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Life Cycle Assessment Data Sets Greenhouse Gas Footprinting Project

Inventory Report:

Coolstores

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The New Zealand Life Cycle Management Centre (NZLCM), founded in 2009 with initial funding from MAF, is a partnership between Massey University, AgResearch, Landcare Research, Plant & Food Research and Scion. Its mission is to build capability for Life Cycle Management (LCM), including Life Cycle Assessment (LCA), in New Zealand. The Centre partners work together to provide education, training and research in the assessment and management of product and service life cycles.

The NZLCM Centre is committed to positioning New Zealand research and activities at the leading edge of LCM and LCA theory and practice, and facilitating integration of LCM into the strategies, managements systems and operations of New Zealand organisations. This will be achieved through constructive dialogue with stakeholders, through partnership-based initiatives, and through education and training that inspires a commitment to shared prosperity across cultures, societies, countries and future generations.

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Inventory Report:

Coolstores

Sarah J. McLaren[1], Richard Love[1] and James McDevitt[2]

[1]Massey University, Palmerston North, New Zealand

[2] Scion Research, 6/111 The Terrace, Wellington, 6143, New Zealand

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Executive Summary

Coolstores are used to store agricultural products throughout the year in New Zealand. Coolstores used to store kiwifruit are mostly located in the Bay of Plenty. They typically use the refrigerant R404a or R22, and some use other refrigerants such as R134a. This project has compiled a series of four datasets to represent initial cooling and ongoing storage in coolstores used for kiwifruit storage, and using two different refrigerants (R22 or R134a). The processes included in modelling the systems under analysis are: production and transport of R22 and R134a refrigerants to coolstores in the Bay of Plenty, refrigerant leakage, and use of electricity by coolstores.

Thirty seven elementary flows that are relevant to global warming were calculated for each of the functional units assessed. A life cycle impact assessment using the IPCC (2007) characterisation factors computed a carbon footprint of approximately 21 kg CO_2e/tonne kiwifruit cooled for the initial cooling phase and between 1.1 - 1.3 CO_2e/tonne kiwifruit stored per day for the normal storage operation for the two refrigerants investigated in this study. The refrigerant losses did not make any significant contribution to the final carbon footprint, and this applied to both refrigerants considered in the study despite the fact that there were differences between their characterisation factors and emissions arising from their production and transport. The overwhelming source of greenhouse gas emissions is from the electricity demand for coolstore operation.

The guidelines in ISO 14044 and the ILCD (International Reference Life Cycle Data System) Handbook have been followed in the methodology used for compilation of the datasets. However, only the flows relevant for calculating the climate change impact associated with coolstores were modelled – based on the greenhouse gases in the IPCC (2007) report.

This project was funded by the Ministry of Agriculture and Forestry and Zespri as part of larger project on “Life Cycle Assessment Datasets Greenhouse Gas Footprinting Project” (MAF Contract No. 12247), and took place between February and June 2011. The larger project involved compilation of ILCD-compatible datasets for diesel, electricity, fertilisers and pesticides as well as coolstores in New Zealand, and development of guidelines on compilation of ILCD-compliant datasets for New Zealand activities.

1. Introduction

Life Cycle Assessment (LCA) is an environmental management tool that quantifies and assesses the environmental impacts associated with products, processes and activities. This is done in four phases: Goal and Scope Definition, Inventory Analysis, Impact Assessment, and Interpretation. The ISO 14040 series of international standards provides guidelines on LCA methodology.

In 2010 the International Reference Life Cycle Data (ILCD) System Handbook was published (available at http://lct.jrc.ec.europa.eu/assessment/projects#d). It provides guidance on LCA methodology that builds on the ISO standards; it also provides a recommended format for inventory datasets, an ILCD Editor that enables compilation of inventory datasets in the ILCD format, and guidance on the review process for life cycle inventory datasets and LCA studies.

Coolstores in New Zealand are used to store a wide variety of agricultural products, such as avocado, cheese, apples and kiwifruit, for periods ranging from a day to many months. This report provides details on the method, data, resources and review process for compilation of four datasets related to operation of coolstores in New Zealand:

- Carbon footprint for initial cooling of product in coolstore using either R22 or R134a refrigerant (per tonne fruit cooled)
- Carbon footprint for ongoing refrigerated storage of product in coolstore using either R22 or R134a refrigerant (per tonne fruit stored/day).

Cooling needs to be considered separately to storage. Cooling requires a large amount of energy over a short period of time whereas storage uses a smaller amount of energy but over a longer time period. In addition (particularly in the kiwifruit industry) cooling is often performed in a different physical facility (albeit on the same site) as storage.

These datasets were compiled as part of bigger project involving compilation of carbon footprint ILCD-compatible datasets for electricity and diesel, pesticides and fertilisers. The project was funded by the Ministry of Agriculture and Forestry, and by Zespri, and took place between January and June 2011.

The data used in the study had been collected for another study of coolstores that store kiwifruit in the Bay of Plenty region of NZ. These data were collected in over the 2007 kiwifruit season, and the dataset and Inventory Report were produced in June 2011.

