thinkstep anz

Carbon Footprint for New Zealand Pork

Created by thinkstep-anz on behalf of NZ Pork

ZP103823
June 2026
Public Report

Document approval and revision

Client:	New Zealand Pork Industry Board (NZ Pork)
Project name:	Carbon Footprint for New Zealand Pork
Project number:	ZP103823
Report title:	Carbon Footprint for New Zealand Pork
Report version:	1.1
Report date:	June 2026
Report copyright:	thinkstep ltd
Cover photo:	NZ Pork
Author(s):	Diana Hawkins | Senior Sustainability Specialist Vi Kie Soo | Principal Sustainability Specialist
Quality assurance:	Chanjief Chandrakumar | Projects and Team Lead - LCA
Approved:	Noa Meron | Head of Data and Digital Solutions
Endorsed:	Emily Townsend | Services Director
Sensitivity:	Not confidential
Audience:	Public
Contact:	thinkstep ltd 11 Rawhiti Road Pukerua Bay Wellington 5026 New Zealand www.thinkstep-anz.com info@thinkstep-anz.com +64 4 889 2520

Suggested citation format:
thinkstep-anz. (2026). Product Carbon Footprint for New Zealand Pork. Wellington: thinkstep-anz.

Version	Date	Changes	Author	QA	Approved
1.0	5/06/2026	First issue	VS, DH	CC	NM
1.1	5/06/2026	Second version, comparative information removed for publication	VS, DH	CC	NM

Executive summary

Why NZ Pork commissioned this report

New Zealand Pork (NZ Pork) commissioned this report to better understand the carbon footprint of New Zealand-produced pork and identify where emissions reduction opportunities exist across the supply chain.

This work reflects the sector's commitment to proactive environmental management and continuous improvement, including identifying practical opportunities to reduce greenhouse gas emissions. In doing this, NZ wants to ensure farmers and others across the supply chain are supported with credible, evidence-based information to help guide future decision-making.

This study gives NZ Pork a baseline estimate of emissions from pork production at the farm gate. It is intended to help the industry understand current performance, identify the main sources of emissions and inform future decision-making. It is not designed to support public comparative claims.

What we did

We carried out a life cycle assessment (LCA) to assess the environmental impacts of pork production:

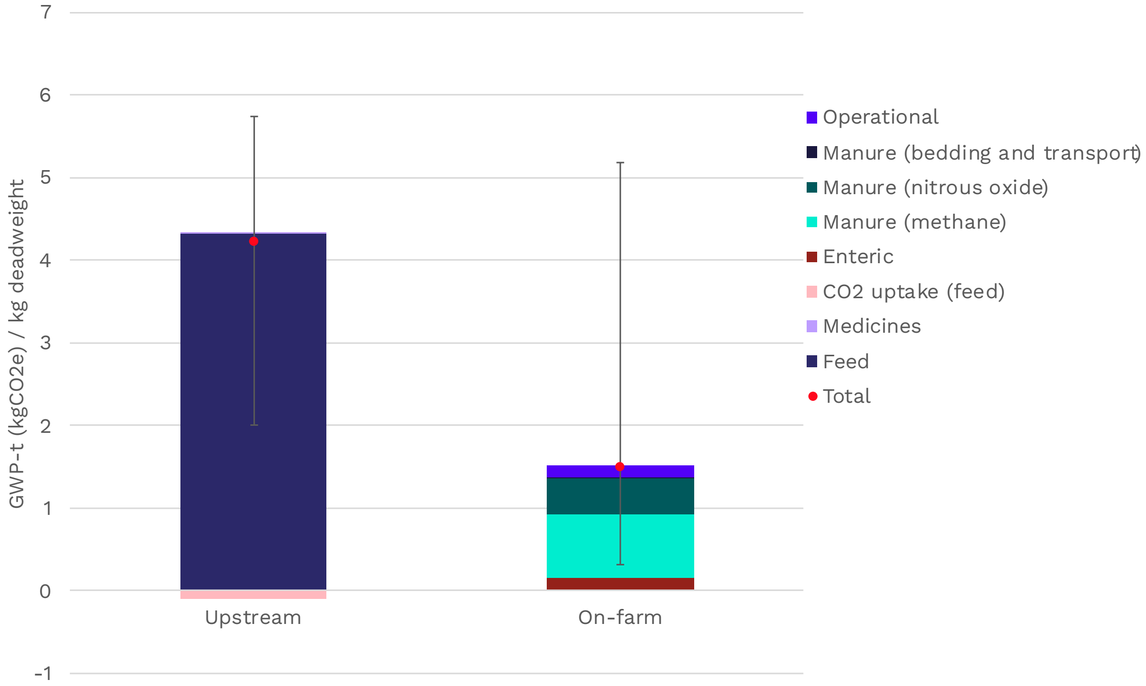
- This study follows ISO 14067 for product carbon footprinting, ISO 14040 and ISO 14044, the international standard for LCA.
- The assessed environmental indicator is the global warming potential (GWP), expressed as carbon dioxide equivalent (CO_2-eq), with detailed breakdown following ISO 14067.
- The declared unit is one kilogram (kg) of New Zealand-produced pork deadweight (also known as carcass weight).
- The system boundary covers 'cradle-to-gate', as presented in Executive Summary Figure 1. This means the study covers emissions from:
  - upstream activities, including feed and input production, and transport
  - on-farm activities, including pig production, energy use and manure management
- It does not include downstream stages such as processing, retail, use or end-of-life.
- 12-month production data was collected from nine commercial pig farms across New Zealand, using data collected between 2022 and 2025.

Executive Summary Figure 1: System boundary

What we found

On average across all farms, the cradle-to-gate carbon footprint of 1 kg of New Zealand-produced pork deadweight is 5.8 kg CO_2-eq. As shown in Executive Summary Figure 2, the emissions are concentrated in a small number of areas.

Most emissions (4.3 kg CO_2-eq./kg deadweight) occurred from feed, followed by manure methane and nitrous oxide emissions, contributing about 0.8 kg CO_2-eq./kg deadweight and 0.4 kg CO_2-eq./kg deadweight, respectively.



Executive Summary Figure 2: Carbon footprint of New Zealand-produced pork (upstream and on-farm stages). Upper and lower values represent minimum and maximum results from individual farms

The main contributors to the carbon footprint of pork:

1) **Feed**
   - Feed ingredients account for more than 90% of total feed-related emissions.
   - Soya meal is a major driver of the carbon footprint due to its high emission factor relative to other feed ingredients.
   - Wheat also represents a high share of total impacts, primarily driven by its large inclusion volume in the feed profiles.

2) **Manure management system (MMS)**
   - Manure management is one of the main contributors to the carbon footprint, mainly due to methane and nitrous oxide emissions.
   - Emissions varied significantly across the manure management systems assessed.
     - Anaerobic lagoons had the highest manure-related emissions.
     - Deep bedding, liquid slurry and pit storage, and anaerobic digestion also contributed significantly.
     - Pasture and solid storage had lower emissions.

These results were calculated using IPCC methodology and are influenced by the estimated number of pigs on each farm, based on an assumed steady-state farm population.

What this means for the pork industry

The results show clear opportunities to reduce emissions in New Zealand pork production. Feed is the biggest driver, followed by manure management. This means the strongest reduction opportunities are likely to come from lower-emission feed ingredients, better sourcing and processing, and lower-emission manure systems.

The study also highlights the need for better farm data. More consistent information on pig numbers, feed inputs and manure handling would improve future carbon footprint estimates and help target the most effective actions.

Overall, this study gives NZ Pork and the wider industry a credible baseline and a clear starting point for emissions reduction.

Our recommendations

Feed production

- Prioritise low-emission feed ingredients and alternative protein sources such as lupins, rapeseed, canola meal, peas, etc.
- Review sourcing options for high-emission ingredients, such as soya products. While Brazilian soy meal is modelled as a conservative baseline based on farm sourcing data, lower-impact origins, such as the US, should be prioritised where feasible.
- Increase the use of suitable local feed ingredients or by-products.
- Use low-carbon electricity for pelletised feed production where possible.
- Develop and use New Zealand-specific emission factors for feed ingredients over time.

Manure management system (MMS)

- Prioritise low-emission manure systems where practical such as covered storage.
- Assess options to cover liquid manure stores or upgrade to covered anaerobic systems for methane capture.
- Where feasible, minimise storage time within high-emitting systems (e.g., liquid slurry/pits) to mitigate anaerobic methane production, subject to regulatory constraints.
- Improve monitoring of manure volumes and storage conditions to support more accurate estimates and better decision-making.

Future studies

- Incorporate additional farm-level metrics, such as pig types and slaughter age to enable a more refined and direct approach to emissions modelling.
- Enhance the reporting of feed inputs—including country of origin, specific pellet formulations, and supplier-level data—to improve the relevancy and precision of the emission factors used.
- Seek higher resolution in the manure management data by including specific handling pathways and multi-stage treatment configurations.
- Use better data to update this baseline and track progress over time.

Table of Contents

1. Goal of the Study

New Zealand Pork (NZ Pork) would like to support pig farmers and others in the pork supply chain to identify opportunities to make emissions reductions. This is essential to ensure pig farming meets or exceeds environmental and social responsibility expectations. This includes contributing to the collective goal of reducing greenhouse gas emissions of Aotearoa New Zealand (NZ), while ensuring people have access to high-quality and affordable protein.

NZ Pork commissioned thinkstep-anz to carry out a carbon footprint (CFP) of New Zealand-produced pork to estimate the cradle-to-gate emissions based on farm case studies. The goal of this study is to calculate the global warming potential (GWP) of pig farming, also known as carbon footprint. GWP is expressed as kilograms of carbon dioxide equivalent (kg CO_2-eq) per declared unit, as specified in ISO 14067 (ISO, 2018).

This study conforms with international standards ISO 14067:2018 (ISO, 2018) for product carbon footprinting, ISO 14040 and ISO 14044 for Life Cycle Assessment (LCA) (ISO, 2006b). The outcomes of the study provide NZ Pork with evidence-based statements for public communication about the CFP of pig farming across NZ and supporting farmers and other stakeholders with credible, evidence-based emission reduction strategies.

2. Scope of the Study

The following sections describe the general scope of the project to achieve the stated goals. This includes, but is not limited to, the identification of specific product systems to be assessed, the product function(s), declared unit and reference flows, the system boundary, allocation procedures, and cut-off criteria of the study.

2.1. Product Information

The product included within this study is pig farming for a range of pig farming systems in NZ. The primary production supply includes crop cultivation, feed production, farm operation and manure management system. Most of the pork produced is consumed locally.

This is a case study including data collected from nine commercial pig farmers (study farms) with about 40% from the North Island and 60% from the South Island. The two main pig farming systems in this study are indoor and outdoor. The farming system type is largely influenced by environmental conditions, such as climate and land types. Drier climates with flat land in the South Island are suited for outdoor farming, whereas the climates and land conditions in the North Island are more suited for indoor farming (NZ Pork, 2022).

As described in Table 2-1, there are six primary manure management systems used across study farms. Some study farms may use several combinations of manure management systems.

Table 2-1: The types of manure management systems used by study farms

Manure Management Systems	Details
Anaerobic lagoon	Uncovered anaerobic lagoon
Deep bedding	Includes bedding material kept for less than 60 days on average
Liquid slurry and pit storage	Located below animal confinements designed to hold weeks to months of manure
Pasture	Used in outdoor farming in which manure is deposited directly onto the soil for natural biological processes
Solid storage	Storage of manure for a period of several months in unconfined piles or stacks
Anaerobic digester	Covered pond / anaerobic digestion

The different farms involved in this study, including their farming and manure management systems, are detailed in Table 2-2.

Table 2-2: Pork farming systems considered in this study

Farm Type	Farm name	Feed Type	Manure Management System(s)
Outdoor	Farm A	Pellets	Deep bedding, pasture
Outdoor	Farm B	Pellets	Pasture
Outdoor	Farm C	Pellets	Deep bedding, pasture
Indoor	Farm D	Pellets	Liquid slurry and pit storage
Indoor	Farm E	Non-pelletised	Covered anaerobic lagoon, deep bedding, liquid slurry and pit storage, solid storage
Indoor	Farm F	Pellets	Covered anaerobic pond, liquid slurry and pit storage, solid storage
Indoor	Farm G	Pellets	Liquid slurry and pit storage
Indoor	Farm H	Non-pelletised	Liquid slurry and pit storage, uncovered anaerobic pond
Outdoor	Farm I	Pellets	Liquid slurry and pit storage, deep bedding, pasture

2.2. Product Function(s) and Declared Unit

The declared unit is the production of one kilogram (kg) of New Zealand-produced pork deadweight at the farm gate (cradle-to-gate). This is commonly used in livestock LCAs to allow comparable reference to assess the impacts associated with feed, manure management systems and avoid the variability in meat cut and processing yields.

In this study, the data and results are presented as a weighted average of pork produced across the nine commercial pig farms.

2.3. Software and Database

The LCA was conducted in Microsoft Excel. The LCA utilises life cycle inventory data from ecoinvent database version 3.10 (Wernet, 2016) and Agri-Footprint version 5 (Mérieux NutriSciences | Blonk, 2019) for several of the raw and process materials obtained from the background system. The ecoinvent datasets have not been adapted as they are provided in Excel and have not been used in conjunction with an LCA software.

2.4. System Boundary

This study has a scope of cradle-to-gate, as shown in Figure 2-1. This includes all impacts from feed production, transport and on-farm production. Inbound packaging is excluded due to lack of data.

Figure 2-1: System boundary included in this study

The main processes as shown in Figure 2-2 include:

- Feed and supply production
  - cultivation of feed crops
  - production of medicines and nutrient additives
  - feed mixing
- Transport
  - transport of feed ingredients, bedding, fuel and supplies
- On-farm pig production
  - energy use (electricity and fuels)
  - heating
  - farm operation
  - release of biogenic carbon (including enteric emissions)
- Manure management system
  - collection and storage of manure
  - effluent
  - solid waste.

Table 2-3: System boundaries

Included	Excluded
→ Feed crop cultivation → Feed processing → Transport of inputs (feed ingredients, supplies, etc.) → Energy input during production (electricity, fuel, water pumping, etc.)	→ Inbound packaging → Capital and infrastructure → Water supply

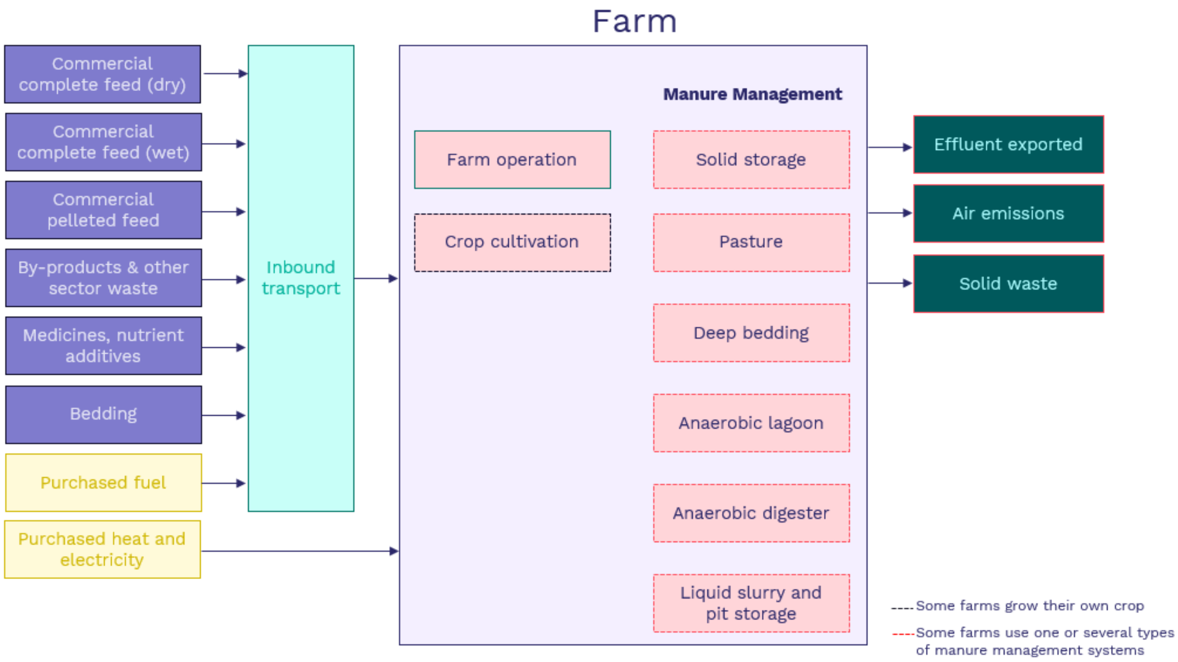


Figure 2-2: High level flow diagram of processes

2.4.1. Time Coverage

All primary data represent a 12-month production data from each farm, ranging from 2022 to 2025, based on data provided by each farm. Data collected is expected to be representative of current operations in the individual farm.

