# Wheat Flour Carbon Footprint

June 2021

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Prepared for:

The Foundation for Arable Research (FAR)

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# Purpose

The objective of this report is to provide a comparison between the greenhouse gas (GHG) emissions from Australian grown wheat and New Zealand grown wheat when processed into flour at a New Zealand flour mill.

The findings of this report should not be considered to make any environmental claims and is not directed at the product consumer, e.g., a packaging claim. This report is intended to give a general indication about the emissions produced in the scenarios tested using publicly available resource inputs. Therefore, environmental claims guidance such as ISO 14021 do not apply to the conclusions from this report. The sensitivity analysis (Section 5.0) demonstrates a range of total emissions under various scenarios.

To make the New Zealand emissions more publicly robust this report could be used to support an Environmental Product Declaration. An EPD is an independent framework for businesses to provide objective, science-based environmental data and other information about their products and services. A full description of the Australasian EPD scheme can be found here https://epd-australasia.com/

*Disclosure Statement:*

Greenhouse gas emissions calculated by Agrilink on behalf of the Foundation for Arable Research (FAR) in accordance with Publicly Available Specification 2050 (BSI, 2011), self-declared.

# Executive Summary

## Introduction

This report uses a life cycle assessment (LCA) methodology to determine the carbon footprint, or greenhouse gas (GHG) emissions, for one tonne of New Zealand and Australian grown wheat flour. The system boundary is upstream of the farm to miller. Based on a literature review and further modelling the carbon footprint of the NZ flour was compared to milled flour using Australian grown wheat. This study is an update, and builds upon, a report by the same author conducted in 2011 (Barber et al., 2011). In 2011 farm inputs and yield were based upon a detailed arable grower survey. The update has used the same resource use and yield inventory, with methodology adjustments where these have occurred in the intervening ten years. The main methodology changes were to field emissions from nitrogen fertilisers. This aligns with He Waka Eka Noa.

The report is based on the internationally recognised Publicly Available Specification (PAS) 2050 and ISO standards 14040:2006 and 14044:2006 methodologies.

## Methodology

This report uses Life Cycle Assessment (LCA) methodology to measure resource use and GHG emissions of wheat used to make flour. The system boundaries for this study encompass a ‘cradle to milling gate’ analysis, that is the upstream, farming, transport, and flour milling emissions. The functional unit being analysed is 1 tonne of wheat flour at the mill gate. This represents a partial LCA, as emissions from the manufacture, distribution, end use, and disposal of the final product (e.g., bread) are not analysed in this study.

The resource input and yield information used in this report originates from the original 2011 study (Barber et al., 2011), where data was collected from 10 surveys and follow-up interviews with arable growers. This information has been reviewed by Foundation for Arable Research (FAR) to determine if current inputs or yield data had changed in the intervening 10 years.

The environmental outputs measured were the emission of the three main GHGs $CO_2$, $CH_4$ and $N_2O$, recorded as carbon equivalents or flour’s carbon footprint.

## Results and Discussion

The on-farm emissions for NZ grown wheat is 280 $kgCO_2e/t$ wheat, which is a 12% decrease when compared to the 2011 study. This compares to on farm emissions for Australian grown wheat of 350 $kgCO_2e/t$ wheat, based on a literature review of similar studies.

In NZ transport of wheat from the farm to a mill, varies widely including distance and type - truck, rail, and coastal shipping. The baseline model included trucking wheat 85 km from a farm in Ashburton to a mill in Christchurch. Transport emitted 10 $kgCO_2e/t$ wheat.

Transport emissions for Australian wheat was modelled on a 300 km truck journey from farm to port, a 2800 km ship voyage between Melbourne and Lyttleton, and a 13 km truck journey from Lyttleton to the Christchurch mill. Transport emitted 52 $kgCO_2e/t$ wheat. It was assumed that there was no empty back haulage, so that return journey emissions were attributed to another product.

NZ wheat, with an average moisture of 13.5%, has a milling yield of 1.282 kg NZ wheat/kg flour.  Australian wheat with a lower moisture content of 10%, has a slightly higher yield (2%) of 1.257 kg Aust. wheat/kg flour. This is reflected in slightly lower milling emissions for Australian wheat processed in the same mill. Based on publicly available information the milling process emitted 170 $kgCO_2e/t$ flour (NZ sourced wheat) and 160 $kgCO_2e/t$ flour (Australian wheat).

New Zealand wheat flour, at the mill, has a carbon footprint of 450 $kgCO_2e/t$ flour. Australian grown wheat has a carbon footprint to the same mill gate of 540 $kgCO_2e/t$ flour.

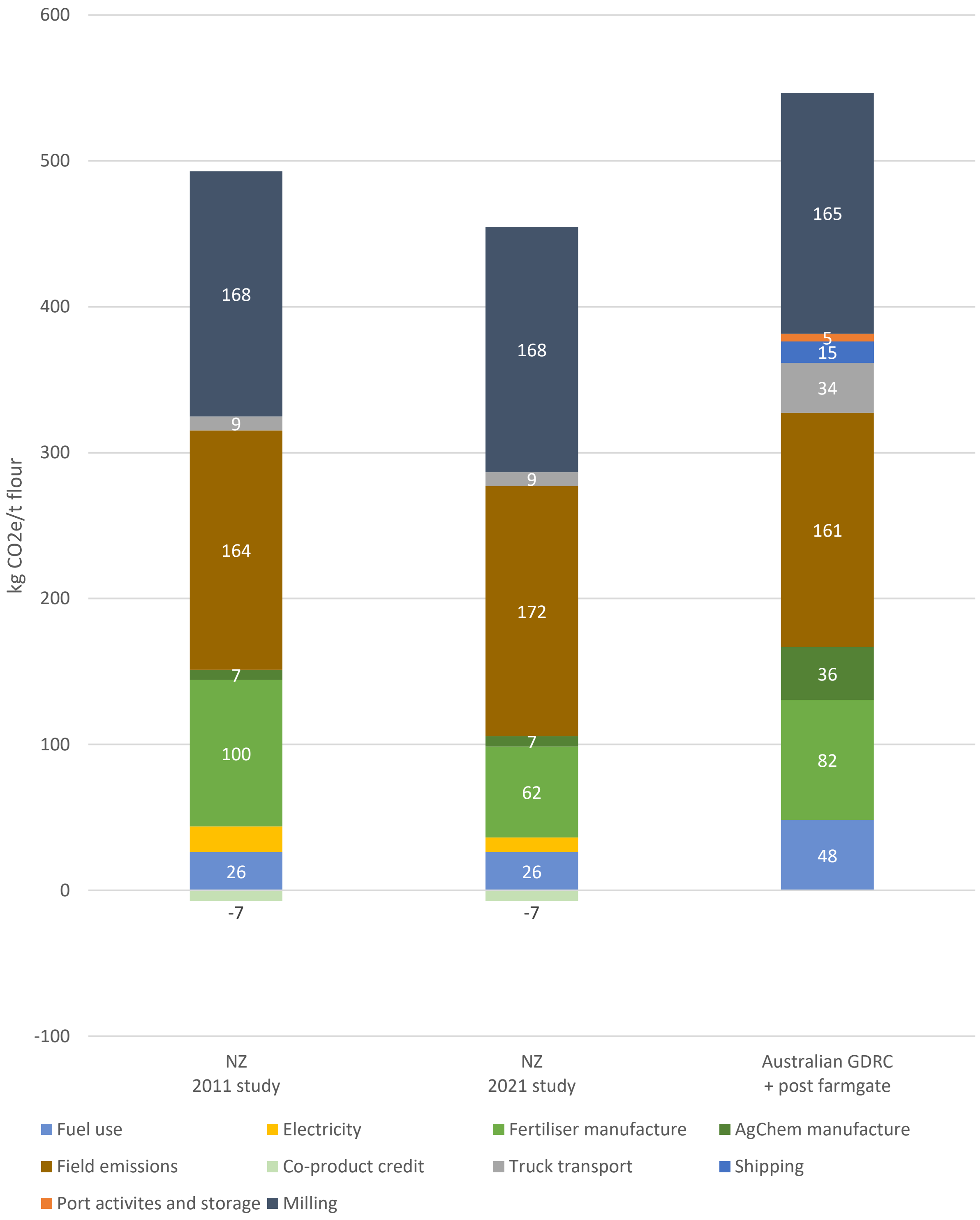


**Figure 1**. Distribution of GHG emission sources from New Zealand and Australian wheat to milled flour.

**Table 1.** GHG emission sources for New Zealand and Australian wheat flour (kg$CO_2$e/t flour).

| **Emission category** | **NZ Original* (2011)** | **NZ Updated (2021)** | **% of total emissions (Updated)** | **Australian (GDRC benchmarking and post-farm emissions)** | **% of total emissions (Australian)** |
|---|---|---|---|---|---|
| *On-farm* | *308* | *270* | *60%* | *327* | *60%* |
| Fuel use | 26 | 26 | 6% | 48 | 9% |
| Electricity | 18 | 10 | 2% | 0 | 0% |
| Agrichemical and fertiliser manufacture | 107 | 69 | 16% | 119 | 22% |
| Field emissions | 164 | 172 | 38% | 161 | 29% |
| Co-product credit | -7 | -7 | -2% | 0 | 0% |
| *Transport* | 9 | 9 | 2% | 49 | 10% |
| Truck | 9 | 9 | 2% | 34 | 6% |
| Shipping | 0 | 0 | 0% | 15 | 3% |
| Storage | 0 | 0 | 0% | 5 | 1% |
| *Milling* | 168 | 168 | 38% | 165 | 30% |
| Co-product credit | -125 | -113 | -25% | -145 | -27% |
| **Total** | **486** | **447** | **-** | **547** | **-** |

*With the addition of post-farm activities and milling co-product allocations

# Contents

# 1.0 Introduction

This report builds on a pilot study conducted in 2011 which had the aim of establishing a partial Life Cycle Assessment (LCA) for 1 tonne of wheat, maize silage, maize grain, and ryegrass seed. The 2011 study was a ‘Cradle to Farm Gate’ analysis which included emissions from on-farm and upstream processes, therefore forming a partial LCA. The report used the UK’s Publicly Available Specification (PAS) 2050, for GHG emission measurement of goods and services (BSI, 2008); GHG Protocol Product and Supply Chain Initiative (World Resource Institute); ISO 14040 and 14044 protocols.