2. Goal of the study

The goal of the study was to produce one or more datasets that represent the greenhouse gas emissions associated with storage of kiwifruit in a coolstore located in the Bay of Plenty in New Zealand using a specified refrigerant. The main refrigerants used by coolstores storing kiwifruit in New Zealand are R404a, R22 and R134a. Datasets were produced for coolstores using the R22 and R134a refrigerants rather than for the R404a refrigerant because no data were available on production of the R404a refrigerant.

The datasets are probably applicable to other horticultural products stored at nearly 0°C. However, care should be taken that the refrigerant and the type of coolstore use in a specific application matches the dataset.

Data compilation for the datasets was undertaken by Richard Love and Andrew East at Massey University, the modelling was undertaken by James McDevitt at Scion, and the Inventory Report was written by Sarah McLaren, Richard Love and James McDevitt. The report and datasets were reviewed by Marlies Zonderland-Thomassen at AgResearch. The LCA and associated modelling was undertaken following the ISO 14044 guidelines with additional guidance from the ILCD Handbook.

This study forms part of a bigger project on inventory datasets for greenhouse gas footprinting; this project aims to produce (a) a number of ILCD-compatible inventory datasets that can be used by the horticultural industry for carbon footprinting studies, and (b) develop capabilities in a range of New Zealand organisations to compile ILCD-compatible datasets. The following organisations have participated in the project: AgResearch, Landcare Research, Massey University, Plant and Food Resarch, and Scion. The project was commissioned by the Ministry of Agriculture and Forestry (MAF), and funded by MAF and Zespri.

The intended audience for the dataset is LCA researchers and practitioners, and those involved with the kiwifruit supply chain. This study is not intended to be used to support comparative assertions that are disclosed to the public.

3. Scope of the study

Function, functional unit and reference flow

The function provided by coolstores is refrigerated storage of agricultural products; kiwifruit are typically stored at about 1°C (with variations depending on the variety and seasonal factors). Some kiwifruit are stored in controlled atmospheres, but this is not included in this analysis. Two datasets were compiled to separately represent initial cooling and ongoing storage in a coolstore: this differentiation recognised that initial cooling requires more energy than ongoing storage. The functional unit for initial cooling is therefore expressed as "initial cooling of 1 tonne kiwifruit," and for ongoing storage as "1 tonne kiwifruit stored for one day." For each of these functional units, datasets were compiled for coolstores using either R22 or R134a refrigerants; initial cooling takes approximately one day and so refrigerant losses for one day were attributed to these initial cooling datasets. The reference flow for these datasets is "1 tonne kiwifruit."

Type of modelling

The modelling was based on an attributional approach.

System boundaries

Figure 1 shows the different processes modelled in the datasets. The life cycle extends from production of the refrigerants and generation of electricity through to use of the coolstores. It includes all life cycle stages for the European-produced refrigerants (from initial production through to loss to the atmosphere), and electricity used in cooling and storage at the coolstore.

In addition, ocean freight transport to NZ and national distribution of refrigerants is included in the analysis. Any losses of kiwifruit during storage are omitted from the analysis. The following processes have been omitted from the model: construction and maintenance of the coolstore infrastructure, the initial charging of the refrigeration equipment, and the fabrication of the steel jugs (although initial steel production was included).

With respect to flows, only the greenhouse gas emissions are modelled for the dataset because it is a carbon footprint dataset.

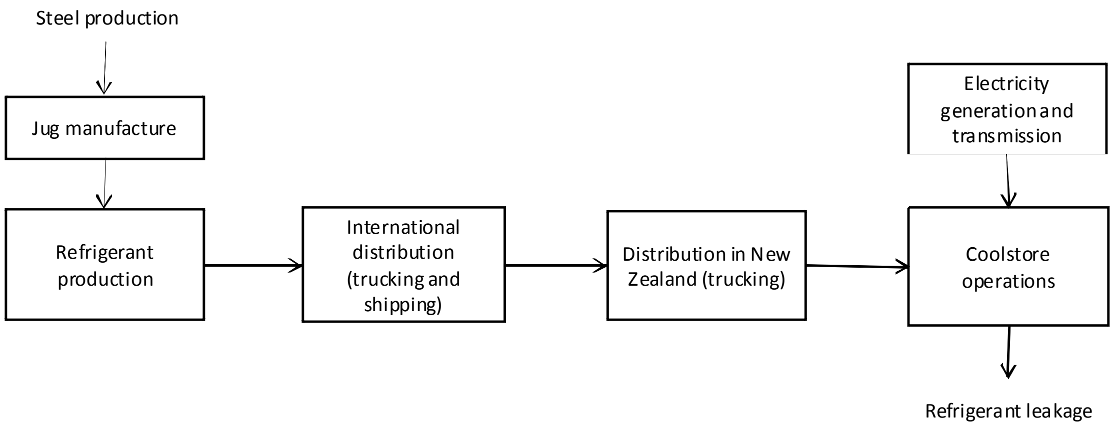

Figure 1. Life Cycle for Coolstore Datasets

Cut-off criteria

No specific cut-off criteria were used for this study.

