# Carbon Performance Assessment of Food Producers Discussion Paper

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Transition Pathway Initiative

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## Executive Summary

The Transition Pathway Initiative (TPI) is a global effort led by asset owners and supported by asset managers. Its mission is to assess the progress of large corporations on the transition to a low-carbon economy, supporting efforts by investors to address climate change. TPI research is led by the TPI Global Climate Transition Centre at the London School of Economics (LSE), in collaboration with FTSE Russell.

TPI assesses companies' progress in two ways: (1) Management Quality and (2) Carbon Performance. Management Quality is a measure of the quality of companies' governance/management of greenhouse gas (GHG) emissions and climate issues. Carbon Performance is a quantitative comparison of companies' current and targeted carbon emissions against international climate goals.

This discussion paper proposes a methodology to assess the Carbon Performance of food producers. It incorporates company feedback on the individual company assessments we have undertaken. We are publishing it now to solicit additional feedback from interested parties, with the aim of improving the methodology still further. To date, TPI has developed methodologies to assess the Carbon Performance of 10 high-carbon sectors, including electricity utilities, oil and gas producers, and high-carbon industrial and transport sectors.

To assess the food sector's Carbon Performance, we extend the Sectoral Decarbonization Approach that we have applied to other sectors. This approach is based on estimating companies' GHG emissions intensity, with emissions and activity – the numerator and denominator of emissions intensity respectively – defined in ways that are appropriate to the sector in question. Companies' emission intensities are compared with three benchmark emissions pathways that reflect the goals of the 2015 Paris Agreement on climate change: 1.5°C, Below 2°C, and 2°C. By applying the methodology, it should be possible to answer the question: is a company aligned with the goals of the Paris Agreement, as translated to its sector?

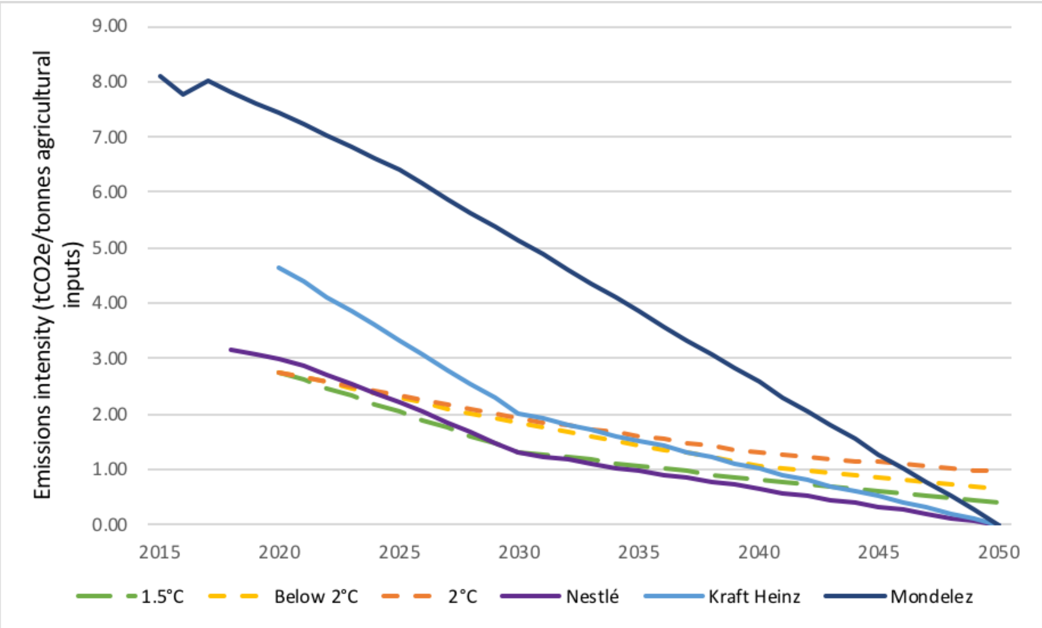
The food sector is significant both to investors and the climate. The world's 20 largest publicly listed food producers had a market capitalisation of over US$710bn in 2021, and the entire food sector contributes, either directly or indirectly, to 19-32% of annual global GHG emissions. Most of the food processing sector's emissions are driven by upstream Scope 3 emissions from purchased goods and services, especially the emissions associated with crop and livestock production, and land-use change.

In developing a methodology for food producers' Carbon Performance, we have had to overcome unique challenges. The main challenge in producing low-carbon benchmark scenarios is that the Integrated Assessment Models (IAMs) used for food-sector emissions pathways do not provide emissions/production figures consistent with disclosure provided by food processing companies, nor do they account for the high level of product differentiation in the sector. To overcome this, the benchmarks are calculated in two steps: (1) we determine the initial (2019) value of the food sector's emissions intensity using data on the real food system from the Food and Agriculture Organization of the United Nations (FAO), as well as academic literature; (2) we use scenario data from three leading IAMs to estimate the *change* in emissions intensity from the initial year as the sector's low-carbon transition unfolds. These models crucially include land use modules. This enables us to make detailed projections of agricultural emissions and output due to the close link between agricultural production and land use.

On the company side, there are many data challenges. The food sector is complicated by a relative lack of standardised, disaggregated, quantified disclosure of companies' raw material inputs, production in physical units, and upstream Scope 3 emissions. It is further complicated by its supply chains, with many ingredients going into diverse product portfolios. Food producers' product portfolios are likely to be a principal driver of their emissions intensities, depending on the emissions factors of the main commodities they source. Commodity emissions factors themselves can vary widely based on geography, agricultural technique, and other farm-specific factors. There is a lack of data on agricultural input volumes across companies, meaning that in some cases input quantities need to be approximated using adjusted output quantities.

We have applied the methodology to the world's ten largest publicly listed food producers, measured in terms of free-float market capitalisation (data from FTSE Russell). Of these ten companies, our analysis of public disclosures from early 2022 revealed that only three disclosed Scope 3 emissions from purchased agricultural inputs -- Kraft Heinz, Nestlé, and Mondelez. Our analysis shows that each of these three companies has set a net zero target across all scopes (including upstream Scope 3 emissions), which aligns with our 1.5°C benchmark by 2050 (Figure ES 1). However, the companies' starting intensities vary greatly, reflecting differing company exposure to high-carbon agricultural inputs today. In addition, the companies also differ in their medium-term alignment, with both Kraft Heinz and Nestlé having set more ambitious medium-term targets.

**Figure ES1: Emissions pathways Nestlé, Mondelez and Kraft-Heinz up to 2050.**



## 1. Introduction

The Transition Pathway Initiative (TPI) is a global initiative led by asset owners and supported by asset managers. Established in January 2017, TPI is now supported by over 130 investors globally with over $50 trillion of combined assets under management and advice.[1]

TPI research is led by the TPI Global Climate Transition Centre at the London School of Economics (LSE), in collaboration with FTSE Russell.

On an annual basis, TPI assesses how companies are preparing for the transition to a low-carbon economy in terms of their:

- *Management Quality* – all companies are assessed on the quality of their governance/management of greenhouse gas emissions and of risks and opportunities related to the low-carbon transition;
- *Carbon Performance* – in selected sectors, TPI quantitatively benchmarks companies' carbon emissions against international climate targets, including as part of the 2015 UN Paris Agreement.

TPI publishes the results of its analysis through an open access online tool: www.transitionpathwayinitiative.org. Investors are encouraged to use the data, indicators and online tool to inform their investment research, decision making, engagement with companies, proxy voting, and dialogue with fund managers and policy makers, bearing in mind the Disclaimer that can be found in section 6 of this report. Further details of how investors can use TPI assessments can be found on the TPI Global Climate Transition Centre website.

The purpose of this note is to provide an overview of the methodology being followed by TPI in its assessment of the Carbon Performance of food companies.

[1] As of December 2022.

## 2. The basis for TPI's Carbon Performance assessment: the Sectoral Decarbonization Approach

TPI's Carbon Performance assessment is based on the Sectoral Decarbonization Approach (SDA).[1] The SDA translates greenhouse gas emissions targets made at the international level (e.g., under the Paris Agreement to the UN Framework Convention on Climate Change) into appropriate benchmarks, against which the performance of individual companies can be compared.[2]

The SDA is built on the principle of recognising that different sectors of the economy (e.g., food production, electricity generation and automobile manufacturing) face different challenges arising from the low-carbon transition, including where emissions are concentrated in the value chain, and how costly it is to reduce emissions. Other approaches to translating international emissions targets into company benchmarks have applied the same decarbonisation pathway to all sectors, regardless of these differences.[2]

Therefore, the SDA takes a sector-by-sector approach, comparing companies within each sector against each other and against sector-specific benchmarks, which establish the performance of an average company that is aligned with international emissions targets.

Applying the SDA can be broken down into the following steps:

- A global carbon budget is established, which is consistent with international emissions targets, for example keeping global warming below 2°C. To do this rigorously, some input from a climate model is required.
- The global carbon budget is allocated across time and to different regions and industrial sectors. This typically requires an Integrated Assessment Model (IAM), and these models usually allocate emissions reductions by region and by sector according to where it is cheapest to reduce emissions and when (i.e., the allocation is cost-effective). Cost-effectiveness is, however, subject to some constraints, such as political and public preferences, and the availability of capital. This step is therefore driven primarily by economic and engineering considerations, but with some awareness of political and social factors.
- In order to compare companies of different sizes, sectoral emissions are normalised by a relevant measure of sectoral activity (e.g., physical production, economic activity). This results in a benchmark pathway for emissions intensity in each sector:

$$\text{Emissions intensity} = \frac{\text{Emissions}}{\text{Activity}}$$

  Assumptions about sectoral activity need to be consistent with the emissions modelled and therefore should be taken from the same economy-energy modelling, where possible.
- Companies' recent and current emissions intensity is calculated, and their future emissions intensity can be estimated based on emissions targets they have set (i.e., this

[2] Another initiative that is also using the SDA is the Science Based Targets Initiative (http://sciencebasedtargets.org/).

assumes companies exactly meet their targets).[3] Together these establish emissions intensity pathways for companies.

- Companies' emissions intensity pathways are compared with each other and with the relevant sectoral benchmark pathway.

[3] Alternatively, future emissions intensity could be calculated based on other data provided by companies on their business strategy and capital expenditure plans.

