Life Cycle Analysis of Embedded CO_2 in Palm Kernel Expeller

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Abstract

With industries now looking to report on Scope 3 greenhouse gas emissions, companies are including Life Cycle Analysis (LCA) of embedded CO_2 in supplementary feeds. Dairy companies are also including this aspect within the calculation of on-farm emission intensity. This paper outlines a methodology of calculating embedded CO_2 emissions in palm kernel expeller (PKE), which is a major supplementary feed imported into New Zealand, and shows a range of figures across the value chain for PKE, up to the point of arrival on-farm.

Background

PKE is a by-product from the production of Palm Oil, a vegetable oil which is used in a wide range of products, from foodstuffs (e.g. margarine, chocolate, baked goods) to cosmetics (lipstick, shampoo), cleaning agents and biofuel. It is favoured for being semi-solid at room temperature, stable at high temperatures for frying, and for providing a long shelf life.

PKE is a high-fibre, moderate-protein, and energy-dense by-product, now commonly used as a cost-effective supplementary feed for cattle, especially dairying, within New Zealand pastoral systems.

LCA Analysis

The purpose of the LCA is to calculate the “embedded” CO_2 within the product, relative to emissions made across the value chain of the product as it is produced. For PKE, this would involve:

- Deforestation/land use change into palm oil
- An offset from carbon sequestration by the palm oil trees
- Growing/management of the plantation
- Transport to the processing plant
- Processing
- Transport from processing plant to the wharf
- Trasport from the wharf in the exporting country to the wharf in NZ
- Transport from the NZ wharf to the farm

Deforestation Liability

This is the liability which accrues as a result of the deforestation of tropical rainforests in order to establish the palm oil plantations. Such action obviously releases the CO_2 which had been sequestered in the trees.

This is particularly so given that the bulk of palm oil/PKE is produced in Malaysia (66.9% of world production) and Indonesia (25.7%).

Estimates of the amount of carbon stored within tropical forests vary, depending on a range of situations and locations.

- Malaysian literature[1] indicates a range of 144 – 198 tonnes of carbon (528.5 – 727 tonnes CO_2e/ha), with an average of 627.6 Tonnes CO_2e/ha.
- Figures from Indonesia[2], across 10 districts, give an average of 663.7 T CO_2e/ha, with a range of 625-739 T CO_2e/ha
- Other figures include:
    - Australia[3] 767 T CO_2e/ha
    - Costa Rica[4] 447 T CO_2e/ha
    - Greenwatch[5], a UK-based environmental NGO gives a general figure of 640 T CO_2e/ha
    - Copper et al[6] gives a figure of 70-110 T CO_2e/ha/year from tropical peat forest

Another report[7] gave details on emissions from a range of land use types across Indonesia, Malaysia, and Papua New Guinea:

Table 1: CO_2 Emissions from Different Land Use Types

	Average	Range	Burning Peat
	T CO_2e/ha		
Undisturbed Upland Forest	694	224-1,464	
Disturbed (cut over) Upland Forest	382	121-917	
Upland Shrubland	110	99-128	
Undisturbed Swamp Forest*	595	330-734	1,211
Disturbed Swamp Forest	308	121-569	1,211
Swamp Shrubland	103	66-128	404

*The emissions from removing the trees/burning the peat is cumulative, so for the Undisturbed Swamp Forest, for example, total emissions would be 1,806 T CO_2e/ha.

For the purposes of this paper, the Indonesian and Malaysian averages were used: 664 T CO_2e/ha and 628 T CO_2e/ha respectively.

Amortisation

Under Scope 3 rules, this deforestation liability is amortised over a 20-year period. Amortisation can be either of two forms; either an annual amortisation, where an equal portion is split over the period of time, i.e. for a 20 year period $^1/_{20}{}^{th}$ is assumed in each year, or on a diminishing linear basis where the original sum is depreciated linearly (at 5%/year cumulative for a 20-year period) through to zero over the period. This gives a much higher figure in Year 1, through to zero in year 20.

Under an annual amortisation regime, for example, the 628 T CO_2e/ha for Malaysia equates to 31.4 T CO_2e/ha/year over 20 years. Under the diminishing linear regime, the mean figure for the Malaysian emission over 20 years is 298.1 T CO_2e/ha.

