallets, each with 174 trays of fruit with a gross weight of 727 kg. Therefore, the total weight of goods transported is 3816.75 t.
- The fuel use intensity to Europe = 1300 ÷ (20796 × 3816.75)
- = 0.0000164 t/t-km = 0.0164 kg/t-km

- Total fuel use by the ship to travel 9141 km from Tauranga to Yokohama in Japan is 312 t of marine diesel. The ship carries 2950 pallets each with 174 trays of fruit with a gross weight of 727 kg. Therefore, the total weight of goods transported is 2144.65 t.
- Therefore, the fuel use intensity to Japan = 312 ÷ (9141 × 2144.65)
- = 0.0000159t/t-km = 0.0159 kg/t-km

Based on Wild (2008), CO_2 emissions due to fuel use for shipping = 0.024 ÷ 0.0075
= 3.2 kg CO_2/kg fuel

The CO_2-equivalent GHG emissions due to the shipping activities based on the above data for fuel use and emissions factors are:

- Ship transporting Europe = 0.0164 × 3.2 = 0.0525 kg CO_2eq/t-km
- Ship transporting to Japan = 0.0159 × 3.2 = 0.0509 kg CO_2eq/t-km

Transport requirement to Europe = (727 ÷ (174 × 1000)) × 20675 = 86.76 t-km
Transport requirement to Japan = (727 ÷ (174 × 1000)) × 9141 = 38.21 t-km

GHG emissions per tray to Europe = 0.0525 × 86.76 = 4.55 kg CO_2eq/TE
GHG emissions per tray to Japan = 0.0509 × 38.21 = 1.94 kg CO_2eq/TE

However, this excludes emissions due to refrigerant leakage.

Repackaging in Europe

Description

At the destination port, fruit are unloaded, checked and may be repacked into single-layer trays, loose bulk, or into six-pack containers. They are then stored on average for 18 days prior to onward transport. For this study, no data were available for energy use at the port or repackaging facility; however, the GHG emissions associated with supplying one spife per ten kiwifruit at the retailer are included in the analysis.

Data

Details of port activities are given in Table 26.

Table 26 Details of activities at overseas port.

Type of data	Item	Relevant data	Source of data
Packaging	Spife	Each one is made of polystyrene and weighs 15 g	J. Chamberlain, pers. comm., 17 April 2008

Transport from Zeebrugge to retailer

Description

Fruit are transported onwards to many European destinations by trucks (V. Parmentier, pers. comm., 21 July 2008). Twenty-eight percent of fruit goes to Spain, 20% to Germany, and 13% to Netherlands.

Data

The transport data in the table below are for average transportation to retail outlets in the UK – and are given as illustrative data. Obviously transportation distances will vary widely depending upon the final destination for the kiwifruit.

Table 27 Details of transport to retail outlets.

Type of data	Item	Relevant data	Source of data
Transport	London port to retailer (via RDC)	176 km by heavy goods vehicle[a] and 98 km by light goods vehicle[b]	Smith et al. 2005, pp. A1–2 (Table A1-1) and pp. A1–6 (Table A1-3)

Notes:

a. Distance travelled by ‘perishable’ and ‘other non-perishable’ foodstuffs (132 km), adjusted to account for empty trips (25% for food and drink). Data are for 2002. Average load is 10.8 t.

b. Average distance travelled by light goods vehicles (64 km) adjusted to account for empty trips (35%). These data are from a study in 1992/93. Average load is 0.75 t. Eighty-five percent of LGVs are diesel (Smith et al. 2005, p. A3-1).

Retailer

Description

Almost all kiwifruit are displayed in non-refrigerated displays at retail outlets

(V. Parmentier, pers. comm., 21 July 2008).

Data

Nielsen et al. (2003) give the following Danish values for energy used during retailing of various products in large modern stores that ‘meet extraordinary requirements on environmental management’:

- For 1 kg potatoes (room temperature storage): 0.03 MJ heat and 0.04 MJ electricity
- For 1 kg pasta (room temperature storage): 0.27 MJ heat and 0.47 MJ electricity

These values include energy used for room heating and lighting; they are based on allocation of energy use according to the exposure area and average flow of each product through the store. The difference in the energy use by the two products is due mainly to the variation in the retention time at the retail outlet. In this study, the value for potatoes has been used as a proxy for this life cycle stage (as the retention time of kiwifruit is more similar to potatoes than pasta).

Wastage at this stage has not been included in the study due to lack of data.

Transport from retailer to household

Description

Transport distances – and associated emissions – between individual retailers and points of consumption are highly variable as they depend upon the behaviour of individual consumers and their geographical location.

Methodological issues

Inclusion of this life cycle stage

As noted in Section 3.2, the PAS 2050 recommends that this life cycle stage should be omitted from the carbon footprinting of products and services. However, its omission means the relative importance of this stage in the kiwifruit life cycle cannot be understood.

Recommendation:

This life cycle stage is included in this scoping study to gain a better understanding of the hotspots in the kiwifruit life cycle. However, its inclusion in future analyses depends upon the purpose of the study.

Allocation of transport emissions among purchased items

Consumers are unlikely to make a shopping trip solely to buy kiwifruit and so the transport emissions should be allocated among the different items purchased on any one trip.

Recommendation:

As this life cycle stage is highly variable, a range of values should be used to demonstrate its relative importance in the kiwifruit life cycle. This should extend from 0% allocation to kiwifruit (representing consumption of kiwifruit at the retail outlet) to 100% allocation to kiwifruit (representing the unlikely situation of a shopping trip solely to purchase kiwifruit).

Data

The data in Table 28 are taken from a UK study on food miles (Smith et al. 2005). They are used as illustrative data for this study.

Table 28 Details of transport from retailer to home.

Type of data	Item	Relevant data	Source of data
Transport	Retailer to home transport	5.5 km each way (carrying 11 kg of shopping) by car	Smith et al. 2005, pp. A1–14, 15

Household consumption

Description

Most kiwifruit are not refrigerated in the home, and therefore the environmental impacts associated with household consumption arise from waste generation at this life cycle stage. There are three relevant aspects here: peelings waste, disposal of over-ripe fruit, and packaging waste.

Data

Table 29 Details of domestic waste related to kiwifruit.

Type of data	Item	Relevant data	Source of data
Waste to landfill	Peelings	Assumed to go to landfill	Milà i Canals et al. (2007, section 5.3)
	Uneaten fruit	Assumed to go to landfill	
	Packaging	Assumed to go to landfill	

Wastewater treatment

Description

After consumption and digestion in the body, the remains of food are excreted and usually pass on to a wastewater treatment plant. This life cycle stage is often omitted from food LCA studies but is, in fact, relevant for inclusion (Sonesson et al. 2004; Munoz et al. forthcoming).

Data

For this study, data in Munoz et al. (forthcoming) were used as a first approximation of the GHG emissions associated with wastewater treatment after consumption of kiwifruit and the subsequent excretion. They calculated 25 L of wastewater and 0.023 kWh electricity were associated with consumption of 985 g of broccoli. The wastewater includes used tap water from flushing the toilet, hand washing and washing towels; the electricity value is related to hand drying. For this study, kiwifruit were assumed to have the same wastewater and electricity consumption values as broccoli (per kg). An emission factor of 0.6 kg CO_2eq per cubic metre of water treated was used as a first approximation (based on EcoInvent (2007) for average wastewater treatment in Switzerland.)

Table 30 Details of wastewater treatment.

Type of data	Item	Relevant data	Source of data
Energy	Energy used by wastewater treatment plant	0.6 kg CO_2eq/m^3	EcoInvent v.2, 2007
	Hand drying	0.023 kWh/985g kiwifruit	Munoz et al. (forthcoming)

Results of Scoping Study

Summary of results

The results in sections 8.1 and 8.2 are for green kiwifruit, with one exception: the GHG emissions associated with gold and organic kiwifruit are discussed in the first part of section 8.2 (under “Different fruit varieties”).

Orchard operations

The GHG emissions shown in Figure 3 are due to orchard operations for 3.3 kg of kiwifruit leaving the orchard (theoretically equivalent to one tray). Orchard operations emit 575 g CO_2eq for each 3.3 kg of fruit leaving the orchard. Of the total emissions, 44% is due to fertilisers and lime, with fuel and electricity use contributing 35%, capital equipment 17%, agrichemical use 4%, and the seasonal workforce 0.4%.