It was determined that this pilot report needed an update to reflect changes in farm production inputs, productivity, and methodology. This study was expanded to include transport from farm to mill, and milling. A comparison is made between NZ and Australian grown wheat to flour.

This study uses the functional unit 1 tonne of wheat flour at the mill using both NZ and Australian grown wheat.

## 1.1 Methodology

This report uses an LCA methodology to measure resource use and GHG emissions from 1 tonne of wheat flour at the mill. This study follows the methodology described in the PAS 2050 (BSI, 2011), and has also been informed by aspects of the ISO standards (14040 series) and methodology developed in the previous 2011 report.

## 1.2 Scope

The functional unit is 1 tonne of wheat flour at the mill.

The system boundary for this analysis is shown in Figure 2, and extends from extraction of raw materials, through farm operations, transport to mill, and processing to wheat flour. It is necessary to clearly define the system boundary in order to prevent relevant inputs and activities from being excluded from the analysis, and for the final emissions figure to be accurate and transparent when reported.

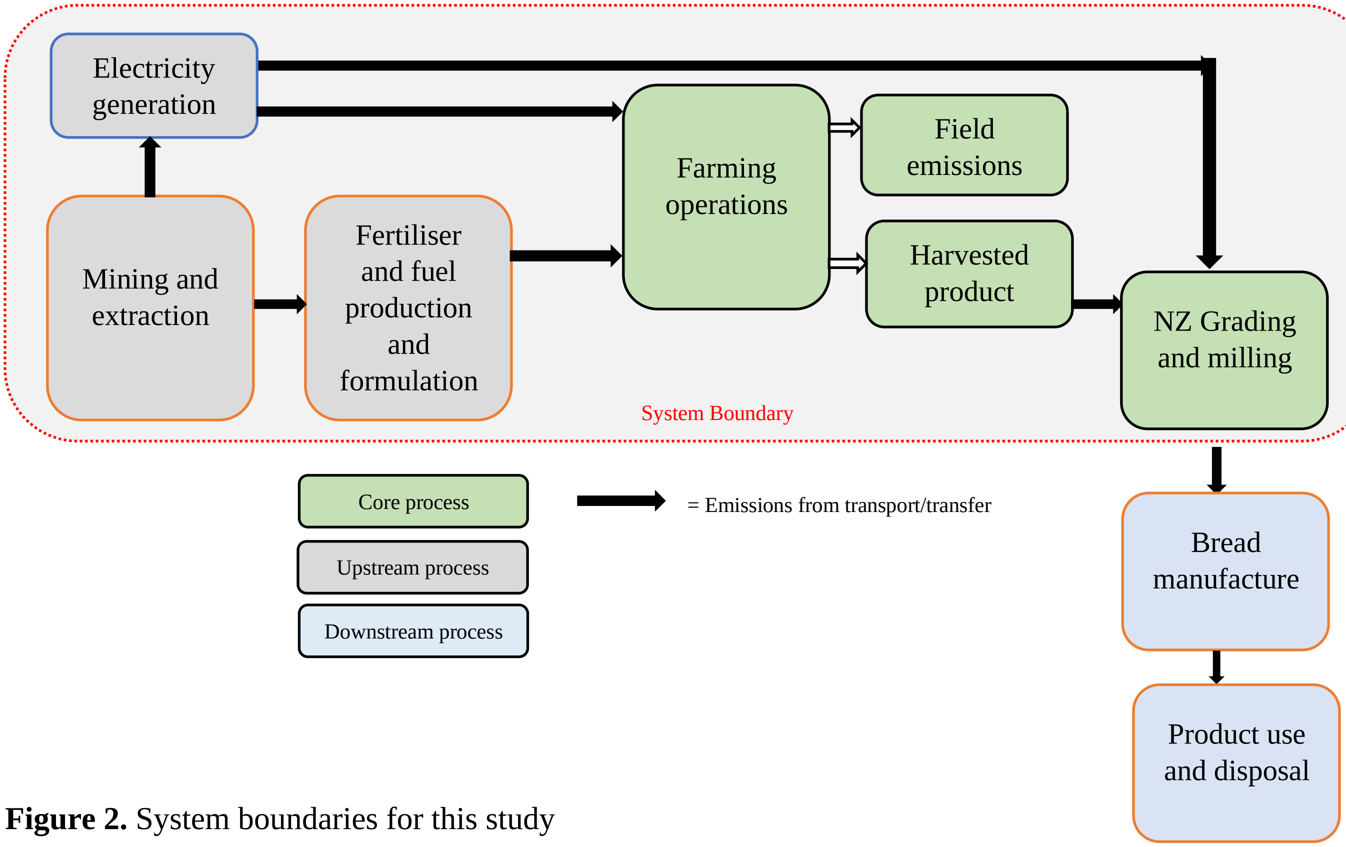


**Figure 2.** System boundaries for this study

**Definitions:**

Functional unit – The unit of analysis. The quantity of a product or service.

Farm gate – The farm gate captures all on farm activities and inputs up to the point where the harvested product leaves the property (farm gate).

Processing mill – All the inputs at a mill where wheat is processed into flour.

# 2.0 Literature Review

## 2.1 Australian on-farm emissions for wheat production

GHG emissions from wheat production in Australia have been well documented, and there are several publicly available studies that can be used for comparisons to the emissions from New Zealand grown wheat documented in this study.

The emissions from pre-farm and on-farm activities to the farm gate to produce 1 tonne of wheat ranged from 150 kg$CO_2$e/t (750 kg$CO_2$e/ha) to 487 kg$CO_2$e/t (1,705 kg$CO_2$e/ha at 3.5 t/ha grain yield). The large range across the four studies reviewed is drive by, the studies system boundary, emission factors, management practices, and grain yield. These studies encompassed all three of the wheat growing regions of Australia (Grains Research & Development Corporation), so they can be considered to represent a cross section of the Australian wheat industry.

Brock et al (2012) analysed GHG emissions from the Central Zone of New South Wales including pre-farm and on-farm activities. Based on a 3.5 t/ha grain yield, the study found total emissions from wheat to the farm gate of 200 kg$CO_2$e/t of wheat grain. Emissions fell to 150 kg$CO_2$e/t of wheat grain when grain yield increased to 5.0 t/ha. The study found the bulk of emissions from wheat production came from production and transport of fertiliser and lime (37%), and from nitrous oxide ($N_2O$) emitted from nitrogenous fertiliser application (26%). Carbon dioxide emissions from fertiliser and lime application made up a further 15%, whilst diesel production, transport and use accounted for 16% of emissions. The remaining 6% of emissions came from all other activities.

A later study by the same author (Brock et al., 2016) analysed GHG emissions from South Eastern Australia, with an emphasis on comparing emissions from a 2-year monoculture wheat crop to break crop sequences. This study found emissions from a 2-year monoculture wheat production system totalled 255 kg$CO_2$e/t of grain to the farm gate, based on a grain yield of 3.0 t/ha. The introduction of break crops to the production system lowered emissions to 199 kg$CO_2$e/t when wheat was grown following canola, and to 172 kg$CO_2$e/t when following field peas.

Another study analysed the GHG emissions of wheat production in Western Australia (Biswas et al., 2008), and included analysis of post-farm gate emissions. This study used measured field emissions. They found total emissions for 1 tonne of Western Australian wheat grain transported to a South-Western Australian port to be 304 kg$CO_2$e/t. When Intragovernmental Panel on Climate Change (IPCC) defaults for nitrous oxide field emissions were used emissions rose to 487 kg$CO_2$e/t (60% increase). This study found contributions to emissions were highest from fertiliser production (35%), followed by on-farm $CO_2$ emissions (27%). Unlike Brock et al (2012), this study found $N_2O$ emissions contributed only 9% to total emissions, likely due to the region-specific emission factor used.

A research bulletin from the Western Australian Department of Agriculture and Food (Fairbanks et al., 2012) estimated emissions from wheat production of 231 kg$CO_2$e/ha, based on a grain yield of 1.8 t/ha (consistent with the generally low yields from Western Australian wheat) using the Grains Greenhouse Accounting Framework and Farm Fuel Calculator. Different tillage practices were modelled and found to make a reasonably large difference to emissions from fuel use, with the lowest emissions coming from zero tillage (30 kg$CO_2$/ha) and the highest coming from the use of a cultivator (84 kg$CO_2$/ha).

The Australian Grains Research & Development Corporation (GRDC) funded a study (National Grains Lifecycle Assessment Project, 2017) by the New South Wales Department of Primary Industries, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Lifecycles Pty Ltd to benchmark the environmental impacts of key grain crops throughout Australia, including GHG emissions. This study analysed emissions from wheat production across 14 Australian regions, accounting for emissions from fertiliser and agrichemical production and use, and emissions from field operations including fuel use. As this study accounted for wheat grain production emissions from across Australia, it was decided to use the average emissions from this study as the baseline Australian benchmark emissions for comparison with New Zealand wheat.

