The carbon cost of palm kernel expeller and its contribution to the dairy carbon footprint in New Zealand

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List of abbreviations and selected definitions

AGB ...... Above ground biomass
BGB ...... Below ground biomass
CPO ...... Crude palm oil
DM .... Dry matter
GHG ...... Greenhouse gas
LCA .... Life cycle analysis
LUC ...... Land use change
MS .... Milk solids
PKO ...... Palm kernel oil
PKE .... Palm kernel expeller
POME ... Palm oil mill effluent
SOC ...... Soil organic carbon
CO_2 .... Carbon dioxide
N_2O .... Nitrous oxide
CH_4 .... Methane
CO_2-e .... Carbon dioxide equivalents
g .... Gram
ha .... Hectare
m .... Metre
t .... Tonne

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Foreword by Pete Smith

Imports of cake from palm oil (known and palm kernel expeller or palm kernel extract; PKE) to New Zealand have increased 300 fold since the year 2000, a proportion of which enters the dairy farming sector as feed. Since much oil palm cake is sourced from South East Asia, there has been a rapid expansion of oil plantations in Malaysia and Indonesia. Where oil palm encroaches into forests and onto peatlands, this expansion is expected to result in significant greenhouse gas emissions. However, the extent of encroachment into forests is uncertain as is the encroachment onto peatlands.

In this report, Rob Carlton assesses the impact of palm oil cake on greenhouse gas emissions. The largest uncertainties about the emissions surround peat depletion, biomass loss and nitrous oxide emissions.

His analysis suggests that most, though not all, land use transitions arising from conversion to oil palm have a significant greenhouse gas cost, but the impact for the New Zealand dairy sector depends upon how PKE emissions are included in the life cycle analysis of the milk. With minimal accounting for PKE, dairy farms using PKE in the feed have a reasonable greenhouse gas footprint, but this is far greater if PKE is included in the life cycle analysis across the dairy sector.

This report explores the complexities of assessing the greenhouse gas footprint of agricultural products, and demonstrates the implications of how different methods of accounting for emissions from primary (e.g. oil from the oil palm) and secondary products (e.g. PKE) in life cycle analyses, greatly influences the apparent greenhouse gas footprint of agricultural products.

Rob Carlton has used the best available data and estimates between 1990 and 2011 to conduct this independent analysis, and his conclusions are useful for those interested in the greenhouse gas footprint of the New Zealand dairy sector, those interested more broadly in the greenhouse gas life cycle assessment of agricultural products, or those interested in indirect emissions from land use change.

Executive Summary

Since 2000 the volumes of palm kernel expeller (PKE) employed by New Zealand dairy farmers as a supplementary feed have increased dramatically. Greenpeace New Zealand commissioned this report to investigate the impact of greenhouse gas (GHG) emissions associated with PKE production on New Zealand dairy production with reference to the Fonterra (2009) report 'Carbon Footprint Measurement'.

PKE is a co-product of palm oil and is derived from cultivated oil palms. GHG emissions associated with oil palm products have attracted international attention due to the rapid expansion of the area under plantations in recent decades. This expansion is most notable in South East Asia where it has frequently entailed the cultivation of previously forested land and is often cited as a driver of deforestation. Deforestation is associated with high GHG emissions from biomass destruction and, where oil palm plantations are established on cleared peatlands, extremely large GHG emissions continue to occur over many decades from oxidation of carbon in peat to carbon dioxide. This is associated with peat depletion that results from drainage, a prerequisite of plantation management on these soils.

There is evidence that establishment of plantations on *Imperata* grasslands in SE Asia could lead to significant sequestration of carbon and this would represent a more sustainable practice than plantation establishment at the expense of natural forest.

The GHG emissions associated with oil palm cultivation are reported for a number of scenarios including plantation establishment on cleared peatland forest, cleared mineral soil forest, former plantations and *Imperata* grassland. In the case of cleared forest, where there are high degrees of uncertainty about the size of emissions, a high emission case and a low emission case are reported.

In this document allocation of GHG emissions to PKE from the emissions associated with oil palm cultivation follows attributional life cycle analysis (LCA) methodology. PKE costs are calculated using both economic allocation and (physical) mass allocation.

GHG fluxes associated with oil palm cultivation range from emissions almost 100 tonnes carbon dioxide equivalents per hectare (t CO_2-e ha^{-1}) (peatland high emissions case) to sequestration of slightly over 4 t CO_2-e ha^{-1} (*Imperata* grassland case).

Taking into account the proportions of land types used to establish oil palm plantations in SE Asia, the emissions associated with PKE production range from 0.55 – 1.02 t CO_2-e t^{-1} PKE (economic allocation) or 3.40 – 6.33 t CO_2-e t^{-1} PKE (mass allocation).

Assuming 90% of the imported PKE is used in the dairy sector, in 2010/2011 PKE accounted for emissions of 38 to 70 grams (g) CO_2-e per litre fresh milk (economic allocation) or 232 to 433 g CO_2-e per litre fresh milk (mass allocation) in New Zealand.

Introduction

New Zealand dairy farming has traditionally been based predominantly on pasture fed stock with little supplementary feed. In recent years there has been a shift towards higher input dairy farming in which greater use is made of supplementary feeds to augment pasture and thereby increase productivity. Palm kernel expeller (PKE)[a] is used as a supplementary feed and since 2000 there has been a dramatic increase in imports to New Zealand.

In 2009 Fonterra, New Zealand's largest dairy company, announced the completion of its Carbon Footprint Measurement study (Fonterra 2009) which was initiated in order to determine the carbon footprint of Fonterra products. Within the Fonterra study the carbon cost of PKE was accounted for in a small proportion of high-input farms. However, feed supplements are used by 85 - 90% of NZ dairy farms (DairyNZ 2011) giving rise to the concern that the study underestimates the true impact of PKE on the carbon footprint of Fonterra products. Furthermore, the Fonterra study is based on data from 2004/5 and by 2010/11 New Zealand imports of PKE had increased 11 fold since 2004/5. These factors have the potential to significantly change the carbon footprint of New Zealand dairy products.

Greenpeace New Zealand commissioned this report to investigate the greenhouse gas (GHG) emissions associated with PKE production with reference to New Zealand dairy production.

Palm kernel expeller (PKE)

Palm kernel expeller is a co-product of crude palm oil (CPO) and palm kernel oil (PKO). PKE is produced when palm kernel oil is extracted from palm kernels. It is used as a feed supplement for livestock, supplying energy and protein (DairyNZ 2008).

PKE being unloaded from a bulk carrier at the Port of Tauranga, September 2009. © Greenpeace / Fraser Newman

a The commodity name palm kernel expeller (PKE) is used throughout this report as this is in common usage and covers all forms of palm kernel cake, including palm kernel extract and cake residue formed from solvent extraction of oil of palm kernels.

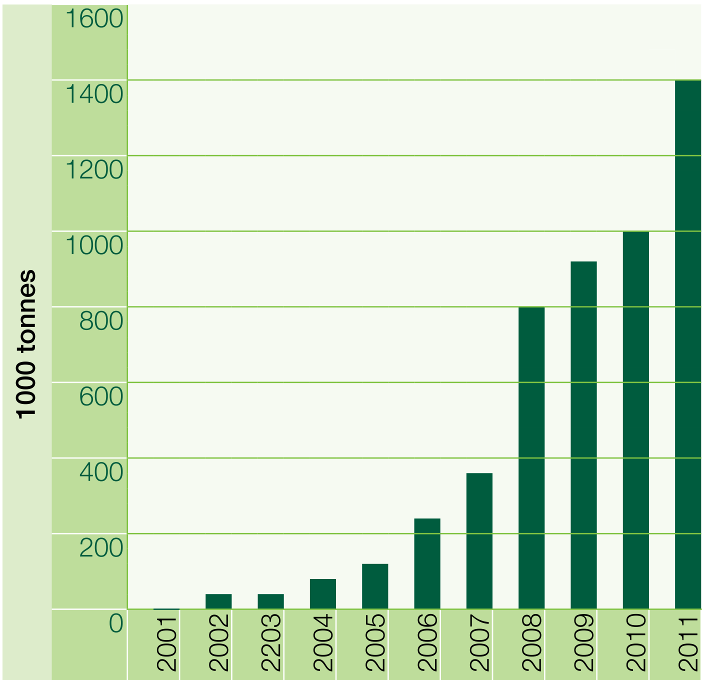
New Zealand dairy farming and the use of palm kernel expeller

In New Zealand PKE is used as a feed supplement on dairy farms. It is principally fed to cattle to supplement pasture feeding in order to increase milk solid production and to extend lactation. Up to 90% of New Zealand dairy farms use supplementary feed and 45% to 55% augment milk production this way (DairyNZ 2011).

Figure 1 shows the evolution of New Zealand imports of oil cake (PKE) and other solids from extracted oil palm fruit since 2000/1. Imports rose from under 5000 tonnes in 2000/1 to 1.4 million tonnes in 2010/11 (Statistics New Zealand 2011). Imports rose following a fairly consistent pattern for 7 years, representing an intensification of New Zealand dairy farming. In 2007/8, imports increased dramatically, almost certainly reflecting a continuation of the earlier trend combined with high milk prices in late 2007 and drought during the first (summer) months of 2008. This combination of climatic and economic factors has continued to influence demand until 2010/11 (see Appendix 1 for detail).