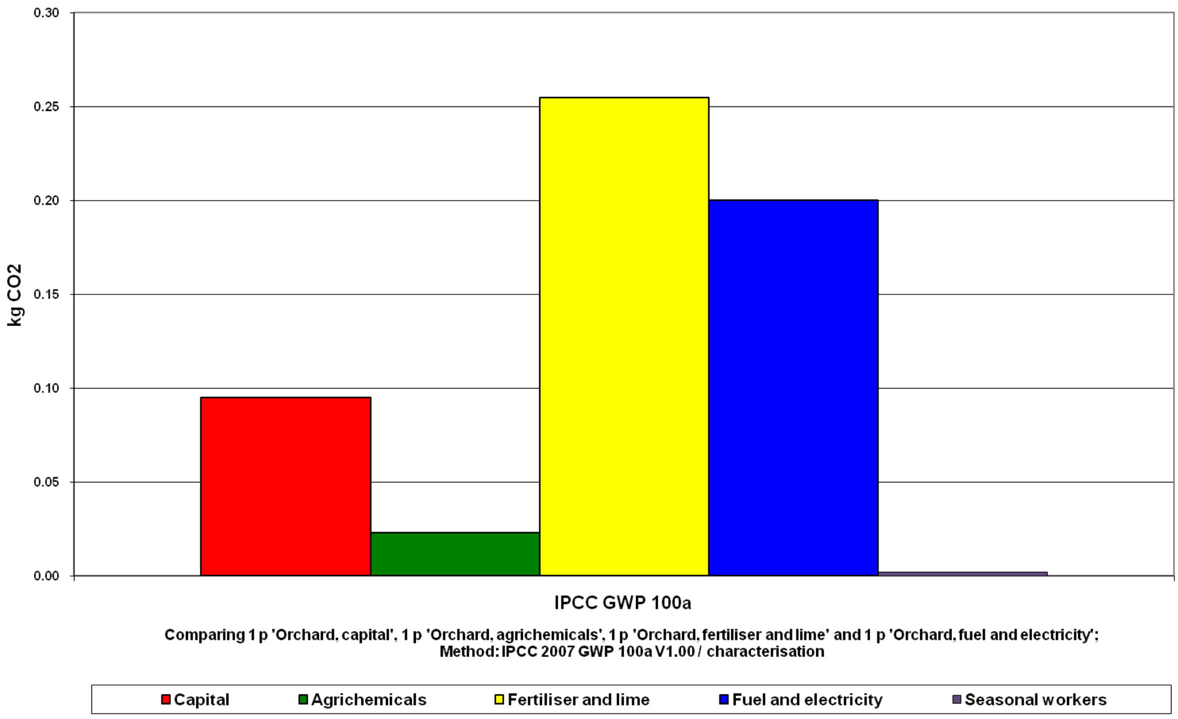

Fig. 3 GHG emissions from individual orchard operations (for every 3.3 kg of fruit leaving the orchard).

Emissions due to fuel and electricity use are dominated by those attributable to fuel use (88% of the total) as New Zealand electricity is relatively low in carbon emissions (as a higher proportion is generated using renewable sources). Mowing and mulching are the operations with the highest contributions to fuel-use emissions.

Emissions for ‘fertiliser and lime’ are those associated with production of fertilisers and compost, transport of compost over a 50-km distance using a 7.5–16-t lorry (European data for transport), and soil emissions (N_2O) due to synthetic-N-fertiliser use, compost and leaf litter/prunings. The main contributors to this life cycle stage are: nitrous oxide emissions (56%), nitrogen fertilisers (21%), lime (10%), and potassium fertilisers (7%).

Emissions due to orchard capital can be mainly attributable to orchard vehicles (46%), growth support (35%), and orchard implements (12%). Sixty-three percent of emissions due to agrichemicals come from the use of hydrogen cyanamide, followed by 23% due to use of general insecticide. The impact of the seasonal workforce is negligible.

Packhouse

Greenhouse-gas-emission contributions from individual packhouse activities are shown in Figure 4. Packhouse activities emit 464 g CO_2eq for each tray that leaves the packhouse.

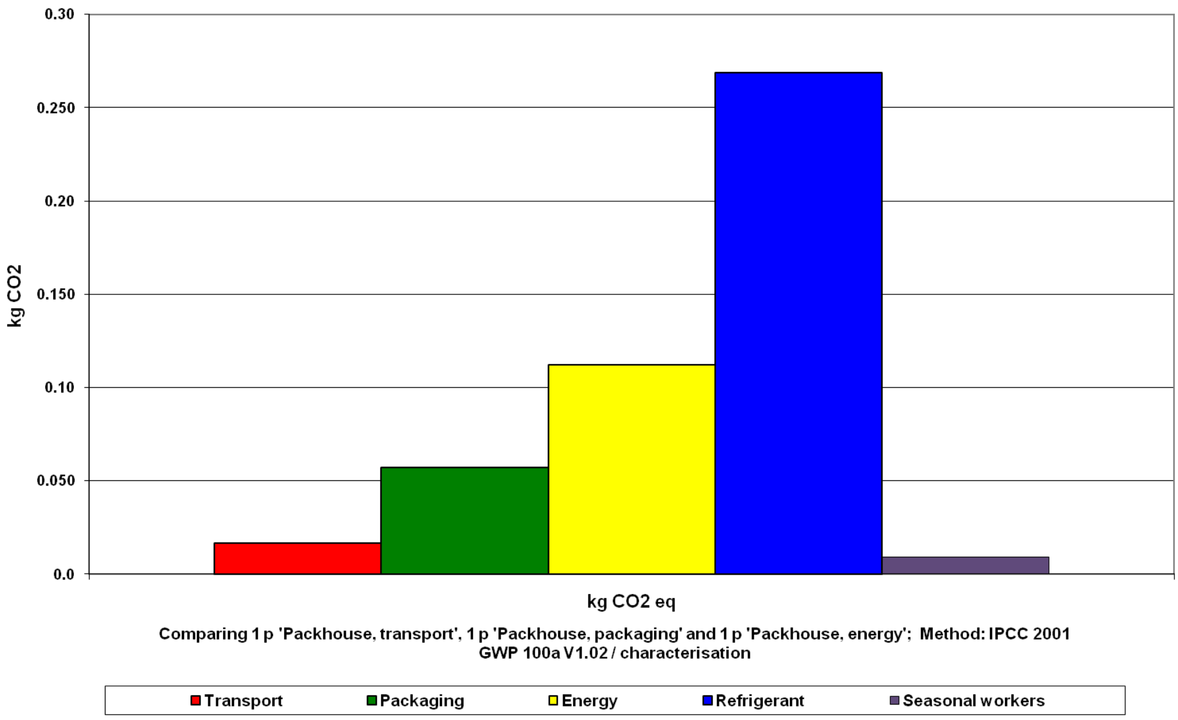

Fig. 4 GHG emissions contributions from individual packhouse activities (for 1 tray equivalent leaving packhouse).

Fifty-eight percent of the emissions are due to refrigerants, while energy use contributes 24% and packaging 12%, and transport 4%. Seasonal workers contribute only 2% to the total. Thirty percent of emissions due to packaging category, which includes both packaging and fruit waste in addition to the packaging materials used, are due to fruit waste sent to landfill. Corrugated cardboard packaging material reduces the carbon emissions (see Appendix 1) as it is presumed that cardboard comes from plantation timber, which is a carbon sink. Emissions due to energy use are dominated by the electricity use for refrigeration (74%) and general activities (22%), while LPG use contributes the balance (4%).

Port

Activities at the New Zealand port contribute 37.5 g CO_2eq per tray leaving the port. Ninety-two percent of the emissions are due to transport activity while electricity use contributes the balance 8% (but note that the other types of energy use are not included in this analysis).

Shipping

(Note that shipping emissions are based on the shipping industry emissions data for reefer ships (Table A2) and the distance and the weight of goods transported.)

Shipping has the highest contribution to the supply chain with 2.1 kg CO_2eq per tray shipped to Europe. Ninety-nine percent of the emissions are due to fuel use while refrigerant leaks contribute only 1%. However, it should be noted that the refrigerant leakage was calculated based on the ship being used throughout the year; in reality, ships are not used every day of the year and so the leakage per tray will be higher (although this will not make any significant difference to the overall results).

Repackaging facility, Zeebrugge

This stage contributes 162 g CO_2eq per tray (but note that packaging materials used other than spifes and energy uses for handling and repackaging are not included in this analysis). Ninety-eight percent of the emissions are due to spifes while packaging waste contributes the balance.

Retailer

This stage contributes 303 g CO_2eq per tray sold. Ninety-one percent of the emissions are due to transport from the port to the retailer, while electricity used by the retailer for lighting etc, contributes 7%, and natural gas used for heating contributes 2%.