**Table 2.** Summary of literature review on Australian grown wheat emissions.

| **Emissions category** | **GHG emissions (kgCO$_2$e/t wheat)** | | | | | |
|---|---|---|---|---|---|---|
| | **Brock et al., 2012** | **Brock et al., 2016** | **Biswas, 2008** | **Fairbanks, 2012** | **National Grains Life Cycle Assessment Project, 2017** | |
| | | | | | **Average***** | **Range** |
| Yield (t/ha) | 3.5 | 3.0 | 2.7 | 1.8 | 2.0 | 1.0 – 5.1 |
| Fuel & electricity | 33 | 32 | 26 | 63 | 51 | 15 – 196 |
| Fertiliser & agrichemical manufacture | 76 | 74 | 135 | - | 126 | 80 - 197 |
| Field emissions (incl. background soil N$_2$O emissions in Brock et al., 2016) | 82 | 90 - 111 | 108 | 352 | 170 | 68 - 272 |
| Other (incl. capital) | 9 | 3.5 | 1 | - | - | - |
| Co-product credit | - | - | - | - | - | - |
| Post-farm | **-** | **-** | 34 | **-** | **-** | **-** |
| **Total** | **200** | **172 - 225** | **304* (487**)** | **415** | **347** | **193 - 504** |

* Region specific measured field emissions

** IPCC default field emissions

*** Weighted average by volume of production from Australian state, divided by number of sub-regions

## 2.2 Wheat flour (milling) production

Building on the previous 2011 report, this study includes the emissions from the milling of wheat grain to flour at a common processing point in New Zealand. In order to accomplish this, literature from international studies were reviewed to find a range of estimated milling GHG emissions.

European Flour Millers consider the flour milling process to account for only 20% of the emissions from bread production, with wheat production and the baking into bread accounting for the bulk of the remaining 80%.

A comprehensive study on plain flour manufactured in Singapore estimated the carbon footprint of one ton of plain flour and the contributors to GHG emissions (Shi et al., 2011). The study used the same PAS 2050, ISO 14040, and ISO 14044 to estimate GHG emissions as used in this analysis, and so can be considered a good benchmark for flour milling emissions. The functional unit defined in this study is one ton (the term “ton” is used in this paper, but appears to mean metric tonne, rather than a US or Imperial ton) of plain flour delivered to a customer in bulk container. The system boundaries for this study encompass both the wheat production and flour milling stages. The emissions from wheat production in Australia and the USA (the primary wheat grain exporter to Singapore) used in this study were 304 kg$CO_2$e/t and 283 kg$CO_2$e/t respectively.

The flour milling process was split by the authors into three sub-processes: preparation, production, and finishing. The first stage covers unloading, transport, and cleaning of the wheat grain. The authors estimated product wastage at this step at less than 0.5%, and this level of wastage was consistent across the other two stages. This stage accounted for approximately 10.2% (hard wheat) to 11.9% (soft wheat) of the GHG emissions from wheat milling. The second stage, the production section, involves milling and mixing of the cleaned wheat and addition of additives (>1% wet weight) – which also produces co-products. The authors estimated that hard wheat generates approximately 25% pollard during this process, while soft wheat generates 26% bran. This stage accounts for 82.6% (soft wheat) and 85.1% (hard wheat) of emissions from milling. The final stage, storage in silos and bulk filling bulk bank trucks for delivery, accounts for 4.7% (hard wheat) and 5.5% (soft wheat) of milling emissions.

Overall, the authors of this study estimated that milling wheat grain into flour accounts for approximately 30% of total emissions from wheat production to milling, with wheat production accounting for around 60% of emissions. The total emissions were estimated at 495 kg$CO_2$e/t hard wheat flour and 468 kg$CO_2$e/t soft wheat flour.

Therefore, milling accounted for 184 kg$CO_2$e/t hard wheat flour (used in bread making) and 157 kg$CO_2$e/t soft wheat flour, with delivery to the customer (business to business) contributing 0.42 kg$CO_2$e/t for both hard and soft wheat.

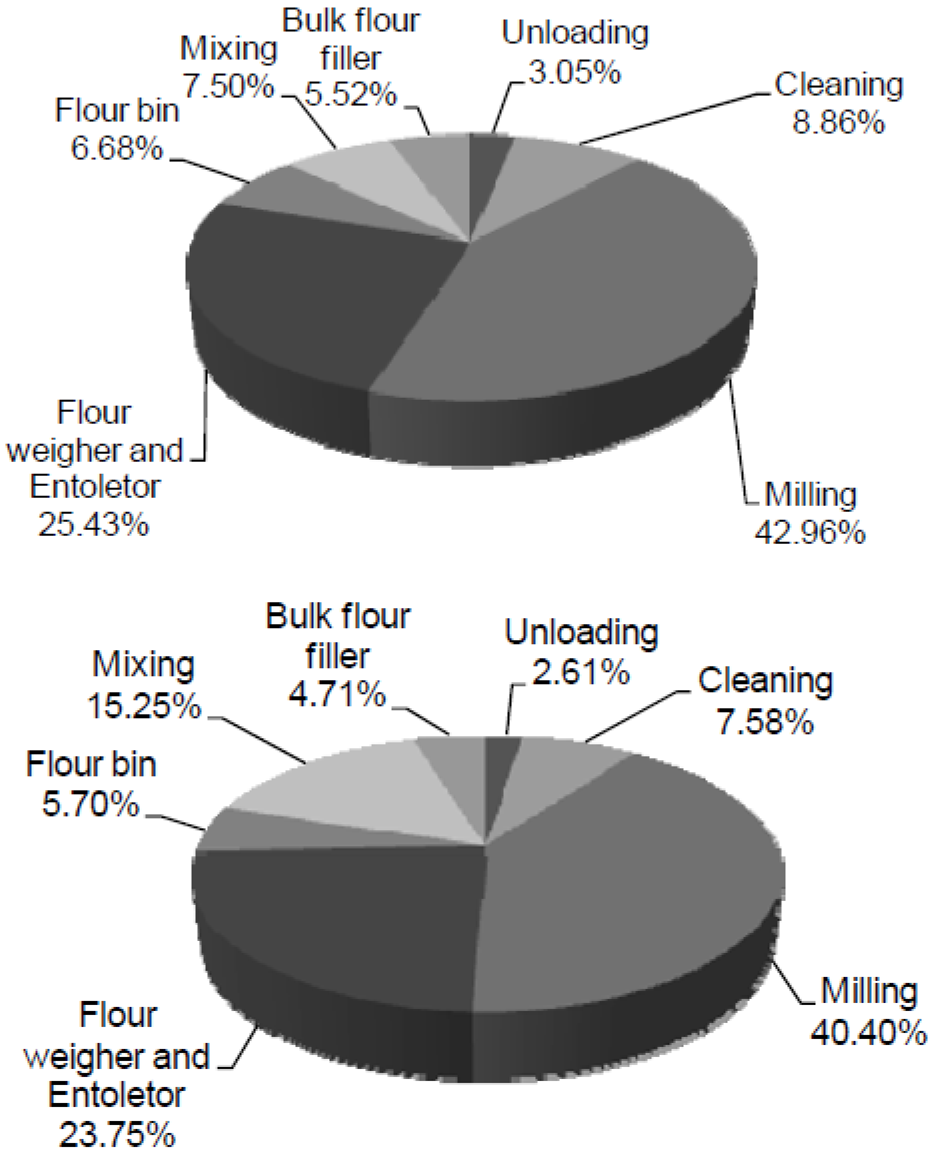


**Figure 3.** Emissions from flour milling for soft wheat (top) and hard wheat (bottom) (Shi et al., 2011).

## 3.0 System inputs and data sources

The original study conducted in 2011 did not distinguish between different wheat varieties or by end uses, therefore the results may incorporate wheat destined for use in stock food which may have lowered the quantity of certain inputs with respect to wheat destined for milling. As in 2011, inputs are reported as averages across the surveyed cohort and by the minimum and maximum emitting operation. The maximum and minimum emitter will not in all cases have the highest inputs for every input type.

More detailed commentary on methodological issues, allocation, data sources, data variability, and recommendations for the 2011 study can be found in the main report (Arable GHG LCA Main Report 2011 – here).

The surveyed farms from the 2011 study are described in Tables 3 and 4.

**Table 3.** Supply chain inputs analysed in this study.

| Supply chain stage | Process stage | Material and energy inputs analysed |
|---|---|---|
| Farm | Fuel & electricity use | Diesel, petrol, lubricants, contractor activity, electricity incl. irrigation. |
| | Fertiliser & agrichemical manufacture | Fertiliser by nutrient, agrichemicals by activity group and manufacturing country. |
| | Field emissions | $CO_2$ from lime, nitrous oxide from nitrogenous fertiliser (split by urea/non-urea and presence of urease inhibitors), nitrous oxide from compost and crop residues, methane and nitrous oxide emitted from field burning. |
| | Co-product credit | Quantity of straw co-product produced and taken off. |
| Transport | Truck transport to port (incl. port activity) and/or mill | Diesel consumed. |
| | Shipping | IFO 380 consumed. |
| Processing to wheat | Mill | Shi et al., 2011 |

**Table 4.** Area and crop production of surveyed farms and updated productivity.

| Number of growers | Total area (ha) | 2011 productivity (t/ha) | | | 2021 productivity (t/ha) * |
|---|---|---|---|---|---|
| | | Average | Minimum emitter (2011) | Maximum emitter (2011) | |
| 8 | 840 | 8.8 | 10.0 | 5.4 | 8.8 |

*Average of reported milling wheat yields for the years 2012-2021, (New Zealand Survey of Cereal Areas and Volumes, April 2021)

## 3.1 Farm fuel and electricity use

The changes since 2011, including system inputs, emission factors, and methodology are described in the sections below.

The fuel use data from 2011 came from grower surveys where the grower provided annual fuel use data in litres or dollars, covering a range of company activities and crops. Many of the growers could not accurately disaggregate fuel use by crop type, which created issues with allocation of emissions from fuel use. This same issue was present when determining electricity use for irrigation. Furthermore, contractor fuel use had to be estimated based on the activity type, time taken, and area covered. However, this is still considered a good estimate when viewing the farm as a whole system of rotating crops.