# 3. Applying the SDA to the food sector

## 3.1. The food sector's role in climate change

The food sector is of global importance, with the combined market capitalisation of the 20 largest food producers amounting to US$710 billion in 2021.[4] In addition to its purely financial importance to investors, the sector is also a crucial driver of economic development, poverty alleviation, and rural employment [3]. For example, Agriculture, Forestry, and Other Land Use (AFOLU), which intersects considerably with the food sector, accounted for 3.7% of global GDP in 2017 [4].

Food producers are one of the most important actors in the global land use system and the food sector is associated with high greenhouse gas (GHG) emissions, as well as other environmental impacts including biodiversity loss. Whilst global emissions from the food sector are uncertain, estimates range from 19-32% [5]–[10], placing the food sector on par with the oil and gas industry's contribution to global GHG emissions. Agriculture constitutes 80% of total food sector emissions [8], [9] , with the remainder being associated with the processing, transport and disposal of food products. The largest single contributor to agricultural emissions is enteric fermentation, which accounts for 40% of total agricultural emissions, followed by manure (25%) and emissions associated with the use of synthetic fertilizers (13%) [11].

To stabilize temperatures at well below 2°C, the food sector must dramatically reduce its GHG emissions, which necessitates a fundamental transformation [12]–[15]. Supply-side mitigation options rely heavily on efficient land use and livestock management, and enhancing carbon removals [16], [17]. Reducing the emissions from agriculture-driven by land use and land use change (LULUC) is also integral to mitigating farm-stage impacts, as LULUC emissions account for around 30% of total food sector emissions [7],[18]. Supply-side mitigation options beyond the farm gate include switching from fossil fuels to renewable energy and improving energy efficiency [9]. Demand-side strategies are also important for reducing the food sector's emissions, as large-scale switching to plant-based diets could reduce food's emissions by almost 50% [10].

The food sector is not only one of the greatest contributors to climate change, it is also one of the most vulnerable to adverse climate impacts, further highlighting the importance of this sector to mitigate and adapt to climate change.

## 3.2. Our definition of the food sector: Food Producers

Applying the SDA methodology to the food sector requires a definition of the sector. According to the Industry Classification Benchmark (ICB) v2.6 [19], the Food Producers sector (3570) is nested in Consumer Goods and consists of the Food Products (3577) and Farming, Fishing, and Plantations (3573) subsectors. The Food Products subsector includes companies that manufacture meat, fruit, dairy, and frozen seafood products, as well as pet food and dietary supplements, but excludes producers of beverages. The farming subsector includes companies that own non-tobacco plantations, grow crops, raise livestock, or operate fisheries.

[4] Based on data provided by FTSE-Russell

In practice, the largest companies in the Food Producers sector by free float market capitalisation, which are the focus of our assessment, are within the Food Products subsector. However, the assessments also reflect the greenhouse gas emissions of the Farming subsector, owing to the inclusion of upstream Scope 3 emissions in the benchmarks and company assessments.

## 3.3. Deriving the benchmark paths

In general, the key inputs to calculating TPI benchmark paths in any sector are:

a) a time path for GHG emissions, which is consistent with meeting a particular climate target (e.g., limiting global warming to 1.5°C);

b) a breakdown of this economy-wide emissions path into emissions from key sectors (the numerator of sectoral emissions intensity), including the sector in focus;

c) consistent estimates of the time path of physical production from, or economic activity in, these key sectors (the denominator of sectoral emissions intensity).

A key challenge in the food industry is to estimate emissions and physical production consistently, both for the benchmarks and for the companies being compared with those benchmarks. The challenge mainly stems from the high complexity of the sector, in particular the transformation of inputs at various stages, as well as co-products from the same basic agricultural commodity. One practical problem it creates is that the IAMs we depend on for future food-sector emissions pathways do not provide emissions and production figures on a basis that is consistent with the boundary most suitable for measuring company emissions (see Section 3.5). In addition, these IAMs do not provide a high level of product differentiation.

We overcome these challenges by calculating the benchmark paths in two steps. The first step is to pin down the initial (2019) value of the food sector's emissions intensity. We do this using Food and Agriculture Organisation of the United Nations (FAO) data and various emissions factors obtained from a major literature review (see Section 3.4). The second step is to use IAM scenarios to estimate the *change* in emissions intensity from the base or initial year as the sector's low-carbon transition unfolds. In particular, we use scenario data from three IAMs (IMAGE, REMIND-MAgPIE and MESSAGE-GLOBIOM) to estimate the appropriate emissions reduction pathways to apply to the base year emissions intensity (Section 3.5). These IAMs differentiate themselves from others by including detailed land use modules. Owing to the close link between agricultural production and land use, they are therefore capable of providing relatively detailed projections of agricultural emissions and output.

Using this approach, we derive three benchmark emissions paths linked to the goals of the 2015 UN Paris Agreement on climate change (specifically Article 2), against which companies are evaluated by TPI:

1. A **1.5 Degrees** scenario. This scenario gives a probability of 50–66% of holding the global temperature increase to 1.5°C.
2. A **Below 2 Degrees** scenario, comprising scenarios classified by the IPCC as 1.5°C with high overshoot (limiting median warming to below 1.5°C in 2100 and with a greater than 67% probability of temporarily overshooting that level earlier) and lower 2°C

(limiting peak warming to below 2°C throughout the 21st century with greater than 66% likelihood).

3. A **2 Degrees** scenario, comprising scenarios classified by the IPCC as limiting warming to 2°C (limiting peak global temperature rise to 2°C with a probability greater than 50%).

## 3.4. Base year intensity

### *3.4.1 General approach*

To estimate our base year emissions intensity, we combine global, food-related agricultural production by commodity, obtained from the FAOSTAT database, with global emissions factor data from Poore and Nemecek (2018) [10], [20], supplemented by a number of additional sources (see Appendix D). This allows us to combine the most comprehensive global agricultural production dataset, which is also an input to the IAMs we use, with emissions factors obtained from the largest emissions factor literature review in the agricultural sector to date.

To determine the base-year intensity, we use a denominator of total volume of agricultural commodities produced in 2019 and a numerator of total emissions from these products. We favoured agricultural commodities produced over final, processed food products for several reasons. First, there is better availability of data on total production of raw commodities than there is of final food product volumes, as the former are provided by FAO. Second, most of the emissions factors used in this study to estimate the base year emissions value correspond to unprocessed agricultural commodities.

### *3.4.2 Base year production weight*

We use global production data for all agricultural products from the FAOSTAT Crops and Livestock Products (CLP) database to estimate total global food production in metric tonnes on a consistent basis with the emissions factors applied at a later stage [20]. Since only a portion of total crops and animal products are destined to become human food, we make several adjustments to the dataset to arrive at the final base year production volume.

To start with, we exclude non-food items such as cotton and tobacco, alcoholic beverages, and a small number of other commodities with low production quantities, due to the lack of credible emissions factors.[5] We also exclude duplicate values. For example, FAO reports both the volume of egg production and the number of eggs produced, so only the former is included in our dataset. A list of all excluded commodities is given in Appendix A.

We also adjust commodity production values to reflect the proportion of total commodities that are destined to become human food by calculating the share of total production of edible

[5] While omitting commodities with low production quantities due to the lack of a credible emissions factor is likely to cause our base year value to understate the total GHG emissions due to food production, we are confident the downward bias is relatively modest, as the excluded commodities are all produced in small quantities. We say the impact of excluding these commodities is 'likely' to cause downward bias in our base year value, rather than 'definitely', as several excluded commodities are spice crops derived from perennial woody plants that tend to have negative emissions factors.

commodities accounted for by human food uses using the FAO's Supply Utilization Accounts (SUA)[6,7] [20], [21].[8] Further details of these adjustments are available in Appendix B.

To calculate a base year emissions intensity, it is important to ensure the production units align with the emissions factor functional units. Since Poore and Nemecek [10] used the dry matter content of certain commodities as the basis of their functional unit, we adjust the volume of these commodities to account for this conversion. These authors also made several further, smaller adjustments, which we do not account for.[9] We do not adjust meat production volumes, as these figures relate to "fat and bone-free meat", which conforms with the Poore and Nemecek functional unit. We also make no adjustment to grain, oilseed, pulse, or soybean production quantities, as FAO production data are already reported in terms of clean, dry weight [22]

This method yields a base year production value of 4.90 billion (metric) tonnes.

### *3.4.3 Base year emissions*

Base year emissions from agricultural food production are estimated by multiplying the adjusted total production volumes of each of the commodities included in the base year production value with a global emissions factor. Most emissions factors are taken from Poore and Nemecek (2018) [10], who estimated the lifecycle emissions of 43 staple food commodities and products, representing roughly 90% of global protein and calorie consumption. These authors conducted a meta-analysis of over 1,500 studies to estimate the emissions factors covering the majority of lifecycle stages for these food products across different geographies (for more information on life cycle emissions factor boundaries see Appendix F). Using these emissions factors, Poore and Nemecek derived an estimate of total global emissions from food of 12 Gt CO2e. We use the median emissions factors estimated by these authors in our study (Appendix C). For commodities not covered by the 43 emissions factors provided by Poore and Nemecek (2018) [10], we use emissions factors provided by a limited number of supplementary sources (Appendix D).

This method yields a base year emissions value of 13.483 Gt CO2e, leading to a base year emissions intensity of 2.75 Gt CO2e/ billion (metric) tonnes product in 2019. The estimated

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[6] FAO. 2022. Supply Utilization Accounts. License: CC BY-NC-SA 3.0 IGO. Extracted from: https://www.fao.org/faostat/en/#data/SCL. Date of Access: 21-01-2022.

[7] The SUA aggregate national data provides data on the following consumption categories: exports, livestock feed, seed use, processing for food use, processing for non-food use, losses during storage and transportation, food supplies available for human consumption. The SUA also include the following production categories for the same commodities: production, imports, change in stocks.

[8] We take two approaches to making these adjustments, depending on whether processed versions of the commodity are included in the dataset. When only the unprocessed form of the commodity (e.g., potatoes) is included in the dataset, we calculate the relative proportion of the commodity used for processing for food use and food supplies available for human consumption, as given by the SUA data. For example, this approach is implemented for wheat, as no processed form of wheat (such as wheat flour) exists in the base year production dataset. When both the unprocessed AND processed forms of the commodity (e.g., soybeans AND soybean oil) are included in the dataset, we modify our approach to prevent double-counting. We calculate the relative proportion of (1) the unprocessed commodity that constitutes food supplies available for human consumption, and (2) the processed commodity that is used for processing for food use and food supplies available for human consumption. Base year production values are then calculated by multiplying the former by the total production quantity of the unprocessed commodity, and the latter by the total production quantity of the processed commodity. For example, this approach is implemented for soybeans (the unprocessed commodity) and soybean oil (the processed commodity). SUA data shows that only 2.3% of all soybeans produced are used for food in their unprocessed form, and that 53.2% of soybean oil is used for food directly or is processed further for food-related use.