Obviously, there is quite a difference between the two. The convention is to use the diminishing linear approach, which is used in this analysis, with the annual figure illustrated in the sensitivity analysis.

Palm oil trees start bearing at 3 years of age, with peak production over 9-18 years of age, with yields then starting to decline. A normal economic life is considered to be 25 years before replanting.

Peak planting within Malysia and Indonesia was in 2015, with the average age of plantations in both countries put at 14 years (in 2019). Within this, 45% of Malaysian plantations are greater than 15 years, 26% greater than 20 years, and 12% greater than 25 years. In Indonesia, 53% of palm oil plantations were over 20 years old as of 2020. In other words, most plantations in both countries are relatively old – with declining yields, and both report delays in replanting due to poor economics.

Yield of Palm Oil/Palm Kernel Expeller

A review of the literature gave some widely varying figures. A report from Farmonaut[8] gave a yield of 7-10 tonnes of palm oil/ha (average of 8.5T/ha assumed). Other literature[9] indicated that: *A mature palm oil plantation can typically yield 3-5 metric tons of CPO per hectare annually. However, through optimized practices and the use of high-yielding varieties, some operations achieve yields of up to 6-8 metric tons per hectare*, and another[10] *Potential oil yield of oil palms planted on a commercial scale has been estimated at 10 to 11 t/ha. The largest reported oil yield at an estate scale (c. 2,000 ha) in Malaysia was more than 8 t/ha and leading plantation groups in Indonesia and Malaysia have achieved average oil yields of 6 t/ha at a larger scale.*

Against this, other reports[11] [12] noted that the average yield in Malaysia is 4T/ha, and in Indonesia 3.8T/ha.

Other reports[13] [14] noted:

- Average yield of Fresh Fruit Bunch (FFB) – within which is the palm nut, averages 10-25 T/ha
    - A young plantation (3-5 years) averages 10-15 Tonne FFB
    - Mature plantation (6-10 years) averages 20-25 T FFB
    - An optimally managed orchard (10-30 years) averages 25-35 T FFB
- 1 tonne of FFB yields 200-240 kg of palm oil
- 1 tonne of FFB yields 50-60 kg of Palm Kernel expeller
- Extracting 1 tonne of crude palm oil (CPO) produces 110-140kg of PKE (average 125kg assumed for the analysis)
- The palm nut comprises 42-48% palm oil, and 52-58% palm kernel

A 2022 report from the Malaysian Palm Oil Board[15] noted that the average FFB yield in Malaysia was 15.49 T/ha.

For the purpose of this paper, calculations were made for both 8.5T/ha and 4.0T/ha of palm oil, to consider the impact of this difference.

Sequestration of Carbon by Palm Oil Trees

Palm oil trees act as efficient carbon sinks due to their rapid growth, perennial nature, and dense canopy, capable of absorbing 23–64.5 tons of CO_2 per hectare annually[16].

In this respect this carbon sequestration helps to offset to some degree the emissions from the deforestation. The general average sequestration rate is given as 36T CO_2e/ha/year[17], with an Indonesian average given as 40T CO_2e/ha/year. The 36T figure is used in this analysis.

Assuming a useful life of the palm oil trees of 25 years before replanting, this gives a total of 900 T/ha CO_2 sequestered by the plantation. However, on the assumption that there is an ongoing regime of felling the trees and replanting after 25 years, then within this there is a process of loss of carbon followed by further sequestration.

Within New Zealand, such a regime is very akin to that of a radiata pine production forest, with the "net" sequestration of carbon over successive rotations prescribed by the Emissions Trading Scheme under the "averaging" scheme. This in effect allows foresters to claim a net figure of 45% of total carbon sequestered within the first rotation.

Applying this to the palm oil plantation system gives a net sequestration of 405T CO_2e/ha, as an offset on the deforestation liability. This was again amortised across 20 years on a diminishing linear basis, giving a mean offset of 192.4T CO_2e/ha.

Transport of palm nuts to processing plant

Emissions per tonne/kilometre vary, depending on the type of transport being used, and the distance to the processing plant. The assumption in this analysis is that the mode of transport is via heavy truck, and the distance travelled is (arbitrarily) 50km.