Data quality

The aim of the study was to collect data that were as specific as possible for cooling and storage of kiwifruit in coolstores in the Bay of Plenty using recent data (year 2007). The estimated data quality is described in the next section.

Life cycle impact assessment

The LCIA was confined to Global Warming Potential using a 100 year time horizon (GWP_{100}), and the characterisation factors used in the LCIA are from IPCC (2007). The 100 year time horizon was chosen—as opposed to a 20 or 500 year time horizon—because it is the most commonly applied time horizon for assessment of climate change in LCA studies.

4. Life Cycle Inventory Analysis

The sections below describe the different activities comprising the life cycle for the two datasets, and provide data and data sources. The inventory results are reproduced in Appendix A, and assumptions are listed in Appendix B.

Refrigerant Production and Delivery

The two refrigerants modelled in the study are R22 and R134a; a survey of 10 kiwifruit coolstore facilities found that by mass 46% of the refrigerant used was R22, 51% was R404a, and 3% was R134a (Frater, 2010). The facilities surveyed were estimated to represent 24% of the New Zealand kiwifruit crop. Other facilities may use other refrigerants. Note that an individual coolstore will utilize only one refrigerant gas (assuming a simple refrigeration system), but a single facility may contain multiple independent refrigeration systems which each have their own separate refrigerant.

For this study, use of the refrigerants R22 and R134a was modelled; R404a was not modelled because no data were found on its production. The data for the production of R22 (chlorodifluoromethane) and R134a (1,1,1,2-Tetrafluoroethane) is from EcoInvent (Althaus et al., 2007); the R22 dataset is for production in the Netherlands and the R134a dataset is for generic European production. These data sets use "generic data" for infrastructure, waste treatment, and emissions associated with the general operations of the manufacturing site. The individual unit processes include the emissions from the chemical production process, energy supply and resource use. R22 is one of several co-products associated with the manufacture of polytetrafluoroethylene; and the emissions are allocated between the co-products using financial value. The R134a data set is derived from the trichlorethylene and tetrachloroethylene data sets and it is assumed that R134a is comprised equally of each chemical. At the refrigerant production site the refrigerants are packed into jugs. A jug of the refrigerant R22 or R134a contains 13.6 kg of refrigerant and the jug weighs 3 kg (Cowley, 2011; Judd, 2011; Rham, 2011). The jug is assumed to be constructed from "low alloyed steel," and the data for this was from EcoInvent.

The filled jugs are then transported to the port for shipping overseas; a one-way trip from the production site to Rotterdam port (100 km) was modelled to represent this stage.

The refrigerants are assumed to be shipped to Auckland from Rotterdam (21074 km) in a bulk container ship; the data for the shipping stage is from EcoInvent, using transoceanic freight ship, (50,000 dwt) (Spielmann et al., 2007). The refrigerants are distributed by truck (27 t payload) to regional distribution centres; for this study, distribution to a Bay of Plenty distribution centre in Tauranga (estimated distance from Auckland 203 km) was modelled. Refrigerants are bought by refrigeration contractors who travel to coolstores and perform maintenance activities on the coolstore refrigeration systems (assuming an average roundtrip distance of 50 km between the distribution centre and a coolstore in the Bay of Plenty, and that two coolstores are visited on each trip).

Supplementary data:

- Jugs are assumed to be made up of 25% recycled steel and used only once before further recycling; the system boundary excludes future recycling activities.

Coolstore Operations

Refrigerant Losses

A previous study (Frater, 2010) assessed refrigerant losses from ten different coolstore facilities in the Bay of Plenty that store kiwifruit. He found that there is large variability in losses between different coolstore facilities; some facilities report zero refrigerant losses whilst others have relatively large losses of up to 40 kg per month. However, based on these ten facilities, Frater (2010) calculated an average loss of 0.043 g per kiwifruit tray of gross yearly throughput. As each tray contains an average of 3.3 kg fruit (Mithraratne et al., 2010, p.4), the refrigerant loss is 0.145 g per tonne fruit stored per day. It is furthermore assumed that each tray is stored for an average period of 90 days (Mithraratne et al., 2010, p.38).

It is important to realise that a worst case example might be three times this average value, and a best case could be approaching zero refrigerant loss per tonne product stored per day. Furthermore, a number of modelling assumptions are implicit in this average value and should be noted when using it in LCA studies involving cold storage:

- The value is calculated from data on coolstores that only store kiwifruit. Some other coolstores are utilised to store other products when empty of kiwifruit; in these cases, refrigerant leakage during these alternate storage periods would need to be allocated to these products.

- Leakage rates per year are generally related to the length of time for which the refrigeration system is operating: when coolstores are empty, and the refrigeration system is shut down, then leakage should be significantly smaller (because leakage typically occurs around pipe joins rather than from refrigerant storage tanks). This was implicitly included in the data calculation used for this study because leakage rates were measured over a calendar year (during which time period the refrigeration system would have been switched off at some points). However, for other studies it is important to be aware that the total refrigerant leakage depends upon the time period for which any one coolstore is operational over a calendar year. In reality, though, it should be noted that an empty, poorly managed store could be leaking refrigerant.