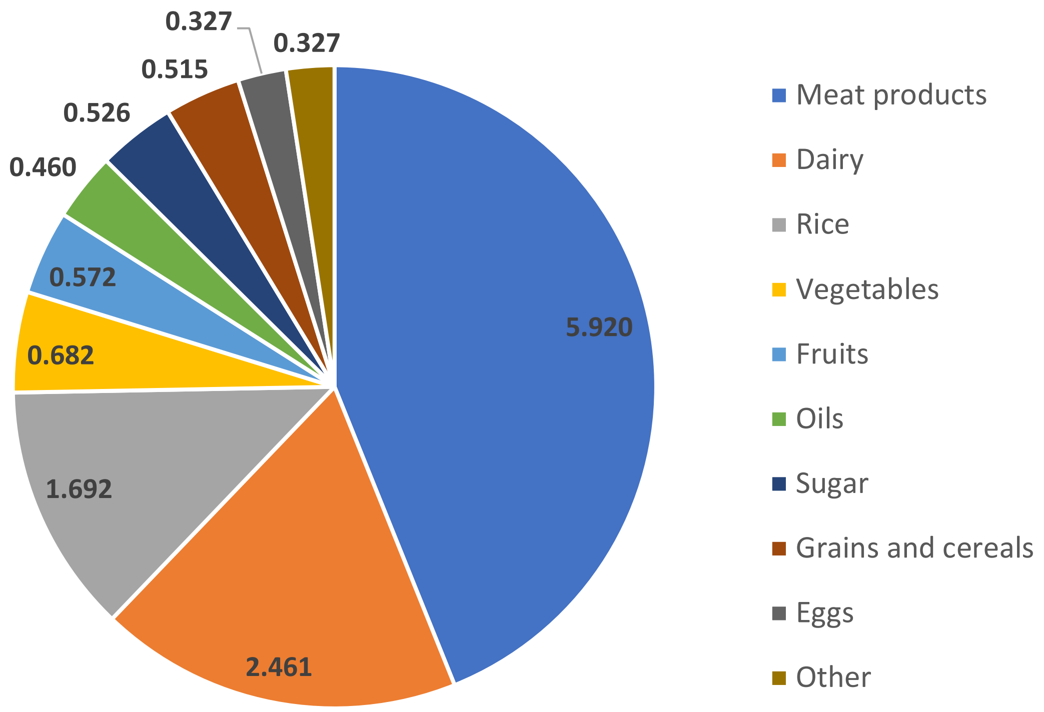
[9] Poore and Nemecek (2018) [10] adjust milk quantities across different species to standardize the fat and protein content, which is an item that we may address in subsequent versions of the Benchmark.

absolute base year emissions are corroborated by other sources. Poore & Nemecek find 13.7 Gt CO2e in 2017, Crippa et al. find 14.6 Gt CO2e in 2015 and recent IPCC estimates range between around 13 Gt CO2e (including all AFOLU but excluding food processing emissions) [7], [10], [23]. Although a direct comparison between our data and these sources is not possible due to differing assessment boundaries, available data confirms a high degree of agreement with recent studies, especially when contrasted against the large variation of food GHG emissions estimates. Table 1 and Figure 1 provide further details of base year quantities and emissions by type of commodity.

**Table 1. Quantities of and emissions due to agricultural products in 2019**

| Commodity group | Weight (billion metric tonnes) | Emissions (Gigatonnes CO2e) |
|---|---|---|
| Meat products | 0.272 | 5.920 |
| Dairy | 0.830 | 2.461 |
| Rice | 0.454 | 1.692 |
| Vegetables | 1.140 | 0.682 |
| Fruits | 0.806 | 0.572 |
| Oils | 0.100 | 0.460 |
| Sugar | 0.182 | 0.526 |
| Grains and cereals | 0.719 | 0.515 |
| Eggs | 0.078 | 0.327 |
| Pulses and beans | 0.065 | 0.066 |
| Molasses | 0.030 | 0.094 |
| Root vegetables | 0.186 | 0.074 |
| Coffee | 0.007 | 0.059 |
| Legumes | 0.005 | 0.018 |
| Cocoa | 0.005 | 0.016 |
| Soybeans | 0.008 | 0.010 |
| Seeds | 0.002 | 0.002 |
| Honey | 0.001 | 0.001 |
| Seafood and fish | 0.000 | 0.000 |
| Spices | 0.000 | 0.000 |
| Nuts | 0.011 | -0.014 |
| **Total** | **4.9013** | **13.483** |

**Figure 1: Estimated emissions due to agricultural products in 2019 in GtCO2e**




## 3.5. Benchmark emissions reduction pathways

We estimate changes in food producers' emissions intensity over time separately for Scope 1, 2, and upstream Scope 3 emissions. Changes in Scope 1 and 2 emissions are estimated using low-carbon modelling scenarios produced by the International Energy Agency (IEA), whereas changes in food producers' upstream Scope 3 emissions intensity are estimated using data from three IAMs with detailed land use modules, compiled in the IAMC AR6 Scenarios Database hosted by IIASA.[24]

To calculate how Scope 1 emissions from food producers should evolve over time in each benchmark scenario, we take the direct emissions budget allocated to industry as a whole and subtract direct emissions allocated to the five principal high-carbon sectors, i.e., aluminium, cement, chemicals, paper, and steel. The rates of change in the resulting *residual* industrial emissions are used to forecast direct Scope 1 emissions from food producers.

To forecast Scope 2 emissions, TPI multiplies a sector's electricity consumption by the emissions intensity of the electricity grid, along each of the IEA scenario paths. However, since there is no electricity consumption allocated to food producers specifically, we calculate residual industrial power consumption in a similar way by subtracting the electricity allocated to aluminium, cement, chemicals, paper, and steel from total industrial electricity consumption. This is then multiplied by the carbon intensity of the electricity grid over time in the three scenarios.

Upstream Scope 3 emissions account for 94.9% of emissions from the food sector considered in this analysis, and therefore changes in these emissions are the main determinant of the benchmark pathways.[10] To estimate changes in these emissions, we use scenario outputs of the IMAGE, MESSAGE-GLOBIOM, and REMIND-MAgPIE IAMs[10]. Confining attention to these three models, the IAMC AR6 Scenarios Database contains simulation results from 574 distinct model-scenario combinations (henceforth referred to as 'scenarios' for conciseness), of which we selected 223 for our analysis.[11]

The 223 scenarios were grouped into the three benchmark scenarios linked to the goals of the 2015 UN Paris Agreement on climate change (specifically Article 2), using the same approach as Dietz et al. (2021) [25]:

1. A 1.5°C scenario, comprising scenarios classified by the IPCC as Below 1.5°C (limiting peak warming to below 1.5°C throughout the 21st century with 50–66% likelihood) and 1.5°C with low overshoot (limiting median warming to below 1.5°C in 2100 and with a 50–67% probability of temporarily overshooting that level earlier).
2. A Below 2°C scenario, comprising scenarios classified by the IPCC as 1.5°C with high overshoot (limiting median warming to below 1.5°C in 2100 and with a greater than 67% probability of temporarily overshooting that level earlier) and lower 2°C (limiting peak warming to below 2°C throughout the 21st century with greater than 66% likelihood). 4
3. A 2°C scenario, comprising scenarios classified by the IPCC as limiting warming to 2°C (limiting peak global temperature rise to 2°C with a probability greater than 50%).

Table 2 summarises the number of scenarios that underpin our calculations for each warming scenario, and their distribution across models.

**Table 2. Number of scenarios included in Scope 3 benchmark calculation by warming scenario and IAM**

| Warming scenario | IMAGE | MESSAGE-GLOBIOM | REMIND-MAgPIE | Total |
|---|---|---|---|---|
| 1.5°C | 7 | 10 | 18 | 35 |
| Below 2°C | 28 | 69 | 47 | 144 |
| 2°C | 9 | 29 | 6 | 44 |

The scenarios in our analysis provide projections for livestock, non-energy crop and energy crop production separately. To isolate food-specific agricultural production (i.e., the

[10] Specifically, we use the following versions of these models: IMAGE 3.0, 3.0.1, 3.0.2 and 3.2; REMIND-MAgPIE 2.0-4.0, 2.1-4.2 and 2.1-4.3; MESSAGE-GLOBIOM 1.0; MESSAGEix-GLOBIOM 1.0, 1.1 and 1.2 and MESSAGEix-GLOBIOM_GEI 1.0.

[11] Out of the 574 scenarios available from the three IAMs, 218 were unsuitable because the scenarios were incompatible with limiting warming to 2°C or below. Additionally, 48 scenarios lacked an IPCC climate category classification, which we use to classify scenarios into warming categories, leaving 308 scenarios of interest. 66 of the remaining 308 scenarios were unsuitable for our analysis as they did not provide results on agricultural production. IAMs with land use components differ in their treatment of bioenergy expansion. As a result, projected energy crop production varies widely across scenarios, with some projecting energy crop production of 10 billion tonnes and higher (26 times the average modelled production in 2020). The feasibility of such large bioenergy expansion is debated and therefore, to mitigate the impact of outlier scenarios on the calculated benchmarks, scenarios whose projected energy crop production in 2100 falls into the upper 5% of the distribution were excluded. This criterion excludes 19, resulting in a final suite of 223 scenarios.

denominator of the benchmark trajectories), all livestock production is assumed to be used for food, and the proportion of non-energy crops used for food is assumed constant at 92.15%. This share excludes energy related non-food uses of crops. [12]

Modelled production values are all reported in dry matter quantities. By contrast, the FAO data used to calculate the base year production value are reported on a fresh-weight basis for all commodities except grains, oilseeds, pulses, and soybeans. We align the denominator of the benchmark pathways with that of the base year value by dividing the modelled quantities by the conversion factors shown in Table 3[13]. More details on the conversion factor calculations are provided in Appendix E.