Emissions per T/km varies depending on the type of truck[18]:
- 100-108 gm CO_2 per T/km for heavy trucks
- 135-144 gm CO_2/T/km average
- 390-400 gm CO_2/T/km for smaller urban trucks

For the purposes of this analysis, a figure of 140gms CO_2/T/km is used, based on the average figure above.

Emissions from Processing of Palm Nuts

This again varies depending on the efficiency of the mill in question.

The literature gives a breakdown of "processing" in the sense of covering:
- Fertiliser and Agrichemicals on the plantation [Which is actually a cost of growing the palm trees but seems have been included in the analysis of processing emissions]
- Mill processing – energy costs
- Waste treatment of Palm Oil Mill Effluent (POME)

For the Malaysian analysis the breakdown was:
- Fertiliser and Agrichemicals 5.3%
- Mill processing – energy consumption 32.1%
- POME waste treatment 59.7%

The processing itself is a 2-stage exercise whereby some oil is extracted from the flesh of the Fresh Fruit Bunch, along with the palm kernel, which is then further processed to extract the oil, + palm kernel expeller.

A paper on Malaysian processing[19], gave a figure of 3,240kg CO_2e/T Crude Palm Oil (CPO), whereas an Indonesian paper[20], gave a figure of 1,442.6 kg CO_2e/T CPO.

Transport of PKE to the Wharf

Again, there are uncertainties, depending on the distance of the processing plant to the wharf, and the mode of transport. For the purposes of the analysis, it was assumed:

- The distance to the wharf is 100km
- Transport is by rail

Emissions per tonne/km by rail is assumed as an average of 32gm/T/km, based on the range of 25-40 gm/T/km[21, 22].

For a tonne of PKE therefore the emission is 3.2 kgCO_2/T

Transport to New Zealand

The distance travelled will vary depending on the port of origin and the destination port. For this analysis the assumption was departing from Port Klang in Malaysia to Port Tauranga in New Zealand, which is 9,728 km by sea. [Port Jakarta in Indonesia to Port Tauranga is 9,724km]

Emissions from sea transport is 0.019 kg CO_2e/tonne/km[23]; for a tonne of PK shipped to New Zealand therefore the emissions are 184.8 kgCO_2/T.

Transport Within New Zealand

The assumption here was transport from the Port of Tauranga to Morrinsville, by truck, a distance of 90km. Assuming the same emission factor as used earlier for heavy trucks, this would equate to 12.6kg CO_2/T PK.

However, fuel in New Zealand already carries a carbon tax, payable by the truck owner. In this situation applying a CO_2 cost against the load (in this case PKE) would mean a double-count and is therefore ignored.

Allocation of Emissions to PKE

The key issue here is the allocation of the different emissions to the PKE itself. The standard approach to do this is on an "economic allocation" basis – where a product has various sub-products, the allocation is based on the economic value of each of these sub-products.

This methodology is recommended by the International Dairy Federation who note that "economic allocation is the recommended method for farm inputs" including imported supplements, aka PKE[24]. Such an approach is also used by the NZ Meat industry and based on averages across the lifespan of the animal[25,26].

This is important when it comes to PKE, as essentially the purpose of deforesting tropical forests and planting in palm oil trees is to produce palm oil, and the major economic gain from such a system is, naturally, to the palm oil industry.

In 2025 the value of palm oil produced was US$75.5 billion[27], and the value of PKE was US$1.68 billion[28], or 2.2% the value of palm oil. [Obtaining long-run data on palm oil/PKE total values over time was problematic, but the estimated ratio (PKE to PO) in 2022 was 1.9%, 1.8% in 2023, and 1.9% in 2024]

In other words, the value of PKE, in 2025, was 2.2% of the value of palm oil. This means that under the economic allocation approach, 97.8% of the CO_2 emissions would be ascribed to palm oil, given that producing palm oil was the key driver of producing the emissions, and 2.2% was ascribed to PKE.