Overall, the figures show that the use of feed supplements is increasing over time, indicating a shift towards higher input dairy farming and this trend is showing no sign of stopping. At the same time, droughts, flooding and volatile milk prices appear to result in periods of peak demand for PKE. The incidence of drought in New Zealand is expected to increase as a result of climate change (New Zealand Ministry for the Environment, 2010) so associated peaks in demand for PKE are likely in the future.

Figure 1: Imports to New Zealand of oil cake and other solids from extracted palm oil fruit (PKE)



**Figures are given for seasonal (July – June) years. The data for April to June 2011 are provisional (Statistics NZ 2011).*

The carbon footprint of New Zealand dairy farming

In 2009 Fonterra completed a study entitled Carbon Footprint Measurement (Fonterra 2009). This study is made up of a number of parts covering methodology, on farm production, processing and distribution. The methodology follows internationally accepted life cycle analysis (LCA) methodology based on ISO standards 14040 and 14044 (ISO 2006a,b) and aims to be broadly consistent with PAS 2050 (BSI 2008).

The copy of Carbon Footprint Measurement used for this study was released to Greenpeace New Zealand under the Official Information Act of New Zealand. Almost all input data for this dairy LCA and almost all results are redacted (blanked out) in the copy. This lack of transparency made it impossible to accurately assess the impact of PKE use on the results reported in the Carbon Footprint Measurement study.

One available result from the Carbon Footprint Measurement study is the overall carbon cost of a litre of milk from New Zealand farms which is published in a press release available on the Fonterra web site (Fonterra 2010). The overall figure is 940 g CO_2 l^{-1} milk.

A debate is on-going about low versus high-input dairy farming in New Zealand which focuses on economics, environmental impacts and farmer lifestyle choices. With respect to environmental impacts, and specifically GHG emissions, conflicting data have been published with some articles indicating that higher emissions are associated with high-input farming (van der Nagel ***et al.*** 2003, Basset-Mens ***et al.*** 2009) while the Fonterra report indicates that high input farming (based on 18 farms in Waikato, South Auckland) shares the lowest GHG emissions with organic farming.

The Fonterra report includes GHG emissions associated with PKE in the LCA based on figures from the Ph.D thesis of Schmidt (2007), although it is not clear what figures are used. The PKE costs are exclusively accounted for high-input dairy production and the report specifically highlights the need to check LCA costs associated with PKE production across all NZ farm categories in order to verify the low GHG emissions associated with dairy farming. The Fonterra report uses data from 2004/5 and since that period imports of oil cake have seen a many-fold increase reinforcing the need to investigate the impact of PKE on all dairy emissions. The information provided within this report addresses the need to check costs associated with PKE production across all NZ farm categories.

Propagation of palm oil and the associated emissions and carbon sequestration

Emissions of GHGs associated with palm oil cultivation result from land use change (LUC), crop production and processing. The principle GHGs associated with palm oil cultivation are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Emissions of CO_2 come from biomass from cleared forest, depletion of soil carbon, energy for production operations and inorganic fertiliser manufacture. Palm oil mill effluent (POME) releases CH_4 although this can be trapped and used as an energy source (converting it to CO_2 thereby reducing its global warming potential). Nitrous oxide is produced from soil nitrogen (N), following application of process residues and fertiliser to the crop, plus release of N from depletion of soil organic matter. In this study all GHG emissions are reported as tonnes carbon dioxide equivalent (t CO_2-e), employing IPCC warming potential conversion factors (Forster ***et al.*** 2007) as necessary (see Appendix 2).

The main areas of focus in this report are emissions from LUC during plantation development. The reason for this choice of focus is that these emissions have the greatest potential to influence the carbon cost of palm oil products. A range of emission factors are reported in the literature, especially for the impact of LUC on tropical peatlands, and this is reflected in this report. Consequently, where appropriate a high and low emissions case attributed to oil palm cultivation is reported.

Carbon sequestration occurs during oil palm crop growth (Chase and Henson 2010). Carbon can also be sequestered in soil organic matter and this is a significant carbon store in plantations cultivated in place of ***Imperata*** grasslands (Syahrinadin 2005).

Land use change

The area under palm oil plantation in Malaysia and Indonesia has increased significantly since 1990 (Table 1) reflecting large scale LUC. Approximately 5 million hectares of this expansion has been at the expense of rainforest (Koh and Wilcove 2008, FAOSTAT 2011, see Appendix 2 for detail). Other sources of land which have been used for the establishment of new palm oil plantations include long-term agricultural land (frequently rubber plantations) and may include ***Imperata*** grassland (although accurate data on this element of LUC are lacking).

Imperata grassland (also known as degraded grassland) refers to land, frequently originating as forest, which has been cleared for agriculture and poorly managed resulting in soil degradation (Syahinudrin 2005). Poor management of selectively logged forest can also lead to the same result. Once the land is degraded its vegetation becomes dominated by ***Imperata cylindrica*** (L.) P. Beauv., a grass species that is extremely difficult to eradicate. Establishment of oil palm plants in place of ***Imperata*** grassland is associated with carbon sequestration (Syahinudrin 2005, Danielsen et al. 2009).

Table 1: The areas of oil palm harvested in Indonesia and Malaysia (FAOSTAT 2010) in 1990 and 2008

Country	Area of palm oil plantation (million ha)	
	1990	2008
Malaysia	1.75	3.90
Indonesia[1]	0.67	5.00
Total	2.42	8.90

[1]Indonesian Ministry of Agriculture figures indicate a greater area of cultivated oil palm area in Indonesia, at 7.8 M ha in 2010 (Directorate General of Plantations 2011).

Koh and Wilcove (2008) estimate that the area of forest converted to oil palm plantation in Indonesia and Malaysia between 1990 and 2005 was 2.7 – 4.1 million ha and the mid-point area is assumed here. The area under oil palm increased by a further 1.66 million ha between 2005 and 2008 (FAOSTAT 2011), of which 1.57 million ha is assumed to have been developed at the expense of forest (Appendix 2). The total area of forest converted to oil palm plantation in Indonesia and Malaysia between 1990 and 2008 is, therefore, assumed to be 5.05 million ha. It should be noted that these areas of oil palm plantation are only a proportion of the total decline in forest area in the region between 1990 and 2008 (24.5 million ha; FAOSTAT 2011). However, there is a broad consensus that the expansion of palm oil plantations has driven a significant area of deforestation (Reijnders and Huijbregts 2008, Hooijer *et al.* 2006, Kanninen *et al.* 2008, Koh and Wilcove 2008, SarVision 2011) and future demand for oil palm products may continue to drive this encroachment (Fitzherbert *et al.* 2008, Hooijer *et al.* 2010). Furthermore, the expansion of oil palm plantations on peatlands is increasing (Teoh 2010, SarVision 2011). One of the reasons cited for the use of forest as a land source is that the economic value of the timber extracted during clearance generates a positive cash flow during the early unproductive years of plantation establishment (Teoh 2010).

Changes in biomass

Changes in biomass can result in significant GHG emissions but can also be a source of carbon sequestration. Conversion of forest to oil palm plantation results in a net loss of biomass with consequential emissions whereas conversion of grassland to plantation results in a net gain in biomass with consequential sequestration.

During forest clearance more than half of the above ground biomass (AGB) is extracted as merchantable timber (FAO 2002). GHG emissions directly associated with merchantable timber biomass are not accounted for in this document as the timber is a commercial product in its own right. The residual biomass left *in situ* represents a source of GHG emissions which is allocated between all commercial products associated with forest clearance. It is assumed here that the residual AGB, plus all of the below ground biomass (BGB) either decomposes or is burnt, both processes releasing CO_2.

There is evidence of human disturbance in the majority of forests in the region (Reiley and Page 2005), although in many cases forest biomass has regenerated to a stature close to primary forest. In this document these primary and regenerated secondary forests are collectively referred to as natural forests. In some areas forests are managed commercially with periodic selective extraction of timber and these are referred to as selectively logged forests. Selectively logged forests are assumed to have half the biomass of natural forests (Wicke *et al.* 2008). Two scenarios are considered here which cover the destruction of natural forest and the destruction of selectively logged forest preceding establishment of oil palm plantations.

There is a broad range of AGB estimates for natural tropical rain forests of South East Asia (Proctor *et al.* 1983, IPCC 2006, Germer and Sauerborn 2008) and a recent average figure of 350 t DM ha^{-1} (IPCC 2006) is used here. IPCC (2006) propose a BGB to AGB ratio of 0.37 which equates to a BGB of 130 t DM ha^{-1}. Total (AGB + BGB) biomass for natural forests based on these figures is 480 t DM ha^{-1}.

A proportion of forest biomass has value as timber (merchantable timber) and a biomass expansion factor is used to convert timber biomass to total biomass. Assuming a biomass expansion factor of 1.74 (FAO 2002) 201 t DM ha^{-1} (57%) of the natural forest AGB would be merchantable timber and removed during forest clearance. A further 149 t DM ha^{-1} (43%) would be left *in situ* as residual AGB alongside 100% of BGB. Total natural forest residues (residual AGB + BGB) of 278 t DM ha^{-1} would be expected to remain *in situ* and combustion or decomposition of these residues would contribute to emissions.