Consumer (and subsequent waste treatment)

This stage is the second-highest contributor to the supply chain with 1.09 kg CO_2eq per tray purchased. Seventy-two percent of emissions are due to the use of passenger cars to travel to and from the retailer, while 21% is due to fruit waste sent to landfill, 4% to electricity used for wastewater treatment, and 2% is due to sewage treatment.

Overall kiwifruit supply chain

The total GHG emissions released for 1 tray equivalent of kiwifruit consumed by a consumer in the UK are 5.326 kg CO_2eq. Total GHG emissions at various stages of the supply chain are shown in Figure 5. It should be noted that these values exclude repackaging materials used in Europe (other than spifes), and energy use for handling and repackaging in Europe. It should also be noted that wastage along the supply chain has been modelled as 10% at the packhouse with a further 10% loss between the overseas port and consumption at the consumer's home.

The contributions by the individual stages of the supply chain are as follows: orchard operations 13%, packhouse operations 10%, New Zealand port 1%, shipping 44%, repackaging at Zeebrugge 3%, retailer 6%, and consumer 23%.

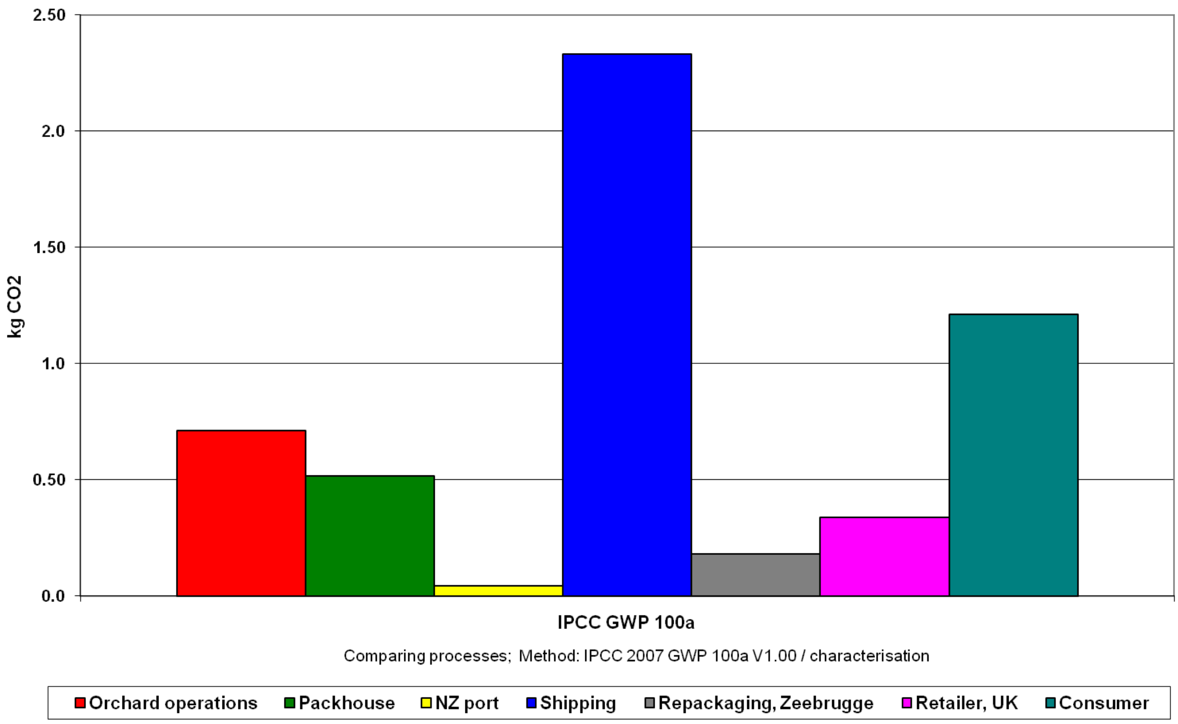

Fig. 5 Total GHG emissions at various stages of the kiwifruit supply chain.

Sensitivity analysis

Different fruit varieties

The GHG emissions for different categories of kiwifruit are shown in Figure 6. In addition to the different production methods and average storage times, different assumptions have been made about wastage in the three categories:

- **Green Kiwifruit:** packhouse 10%, consumer's home 10% (assumed), and zero wastage at all other stages
- **Gold kiwifruit:** packhouse 15% (assumed), consumer's home 12% (assumed), and zero wastage at all other stages
- **Green organic kiwifruit:** packhouse 13% (assumed), consumer's home 11% (assumed), and zero wastage at all other stages

The differences in results between green kiwifruit and the other categories are explained as follows:

- Gold – higher yields per hectare, lower N fertiliser and compost use at the orchard, shorter storage at packhouse (six weeks vs three months), slightly lower transport requirement (due to lighter weight per tray)
- Organic – lower yield per hectare, agrichemicals use largely limited to biological control agents and oil, higher use of vehicles, and implements but lower use of pipe materials, no N fertiliser use and lower use of all other fertilisers but high use of compost.

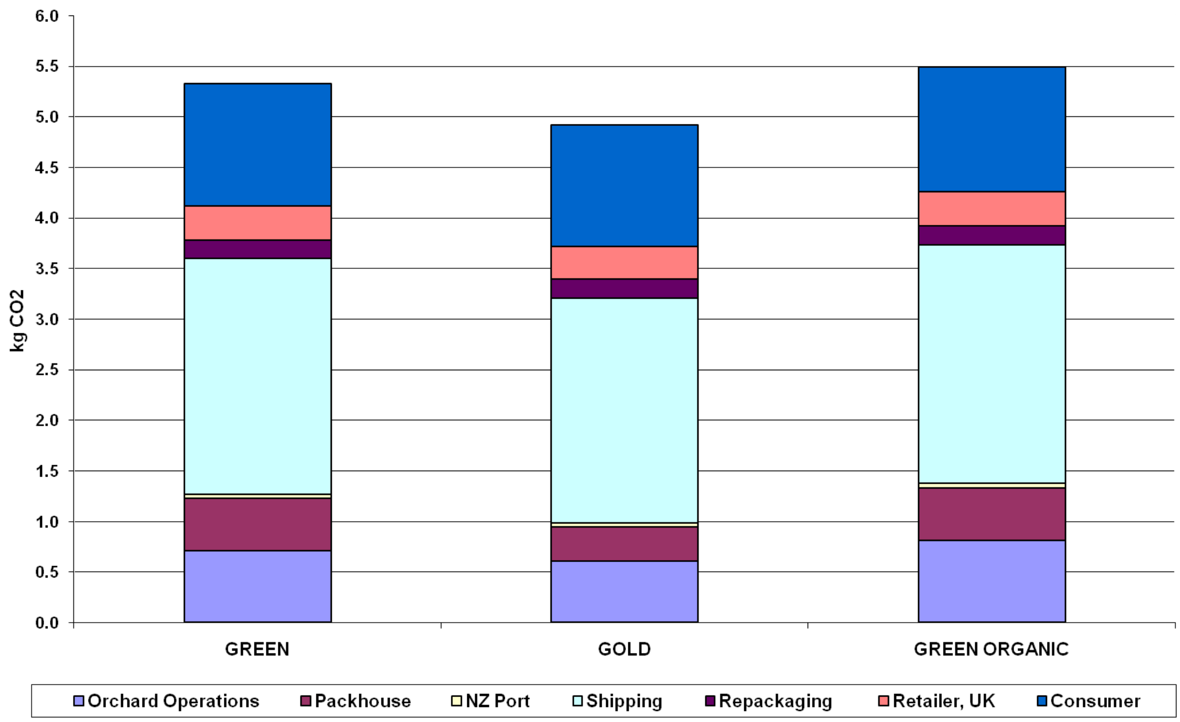

Fig. 6 GHG comparison (per tray consumed) for different varieties of kiwifruit.

Variation in orchard practices

The impact of variation in orchard practices is analysed based on the orchards with the highest and lowest GHG emissions from the database of 32 green orchards, compared with the average orchard. Both the best and the worst orchards do not use compost; agrichemicals use is limited to plant growth regulator and very low levels of fungicide and insecticide in the best orchard. Herbicides and insecticides are also used in the worst orchard.