Overall, therefore, the allocation of the various components of the system to PKE would be:

Table 2: GHG Emission Allocation to Palm Kernel Expeller

	Liability to PKE
Deforestation Liability	2.2%
Sequestration Credit	2.2%
Transport to mill	2.2%
Processing (+ growing emissions)	2.2%
Transport of PKE from Mill to Wharf	100%
Wharf to NZ	100%
Transport within NZ	0%

A calculation therefore of the embedded CO_2 in PKE is illustrated in Table 3:

Table 3: PKE CO_2 Liability

	Malaysia			**Indonesia**	
Mean Amortised Deforestation (T CO_2e/ha)	298.1			315.4	
Mean Amortised Sequestration Credit (T CO_2e/ha)	192.4			192.4	
Net Emissions (T CO_2e/ha)	105.7			123.0	
	Palm Oil (PO) Yield T/ha			**PO Yield T/ha**	
	8.5	4.0		8.5	4.0
Net Forestry Emissions T CO_2e/T Palm Oil	12.44	26.43		14.47	30.75
Net Forestry Emissions kg CO_2e/T PKE*	34.2	72.7		39.8	84.6
Processing kg CO_2e/T PKE*	51.2	51.2		31.3	31.3
Transport kg CO_2e/T PKE	188.2	188.2		188.2	188.2
Total CO_2e kg/T PKE	273.6	312.1		259.3	304.0
kg CO_2e/kg PKE DM**	0.304	0.347		0.288	0.338
kg CO_2e/kg PKE DM excluding forestry	0.266	0.266		0.244	0.244

*Adjusted to allow for the 2.2% liability to PKE
**DM = dry matter, where 1 T PKE = 900 kg DM

As can be seen from Table 3:

(i) The main contributor to the embedded CO_2 in PKE is transport, followed by the processing emissions

(ii) The deforestation emissions are relatively small, due in part to the sequestration offset, and particularly to the 2.2% liability.

(iii) The impact of the differing Palm Oil yields is also relatively minor.

As noted earlier, palm oil plantations in both Malaysia and Indonesia are aging quickly, such that the average age is now over 20 years, meaning, in effect, the deforestation liability is now zero. In stating this, it is tricky to be definitive, inasmuch as new areas are deforested/planted in palm oil every year, with an estimated average of 33,400 hectares converted annually from 2018 to 2022 in Indonesia[29]. Deforestation in Malaysia is around 6,000 hectares/year (in 2024)[30], down from an average of 64,000 ha/year over 1990-2020. In noting this, deforestation rates in Indonesia (2023, 2024) have recently increased.

Sensitivity Analysis

(i) A sensitivity analysis relative to the land cover type/deforestation liabilities outlined in Table 1 showed:

Table 4: Embedded CO_2 in PKE relative to Landcover type [Malaysia, 4 T PO/ha]

	Undisturbed Upland Forest	**Disturbed (cut-over) Upland Forest***	**Upland Shrubland***	**Undisturbed Swamp Forest**	**Disturbed Swamp Forest**	**Swamp Shrubland**
Deforestation Liability (T CO_2e/ha)	694	382	110	1,806	1,519	506
kg CO_2e/kg PKE DM (Annual amortisation)	0.277	0.265	0.255	0.319	0.309	0.270
kg CO_2e/kg PKE DM (diminishing linear amortisation)	0.371	0.266	0.266	0.774	0.672	0.303

*For both these land uses, there was a net gain in carbon in the "deforestation liability" due to sequestration by the palm oil trees. For simplicity, the net deforestation liability was set to zero.

This shows the relative difference between the two amortisation approaches, particularly the significant (>100%) differences for the peat forests.

(ii) The impact of altering transport differences were:

- If the inland transport figures are doubled, i.e. 100km from plantation to the processing mill/200km from the mill to the wharf the resultant intensity figures are:

Table 5: Increased Inland Transport [4T PO/ha]

	Malaysia	Indonesia
kg COe2/kg PKE DM	0.350	0.342
kg COe2/kg PKE DM excluding forestry	0.27	0.248

This increases the embedded CO_2 by around 3% relative to the base calculation.

- If the shipping distance was increased, for example from Penang Port (northwest Malaysia) to Port Lyttleton, a distance of 10,200km by sea. The impact of this on embedded CO_2 in PKE is:

Table 6: Increased Sea Transport Distance [4t PO/ha]

	Malaysia
kg COe2/kg PKE DM	0.357
kg COe2/kg PKE DM excluding forestry	0.276

This increases the embedded CO_2 by 2.8% relative to the base calculation.