Background data for all energy inputs, transport processes, and raw materials are from ecoinvent database version 3.10 (Wernet, 2016) and Agri-Footprint version 5 (Mérieux NutriSciences | Blonk, 2019). The reference year for the data ranges from 2019-2023. Details for data used in the background system are provided in Section 3.3.

2.4.2. Technology Coverage

This study focuses on the production technologies currently used by the pig farmers involved in this study. Material and process data are specific to each farm. For some materials, background data represents European or global technology where no primary technological information is available for a given process.

2.4.3. Geographical Coverage

Primary data for feeding mix/type and manure management systems were collected from each farm. Application is modelled for NZ.

Geographically correct data were used where regional data was available. Primary data for feeding materials used were obtained from individual farms. Supporting background data from ecoinvent that is specific to the country of origin of the raw materials was used whenever possible. When such background data was not available, global or regional datasets were used as proxy. All electricity and water data were regionalised for NZ. The use of background data is further explained in Section 3.3.

2.4.4. Boundaries to nature

System boundaries to and from nature are jointly described by so-called elementary flows. The inclusion of resource flows from nature to the technosphere corresponds to resource use and explorative impact, and on the output side emissions and resource consumption. In an ideal LCA, all flows studied shall be traceable to a natural source or recipient. As such, processes such as feed and waste production have been modelled to elementary flow level.

For example, datasets for raw materials such as crop cultivation include mineral extraction from the ground for fertiliser; enteric emissions are included as emission to air, outputs to water (from wastewater treatment) are modelled as emissions to water rather than an emission of untreated waste. Waste to landfill is modelled assuming a 100-year time horizon.

2.5. Allocation

2.5.1. Feed Allocation

All feed datasets use economic allocation, which are co-products of another system. Co-product allocation should be done in a way that reflects other relationships between them (when physical allocation cannot be done). As most of the products used in the feed are co-products of another system (e.g., bread waste, meat meal), it makes sense to use economic allocation as this is the allocation most likely to be used by the system where these products come from (Wiedemann, et al., 2016).

2.5.2. Multi-output Allocation

Multi-output allocation follows the requirements of ISO 14044, Section 4.3.4.2 (ISO, 2006b). When allocation becomes necessary during the data collection phase, the allocation rule most suitable for the respective process step is applied and documented along with the process in Section 3.3.

2.5.2.1 Allocation of co-products

Some farms produce co-products such as straw, breeding stock and liquid genes (semen) which are sold. Two allocation approaches are considered, but they have no impact or are negligible as described below:

- Protein-based allocation is typically used to reflect the physical relationships between co-products. When protein-based allocation is applied, the upstream impacts are wholly allocated towards pork product (pork deadweight).
- When considering economic allocation, the low economic values for co-products are assumed to have insignificant impact. Almost all the impacts are likely to be allocated to the pork product (pork deadweight).

2.5.3. Allocation of background data

Allocation of background data (energy and materials) taken from the ecoinvent and Agri-Footprint databases are documented online at https://ecoquery.ecoinvent.org/3.10/EN15804/search and https://blonksustainability.nl/agri-footprint#gsc.tab=0).

2.6. Cut-off Criteria

The following cut-off criteria were applied during data collection and analysis:

- Data for elementary flows to and from the product system contributing to a minimum of 99% of the declared environmental impacts shall be included (not including processes that are explicitly outside the system boundary).
- The application of these cut-off rules was a combination of expert judgment based on experience of similar product systems and a sensitivity analysis in which it is possible to understand how the input or output not investigated could affect the final results.

The choice of proxy data is documented in Section 3.3. The influence of these proxy data on the results of the assessment has been carefully analysed and is discussed in Section 4.3.2.

2.7. Selection of LCIA Methodology and Impact Categories

2.7.1. ISO 14067 Carbon Footprint Indicators

Carbon footprint, measured using Global Warming Potential (GWP), is presented in detail within this study to follow ISO 14067 (ISO, 2018) and as climate change is of high public and institutional interest and is often deemed to be the most pressing environmental issue of our time (Bjørn & Hauschild, 2015).

Within this study, carbon footprint is measured using the GWP impact category, which is assessed based on the characterisation factors for GWP100 from the IPCC's Sixth Assessment Report (IPCC, 2021). This report and the modelling behind the results follow the requirements of ISO 14067 (ISO, 2018).

The carbon indicators considered are presented in Table 2-4. These indicators are assessed based on the characterisation factors (CFs) for GWP_{100} from the IPCC's latest Assessment Report (IPCC, 2021), as required by ISO 14067 (ISO, 2018). Table 2-5 provides the CFs used for carbon dioxide, methane, and nitrous oxide.

Table 2-4: Life cycle assessment carbon footprint indicators

Impact Category	Abbreviation	Description	Unit	Reference
GWP100, total	GWP-t	Total global warming potential, including biogenic carbon and including land use and change, over a 100-year time horizon	kg CO_2-eq	(IPCC, 2021)
GWP100, aviation	GWP-avi	Global warming potential from aviation over a 100-year time horizon	kg CO_2-eq	(IPCC, 2021)
GWP100, biotic emissions	GWP-bioE	Global warming potential due to biogenic emissions over a 100-year time horizon	kg CO_2-eq	(IPCC, 2021)
GWP100, biotic uptake	GWP-bioR	Global warming potential due to biogenic removal over a 100-year time horizon	kg CO_2-eq	(IPCC, 2021)
GWP100, fossil	GWP-f	Global warming potential due to fossil fuels over a 100-year time horizon	kg CO_2-eq	(IPCC, 2021)
GWP100, land use and land use change	GWP-luluc	Global warming potential impact of land use and transformation over a 100-year time horizon	kg CO_2-eq	(IPCC, 2021)

Table 2-5: ISO 14067 (AR6) GWP characterisation factors (for carbon dioxide, methane, and nitrous oxide)

	GWP-t	GWP-avi	GWP-bioE	GWP-bioR	GWP-f	GWP-luluc
CO_2 fossil	1	0	0	0	1	0
CO_2 aviation	1	1	0	0	0	0
CO_2 biogenic emissions	1	0	1	0	0	0
CO_2 biogenic removal	-1	0	0	1*	0	0
CO_2 land use change	1	0	0	0	0	1
CH_4 fossil	29.8	0	0	0	29.8	0
CH_4 biogenic	27.0	0	27.0	0	0	0
CH_4, from soil or biomass stock	27.0	0	0	0	0	27.0
N_2O	273	0	0	0	273	0

*Listed as positive when removal and negative as GWP-t

2.8. Interpretation to be used

The results of the LCI and LCIA were interpreted according to the Goal and Scope. The interpretation addresses the following topics:

- Identification of significant findings, such as the main process step(s), material(s), and/or emission(s) contributing to the overall results.
- Evaluation of completeness, sensitivity, and consistency to justify the exclusion of data from the system boundaries as well as the use of proxy data.
- Conclusions, limitations and recommendations.

2.9. Data Quality Requirements

The data used to create the inventory model shall be as precise, complete, consistent, and representative as possible with regards to the goal and scope of the study under given time and budget constraints.

- Measured primary data are considered to be of the highest precision, followed by calculated data, literature data, and estimated data. The goal is to model all relevant foreground processes using measured or calculated primary data.
- Completeness is judged based on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves. The goal is to capture all relevant data in this regard.
- Consistency refers to modelling choices and data sources. The goal is to ensure that differences in results reflect actual differences between product systems and are not due to inconsistencies in modelling choices, data sources, emission factors, or other artefacts.
- Reproducibility expresses the degree to which third parties would be able to reproduce the results of the study based on the information contained in this report. The goal is to provide enough transparency with this report so that third parties are able to approximate the reported results. This ability may be limited by the exclusion of confidential primary data and access to the same background data sources.
- Representativeness expresses the degree to which the data matches the geographical, temporal, and technological requirements defined in the study's goal and scope. The goal is to use the most representative primary data for all foreground processes and the most representative industry-average data for all background processes. Whenever such data were not available (e.g., no industry-average data available for a certain country), best-available proxy data were employed.

An evaluation of the data quality with regard to these requirements is provided in Chapter 5 of this report.

2.10. Type and format of the report

In accordance with the ISO requirements (ISO, 2006b) this document aims to report the results and conclusions of the LCA completely, accurately and without bias to the intended audience. The results, data, methods, assumptions and limitations are presented in a transparent manner and in sufficient detail to convey the complexities, limitations, and trade-offs inherent in the LCA to the reader. This allows the results to be interpreted and used in a manner consistent with the goals of the study.

2.11. Critical Review

No critical review was undertaken for this study.

3. Life Cycle Inventory Analysis

3.1. Data Collection Procedure

3.1.1. Primary data collection

Primary data was collected using customised data collection templates. NZ Pork collected data from participating farms. Upon receipt by thinkstep-anz, each questionnaire was cross-checked for completeness and plausibility against literature values and typical values for the pork industry. If gaps, outliers, or other inconsistencies occurred, thinkstep-anz engaged with NZ Pork to resolve.

The checking of the data involved comparing against literature values and other farms within this study. Feed conversion factors (kg feed / kg deadweight) were determined for each farm. They ranged between 2.91 – 4.85, with the highest value reflecting an outlier farm with non-pelletised feed and significant waste byproducts. The conversion factors were found to be within expected range as provided by NZ Pork.

3.1.2. Calculation of number and type of pigs on farm

Primary data on the number of pigs at the beginning and end of the year were averaged for each farm. Reported pig types were classified as either “breeding stock” or “sold stock” (also referred to as growing stock) based on literature (Ritchie, 2024).

3.1.2.1 Steady state vs. non-steady state farm systems

Using reported on-farm stock numbers was decided upon in conjunction with NZ Pork. This methodology assumes steady state on-farm populations. However, two farms reported variances of over 10% in beginning and ending stock numbers, suggesting these farms were not steady-state systems. For non-steady state systems, IPCC recommends annual average stock numbers are determined based on the number of pigs sold and days alive prior to slaughtering (IPCC, 2019).

Farms did not report days alive prior to slaughtering, and only some farms reported the type of pigs sold. Potential approaches to address these data gaps, including the use of country-level averages and IPCC-based estimation methodologies, were discussed extensively with NZ Pork.

However, because this information was not consistently collected during the farm data collection process, applying these methodologies would have required significant reliance on assumptions, averages, and estimated proxy data. NZ Pork considered this would introduce additional uncertainty and potentially reduce the accuracy and representativeness of farm-level results.

As a result, the treatment of non-steady state farm systems remains a limitation of this study.

3.1.3. Calculation of enteric fermentation emissions

As suggested by IPCC, IPCC tier 1 methodology was used to calculate enteric fermentation emissions, whereby the emission factor for pigs (CH_4 head^{-1} year^{-1}) was applied to the number of pigs on farm (IPCC, 2019). New Zealand and stock specific emission factors were utilised in calculations (Ritchie, 2024).

$$E_T = \sum_{(P)} EF_{(T,P)} \left(\frac{N_{(T,P)}}{10^6} \right)$$

Where:

- E_T= methane emissions from enteric fermentation in animal category T, in Gg CH_4 yr^{-1}
- $EF_{(T,P)}$= emission factor for the defined livestock population T and the productivity system P, in kg CH_4 head^{-1} yr^{-1}
- $N_{(T,P)}$= the number of head of livestock species/category T in the country classified as productivity system P (not considered)
- T= species/category of livestock
- P= productivity system
- Note: productivity system was not considered as part of this study.

3.1.4. Calculation of manure emissions

Manure emissions were calculated using IPCC methodology (IPCC, 2019). All manure emissions were allocated to pig product, including any transport offsite.

Unless otherwise specified by NZ Pork, it was assumed that the MMS reported by each farm was the primary, if not only, MMS. Impacts associated with subsequent MMS were not calculated, per IPCC methodology (IPCC, 2019).

As described by IPCC, all manure, regardless of MMS, was assumed to be eventually deposited to pasture (IPCC, 2019).

Note: NZ Pork identified three farms that did not report manure deposited to pasture in their data collection sheets; however, NZ Pork flagged that these farms reported depositing 10% of their manure to pasture in other datasets. To account for this, the manure reported was increased by 10%, with that 10% allocated to pasture.

3.1.4.1 Methane emissions

Emissions were calculated using IPCC tier 2 methodology, where annual volatile solids excreted were multiplied by the maximum methane producing capacity for pigs, methane conversion factor for each MMS, density of methane, and percent of manure managed via the MMS (IPCC, 2019).

This value was then multiplied by the GWP for methane.

$$EF_{(T)} = (VS_T \times 365)\left[B_{0(T)} * 0.67 \times \sum_{S,k} \frac{MCF_{S,k}}{100} \times AWMS_{(T,S,k)}\right]$$

Where:

- $EF_{(T)}$ = annual CH_4 emission factor for livestock category T, kg CH_4 animal^{-1} yr^{-1}
- VS_T = daily volatile solids excreted for livestock category T, kg dry matter animal^{-1} day^{-1}
- 365 = basis for calculating annual VS production, days yr^{-1}
- $B_{0(T)}$ = maximum methane-producing capacity for manure produced by livestock category T, m^3 CH_4 kg^{-1} of VS excreted
- 0.67 = conversion factor of m^3 CH_4 to kilograms CH_4
- $MCF_{S,k}$ = methane conversion factor for each manure management system S by climate region k, percent
- $AWMS_{(T,S,k)}$ = fraction of livestock category T's manure handled using animal waste management system S in climate region k, dimensionless.

Volatile solids

Volatile solids were determined using IPCC tier 1 methodology (IPCC, 2019) and stock-specific values for New Zealand pigs (kg volatile solids head^{-1} day^{-1}) (Ritchie, 2024), multiplied by the corresponding number of pigs on farm.

Bedding materials (straw, sawdust, chippings, etc.) were not included as volatile solids, per IPCC (IPCC, 2019). This is because the type and use of these materials is highly variable, and since they typically are associated with solid storage systems, their contribution would not add significantly to overall methane production (IPCC, 2019).

Methane conversion factors (MCF)

Specific climate zones for each farm were not taken into consideration. An average of "warm temperate moist" and "warm temperate dry" clime zone factors was used, where applicable (IPCC, 2019).

NZ Pork advised that New Zealand pig farms using deep bedding MMS have a storage time of less than 60 days. IPCC does not provide an MCF for a less than 60-day storage duration (IPCC, 2019). So, the MCF for less than 60 days used in Ritchie (2024) was utilised.

One farm specified a shorter duration for their liquid/slurry, and pit storage below animal confinement MMS. A linear model was used to determine the MCF based on other IPCC values. A sensitivity analysis was performed to determine the impact of this assumption.

Effluent transportation

If manure was transported offsite but a distance wasn't provided, a 15 km trip was assumed, which was the highest distance reported by any farm.