- An average storage time of 90 days was assumed for the kiwifruit (after Mithraratne et al., 2010, p.38).

Electricity Use at Coolstore

Based on studies undertaken of a coolstore in 2008, in the Bay of Plenty, an average value of electricity use for refrigeration during storage is 2.9 kWh/tonne stored product per day of storage (Mawson et al., 2008). This average was calculated over the period when the coolstore was fully loaded with product. It should be noted that, when using the compiled inventory dataset for a coolstore that is only partially loaded, this electricity value will be an underestimate because electricity is required to counteract heat infiltration through the walls and doors regardless of whether the coolstore is fully loaded or not i.e. approximately the same electricity use will be allocated to a smaller quantity of stored product in a partially filled coolstore and so the electricity use per tonne stored product will be higher.

For initial cooling a value of 54 kWh/tonne cooled was used in this study based on a study of forced draft cooling in California (Thompson and Singh, 2008). The results of Thompson and Singh (2008) are broadly applicable to different products and climates. The cooling technology (forced draft versus static cooling) does not make much difference to the total energy use of cooling — only the timeframe that cooling occurs over.

Data Quality

The quality of data used to model the different activities is described below (following the ILCD indicator categories for data quality).

Technological representativeness

The data sets represent typical refrigerants and energy use for the New Zealand kiwifruit industry (and apply equally to both green and gold kiwifruit).

It is important to note that the Global Warming Potential of different refrigerants can differ a lot. It is also important to note that there were large differences in the amount of refrigerant leakage from different stores. The amount of refrigerant leakage per tonne of product is strongly influenced by the design of the store (which influences the total amount of refrigerant present), the maintenance regime followed by the operators and the utilisation of the coolstore.

The energy use data can be highly dependent on the way that the refrigeration plant is managed, both positively and negatively. Whilst it is possible for old plants to be operated in a very energy efficient manner, many newer plants have more monitoring available that allows operators to better determine the energy efficiency of their plant. The figures used in this study are from a survey that focused on the main kiwifruit growing regions in NZ, so whilst the single figure used in the data set may not represent the likely variability the underlying study does.

Geographical representativeness

The refrigerant leakage data is based on stores that in combination represent 24% of the NZ kiwifruit industry. The energy use data, on the other hand, is based on a smaller sample but seems consistent with historic data for NZ conditions (McLaren et al., 2008). It should be noted that operational practice can strongly influence energy use and there is likely to be significant variability in operational practice amongst coolstore operators.

Time-related representativeness

The data for energy and refrigerant use are as up-to-date as was available at the time of writing, and were gathered over a whole season (Frater, 2010). Although data were collected over one year, it is unlikely that the energy values would change much from year to year so this can be considered representative.

Completeness

All gases included in the IPCC (2007) listing of greenhouse gases are included in this study regardless of their percentage contribution to the final inventory results.

Precision uncertainty

See discussion under “Technological representativeness” above.

Methodological appropriateness and consistency

The applied methods are in line with the goal and scope for this dataset.

Allocation Issues

Allocation is an issue in coolstore storage when more than one product is stored throughout the year, and when the coolstore is partially loaded or empty but still using electricity and leaking refrigerants. In this study, it is assumed that all stored products require equivalent amounts of electricity for cooling during storage (on a per tonne per day basis), and that the coolstore is either fully loaded and using electricity and leaking refrigerants, or empty and not using electricity or leaking refrigerants. Therefore allocation is not an issue.

For the steel jugs, although they are likely to be recycled after use, the impacts associated with recycling and future use of the steel jugs has not been included in this study.

No other allocation issues were identified as relevant for this study.

5. Results

Figure 2 shows the CO_2 equivalent (CO_2-e) emissions associated with the four functional units investigated in this study.