With best practices orchard GHG emissions reduce from an average of 0.575 kg CO_2eq per tray equivalent (3.3 kg fruit) leaving the orchard to 253 g CO_2eq per tray equivalent (3.3 kg fruit) leaving the orchard (56% reduction). Thirty-nine percent of the emissions are due to fertiliser and lime use while fuel and electricity use contribute 36% and capital equipment 24%. Worst orchard practices increase GHG emissions to 1.23 kg CO_2eq per tray equivalent (3.3 kg fruit) leaving the orchard (114% increase), with 43% attributable to fertiliser and lime use, 36% to fuel and electricity use, and 17% to capital equipment. The contribution from agrichemicals is limited to 3% of the total.

The impact of variation in orchard practices on the total GHG emissions is shown in Fig. 7.

The life cycle GHG emissions increase to 6.13 kg CO_2eq per tray equivalent (3.3 kg fruit) (15% increase) with worst orchard practices, and reduce to 4.93 kg CO_2eq per tray equivalent (3.3 kg fruit) (7% reduction) with best orchard practices. In the worst-orchard-practices scenario, 25% of the emissions (1.52 kg CO_2eq per tray equivalent (3.3 kg fruit)) are due to orchard practices, while shipping and consumer stages contribute 38% and 20% respectively.

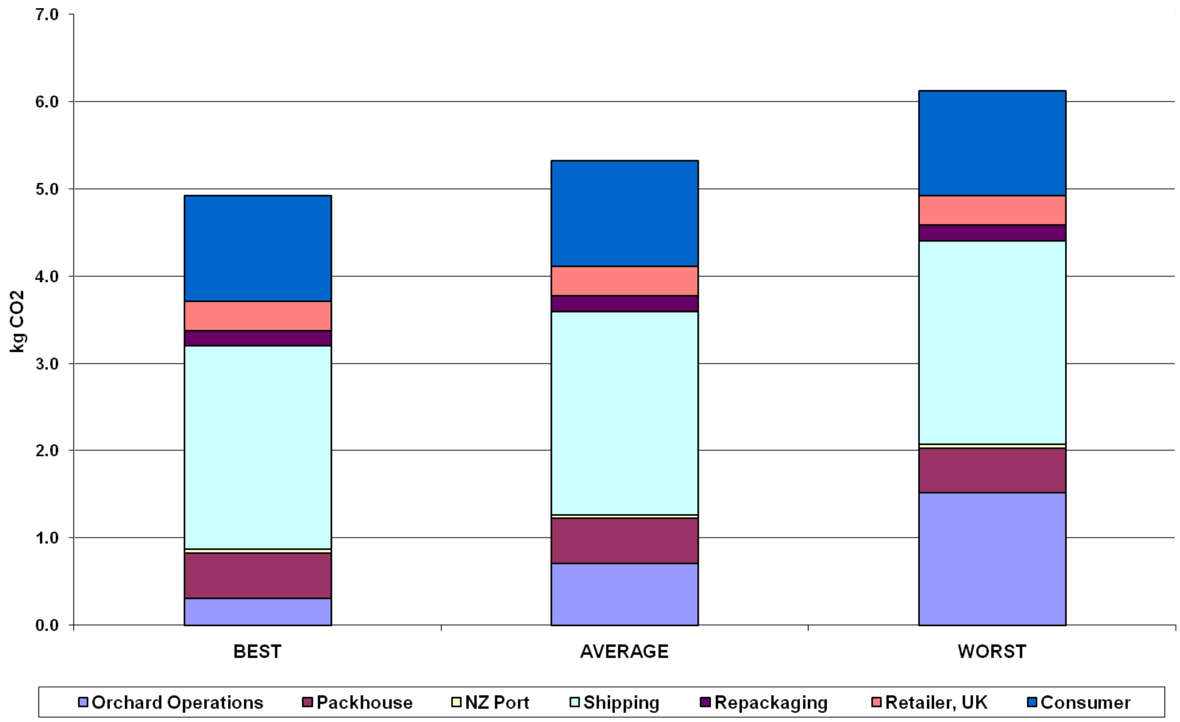

Fig. 7 Impact of orchard operations on total GHG emissions.

Irrigation

The base-case scenario uses a weighted average electricity use for irrigated (25%) and non-irrigated orchards. If all the orchards are irrigated the electricity use for the orchard operation increases from 122 kWh/tray to 297 kWh/tray, while if no irrigation is used this would reduce to 17 kWh/tray. The life cycle GHG emissions only increase marginally to 5.37 kg CO_2eq/tray (0.8% increase) with irrigation and reduce to 5.30 kg CO_2eq/tray (0.5% decrease) with no irrigation. This is a result of New Zealand electricity being relatively low in carbon emissions as a higher proportion is generated using hydro sources. Figure 8 is a comparison of the impact of irrigation on life cycle GHG emissions for a kiwifruit tray.

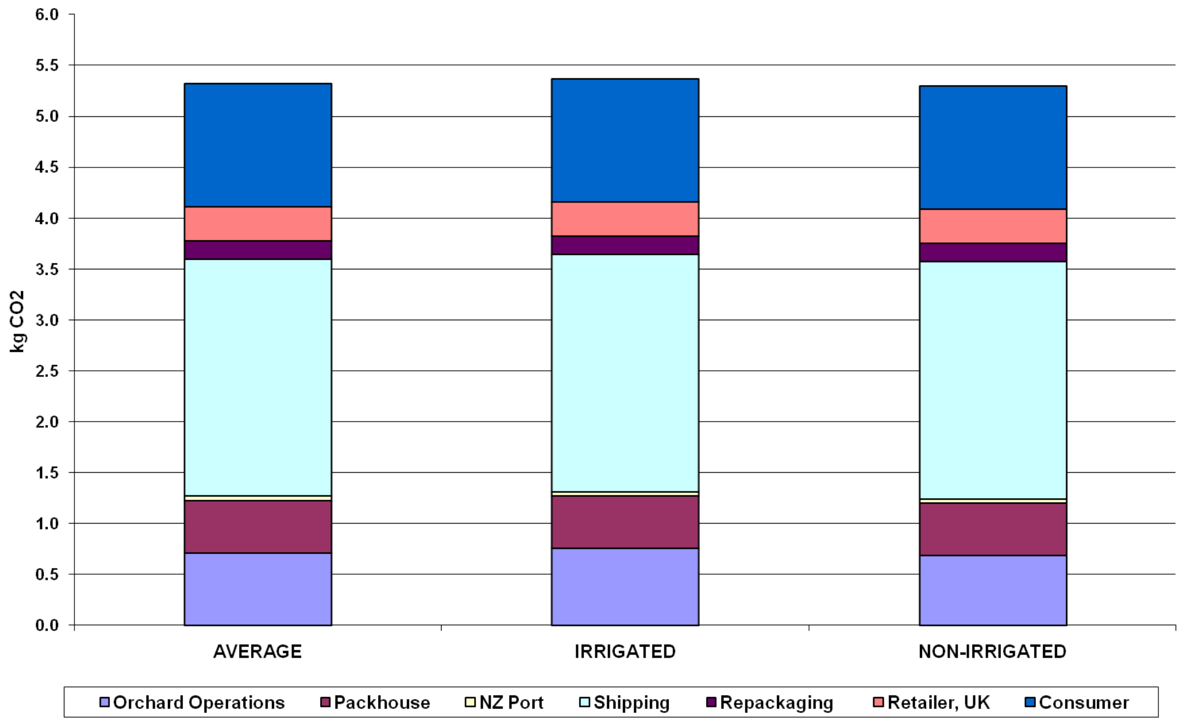

Fig. 8 Impact of irrigation on life cycle GHG emissions.

Influence of allocation method

According to Figure 2, local/regional and export quality fruit are produced in the ratio 9:111, i.e. for every 100 trays sold into markets, seven are local and 93 are export quality. Therefore on average 100 trays sold into local and export markets will be worth NZ$ 290.07 (see Table 3), and emit 57.5 kg CO_2eq (see section 8.1). So if GHG emissions are divided based on the economic allocation, each tray exported is associated with 616 g CO_2eq per tray. This increases the life cycle GHG emissions by 1% to 5.37 kg CO_2eq per tray.