3.1.4.2 Direct nitrous oxide emissions

Direct nitrous oxide (N_2O) emissions are from nitrogen added and released from soil by direct deposition of excrement or application of effluent. Emissions were calculated using IPCC tier 1 methodology, where annual average nitrogen excreted was multiplied by the number of pigs on farm, direct nitrous oxide emission factor for each MMS, conversion of N_2O-N to N_2O emissions, and percent of manure managed via the MMS (IPCC, 2019). This value was then multiplied by the GWP for N_2O.

Nitrogen excreted was determined using an average value for New Zealand pigs (kg nitrogen animal^{-1} day^{-1}) (Ritchie, 2024).

$$N_2O_{D(mm)} = \left[\sum_{S}\left[\sum_{T,P}\left(\left(N_{(T,P)} \times Nex_{(T,P)}\right) \times AWMS_{(T,S,P)}\right) + N_{cdg(s)}\right] \times EF_{3(S)}\right] \times \frac{44}{28}$$

Where:

- $N_2O_{D(mm)}$ = direct N_2O emissions from manure management in the country, kg N_2O yr^{-1}
- $N_{(T,P)}$ = number of head of livestock species/category T in the country, for productivity system P (when applicable)
- $Nex_{(T,P)}$ = annual average N excretion per head of species/category T in the country, for productivity system P (when applicable), in kg N animal^{-1} yr^{-1}
- $N_{cdg(s)}$ = annual nitrogen input via co-digestate in the country, kg N yr^{-1}, where the system(s) refers exclusively to anaerobic digestion
- $AWMS_{(T,S,P)}$ = fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S in the country, dimensionless; productivity class P (not considered)
- $EF_{3(S)}$ = emission factor for direct N_2O emissions from manure management system S in the country, kg N_2O-N/kg N in manure management system S
- S = manure management system
- T = species/category of livestock
- P = productivity class, high or low (not considered)
- 44/28 = conversion of N_2O-N emissions to N_2O emissions
- Note: productivity class was not considered as part of this study.

3.1.4.3 Indirect nitrous oxide emissions

Indirect nitrous oxide emissions occur from volatilisation of nitrogen from soil and leaching and run-off following land application. Bedding was included from reported manure values, since, per IPCC, mineralisation of nitrogen in bedding occurs more slowly compared to manure and volatilisation and leaching losses during storage of bedding can be assumed to be zero (IPCC, 2019).

Volatilisation

Emissions were calculated using IPCC tier 1 methodology, where annual average nitrogen excreted was multiplied by the number of pigs on farm, percent of manure managed via the MMS, fraction of managed manure nitrogen that volatilises as NH_3 and NO_x in the MMS, emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces, and conversion of N_2O-N to N_2O emissions (IPCC, 2019). This value was then multiplied by the GWP for N_2O.

Nitrogen excreted was determined using an average value for New Zealand pigs (kg nitrogen animal^{-1} day^{-1}) (Ritchie, 2024).

$$N_{volatization-MMS} = \sum_{S}\left[\sum_{T,P}\left[\left(\left(\left(N_{(T,P)} \times Nex_{(T,P)}\right) \times AWMS_{(T,S,P)}\right) + N_{cdg(S)}\right) \times Frac_{GasMS(T,S)}\right]\right]$$

Where:

- $N_{volatization-MMS}$ = amount of manure nitrogen that is lost due to volatilization of NH_3 and NO_x, kg N yr^{-1}
- $N_{(T,P)}$ = number of head of livestock species/category T in the country, for productivity system P (when applicable)
- $Nex_{(T,P)}$ = annual average N excretion per head of species/category T in the country, for productivity system P (when applicable), in kg N animal^{-1} yr^{-1}
- $N_{cdg(S)}$ = amount of nitrogen from co-digestates added to biogas plants (e.g., food wastes or purpose-grown crops), kg N yr^{-1}, where the system(s) refers exclusively to anaerobic digestion
- P = productivity class, high or low (not considered)
- $AWMS_{(T,S,P)}$ = fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S in the country, dimensionless; consider productivity class P (not considered)
- $Frac_{GasMS(T,S)}$ = fraction of managed manure nitrogen for livestock category T that volatilizes as NH_3 and NOx in the manure management system S
- Note: productivity class was not considered as part of this study.

$$N_2O_{G(mm)} = \left(N_{volatization-MMS} \times EF_4\right) \times \frac{44}{22}$$

Where:

- $N_2O_{G(mm)}$= indirect N_2O emissions due to volatilization of N from manure management in the country, kg N_2O yr^{-1}
- EF = emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N_2O-N per (kg NH_3-N + NOx-N volatilized).

Leaching

Emissions were calculated using IPCC tier 1 methodology, where annual average nitrogen excreted was multiplied by the number of pigs on farm, percent of manure managed via the MMS, fraction of managed manure nitrogen that is leached from the MMS, emission factor for N_2O emissions from leaching and runoff, and conversion of N_2O-N to N_2O emissions (IPCC, 2019). This value was then multiplied by the GWP for N_2O.

Nitrogen excreted was determined using an average value for New Zealand pigs (kg nitrogen animal-1 day-1) (Ritchie, 2024).

$$N_{leaching-MMS} = \sum_{S}\left[\sum_{T,P}\left[\left(\left(N_{(T,P)} \times Nex_{(T,P)} \times AWMS_{(T,S,P)}\right) + N_{cdg(s)}\right) \times Frac_{LeachMS(T,S)}\right]\right]$$

Where:

- $N_{leaching-MMS}$= Amount of manure nitrogen lost due to leaching (kg N·yr^{-1})
- $N_{(T,P)}$ = Number of head of livestock species/category T in the country, for productivity system P, when applicable
- $Nex_{(T,P)}$ = Annual average nitrogen excretion per head of livestock species/category T in the country, for productivity system P, when applicable (kg N·animal^{-1}·yr^{-1})
- $N_{cdg(s)}$ = Amount of nitrogen from co-digestates added to biogas plants, kg N·yr^{-1} where the system (s) refers exclusively to anaerobic digestion
- P = Productivity class (high or low), considered when using the Tier 1a approach
- $AWMS_{(T,S,P)}$ = Fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S in the country, for productivity system P, when applicable (dimensionless)
- $Frac_{LeachMS(T,S)}$ = Fraction of managed manure nitrogen for livestock category T that is leached from manure management system S (dimensionless)

$$N_2O_{L(mm)} = \left(N_{leaching-MMS} \times EF_5\right) \times \frac{44}{28}$$

Where:

- $N_2O_{L(mm)}$ = indirect N_2O emissions due to leaching and runoff from Manure Management in the country, kg N_2O yr^{-1}
- $N_{leaching-MMS}$ = amount of manure nitrogen that is lost due to leaching, kg N yr^{-1}
- EF_5 = emission factor for N_2O emissions from nitrogen leaching and runoff, kg N_2O–N per kg N leached and runoff

3.1.4.4 Agricultural soil nitrous oxide emissions

After storage or treatment by MMS, remaining manure will be applied to land (IPCC, 2019). A large portion of nitrogen excreted is lost prior to application to land (IPCC, 2019). Agricultural soil emissions account for emissions associated with remaining nitrogen.

Emissions were calculated using IPCC tier 1 methodology, where annual average nitrogen excreted was multiplied by the number of pigs on farm, percent of manure managed via the MMS, (1 – total fraction of managed manure nitrogen that is lost in the MMS), and nitrogen from bedding, if applicable (IPCC, 2019). This is then multiplied by an IPCC emission factor for nitrogen additions to soil (IPCC, 2019). The resulting value was then multiplied by the GWP for N_2O.

Emissions from pasture-based systems were determined by multiplying the annual amount of excrement deposited to pasture by the IPCC emission factor for grazing pigs (IPCC, 2019).

$$N_2O_{Direct}\text{-}N = N_2O\text{-}N_{Ninputs} + N_2O\text{-}N_{PRP}$$

$$N_2N_2O\text{-}N_{Ninputs} = F_{ON} \times EF_1$$

$$N_2O\text{-}N_{PRP} = \left(F_{PRP,CPP} \times EF_{3PRP,CPP}\right)$$

Where:

- F_{ON}= annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils (Note: If including sewage sludge, cross-check with Waste Sector to ensure there is no double counting of N_2O emissions from the N in sewage sludge), kg N yr^{-1}
- F_{PRP}= annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N yr^{-1} (Note: the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively)

$$FRAC_{LOSS_{MS(T,S)}} = FRAC_{GAS_{MS(T,S)}} + FRAC_{LEACHS_{MS(T,S)}} + FRAC_{N_2MS_{(S)}} + EF_{3_{(S)}}$$

Where:

- $FRAC_{LOSS_{MS(T,S)}}$= total fraction of managed manure nitrogen for livestock category T that is lost in the manure management system S
- ($FRAC_{GAS_{MS(T,S)}}$ = fraction of managed manure nitrogen for livestock category T that is lost by volatilisation in the manure management system S as NH_3 or NO_X
- $FRAC_{LEACHS_{MS(T,S)}}$ = fraction of managed manure nitrogen for livestock category T that is lost in the manure management system S by leaching or run-off
- $FRAC_{N_2MS_{(S)}}$ = fraction of managed manure nitrogen that is lost in the manure management system S as N_2
- $EF_{3_{(S)}}$ = emission factor for direct N_2O emissions from manure management system S; in this case considered dimensionless

$$N_{MMSavb} = \sum_{S} \left\{ \sum_{(T)} \left[\left[\left(N_{(T)} \times Nex_{(T)} \times AWMS_{(T,S)} + N_{cdg} \right) * \left(1 - Frac_{LossMS_{(T,S)}} \right) \right] + \left[N_{(T)} \times AWMS_{(T,S)} \times N_{beddingMS_{(T,S)}} \right] \right] \right\}$$

Where:

- N_{MMSavb} = amount of managed manure nitrogen available for application to managed soils or for feed, fuel, or construction purposes, kg N yr^{-1}
- $N_{(T)}$ = number of head of livestock species/category T in the country
- $Nex_{(T)}$ = annual average N excretion per animal of species/category T in the country, kg N $animal^{-1}$ yr^{-1}
- $AWMS_{(T,S)}$= fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S in the country, dimensionless
- $Frac_{LossMS_{(T,S)}}$= total fraction of managed manure nitrogen for livestock category T that is lost in the manure management system S in the country, dimensionless.
- $N_{beddingMS_{(T,S)}}$= amount of nitrogen from bedding (to be applied for solid storage and deep bedding MMS if known organic bedding usage), kg N $animal^{-1}$ yr^{-1}
- N_{cdg} = amount of nitrogen from co-digestates added to biogas plants such as food wastes or purpose grown crops, kg N yr^{-1}
- S = manure management system
- T = species/category of livestock

3.1.5. Land use

Seven out of nine study farms provided data on land-use change and indicated the farms were agricultural for over 20 years. So, it was assumed no forestry conversions occurred (i.e. no land-use changes), and, therefore, all soils are mineral soils (as opposed to organic) and have been for some time.

3.2. Pork Product System

3.2.1. Overview of Product System

A high-level overview of the product system is shown in Figure 2-2, and described in Section 2. The relevant datasets used in modelling can be found in Section 3.3.

3.2.2. Product Composition

The composition of standard pork production per kg of deadweight (carcass weight) includes meat, head, feet, bone, fat and skin. Other parts such as blood, internal organs and gut contents are excluded. The average meat yield of the pork product (deadweight) is about 77% (ranging from 74% to 85%) of the whole pig based on data collected.

3.2.2.1 Biogenic carbon

This report assumes that the biogenic carbon sequestered in the bio-based materials is released as carbon dioxide (CO_2) to the atmosphere when those materials are consumed. This assumption is in line with ISO 14067:2018 and supported by standards such as EN 16485:2014 and ISO 21930:2017.

The results for upstream and core processes (farm operations) include 'balancing-out reporting' for the biogenic CO_2 of pork product. This means the biogenic CO_2 sequestrated in on-farm pigs is artificially released in the core process. This approach was used because the carbon sequestered in on-farm pigs eventually returns to air upon consumption. Since the downstream stages, such as use and end-of-life, are not included in this study, sequestered carbon is manually released in the core stage.

3.2.3. Feed

3.2.3.1 Feed ingredients

Feed composition data was collected from study farms. Table 3-1 shows the categorisation of feed ingredients.

Table 3-1: Categorisation of feed ingredients

Feed Category	Feed Ingredient Type
Cereal grains (energy)	Wheat, barley, maize, barley seed
Protein meals (plant)	Soya meal, soya, canola seed, sunflower seed
Protein meals (animal)	Meat meal (unspecified), meat meal (poultry), blood meal, meat meal (fish)
By-products (energy/protein)	Palm kernel, bread (or similar) waste product, cheese waste product, yogurt waste product
Minerals & additives	Salt, lime, mineral, additive or vitamin
Dairy protein ingredients	Milk powder, skim milk powder, whey protein
Fats & oils	Soya oil, canola oil
Fats & oils (animal)	Tallow (unspecified)

The main feed ingredient for majority of study farms is wheat. However, there are variations for other feed ingredients. To further distinguish the differences, feed ingredients used by the study farms can be further grouped into four main types (refer to Figure 3-1):

1) High soya meal without by-products
   → Cereal grain and protein meals with higher soya meal without by-products feed
2) High barley and soya feed without by-products
   → Cereal grain with higher barley feed and protein meals with higher soya feed without by-products feed
3) High by-products and soya meal
   → High by-products feed with protein meals with higher soya meal
4) High mineral and additives with by-products
   → Cereal grain and protein meals with higher mineral and additives including by-products feed

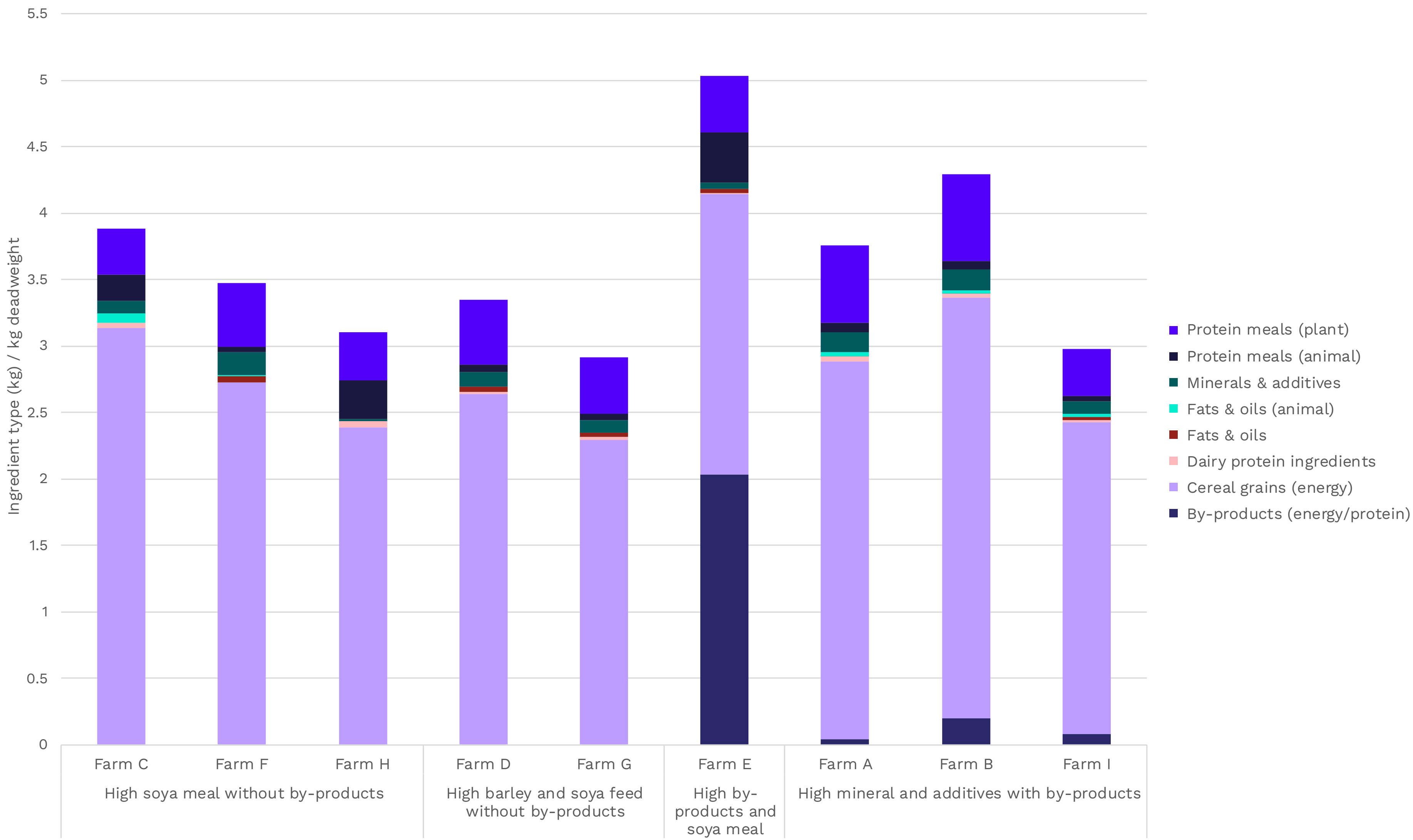


Figure 3-1: Mass of ingredient types used by each pig farm in this study

Table 3-2: Average mass of feed ingredient types for the different groups (minimum and maximum values across all participating farms are provided in brackets)