Diesel, petrol, oil, and electricity use includes all fuel purchased by the grower and their agricultural contractors (Table 5). This study uses the same quantities as the original 2011 study, as this remains the most robust energy use data.

**Table 5.** Wheat growing operation fuel and electricity use (per ha), 2011 and 2021.

| Study year | Category | Units | Survey average | Minimum emitter | Maximum emitter |
|---|---|---|---|---|---|
| 2011 and 2021 | Field operations (diesel equivalent) | L/ha | 77 | 82 | 75 |
| 2011 and 2021 | Electricity | kWh/ha | 830 | 45 | 3,865 |

**Table 6.** Fuel and electricity primary energy and GHG emissions

| **Category** | **Units** | **GHG (kgCO$_2$e/unit)** |
|---|---|---|
| Diesel | Litre | 3.13 |
| Petrol | Litre | 2.74 |
| Electricity (2009)* | kWh | 0.19 |
| Electricity (2018)* | kWh | 0.11 |

* These are the most recent years available for each study.

## 3.2 Fertiliser production and use

Most growers use a combination of synthetic and mineral fertilisers and lime. The main nutrient elements are nitrogen (N), phosphorus (P), potassium (K), sulphur (S), and magnesium (Mg). Lime is applied to the soil for calcium and pH control, however not all growers apply it before planting each crop.

In the 2011 grower surveys urea was found to be the dominant form of nitrogen used, accounting for 96% of the nitrogen applied to wheat. In 2011 a universal energy and emission factor was applied to all nitrogen fertilisers. In 2021 the emission factors for nitrogen have been updated and split between urea and non-urea sources. No wheat growers used any form of compost on their crops. This study uses the same quantities as the original 2011 study, as this remains the most robust fertiliser use data.

**Table 7.** Energy requirements and GHG emissions to manufacture fertiliser components.

| Fertiliser component | GHG ($kgCO_2e/kg$) | |
|---|---|---|
| | 2011 | 2021 |
| N (Urea) | 4.01 [a] | 2.10 [c] |
| N (non – urea) | | 3.38 [b] |
| P [a] | 3.18 | 3.18 |
| K [a] | 0.74 | 0.74 |
| S [b] | 0.32 | 0.32 |
| Mg [b] | 0.32 | 0.02 |
| Limestone | 0.041 | 0.036 |

[a] Ledgard and Boyes (2008)
[b] Wells (2001)
[c] Ledgard and Falconer (2019)

**Table 8.** Quantity of nutrients applied to wheat (per ha)

| Fertiliser | 2011 and 2021 (kg/ha) | | |
|---|---|---|---|
| | Average | Min emitter | Max emitter |
| Nitrogen | 192 | 100 | 240 |
| Phosphorous | 30 | 14 | 0 |
| Potassium | 26 | 45 | 0 |
| Sulphur | 46 | 1 | 0 |
| Magnesium | 8 | 0 | 0 |
| Lime | 432 | 15 | 385 |

## 3.3 Agrichemical production and use

The 2011 study used grower spray diaries to determine the plant protection programme.

For each agrichemical in the 2011 study the manufacturing energy, associated emissions, chemical formulation, packaging, and transport emissions were determined from the literature. Where this was not available the average for the chemical type was used (Green, 1987). This study uses the same quantities as the original 2011 study, as this remains the most robust agrichemical use data.

**Table 9.** Quantity of agrichemicals applied to wheat (per ha)

| **Category** | **2011 and 2021 (l/ha)** | | |
|---|---|---|---|
| | **Average** | **Min emitter** | **Max emitter** |
| Herbicide | 3.7 | 3.0 | 2.2 |
| Fungicide | 5.6 | 25.7 | 2.3 |
| Insecticide | 0.5 | 0.0 | 0.0 |
| Plant Growth Regulators | 0.6 | 0.0 | 0.0 |

## 3.4 Seed production

Seed production was not determined in the 2011 study and has only been used in one other study (Brock et al., 2016) at 6 kg$CO_2$e/t wheat, which represented 2.6% of their study's total wheat emissions. As other comparative studies have not included seed production it has not been included in this study, although at 6 kg$CO_2$e/t wheat it would also add approximately 2% to on-farm wheat emissions. Seeding rates average 100 kg/ha, at a wheat emissions rate of 300 kg$CO_2$e/t (on-farm emissions plus an allowance for some postharvest transport and processing) seed production would add 30 kg$CO_2$e/ha or 3 kg$CO_2$e/t wheat, or 1% of total emissions, and therefore not a material addition to the emissions profile of wheat production.

## 3.5 Machinery production and maintenance

GHG emissions associated with farm capital (equipment, buildings etc.) manufacture and maintenance are excluded from the PAS 2050. However, as these items are included in ISO 14044 and maybe included in future revisions of PAS 2050, an assessment of farm capital was included in the 2011 analysis.

New Zealand specific data on total energy use during arable production, including farm capital manufacture and maintenance was collected previously (Barber, 2004). This was updated in 2011 using more recent energy and GHG emission factors.

Allocating the 2011 emissions over the working life of the capital results in 125 kg$CO_2$/ha/yr. Based on a farms' yield, this per hectare emission factor can be converted into GHG emissions per tonne of production. For the surveyed wheat operations this equates to 14.2 kg$CO_2$/t, making up 5% of total on-farm GHG emissions.

These capital emissions are not included in the final results.

## 3.6 Straw and residues

In the 2011 study it was found that 5% of emissions should be allocated to straw, resulting in GHG emissions of 34 kg$CO_2$e/t hay harvested. These factors were then applied to the wheat grain from each farm that produced these co-products.

## 3.7 Changes in soil carbon and Land Use Change (LUC)

Soil carbon has historically been difficult to estimate and represent in an LCA. There is considerable uncertainty as to how to accurately account for changes in soil carbon, and it is not included in PAS 2050. Therefore, emissions or uptake of GHGs from changes in soil carbon were not considered in the 2011 analysis and have not been included in this update.

PAS 2050 (Section 5.5) requires the inclusion of all direct LUC occurring on or after 1 January 1990. 5% of the of the potential emissions arising from the LUC shall be included in the GHG emissions of these products in each year over the 20 years following the change in land use. Where land use has not changed then PAS (and the New Zealand GHG Inventory) assume that soil carbon levels remain the same.

From 1990 to 2020, the area of wheat production recorded by Statistics New Zealand has oscillated between 40,000 and 55,000 hectares, which suggests that most of the current wheat crop has been in arable production for greater than 20 years, therefore it was assumed that there were no significant changes in soil carbon from land use change (LUC). This was also the case in the 2011 study which also did not attribute any GHG emissions to LUC.

## 3.8 Field emissions

Application of nitrogen to soil produces $N_2O$, alongside indirect emissions from leaching. Synthetic nitrogen fertiliser, organic nitrogen (e.g., compost) and nitrogen in above ground crop residues all contribute to $N_2O$ emissions.

Since 2011 the methodology for calculating field emissions has been updated. Table 10 contains the updated emission factors. This new methodology is dependent on the form of nitrogen fertiliser (urea – with and without inhibitor, and non-urea).

**Table 10.** Relevant factors for use in evaluating nitrous oxide emissions from soil

| Category | Description | Default value (2011) | Default value (2021) |
|---|---|---|---|
| $GWP_{N2O}$ | Global warming potential of nitrous oxide (IPCC Fourth Assessment Report, 2007) | 298 | 265 |
| $EF_1$ | Emission factor for direct emissions from N input to soil | 0.01 | 0.01 |
| $EF_4$ | Emission factor for indirect emissions from volatising nitrogen | 0.01 | 0.01 |
| $EF_5$ | Emission factor for indirect emissions from leaching nitrogen | 0.0075 | 0.0075 |
| $Frac_{GASF}$ | Fraction of synthetic N fertiliser emitted as $NO_x$ or $NH_3$ | 0.1 | 0.1 |
| $Frac_{LEACH}$ | N input to soil that is lost through leaching and run-off | 0.07 | 0.07 |
| Non-urea nitrogen fertiliser | Emission factor (tonnes $CO_2$e/tonne fertiliser applied) | - | 5.40 |
| Urea nitrogen fertiliser not coated with urease inhibitor | Emission factor (tonnes $CO_2$e/tonne fertiliser applied) | - | 5.07 |
| Urea nitrogen fertiliser coated with urease inhibitor | Emission factor (tonnes $CO_2$e/tonne fertiliser applied) | - | 4.86 |

In 2011 and in this review the quantity of crop residue left after harvesting wheat was calculated based on the crop yield, less any residue burned or removed as the co-product wheat straw. This was based on the methodology described in the New Zealand GHG Inventory (MfE, 2009 and 2020). The quantity of nitrogen in the wheat and maize grain crop residue was calculated based on the factors used in the New Zealand GHG Inventory (MfE, 2009 and 2020). The following equation was then used to determine the quantity of $N_2O$ emissions converted into $CO_2e$ values.

Direct soil emissions = kgN in crop residue × $EF_1$ × 44/28 × $GWP_{N2O}$

In addition to mining, transport and manufacturing GHG emissions, when limestone (calcium carbonate $CaCO_3$) or dolomite (calcium magnesium carbonate $CaMg(CO_3)_2$) is applied to the soil $CO_2$ is released over time. This rate based on the IPCC guidelines, and assuming 90% purity, equals 0.396 $kgCO_2$/kg limestone and 0.429 $kgCO_2$/kg dolomite.

Another source of field emissions arises from farmers burning their wheat crop residues, some of which was picked up in the 2011 grower surveys. The burning of crop residues is not a net source of $CO_2$ because the carbon released to the atmosphere during burning is reabsorbed by the crop the following season. However, the burning process also releases $CH_4$ and $N_2O$, which needs to be accounted for.