Biomass in selectively logged forest is assumed to be half that of natural forest (Wicke *et al.* 2008) giving a residue biomass of 139 t DM ha^{-1} (AGB + BGB) that is expected to remain *in situ* and contribute to emissions.

The carbon content of biomass can be derived using a carbon fraction of 0.47 t C t^{-1} DM (IPCC 2006) giving and overall emissions figure of 480 t CO_2 ha^{-1} (131 t C ha^{-1}) for natural forest and an overall emissions figure of 240 t CO_2 ha^{-1} (66 t C ha^{-1}) for selectively logged forest. The emissions associated with biomass loss are allocated between merchantable timber and oil palm production (see section on cost allocation below and Appendix 2). Where plantations replace natural forest 63% of the biomass emissions are allocated to oil palm products. Where plantations replace selectively logged forest 77% of the biomass emissions are allocated to oil palm products. Using these figures annualised over the 25 year oil palm cycle the emissions allocated to oil palm products from the clearance of natural forest and selectively logged forest are 11.7 t CO_2 ha^{-1} y^{-1} and 7.3 t CO_2 ha^{-1} y^{-1} respectively. These figures are used to represent the high and low emissions cases following forest clearance.

When oil palm plantations replace existing plantations no significant change in biomass is expected. Small changes may occur following a crop change (e.g. rubber to oil palm) but these have a negligible impact on the overall figures and no change is assumed here.

Where plantations are established in place of *Imperata* grassland carbon is sequestered as the biomass in the oil palm trees exceeds the lost grassland biomass. Biomass is lost from grassland at a rate equivalent to 0.7 t CO_2 ha^{-1} y^{-1} and is sequestered within oil palm plantations at a rate equivalent to 8.4 t CO_2 ha^{-1} y^{-1} (Chase and Henson 2010).

Carbon sequestration in peat soils

Peat is formed from plant residues under conditions which favour incomplete decomposition and lead to build up of waterlogged organic deposits. Over thousands of years these deposits can form a raised dome many metres thick. Peat soils have very high levels of porous saturated organic matter and a large water storage capacity. A number of peat domes in SE Asia are continuing to develop and sequester carbon at a median rate of 0.67 t C ha^{-1} y^{-1} (Page ***et al.*** 2010) although peat accrual appears to have been disrupted in many sites. As this element of carbon sequestration is not relevant to all sites it is only included as lost sequestration potential in the high emissions case.

Drainage and peat depletion

Drainage results in loss of water from the drained horizon leading to compression of peat followed by depletion. Annual C emissions from drainage-related peat decomposition are of the order of 170 Mt C y^{-1} (Hooijer et al., 2006, Page ***et al.*** 2010), equivalent to 2.0% of annual global fossil fuel carbon emissions.

Drainage is required for the cultivation of oil palm with an optimal water table depth between 60 cm and 75 cm below the surface (Reiley and Page 2005) although recent work indicates a typical ground water depth of 95 cm in plantations (Hooijer ***et al.*** 2010). Depletion of carbon is related to ground water depth with two recent assessments (Couwenberg ***et al.*** 2010, Hooijer ***et al.*** 2010) suggesting emissions of 90 and 91 t CO_2 ha^{-1} y^{-1} m^{-1} groundwater depth.

Couwenberg ***et al.*** (2010) indicate that peat depletion may only be proportional to water table depth to a limit of 50 cm with no increase of depletion being associated with deeper ground water. In this case emissions of 45 t CO_2 ha^{-1} y^{-1} would be predicted. However, Hooijer ***et al.*** (2010) indicate that depletion remains proportional to at least 1 m ground water depth, suggesting likely emissions of 86 t CO_2 ha^{-1} y^{-1} based on a drainage depth of 95 cm. Given the uncertainty represented by these two publications 86 t CO_2 ha^{-1} y^{-1} and 45 t CO_2 ha^{-1} y^{-1} are employed here to represent high and low emissions cases respectively. These peat emissions figures are significantly higher than IPCC (2006) default values and are used here as, at time of writing, they represent the most recent research pertinent to the peatlands in question.

Soil organic matter change in mineral soils

The disturbance of forest soil during forest clearance and subsequent cultivation leads to losses of soil organic carbon (SOC) due to microbial decomposition of soil organic matter. Losses of 20 t C ha^{-1} are reported from this source (Wicke ***et al.*** 2008), equivalent to 2.9 t CO_2 ha^{-1} y^{-1} annualised over 25 years.

Oil palm plantation establishment on *Imperata* grassland increases SOC. Within the top metre Syahinadrin (2005) determined an SOC sequestration rate equivalent to 0.7 t CO_2 ha^{-1} y^{-1} and this figure is used here. This may represent an underestimate of the sequestration potential of oil palm plantation establishment on these soils as it ignores SOC changes below 1 m.

Other emissions

Cultivated peatlands may be a source of significant N_2O emissions. Nitrous oxide and nitrogen gas can be produced through de-nitrification of nitrates under anaerobic conditions. Anaerobic conditions are generated in peat by saturation at the level of the water table and may also exist temporarily in drained peat after heavy rainfall. Furthermore, the high rates of carbon oxidation which accompany peat depletion may also generate localised anaerobic conditions.

In cultivated peat lands nitrogen is applied as N-fertiliser and organic N in recycled waste biomass. Oxidation of carbon from peat associated with drainage would also be expected to liberate organic nitrogen. Although peat is considered to be poor in nutrients including N, with a carbon to nitrogen ratio in the range of 29:1 to 52:1 (Reiley and Page 2005), the high rate of peat depletion would be expected to provide a significant source of available nitrogen in addition to applied fertilisers.

To estimate N_2O emissions from oil palm plantations on peatlands Wicke ***et al.*** (2008) use the IPCC's default figure for emissions from tropical drained organic soils in managed forests (8 kg N_2O-N ha^{-1} yr^{-1}; IPCC 2006). However, Couwenberg (2009) has challenged the IPCC defaults for drained organic soils and indicates N_2O emissions are likely to be lower. Couwenberg's figures for N_2O emissions from plantations on peat (3.4 kg N_2O-N ha^{-1} y^{-1}) are used here. In soils other than peat, Chase and Henson's (2010) N_2O emission figures, based on IPCC (2006) methodology, are used.

Methane emissions from saturated peatlands tend to be negligible from peat with a low (drained) water table (Couwenberg 2010) and remain relatively low in saturated tropical peat so no attempt is made here to account for methane emissions from drained peatland.

GHG emissions associated with oil palm plantations

Table 2 shows the range of emissions on an area basis associated with palm oil plantations. By far the largest source of emissions, and the largest source of variation, comes from oxidised SOC in peatlands. The second largest source of emissions is associated with forest clearance. Other sources of emissions contribute relatively little to the overall emissions figures. Crop biomass contributes significantly to net sequestration when plantations are established on *Imperata* grassland.

Areas of Significant Uncertainty

There are elements of uncertainty associated with some of the data used in this report. In addition to reporting a high and low emissions case a conservative approach has been adopted which is likely to underestimate rather than overestimate emissions.

The IPCC (2006) biomass figures for natural forest used here may be towards the lower end of the range. A recent Indonesian Government publication (Boer ***et al.*** 2009) indicates that natural forest biomass may be more than double the IPCC default and selectively logged forest biomass may also be more than double the figure adopted here.

Couwenberg ***et al.*** (2010) suggest that their approach to determining emissions from peat depletion could be considered conservative as it assumes that 40% of the depleted carbon undergoes oxidation to CO_2. During peat depletion between 40% and 60% of the soil carbon is oxidised to CO_2 (Wösten ***et al.*** 1997) and emissions equivalent to 133 t CO_2 ha^{-1} y^{-1} m^{-1} groundwater depth (Wösten & Ritzema 2001) from peat depletion are representative of the upper range (60%) of C oxidation. In this study the more conservative 40% C oxidation (90 t CO_2 ha^{-1} y^{-1} m^{-1}) groundwater depth is assumed.

The carbon footprint of PKE

Oil palm plantations are typically cultivated on a 25-year cycle and are not productive for the first 2 to 3 years after the establishment of a new crop. Productivity reaches a maximum after 7 to 8 years and begins to gradually drop after 15 years. The average yield of fresh palm oil fruit bunches (FFB) from Malaysia and Indonesia is 18.9 t ha^{-1} (FAOSTAT 2011).

Processing of palm oil fruit results in 3 major commercial commodities: crude palm oil (CPO), palm kernel oil (PKO) and palm kernel expeller (PKE). The determination of the carbon cost of PKE depends upon the GHG emissions associated with oil palm production (described above), production yields and the method of allocation costs to the different co-products.

Table 2: Emissions associated with palm oil plantations over 25 years showing the impact of land source.