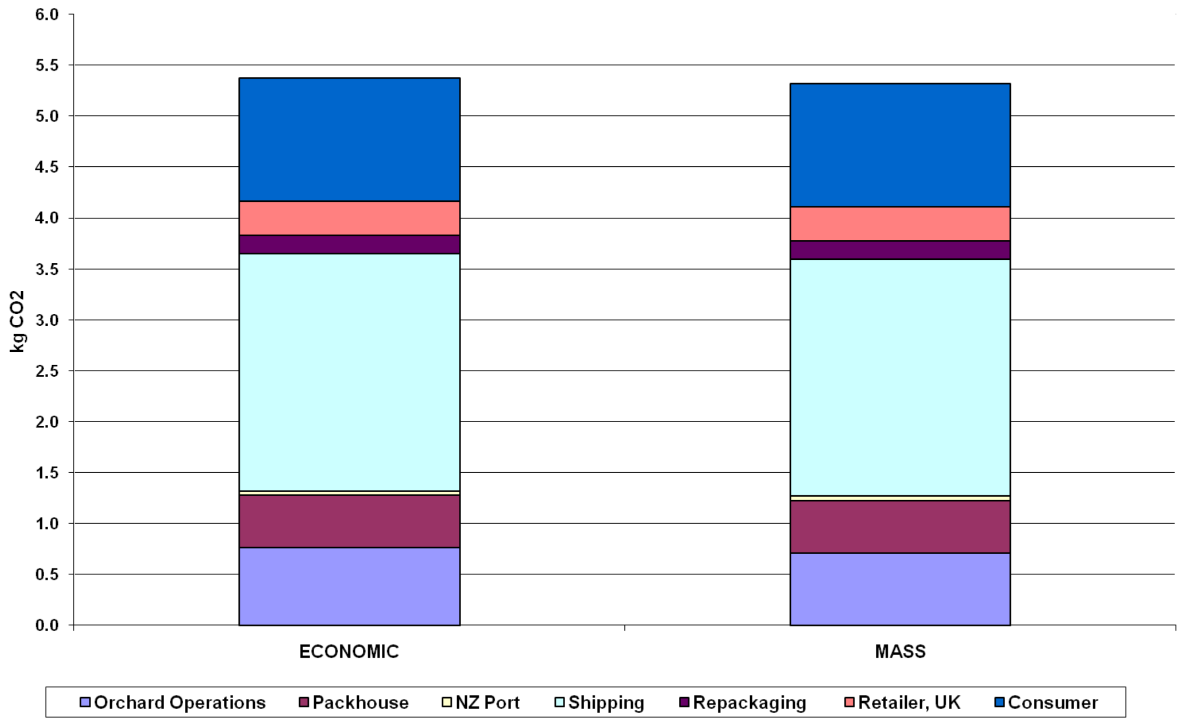

Fig. 9 Impact of allocation method on life cycle GHG emissions of export fruit.

Influence of travel distance between the overseas port and retailer

Figure 10 compares the impact of travel distance between the overseas port and the retailer on the GHG emissions of kiwifruit.

Doubling the distance increases the life cycle GHG emissions by 6% to 5.63 kg CO_2eq/tray, while halving the distance reduces the life cycle GHG emissions by 3% to 5.17 kg CO_2eq/tray. However, the vehicle type used has a significant impact due to variability in emission factors for different types of trucks (see Appendix 1).

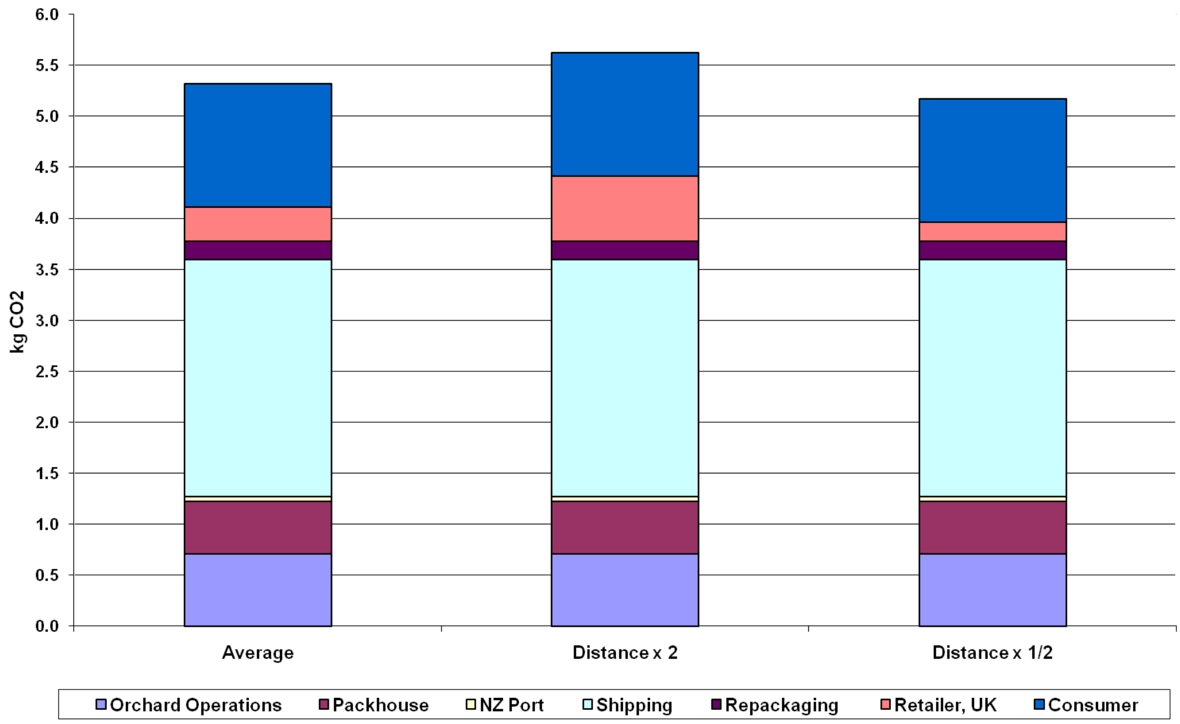

Fig. 10 Impact of travel distance between overseas port and the retailer.

Storage times

The base-case scenario is for kiwifruit being stored at the packhouse for 90 days. If the storage time at the packhouse is reduced to 45 days, the electricity used for refrigeration would be reduced from 0.34 kWh/tray to 0.17 kWh/tray. The total contribution of GHG emissions due to packhouse operations reduces to 0.302 kg CO_2eq/tray (from 0.515 kg CO_2eq/tray) and the life cycle GHG emissions to supply a tray of kiwifruit to a consumer in the UK reduces to 5.11 kg CO_2eq (4% reduction). This is based on the saving of electricity and refrigerant losses as a result of shorter storage time. Figure 11 is a comparison of the impact of storage times on life cycle GHG emissions of a kiwifruit tray.

Shipping distances

The base-case scenario is for transport of kiwifruit by ship to Zeebrugge in Belgium. If kiwifruit were sent to Yokohama, Japan, by ship instead, the travel distance would reduce from 20765 km to 9141 km. Figure 12 shows GHG emissions contribution for kiwifruit sent to Japan.

The total contribution due to shipping reduces to 1.04 kg CO_2eq/tray (from 2.33 kg CO_2eq /tray) and the total life cycle GHG emissions to supply a tray of kiwifruit to a consumer in Japan are only 4.03 kg CO_2eq (24% less than for Europe).

Shipping data and calculation methods

The base-case scenario is calculated using shipping industry data for GHG emissions for transport of kiwifruit by reefer ship to Zeebrugge in Belgium. As shown in Box 2, however, the shipping emissions could be significantly higher if calculated using alternative data on fuel use for shipping. Figure 13 is a comparison of total GHG emissions to supply a tray of kiwifruit to Europe if calculated based on shipping industry data, alternative fuel use data, and the EcoInvent dataset for transoceanic freight shipping.