The emissions from burning crop residues are estimated using the equations below, and factors described in the revised 1996 IPCC guidelines.

Carbon released = annual production (t) × ratio of residue to crop production × average dry matter fraction of residue × fraction oxidised × carbon fraction

$CH_4$ emissions = carbon released × emissions ratio × 16/12

$N_2O$ emissions = carbon released × N/C ratio × emissions ratio × 44/28

Based on the factors used in the New Zealand GHG Inventory (MfE, 2009) in the 2011 study wheat had a residue to crop ratio of 1.3 and a dry matter fraction of 0.83. 90% of the residue is oxidised and the carbon fraction of the residue is 0.49. For the $N_2O$ emissions the nitrogen to carbon ration (N/C ratio) is 0.01. These factors have been updated from the most recent New Zealand GHG Inventory (MfE, 2020), with an updated residue to crop ratio of 1.44 and a dry matter fraction of 0.86 for wheat.

Converted into $CO_2e$ values, when a wheat crop’s residues are burned in the field it releases 106 $kgCO_2e$/t wheat produced. In 2011 this figure was 97 $kgCO_2e$/t wheat produced.

The proportion of the wheat crop burned remained the same as the original 2011 study.

## 3.9 Transport to mill

Transport emissions from the farm gate to the mill were analysed for both New Zealand and Australian wheat growing operations.

Transport emission factors are assumed to be combustion emissions, unless the source stated that they were life-cycle emissions that considered upstream fugitive emissions. Therefore, a conversion factor from combustion to life-cycle emissions was applied. This was calculated based on dividing a fuel's life-cycle emissions by its combustion emissions. The respective emission factors were taken from Table 2 in New Zealand fuel and electricity total primary energy and life cycle greenhouse gas emission factors 2021 (Barber and Stenning, 2021). For example, intermediate fuel oil used in shipping has a conversion factor of 1.162, calculated as the LCA emission factor of 3,520 $gCO_2e/L$ divided by its combustion emission factor of 3,030 $gCO_2e/L$.

Emissions for transporting wheat to the mill in New Zealand are based on fuel use from trucks and shipping. The average emissions for a >32 t truck is 0.116 $kgCO_2e$/t-km (Mithraratne et al., 2010). Large bulk carrying ships have an emission factor of 0.0056 $kgCO_2e$/t-km. This has been calculated using the International Maritime Organisation (2020) figure of 8.9 gCO2e/t.nm (Table 61 – Option 2). Therefore 8.9 / 1.852 (km/nm) = 4.8 $gCO_2e$/t-km. As the IMO figures are combustion emissions, they need to be converted to LCA emissions. International Fuel Oil (IFO 380) has a combustion emission factor of 3,030 $gCO_2e/L$ and LCA emission factor of 3,520 $gCO_2e/L$ (Barber and Stenning, 2021), therefore a conversion factor of 1.162. This was applied to the combustion emissions, 4.8 x 1.162 / 1000 = 0.0056 $kgCO_2e$/t-km. The results are shown in Table 12 for a range of transport types.

Emissions from Australian wheat grain transport to New Zealand for processing can be broken into three sub-processes:

- Transport from farm to port in Australia
- Transport to New Zealand by ship
- Transport to processing mill in New Zealand

Each stage needs to be accounted for to get a complete picture of total emissions from Australian grown wheat processed in New Zealand. Emissions from transfer of product at each port and at the mill also need to be included. Table 11 and Table 12 show distance assumptions and GHG emission factors by input. Emission factors were sourced from the Ministry for the Environment and the International Maritime Organisation. A search of New Zealand port shipping schedules showed an average deadweight tonnage (dwt) of bulk carriers transporting grain of approximately 39,000 dwt. Therefore, it was decided to use the emission factor for 35,000 – 60,000 dwt bulk carriers.

Backhauling has not been accounted for, it has been assumed that ships returning to the export port or sailing onto other ports following grain delivery will have the emissions from that voyage attributed to the next cargo.

**Table 11.** Distance between farm gate and wheat flour mill.

| Stage | Distance (km) |
|---|---|
| New Zealand farm gate to Christchurch mill | 85 |
| Australian farm gate to Melbourne port | 300 |
| Shipping from Melbourne to Lyttleton | 2,811 |
| Lyttleton to Christchurch mill | 13 |

**Table 12.** Emission and usage factors for each transport stage

| Stage | Greenhouse gas emissions ($kgCO_2e/t\text{-}km$) | Convert from combustion to LCA emissions | LCA GHG emissions ($kgCO_2e/t\text{-}km$) |
|---|---|---|---|
| Trucking (> 32 t) | 0.116 | 1.000 | 0.116 |
| Shipping (Bulk carrier 10,000 – 35,000 dwt) | 0.0064 | 1.162 | 0.0075 |
| Shipping (Bulk carrier 35,000 – 60,000 dwt) | 0.0048 | 1.162 | 0.0056 |
| Rail (freight) | 0.081 | 1.170 | 0.0948 |
| Ferry | 0.050 | 1.162 | 0.0581 |

## 3.10 Wheat flour production (milling)

Hard wheat is the benchmark for this analysis, as it is more commonly used to make bread and all-purpose flour. Primary data for the resource inputs for this stage were not available so a literature review was conducted (Section 2.2).

Milling of wheat into flour produces co-products alongside the plain flour, these being bran, pollard, and stock food. As these co-products end up in other end-products in a different supply chain, an emissions allocation needs to be applied. According to Shi et al., (2012), 25% of the total wheat milled becomes co-product at the milling stage.

Using mass allocation, 75% of emissions up to the wheat milling stage were allocated to wheat.

# 4.0 GHG Life Cycle Impact Assessment

The results in this section represent the average GHG emissions per functional unit for the original 2011 resource use inventory (up to farm gate), the updated New Zealand farm analysis, transport to the mill gate, and for wheat grown on Australian farms to the New Zealand mill.

## 4.1 Wheat grain production

Figures 4 and 5 compare emissions from wheat growing in NZ and Australia.