**Table 3. Agricultural production conversion factor by IAM and product category**

| Model | Conversion factor | |
|---|---|---|
| | **Crops** | **Livestock products** |
| **IMAGE** | 0.68002689 | 0.522722334 |
| **MESSAGE-GLOBIOM** | 0.687850122 | 0.534184565 |
| **REMIND-MAgPIE** | 0.68002689 | 0.522722334 |

The scenarios in our analysis provide projections for total AFOLU CO2, CH4 and N2O[14]. The following assumptions are used to isolate emissions attributable to food producers:

- AFOLU CH4 emissions are solely due to food-related agricultural production. This is justified by the observation that 99% of anthropogenic CH4 emissions from agriculture are due to enteric fermentation by livestock (67%), manure management (8%) and flooded rice cultivation (24%).[26]
- AFOLU N2O emissions due to food crop and livestock production are directly proportional to the share of food crops and livestock in total agricultural production. This is justified by FAO data[15] [20] that show manure left on pasture and manure management account for approximately the same amount of N2O emissions as synthetic fertilizers, manure applied to soils, crop residues and crop residue burning.

[12] The 92.15% figure is derived from Cassidy et al. (2013) [30], who show that 'crops used for industrial uses, including biofuels, make up 9% of crops by mass'. As the authors are not able to provide the share of all crops allocated to industrial uses *excluding* biofuels, this is estimated by calculating 9% of the sum of energy and non-energy crop production in 2010 (the closest year in the scenario output data to that of Cassidy et al's), subtracting energy crop production and expressing the residual as a share of non-energy crop production. The mean value of this calculation across the 67 scenarios considered is 7.85% and hence the share used for food is the residual 92.15%.

[13] The conversion factors are a weighted mean across the agricultural commodities modelled by each IAM. The factors are taken as 1 for cereal crops, oilseeds, pulses, and soybeans and the dry matter percentage for other crops and livestock products. The weights are calculated using FAO production data as commodity production values in 2019 expressed as a share of all production across modelled commodities, calculated separately for crops and livestock products. The conversion factors are the same for IMAGE 3.0.1 and REMIND-MAgPIE 1.7-3.0 as these models simulate essentially the same suite of agricultural commodities.

[14] CH4 and N2O emissions are converted to CO2e using 100-year Global Warming Potentials taken from the IPCC Sixth Assessment report. [27]

[15] FAO. 2022. Emissions Totals. License: CC BY-NC-SA 3.0 IGO. Extracted from: https://www.fao.org/faostat/en/#data/GT. Date of Access: 23-03-2022.[20]

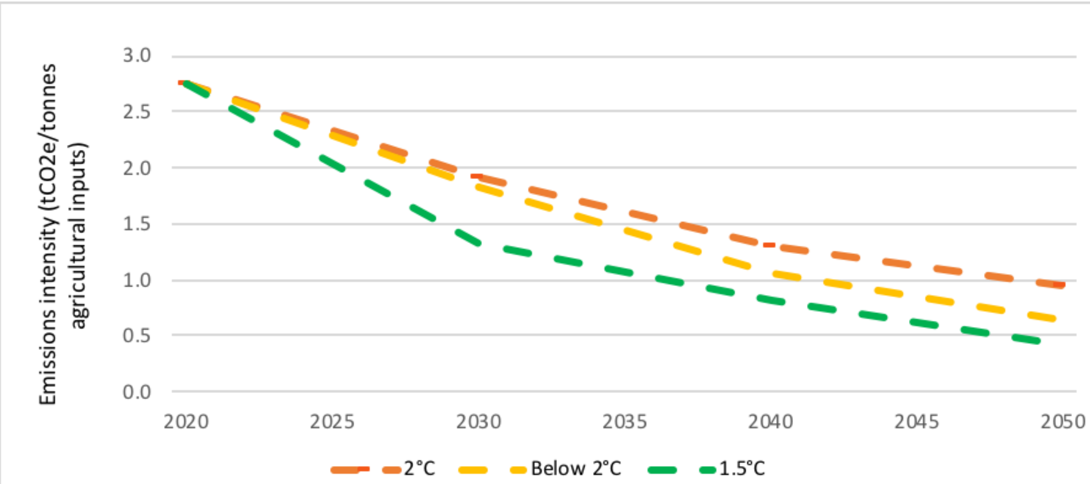
- AFOLU CO2 is entirely attributable to food processors. As the vast majority of AFOLU CO2 emissions are due to land use change[16] [27], this inclusion is justified by agriculture's major role in driving land conversion. [28], [29]

For each scenario, upstream Scope 3 emissions are combined with food processor's Scope 1 and 2 emissions and divided by agricultural production quantities (all calculated using the methods described above). These scenario-specific emissions intensities are converted into a pathway for each warming scenario using the averaging approach developed in Dietz et al. (2021)[17] and calculating the change in intensity from 2020 (the closest modelled year to 2019, which is the year used to calculate a baseline emissions value). The resulting benchmark pathways are shown in Table 4 and Figure 2.

**Table 4. Emissions intensity benchmark pathway by warming scenario (tCO2e/tonnes agricultural input)**

| Warming scenario | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|
| 1.5°C | 2.751 | 1.315 | 0.807 | 0.414 |
| Below 2°C | 2.751 | 1.821 | 1.063 | 0.643 |
| 2°C | 2.751 | 1.906 | 1.295 | 0.958 |

**Figure 2: Emissions intensity benchmark pathway by warming scenario**




## 3.6. Estimating company emissions intensities

In applying the SDA to the food sector, the specific measure of emissions intensity developed by TPI is Scope 1, 2 and 3 (purchased agricultural goods) emissions, in units of tonnes of $CO_2$

[16] As illustrated, for example, by figure 7.3.a of IPCC AR6 WGI Chapter 7 [27]

[17] Specifically, the emissions intensities were first averaged across scenarios *within* IAM and warming category. The warming scenario value of these variables was then calculated as a weighted mean of the within-IAM averages, using equal weights across IAMs.

equivalent per tonne of agricultural inputs. Both company emissions and agricultural input/production quantities are obtained directly from company disclosures.

Recognising that most emissions stem from the sourcing of food producers' agricultural inputs, the scope of the assessment includes emissions from purchased goods – including emissions due to land use change – as well as the contribution from direct and indirect operational emissions (i.e., Scope 1 and 2). The denominator in the intensity measure is agricultural inputs rather than food products, as the former aligns more closely with the commodities that are modelled by the IAMs used to derive the benchmark pathways.

In several cases, companies' do not publicly disclose the data necessary to calculate this specific measure. This necessitates the following approximations:

- Scope 3 emissions from purchased goods and services are used to approximate emissions from purchased agricultural goods if the latter are not disclosed. By adopting this approach, emissions due to non-agricultural inputs and purchased services are also included in a company's emissions intensity, along with purchased agricultural goods. However, data from companies that disclose both emissions categories show that purchased agricultural inputs account for the vast majority of total Scope 3 purchased goods and services emissions. Thus, although this approximation causes a minor upward bias in our calculated emissions intensity relative to the scope of emissions covered in the benchmark pathways, we are confident the bias is small.

- Output quantities are adjusted to approximate agricultural input quantities if the latter are not disclosed. Few companies disclose raw input materials by weight (excluding packaging materials), which is the quantity required to calculate an emissions intensity metric comparable to the benchmark pathways. As disclosure of output quantities is more widely available, we therefore approximate inputs by multiplying output quantities using an input/output ratio calculated using the best available data.

# 4. Company emissions disclosures

## 4.1. Emissions reporting boundaries

Companies disclose emissions using different organisational boundaries. There are two high-level approaches: the equity share approach and the control approach, and within the control approach there is a choice of financial or operational control. Companies are free to choose which organisational boundary to set in their voluntary disclosures and there is variation between companies assessed by TPI.

TPI accepts emissions reported using any of the above approaches to setting organisational boundaries, as long as:

1. the boundary that has been set appears to allow a representative assessment of the company's emissions intensity;
2. the same boundary is used for reporting company emissions and activity, so that a consistent estimate of emissions intensity is obtained.

At this point in time, limiting the assessment to one particular type of organisational boundary would severely restrict the breadth of companies TPI can assess.

When companies report historical emissions or emissions intensities using *both* equity share and control approaches, TPI chooses the reporting boundary based on which method provides the longest available time series of disclosures, or is most consistent with disclosure on activity, and any targets.

## 4.2. Data sources and validation

All TPI's data are based on companies' own disclosures. The sources for the Carbon Performance assessment include responses to the annual CDP questionnaire, as well as companies' own reports, e.g., sustainability reports.

Given that TPI's Carbon Performance assessment is both comparative and quantitative, it is essential to understand exactly what the data in company disclosures refer to. Company reporting varies not only in terms of what is reported, but also in terms of the level of detail and explanation provided. The following cases can be distinguished:

- Some companies provide data in a suitable form and they provide enough detail on those data for analysts to be confident appropriate measures can be calculated or used.
- Some companies also provide enough detail, but from the detail it is clear that their disclosures are not in a suitable form for TPI's Carbon Performance assessment (e.g., they do not report the measure of company activity needed). These companies cannot be included in the assessment.
- Some companies do not provide enough detail on the data disclosed and these companies are also excluded from the assessment (e.g., the company reports an emissions intensity estimate, but does not explain precisely what it refers to).
- Some companies do not disclose their carbon emissions and/or activity.

Once a preliminary Carbon Performance assessment has been made, it is subject to the following procedure to provide quality assurance:

- *Internal review*: the preliminary assessment is reviewed by an analyst that was not involved in the original assessment.
- *Company review*: the reviewed assessment is sent to the company, which then has the opportunity review it and confirm the accuracy of the disclosures used. Only information in the public domain can be accepted as a basis for any change. This review includes all companies including those who provide unsuitable or insufficiently detailed disclosures.
- *Final assessment*: feedback from the company is reviewed and, if it is considered appropriate, incorporated.

## 4.3. Coverage of target

Companies disclose various types of emissions reduction targets, but they can be broadly categorised into absolute emissions targets and emissions intensity targets. Absolute emissions targets are expressed in terms of a decrease in total company emissions. By contrast, emissions intensity targets are expressed in terms of company emissions per unit of output/activity and make no direct reference to total emissions. To convert an absolute emissions target into an intensity target, we make an assumption about the future growth of agricultural inputs purchased by the company. Consistent with the approach adopted in other TPI sectors, we assume that a company's agricultural inputs grow in line with projected agricultural production calculated using the IAMs described above. If both an absolute and intensity target are disclosed, we verify that both are consistent with/complement each other. If so, we prefer the intensity target. If not, further research is needed to accurately reflect a company's decarbonization pathway.