Feed ingredient type	High soya meal without by-products (Mass per kg deadweight (kg))	High barley and soya feed without by-products (Mass per kg deadweight (kg))	High by-products and soya meal (Mass per kg deadweight (kg))	High mineral and additives with by-products (Mass per kg deadweight (kg))
Meat meal (unspecified)	0.146 (0-0.265)	0.028 (0.026-0.03)	0.249	0.027 (0.017-0.034)
Soya (meal)	0.385 (0.35-0.443)	0	0.427	0
Meat meal (poultry)	0	0	0.09	0
Palm Kernel	0	0	0	0.146 (0.081-0.199)
Average of Mineral, additive, or vitamin	0.075 (0.02-0.137)	0.058 (0.054-0.062)	0.028	0.086 (0.053-0.104)
Wheat	2.175 (0.986-3.051)	1.587 (1.476-1.697)	0	2.515 (1.91-3.003)
Soya	0	0.456 (0.424-0.488)	0	0.216 (0.125-0.267)
Tallow (unspecified, assume beef)	0.028 (0-0.073)	0	0	0.024 (0.02-0.027)
Milk powder	0.015 (0-0.045)	0	0.011	0
Barley	0.195 (0-0.499)	0.88 (0.819-0.941)	0.269	0.269 (0.162-0.432)
Blood meal	0.002 (0-0.005)	0.016 (0.015-0.017)	0.019	0.014 (0.008-0.019)
Skim milk powder	0.012 (0-0.035)	0.012 (0.011-0.013)	0	0.022 (0.014-0.033)
Maize	0.38 (0-0.9)	0	0	0
Canola (seed)	0	0	0	0.311 (0.227-0.396)
Soya (oil)	0	0	0	0.007 (0-0.022)
Whey protein	0	0.007 (0.006-0.007)	0	0.007 (0.006-0.007)

Feed ingredient type	High soya meal without by-products (Mass per kg deadweight (kg))	High barley and soya feed without by-products (Mass per kg deadweight (kg))	High by-products and soya meal (Mass per kg deadweight (kg))	High mineral and additives with by-products (Mass per kg deadweight (kg))
Fertiliser	0	0	0.141	0
Canola oil	0.015 (0-0.044)	0.035 (0.032-0.037)	0.032	0.001 (0.001-0.002)
Chemicals (to grow barley)	0	0	0.003	0
Meat meal (fish)	0.027 (0.017-0.036)	0.008 (0.008-0.009)	0.018	0.016 (0.011-0.022)
Barley (seed)	0	0	0.04	0
Sunflower seed	0.012 (0-0.035)	0	0	0
Salt	0.001 (0-0.002)	0.013 (0.012-0.014)	0.014	0.02 (0.016-0.024)
Lime	0.02 (0-0.036)	0.032 (0.029-0.034)	0.006	0.031 (0.028-0.035)
Barley (grown feed)	0	0	1.653	0
Bread or similar - waste product	0	0	1.507	0
Cheese - waste product	0	0	0.055	0
Yogurt - waste product	0	0	0.473	0

3.2.3.2 Feed Type

Two main types of feed are used in pig farms: pelletised and non-pelletised. Pelletised feed uses additional energy for feed processing, including milling or grinding of feed ingredients, mixing, conditioning (hydrothermal process), pelleting, cooling and drying.

The energy used during feed pelleting process is based on data collected from only two study farms. The energy data was calculated per tonne of feed and used as a proxy for all study farms using pelletised feed due to lack of data. This data cannot be reported due to confidentiality requirements from the data provider.

3.2.3.3 Feed Transport

The data for transportation of feed ingredients from supplier to the farms is detailed in Table 3-3. In cases where transport data was not provided, a proxy distance was estimated based on the supplier location.

Table 3-3: Feed ingredients transport data for each farm

Farm name	Truck travel distance (tkm)	Sea travel distance (tkm)
Farm A	1,985,369	8,120,773
Farm B	692,575	2,652,016
Farm C	3,060,723	28,451,380
Farm D	478,098	4,004,591
Farm E	1,151,262	6,511,367
Farm F	1,004,395	18,855,083
Farm G	492,233	5,252,565
Farm H	908,706	19,541,515
Farm I	378,729	2,073,235

3.2.4. Farm Operation

Farming data such as energy consumption (energy and utilities), purchased goods (semen, medicine, etc.) and waste used in this case study is presented in Table 3-4.

Only one study farm reported detailed medicine and supplement consumption rates. This data was multiplied by appropriate emission factors and used as a proxy for all other study farms.

Medical equipment to administer drugs was excluded due to lack of data and the fact that these items are inert and multi-use (example: syringes, metal nose clips, etc.).

Transport of purchased goods and waste was also included. Transport emissions were calculated based on estimated mass and reported distance. If transport mode was not provided, truck was assumed. If air freight was reported, all impacts were treated as air freight, to be conservative.

Table 3-4: Input and output during farm operation per kg of deadweight

Input/Output	Unit	Farm A	Farm B	Farm C	Farm D	Farm E	Farm F	Farm G	Farm H	Farm I
Energy/Utilities										
Electricity	kWh	0.361	0.432	0.024	0.547	0.371	0.437	0.450	0.391	0.207
Electricity - on-site solar	kWh	0	0	0	0	0	0	0	0.3	0
Diesel	mL	7.57	48.5	22	10	49.5	32	0.5	0.375	18
Natural gas	MJ	0	0	0	0	0	0	0.014	0	0
Petrol	mL	0	0	3.55	0.47	0	0	0	0	0
Purchased goods										
Semen	g	0	0	0.001	0	0	0.01	0	0	0
Salt	kg	0	0	0	0	0	0	0.004	0	0
Transport (plane)	gkm	0	0	0.866	0	0	0	0	0	0
Transport (truck)	gkm	0	0	0	995	514	860	774	0	0
Output										
Landfilled waste	g	16.2	9.05	1.21	6.84	7.75	9.40	2.00	8.84	8.22
Recycled waste	g	0.901	1.08	0.976	0.813	0.652	1.12	0.799	1.05	0.978
Landfilled waste transport (truck)	gkm	973	277	44	209	178	287	61	530	251
Recycled waste transport (truck)	gkm	28	33	30	25	20	34	28	32	30

3.2.5. Manure Management System (MMS)

Manure generated from pig farms is treated using a range of MMS. Study farms use one or more of several MMS described in Table 3-5. Upon reviewing reported MMS data, NZ Pork advised that farms who reported composting as their primary MMS, were erroneously reporting their secondary MMS instead of their primary MMS (deep bedding), which emissions are calculated for. Based on this advice, thinkstep-anz treated all farms who reported composting as deep bedding to reflect their primary MMS system.

It should be noted that manure emissions calculated according to IPCC methodology outlined in Section 3.1.4 are driven by the number of pigs on farm (methodology described in Section 3.1.2). The quantity of manure reported by study farms was used to determine the percentage of manure processed by a particular MMS, which is used in these calculations. The overall percentage of manure managed by different MMS based on this study is also provided in Table 3-5.

Table 3-5: Percentage of manure management system (MMS) used for each farm and the overall percentage of each MMS reflected in the study

MMS	Description	Manure managed by MMS in study	Farm A	Farm B	Farm C	Farm D	Farm E	Farm F	Farm G	Farm H	Farm I
Anaerobic lagoon	Manure/effluent discharged to uncovered anaerobic lagoon	5.7%	-	-	-	-	-	-	-	98.3%	-
Deep bedding	Deep bedding (<60 days)	52.6%	90%	-	90%	-	2.1%	-	-	-	21.8%
Liquid slurry and pit storage	Liquid/slurry and pit storage below animal confinements - <5 days	4.3%	-	-	-	89.4%	-	-	-	-	-
	Liquid/slurry and pit storage below animal confinements - 1 month	11.6%	-	-	-	-	3.6%	5.3%	100%	1.7%	68.2%
	Liquid/slurry, and pit storage below animal confinements - 14 days	0.5%	-	-	-	10.6%	-	-	-	-	-
Pasture	Pasture	9.8%	10%	100%	10%	-	-	-	-	-	10%
Solid storage	Manure stored for a period of several months in unconfined piles/stacks	2.0%	-	-	-	-	0.8%	26.3%	-	-	-
Anaerobic digester	Covered pond/anaerobic digestion	13.7%	-	-	-	-	93.6%	68.4%	-	-	-
Total:		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

3.3. Background Data

The most relevant LCI datasets used in modelling the product systems are detailed below. New Zealand average datasets were used when available.

Most background datasets were obtained from the ecoinvent database v3.10 (related documentation can be found at: https://ecoquery.ecoinvent.org/3.9.1/EN15804) and the Agri-Footprint version 5 (related documentation can be found at: https://blonksustainability.nl/agri-footprint#gsc.tab=0).

The proxy column is used to indicate whether a dataset accurately represents the desired material or process; a No* indicates the use of a geographical proxy for a correct dataset where the region of manufacture is expected to have little influence on its environmental profile; and a Yes* indicates the use of a geographical proxy for a correct dataset where the region of manufacture is expected to materially influence its environmental profile.

3.3.1. Fuels and Energy

National averages for fuel inputs and electricity grid mixes were obtained from the ecoinvent database.

As discussed in Section 3.2.3.2, pelletised feed uses additional energy. Energy data collected from two farms was used to approximate carbon emissions for other study farms using pelletised feed. The calculated GWP emissions were:

- Fuel consumption per tonne of feed: 12 kg CO2-eq
- Electricity per tonne of feed: 23 kg CO2-eq.

Table 3-6 shows the most relevant electricity datasets and Table 3-7 shows other energy datasets used in modelling the product systems.

Table 3-6: Key electricity datasets used in inventory analysis

Material/process	Location	Dataset	Data Provider	Reference Year	Proxy?
Electricity	NZ	NZ: market for electricity, low voltage	ecoinvent	2019	No
Electricity	NZ	RoW: electricity production, solar tower power plant, 20 MW	ecoinvent	2019	No

Table 3-7: Key energy datasets used in inventory analysis

Energy	Location	Dataset	Data Provider	Reference Year	Proxy?
Petrol	NZ	GLO: market for petrol, unleaded, burned in machinery	ecoinvent	2023	No
Diesel	NZ	GLO: diesel, burned in agricultural machinery	ecoinvent	2023	No
Diesel	NZ	RoW: water pump operation, diesel	ecoinvent	2023	No
LPG	NZ	RoW: heat production, propane, at industrial furnace >100kW	ecoinvent	2023	No
Natural gas	NZ	RoW: market for heat, district or industrial, natural gas	ecoinvent	2023	No

3.3.2. Raw Materials and Processes

Data for upstream and downstream raw materials and unit processes were obtained from the ecoinvent and Agri-Footprint databases. Table 3-8 shows the most relevant LCI datasets used in modelling the product systems. Documentation for all ecoinvent datasets can be found at https://ecoquery.ecoinvent.org/3.10/EN15804 and the documentation for Agri-Footprint database can be found at: https://blonksustainability.nl/agri-footprint#gsc.tab=0).

Some raw material and co-products datasets were obtained from literature.

Table 3-8: Key material and process datasets used in inventory analysis

Material/ process	Location	Dataset	Data Provider/Source	Reference Year	Proxy?
Milk powder	NZ	NL: Milk powder (full fat), at processing/NL Economic	Agri-footprint	2019	No
Skim milk powder	NZ	NL: Milk powder (skimmed), at processing/NL Economic	Agri-footprint	2019	No
Cheese	NZ	NL: Cheese (Gouda 48+), at processing/NL Economic	Agri-footprint	2019	No
Canola oil	NZ	NL, DE, BE: Refined rapeseed oil (pressing), at processing/Average Economic	Agri-footprint	2019	Yes
Yogurt	NZ	NL: Cream (full fat), at processing/NL Economic	Agri-footprint	2019	Yes
Fertiliser	GLO	RER: Urea, as 100% CO(NH2)2 (NPK 46.6-0-0), at plant/RER Economic	Agri-footprint	2019	No
Insecticide (to grow barley)	GLO	RER: Insecticide, at plant/RER Economic	Agri-footprint	2019	No
Herbicide (to grow barley)	GLO	RER: Herbicide, at plant/RER Economic	Agri-footprint	2019	No
Fungicide (to grow barley)	GLO	RER: Fungicide, at plant/RER Economic	Agri-footprint	2019	No
Chemicals (to grow barley)	GLO	RER: Insecticide, at plant/RER + Herbicide, at plant/RER + Fungicide, at plant/RER Economic	Agri-footprint	2019	Yes
Barley (seed)	GLO	GLO: barley seed production, for sowing/Economic	ecoinvent	2023	No
Bread or similar	NZ	NL: Wheat flour, at processing/NL Economic	Agri-footprint	2019	Yes

Material/ process	Location	Dataset	Data Provider/Source	Reference Year	Proxy?
Wheat	NZ, AU	NL: Wheat middlings & feed, at processing/NL Economic	Agri-footprint	2019	No
Whey protein	NZ	NL: Whey powder dried, at processing/NL Economic	Agri-footprint	2019	No
Soya (meal)	US, AR	BR: Soybean meal (solvent), at processing/BR Economic	Agri-footprint	2019	No
Sunflower seed	US	AR: Sunflower seed meal (solvent), at processing/AR Economic	Agri-footprint	2019	No
Soya	AR	NL: Soybean, heat treated, at processing/NL Economic	Agri-footprint	2019	No
Lupin	AR	NL: Lupins meal, at processing/NL Economic	Agri-footprint	2019	No
Palm Kernel	ID	ID: Palm kernel expeller, at processing/ID Economic	Agri-footprint	2019	No
Meat meal (fish)	NZ	PE, NO, NL, GB, DK, DE, CL: Fish meal, at processing/Average Economic	Agri-footprint	2019	No
Blood meal	NZ, AU	NL: Blood meal, at processing/NL Economic	Agri-footprint	2019	No
Meat meal (unspecified)	NZ	NL: Animal meal, at processing/NL Economic	Agri-footprint	2019	No
Meat meal (poultry)	NZ	NL: Animal meal, at processing/NL Economic	Agri-footprint	2019	No
Maize	NZ, US	US: Maize middlings, at processing/US Economic	Agri-footprint	2019	No
Barley	NZ, AU	AU: Barley grain, dried, at farm/AU Economic	Agri-footprint	2019	No
Soya (oil)	MY	BR, AR: Refined soybean oil (solvent), at processing/Average Economic	Agri-footprint	2019	No
Tallow (unspecified, assume beef)	NZ	NL: Food grade fat, at processing/NL Economic	Agri-footprint	2019	No
Canola (seed)	NZ	CN: Rapeseed meal (solvent), at processing/CN Economic	Agri-footprint	2019	Yes

Material/ process	Location	Dataset	Data Provider/Source	Reference Year	Proxy?
Mineral, additive, or vitamin	GLO	SK: ValAMINO®, 98.0% L-Valine, at Evonik plant/SK Economic SK: TrypAMINO®, 98.0% L-Tryptophan, at Evonik plant/SK Economic HU: ThreAMINO®, 98.5% L-Threonine, at Evonik plant/HU Economic	Agri-footprint	2019	No
Salt	NZ	RoW: sodium chloride production, powder/Economic and Mass	ecoinvent	2023	No
Lime	NZ	RoW: limestone production, crushed, washed/Economic	ecoinvent	2023	No
Bedding – wood shaving	NZ	RoW: suction, shavings, softwood	ecoinvent	2023	No
Bedding – straw	NZ	RoW: market for straw, stand-alone production	ecoinvent	2023	No
Pig co-product	NZ	NL: Pig co-product, food grade, at slaughterhouse/NL Mass	Agri-footprint	2019	No
Parasiticide	NZ	Parasiticide	(Kaji, et al., 2025)	2025	Yes
Antibiotic	NZ	Antibiotic - per dose (mass)	(De Jaegher, 2024)	2024	Yes
Vaccine	NZ	AU: vaccination and anthelmintic, herd requirement per breeder, northern cattle	ecoinvent	2023	No
Medicine	NZ	Parasiticide	(Kaji, et al., 2025)	2025	Yes

3.3.3. Transportation

Average transportation distances and modes of transport are included for the transport of the raw materials, operating materials, and auxiliary materials to farms.