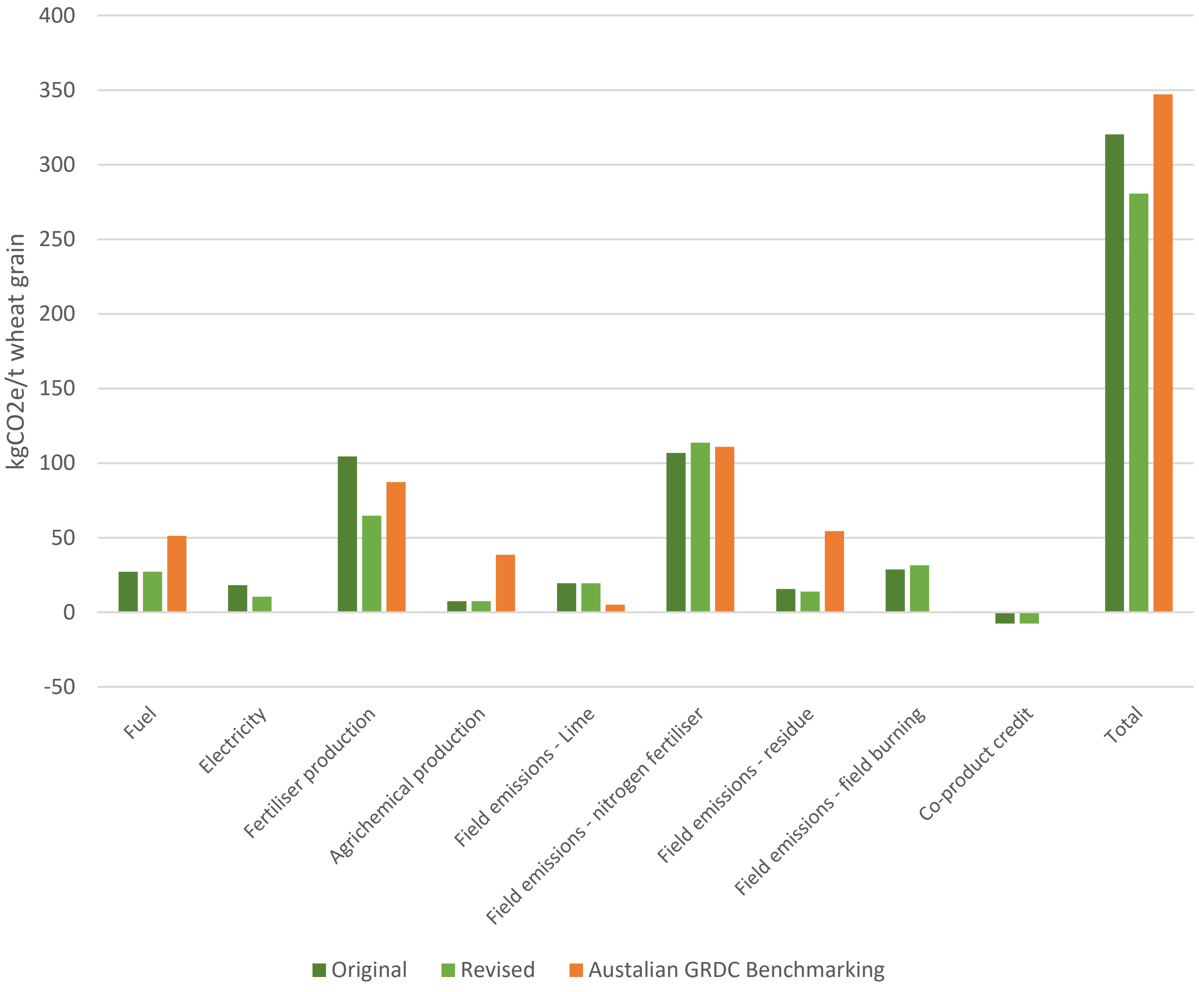


**Figure 4.** GHG emissions from wheat grain production in NZ and Australia (per t wheat grain)

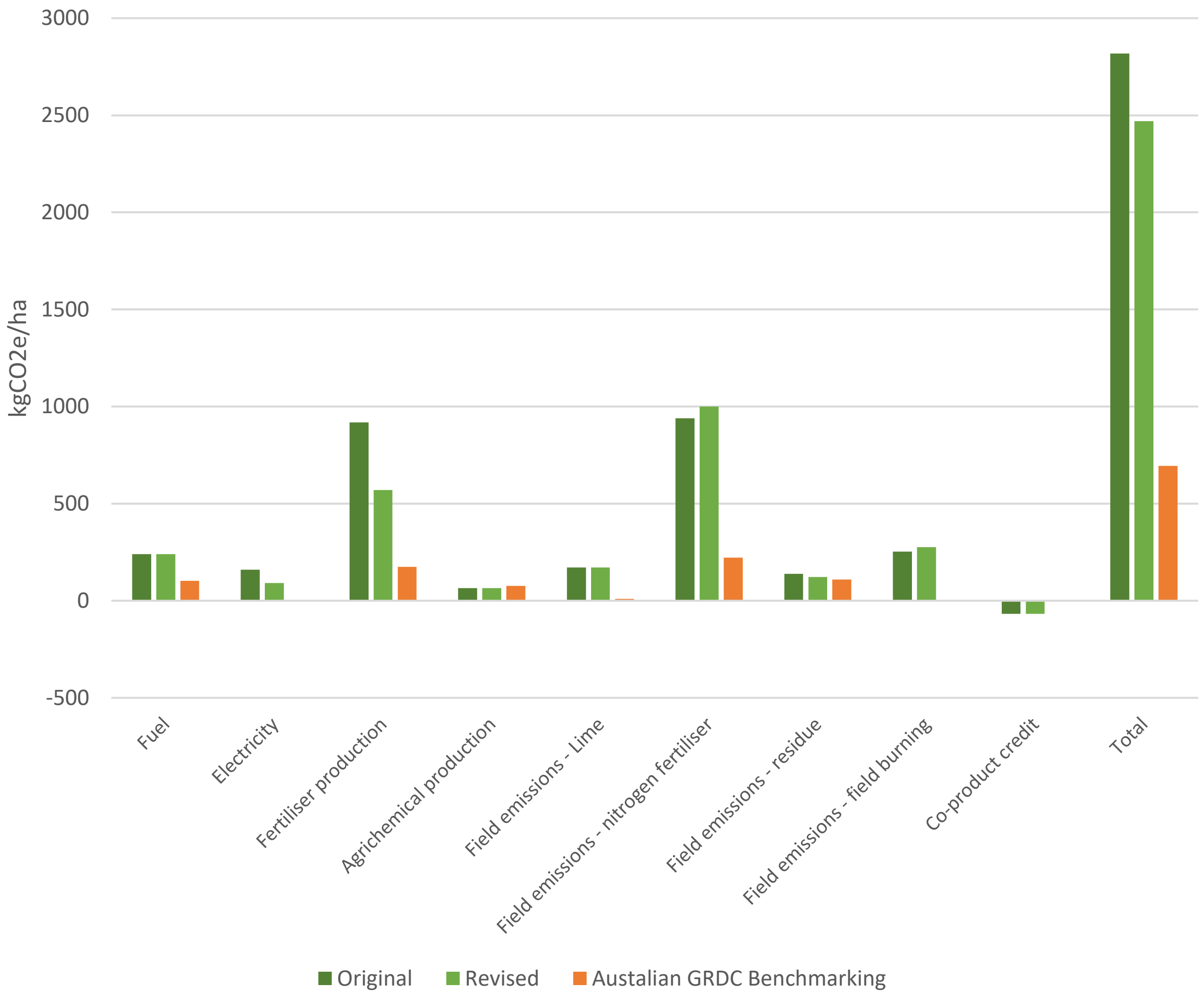
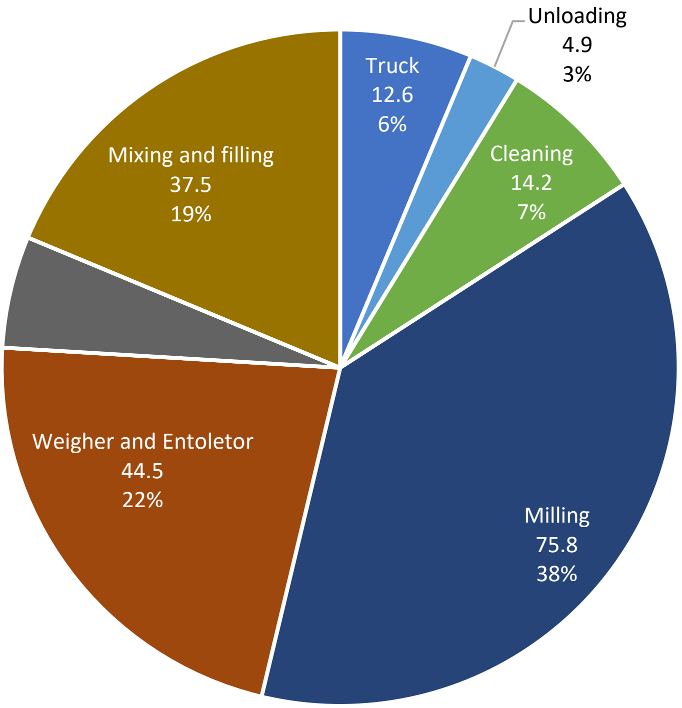


**Figure 5.** GHG emissions from wheat grain production in NZ and Australia (per ha)

## 4.2 Post-harvest

Figure 6 compares emissions from post-harvest operations (transport and milling) across the two scenarios for which post-harvest inputs were collected and analysed in this study.



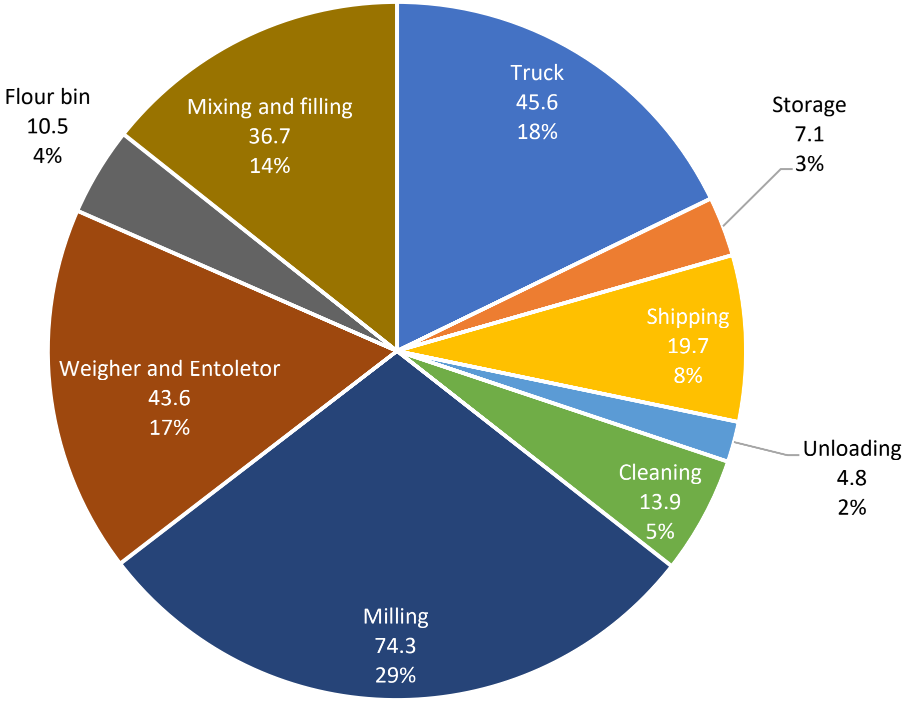


**Figure 6.** Quantities of GHG emissions (kg$CO_2$e) from post-harvest operations in New Zealand (top) and Australia (bottom) per tonne wheat flour.

## 4.3 Total emissions

Figure 7 compares the total greenhouse emissions, or the carbon footprint, of New Zealand and Australian sourced wheat, milled in NZ, and expressed per tonne of flour at the mill gate.

New Zealand wheat flour, at the mill gate, has a carbon footprint of 450 kg$CO_2$e/t flour. Australian grown wheat has a carbon footprint to the same mill gate of 550 kg$CO_2$e/t flour.