	Emissions associated with land source (t CO_2-e ha^{-1} y^{-1})*					
	Peatland Forest High Case	Peatland Forest Low Case	Mineral Soil Forest High Case	Mineral Soil Forest Low Case	Previous Oil Palm Plantation	*Imperata* Grassland
Biomass loss	11.7	7.3	11.7	7.3	8.4	0.7
SOC change	86.0	45.0	2.9	2.9	0.0	-0.7
Lost peat sequestration	2.5	0.0	0.0	0.0	0.0	0.0
N_2O	1.6	1.6	0.7	0.7	0.7	0.7
Production	3.5	3.5	3.5	3.5	3.5	3.5
Crop sequestration	-8.4	-8.4	-8.4	-8.4	-8.4	-8.4
Total	96.0	49.0	10.4	6.0	4.2	-4.2

** See the text for data sources.*

Table 3: The impact of land source and allocation procedure on emissions associated with PKE

	Emissions t CO_2-e t^{-1} PKE					
	Peatland Forest High Case	Peatland Forest Low Case	Mineral Soil Forest High Case	Mineral Soil Forest Low Case	Oil Palm Plantation	*Imperata* Grassland
Economic allocation	2.94	1.49	0.32	0.18	0.13	-0.13
Mass allocation	18.22	9.21	1.97	1.13	0.79	-0.79

Allocation of carbon costs between oil palm products

Where more than one product arises from a commercial activity, costs associated with the activity may be distributed among the co-products. Various accounting methods exist to allocate costs and the choice of allocation procedure can have a significant impact on the distribution of costs.

International guidance on co-product allocation exists in ISO14044 (ISO 2006b) and PAS2050 (BSI, 2008). In both documents co-product allocation is only recommended if it cannot be avoided either by system expansion (ISO 14044 and PAS 2050) or by subdividing processes (PAS2050). When co-product allocation is employed allocation based on either physical properties (e.g. mass allocation) or co-product value (economic allocation) is recommended.

Economic allocation entails the division of emissions based on the economic value of the commercial products. The main advantage is that prices can be readily determined, they are comparable and international accountancy systems for financial transactions are established. The key disadvantage is that prices and corresponding allocation factors can vary with market conditions.

Mass allocation entails the division of emissions based on the physical mass of the commercial products. The key advantage is that mass does not vary with market conditions. The disadvantages are that mass does not reflect the value society puts on a product, accountancy systems for mass are not so well established and measurement standards can differ (e.g. between the dry mass of timber and the fresh weight of oil palm fresh fruit bunches), making it difficult to make comparisons.

System expansion is associated with consequential LCA and involves expanding the boundaries of a system undergoing LCA to determine the impact of changes in production at the centre of the analysis on the production of similar products in other systems. For example, production of PKE as a supplementary food for cattle would be expected to reduce demand for alternative supplementary feedstuffs (e.g. soy and maize) and should be accounted for by expanding the system to take account of the impact on GHG emissions associated with the production of these other feedstuffs. The advantage of system expansion is that it allows the LCA to determine the global consequences of changes within a production system. The key disadvantage is that it can rapidly become very complex and this complexity can increase levels of uncertainty in the LCA outcome.

Co-product allocation is adopted in the Carbon Footprint Measurement study (Fonterra 2009) as system expansion is considered to be extremely complex and impractical. A number of different methods are combined in the Carbon Footprint Measurement study including a physical (time based) approach for the allocation of emissions between milk and meat production and economic allocation to determine the carbon cost of supplementary feed inputs including PKE. Economic allocation is also adopted in an FAO analysis from the dairy sector (FAO 2010) with respect to those GHG emissions associated with supplementary feed inputs.

Co-product allocation is preferred here over system expansion for reasons of practicality and simplicity, in line with the approaches to dairy LCAs adopted by Fonterra (2009) and FAO (2010). The outcomes of both economic and physical mass allocation are reported.

An economic allocation factor for PKE production is derived from its value as a proportion of the combined value of CPO, PKO and PKE production (all values as of January 2011; MPBO 2011). The factor is 0.018. The mass allocation factor is derived from the mean annual mass of total PKE production in Malaysia and Indonesia as a proportion of the mean combined mass of CPO, PKO and PKE production in Malaysia and Indonesia (USDA FAS 2011). The factor is 0.109.

In this study the emissions associated with forest biomass loss are allocated between oil palm products and extracted timber. Assuming 57% of the AGB is extracted as timber (FAO 2002) and using January 2011 timber prices (Meranti logs – *Shorea spp*.; ITTO 2011) economic allocation factors of 0.61 (oil palm cultivation following clearance of natural forest) and 0.76 (oil palm cultivation following clearance of selectively logged forest) are applied to oil palm products. The corresponding mass allocation factors are 0.68 and 0.81.

GHG emissions are allocated between milk and meat using the same ratio (86:14) as Fonterra (2009). This ratio is adopted both for economic and physical allocation as Basset Mens *et al.* (2009) which indicates a similar ratio for both approaches within the New Zealand dairy sector.

The GHG emissions associated with palm kernel expeller

Table 3 gives the emissions associated with a tonne of PKE associated with the different LUC possibilities and calculated with the two allocation factors.

Table 3 shows that the GHG emissions associated with PKE vary according to the land type and use prior to the establishment of oil palm plantations. In the current market the source of PKE is rarely, if ever, distinguished so it is not possible to determine the level of emissions associated with a specific shipment of PKE based on plantation land type and prior use. However, a composite figure can be calculated on the basis of proportional areas of each plantation land type and prior use. The proportions of land types (based on their pre-1990 status) used to establish plantations in this analysis are 30% peatland forest, 26% mineral soil forest, 43% existing plantation and (a nominal) 1% ***Imperata*** grassland based on data from Koh and Wilcove (2008), Omar ***et al.*** (2010), Kaas and Silvius (2011) and FAOSTAT (2011) (see Appendix 2 for details). Since 2005, much of the expansion of oil palm plantations has been at the expense of forest and, in particular, peatland forest (Fitzherbert ***et al.*** 2008, Danielsen ***et al.*** 2009) suggesting that these 2008 figures may underestimate the current proportion of oil palm plantation on cleared forest.

The overall emissions based on this approach are given in Table 4 and these are considered to be representative of the emissions associated with PKE imported into New Zealand. Using economic allocation of environmental costs, GHG emissions associated with the total New Zealand imports of oil cakes in 2010/2011 ranged from 0.78 million to 1.45 million t CO_2-e. The corresponding figures calculated using mass allocation are 4.80 million to 8.95 million t CO_2-e.

Table 4: Emissions associated with oil cake (PKE) imported into New Zealand

	Emissions t CO2-e t^{-1} oil cake		Emissions associated with 2010/11 imports of oil cake (000 t CO_2-e)	
	High Case	Low Case	High Case	Low case
Economic allocation	1.02	0.55	1445	776
Mass allocation	6.33	3.40	8952	4803

It is not certain exactly what proportion of these imports were accounted for by the dairy sector and it is assumed here that 90% of PKE imports go towards dairy production. Furthermore, in line with the approach adopted by Fonterra (2009), 86% of the costs are allocated to dairy products with the remaining 14% being allocated to meat products (calves and carcass).

Assuming 77% (90% x 86%) of the carbon emissions in Table 4, based on economic allocation, are spread across the total New Zealand milk production (16,000 million litres) this represents GHG emissions associated with PKE between 38 and 70 g CO_2-e per litre of fresh milk. The corresponding emissions, calculated using mass allocation, are 232 to 433 g CO_2-e per litre of fresh milk. The use of PKE is, therefore, likely to represent a significant source of unaccounted GHG emissions in this sector.

In this case study the GHG emissions associated with the use of PKE in high input dairy farms in New Zealand are investigated. In the Carbon Footprint Measurement study (Fonterra 2009) the productivity of high-input farms and the level of PKE use are discussed. The productivity cited for the 18 high-input Waikato farms was 468 kg MS per cow (6083 l fresh milk per cow) and this relied on minimum imports of 3.5 t DM PKE ha^{-1}.

Assuming an average stocking rate of 3 cows ha^{-1} on these farms the GHG emissions due to PKE would be expected to range from 101 to 187 g CO_2-e per litre fresh milk based on economic allocation; and 623 to 1160 g CO_2-e per litre fresh milk based on mass allocation.

The rain forests of South East Asia are among the richest, most diverse and complex ecosystems on Earth. Although the primary aim of this work is to investigate the GHG emissions associated with PKE, the rapid expansion of oil palm plantations at the expense of forest in South East Asia is associated with significant impacts on biodiversity in the region (Koh ***et al.*** 2010) and this represents a further adverse environmental impact.

The age structure and vegetation of plantations are less complex than natural forest (Fitzherbert ***et al.*** 2008). Typically, plantations have a uniform canopy, a uniform tree density and sparse undergrowth. A number of recent publications indicate that biodiversity is significantly lower in oil palm plantations than in natural forest and that the species composition can also be different. Koh and Wilcove (2008) indicate that the species richness of forest birds is reduced by more than 70% following the conversion of primary and selectively logged forest to plantation and the corresponding impact in butterfly species is of the order of an 80% reduction. In a meta-analysis Danielsen ***et al.*** (2009) determined that the vertebrate species richness of oil palm plantations is 38% that of natural forest while only 23% of forest vertebrate species are found in plantations. The same paper suggests that invertebrate species richness may be greater in plantations than in forests but that only 31% of forest species are found in plantations. The flora associated with plantations is impoverished and is dominated by the plantation monoculture with active weed management between trees.