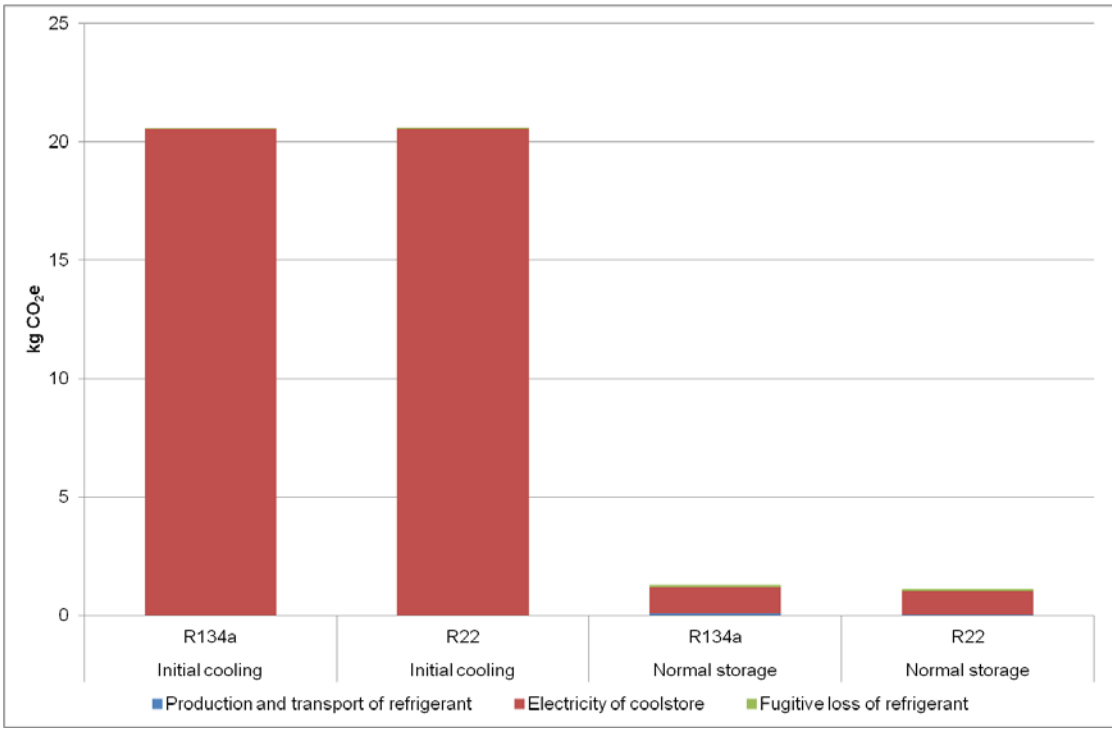

Figure 2: The CO_2e emissions for the four functional units investigated in this study.

There are only minor differences in the CO_2e emitted between the R22 and R134a during 'normal storage' (1.1 – 1.3 kg CO_2e respectively). Initial cooling has an almost 20-fold higher carbon footprint compared to normal storage (21 kg CO_2e) for bother R22 and R134a refrigerants. The overwhelming CO_2e hotspot for both initial cooling and normal storage is from the electricity demand for the coolstore operation (Figure 2).

6. Conclusions

This study has made use of the limited existing data available on electricity use and refrigerant emissions associated with coolstores in New Zealand, interpreted by experts in the subject matter. It has used LCA methods based on guidance in the ISO 14040 LCA series and ILCD Handbook. This provides a reasonable basis for future LCA studies involving use of coolstores, although – as this report has shown – the carbon footprint for coolstores depends to a large extent upon the individual management practices at different coolstores and this should be recognised in interpretation of the datasets and the LCA studies in which the datasets are used. The datasets, and descriptions of associated methodological and technical issues, are freely available for third party use. Therefore this study reflects MAF's and Zespri's dedication to transparent reporting of enviro-metrics.

It was found that the electricity demand for coolstore operation was the primary source of greenhouse gas emissions for all the functional units in this study. Therefore, future work that is designed to reduce greenhouse gas emissions from the coolstore phase should focus on energy efficiency measures.

7. Critical Review

This report and datasets were reviewed by Marlies Zonderland-Thomassen (AgResearch). The main comments concerned clarification of the assumptions and methods used in the study; these were all addressed. The review was undertaken according to the ISO 14044 guidelines.

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Annex A Full LCI Results

Table A: The GHG LCI from coolstore use, during the initial cooling phase, using the R134a refrigerant.