Targets can also cover different scopes of emissions and apply only to specific operations, or to the whole organisation. When company targets do not cover the full scope of our analysis, assumptions are required to calculate how emissions outside the scope of the target evolve. Consistent with the approach used in other TPI sectors, we assume the emissions intensity of activities outside the scope of the target remains constant at the level in the latest disclosure year. In the context of food, companies' targets typically include more Scope 3 categories than solely purchased agricultural goods. In this case, we assume that reduction efforts are uniform across all scopes covered (i.e., ruling out that some emissions categories are reduced at a faster rate than others).

Some companies disclose net targets. Unlike gross targets, net targets include emissions offsets and/or negative emissions, either within company boundaries or outside. Currently, TPI accepts both types of targets and does not make an explicit distinction between them. Although we recognise that there are additional risks related to relying heavily on offsetting, in principle it is a cost-effective mechanism to reduce emissions. Moreover, no company currently discloses from the detailed contribution of offsets to their overall targets.

Furthermore, some companies disclose a target range. In this case the midpoint value is used. Finally, most companies express targets relative to emissions in a base year (e.g., 2010). However, some companies disclose targets without disclosing the base year. TPI then assumes that the base year is the latest year of disclosure prior to the publication of the target.

### 4.4. Responding to companies

Allowing companies the opportunity to review their assessments is an integral part of TPI's quality assurance process. Each company receives its draft TPI assessment and the data that underpins the assessment, offering them the opportunity to review and comment on the data and assessment. We also allow companies to contact us at any point to discuss their assessment.

If a company seeks to challenge its result/representation, our process is as follows:

- TPI reviews the information provided by the company. At this point, additional information may be requested.
- If it is concluded that the company's challenge has merit, the assessment is updated and the company is informed.
- If it is concluded that there are insufficient grounds to change the assessment, TPI publishes its original assessment.
- If the company requests an explanation regarding its feedback after the publication of its assessment, TPI explains the decisions taken.
- If a company requests an update of its assessment based on data publicly disclosed after the research cut-off date communicated to the company, TPI can note the new disclosure on the company's profile on the TPI website.

If a company chooses to further contest the assessment and reverts to legal means to do so, the company's assessment is withheld from the TPI website and the company is identified as having challenged its assessment.

# 5. Results

## 5.1. Company Selection and data availability

Here we apply our methodology to the world's ten largest publicly listed companies in the Food Producers sector (as defined in Section 3.2). We measure size in terms of free float market capitalisation as identified using data from FTSE Russell for 2021. Table 5 summarises the state of company disclosure as of February 1st 2022. All ten companies disclosed Scope 1 and 2 emissions and all but two companies disclosed upstream Scope 3 emissions from purchased goods and services. However, only four companies disclosed their total annual agricultural inputs or production quantities. These companies were Hershey's, Mondelez, Nestlé, and Danone.

At the time of company selection, only three out of ten publicly disclosed enough data on emissions and production for our analysis: Kraft Heinz, Mondelez, and Nestlé.[18] These are the companies analysed below. Since then, disclosures have improved, particularly Scope 3 emissions from purchased goods and services. Appendix G shows how disclosures have rapidly evolved between 1st February and 25th November 2022, and this should allow a larger sample of companies to be assessed in future.

Out of the three companies selected for further analysis, only Nestlé directly discloses all relevant information for our analysis by providing upstream Scope 3 emissions including land use change, as well as the total amount of agricultural inputs used by the company. Mondelez discloses upstream Scope 3 emissions including land use change, but only total production volumes, not agricultural inputs. Therefore, we have estimated Mondelez's inputs under the assumption that the input/output ratio would be similar to Nestlé's given their product portfolios. The same assumption is applied to Kraft-Heinz' assessment, but in addition Kraft Heinz does not explicitly disclose whether its Scope 3 emissions from purchased goods and services include land use change. We present our assessments of all three companies acknowledging these limitations.

[18] Whilst Danone discloses production figures, its disclosed agricultural input figures only refer to a fraction of total input figures. Danone's total production figures do not provide a breakdown by product category. Due to its large drinks business (mainly bottled water), assuming that Danone's input/output ratio would be similar to Nestle's was deemed too inaccurate to impute Danone's input volumes from its production volume. Hence the company was not assessed for the sake of this discussion paper.

Table 5: Available emissions, input, and production disclosures by the world's largest food processing companies as of 1st February 2022.

| Company Metadata | | | Emissions Data | | | Production/Input Data | | Data Sources |
|---|---|---|---|---|---|---|---|---|
| **Company** | **Market Cap ($billion)** | **Sourced Commodities** | **Discloses Scope 3 purchased goods and services (PGS)** | **Scope 3 from agricultural inputs and PGS distinct?** | **Upstream Scope 3 includes land-use change emissions?** | **Production** | **Input** | |
| **Nestlé** | 313.47 | Coffee, wheat, dairy, soybeans, palm oil, cocoa | ✓ | ✓ | ✓ | ✓ | ✓ | CDP 2014-2021; Consolidated Environmental Performance Indicators 2020; Net Zero Roadmap 2021; Sustainability Report 2020 |
| **Mondelez International Inc.** | 76.31 | Cocoa, wheat, dairy, coffee, corn products, oils, sugar, sweeteners | ✓ | | ✓ | ✓ | | CDP 2014-2021; Annual Report 2013-2020; ESG Report 2020 and 2019 |
| **Danone** | 39.82 | Milk, sugar, corn, palm oil | ✓ | ✓ | | ✓ | | CDP 2014-2021; Environmental Data 2020; Integrated Annual Report 2019; Universal Registration Document 2020 |
| **General Mills** | 35.09 | Oats, wheat, cattle products, palm oil, sugar | ✓ | ✓ | | | | CDP 2014-2021; Global Responsibility Report 2021 |
| **Archer Daniels Midland (ADM)** | 25.27 | Corn, palm oil, cotton, rice, soy | ✓ | | | | | CDP 2014-2021; Corporate Sustainability Report 2020 |
| **McCormick & Co** | 21.59 | Dairy, pepper, capsicums, onion, vanilla, garlic, salt | ✓ | | | | | CDP 2014-2021 |
| **Hershey Company** | 20.61 | Cocoa, sugar, timber, dairy, palm oil | ✓ | ✓ | ✓ | | | CDP 2013-2017 and 2019; 2021 Proxy Statement and 2020 Annual Report; Sustainability Report 2020 |
| **Kraft Heinz** | 20.24 | Dairy, meat, coffee, nuts, tomatoes, potatoes, oils, sugar, corn, wheat | ✓ | ✓ | | ✓ | | CDP 2016-2021; ESG Report 2021 |
| **Kerry Group PLC** | 19.31 | Palm oil, dairy, soy, coffee, cocoa | | | | | | Annual Report 2020 and 2019 |
| **Tyson Foods Inc** | 17.72 | Cattle products, pork, animal feed | | | | | | CDP 2016-2021; Sustainability Report 2020 |

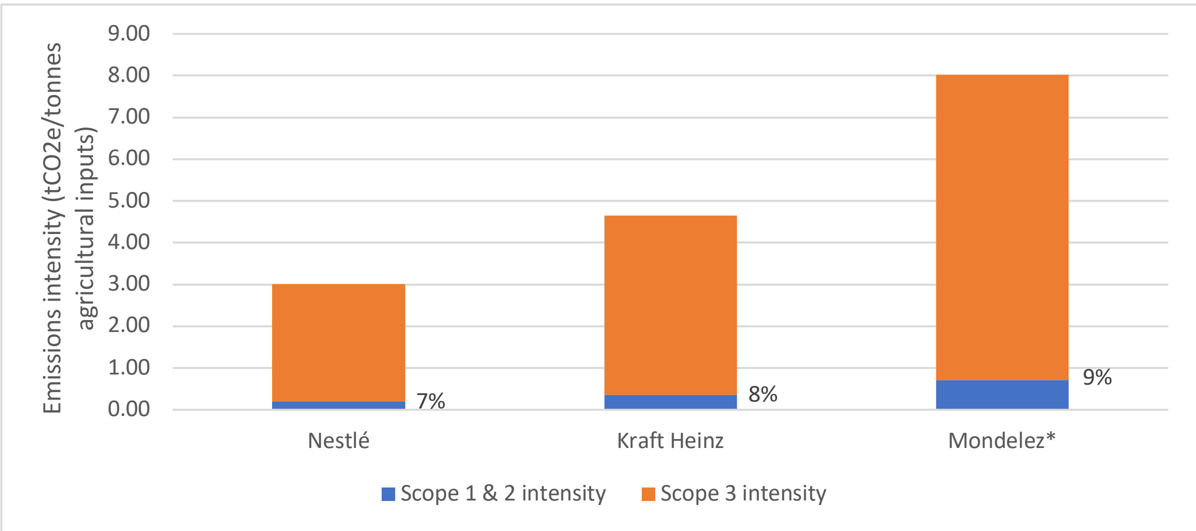
## 5.2. Company Performance

In July 2022, provisional assessments were sent to the three companies, alongside a preliminary methodology note, and their feedback was solicited.

Using the latest year of disclosure for each company, the emissions intensity is 8.09 $tCO_2e/t$ agricultural inputs for Mondelez (2017 data), 3.34 for Nestlé (2020 data), and 4.65 for Kraft Heinz. Each company's intensity is dominated by Scope 3 emissions from purchased goods and services.

Attributing differences in observed emissions intensities to specific product portfolios or business practices is currently complicated by a relative lack of standardised, disaggregated, and quantified disclosure of companies' raw material inputs and production in physical units, as well as uncertainty about emissions factors. However, we note that chocolate-related products are a particularly large share of the product portfolio of Mondelez, suggesting the high share of cocoa and dairy inputs required by Mondelez at least partially explain its high emissions intensity compared to Nestlé and Kraft Heinz.

**Figure 3: Companies' scope 1,2 and upstream scope 3 intensities in 2020***




*Mondelez' emissions intensities are based on 2017 data, as the company stopped disclosing sufficient information on its production volumes in that year, which are needed to normalise emissions and estimate an emissions intensity.