Transportation was modelled using the ecoinvent global transportation datasets. Fuels were modelled using the geographically appropriate datasets.

Table 3-9: Transportation and road fuel datasets

Mode	Location	Dataset	Data Provider	Reference Year	Proxy?
Ship	NZ, GLO	GLO: market for transport, freight, sea, container ship	ecoinvent	2023	No
Truck	NZ, GLO	RoW: market for transport, freight, lorry, unspecified	ecoinvent	2023	No
Air freight	NZ, GLO	GLO: market for transport, freight, aircraft, unspecified	ecoinvent	2023	No

3.3.4. Enteric Fermentation

As described in Section 3.1.3, the average weighted value of 0.91 kg CH_4 head^{-1} year^{-1} is used to calculate the enteric fermentation emissions. The calculated methane emissions from enteric fermentation for each farm is shown in Table 3-10.

Table 3-10: Calculated enteric fermentation emission (methane) for each farm

	Farm A	Farm B	Farm C	Farm D	Farm E	Farm F	Farm G	Farm H	Farm I
Enteric methane emissions (kg CO2-eq /kg deadweight)	0.327	0.370	0.464	0.295	0.293	0.389	0.303	0.457	0.348

3.3.5. Manure Management System

The manure emissions are calculated based on the information described in Section 3.1.4. The calculated methane and nitrous oxide emissions based on the different MMS are shown in Table 3-11.

Table 3-11: Calculated manure emissions based on the different manure management systems

MMS	Description	kg deadweight	Manure - methane kg CO2-eq /kg deadweight	Manure - nitrous oxide kg CO2-eq /kg deadweight
Anaerobic lagoon	Manure/effluent discharged to uncovered anaerobic lagoon	787,189	3.70	0.258
Deep bedding	Deep bedding (<60 days)	7,333,117	0.644	1.14
Liquid slurry and pit storage	Liquid/slurry and pit storage below animal confinements - <5 days	592,862	0.021	0.304
	Liquid/slurry and pit storage below animal confinements - 1 month	1,610,126	0.581	0.275
	Liquid/slurry, and pit storage below animal confinements - 14 days	70,397	0.069	0.304
Pasture	Pasture	1,361,839	0.023	0.093
Solid storage	Manure stored for a period of several months in unconfined piles/stacks	273,421	0.208	0.425
Anaerobic digester	Covered pond/anaerobic digestion	1,901,696	0.53	0.199

3.3.6. Waste Treatment Processes

The datasets used for modelling wastewater treatment are provided in Table 3-12.

Table 3-12: Waste treatment processes

Treatment/ Process	Location	Dataset	Data Provider	Reference Year	Proxy?
General waste	NZ	RoW: treatment of municipal solid waste, sanitary landfill	ecoinvent	2023	No

4. Life Cycle Impact Assessment

This chapter contains the results for the impact categories and additional metrics defined in Section 2.7. It shall be reiterated at this point that the reported impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen declared unit (relative approach).

LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

4.1. Assessment Results

This section provides the average assessment results across all farms, expressed per kg of pig carcass weight (deadweight). The total carbon footprint at the farm gate (cradle-to-gate) is shown in Figure 4-1.

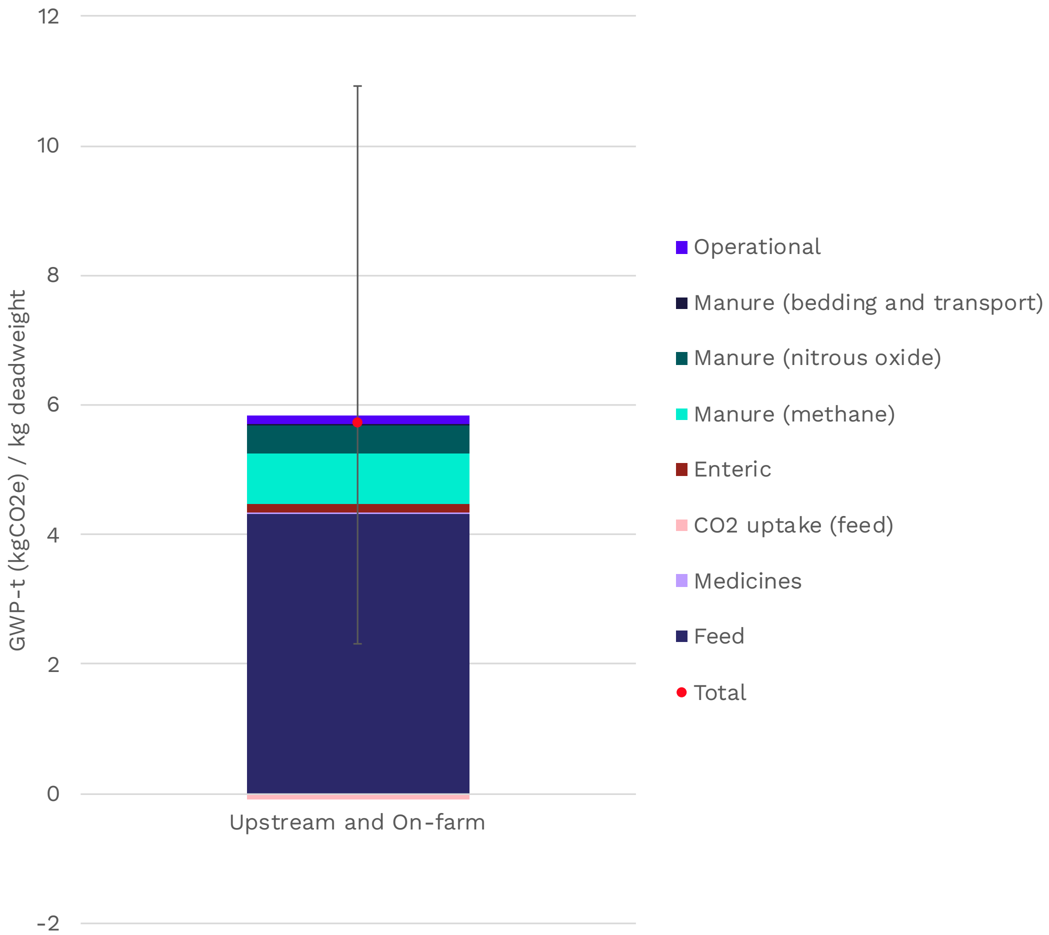


Figure 4-1: Total carbon footprint cradle-to-gate (error bars denote the minimum and maximum values across all participating farms; markers indicate the mean)

Table 4-1 presents ISO 14067 core environmental indicators for the upstream (feed and consumables production) and on-farm (farming operation, enteric and MMS impacts). The total carbon footprint based on processes in these stages is shown in Figure 4-2.

The results for upstream and farming stages include 'balancing-out reporting' for the biogenic CO_2 of feed. This is because downstream stage is not included in the system boundary for this study.

The weighted average results show:

- **Upstream stage** has higher carbon footprint compared to the on-farm stage.
- **Feed** has the greatest impact on the carbon footprint in the upstream stage.
- **Manure management system** contributes significantly to the carbon footprint in the farming stage.

Table 4-1: ISO 14067 core environmental indicator average results across all farms per 1 kg of pig carcass weight (deadweight). Minimum and maximum values across all participating farms are provided in brackets.

Stage	Breakdown	GWP-t	GWP-avi	GWP-bioE	GWP-bioR	GWP-f	GWP-luluc
		kg CO_2-eq.	kg CO_2-eq.	kg CO_2-eq.	kg CO_2-eq.	kg CO_2-eq.	kg CO_2-eq.
Upstream	Feed	4.32 (2.38 to 5.75)	0	0.54 (0.251 to 0.818)	0	2.221 (1.229 to 2.907)	1.56 (0.904 to 2.023)
Upstream	Medicine	0.01 (0.007 to 0.012)	0	0	0	0.01 (0.007 to 0.012)	0
Upstream	CO_2 uptake (feed)	-0.094 (-0.388 to -0.016)	0	0	-0.094 (-0.388 to -0.016)	0	0
On-farm	Enteric	0.148 (0.113 to 0.171)	0	0.148 (0.113 to 0.171)	0	0	0
On-farm	Manure (methane)	0.774 (0.024 to 3.65)	0	0.774 (0.024 to 3.65)	0	0	0
On-farm	Manure (nitrous oxide)	0.437 (0.122 to 1.05)	0	0.437 (0.122 to 1.05)	0	0	0
On-farm	Manure (bedding and transport)	0.022 (0 to 0.083)	0	0.008 (0 to 0.03)	0	0.013 (0 to 0.053)	0
On-farm	Operational	0.127 (0.059 to 0.227)	0	0.007 (0.001 to 0.012)	0	0.121 (0.058 to 0.214)	0

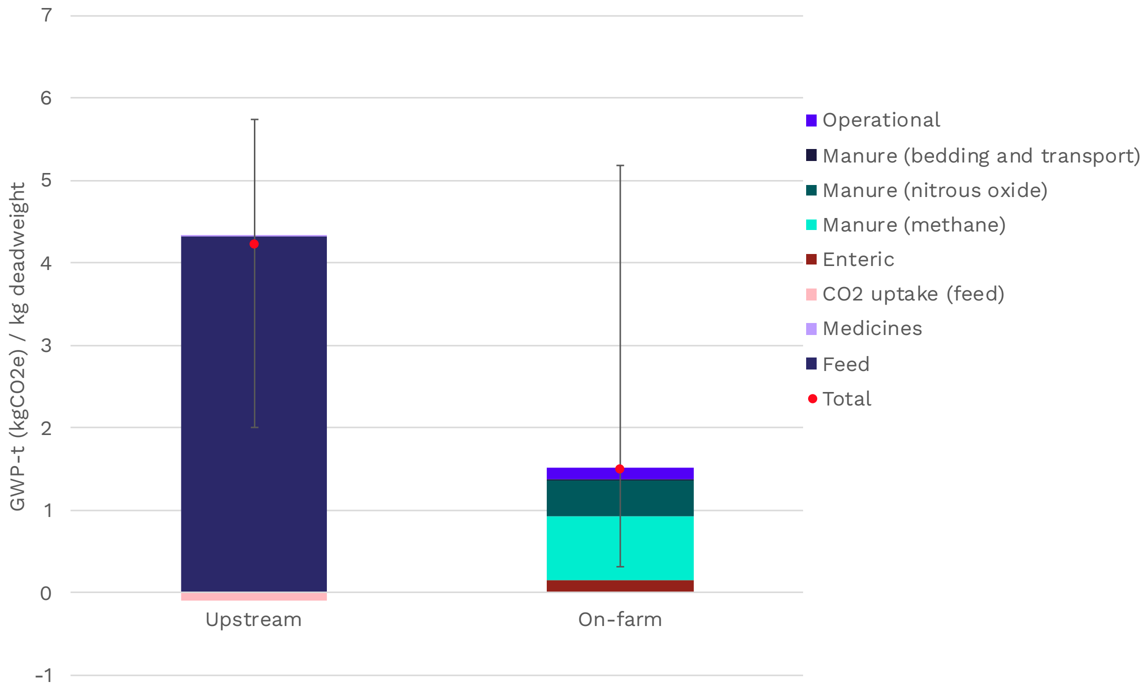


Figure 4-2: Total carbon footprint of different processes in the upstream and on-farm stages (error bars denote the minimum and maximum values across all participating farms; markers indicate the mean)

4.1.1. Results based on feed (upstream)

As shown in Figure 4-2, feed contributes significantly to the total carbon footprint (GWP-t). This section discusses the results based on feed and ingredient types.

4.1.1.1 Feed type

The results based on two main feed types, non-pelletised and pelletised feed, are shown in Figure 4-3. On average, the farms using non-pelletised feed have slightly lower GWP-t compared to the pelletised feed. Feed ingredients have the highest contribution (>90%) to the total feed GWP-t. Farms using pelletised feed have higher energy emissions due to additional energy required during the process of feed pelletising, which includes grinding, steam conditioning, pressing and cooling/drying.

Feed transport also has notable contribution to the feed GWP-t. The amount of contribution is influenced by the mass of feed ingredient and the source location. Feed waste has insignificant contribution to the feed GWP-t.

4.1.1.2 Feed ingredient type

Feed ingredient contributes significantly to the total feed and cradle-to-gate GWP-t results. The results presented in Figure 4-4 are categorised based on the four main feed categories in this study. Note that soya meal and soya are treated separately, as soya meal has a higher emission factor due to additional processing involved, even though farmers may use both ingredients interchangeably as protein sources. The results show:

High soya meal without by-products

- On average, farms using high soya meal without by-products feed have higher carbon impacts compared to other feed ingredient types.
- Soya (meal) has the highest contribution to the total feed GWP-t followed by mineral, additive or vitamin and wheat.

High barley and soya feed without by-products

- Soya feed has the highest contribution to the total feed GWP-t followed by barley, mineral, additive or vitamin and wheat.

High by-products and soya meal

- Similar to other feed categories, soya (meal) is the highest contributor to the total feed GWP-t followed by mineral, additive or vitamin and barley.
- Despite the use of high masses of by-products such as bread, cheese and yoghurt waste products (refer Figure 3-1), the carbon impacts are less significant than the soya (meal), which has a significantly higher carbon footprint.

High mineral and additives with by-products

- Mineral, additive or vitamin is the highest contributor to the carbon impacts, followed closely by wheat and soya.
- Barley has notable contribution to the carbon impacts.