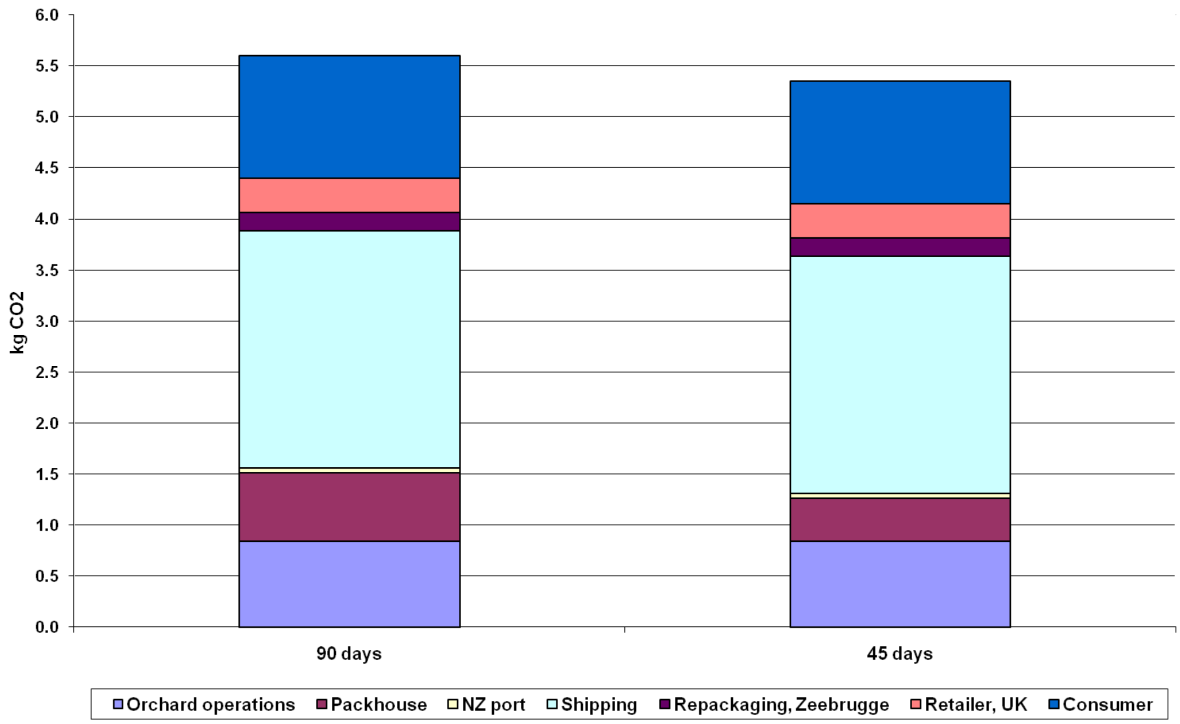

Fig. 11 Impact of storage times on life cycle GHG emissions.

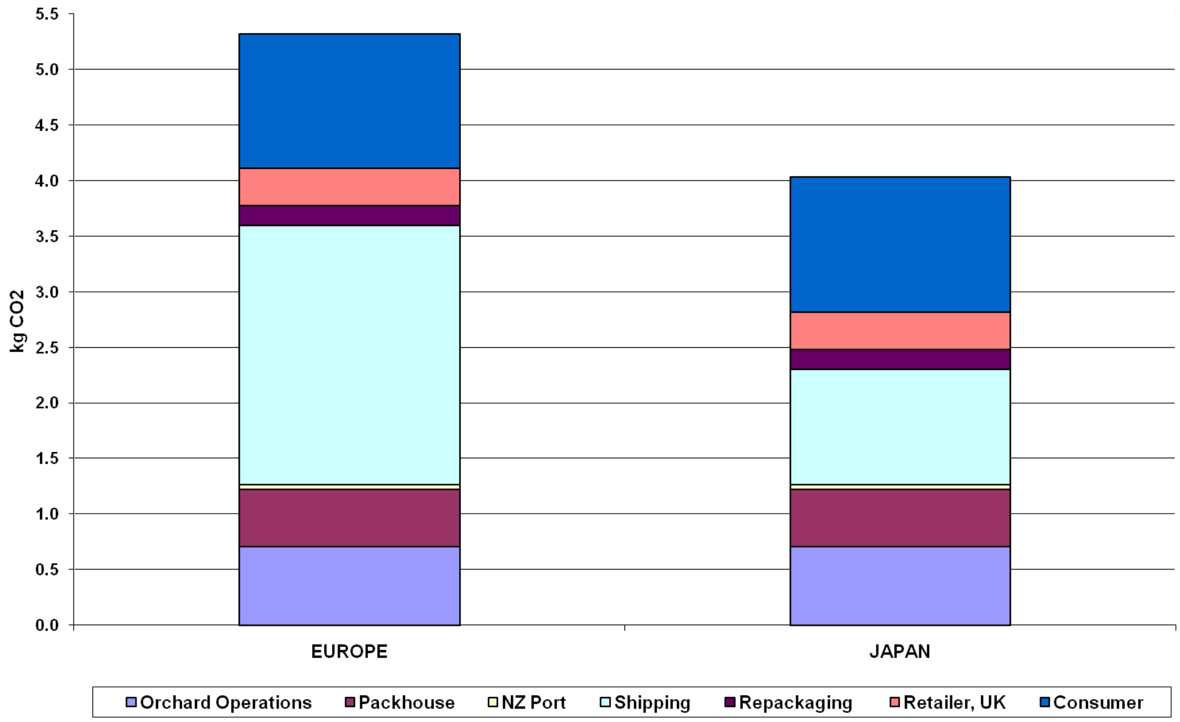

Fig. 12 GHG emissions at various stages of the supply chain for export to Japan.

The total GHG emissions increase by 51% to 8.04 kg CO_2eq/tray with the fuel use data while it reduces by 24% to 4.02 kg CO_2eq/tray with the EcoInvent dataset.

Distances between retailer and home

Figure 5 shows the importance of transportation between the retailer and home in the overall GHG emissions associated with kiwifruit; 16% of the total life cycle GHG emissions are associated with this transportation stage. This would increase to 25% of the total life cycle GHG emissions if the consumer travelled twice as far to the retailer, and would decrease to 0% if the consumer walked to the retailer.

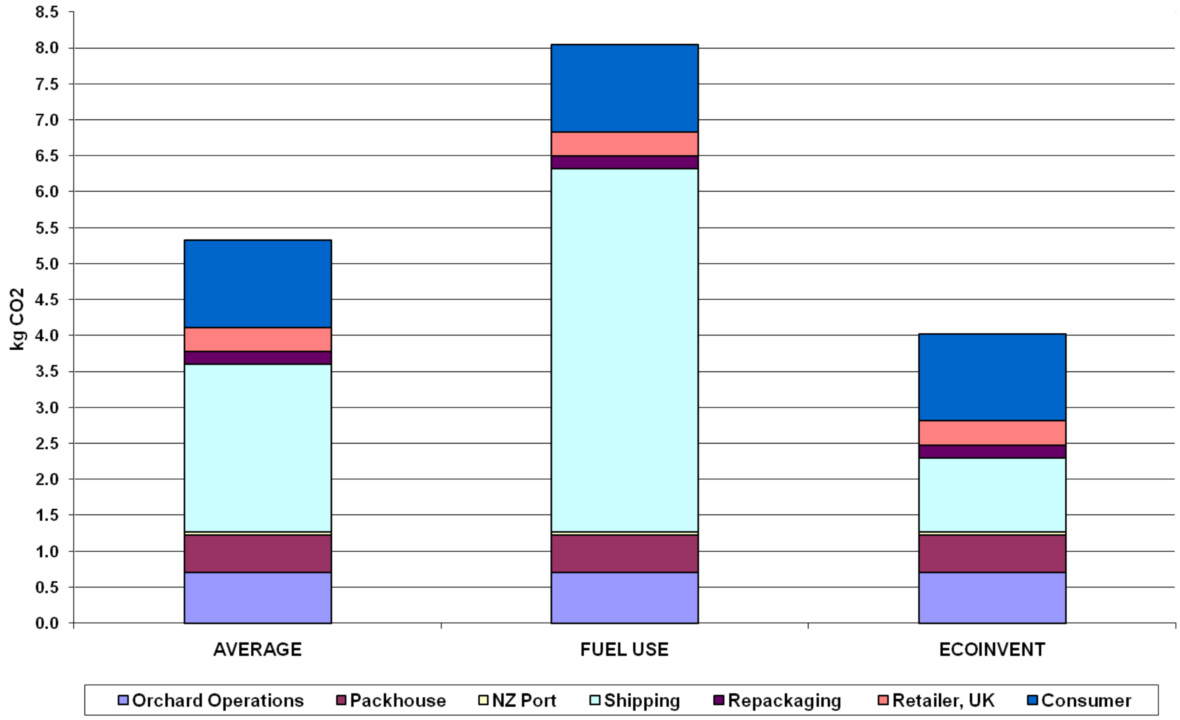

Fig. 13 Impact of using different datasets for modelling shipping.

Implications and Application of Main Findings

This study indicates that the main life cycle stages that contribute to the carbon footprint of the kiwifruit supply chain are shipping, consumer, orchard and packhouse (each contributing more than 10% to the total carbon footprint). However, there are uncertainties around the data used for calculation of these life cycle stages that require further research. In particular, further work is needed to refine:

- GHG emissions associated with nitrogen fertiliser and compost production and use (including soil emissions)
- GHG emissions associated with coolstore refrigerant leakage
- GHG emissions associated with refrigerated shipping
- Changes in soil carbon associated with occupation of land by kiwifruit orchards.