The companies' emissions targets are as follows:

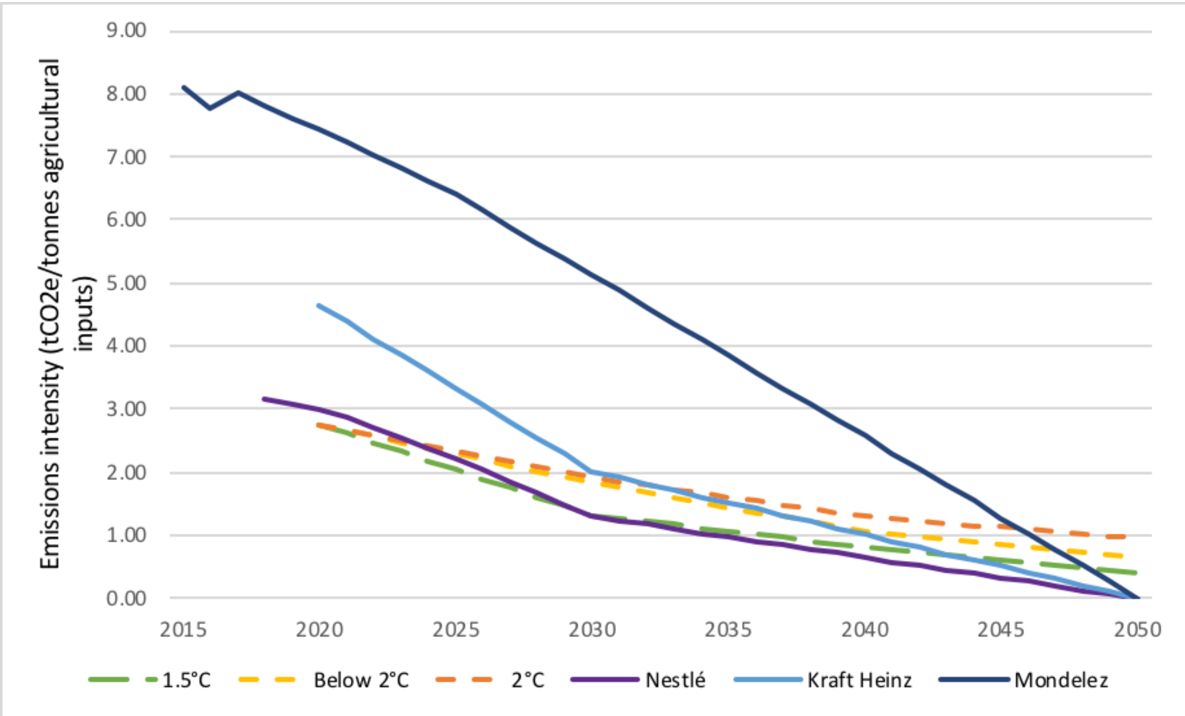
- Nestlé's path to decarbonisation commits the company to net zero by 2050, with their target covering Scope 1, 2, and 'more than 80%' of its Scope 3 emissions. The company also sets interim targets of a 20% reduction from a 2018 baseline by 2025, and a 50% reduction from the same baseline by 2050.
- Mondelez committed to achieving net zero emissions by 2050 across its full value chain. While exact details on the scopes included in its net zero target are not disclosed, the target is accepted under the assumption that it covers 100% of their Scope 1, 2, and purchased goods and services of Scope 3 emissions. The company has

also set a short-term absolute emissions reduction target of 10% reduction by 2025 (CDP Climate Change 2021).

- Kraft Heinz pledged to achieve net zero greenhouse gas emissions across all three scopes by 2050. The company also set out a "milestone" on that pledge; it is targeting a reduction of 50% across all three Scopes by 2030.

Using these targets to assess the three selected companies against the sectoral benchmarks developed for the food sector, we find that all three companies are aligned with the 1.5°C benchmark by 2050. However, Kraft Heinz and Nestlé differ from Mondelez in (a) having a much lower carbon footprint per unit of agricultural input at present and (b) setting more significant medium-term targets. These lead to company pathways that are more closely aligned with a 1.5°C benchmark in the short and medium terms. Nestlé aligns with the 1.5°C benchmark in 2030, but neither of the other two companies aligns with 1.5°C in the medium term (2026-2035).

**Figure 4: Emissions pathways Nestle, Mondelez and Kraft-Heinz up to 2050**



## 6. Discussion and limitations

In this paper, we have proposed a methodology for applying the SDA to food producers. A key consideration has been that the vast majority of emissions stem from the sourcing of food producers' agricultural inputs. Therefore, the scope of the assessment should include emissions from purchased goods – including emissions due to land use change – as well as the contribution from direct and indirect operational emissions (i.e., Scope 1 and 2).

The measure of physical production we have chosen to serve as the denominator of the sector's emissions intensity is agricultural inputs, rather than food products. The former aligns more closely with the commodities that are modelled by the IAMs used to derive the benchmark pathways.

Hence, in the food sector, the specific measure of emissions intensity developed by TPI is **Scope 1, 2, and 3 (purchased agricultural goods) emissions, in units of tonnes of $CO_2$ equivalent per tonne of agricultural inputs.**

Companies do not always publicly disclose the data necessary to calculate this measure. Scope 3 emissions from purchased goods and services are used to approximate purchased agricultural goods emissions if the latter are not disclosed. When implemented, this approach means emissions due to non-agricultural inputs (e.g., packaging materials) and purchased services are included in a company's emissions intensity. However, in instances where companies disclose both emissions categories, purchased agricultural inputs account for most of the total Scope 3 emissions from purchased goods and services. Therefore, while this approximation does create a slight upward bias in our calculated emissions intensity, we are confident that the bias is small.

Output quantities are adjusted to approximate agricultural input quantities if the latter are not disclosed. Few companies disclose raw input materials by weight (excluding packaging materials), which is the quantity required to calculate an emissions intensity metric comparable to the benchmark intensity pathways. Disclosure of output quantities is more common, and we therefore approximate inputs by multiplying output quantities using an input/output ratio[19].

Food companies typically describe the methodology used to estimate their Scope 3 emissions from purchased goods and services in their CDP disclosures. In several instances, changes to these methodologies lead to large year-on-year increases in disclosed emissions, which do not appear plausible given changes in production over the same period. In these instances, we adjust the disclosed emissions values to be consistent using an average ratio of emissions calculated over the period for which the methodology is constant[20].

Within the food industry, supply chains are complex, with many ingredients going into diverse product portfolios. Food producers' product portfolios are likely to be a principal driver of their emissions intensities depending on the emissions factors of the commodities they predominantly produce. Meat and dairy producers are expected to be the highest emitters given the lifecycle emissions of these products[10]. Companies, such as Nestlé, who are taking

[19] Currently the only source of this ratio we are aware of is Nestlé's corporate disclosures, meaning we apply Nestlé's input/output ratio to other companies. When this adjustment is necessary, we review companies' breakdown of revenues by product category as a check that their product profile is similar to that of Nestlé's.

[20] Production volume if this is disclosed and revenue if it is not.

early action to diversify their product portfolio to include more plant-based alternatives with a lower emissions factor than dairy, are expected to make a faster transition to a 1.5°C pathway.

For the companies sourcing agricultural commodities (especially beef, soy, and palm oil), a major driver of their emissions outside of direct operations is often linked to agriculturally induced land-use change and deforestation. Whilst most companies do not report on LUC emissions, Mondelez's emissions linked to deforestation within their supply chain represented the largest single contributor to the end-to-end carbon footprint[1].

The lack of reporting from food producers around Scope 3 emissions, especially linked to land-use change, prevents more companies from being included in our sample and a more in-depth analysis of the drivers of emissions intensity across the supply chain. Broadly speaking, the sample companies also varied widely in business structure regarding what food production stages they include in their direct operations. For example, Mondelez is mostly vertically integrated, as it owns farms, produces, and processes food products. As such, it exercises more significant and direct control over its supply chains, allowing for better reporting of Scope 3 coverage.

## 7. Disclaimer

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# Appendices

## Appendix A. Excluded commodities.

| Reason for exclusion | FAO item name | FAO Item Code |
|---|---|---|
| Alcoholic beverage | Beer of barley | 51 |
| | Wine | 564 |
| Duplicate | Offals, edible, buffaloes | 948 |
| | Butter and ghee, sheep milk | 983 |
| | Butter, buffalo milk | 952 |
| | Butter, cow milk | 886 |
| | Butter, goat milk | 1022 |
| | Cheese, buffalo milk | 955 |
| | Cheese, goat milk | 1021 |
| | Cheese, sheep milk | 984 |
| | Cheese, skimmed cow milk | 904 |
| | Cheese, whole cow milk | 901 |
| | Cream fresh | 885 |
| | Ghee, buffalo milk | 953 |
| | Ghee, butteroil of cow milk | 887 |
| | Milk, dry buttermilk | 899 |
| | Milk, skimmed condensed | 896 |
| | Milk, skimmed cow | 888 |
| | Milk, skimmed dried | 898 |
| | Milk, skimmed evaporated | 895 |
| | Milk, whole condensed | 889 |
| | Milk, whole dried | 897 |
| | Milk, whole evaporated | 894 |
| | Whey, condensed | 890 |
| | Whey, dry | 900 |
| | Yoghurt | 891 |
| | Eggs, hen, in shell (number) | 1067 |
| | Eggs, other bird, in shell (number) | 1092 |
| | Chillies and peppers, dry | 689 |
| | Maize, green | 446 |
| | Offals, edible, camels | 1128 |

| | | |
|---|---|---|
| | Offals, edible, cattle | 868 |
| | Offals, edible, cattle | 868 |
| | Offals, edible, goats | 1018 |
| | Offals, horses | 1098 |
| | Offals, pigs, edible | 1036 |
| | Offals, sheep,edible | 978 |
| | Fat, buffaloes | 949 |
| | Fat, camels | 1129 |
| | Fat, goats | 1019 |
| | Fat, sheep | 979 |
| | Margarine, short | 1242 |
| | Oil palm fruit | 254 |
| | Oil, maize | 60 |
| | Oilseeds nes | 339 |
| | Rapeseed | 270 |
| | Rice, paddy | 27 |
| | Safflower seed | 280 |
| | Sugar beet | 157 |
| | Sugar cane | 156 |
| | Sugar crops nes | 161 |
| | Onions, dry | 403 |
| | Peas, dry | 187 |
| | Palm kernels | 256 |
| Non-food product | Triticale | 97 |
| | Agave fibres nes | 800 |
| | Bastfibres, other | 782 |
| | Beeswax | 1183 |
| | Canary seed | 101 |
| | Castor oil seed | 265 |
| | Chicory roots | 459 |
| | Coir | 813 |
| | Cotton lint | 767 |
| | Cottonseed | 329 |
| | Fibre crops nes | 821 |
| | Flax fibre and tow | 773 |