Chemical	Mass (kg)	Sink/Emission
Carbon dioxide, in air [in air]	9.79E-01	Sink
Carbon, in organic matter, in soil [Non renewable resources]	1.85E-06	Sink
1,1,1-Trichloroethane [Halogenated organic emissions to air]	1.03E-15	Emission
Butane [Group NMVOC to air]	7.78E-09	Emission
Butane (n-butane) [Group NMVOC to air]	1.19E-13	Emission
Carbon dioxide [Inorganic emissions to air]	1.91E+01	Emission
Carbon monoxide [Inorganic emissions to air]	7.35E-03	Emission
Chloromethane (methyl chloride) [Halogenated organic emissions to air]	2.78E-14	Emission
Dichloromethane (methylene chloride) [Halogenated organic emissions to air]	3.61E-14	Emission
Ethane [Group NMVOC to air]	6.37E-04	Emission
Ethane, 1,1,1-trichloro-, HCFC-140 [Flows]	2.23E-17	Emission
Methane [Organic emissions to air (group VOC)]	4.81E-02	Emission
Methane, bromo-, Halon 1001 [Flows]	3.27E-17	Emission
Methane, chlorodifluoro-, HCFC-22 [unspecified]	1.80E-07	Emission
Methane, dichloro-, HCC-30 [unspecified]	6.58E-10	Emission
Methane, dichlorodifluoro-, CFC-12 [unspecified]	3.47E-10	Emission
Methane, monochloro-, R-40 [unspecified]	2.45E-11	Emission
Methane, tetrachloro-, CFC-10 [Flows]	3.18E-09	Emission
Methane, tetrafluoro-, R-14 [unspecified]	9.33E-12	Emission
Methane, trichlorofluoro-, CFC-11 [unspecified]	2.29E-14	Emission
Nitrous oxide (laughing gas) [Inorganic emissions to air]	4.80E-04	Emission
NMVOC (unspecified) [Group NMVOC to air]	9.40E-04	Emission
Pentane (n-pentane) [Group NMVOC to air]	1.00E-08	Emission
R 11 (trichlorofluoromethane) [Halogenated organic emissions to air]	1.95E-15	Emission
R 113 (trichlorofluoroethane) [Halogenated organic emissions to air]	1.49E-06	Emission
R 114 (dichlorotetrafluoroethane) [Halogenated organic emissions to air]	4.00E-12	Emission
R 116 (hexafluoroethane) [Halogenated organic emissions to air]	1.43E-11	Emission
R 12 (dichlorodifluoromethane) [Halogenated organic emissions to air]	2.42E-08	Emission
R 124 (chlorotetrafluoroethane) [Halogenated organic emissions to air]	1.49E-06	Emission
R 13 (chlorotrifluoromethane) [Halogenated organic emissions to air]	2.25E-16	Emission
R 134a (tetrafluoroethane) [Halogenated organic emissions to air]	1.52E-04	Emission
R 152a (difluoroethane) [Halogenated organic emissions to air]	2.98E-13	Emission
R 21 (Dichlorofluoromethane) [Halogenated organic emissions to air]	1.75E-16	Emission
R 22 (chlorodifluoromethane) [Halogenated organic emissions to air]	3.04E-11	Emission
R 23 (trifluoromethane) [Halogenated organic emissions to air]	5.57E-14	Emission
Sulphur dioxide [Inorganic emissions to air]	1.42E-05	Emission
Sulphur hexafluoride [Inorganic emissions to air]	4.17E-06	Emission
Trichloromethane (chloroform) [Halogenated organic emissions to air]	5.80E-13	Emission

Table B: The GHG LCI results of from coolstore use during normal operation using the R134a refrigerant.

Chemical	**Mass (kg)**	**Sink/Emission**
Carbon dioxide, in air [in air]	0.05258	Sink
Carbon, in organic matter, in soil [Non renewable resources]	9.98E-08	Sink
1,1,1-Trichloroethane [Halogenated organic emissions to air]	1.03E-15	Emission
Butane (n-butane) [Group NMVOC to air]	1.19E-13	Emission
Carbon dioxide [Inorganic emissions to air]	1.026642	Emission
Carbon monoxide [Inorganic emissions to air]	0.000396	Emission
Chloromethane (methyl chloride) [Halogenated organic emissions to air]	2.78E-14	Emission
Dichloromethane (methylene chloride) [Halogenated organic emissions to air]	3.61E-14	Emission
Ethane [Group NMVOC to air]	3.42E-05	Emission
Ethane, 1,1,1-trichloro-, HCFC-140 [Flows]	1.20E-18	Emission
Methane [Organic emissions to air (group VOC)]	0.002584	Emission
Methane, bromo-, Halon 1001 [Flows]	1.76E-18	Emission
Methane, chlorodifluoro-, HCFC-22 [unspecified]	9.67E-09	Emission
Methane, dichloro-, HCC-30 [unspecified]	3.54E-11	Emission
Methane, dichlorodifluoro-, CFC-12 [unspecified]	1.86E-11	Emission
Methane, monochloro-, R-40 [unspecified]	1.31E-12	Emission
Methane, tetrachloro-, CFC-10 [Flows]	1.71E-10	Emission
Methane, tetrafluoro-, R-14 [unspecified]	5.01E-13	Emission
Methane, trichlorofluoro-, CFC-11 [unspecified]	1.23E-15	Emission
Nitrous oxide (laughing gas) [Inorganic emissions to air]	2.58E-05	Emission
NMVOC (unspecified) [Group NMVOC to air]	5.13E-05	Emission
Pentane (n-pentane) [Group NMVOC to air]	1.00E-08	Emission
R 11 (trichlorofluoromethane) [Halogenated organic emissions to air]	1.95E-15	Emission
R 113 (trichlorofluoroethane) [Halogenated organic emissions to air]	1.49E-06	Emission
R 114 (dichlorotetrafluoroethane) [Halogenated organic emissions to air]	4.00E-12	Emission
R 116 (hexafluoroethane) [Halogenated organic emissions to air]	1.43E-11	Emission
R 12 (dichlorodifluoromethane) [Halogenated organic emissions to air]	2.42E-08	Emission
R 124 (chlorotetrafluoroethane) [Halogenated organic emissions to air]	1.49E-06	Emission
R 13 (chlorotrifluoromethane) [Halogenated organic emissions to air]	2.25E-16	Emission
R 134a (tetrafluoroethane) [Halogenated organic emissions to air]	0.000152	Emission
R 152a (difluoroethane) [Halogenated organic emissions to air]	2.98E-13	Emission
R 21 (Dichlorofluoromethane) [Halogenated organic emissions to air]	1.75E-16	Emission
R 22 (chlorodifluoromethane) [Halogenated organic emissions to air]	3.04E-11	Emission
R 23 (trifluoromethane) [Halogenated organic emissions to air]	5.57E-14	Emission
Sulphur dioxide [Inorganic emissions to air]	1.42E-05	Emission
Sulphur hexafluoride [Inorganic emissions to air]	2.24E-07	Emission
Trichloromethane (chloroform) [Halogenated organic emissions to air]	5.80E-13	Emission
VOC (unspecified) [Organic emissions to air (group VOC)]	1.91E-13	Emission

Table C: The GHG LCI from coolstore use, during the initial cooling phase, using the R22 refrigerant.