In order to get a more accurate calculation, more precise data would be required on:

- Geographic location of the plantation
- Original land cover
- Age of the trees and average yield
- Distance of the plantation to the processing mill, and mill to wharf
- Modes of transport
- Processing emissions
- Distance of the wharf to New Zealand.

New Zealand Average

Determining an "average" figure for New Zealand is somewhat problematic. Using the Malaysian/Indonesian- based averages (Table 3), and assuming supply to New Zealand is 70% Malaysian and 30% Indonesian, this gives a NZ average of 0.334 kg CO_2e/kg PKE DM.

A more detailed analysis against the original land cover type (aka Table 1) requires a breakdown of land use change over time. A 2013 report[31] gave the following breakdown for land use change into palm oil across Malaysia, Indonesia and Papua New Guinea, from 1990 to 2010, relative to the land covers outlined in Table 1.

Table 7: Proportional Land Use Change relative to Original Land Cover (1990-2010)

	Proportion planted	**Area (ha)**
Undisturbed Upland Forest	0.2%	19,262
Disturbed (cut-over) Upland Forest	25.6%	2,465,536
Upland Shrubland	13.5%	1,300,185
Undisturbed Swamp Forest	4.0%	385,240
Disturbed Swamp Forest	6.8%	654,908
Swamp Shrubland	4.4%	423,764
Agroforest (e.g. rubber plantation)	33.8%	3,255,278
Bare soil/Replant existing PO plantations	8.3%	799,373
Miscellaneous	3.4%	327,454
	100.0%	9,631,000

The report also notes that *in Indonesia, the largest single cause of historical forest loss can be attributed to unsustainable logging followed by the impact of fire, which in combination led to the progressive transition of large areas of forest landscape into agroforest or shrub land.*

Finding data on areas converted, by original land cover, from 2010 onwards was difficult. A 2022 report[32] notes that forest land (without defining "forest") converted to palm oil in Indonesia from 2001 to 2019 made up 29-32% of all the land converted to palm oil, with the remaining ~70% classified as "non-forest". An AI search noted that *the majority of post-2010 land use change in Malaysia came from the conversion of existing agricultural lands, particularly rubber and other tree crops, followed by the clearing of peatlands and upland forests, mostly in Sabah and Sarawak.* Total area converted since 2010 is 850,000 hectares.

If the proportional conversion figures in Table 7 are multiplied by the CO_2 figures in Table 4, then the NZ "average" is 0.195 kg CO_2e/kg PKE DM.

Comparisons

The embedded CO_2e figures shown in Table 3 can be compared with average figures for other supplementary feeds. A 2016 New Zealand[33] paper shows:

Table 8: Embedded CO_2e for a range of feedstuffs

	kg CO_2e/kg DM
Barley grain	0.355
Pasture silage	0.201
Maize silage (contract grown)	0.188
Kale	0.192
Molasses	0.079
Palm Kernel expeller	0.506

The emissions factors used in Overseer[34], including recent updates[36], show

Table 9: Overseer emission factors (kg CO_2e/kg DM)

Hay/Silage	0.201
Maize/cereal silage	1.564
Greenfeeds (e.g. fodder beet/swedes)	0.264
Soya bean meal	5.417
Golden Dried distillers grain	0.423
Barley Straw	0.049
Turnips	0.264
Kale	0.220
Peas	0.550
Vegetables	0.025
Palm Kernel Expeller	0.502

As can be seen from these tables, PKE is higher than many of the common supplements such as hay and silage, and fodder crops, but lower than some other by-product feeds such as soya meal and DDG, and lower than maize/cereal silage.

Conclusion

While deforestation of tropical forests give rise to significant emissions of CO_2, the overall impact on embedded CO_2 within PKE is reasonably small, due in part to the sequestration offset by the palm oil trees, and the relatively minor, circa 2%, liability accruing to PKE.

The main activities resulting in higher embedded CO_2 in PKE comes mainly from transport, and to a lesser extent from processing.

Relative to other supplementary crops it is higher than many other common supplements, but lower than other by-product feedstuffs.