| | | |
|---|---|---|
| | Hemp tow waste | 777 |
| | Hempseed | 336 |
| | Hides, buffalo, fresh | 957 |
| | Hides, cattle, fresh | 919 |
| | Jojoba seed | 277 |
| | Jute | 780 |
| | Kapok fruit | 310 |
| | Linseed | 333 |
| | Lupins | 210 |
| | Manila fibre (abaca) | 809 |
| | Melonseed | 299 |
| | Oil, cottonseed | 331 |
| | Oil, linseed | 334 |
| | Pyrethrum, dried | 754 |
| | Ramie | 788 |
| | Rubber, natural | 836 |
| | Seed cotton | 328 |
| | Silk-worm cocoons, reelable | 1185 |
| | Silk, raw | 1186 |
| | Sisal | 789 |
| | Skins, goat, fresh | 1025 |
| | Skins, sheep, fresh | 995 |
| | Tallow | 1225 |
| | Tallowtree seed | 305 |
| | Tobacco, unmanufactured | 826 |
| | Vetches | 205 |
| | Wool, greasy | 987 |
| Small production value and no credible emissions factor | Areca nuts | 226 |
| | Meat, camel | 1127 |
| | Meat, game | 1163 |
| | Meat, horse | 1097 |
| | Meat, mule | 1111 |
| | Meat, other camelids | 1158 |
| | Meat, other rodents | 1151 |

| | | |
|---|---|---|
| | Meat nes | 1166 |
| | Meat, ass | 1108 |
| | Poppy seed | 296 |
| | Cloves | 698 |
| | Mustard seed | 292 |
| | Anise, badian, fennel, coriander | 711 |
| | Spices nes | 723 |
| | Vanilla | 692 |
| | Maté | 671 |
| | Hops | 677 |
| | Fat, cattle | 869 |
| | Fat, pigs | 1037 |
| | Lard | 1043 |
| Subsistence production | Bambara beans | 203 |

## Appendix B. Adjustments made to commodity weights.

| SUA adjustment type | FAO item name | FAO item code | Weight (tonnes) | SUA adjustment factor | Other ad hoc weight adjustment | Final weight | Source for ad hoc weight adjustments |
|---|---|---|---|---|---|---|---|
| Food as % of production | Groundnuts, with shell | 242 | 48756790 | 0.156 | Shell removed from weight using [i] | 5321348 | [i] https://www.fao.org/waicent/faoinfo/economic/faodef/fdef05e.htm#5.02 |
| | Coconuts | 249 | 62455084 | 0.339 | | 21144677 | |
| | Dates | 577 | 9075446 | 0.849 | | 7708168 | |
| | Rice, paddy (rice milled equivalent) | 30 | 503901025 | 0.900 | | 453738111 | |
| | Sesame seed | 289 | 6549725 | 0.306 | | 2003270 | |
| | Soybeans | 236 | 333671692 | 0.023 | | 7803089 | |
| | Sunflower seed | 267 | 56072746 | 0.007 | | 395622 | |
| Food and processed as % of production | Meat, goat | 1017 | 6252564 | 0.953 | Bone removed from carcass weight using [i]. | 4689423 | [i] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4093053/ |
| | Sugar Raw Centrifugal (sugar beet portion) | 162 | 182166152 | 0.972 | Total centrifugal sugar divided into sugar cane portion using [i]. | 36433230 | [i] https://www.isosugar.org/sugarsector/sugar |
| | Sugar Raw Centrifugal (sugar cane portion) | 162 | 182166152 | 0.972 | Total centrifugal sugar divided into sugar cane | 145732922 | [i] https://www.isosugar.org/sugarsector/sugar |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | portion using [i]. | | |
| | Brazil nuts, with shell | 216 | 70256 | 0.985 | Shell removed from weight using [i] | 38051 | [i] https://www.fao.org/waicent/faoinfo/economic/faodef/fdef05e.htm#5.02 |
| | Cashew nuts, with shell | 217 | 3960680 | 1.054 | Shell removed from weight using [i] | 990170 | [i] https://www.fao.org/waicent/faoinfo/economic/faodef/fdef05e.htm#5.02 |
| | Hazelnuts, with shell | 225 | 1125178 | 0.944 | Shell removed from weight using [i] | 531041 | [i] https://www.fao.org/waicent/faoinfo/economic/faodef/fdef05e.htm#5.02 |
| | Walnuts, with shell | 222 | 4498442 | 0.929 | Shell removed from weight using [i] | 2384174 | [i] https://www.fao.org/waicent/faoinfo/economic/faodef/fdef05e.htm#5.02 |
| | Meat, turkey | 1080 | 5991771 | 0.971 | Bone removed from carcass weight using [i]. | 4361741 | [i] https://www.e3s-conferences.org/articles/e3sconf/pdf/2021/49/e3sconf_interagromash2021_02019.pdf |
| | Meat, cattle (beef herd) | 867 | 68313894 | 0.982 | Total cattle herd divided into beef herd portion using [i] and [ii]. Bone removed from carcass weight using [iii]. | 57436970 | [i] https://www.ciwf.org.uk/media/5235182/Statistics-Dairy-cows.pdf,<br><br>[ii] https://www.diva-portal.org/smash/get/diva2:943348/FULLTEXT01.pdf<br><br>[iii] https://www.ers.usda.gov/webdocs/publications/41880/33132_ah697_002.pdf |
| | Meat, cattle (dairy herd) | 867 | 68313894 | 0.982 | Total cattle herd divided into dairy herd portion using [i] and [ii]. Bone removed | 4087239 | [i] https://www.ciwf.org.uk/media/5235182/Statistics-Dairy-cows.pdf,<br><br>[ii] https://www.diva-portal.org/smash/get/diva2:943348/FULLTEXT01.pdf<br><br>[iii] https://www.ers.usda.gov/webdocs/publications/41880/33132_ah697_002.pdf |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | from carcass weight using [iii]. | | |
| | Meat, rabbit | 1141 | 883936 | 1.013 | Bone removed from carcass weight using [i]. | 751346 | [i] https://www.canr.msu.edu/resources/rabbit_tracks_meat_quality_and_carcass_evaluation#:~:text=Sometimes%20they%20go%20to%20market,percent%20of%20the%20dressed%20weight. |
| | Meat, pig | 1035 | 110109911 | 1.094 | Bone removed from carcass weight using [i]. | 71571442 | [i] https://livestock.extension.wisc.edu/articles/how-much-meat-should-a-hog-yield/ |
| | Meat, goose and guinea fowl | 1073 | 2760973 | 1.005 | Bone removed from carcass weight using [i]. | 2207557 | [i] https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.821.8091&rep=rep1&type=pdf |
| | Wheat | 15 | 765769635 | 0.694 | Convert grain weight to flour equivalent using [i]. | 420275992 | [i] https://www.fao.org/fileadmin/templates/ess/documents/methodology/totdoc.pdf |
| | Coffee, green | 656 | 10035576 | 0.906 | Converted to roasted coffee equivalent using [i]. | 7274396 | [i] https://pubs.acs.org/doi/pdf/10.1021/acs.jafc.7b03310 |
| | Apples | 515 | 87236221 | 0.915 | | 79814977 | |
| | Apricots | 526 | 4083861 | 0.906 | | 3699662 | |
| | Artichokes | 366 | 1594385 | 0.896 | | 1428890 | |
| | Asparagus | 367 | 9432062 | 0.944 | | 8905404 | |
| | Avocados | 572 | 7179689 | 0.882 | | 6335105 | |
| | Bananas | 486 | 116781658 | 0.831 | | 97094033 | |
| | Barley | 44 | 158979610 | 0.272 | | 43223348 | |
| | Beans, dry | 176 | 28902672 | 0.737 | | 21302340 | |
| | Beans, green | 414 | 26981784 | 0.954 | | 25753614 | |
| | Berries nes | 558 | 922681 | 0.841 | | 776059 | |
| | Blueberries | 552 | 823328 | 1.023 | | 842483 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Broad beans, horse beans, dry | 181 | 5431503 | 0.532 | | 2891863 | |
| | Buckwheat | 89 | 1612235 | 0.261 | | 420962 | |
| | Cabbages and other brassicas | 358 | 70150406 | 0.868 | | 60866898 | |
| | Carobs | 461 | 46604 | 0.173 | | 8047 | |
| | Carrots and turnips | 426 | 44762859 | 0.856 | | 38332593 | |
| | Cashewapple | 591 | 1324050 | 0.706 | | 331013 | |
| | Cassava | 125 | 303568814 | 0.838 | | 254312367 | |
| | Cauliflowers and broccoli | 393 | 26918570 | 0.897 | | 24159049 | |
| | Cereals nes | 108 | 7909001 | 0.805 | | 6366391 | |
| | Cherries | 531 | 2595812 | 0.862 | | 2238126 | |
| | Cherries, sour | 530 | 1411608 | 0.922 | | 1301336 | |
| | Chestnut | 220 | 2406903 | 0.936 | | 2253480 | |
| | Chick peas | 191 | 14246295 | 0.737 | | 3561574 | |
| | Chillies and peppers, green | 401 | 38027164 | 0.922 | | 9506791 | |
| | Cinnamon (cannella) | 693 | 242635 | 0.884 | | 214589 | |
| | Cocoa, beans | 661 | 5596397 | 0.904 | | 5060761 | |
| | Cow peas, dry | 195 | 8903329 | 0.511 | | 2225832 | |
| | Cranberries | 554 | 687534 | 0.882 | | 606704 | |
| | Cucumbers and gherkins | 397 | 87805086 | 0.911 | | 21951272 | |
| | Currants | 550 | 647815 | 0.973 | | 161954 | |
| | Eggplants (aubergines) | 399 | 55197878 | 0.935 | | 13799470 | |
| | Eggs, hen, in shell | 1062 | 83483675 | 0.866 | | 72301491 | |
| | Eggs, other bird, in shell | 1091 | 6039581 | 0.893 | | 5396194 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Figs | 569 | 1315588 | 0.941 | | 328897 | |
| | Fonio | 94 | 700501 | 0.377 | | 264289 | |
| | Fruit, citrus nes | 512 | 14496484 | 0.909 | | 13172565 | |
| | Fruit, fresh nes | 619 | 39505413 | 0.916 | | 36171033 | |
| | Fruit, pome nes | 542 | 127620 | 0.840 | | 107150 | |
| | Fruit, stone nes | 541 | 608431 | 0.743 | | 451969 | |
| | Fruit, tropical fresh nes | 603 | 25331691 | 0.921 | | 23329436 | |
| | Garlic | 406 | 30708243 | 0.928 | | 7677061 | |
| | Ginger | 720 | 4081374 | 0.568 | | 1020344 | |
| | Gooseberries | 549 | 80014 | 0.975 | | 78037 | |
| | Grain, mixed | 103 | 3416985 | 0.207 | | 706999 | |
| | Grapefruit (inc. pomelos) | 507 | 9289462 | 0.902 | | 8382702 | |
| | Grapes | 560 | 77137016 | 0.973 | | 75028495 | |
| | Honey, natural | 1182 | 1852598 | 0.803 | | 1487200 | |
| | Karite nuts (sheanuts) | 263 | 759764 | 0.670 | | 509370 | |
| | Kiwi fruit | 592 | 4348011 | 0.912 | | 3966675 | |
| | Kola nuts | 224 | 306415 | 0.902 | | 276369 | |
| | Leeks, other alliaceous vegetables | 407 | 2192476 | 0.921 | | 548119 | |
| | Lemons and limes | 497 | 20049630 | 0.902 | | 18092487 | |
| | Lentils | 201 | 5734201 | 0.792 | | 4539206 | |
| | Lettuce and chicory | 372 | 29134653 | 0.886 | | 25825065 | |
| | Maize | 56 | 1148487291 | 0.199 | | 186268979 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Mangoes, mangosteens, guavas | 571 | 55853238 | 0.900 | | 50275783 | |
| | Meat, buffalo | 947 | 4290212 | 0.745 | | 3195464 | |
| | Meat, chicken | 1058 | 118017161 | 0.927 | | 109396656 | |
| | Meat, duck | 1069 | 4858137 | 0.979 | | 4755612 | |
| | Meat, sheep | 977 | 9922238 | 0.964 | | 9567764 | |
| | Melons, other (inc.cantaloupes) | 568 | 27501360 | 0.823 | | 22629735 | |
| | Milk, whole fresh buffalo | 951 | 133752296 | 0.928 | | 124065560 | |
| | Milk, whole fresh camel | 1130 | 3111462 | 0.834 | | 2594578 | |
| | Milk, whole fresh cow | 882 | 715922506 | 0.947 | | 678229684 | |
| | Milk, whole fresh goat | 1020 | 19910379 | 0.917 | | 18251777 | |
| | Milk, whole fresh sheep | 982 | 10587020 | 0.901 | | 9535328 | |
| | Millet | 79 | 28371792 | 0.735 | | 20841226 | |
| | Molasses | 165 | 63705325 | 0.465 | | 29591840 | |
| | Mushrooms and truffles | 449 | 11898399 | 0.890 | | 10585314 | |
| | Nutmeg, mace and cardamoms | 702 | 141700 | 0.734 | | 104025 | |
| | Nuts nes | 234 | 997225 | 0.836 | | 834015 | |
| | Oats | 75 | 23104147 | 0.214 | | 4939408 | |
| | Oil, coconut (copra) | 252 | 3278258 | 0.869 | | 2849742 | |
| | Oil, groundnut | 244 | 5551574 | 0.865 | | 4802379 | |
| | Oil, olive, virgin | 261 | 3574336 | 1.027 | | 3670659 | |
| | Oil, palm | 257 | 71468153 | 0.468 | | 33472777 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Oil, palm kernel | 258 | 7842084 | 0.572 | | 4488274 | |
| | Oil, rapeseed | 271 | 24579588 | 0.444 | | 10908443 | |
| | Oil, sesame | 290 | 1059146 | 0.782 | | 761701 | |
| | Oil, soybean | 237 | 56912719 | 0.533 | | 30313431 | |
| | Oil, sunflower | 268 | 18409217 | 0.696 | | 12813083 | |
| | Okra | 430 | 9953537 | 0.792 | | 2488384 | |
| | Olives | 260 | 19464495 | 0.922 | | 4866124 | |
| | Onions, shallots, green | 402 | 4491246 | 0.972 | | 4363374 | |
| | Oranges | 490 | 78699604 | 0.911 | | 71674438 | |
| | Papayas | 600 | 13735086 | 0.900 | | 12366892 | |
| | Peaches and nectarines | 534 | 25737841 | 0.933 | | 24018394 | |
| | Pears | 521 | 23919075 | 0.883 | | 21111426 | |
| | Peas, green | 417 | 21766060 | 0.947 | | 5441515 | |
| | Peppermint | 748 | 74232 | | | 74232 | |
| | Persimmons | 587 | 4270074 | 0.961 | | 4105535 | |
| | Pigeon peas | 197 | 4425969 | 0.866 | | 3831983 | |
| | Pineapples | 574 | 28179348 | 0.868 | | 24464250 | |
| | Pistachios | 223 | 911829 | 0.706 | | 643998 | |
| | Plantains and others | 489 | 41580022 | 0.902 | | 37512648 | |
| | Plums and sloes | 536 | 12601312 | 0.938 | | 11817964 | |
| | Potatoes | 116 | 370436581 | 0.716 | | 265263030 | |
| | Pulses nes | 211 | 4553029 | 0.609 | | 1138257 | |
| | Pumpkins, squash and gourds | 394 | 22900826 | 0.850 | | 19473889 | |
| | Quinces | 523 | 666589 | 0.920 | | 166647 | |
| | Quinoa | 92 | 161415 | 0.787 | | 126972 | |
| | Roots and tubers nes | 149 | 9871094 | 0.626 | | 6182696 | |
| | Rye | 71 | 12801441 | 0.408 | | 5218372 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Sorghum | 83 | 57893378 | 0.519 | | 30024788 | |
| | Spinach | 373 | 30107231 | 0.943 | | 28400304 | |
| | Strawberries | 544 | 8885028 | 0.903 | | 8022564 | |
| | String beans | 423 | 1387667 | 0.888 | | 1231626 | |
| | Sweet potatoes | 122 | 91820929 | 0.631 | | 73456743 | |
| | Tangerines, mandarins, clementines, satsumas | 495 | 35444080 | 0.887 | | 28355264 | |
| | Taro (cocoyam) | 136 | 10541914 | 0.590 | | 8433531 | |
| | Tea | 667 | 6497443 | 0.815 | | 5197954 | |
| | Tomatoes | 388 | 180766329 | 0.893 | | 144613063 | |
| | Tung nuts | 275 | 332447 | 0.656 | | 265958 | |
| | Vegetables, fresh nes | 463 | 311823678 | 0.805 | | 249458942 | |
| | Vegetables, leguminous nes | 420 | 1566331 | 0.898 | | 1253065 | |
| | Watermelon s | 567 | 100414933 | 0.811 | | 80331946 | |
| | Yams | 137 | 74321821 | 0.543 | | 59457457 | |
| | Yautia (cocoyam) | 135 | 481199 | 0.708 | | 120300 | |
| Food and processed as % of use categories | Almonds, with shell | 221 | 3497148 | 0.960 | Shell removed from weight using [i] | 1846331 | [i] https://www.fao.org/waicent/faoinfo/economic/faodef/fdef05e.htm#5.02 |
| | Meat, bird nes | 1089 | 19197 | 1.000 | | 19197 | |
| | Oil, safflower | 281 | 95728 | 0.536 | | 47188 | |
| | Pepper (piper spp.) | 687 | 1103024 | 0.918 | | 1012638 | |
| | Raspberries | 547 | 822493 | 0.935 | | 768867 | |
| | Snails, not sea | 1176 | 20164 | 1.000 | | 20164 | |