Fitzherbert *et al.* (2008) found that across all taxa a mean of only 15% of species found in primary forest remain in oil palm plantations while many of the species in plantations are not found in forests and, in some cases, are not indigenous to the region. Species which are found in both forests and plantations tend to be generalists while species with specialised diets or dependant on niche forest habitats are not found in plantations.

The production of PKE is associated with significant GHG emissions and the full extent of PKE use in New Zealand dairy farming should be incorporated into the carbon footprint of New Zealand dairy products.

Peat depletion has the biggest impact on GHG emissions associated with PKE. Peat depletion under plantations can continue for more than one plantation cycle and represent a continuing, major source of GHG emissions so the further development of oil palm plantations on peatlands should be avoided. It may be possible to decrease the area of oil palm plantation on peatlands and increase the corresponding area of plantation in place of *Imperata* grasslands in order to reduce emissions, although the feasibility of this option would require further investigation. If feasible, this would leave open the possibility of restoring the hydrological functioning of peatlands by reducing drainage and re-establishing mixed indigenous hardwood forest, thus arresting peat depletion whilst augmenting biomass sequestration (Reiley and Page 2005). Biodiversity loss is a further adverse impact associated with the replacement of forest by oil palm plantations and this could be partially reversed if mixed indigenous hardwood forest were to be re-established

Developing oil palm plantations in place of *Imperata* grasslands could represent a significant carbon sequestration opportunity (Syahinudrin 2005, Fitzherbert *et al.* 2008, Wicke *et al.* 2008, Danielsen et al. 2009). Germer and Sauerborn (2008) suggest that between 20 and 50 million ha of depleted grassland exists in the region although Teoh (2010) indicates that the upper limit may be closer to 20 million ha and Danielsen *et al.* (2009) refer to an area of 8.5 million ha *Imperata* grassland. However, it is not clear whether all this land is suitable for oil palm cultivation and yields could be lower (Wicke *et al.* 2008). Much of the land is owned by small local communities and this may be seen as an obstacle to larger oil palm companies, although such small scale oil palm initiatives would be likely to bring considerable local benefits and also have a positive impact on GHG inventories at a national and regional level.

Initiatives to establish oil palm plantations in place of *Imperata* grassland could increase the supply of low carbon products, including PKE, over the medium to long term. In the short term the opportunity may exist for NZ farmers to source PKE from plantations which are not associated with peatland or recently cleared forest. This option could be pursued through the supply chain.

Recommendations

1. The carbon footprint of New Zealand dairy products should be updated to reflect the carbon cost and the extent of palm kernel expeller used as a feed stock.
2. The carbon cost of PKE depends upon its source. In order to reduce the carbon cost of their products in the near term, New Zealand dairy farmers could demand that their supplies of PKE are not sourced from oil palm plantations that are:

   a. cultivated on drained peat soils

   b. cultivated on land recently converted from rainforest.
3. A fully certified traceability system that allows the source identification of PKE is required to achieve point 2.
4. To further reduce the carbon footprint of dairy products in the medium to long term New Zealand farmers could work with their suppliers, the suppliers and consumers of palm oil, and other interested organisations to develop sources of low-carbon oil palm products (e.g. from oil palm cultivated in place of *Imperata* grasslands)

I would like to thank Pete Smith for his input throughout this project, Henk Wörsten for advice on peat depletion dynamics, Alex Kaat and others at Wetlands International for information on the extent of peatland forest conversion to oil palm plantation and Chairil Siregar for data on rainforest biomass and composition. I would also like to thank Nathan Argent for his help throughout and other members of the Greenpeace team for comments on the report.

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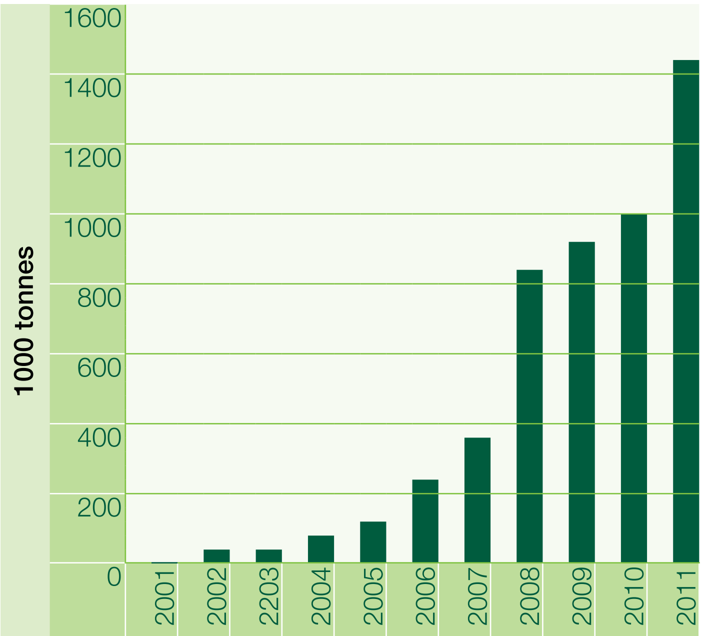
Appendix 1: Imports of palm kernel expeller to New Zealand

Figure A1.1: Imports to New Zealand of oil cake and other solids from extracted palm oil fruit (PKE)



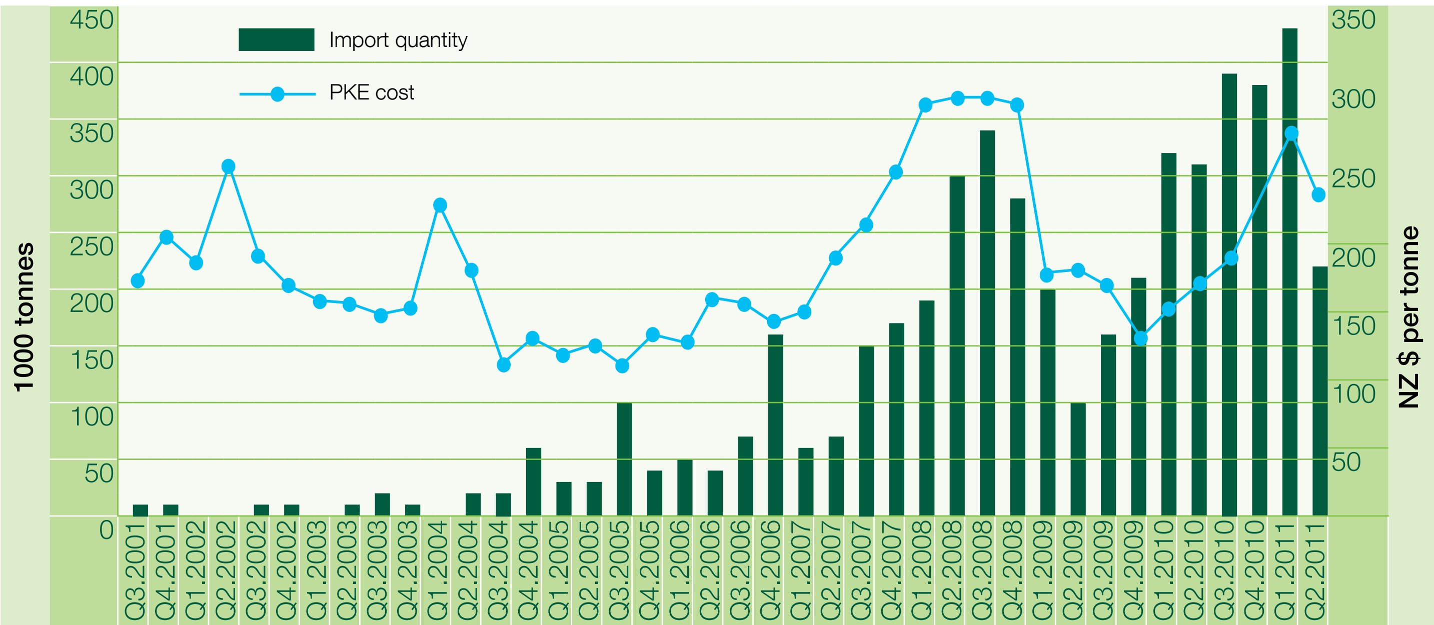
**Figures are given for seasonal (July – June) years. The data for April to June 2011 are provisional (Statistics NZ 2011) .*

Figure A1.2: Quarterly New Zealand PKE imports and import costs between 2001/2 and 2010/11 (Data source: Statistics NZ 2011)

Significant volumes (>10,000 t) of PKE were first imported into New Zealand in 2001/2 (July – June) period (Statistics New Zealand 2011). Since then imports have increased dramatically and over 1.4 million tonnes were imported in 2010/11 (Figure A1.1). Import volumes have risen every year indicating that demand for PKE has been increasing year on year. Between 2001/2 and 2006/7 this appeared to be following a predictable pattern (approximately 70% more imports each year). In 2007/8 imported volumes more than doubled. Over the following two years more gradual rates of increase have been recorded with a relatively a sharp increase (>40%) in 2010/11.