References

1. Raihan A, Begum R, Said M, Pereira, J. 2021. Assessment of Carbon Stock in Forest Biomass and Emission Reduction Potential in Malaysia. https://www.mdpi.com/1999-4907/12/10/1294
2. Agus Sugiarto, Sugeng Utaya, Syamsul Bachri, Rajendra P. Shrestha. 2024. Estimation of carbon stocks and CO_2 emissions resulting from the forest destruction in West Kalimantan, Indonesia. https://www.sciencedirect.com/science/article/pii/S2667010024001768
3. Liz Kimbrough. 2025.Tropical forests in Australia are emitting more carbon than they capture: Study. https://news.mongabay.com/2025/12/tropical-forests-in-australia-are-emitting-more-carbon-than-they-capture-study/
4. Greenmatch. 2025. Is Palm Oil Bad For The Environment? Statistics & Facts. https://www.greenmatch.co.uk/is-palm-oil-harming-the-environment
5. Paniagua-Ramirez, A., Krupinska, O., Jagdeo, V. *et al.* Carbon storage estimation in a secondary tropical forest at CIEE Sustainability Center, Monteverde, Costa Rica. *Sci Rep* **11**, 23464 (2021). https://doi.org/10.1038/s41598-021-03004-5
6. Cooper, H., Evers, S., Aplin, P. *et al.* Greenhouse gas emissions resulting from conversion of peat swamp forest to oil palm plantation. *Nat Commun* **11**, 407 (2020). https://doi.org/10.1038/s41467-020-14298-w
7. Fahmuddin Agus1, Petrus Gunarso, Bambang Heru Sahardjo, Nancy Harris, Meine van Noordwijk, Timothy J. Killeen. 2013. Historical CO_2 Emissions from Land Use and Land Use Change from the Oil Palm Industry in Indonesia, Malaysia and Papua New Guinea. *www.rspo.org*
8. Farmonaut. Maximizing Oil Palm Yields: A Comprehensive Guide to Planting Density, Age, and Acre Productivity. 2025. https://farmonaut.com/precision-farming/maximizing-oil-palm-yields-a-comprehensive-guide-to-planting-density-age-and-acre-productivity
9. Financial Model. 2025. How Can You Maximize Profitability in Your Palm Oil Plantation with These 5 Strategies? https://financialmodel.net/blogs/profitability/palm-oil-plantation-sustainable#:~:text=Yield%20is%20a%20critical%20factor,increase%20in%20palm%20oil%20revenue.
10. C.R. Donough, C. Witt, and T.H. Fairhurst. 2009. Yield Intensification in Oil Palm Plantations through Best Management Practice. https://www.researchgate.net/profile/Christian-Witt-6/publication/237351969_Yield_Intensification_in_Oil_Palm_Plantations_through_Best_Management_Practice/links/5419b0290cf25ebee9887c23/Yield-Intensification-in-Oil-Palm-Plantations-through-Best-Management-Practice.pdf
11. Malaysian Palm Oil Council. 2020. Malaysian Palm Oil Fact Sheets. https://www.mpoc.org.my/wp-content/uploads/2024/01/Malaysian-Palm-Oil-Fact-Sheets-2020.pdf
12. Jing Zhao, Andrew J. Elmore , Janice Ser Huay Lee, Izaya Numata, Xin Zhang, Mark A. Cochrane. 2023. Replanting and yield increase strategies for alleviating the potential decline in palm oil production in Indonesia. https://www.sciencedirect.com/science/article/abs/pii/S0308521X23001191#:~:text=One%20strategy%20for%20slowing%20the,et%20al.%2C%202021).
13. Facebook. Centre for Hybrid Economic Trees. 2025. Oil Palm Yield per Hectare. https://www.facebook.com/centerforhybrideconomictrees/posts/oil-palm-yield-per-hectarethe-yield-of-fresh-fruit-bunches-ffb-and-crude-palm-oi/1047531767394176/