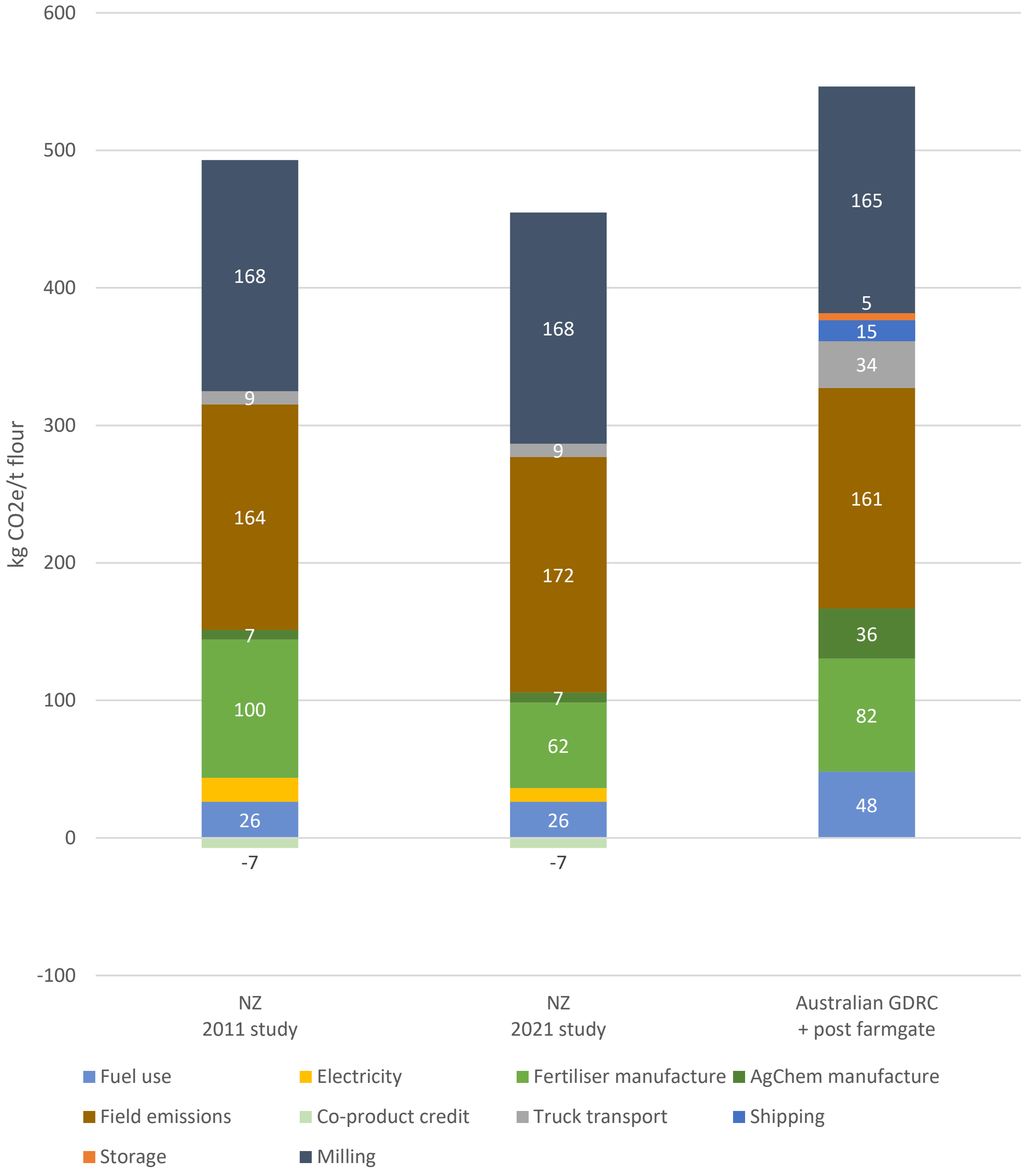


**Figure 7.** Quantities of GHG emissions for wheat flour across three scenarios

# 5.0 Sensitivity Analysis

## 5.1 Australian regions

The comparative Australian wheat growing emissions used in this study came from the GRDC National Grains Life Cycle Assessment project, with a weighted average from the 14 sub-regional studies used as the comparative emissions. With the absence of available area or production data by sub-region, the average emissions were weighted by Australian state wheat production (Australian Export Grains Innovation Centre, 2020) divided by the number of sub-regions in that state or state grouping (where sub-regions crossed state borders). This had the primary effect of weighing the overall average towards the emissions produced from wheat grown in Western Australia (the most productive wheat growing state). Table 13 shows the results when other sub-regional emissions were used for comparison to New Zealand grown wheat emissions.

**Table 13.** On-farm emissions for Australian grown wheat by sub-region.

| Sub-region | On-farm emissions ($kgCO_2e/t$ wheat grain) | % difference from NZ grown wheat on-farm emissions (2021) |
|---|---|---|
| NSW Central | 283 | 2.2% |
| NSW NE Qld SE | 504 | 82.3% |
| NSW NW Qld SW | 193 | -30.2% |
| NSW Vic Slopes | 271 | -2.0% |
| Qld Central | 386 | 39.4% |
| SA Mid North Lower Eyre Peninsula | 271 | -2.0% |
| SA Vic Bordertown Wimmera | 254 | -8.3% |
| SA Vic Mallee | 335 | 21.1% |
| Tasmania | 286 | 3.6% |
| Vic High Rainfall | 289 | 4.4% |
| WA Central | 388 | 40.2% |
| WA Eastern | 415 | 50.0% |
| WA Mallee Sandplain | 385 | 39.3% |
| WA Northern | 396 | 43.0% |
| **Weighted average** | **347** | **25.5%** |
| **NZ grown wheat** | **280** | **-** |

The sub-region that the wheat exported to New Zealand was grown in has a large impact on the on-farm emissions used for comparison. While on average when compared to NZ grown wheat Australian wheat produces more emissions on farm per tonne of wheat grain, this is dependent on the sub-region that is producing the wheat grain. Wheat grown in North-West New South Wales/South-East Queensland has less emissions than wheat grown in New Zealand, whilst Eastern Western Australian grown wheat has much higher emissions. Based on a weighted average, Australian grown wheat has 25% higher emissions per tonne than NZ grown wheat to the same farm gate stage.

## 5.3 Transport emissions

Shipping, storage, and truck transport account for approximately 10% of the total emissions produced from Australian grown wheat converted into wheat flour in New Zealand, whilst truck transport accounts for 2% of New Zealand grown wheat flour emissions. Wheat is grown across Australia, and so transport emissions are heavily dependent on the distance between the farm and the export port and the location of the export port itself and its distance to the import port in New Zealand.

In the scenarios tested in Table 14 modifying the distances involved in trucking and shipping wheat grain from Australia has the potential to change the total emissions by -5% to +5% from the baseline scenario.

**Table 14.** Effect of different transport scenarios on total GHG emissions for Australian and New Zealand grown wheat flour, the scenarios used in the main study are shown at the bottom of the table for comparison.

| Scenario number | Export port | Distance between farm and export port (km) | Import port | Mill location | Distance between import port and mill (km) | Total GHG emissions (kgCO$_2$e/t flour) |
|---|---|---|---|---|---|---|
| 1 | Melbourne | 500 | Lyttleton | Christchurch | 13 | 563 |
| 2 | Melbourne | 100 | Lyttleton | Christchurch | 13 | 519 |
| 3 | Melbourne | 300 | Auckland | Tirau | 177 | 560 |
| 4 | Melbourne | 300 | Tauranga | Tirau | 65 | 549 |
| 5 | Port Kembla | 300 | Lyttleton | Christchurch | 13 | 540 |
| 6 | Port Kembla | 300 | Auckland | Tirau | 177 | 557 |
| 7 | Port Kembla | 300 | Tauranga | Tirau | 65 | 545 |
| 8 | Brisbane | 300 | Lyttleton | Christchurch | 13 | 542 |

| **Scenario number** | **Export port** | **Distance between farm and export port (km)** | **Import port** | **Mill location** | **Distance between import port and mill (km)** | **Total GHG emissions (kgCO$_2$e/t flour)** |
|---|---|---|---|---|---|---|
| 9 | Brisbane | 300 | Auckland | Tirau | 177 | 558 |
| 10 | Brisbane | 300 | Tauranga | Tirau | 65 | 546 |
| 11 | Bunbury | 300 | Lyttleton | Christchurch | 13 | 555 |
| 12 | Bunbury | 300 | Auckland | Tirau | 177 | 575 |
| 13 | Bunbury | 300 | Tauranga | Tirau | 65 | 563 |
| 14 | Bunbury | 100 | Lyttleton | Christchurch | 13 | 533 |
| **Scenarios used in this study** | | | | | | |
| **Aust.** | **Melbourne** | **300** | **Lyttleton** | **Christchurch** | **13** | **547** |
| **NZ** | **-** | **-** | **-** | **Christchurch** | **85** | **447** |

Table 14 demonstrates the influence that the location of the farm, export port, import port and receiving mill have on the total emissions profile of Australian grown wheat. Of the scenarios tested, an Australian farm producing wheat 100 km away from the port of Melbourne for export to a Christchurch mill via the port of Lyttleton has the smallest emissions profile when compared to the baseline scenario (-5%). The highest emitting scenario, a Western Australian farm 300 km away from the exporting port at Bunbury with wheat delivered to a mill in Tirau via the port of Auckland, emits 5% more GHG's than the default scenario.

Therefore, the origin of the wheat grown in Australia, and the destination it is shipped to, has a significant effect on the total comparative emissions, with Australian grown wheat flour emissions being 16% to 29% higher than New Zealand flour emissions, dependent on the transport scenario and when using the average Australian farm emissions.

**Table 15.** Land and inter-NZ sea transport scenarios, the scenarios used in the main study are shown at the bottom of the table for comparison.

| Transport chain | Transport 1 type | Transport 1 distance (km) | Transport 2 type | Transport 2 distance (km) | Emissions from land transport (kgCO$_2$e/t wheat grain) |
|---|---|---|---|---|---|
| Ashburton – Tauranga port | Rail | 935 | Ferry | 100 | 94 |
| Ashburton - Wellington | Rail | 417 | Ferry | 100 | 45 |
| Ashburton - Auckland | Rail | 1,060 | Ferry | 100 | 106 |
| Ashburton – Tauranga port | Truck | 935 | Ferry | 100 | 114 |
| Ashburton - Wellington | Truck | 417 | Ferry | 100 | 48 |
| Ashburton - Auckland | Truck | 1,060 | Ferry | 100 | 129 |
| Auckland port – Tirau mill | Truck | 177 | NA | NA | 21 |
| Tauranga port – Tirau mill | Truck | 65 | NA | NA | 8 |
| Timaru port – Tauranga Port | Ship | 1,232 | NA | NA | 7 |
| **Aust. farm to Melbourne port. Lyttleton port to Chch mill** | **Truck** | **313** | **NA** | **NA** | **36** |
| **Ashburton farm to Chch mill** | **Truck** | **85** | **NA** | **NA** | **10** |

Table 15 highlights the effect that different modes of land transport and New Zealand port to port transport have on emissions, with rail transport lowering the emissions per t-km in comparison to truck transport on roads, this may help induce a greater freight mode-shift towards rail transport in the future. Shipping, due to the much greater carrying capacity of ships, is even more efficient than rail, and port to port transport via shipping is the most emissions efficient mechanism of transport. It is important to note that the scenarios in Table 15 exclude emissions associated with loading and unloading activities at ports and railyards.