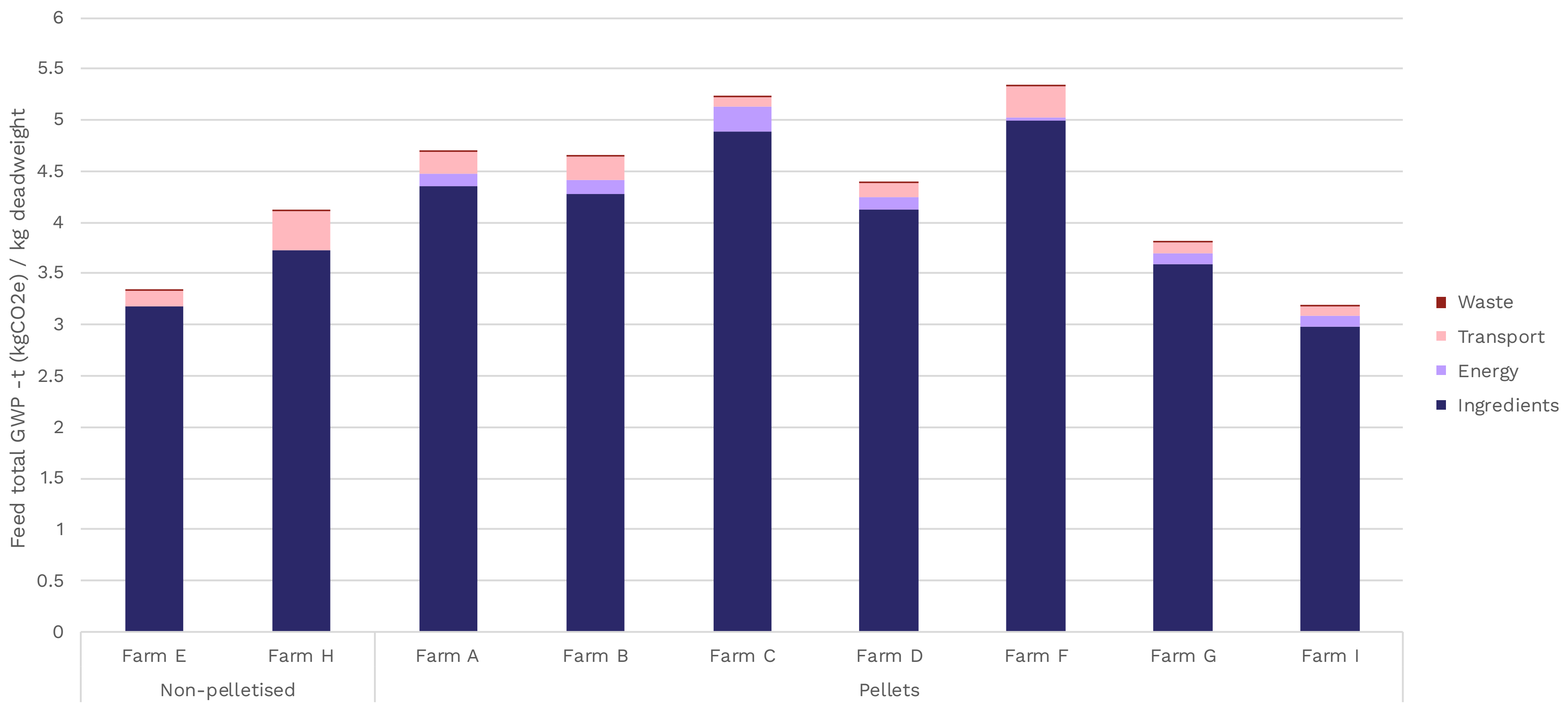


Figure 4-3: Feed results breakdown (GWP-t) based on feed types

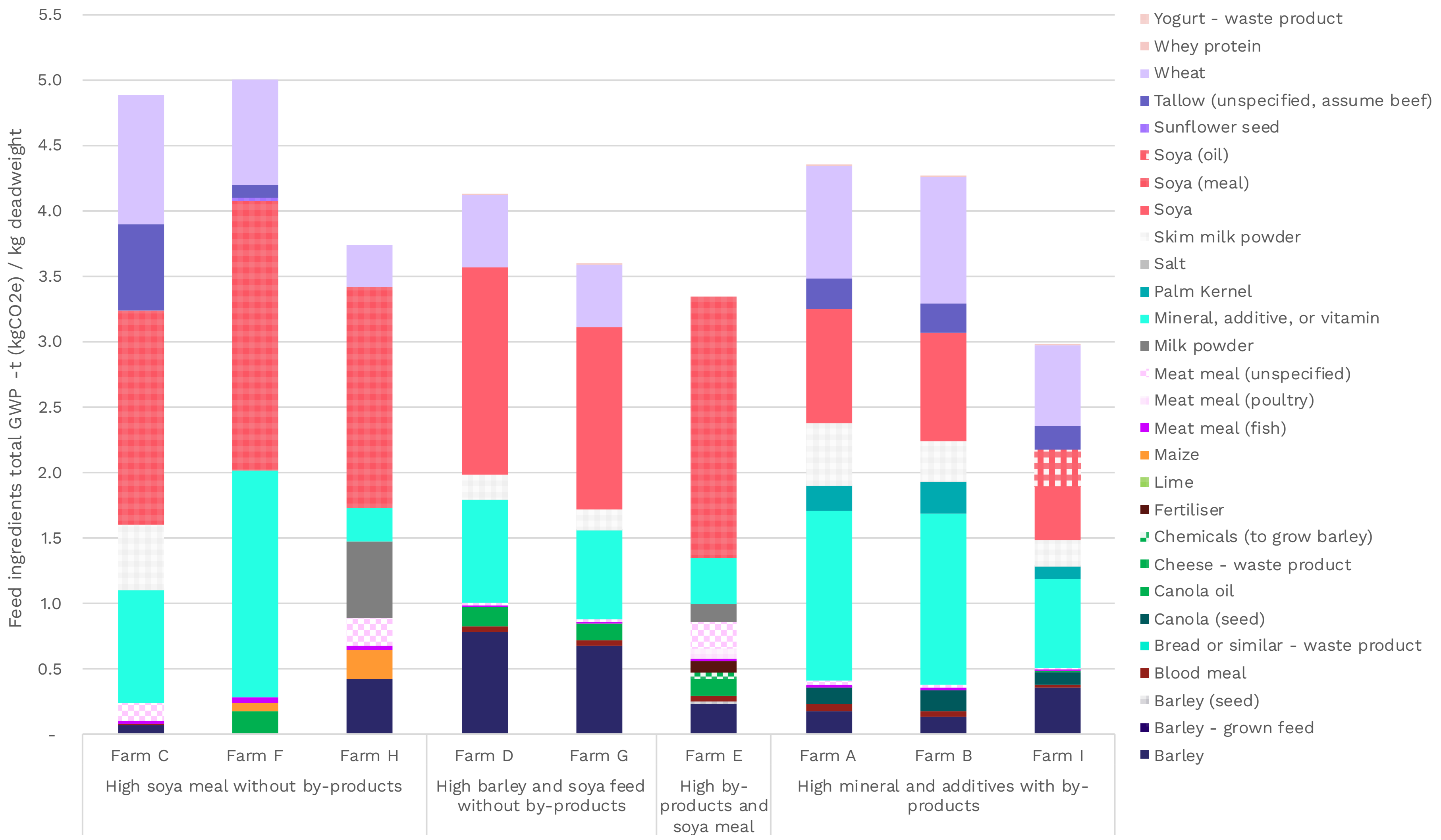


Figure 4-4: Feed results (GWP-t) based on feed ingredient type

4.1.2. Results based on manure (on-farm)

As shown in Figure 4-2, manure contributes significantly to the GWP-t in the on-farm phase. This section discusses the results based on the range of MMS used in the farm case studies, and the carbon impacts for each MMS type.

4.1.2.1 Manure management system used by each farm

The manure GWP-t results presented in Figure 4-5 are expressed relative to the share of MMS types used on each farm. The results show:

- On average, manure methane and nitrous oxide emissions for indoor farms are slightly higher than the outdoor farms (see Figure 4-5). This is influenced by the combination types of MMS used in each farm. The manure methane and nitrous emissions for each type of manure management system are discussed in Section 4.1.2.2.
- Pasture has low methane and nitrous oxide emissions to the GWP-t (refer Farm B). This is because pasture manure is exposed to oxygen on the soil surface when it is spread over a large area, leading to minimal anaerobic conditions and diluted nitrogen taken up by soil.
- Farm H, with most of the manure managed through uncovered pond (anaerobic lagoon), has the highest manure methane and nitrous oxide emissions to the GWP-t on-farm. This is due to the use of high-methane and nitrous oxide-emitting manure system.

4.1.2.2 Manure management system type

The manure GWP-t results shown in Figure 4-5 (right y-axis) are based on manure methane and nitrous oxide emissions for different MMS used in this case study. The results show:

- Anaerobic lagoon has the highest manure methane and nitrous oxide emissions GWP-t compared to other MMS used in this case study due to the ideal anaerobic conditions for methane production.
- Other MMS, such as deep bedding (<60 days), liquid slurry and pit storage (1 month), and anaerobic digester, also have significant manure methane and nitrous oxide emissions GWP-t. This is caused by the conversion factors for methane and nitrous oxide emissions for the different types of MMS influenced by the anaerobic conditions, storage duration, and volatile solids content in New Zealand. Longer storage conditions, as observed for liquid slurry and pit storage, has higher carbon footprint.
- Pasture and solid storage have low methane and nitrous oxide emissions, leading to lower GWP-t compared to other MMS considered in this study.

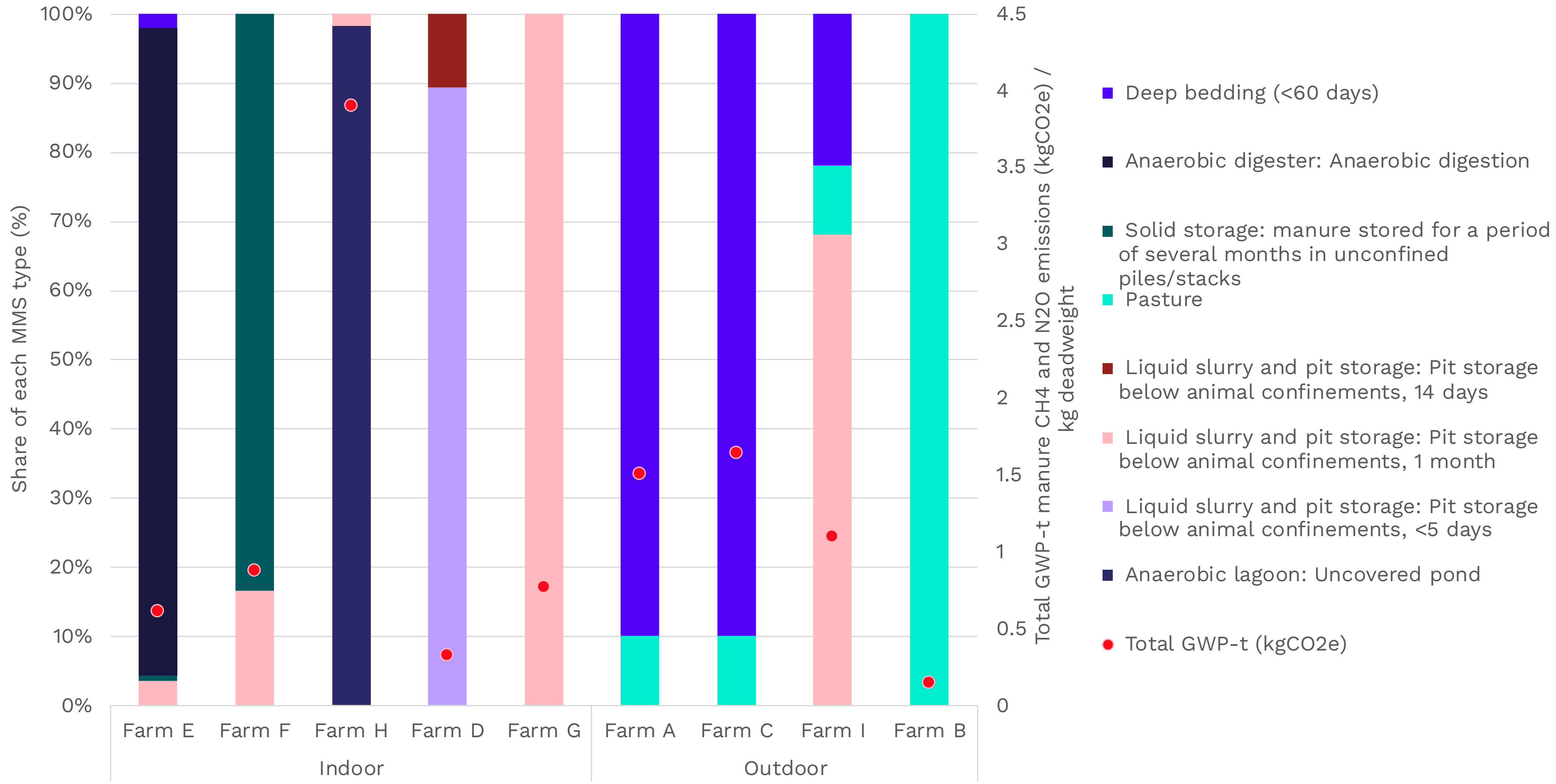


Figure 4-5: Percentage share of each MMS (left y-axis), and carbon impacts of methane and nitrous oxide emissions (right y-axis) for each farm

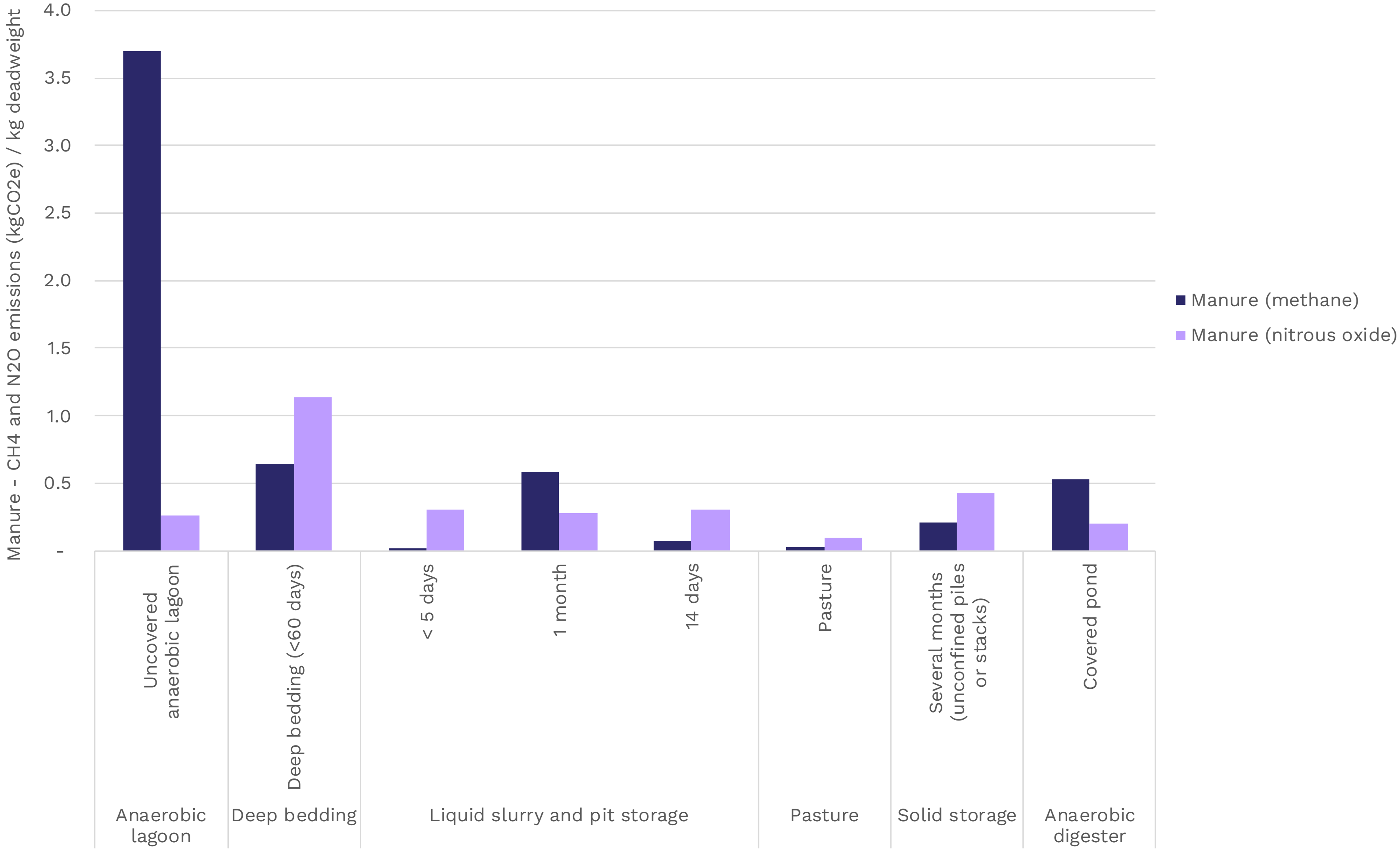


Figure 4-6: Total manure methane and nitrous oxide emissions for each manure management system

4.2. Hotspot analysis

Hotspot analysis examines the percentage contribution of each process to the total impact. Therefore, products with lower overall upstream and on-farm carbon impact will show higher percentage contributions from each process. Percentage contributions should therefore be understood within the context of the relative impact per product and not assumed to imply that the impacts from that process are higher for a particular product.