14. MAS Group. 2025. How Many Kg of Palm Kernel Cake From 1 Ton Nuts? [Ultimate 2025 Guide]. https://makmuramanah.co.id/2025/07/22/pkc-yield-per-ton-palm-kernel-nuts/
15. Malaysian Palm Oil Board. 2022. Overview of the Malaysian oil palm industry 2022. https://bepi.mpob.gov.my/images/overview/Overview2022.pdf
16. https://palmoilina.asia/berita-sawit/carbon-sink-in-oil-palm-plantations/
17. Denis J. Murphy. 2024. Carbon Sequestration by Tropical Trees and Crops: A Case Study of Oil Palm. https://www.mdpi.com/2077-0472/14/7/1133
18. Real-world fuel economy of heavy trucks. 2019. https://www.knowledgehub.transport.govt.nz/assets/TKH-Uploads/TKC-2019/Real-world-fuel-economy-of-heavy-trucks.pdf
19. Malaysian Palm Oil Council (MPOC) and Swinburne University of Technology Sarawak Campus, 2024. Review Of Current State, Gaps, and Opportunities for Technologies in the Malaysian Oil Palm Estates and Palm Oil Mills Towards Net Zero Emissions. https://www.mpoc.org.my/wp-content/uploads/2024/11/MPOC-Net-Zero-Emission-Booklet.pdf
20. Hanlei Wang, Xia Li, Mingxing Sun, Yulei Xie, Hui Li. 2025. Life Cycle Carbon Footprint of Indonesian Refined Palm Oil and Its Embodied Emissions in Global Trade. https://www.mdpi.com/2073-445X/14/6/1223
21. Office of Rail and Road. 2025. Rail Environment. https://dataportal.orr.gov.uk/statistics/infrastructure-and-environment/rail-environment/
22. www.cocooncarbon.co.uk
23. Climate Action Accelerator. 2025. Shift from Air to Sea freight. https://climateactionaccelerator.org/solutions/sea_freight/
24. Bulletin of the IDF N°520/2022: The IDF global Carbon Footprint standard for the dairy sector https://doi.org/10.56169/FKRK7166
25. Andre M. Mazzetto, Shelley Falconer, Stewart Ledgard. 2023. Carbon footprint of New Zealand beef and sheep meat exported to different markets. https://www.sciencedirect.com/science/article/pii/S0195925522002128
26. Aurélie Wilfart, Armelle Gac, Yvon Salaün, Joel Aubin, Sandrine Espagnol. 2021. Allocation in the LCA of meat products: is agreement possible? https://www.sciencedirect.com/science/article/pii/S2666789421000209
27. Grand View Research. Palm Oil Market 2026-2035. https://www.grandviewresearch.com/industry-analysis/palm-oil-market
28. Tridge. 2025. Overview of Global Palm Kernel Expeller Market. https://www.tridge.com/intelligences/palm-kernel-expeller#:~:text=Here's%20some%20information%20about%20the%20global%20market,export%20value%2C%200.25%25%20share%20in%20export%20value
29. Trase: Indonesian palm oil exports and deforestation. 2022. https://www.sei.org/features/indonesian-palm-oil-exports-and-deforestation/
30. Satelligence. 2025. Deforestation in the Tropics: Malaysia's Success and Indonesia's Ongoing Journey. https://satelligence.com/deforestation-in-the-tropics-malaysias-success-and-indonesias-ongoing-journey/
31. Gunarso P., Hartoyo H., Agus F., KilleenT. 2013. Oil palm and land use change in Indonesia, Malaysia and Papua New Guinea. http://fire-smart-landscapes.tropenbos.org/resources/publications/oil+palm+and+land+use+change+in+indonesia,+malaysia+and+papua+new+guinea
32. Gaveau DLA, Locatelli B, Salim MA, Husnayaen, Manurung T, Descals A, et al. (2022) Slowing deforestation in Indonesia follows declining oil palm expansion and

lower oil prices. PLoS ONE 17(3): e0266178. https://doi.org/10.1371/journal.pone.0266178

33. Ledgard, S.F., Chobtang, J., Falconer, S.J. and McLaren, S., 2016. Life cycle assessment of dairy production systems in New Zealand In: Integrated nutrient and water management for sustainable farming. (Eds L.D. Currie and R.Singh). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 29. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand
34. Release Notes – for Overseer version 6.3.3. 2020. https://support.overseer.org.nz/hc/en-us/article_attachments/900001769866
35. Release notes – Overseer version 6.5.11. 2025. https://support.overseer.org.nz/hc/en-us/article_attachments/49379177656345