A more detailed view of the evolution of PKE import volumes emerges from Figure A1.2. Over the first six years there is a relatively consistent pattern with volumes increasing each year and peak imports reported during the first half of the season (in either quarter 3 [Q3] or Q4). This pattern fits well with a general increase in the use of PKE as a livestock food supplement with the highest use in late winter and spring. However, PKE can be stored for 4 to 6 months (DairyNZ 2008) so this may also reflect stock-building (either on farm or by importers) in anticipation of autumn use.

The pattern changed in 2007/8 with a doubling of imports and increased volumes each quarter, resulting in the highest imports for the period in Q2 2008. Imports continued to grow into the following year and peaked in Q3 2008, before falling sharply over the rest of the 2008/9 period. In 2009/10 imports rose again and imports during the Q1 and Q2 2010 were similar to the corresponding period in 2007/8. Volumes continued to rise during the following 3 quarters before falling back in the last quarter (Q2 2011).



The two factors which are likely to have triggered the change in the pattern of imports first seen in 2007/8 are climate and commodity prices.

Climate

Prolonged drought conditions were widespread in New Zealand in 2007/8. Abnormally dry conditions (determined as soil moisture deficit) were recorded in the key North Island areas of South Auckland and Taranaki (representing 47.3% of the NZ dairy herd) between November 2007 and March 2008, severe conditions existing during summer months (NIWA 2007, 2008). Unusually dry conditions were also experienced in eastern regions and central regions of the South Island, and Southland. Such conditions not only reduce the quantity and quality of pasture for grazing but also reduce the production of silage and of locally produced feed supplements such as maize.

These drought conditions led to a reduction in production of both milk solids per cow and total milk during 2007/8 (Figure A1.3). It is likely that the difficult conditions experienced during this period, especially during summer and autumn, and the consequential lack of fodder during the following winter drove the high levels of PKE imports recorded in Q4 2007, Q1 Q2 and Q3 2008.

In 2008/9 dry soil conditions were recorded over short periods (NIWA 2008, 2009) but prolonged drought was absent. Imports of PKE dropped during with lowest imports recorded in Q2 2009.

In 2009/10 dry conditions were experienced in some regions of New Zealand (NIWA 2009, 2010) although these were not as widespread or, in most cases, as severe as those experienced in 2007/8. Increased imports of PKE were recorded, especially in Q1 and Q2 2010. While dry conditions may have contributed to the increase in imports at this time, they were unlikely to have been the sole factor.

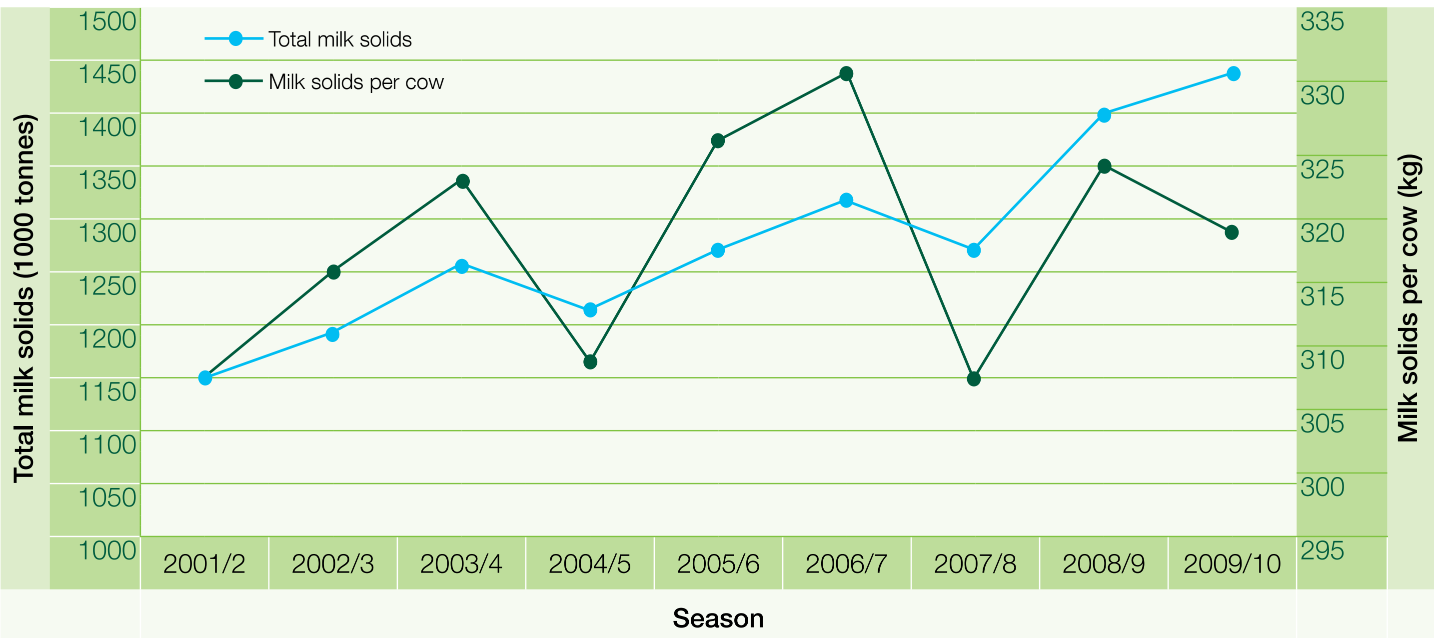
The 2010/11 year started with high levels of sunshine and corresponding dry conditions leading to severe soil moisture deficits in many regions in November and early December 2010 (NIWA 2010, 2011). Conditions changed across much of the country later in December with above-average rainfall, especially in western regions. Rainfall levels were extremely high across most of the North Island in January 2011 with some flooding. Extremely wet conditions were also experienced in March and April, also leading to flooding. The extremes of climate (dry and wet) during the 2010/11 spring and summer are likely to have increased demand for PKE to supplement grazing in the first three quarters of the period.

Commodity prices

Dairy prices and feedstock costs may also have influenced demand for PKE in New Zealand between 2007 & 2011. Dairy prices in New Zealand rose sharply in late 2006 and early 2007 from a 2006 base of NZ\$ 4 kg^{-1} MS, peaking at over NZ\$ 8 kg^{-1} MS in mid-2007 (Riden 2010). Dairy prices remained above NZ\$ 7 kg^{-1} MS for approximately a year before falling back sharply in the second half of 2008. Prices rose again to roughly NZ\$ 5 kg^{-1} MS in Q3 2009 and remained around this level until Q4 2010.

High dairy prices coincided with the increase in demand for PKE and may have initially prompted the rising demand. However, demand for PKE continued to increase during late 2007 and most of 2008 while dairy prices were falling. Furthermore, PKE costs increased with demand during this period (Figure A1.2) and the ratio of PKE cost to milk price increased (Table A1.1). These data suggest that high dairy prices alone were not responsible for rising PKE imports at this time.

Figure A1.3: New Zealand dairy production between 2001/2 and 2009/10 (Data source: DairyNZ 2010)



During late 2008 PKE prices remained relatively high at a time when milk prices had fallen increasing the cost/price ratio and this may have contributed to the fall in demand once more favourable climatic conditions returned.

In 2009/10 the rising demand for PKE also coincided with increasing dairy prices. Furthermore, PKE costs remained lower decreasing the cost/price ratio suggesting that low PKE costs coupled to a high milk price may have been a factor driving demand.

In 2010/11 PKE costs rose with demand whilst the milk price also continued to rise. This period saw a slight increase in the cost/price ratio although it remained marginally below typical historical levels. It seems unlikely that commodity prices were the most important factor driving increasing demand for PKE during the first three quarters of this period.

Table A1.1: The relationship between PKE and New Zealand milk prices

Period	PKE cost[1] (NZ$ kg^{-1})	Milk price[2] (NZ$/$kg^{-1}$ MS)	Ratio
2001/2	0.19	5.35	0.036
2002/3	0.16	3.66	0.043
2003/4	0.17	4.25	0.039
2004/5	0.11	4.58	0.025
2005/6	0.13	4.1	0.031
2006/7	0.15	4.46	0.034
2007/8	0.25	7.67	0.033
2008/9	0.23	5.14	0.044
2009/10	0.15	6.37	0.024
2010/11	0.23	7.5[3]	0.030

[1]Data source: NZ Statistics. [2]Data sources: Dairy NZ (2010) and Fonterra (2011). [3]Forecast price.

Conclusions

Demand for PKE in New Zealand dairy farming has been growing for a decade. This underlying trend does not appear to correspond to fluctuations in commodity prices or to climatic conditions and almost certainly reflects changing farming practices focused on increasing productivity.

Commodity prices and climatic conditions in 2007/8 probably acted in concert to dramatically increase demand for PKE with drought representing the more significant factor, especially in 2008.

Decreasing PKE imports in 2008/9 correspond to high PKE prices and low milk prices during a period when drought conditions had abated.

A favourable PKE-to-milk price ratio is likely to have been a significant driver of increasing demand for PKE in 2009/10 with localised drought conditions playing a significant, though smaller, role than during 2007/8.

In 2010/11 climatic factors are likely to have been the main driver of increasing demand for PKE although high milk prices may also have encouraged demand.

It is probable that farmer familiarity with PKE as a supplementary food stock will have increased in 2007/8, and again in 2010/11, due to the lack of local feed alternatives. This familiarity with PKE as a supplementary feed is also likely to increase the likelihood of future use.