Chemical	Mass (kg)	Sink/Emission
Carbon dioxide, in air [in air]	0.979078	Sink
Carbon, in organic matter, in soil [Non renewable resources]	1.85E-06	Sink
1,1,1-Trichloroethane [Halogenated organic emissions to air]	1.25E-15	Emission
Butane (n-butane) [Group NMVOC to air]	1.19E-13	Emission
Carbon dioxide [Inorganic emissions to air]	19.09836	Emission
Carbon monoxide [Inorganic emissions to air]	0.007345	Emission
Chloromethane (methyl chloride) [Halogenated organic emissions to air]	3.39E-14	Emission
Dichloromethane (methylene chloride) [Halogenated organic emissions to air]	7.15E-08	Emission
Ethane [Group NMVOC to air]	0.000637	Emission
Ethane, 1,1,1-trichloro-, HCFC-140 [Halogenated organic emissions to fresh water]	9.24E-13	Emission
Methane [Organic emissions to air (group VOC)]	0.048061	Emission
Methane, bromo-, Halon 1001 [Flows]	3.27E-17	Emission
Methane, chlorodifluoro-, HCFC-22 [unspecified]	1.80E-07	Emission
Methane, dichloro-, HCC-30 [unspecified]	6.58E-10	Emission
Methane, dichlorodifluoro-, CFC-12 [unspecified]	3.47E-10	Emission
Methane, monochloro-, R-40 [unspecified]	2.45E-11	Emission
Methane, tetrachloro-, CFC-10 [Flows]	3.18E-09	Emission
Methane, tetrafluoro-, R-14 [unspecified]	9.33E-12	Emission
Methane, trichlorofluoro-, CFC-11 [unspecified]	2.29E-14	Emission
Nitrous oxide (laughing gas) [Inorganic emissions to air]	0.00048	Emission
NMVOC (unspecified) [Group NMVOC to air]	0.00094	Emission
Pentane (n-pentane) [Group NMVOC to air]	9.79E-09	Emission
R 11 (trichlorofluoromethane) [Halogenated organic emissions to air]	1.71E-09	Emission
R 113 (trichlorofluoroethane) [Halogenated organic emissions to air]	3.49E-14	Emission
R 114 (dichlorotetrafluoroethane) [Halogenated organic emissions to air]	4.82E-12	Emission
R 116 (hexafluoroethane) [Halogenated organic emissions to air]	1.85E-11	Emission
R 12 (dichlorodifluoromethane) [Halogenated organic emissions to air]	1.22E-07	Emission
R 13 (chlorotrifluoromethane) [Halogenated organic emissions to air]	2.25E-16	Emission
R 134a (tetrafluoroethane) [Halogenated organic emissions to air]	3.61E-13	Emission
R 152a (difluoroethane) [Halogenated organic emissions to air]	3.57E-13	Emission
R 21 (Dichlorofluoromethane) [Halogenated organic emissions to air]	1.64E-09	Emission
R 22 (chlorodifluoromethane) [Halogenated organic emissions to air]	5.66E-07	Emission
R 23 (trifluoromethane) [Halogenated organic emissions to air]	5.22E-07	Emission
Sulphur dioxide [Inorganic emissions to air]	8.09E-06	Emission
Sulphur hexafluoride [Inorganic emissions to air]	4.17E-06	Emission
Trichloromethane (chloroform) [Halogenated organic emissions to air]	2.40E-06	Emission
VOC (unspecified) [Organic emissions to air (group VOC)]	1.91E-13	Emission

Table D: The GHG LCI results of from coolstore use during normal operation using the R22 refrigerant.