4.2.1. Hotspot analysis – Farm case studies

The main contributors to GWP-t for each farm are shown in Figure 4-7. On average, feed (upstream) is the highest contributor, about 77% of the GWP-t. Manure methane and nitrous oxide emissions also contribute significantly to the GWP-t, contributing about 12% and 7%, respectively.

4.2.2. Hotspot analysis – Feed ingredient impact breakdown

As the feed ingredient is a significant source of impact for the GWP-t, the carbon footprint based on each ingredient type was studied further. As can be seen in Figure 4-8, most of the impacts come from soya (meal), wheat, mineral, additive or vitamin, and tallow. All of the datasets use economic allocation taken from the Agri-footprint database.

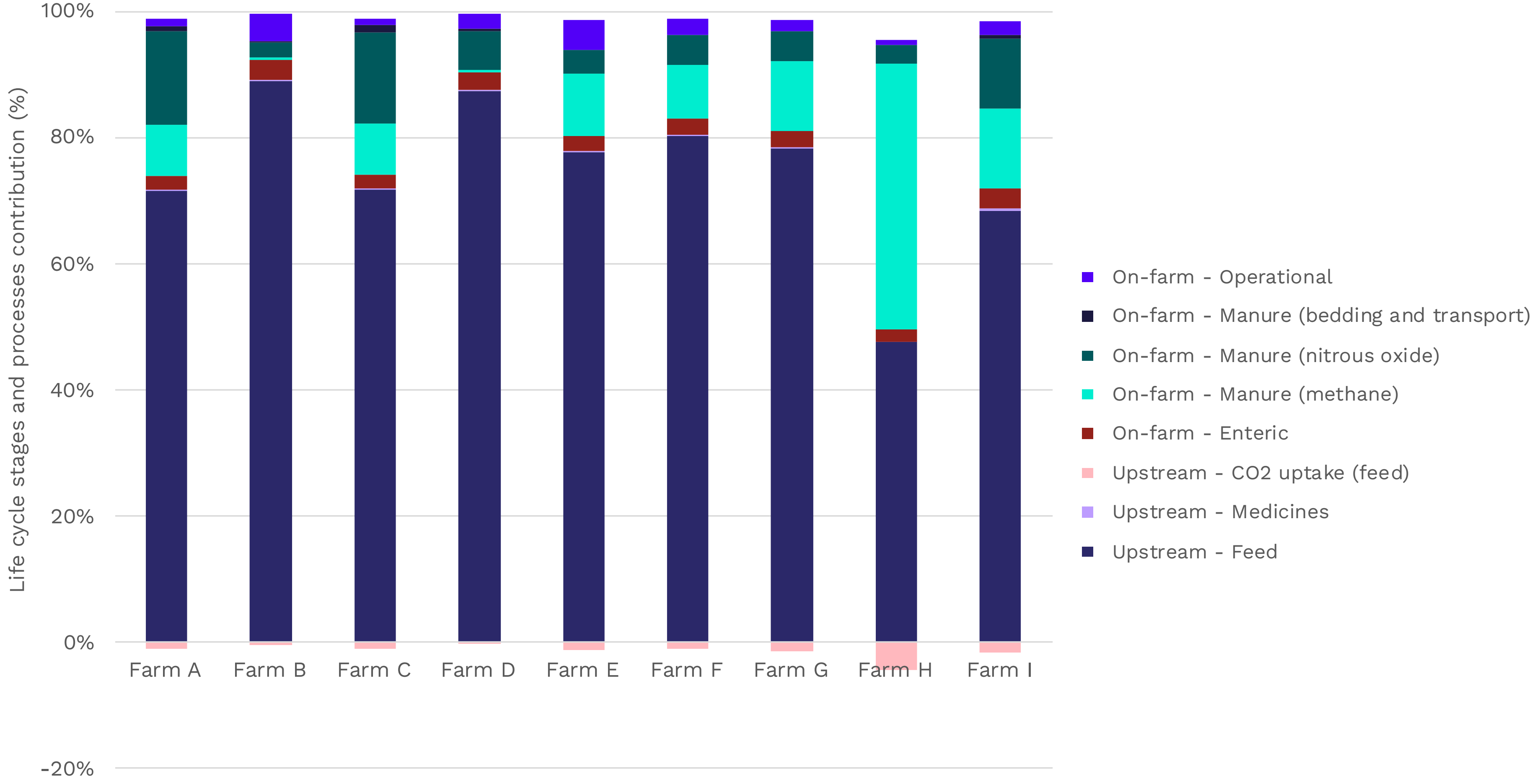
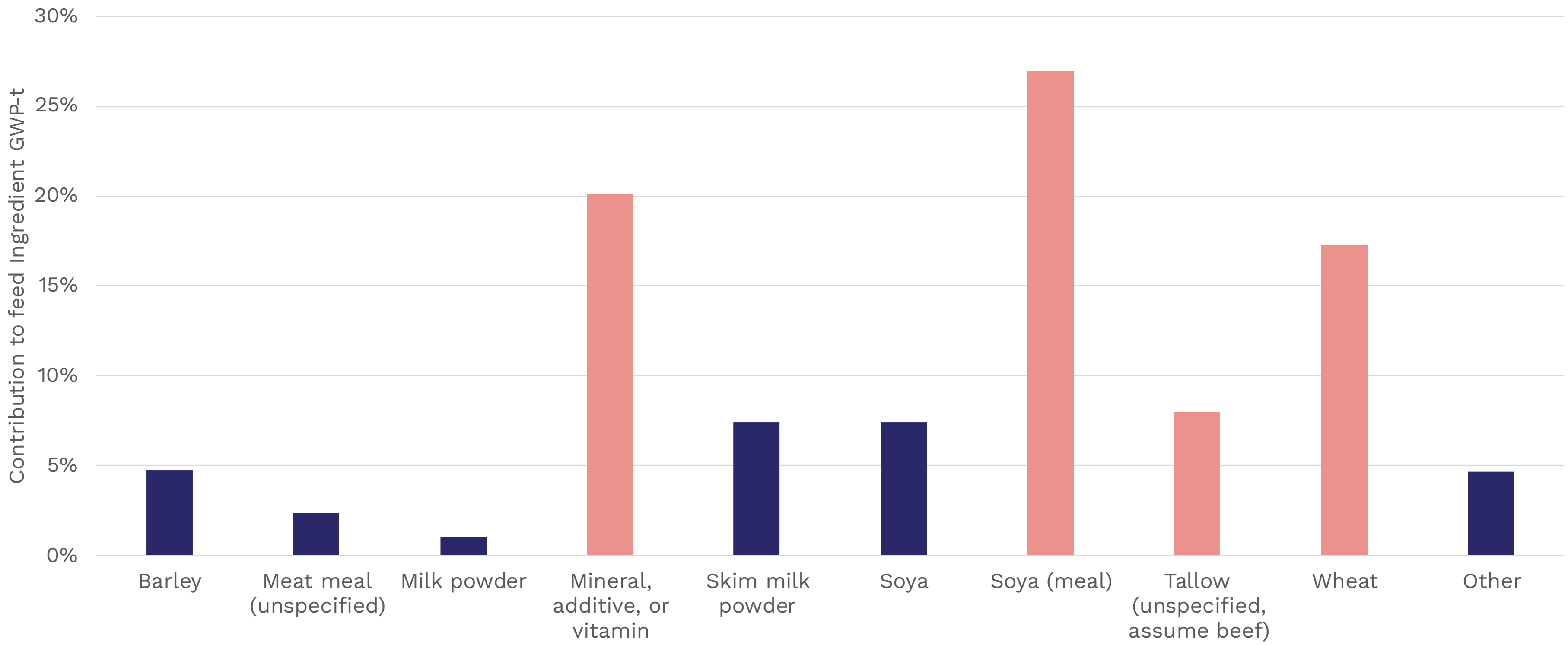


Figure 4-7: Total GWP-t by process for each farm



Note: Ingredients with less than 1% contribution is grouped as 'other'

Figure 4-8: Percentage contribution of different feed ingredients on GWP-t (across all farms)

4.3. Sensitivity Analysis

4.3.1. Economic vs. mass allocation

Allocation choice is a known source of methodological uncertainty in agricultural products, particularly for livestock systems, where feed production contributes a substantial share of total impacts. Feed ingredients are typically co-products of multi-output processes, and the choice of allocation method can influence the environmental burdens assigned to these co-products. To assess the robustness of the results, a sensitivity analysis was conducted comparing economic allocation (used in the main analysis) with mass allocation as shown in Figure 4-9.

The results of the sensitivity analyses show that the mass allocation method for feed ingredients has increased the feed GWP-t by at least 3% or more, when compared to the economic allocation method. The percentage increase in GWP-t is largely driven by the feed ingredient types.

Economic allocation is the primary method used because co-products from feed production vary significantly in market value, and mass allocation does not represent the economic drivers of the system. Additionally, the mass allocation approach used for feed assigns disproportionately high impacts to low-value and high-mass by-products such as soybean meal and protein meals.

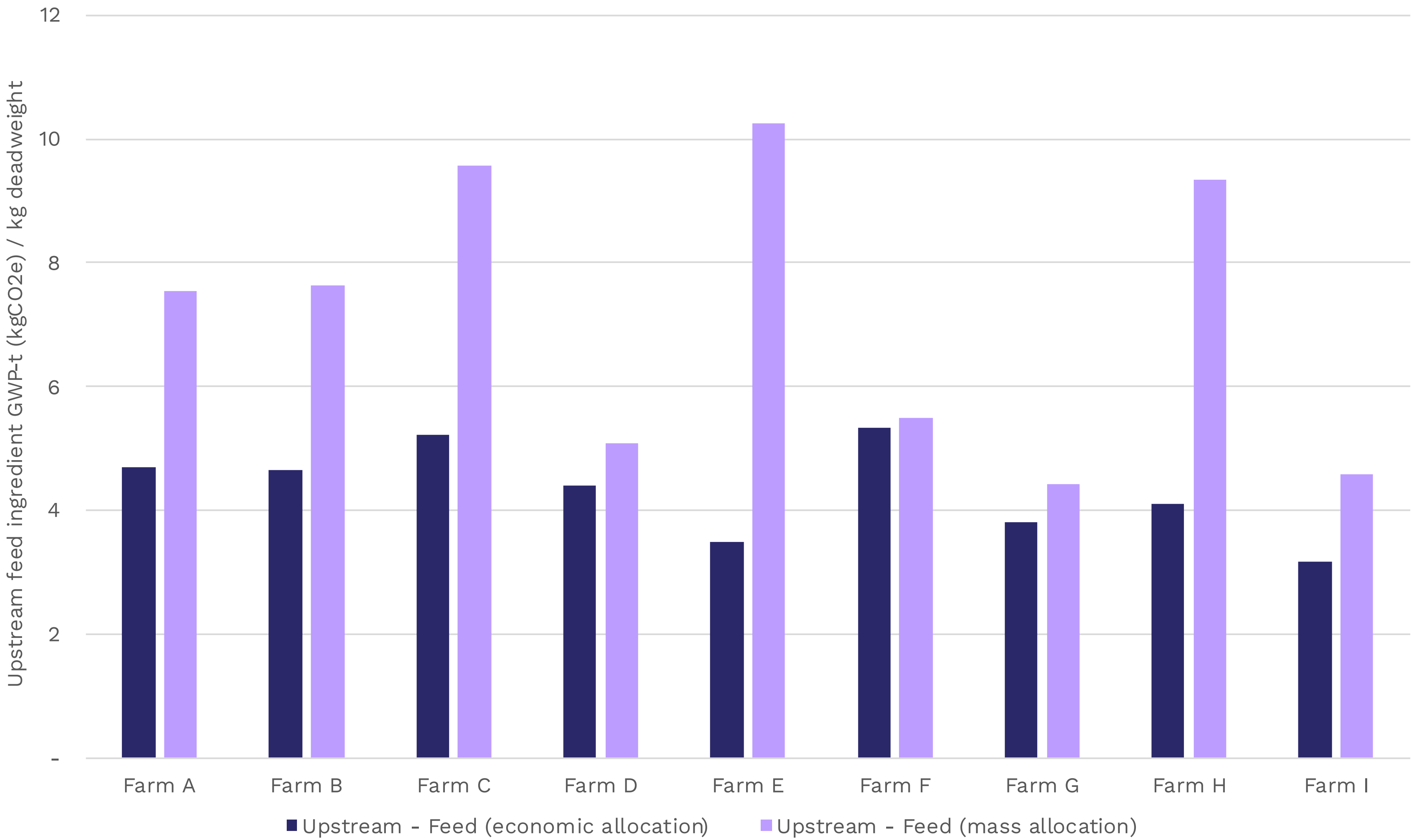


Figure 4-9: Sensitivity results for feed GWP-t (upstream) based on different allocation methods

4.3.2. Soy products vs. lupins

Soya products were identified as feed hotspots. The emission factors for these products are intensive compared to other plant-based protein sources. Australia uses more lupins than soy products in its pork feed mix (Wiedemann, et al., 2016). The lupin emission factor was used instead of soya to determine the impact of this protein source.

The results showed a reduction in economic-based feed GWP-t of about 23% and overall GWP-t of 17%. This suggests that feed emissions can be modulated by changing protein sources to less emission intensive ingredients.

4.3.3. Average vs. maximum on-farm population

As discussed in Section 3.1.2.1, the model is highly sensitive to the on-farm population, which drives biogenic emissions (enteric and MMS emissions). To test the sensitivity, the maximum reported on-farm stock numbers were used instead of the average of beginning and ending stock numbers as described in Section 3.1.2.

The results of the sensitivity analyses show that maximum population method increased biogenic GWP-t (excluding uptake) by about 10% and overall GWP-t by about 2%, when compared to the average population method.

5. Data Quality Assessment

Inventory data quality is judged by its precision (measured, calculated or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied) and representativeness (geographical, temporal, and technological).

To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent background LCA information from the ecoinvent and Agri-footprint databases were used. The LCI datasets from these databases are widely distributed and used with the MS Excel. The datasets have been used in LCA models worldwide in industrial and scientific applications in internal as well as in many critically reviewed and published studies. In the process of providing these datasets they are cross-checked with other databases and values from industry and science.

5.1. Representativeness

The data quality assessment details are provided below.

- **Temporal:** All primary data were collected for the year 2022-2025. All secondary data come from the ecoinvent and Agri-footprint databases and are representative of the years 2019-2023. As the study intended to compare the product systems for the reference year 2022-2025, temporal representativeness is considered to be high.
- **Geographical:** All primary and secondary data were collected specific to the countries or regions under study. Where country-specific or region-specific data were unavailable, proxy data were used. Geographical representativeness is considered to be high.
- **Technological:** All primary and secondary data were modelled to be specific to the technologies or technology mixes under study. Where technology-specific data were unavailable, proxy data were used. Technological representativeness is considered to be high.