Table 16 demonstrates the increase to emissions when a smaller bulk carrier is used to ship wheat grain from an Australian or New Zealand port to the receiving port in New Zealand. It is immediately apparent that there is an increase in emissions per tonne of flour produced when the wheat grain has been transported in a smaller capacity bulk carrier. Therefore, the main scenario analysed in this report can be considered somewhat conservative when comparing the emissions from Australian grown wheat to New Zealand grown wheat due to the assumption that the Australian wheat grain was shipped in a 35,000 – 60,000 dwt category bulk carrier.

**Table 16.** Transport emissions if grain was shipped in 10,000 – 35,000 dwt bulk carriers in comparison to default bulk carrier size category assumption.

| **Transport chain** | **Emissions from shipping (kgCO$_2$e/t wheat grain)** | |
|---|---|---|
| | **10,000 - 35,000 dwt** | **35,000 – 60,000 dwt** |
| Melbourne – Lyttleton | 21.0 | 15.7 |
| Melbourne – Tauranga | 23.8 | 17.8 |
| Port Kembla – Lyttleton | 19.1 | 14.3 |
| Port Kembla - Tauranga | 18.8 | 14.1 |
| Brisbane – Lyttleton | 21.9 | 16.4 |
| Brisbane - Tauranga | 19.9 | 14.8 |
| Bunbury – Lyttleton | 39.9 | 30.0 |
| Bunbury – Tauranga | 44.2 | 33.1 |
| Lyttleton – Tauranga | 8 | 6 |
| Timaru - Tauranga | 9 | 7 |

# 6.0 Discussion

## 6.1 Changes to New Zealand GHG emissions since 2011

The estimate for the on-farm New Zealand wheat emissions has been updated in this report based on changes in methodology and emission factors. Nitrogen type (urea, coated urea, and non-urea) was the only resource use input that was accounted for differently. For all other resource inputs recent data was not considered robust enough to justify a change. Likewise, yields were not changed as they were considered a good representation of average current yields for milling wheat (Arable Industry Marketing Initiative, 2021).

The main changes made to the on-farm emissions calculations have been in the emission factors used to estimate the GHG emissions. Emission factor updates have been made for emissions from electricity, nitrogen fertiliser production, and field nitrous oxide emissions. These emission factor updates, and the splitting of nitrogen fertiliser quantity by type, has resulted in a 12% reduction in the total estimated on-farm emissions. Almost the entire reduction has been due to an update in the nitrogen fertiliser production emission factors and the quantity split by type, causing a 38% reduction in estimated emissions from this process. A 43% reduction in the estimated emissions from electricity usage also resulted from updating the electricity LCA emission factor. In contrast, estimated field emissions increased by 5% due to the nitrogen quantity split and updated emission factors by type - even though the latest $N_2O$ Global Warming Potential (GWP) is less than was used in the 2011 study. Changes in the residue to wheat ratio used in calculating field burning emissions also contributed to this increase in field emissions.

The impact that emission factor changes have had on results highlights the need to use the most up to date emission factors and methodology to obtain the most accurate possible result. This same conclusion was evident in a similar study on the global warming potential of Western Australian wheat production conducted in 2008, where a regional specific nitrous oxide emission factor decreased the total estimated on-farm emissions from wheat production when compared to IPCC defaults (Biswas et al., 2008).

## 6.2 Comparison to emissions from Australian grown wheat

Environmental claims made in Australia have stated New Zealand wheat emits 1000 kg$CO_2$e/tonne wheat grain (GRDC Groundcover Magazine Issue 131, Dec 2017). The results of this study have shown that on-farm emissions from New Zealand wheat are approximately four-times less than this (280 kg$CO_2$e/tonne wheat grain). Australian grown wheat emits less per-hectare than New Zealand grown wheat but produce significantly less wheat grain per hectare. This difference in productivity drives a 24% difference in on-farm emissions per tonne of wheat grain produced, though the sensitivity analysis in Section 5.1 shows that this is highly dependent on the Australian sub-region the wheat is being grown in.

When transport to a New Zealand processing mill and processing to flour is accounted for, wheat flour derived from Australian grown wheat emits 22% more GHG emissions than flour derived from New Zealand grown wheat. Depending on the Australian sub-region and transport chain this difference in total emissions ranges from 12% less to 42% greater (394 – 634 kg$CO_2$e/tonne flour) than wheat grown in New Zealand (447 kg$CO_2$e/tonne flour).

Developing an Environmental Product Declaration (EPD) for New Zealand grown wheat to flour could be the next step for publicising NZ’s emissions through an independent framework that would provide an objective, science-based assessment. A full description of the Australasian EPD scheme can be found here https://epd-australasia.com/

# 7.0 Individual farm GHG emissions from ProductionWise data

GHG emissions were calculated for an individual farm using data from ProductionWise, a tool developed by FAR for crop record keeping. The data for this farm included records on irrigation use, fertiliser applications, agrichemical spray applications, cultivation, sowing, and harvesting operations for a wheat crop.

These inputs were substituted into the emissions model to produce a tailored farm emissions profile per hectare and per tonne of wheat grain. Required inputs not collected by ProductionWise used the 2021 defaults.

Table 17 describes the input changes and resultant change in emissions from this study. There is an 8% emissions difference per tonne of grain between total emissions from using farm specific data from ProductionWise instead of the average inputs used in the 2011 and updated 2021 emissions studies. This difference rises to 34% when measured per hectare due to yield differences.

**Table 17.** Input and emissions changes when using farm ProductionWise data in comparison to 2021 defaults.

| **Input category** | **Unit/ha** | **ProductionWise data** | **2021 default value** | **GHG emissions from ProductionWise data ($kgCO_2e/ha$) *** | **GHG emissions from ProductionWise data ($kgCO_2e/t$ wheat grain) *** |
|---|---|---|---|---|---|
| Yield | t | 10.9 | 8.8 | - | - |
| Diesel | l | - | 69 | 218 (0%) | 20 (-19%) |
| Petrol | l | - | 2.8 | 4 (0%) | <1 (-19%) |
| Lubricants | l | - | 0.7 | 1 (0%) | 0.1 (-19%) |
| Electricity | kWh | 1,505 (Irrigation)** | 828 (All uses) | 166 (82%) | 15 (47%) |
| Nitrogen fertiliser production (non-urea) | kgN | 45 | 8 | 151 (489%) | 14 (376%) |
| Nitrogen fertiliser production (urea) | kgN | 274 | 189 | 572.2 (45%) | 53 (17%) |
| Phosphorous | kgP | 25 | 30 | 80 (-16%) | 7 (-32%) |
| Potassium | kgP | 60 | 26 | 44 (133%) | 4 (88%) |
| Sulphur | kgS | 49 | 46 | 16 (5%) | 1 (-15%) |
| Magnesium | kgMg | 13 | 8 | 4 (60%) | <1 (29%) |

| Input category | Unit/ha | ProductionWise data | 2021 default value | GHG emissions from ProductionWise data (kgCO$_2$e/ha) * | GHG emissions from ProductionWise data (kgCO$_2$e/t wheat grain) * |
|---|---|---|---|---|---|
| Lime | kgLime | 0 | 432 | 0 | 0 (-100%) |
| Herbicide | kg | 4.5 | 3.7 | 48 (20%) | 4 (-3%) |
| Fungicide | kg | 4.8 | 5.6 | 15 (-14%) | 1 (-31%) |
| Insecticide | kg | 0.1 | 0.5 | <1 (-83%) | <1 (-87%) |
| PGR | kg | 2.0 | 0.6 | 12 (218%) | 1 (157%) |
| Miscellaneous (incl. adjuvants) | kg | 2.6 | 0.3 | 5 (903%) | 0.5 (710%) |
| CO$_2$ from Lime | kgLime | 0 | 432 | 0 | 0 (-100%) |
| N$_2$O from non-urea N fertiliser | kgN | 45 | 8 | 240 (489%) | 22 (376%) |
| N$_2$O and CO$_2$ from urea N fertiliser (w/o Urease Inhibitor) | kgN | 274 | 189 | 1,389 (45%) | 127 (17%) |
| N$_2$O and CO$_2$ from urea N fertiliser (w/ Urease Inhibitor) | kgN | 0 | 0 | 0 | 0 |
| N$_2$O from crop residue | kgN | - | 30 | 123 (0%) | 11 (-19%) |
| N$_2$O and methane from field burning | kgDM | - | 2,523 | 276 (0%) | 23 (-19%) |
| Co-product credit | kg | - | 1,974 | 67 (0%) | 6 (-19%) |
| **Total (all emission sources)** | | | | **3,317 (34%)** | **304 (8%)** |

* In brackets is the percentage difference between the individual and 2021 emissions calculated in this report.

** Electricity used for irrigation was back-calculated from cost data at a rate of $0.3/kWh. This assumes the entire cost of irrigation is in electricity.

Whilst ProductionWise does not capture all the data required for a complete on-farm GHG emissions assessment, it does provide more specific farm data in input categories that have a large effect on the total farm emissions, specifically fertiliser use and resultant field emissions. Therefore, there is potential to use ProductionWise data to provide reasonably specific GHG emissions profiles on an individual farm basis to New Zealand wheat growers. Similarly, it could provide an estimate of their carbon costs through He Waka Eke Noa.

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