Chemical	Mass (kg)	Sink/Emission
Carbon dioxide, in air [in air]	0.05258	Sink
Carbon, in organic matter, in soil [Non renewable resources]	9.98E-08	Sink
1,1,1-Trichloroethane [Halogenated organic emissions to air]	1.25E-15	Emission
Butane (n-butane) [Group NMVOC to air]	1.19E-13	Emission
Carbon dioxide [Inorganic emissions to air]	1.026429	Emission
Chlorodifluoromethane (R22) [Organic intermediate products]	0.000149	Emission
Chloromethane (methyl chloride) [Halogenated organic emissions to air]	3.39E-14	Emission
Dichloromethane (methylene chloride) [Halogenated organic emissions to air]	7.15E-08	Emission
Ethane [Group NMVOC to air]	3.43E-05	Emission
Ethane, 1,1,1-trichloro-, HCFC-140 [Flows]	1.20E-18	Emission
Methane [Organic emissions to air (group VOC)]	0.002583	Emission
Methane, bromo-, Halon 1001 [Flows]	1.76E-18	Emission
Methane, chlorodifluoro-, HCFC-22 [unspecified]	9.67E-09	Emission
Methane, dichloro-, HCC-30 [unspecified]	3.54E-11	Emission
Methane, dichlorodifluoro-, CFC-12 [unspecified]	1.86E-11	Emission
Methane, monochloro-, R-40 [unspecified]	1.31E-12	Emission
Methane, tetrachloro-, CFC-10 [Flows]	1.71E-10	Emission
Methane, tetrafluoro-, R-14 [unspecified]	5.01E-13	Emission
Methane, trichlorofluoro-, CFC-11 [unspecified]	1.23E-15	Emission
Nitrous oxide (laughing gas) [Inorganic emissions to air]	2.58E-05	Emission
NMVOC (unspecified) [Group NMVOC to air]	5.07E-05	Emission
Pentane (n-pentane) [Group NMVOC to air]	9.79E-09	Emission
R 11 (trichlorofluoromethane) [Halogenated organic emissions to air]	1.71E-09	Emission
R 113 (trichlorofluoroethane) [Halogenated organic emissions to air]	3.49E-14	Emission
R 114 (dichlorotetrafluoroethane) [Halogenated organic emissions to air]	4.82E-12	Emission
R 116 (hexafluoroethane) [Halogenated organic emissions to air]	1.85E-11	Emission
R 12 (dichlorodifluoromethane) [Halogenated organic emissions to air]	1.22E-07	Emission
R 13 (chlorotrifluoromethane) [Halogenated organic emissions to air]	2.25E-16	Emission
R 134a (tetrafluoroethane) [Halogenated organic emissions to air]	3.61E-13	Emission
R 152a (difluoroethane) [Halogenated organic emissions to air]	3.57E-13	Emission
R 21 (Dichlorofluoromethane) [Halogenated organic emissions to air]	1.64E-09	Emission
R 22 (chlorodifluoromethane) [Halogenated organic emissions to air]	5.66E-07	Emission
R 23 (trifluoromethane) [Halogenated organic emissions to air]	5.22E-07	Emission
Sulphur dioxide [Inorganic emissions to air]	8.09E-06	Emission
Sulphur hexafluoride [Inorganic emissions to air]	2.24E-07	Emission
Trichloromethane (chloroform) [Halogenated organic emissions to air]	2.40E-06	Emission
VOC (unspecified) [Organic emissions to air (group VOC)]	1.91E-13	Emission

Annex B Assumptions

Activity	Assumption
Refrigerant production	R22 and R134a assumed to be produced in the Netherlands.
Distribution in New Zealand	Refrigerants travel from Auckland to a distribution centre in the Bay of Plenty which contains 85% of NZ's kiwifruit orchard area
Coolstore operations: refrigerant losses	As noted in the report, refrigerant losses are highly variable between individual coolstores. An average value was calculated based on data for ten facilities. Also, leakage of refrigerants from the coolstore may vary throughout the year depending upon whether the coolstore is full, partially loaded or empty. For this study, it was assumed that the coolstore was either fully utilised and leaking refrigerant, or empty and not leaking refrigerant. An average storage period of 90 days was used in the analysis to calculate the loss of refrigerant per kg kiwifruit per day,
Coolstore operations: electricity use	As noted in report, electricity use varies depending upon operational management procedures. The value used was from a study of kiwifruit storage in 2008 (Mawson et al., 2008). A very small amount electricity might be used by an empty coolstore. However, if the coolstore is being used for storage, a similar amount of energy will be used regardless of loading because most of the energy use comes from removing heat that penetrates through the walls of the facility. For this study, it was assumed that the coolstore was either fully utilised or was empty and not using electricity; therefore it was not necessary to allocate additional electricity use to the stored product associated with cooling of a partially loaded or empty coolstore.

Annex C Reviewer report

The main concerns on an earlier version of the report and datasets were on computations and assumptions made. For example, it was unclear how refrigerant losses were incorporated in the datasets, and how the environmental load between fruit and other products were allocated. In most cases, it was a matter of improving the description to make it more transparent. There was a bit of a discussion on how to compute the highly variable refrigerant losses. The authors chose the best practice approach after asking feedback of the reviewer, by dividing the gross value for refrigerant loss by the known industry average three months (90 days) to get a per day value on refrigerant. This enables the LCA practitioner to vary the length of storage of the kiwifruit in a particular study. The authors took all other comments into account, and revised the report. After three iterations, the report and datasets were completed to satisfaction of the reviewer.

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Phone
0800 Massey (0800 627739) (NZ residents) ext 81446
+ 64 6 356-9099 (international) ext 81446
Email
info@lcm.org.nz

Postal
C/- IFNHH, Massey University
Private Bag 11222
Palmerston North 4442