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Appendix 2: Calculations

Conversion Factors

Mass of C to mass of CO_2: 3.67 (44/12)

Mass of N_2O-N to mass of N_2O: 1.57 (44/28)

Global warming potential of CO_2: 1 (Forster *et al.* 2007)

Global warming potential of N_2O: 298 (Forster *et al.* 2007)

Emissions from forest biomass following forest clearance:

1. Natural forest

    Above ground biomass (AGB)b: .... 350 t DM ha^{-1} (IPCC 2006)
    Biomass expansion factor .... 1.74 (FAO 2002)
    Proportion of AGB as merchantable (timber) 57%
    Merchantable biomass (timber) .... 201.1 t DM ha^{-1}
    Proportion of residual AGB forest clearance 43%
    Residual AGB left in situ after forest clearance .... 148.9 t DM ha^{-1}

    Ration of below ground biomass (BGB) to AGB .... 0.37 (IPCC 2006)
    Below ground biomass (BGB) .... 129.5 t DM ha^{-1}
    Proportion left in situ after logging 100%

    AGB + BGB left in situ after forest clearance .... 278.4 t DM ha^{-1}

    Carbon content of biomass .... 0.47 t C t-1 DM (IPCC 2006)

    Carbon remaining after logging .... 130.8 t C ha^{-1}

    It is assumed that all biomass left in situ after logging operations is subsequently burnt or degraded releasing all carbon as CO^2.

    Emissions from natural forest biomass following forest clearance .... **480 t CO^2-e ha-¹**

2. Selectively logged forest.

    The biomass associated with selectively logged forest is assumed to be 50% of natural forest (Wicke et al. 2008). All other factors remain unchanged.

    Emissions from selectively logged forest biomass following forest clearance .... **240 t CO^2-e ha-¹**

b t DM ha^{-1} = tonnes dry matter per hectare

Emission allocation factors associated with forest biomass.

Emissions are allocated between forestry products (merchantable biomass) associated with forest clearance and palm oil products associated with 25 years of subsequent oil palm cultivation. These can be based either on economic data or physical mass data.

1. Natural forest

Merchantable biomass (timber) .... 201.1 t DM ha^{-1} ((see above)
Average yield of fresh fruit bunches (FFB) .... 18.9 t ha^{-1} (FAOSTAT 2011)
FFB production over 23 years[c] .... 434.7 t ha^{-1}

Timber price (*Shorea sp* - Meranti logs - Sarawak) .... US$ 250 m^{-3} (ITTO 2011)[d]
Timber density .... 0.675 t m^3 (MTC 2010)
Value of merchantable biomass........ US$ 74,500

FFB price .... US$ 270 t^{-1} (MPOB 2011)
Value of FFB production........ US$ 117,400

Economic allocation to oil palm products........ 0.61 (117,400/[74,500 + 117,400])

Mass allocation to oil palm products[e]........ 0.68 (434.7/[201.1 + 434.7])

2. Selectively logged forest

The biomass associated with selectively logged forest is assumed to be 50% of natural forest (Wicke *et al.* 2008).

Merchantable biomass (timber) .... 100.6 t DM ha^{-1}
Average yield of oil palm fresh fruit bunches (FFB) .... 18.9 t ha^{-1} (FAOSTAT 2011)
FFB production over 23 years .... 434.7 t ha^{-1}

Timber price (*Shorea sp* - Meranti logs - Sarawak) .... US$ 250 m^{-3} (ITTO 2011)
Timber density .... 0.675 t m^3 (MTC 2010)
Value of merchantable biomass........ US$ 37,200

FFB price .... US$ 270 t^{-1} (MPOB 2011)
Value of FFB production........ US$ 117,400

Economic allocation factor for oil palm products .... 0.76 (117,400/[37,200 + 117,400])

Mass allocation factor for oil palm products .... 0.81 (434.7/[100.6 + 434.7])

The economic allocation factors are used in the ensuing calculations to avoid complexity and because the mass allocation factors are problematic (see footnote e). The use of the mass allocation factor would increase the apparent carbon cost of oil palm products although this would have a relatively small impact on the overall calculations.

c The first 2 years of the oil palm cycle are unproductive so the productive period is 23 years

d Sarawak prices range from 234 – 273 US$ m^3 Meranti logs

e The calculation of mass allocation factors is problematic as timber is measured in units of dry mass and oil palm fresh fruit bunches are measures in units of fresh mass.

Emission associated with forest biomass allocated to oil palm plantations.

1. **Plantation following clearance of natural forest.**

   Emissions from biomass .... 480 t CO_2-e ha^{-1}

   Allocation factor 0.61

   Typical lifespan of plantation .... 25 years

   Annualised emissions .... **11.7 t CO_2-e ha^{-1} y^{-1}**

2. **Plantation following clearance of selectively logged forest.**

   Emissions from biomass .... 240 t CO_2-e ha^{-1}

   Allocation factor 0.76

   Typical lifespan of plantation .... 25 years

   Annualised emissions .... **7.3 t CO_2-e ha^{-1} y^{-1}**

Biomass sequestration and emissions associated with plantation replacing plantation

The carbon sequestration associated with cultivation of oil palm plantations .... **8.4 t CO_2-e ha^{-1} y^{-1}** (Chase & Henson 2010)

The emissions associated with clearance of oil palm plantations .... **8.4 t CO_2-e ha^{-1} y^{-1}** (Chase & Henson 2010)

There is assumed to be zero net biomass change when oil palm plantation replaces oil palm plantation.

Biomass emissions associated with conversion of *Imperata* grassland to plantation

Total biomass in grassland.. 18.3 t CO_2-e ha^{-1} y^{-1} (Chase & Henson 2010)

Typical lifespan of plantation .... 25 years

Annualised emissions .... **0.7 t CO_2-e ha^{-1} y^{-1}**

Carbon sequestration and depletion in peat soils

Carbon sequestration occurs as peat domes accrue organic matter but this process appears to have been disrupted in many forest sites. Conversion of forest to plantation on peat domes disrupts peat accrual. As disruption of peat accrual may occur independently of conversion to plantation the loss of sequestration is accounted for in the peatland forest high case alone.

Carbon sequestration .... 0.67 t C ha^{-1} y^{-1} (Page *et al.* 2010)

Equivalent to.. **2.5 t CO_2-e ha^{-1} y^{-1}**

Peat depletion in plantations is associated with drainage. Two recent publications give very similar figures. The lower figure is used in these calculations

Peat depletion per m drainage depth[f] .... 90 t CO_2 ha^{-1} y^{-1} (Couwenberg *et al.* 2010)

91 t CO_2 ha^{-1} y^{-1} (Hooijer *et al.* 2010)

Hooijer *et al.* (2010) indicate that the above relationship between peat depletion and drainage depth holds true to depths over 1 m although Couwenberg *et al.* (2010) suggest that peat depletion may only be proportional to drainage depths at depths of 50 cm or less, with little further depletion occurring with increasing depth. Drainage depth can vary depending on local management practice. Hooijer *et al.* (2010) suggest a minimum drainage depth of 0.8 m in plantations, a likely depth of 0.95 m and a maximum depth of 1.1 m.

Given the range of emission figures that can be derived from these data, both low and high emissions scenarios are reported in this document. The low emission scenario is based on depletion to a maximum depth of 50 cm following the more conservative scenario of Couwenberg *et al.* (2010). The high emission scenario is based on peat depletion being proportional to depth at the likely drainage depth of 0.95 m (Hooijer *et al.* 2010).

Low emission scenario .... **45 t CO_2 ha^{-1} y^{-1}** (90 t CO_2 ha^{-1} y^{-1} m^{-1} x 0.5 m)

High emission scenario.. **86 t CO_2-e ha^{-1} y^{-1}** (90 t CO_2 ha^{-1} y^{-1} m^{-1} x 0.95 m)

f The figures reported here are significantly higher than IPCC (2006) defaults and are used as they are pertinent to plantations in South East Asia. For further information see Couwenberg (2009) who specifically challenges selected IPCC defaults for managed peat soils.

Soil organic matter changes in mineral soils

1. Soil organic carbon (SOC) losses following conversion of mineral soil forest to oil palm plantation .... 20 t C ha^{-1} (Wicke ***et al.*** 2008)[g]

   Typical duration of plantation .... 25 years

   Annualised emissions .... **2.9 t CO_2-e ha^{-1} y^{-1}**

2. SOC sequestration following conversion of *Imperata* grassland to oil palm plantation:

   Emissions **reduction** .... **0.7 t CO_2-e ha^{-1} y^{-1}** (Syahinadrin 2005)[h]

Nitrous oxide emissions

Emissions on peat[i] .... 5.4 kg N_2O ha^{-1} y^{-1} (Couwenberg ***et al.*** 2010)
Equivalent to .... **1.6 t CO_2-e ha^{-1} y^{-1}**

Emissions on mineral soils .... **0.7 t CO_2-e ha^{-1} y^{-1}** (Chase & Henson (2010)

Other emissions associated with the production of oil palm products

Other emissions .... **3.5 t CO_2-e ha^{-1} y^{-1}** (Chase & Henson (2010)

Total emissions

The sum of all emissions for oil palm products are presented in Table 2 (main document).

g Assuming low activity clay soils.

h This figure represents SOC change in the top 1 m soil which is reported to be consistent with the SOC loss figures from Wicke ***et al.*** (2008). Syahinadrin reports total SOC change of 2.6 t CO_2 ha^{-1} y^{-1} to a depth of 5 m indicating that the full sequestration potential is likely to be greater than reported here.

i This figure reported here is significantly lower than IPCC (2006) defaults and is used as it is pertinent to plantations in South East Asia. For further information see Couwenberg (2009) who specifically challenges selected IPCC defaults for managed peat soils.