5.2. Precision and Completeness

- **Precision:** As the majority of the relevant foreground data are measured data or calculated based on primary information sources of the owner of the technology, precision is considered to be high. Seasonal variations/variations across different manufacturers were balanced out by using yearly averages/weighted averages. All background data are sourced from ecoinvent and Agri-footprint databases with the documented precision.
- **Completeness:** Each foreground process was checked for mass balance and completeness of the emission inventory. No data were knowingly omitted. Completeness of foreground unit process data is considered to be high. All background data are sourced from ecoinvent and Agri-footprint databases with the documented completeness.

5.3. Consistency and Reproducibility

- **Consistency:** To ensure data consistency, all primary data were collected with the same level of detail, while all background data were sourced from the ecoinvent and Agri-footprint databases.
- **Reproducibility:** Reproducibility is supported as much as possible through the disclosure of input-output data, dataset choices, and modelling approaches in this report. Based on this information, any third party should be able to approximate the results of this study using the same data and modelling approaches.

5.4. Model Completeness and Consistency

5.4.1. Completeness

All relevant process steps for each product system were considered and modelled to represent each specific situation. The process chain is considered sufficiently complete and detailed with regards to the goal and scope of this study.

5.4.2. Consistency

All assumptions, methods and data are consistent with each other and with the study's Goal and Scope. Differences in background data quality were minimised by predominantly using LCI data from the ecoinvent and Agri-footprint databases. System boundaries, allocation rules, and impact assessment methods have been applied consistently throughout the study.

6. Interpretation

6.1. Identification of Relevant Findings

On average across all farms, the carbon footprint of 1 kilogram (kg) of New Zealand-produced pork deadweight at the farm gate (cradle-to-gate) was found to be 5.8 kg CO_2-eq. Most emissions (4.3 kg CO_2-eq./kg deadweight) occurred from feed (upstream), followed by manure methane and nitrous oxide emissions, contributing about 0.8 kg CO_2-eq./kg deadweight and 0.4 kg CO_2-eq./kg deadweight, respectively.

Some of the relevant findings from this study are:

1) Feed production dominates the carbon footprint.
   - Feed ingredient has the highest contribution (>90%) to the total feed GWP-t.
   - Farms using pelletised feed have slightly higher energy emissions due to additional energy required for the feed pelletising process.
   - Feed transport also has notable contribution to the feed GWP-t. The amount of contribution is influenced by the mass of feed ingredient and the source location of the feed.
   - Feed ingredient contributes significantly to the total feed and cradle-to-gate GWP-t results. On average, farms using high amount of soya meal and wheat have higher carbon impacts compared to other feed ingredient types.

2) Manure management system (MMS) is the second-largest hotspot after feed due to the significant contribution of manure methane and nitrous oxide emissions.
   - Different MMS produces very different methane and nitrous oxide emissions.
   - Anaerobic lagoon has the highest manure methane and nitrous oxide emissions GWP-t compared to other MMS used in this case study.
   - Other MMS, such as deep bedding (<60 days), liquid slurry and pit storage (1 month) and anaerobic digester, also have significant manure methane and nitrous oxide emissions GWP-t. This is caused by the conversion factors for methane and nitrous oxide emissions for the different types of MMS influenced by the anaerobic conditions, storage duration, and volatile solids content in New Zealand. Longer storage conditions, as observed for liquid slurry and pit storage, has higher carbon footprint.
   - Pasture and solid storage have lower methane and nitrous oxide emissions, leading to lower GWP-t compared to other MMS considered in this study.

6.2. Assumptions and Limitations

The carbon footprint of pork is heavily dependent on the feed type and the life cycle inventory data selected for each feed. The life cycle impact assessment results are therefore highly dependent on the choice of database. The databases used are:

- ecoinvent database version 3.9.1 (Wernet, 2016)
- Agri-Footprint version 5 (Mérieux NutriSciences | Blonk, 2019).

The methodology used to calculate the number of pigs on farm assumes steady state on-farm populations. Farms did not report days alive prior to slaughtering, and only some farms reported the type of pigs sold. Potential approaches to address these data gaps, including the use of country-level averages and IPCC-based estimation methodologies, were discussed extensively with NZ Pork. However, because this information was not consistently collected during the farm data collection process, applying these methodologies would have required significant reliance on assumptions, averages, and estimated proxy data. NZ Pork considered this would introduce additional uncertainty and potentially reduce the accuracy and representativeness of farm-level results. As a result, the treatment of non-steady state farm systems remains a limitation of this study.

6.3. Results of Sensitivity Analysis

6.3.1. Sensitivity Analysis

Sensitivity analyses were performed to test the sensitivity of the results towards changes in allocation method. The analyses showed that the mass allocation method for feed ingredients has increased the feed GWP-t by at least 3% or more when compared to the economic allocation method. The percentage increase in GWP-t is largely driven by the feed ingredient types.

Economic allocation is the primary method used because co-products from feed production vary significantly in market value, and mass allocation does not represent the economic drivers of the system. Additionally, the mass allocation approach used for feed assigns disproportionately high impacts to low-value and high-mass by-products such as soybean meal.

Soya products were identified as feed hotspots. The emission factors for these products are intensive compared to other plant-based protein sources. The results showed a potential decrease in economic-based feed GWP-t of about 23% and overall GPW-t of 17% by replacing soy products with lupins. This suggests that feed emissions can be modulated by changing protein sources to less emission intensive ingredients.

The model is highly sensitive to the on-farm population, which drives biogenic emissions (enteric and MMS emissions). To test the sensitivity, the maximum reported on-farm stock numbers were used instead of the average of beginning and ending stock numbers. The results of the sensitivity analyses show that maximum population method increased biogenic GWP-t (excluding uptake) by about 10% and overall GWP-t by about 2%, when compared to the average population method.

6.4. Conclusions and Recommendations

6.4.1. Conclusions

The results show clear opportunities to reduce emissions in New Zealand pork production. Feed is the biggest driver, followed by manure management. This means the strongest reduction opportunities are likely to come from lower-emission feed ingredients, better sourcing and processing, and lower-emission manure systems.

The study also highlights the need for better farm data. More consistent information on pig numbers, feed inputs and manure handling would improve future carbon footprint estimates and help target the most effective actions.

Overall, this study gives NZ Pork and the wider industry a credible baseline and a clear starting point for emissions reduction.

6.4.2. Recommendations

Feed production

- Prioritise low-emission feed ingredients and alternative protein sources such as lupins, rapeseed, canola meal, peas, etc.
- Review sourcing options for high-emission ingredients, such as soya products. While Brazilian soy meal is modelled as a conservative baseline based on farm sourcing data, lower-impact origins, such as the US, should be prioritised where feasible.
- Increase the use of suitable local feed ingredients or by-products.
- Use low-carbon electricity for pelletised feed production where possible.
- Develop and use New Zealand-specific emission factors for feed ingredients over time.

Manure management system (MMS)

- Prioritise low-emission manure systems where practical, such as covered storage.
- Assess options to cover liquid manure stores or upgrade to covered anaerobic systems for methane capture.
- Reduce storage time where feasible, particularly when manure emissions are highest while ensuring compliance with regulatory requirements.
- Improve monitoring of manure volumes and storage conditions to support more accurate estimates and better decision-making.

Future studies

- Incorporate additional farm-level metrics, such as pig types and slaughter age to enable a more refined and direct approach to emissions modelling.
- Enhance the reporting of feed inputs—including country of origin, specific pellet formulations, and supplier-level data—to improve the relevancy and precision of the emission factors used.
- Seek higher resolution in the manure management data by including specific handling pathways and multi-stage treatment configurations.
- Use better data to update this baseline and track progress over time.

7. References

Bjørn, A., & Hauschild, M. (2015). Introducing carrying capacity-based normalisation in LCA: framework and development of references at midpoint level. *The International Journal of Life Cycle Assessment, 20*(7), 1005-1018. doi:10.1007/s11367-015-0899-2

De Jaegher, N. (2024). *LCA comparison between oral and intravenous antibiotics: The ciprofloxacin case.* Retrieved from https://thesis.dial.uclouvain.be/server/api/core/bitstreams/38fd34e9-678f-4440-b3c9-edb7e5c7c015/content

IPCC. (2019). Volume 4: Agriculture, Forestry and Other Land Use. In *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (Chapter 10: Emissions from livestock and manure management).

IPCC. (2021). *Climate Change 2021: The Physical Science Basis.* Geneva: IPCC.

ISO. (2006b). *ISO 14044: Environmental management – Life cycle assessment – Requirements and guidelines.* Geneva: International Organization for Standardization.

ISO. (2018). *ISO 14067:2018 Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification.* Geneva: International Organization for Standardization.

JRC. (2010). *ILCD Handbook: General guide for Life Cycle Assessment – Detailed guidance. EUR 24708 EN* (1st ed.). Luxembourg: Joint Research Centre.

Kaji, R., Shimizu, T., Kikuchi, Y., & Ohara, S. (2025). Life cycle assessment of active pharmaceutical ingredient production: A case study of Citicoline. *Process Safety and Environmental Protection*.

Mérieux NutriSciences | Blonk. (2019). Agri-footprint.

NZ Pork. (2022). *Submission on Draft Waitaki District Plan (August 2022).*

Ritchie, H. (2024). *Updating emissions calculations for pigs in the New Zealand Greenhouse Gas Inventory Report.* New Zealand Ministry for Primary Industries.

Wernet, G. B.-R. (2016). The ecoinvent database version 3 (part I): overview and methodology. *The International Journal of Life Cycle Assessment, 21(9)*([online]), 1218–1230.

Wiedemann, G. S., McGahan, E. J., & Murphy, C. M. (2016). Environmental impacts and resource use from Australian pork production assessed using life-cycle assessment. *Animal Production Science*, 1418–1431. doi:http://dx.doi.org/10.1071/AN15881

List of figures

List of tables

Abbreviations and glossary

Term	Definition
avi	Aviation
CF	Characterization factor
GWP	Global Warming Potential (Climate Change)
ILCD	International Cycle Data System
ISO	International Organization for Standardization
kgkm	Kilogram-kilometre
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
luluc	Land use and land use change
MMS	Manure management system
NZ	New Zealand
ODP	Depletion potential of the stratospheric ozone layer
tkm	tonne-kilometre

Glossary

Life cycle

A view of a product system as "consecutive and interlinked stages … from raw material acquisition or generation from natural resources to final disposal" (ISO 14040:2006, Section 3.1). This includes all material and energy inputs as well as emissions to air, land and water.

Life Cycle Assessment (LCA)

"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040:2006, Section 3.2)

Life Cycle Inventory (LCI)

"Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle" (ISO 14040:2006, Section 3.3)

Life Cycle Impact Assessment (LCIA)

"Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product" (ISO 14040:2006, Section 3.4)

Life cycle interpretation

"Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations" (ISO 14040:2006, Section 3.5)

Environmental Product Declaration (EPD)

"Independently verified and registered document that communicates transparent and comparable information about the life-cycle environmental impact of products."

Product Category Rule (PCR)

"Defines the rules and requirements for EPDs of a certain product category."

Functional / Declared unit

"Quantified performance of a product system for use as a reference unit." (ISO 14040:2006, Section 3.20)

Functional unit = LCA/EPD covers entire life cycle "cradle to grave".

Declared unit = LCA/EPD is not based on a full "cradle to grave" LCA.

Allocation

"Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems" (ISO 14040:2006, Section 3.17)

Foreground system

"Those processes of the system that are specific to it … and/or directly affected by decisions analysed in the study." (JRC, 2010, 97) This typically includes first-tier suppliers, the manufacturer itself and any downstream life cycle stages where the manufacturer can exert significant influence. As a general rule, specific (primary) data should be used for the foreground system.

Background system

"Those processes, where due to the averaging effect across the suppliers, a homogenous market with average (or equivalent, generic data) can be assumed to appropriately represent the respective process … and/or those processes that are operated as part of the system but that are not under direct control or decisive influence of the producer of the good…." (JRC, 2010, 97-98) As a general rule, secondary data are appropriate for the background system, particularly where primary data are difficult to collect.

Closed-loop and open-loop allocation of recycled material

"An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties."

"A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials."

(ISO 14044:2006, Section 4.3.4.3.3)

Critical Review

"Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment" (ISO 14044:2006, Section 3.45).

Applicability and limitations

Statement of rights, title and interest

This document, its design and content has commercial value to thinkstep-anz, which owns all right, title and interest, including without limitation all intellectual property rights to it.

thinkstep-anz grants the user a revokable, non-exclusive, non-transferable licence to use the document and its contents for the purposes set out in the Proposal, and for no other purpose. thinkstep-anz does not grant a licence to reproduce or distribute the intellectual property without its written permission.

Restrictions and intended purpose

This report has been prepared by thinkstep-anz with all reasonable skill and diligence within the agreed scope, time and budget available for the work. thinkstep-anz does not accept responsibility of any kind to any third parties who make use of its contents. Any such party relies on the report at its own risk. Interpretations, analyses, or statements of any kind made by a third party and based on this report are beyond thinkstep-anz's responsibility.

If you have any suggestions, complaints, or any other feedback, please contact us at: feedback@thinkstep-anz.com

Legal interpretation

Opinions and judgements expressed herein are based on our understanding and interpretation of current regulatory standards and should not be construed as legal opinions. Where opinions or judgements are to be relied on, they should be independently verified with appropriate legal advice.

About thinkstep-anz

We're an independent and award winning sustainability firm with offices in Australia and Aotearoa New Zealand – and a global reach.

Our team works with you to put sustainability at the heart of your business, to set you up to succeed and inspire you to keep achieving more.

We focus on what matters and use data to understand organisations and their impact. We provide practical resources and ideas that move you ahead.

We create value for organisations like yours, bringing our technical expertise and business know-how to help you tell your story. It's what we've been doing since 2006.

Our services cover:

LCA and EPD services

Measure environmental impacts to support informed decision-making.

- Life Cycle Assessment (LCA)
- Environmental Product Declarations (EPD)
- Product carbon footprinting
- Critical review

Carbon footprint services

Calculate your carbon footprint, develop net zero strategies and targets.

- Carbon footprint: Scope 1 & 2
- Scope 3
- Carbon reduction strategy
- Net zero targets

Circular economy services

Identify opportunities to improve resource efficiency and reduce waste.

- Material Circularity Indicator
- Circular economy workshops
- Circular economy strategy
- Circularity declaration

Sustainability strategy

Turn sustainability priorities into practical roadmaps and targets.

- Materiality assessment
- Double materiality
- Sustainability strategy
- ESG policies

ESG and climate reporting

Prepare reports and disclosures supported by robust data and practical implementation.

- Climate related disclosures
- Disclosurekit
- GRI and sustainability reports
- Greenwashing risk review

Communications and design services

We turn complex data into graphics, summary reports and presentations.

- Sustainability reports
- Summary reports
- Board presentations
- Case studies
- Infographics

Software, data and tools

- LCA calculators
- LCA software
- Material Circularity Indicator
- Spend based emission factors
- Residual grid mix factors
- LCA data
- Carbon reporting software

Upskilling and training

- LCA training
- Carbon workshops
- Supplier workshops
- Training for industry associations
- Taylored in-house workshops
- Greenwash risk training

thinkstep anz

Succeed sustainably

www.thinkstep-anz.com

We don't just talk about sustainability – we practise it too

Certified B Corporation | SCIENCE BASED TARGETS – DRIVING AMBITIOUS CORPORATE CLIMATE ACTION | UN GLOBAL COMPACT | CLIMATE LEADERS COALITION – ON A MISSION TO REDUCE EMISSIONS IN NEW ZEALAND

thinkstep ltd (NZ)

11 Rawhiti Road,
Pukerua Bay 5026
+64 4 889 2520

Wellington | Auckland | Hamilton | Christchurch | Tauranga

thinkstep pty ltd (AU)

25 Jubilee Street,
South Perth WA 6151,
+61 2 8007 3330

Sydney | Perth | Canberra | Adelaide | Melbourne

meet@thinkstep-anz.com

thinkstep-anz

thinkstep-anz