Two further points are worth noting. Firstly, there is discussion about whether the final PAS 2050 guidelines will suggest that the GHG emissions are to be calculated excluding capital equipment and soil emissions from orchard activities, and the consumer stage. In addition, the current draft PAS 2050 suggests that GHG emissions are to be allocated based on economic allocation rather than the mass allocation method. Using economic allocation, and excluding capital equipment and soil emissions, and the consumer stage (including transport from the retailer to the consumer), a tray leaving the orchard is associated with 0.394 kg CO_2eq per tray equivalent (3.3 kg fruit) and life cycle GHG emissions are 3.96 kg CO_2eq/tray. Figure 14 shows the GHG emissions comparison using the two methods: LCA and the draft PAS 2050.

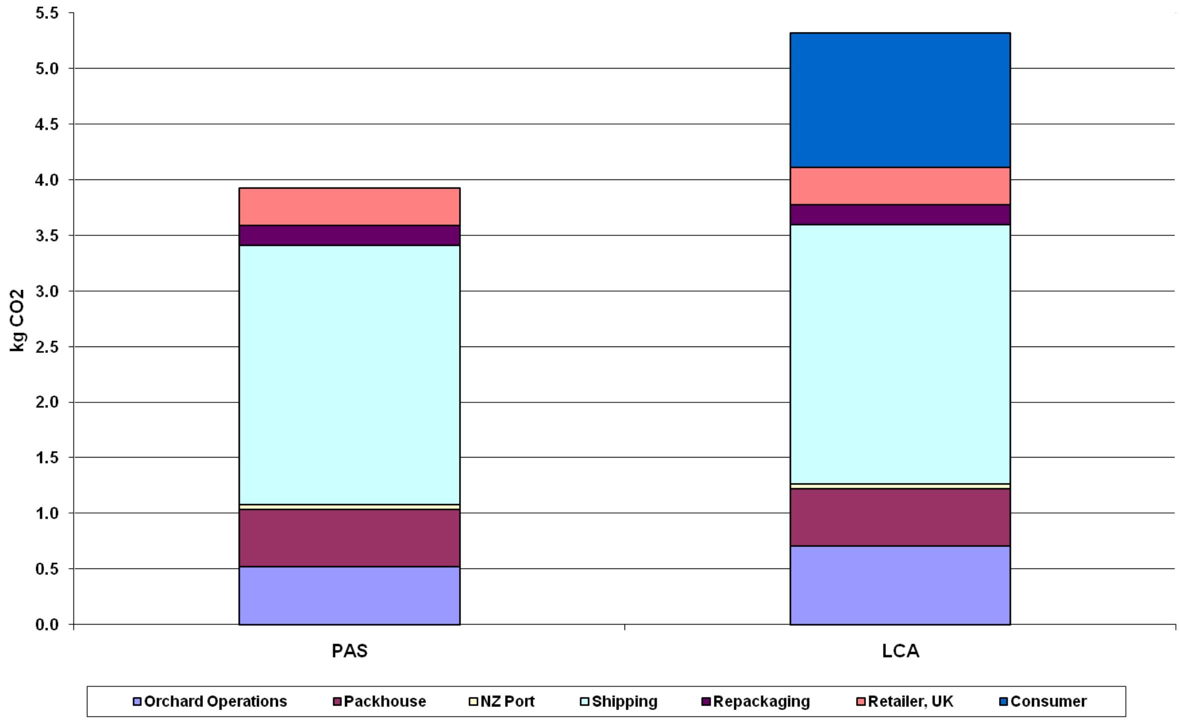

Fig. 14 GHG emissions comparison for export of a tray to Europe calculated based on the ISO 14040 series LCA standards and PAS 2050 method.

Secondly, the base-case scenario is for one tray equivalent eaten by a consumer in Europe. If the functional unit is changed to one kg fruit eaten by a consumer in Europe, the equivalent carbon footprint is 1.64 kg CO_2eq. The contribution from various stages is shown in Figure 15. This functional unit may be more easily understood by consumers if communicating the results of this study to a mass market.

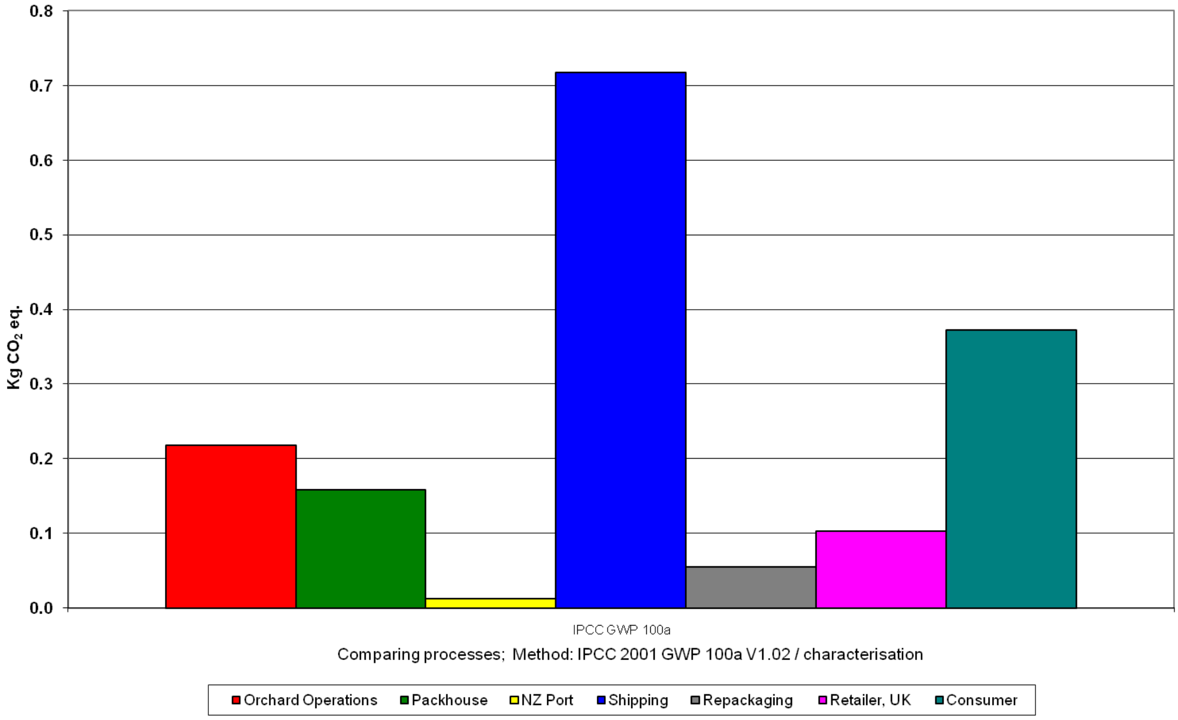

Fig. 15 GHG emissions contribution for 1kg kiwifruit consumed in Europe.

Acknowledgements

The authors wish to acknowledge the valuable contributions from Jayne Chamberlain and Alistair Mowat of Zespri New Zealand (data collection), Don Cleland of Massey University (refrigeration data and associated calculations), and Robbie Andrew and Vicky Forgie of Landcare Research (numerous discussions on the subject).

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Appendix 1 Secondary data sources

A summary of the energy content and GHG emission factors per unit of energy is shown in Table A1; a full description is included in Barber (2008). Table A2 details emissions factors for activities at other stages of the kiwifruit supply chain.

Table A1 Summary of fuel energy and emission factors.

Fuel type	Unit	Consumer energy (MJ/unit)	Fugitive energy coefficient	Primary energy (MJ/unit)	GHG (g CO_2eq/ $MJ_{primary}$)	GHG (g CO_2eq/ unit)	MED‡ GHG (g CO_2eq/ unit)
Diesel	litres	37.9	1.19	45.2	68.80	3108	2678
Petrol (regular unleaded)	litres	34.9	1.19	41.6	65.70	2735	2339
Avg electricity (2006)	kWh	3.6	2.23	8.03	30.40	244.1	228.7

‡ Energy greenhouse gas emissions 1990–2006 (June 2007). These are not LCA-based emissions, but rather in-use emissions. They are included for comparison.

Table A2 Emissions factors for activities involved in the kiwifruit supply chain.