Allocation of carbon costs between oil palm products

Emissions are allocated between oil palm products. These can be based either on economic data or physical mass data.

1. Mass allocation factor (Indonesian plus Malaysian production in 2010) (USDA FAS 2011)

   Production volume of crude palm oil (CPO) .... 41.6 million tonnes

   Production volume of palm kernel oil (PKO) .... 4.8 million tonnes

   Production volume of palm kernel expeller (PKE) .... 5.7 million tonnes

   The mass allocation factors (MAF) are calculated using the following formula:

   $MAF = M/\sum[(M_{CPO}), (M_{PKO}), (M_{PKE})]$ where M is the commodity production volume.

   Crude palm oil MAF **0.798**

   Palm kernel oil MAF **0.093**

   Palm kernel expeller MAF **0.109**

2. Economic Allocation (Malaysian commodity prices in February 2011) (MPOB 2011)

   Crude palm oil price .... US$ 1,270 t^{-1}

   Palm kernel oil price .... US$ 2,240 t^{-1}

   Palm kernel expeller price .... US$ 200 t^{-1}

   The economic allocation factors (EAF) can be calculated using the following formula:

   $EAF = P \times M/\sum[(P_{CPO} \times M_{CPO}), (P_{PKO} \times M_{PKO}), (P_{PKE} \times M_{PKE})]$

   where P is the commodity (P_{CPO}, P_{PKO} or P_{PKE}) price and M is the production volume (M_{CPO}, M_{PKO} or M_{PKE}) for each commodity.

   Crude palm oil EAF **0.816**

   Palm kernel oil EAF **0.166**

   Palm kernel expeller EAF **0.018**

The GHG emissions associated with PKE

Emissions associated with PKE production are determined using mass and economic allocation principles and are calculated by multiplying the total emissions in Table 2 by the appropriate allocation factor to give costs per hectare. These are transformed to costs per tonne PKE using the average yield of PKE (see below).

Emissions (t CO_2-e ha^{-1}) x Allocation Factor/Yield (t PKE ha^{-1})

These results are presented in Table 3 (main document).

Yield of PKE

These calculations are based on 2008 data as this is the most recent year for which all relevant data are available.

Production of oil palm fresh fruit bunches (FFB) .... 168 million tonnes (FAOSTAT 2011)

Production of PKE .... 5.13 million tonnes (USDA FAS 2011)

Yield of FFB .... 18.9 t ha^{-1} (FAOSTAT 2011)

Yield PKE .... 5.13 Mt /168 Mt x 18.9 t ha^{-1}

0.58 t PKE ha^{-1}

The GHG emissions associated with New Zealand imports of PKE

A range of GHG emissions have been determined for PKE in this document dependant on land type and its use prior to the cultivation of oil palm. In order to calculate the figures for imports it is necessary to know what proportion of oil palm production is associated with prior land-type and use. In this document, where land use has changed (e.g. forest to plantation), the change is based on plantation establishment since 1990:

Total area of harvested oil palm in 2008 .... 8.90 million ha (FAOSTAT 2011)

Area ex-forest .... 5.01 million ha (Koh and Wilcove 2008, FAOSTAT 2011)[j]

Area ex-peatland forest .... 2.68 million ha (Omar ***et al.*** 2010, Kaat and Silvius 2011)[k]

Area ex-mineral forest .... 2.32 million ha (by subtraction: forest area - peatland forest area)

Imperata grassland: .... 0.09 million ha (nominal 1% of total area)

Plantation .... 3.80 million ha (by subtraction: total area – forest area – *Imperata* grassland area)

Area proportions of each land type under oil palm

Ex-peatland forest (AP_{PF}) 0.30 (2.68/8.90)

Ex-mineral forest (AP_{MF}) 0.26 (2.32/8.90)

Imperata grassland (AP_{IG}) .... 0.01 (nominal 1% of total area)

Plantation (AP_{Pl}) 0.43 (3.80/8.9)

j Koh and Wilcove (2008) indicate that between 2.7 and 4.1 million ha of forest were converted to oil palm between 1990 1nd 2005. The midpoint (3.4 million ha) is used here. FAOSTAT (2011) indicates that between 2005 and 2008 the reductions in forest area in Indonesia and Malaysia were 2.06 and 0.26 million ha respectively and the increases in oil palm area harvested were 1.31 and 0.34 million ha respectively. It is assumed that all expansion of oil palm between 2005 and 2008 in Indonesia (1.31 M ha) was at the expense of forest and that the total area of forest lost in Malaysia during this period (0.26 M ha) was converted to oil palm. Thus the total area of forest converted to oil palm between 1990 and 2008 is 5.05 million hectares.

k 666,038 ha in Malaysia in 2009 (Omar *et al.* 2010). Kaat and Silvius (2011) estimate that 60% of Indonesian oil palm concessions on peatland had been converted to plantation (based on 2006 figures). There were 3.36 million ha of peatland concessions in 2008 so 2.02 million ha are assumed to have been converted to oil palm plantation.

A high emissions case and a low emissions case is reported for oil palm plantations established on peatland forest so two emission figures have been generated for each allocation approach.

Emissions from economic allocation high case (EE_{PKEHC}) .... **1.02 t CO_2-e t^{-1} PKE**

$EE_{PKEHC} = \sum(EE_{PFHC} \times AP_{PF}), (EE_{MF} \times AP_{MF}), (EE_{PI} \times AP_{PI}), (EE_{DL} \times AP_{IG})$

Emissions from economic allocation low case (EE_{PKELC}) .... **0.55 t CO_2-e t^{-1} PKE**

$EE_{PKELC} = \sum(EE_{PFLC} \times AP_{PF}), (EE_{MF} \times AP_{MF}), (EE_{PI} \times AP_{PI}), (EE_{DL} \times AP_{IG})$

Emissions from mass allocation high case (ME_{PKEHC}) .... **6.33 t CO_2-e t^{-1} PKE**

$ME_{PKEHC} = \sum(ME_{PFHC} \times AP_{PF}), (ME_{MF} \times AP_{MF}), (ME_{PI} \times AP_{PI}), (ME_{DL} \times AP_{IG})$

Emissions from mass allocation low case (ME_{PKELC}) .... **3.40 t CO_2-e t^{-1} PKE**

$ME_{PKELC} = \sum(ME_{PFLC} \times AP_{PF}), (ME_{MF} \times AP_{MF}), (ME_{PI} \times AP_{PI}), (ME_{DL} \times AP_{IG})$

EE = Emissions per tonne PKE based on economic allocation

ME = Emissions per tonne PKE based on mass allocation

AP = Area proportion of each land type.

PFHC = Peatland forest high case

PFLC = Peatland forest low case

MF = Mineral forest

PI = Plantation

IG = *Imperata* grassland

The total emissions associated with imports are calculated by multiplying the emissions per tonne of PKE in each case by the number of tonnes of PKE imported (Table 4).

The emissions for fresh milk associated with PKE assume that 90% of New Zealand PKE imports are used in the dairy sector. In line with the approach adopted by Fonterra (2009), 86% of the costs are allocated to dairy products with the remaining 14% being allocated to meat products (calves and carcass). The associated emissions are calculated by dividing 77% (90% x 86%) of the total emissions from Table 4 by the annual milk production volume (16,000 million litres) to give the range of values.

Case study – high input farms (Waikato)

Input per hectare .... 3.5 t dry mass PKE (Fonterra 2009)

Typical moisture content of PKE 10% (RD1 2009)

Mass if imported PKE per hectare .... 3.9 t

Production per cow (kg milk solids) .... 468 kg milk solids (Fonterra 2009)

Conversion factor for fresh milk .... 1 kg milk solids = 13 l fresh milk (litres fresh milk x 1.031 kg l^{-1} ÷ 13.4 [Fonterra 2009])

Production per cow (litres fresh milk) .... 6084 l fresh milk

Cows per hectare .... 3 (based on 2.9 cows per hectare in Waikato in 2 004/5[I] [LIC 2005] and assuming a slightly elevated grazing intensity on high input farms)

Milk production per hectare .... 18252 l fresh milk

The PKE associated GHG emissions can be calculated using the formula:

Economic allocation emissions$_{fresh\ milk}$ .... = 3.9 t PKE x EE_{PKE}/18252

= **187 g CO_2 l^{-1}** (high case)

= **101 g CO_2 l^{-1}** (low case)

Mass allocation emissions$_{fresh\ milk}$ .... = 3.9 t PKE x ME_{PKE}/18252

= **1,160 g CO_2 l^{-1}** (high case)

= **623 g CO_2 l^{-1}** (low case)

I 2004/5 was the period of the Fonterra study

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