Data category	CO_2eq emissions (kg/unit)	Source of data	Notes
Transport		EcoInvent v.2 2007	
Passenger transport			
Intercontinental	0.108 kg/pkm	Aircraft/RER/U	Transport of seasonal workers
	0.154 kg/pkm	Aircraft/RER/U	Transport of seasonal workers
Goods transport			
7.5–16 t lorry	0.268 kg/tkm	EUR05/RER/U	Transport of compost to orchard
>32 t lorry	0.116 kg/tkm	EUR04/RER/U	Transport of fruit - orchard to packhouse, packhouse to NZ port
>16 t lorry	0.125 kg/tkm	Fleet average/RER/U	Overseas port to retailer
3.5–16 t lorry	0.331 kg/tkm	Fleet average/RER/U	Overseas port to retailer
3.5–7.5 t lorry	0.626 kg/tkm	EUR04/RER/U	–
Shipping	0.024 kg/tkm	Wild Ing 2008	Reefer ship
Refrigerant leakage	0.0024kg/tkm	Cleland 2008	New reefer ship
Packaging		EcoInvent v.2 2007	
Corrugated board	−0.212 kg/kg	Fresh fibre, single wall/RER/U	Cardboard use at packhouse
Mixed waste (packaging waste)	0.874 kg/kg	MfE 2008	Sent to landfill without recovery of methane
Fruit waste	0.945 kg/kg	MfE 2008	Sent to landfill without recovery of methane
Energy for waste water treatment	0.642 kg/m^3	EcoInvent v.2, 2007	Sewage from residence to wastewater treatment
Domestic waste to landfill	0.7 kg/kg	EcoInvent v.2, 2007	Municipal waste sent to sanitary landfill
Packaging waste to landfill			
Packaging board	0.0071 kg/kg	EcoInvent v.2, 2007	Cardboard packaging sent to inert landfill
PET	0.081 kg/kg	EcoInvent v.2, 2007	Plastic sleeve to sanitary landfill
Polyethylene to sanitary landfill	0.113 kg/kg	EcoInvent v.2, 2007	Liners to sanitary landfill
Polystyrene to landfill	0.118 kg/kg	EcoInvent v.2, 2007	Spife to sanitary landfill

Refrigerant HCFC 22	1810 kg/kg	EcoInvent v.2, 2007	
LPG	2.97 kg/kg	MfE 2008	Forklift for moving pallets

Appendix 2 Reviewer’s report

THE SWEDISH INSTITUTE FOR FOOD AND BIOTECHNOLOGY

Review of “Carbon Footprinting for the Kiwifruit Supply Chain – Draft Report on Methodology and Scoping Study”

Dr Ulf Sonesson

July 2008

Background

Dr Ulf Sonesson at SIK – The Swedish Institute for Food and Biotechnology was invited to review the report "Carbon Footprinting for the Kiwifruit Supply Chain – Draft report on Methodology and Scoping Study" by Dr Sarah McLaren at Landcare Research.

General comments

The draft report is well written, clear and logically structured. The objectives are clearly defined and the work is performed in manner that leads to fulfilment of the goals.

Comments on specific issues

Choice of methodology:
The choice of the attributional approach in the LCA method is appropriate considering the objectives.

Section 3.1:
The choice of functional unit is logical and understandable, but since it deviates from what's usual in food LCA's, some additional information would be useful and the choice should be discussed. Factors for translating the chosen FU to e.g. kg of fruit should be supplied in the report, for the sake of transparency.

The question whether unit of whole fruit or peeled fruit (which is what actually is consumed) is the appropriate choice should be discussed (regardless of the final choice).

Section 3.2:
The omitted parts include "adhesive used for trays". This is one of the largest material uses in the packhouse (Table 24), perhaps it should be included.

The waste management of the reject is also omitted. This could be of importance, and models for calculating methane emissions from landfills exist.

Yield variability between years should be managed by using rolling averages (I do not know how many years that is relevant, it depends on the variability).

I fully support the recommendation for "Infrequent activities"

Section 5:
The inclusion of seasonal workers is good, since it is an issue which (to my knowledge) never been included in food LCA's. However, it should be reasonable to include also the local workers, just to investigate the importance of their travelling to work. For example, one worker travelling 200 days/year, 10 km one-way, cause around 800 kg of CO_2 equivalents. I don't know if this is applicable for NZ conditions, but it might be.

The text above table 4 and the table for are unclear to me.

Section 6.2
The emissions of GHG from fertiliser production is rather important, thus it should be described in more detail, especially for synthetic nitrogen. Around 50% of the total GHG from production of N-fertilisers is CO_2 and the rest N_2O, so to state "GHG emissions for these nutrients were lifted slightly to account for methane and nitrous oxide" is not sufficiently accurate. I suggest the reference below for updated and detailed data on

fertiliser production (if it is difficult to find, I can assist)
Jensen TK, Kongshaug G 2003. Energy consumption and greenhouse gas emissions in fertiliser production. Proceedings 509, International Fertiliser Society, York, UK. Pp. 1–28.

Application of fertiliser and lime with benefits over several years. It might be that the number of orchards is large enough to justify the recommendation, but still it might be better to use rolling averages (as for yield variations, preferably using the same number of years as for yields).

Section 6.4:
This is an important part, which is rarely included in agricultural LCA's, even if it probably should be. It should however also include contractors work (even if smaller contribution, but it might not be that much smaller; the working hours per year are more, but the lifetime in years probably shorter). This is a matter of having similar systems boundaries for the same activity, hence it is important for the credibility.

Section 6.6:
The calculations of soil-N_2O emissions look very similar to the IPCC guidelines, are the NZ GHG Inventory based on IPCC guidelines (which I suppose). If so it should perhaps be mentioned.

Section 6.7:
The issue of soil carbon is very complicated, but needs attention and should be included. I strongly support the conclusion that it needs more research, but the PAS 2050 do suggest a procedure for quantification that can be used.

Section 7.2:
The notion that waste fruit used as feed "prevents starvation" is perhaps not a well phrased sentence, it might be put in another way (I doubt NZ cows would actually starve if not for the supply of wasted kiwi fruits).

Methodological issues: The recommendation to use systems expansion is according to ISO, which is strength. The question is of course the definition of what is replaced (here: other Kiwi), so I would suggest to use mass allocation in this case, which is the second preferred choice in ISO.
The recommendation for allocation to waste kiwi is similar to economic allocation, this could be mentioned.

Section 7.7:
The reason for the difference between potato and pasta in retail is the retention time in the store more than the space occupied (as I understand the reference); pasta is on average kept significantly longer at the shelf. So, the logic of using data for potatoes as a proxy for kiwi is more about them having similar retention times, rather than space occupation.

I would suspect that kiwi fruits are wasted also at the retail stage, even if data availability is poor. I suggest this is at least mentioned and discussed in the report.

Section 7.9:
Very recent and detailed data on domestic waste generation is presented in a report from

WRAP (www.wrap.uk) in the UK. The values are very high for fruits (significantly higher than 10%), and it might be used in this scoping study (but not in later studies, if the recommendations in the PAS 2050 is followed). I can supply that report if needed. This will also affect the waste water treatment results.

Section 8.2:
The "best practice" defined as one extreme is based in survey data, where some orchards use no fertilisers at all. I suspect such farming will not sustain yield levels over the years; hence it might be questionable to use that as I benchmark. Is it possible to use average values for some years to define best/worst practices instead? I think that would be more valuable.

Final remark
The layout of many of the data tables could be improved; the long tables with production data could be modified by inserting "supporting lines", dividing the different categories (see below).

	Orchard type	etc	etc	etc	
	Green				
Buildings	Gold				
	Organic				
	Green				
Steel	Gold				
	Organic				

Box 3. Actions on reviewer's comments

Section 3.1: Functional unit
See Section 3.1, description and Figure 14 in section 9

Section 3.2:
Adhesive use is negligible in the whole life cycle.
The waste management of the reject fruit is now included in packhouse activities.

Section 5:
The travel to work by local workers is excluded according to standard practice in LCA.
Earlier table 4 removed and data added as text.

Section 6.2:
Rephrased so it is clear that these nitrous oxide emissions are from fertiliser manufacture and that the larger nitrous oxide emissions that occur after application are accounted for in the Section 6.6 on field emissions.

Further investigation is needed into the fertiliser manufacturing emissions, although any adjustments are likely to be negligible.

Section 6.4:
The working life of capital needs further consideration and as part of this a suitable methodology to account for contractors needs to be developed.

Included reference to the IPCC

Section 7.2:
Rephrased to read 'Waste fruit is mainly (95%) sent to farmers for stockfeed; this supplements feedstock and……….'.

Section 7.7:
Corrected accordingly.

Section 7.9:
The results of the WRAP study are noted but not included in the model due to uncertainty.

Section 8.2:
Figure 7 has been changed to give a comparison between the two orchards recorded in the survey that have the lowest and highest GHG emissions. Now the comparison is between real – rather than hypothetical – orchards.