## Appendix C. Emissions factors and functional units of commodities from Poore and Nemecek (2018).

| Commodity | Functional unit | Median global emissions factor |
|---|---|---:|
| Apples | 1 kg of fresh fruit or vegetable | 0.4 |
| Bananas | 1 kg of fresh fruit or vegetable | 0.8 |
| Barley (Beer) | 1 liter of beer | 1.2 |
| Beet Sugar | 1 kg of raw/refined sugar | 1.8 |
| Berries & Grapes | 1 kg of fresh fruit or vegetable | 1.4 |
| Bovine Meat (beef herd) | 1 kg fat and bone-free meat and edible offal | 60.4 |
| Bovine Meat (dairy herd) | 1 kg fat and bone-free meat and edible offal | 34.1 |
| Brassicas | 1 kg of fresh fruit or vegetable | 0.4 |
| Cane Sugar | 1 kg of raw/refined sugar | 3.2 |
| Cassava | 1 kg soil free tuber | 1.1 |
| Cheese | 1 kg cheese | 18.6 |
| Citrus Fruit | 1 kg of fresh fruit or vegetable | 0.3 |
| Coffee | 1 kg of ground, roasted beans | 8.2 |
| Crustaceans (farmed) | 1 kg of head-free meat (shell-free for large shrimp) | 14.7 |
| Dark Chocolate | 1 kg of dark chocolate | 5.0 |
| Eggs | 1 kg eggs | 4.2 |
| Fish (farmed) | 1 kg edible fish | 7.9 |
| Groundnuts | 1 kg shell free, roasted nut | 3.3 |
| Lamb & Mutton | 1 kg fat and bone-free meat and edible offal | 40.6 |
| Maize (Meal) | 1 kg meal (for polenta) | 1.2 |
| Milk | 1 liter of pasteurized milk (4% fat) | 2.7 |

| | | |
|---|---|---|
| Nuts | 1 kg shell free, dry nut | -1.3 |
| Oats | 1 kg rolled oats | 2.6 |
| Olive Oil | 1 liter of refined/filtered oil | 5.1 |
| Onions & Leeks | 1 kg of fresh fruit or vegetable | 0.4 |
| Other Fruit | 1 kg of fresh fruit or vegetable | 0.7 |
| Other Pulses | 1 kg dry pulse without pod | 1.4 |
| Other Vegetables | 1 kg of fresh fruit or vegetable | 0.4 |
| Palm Oil | 1 liter of refined/filtered oil | 7.2 |
| Peas | 1 kg dry pea without pod | 0.8 |
| Pig Meat | 1 kg fat and bone-free meat and edible offal | 10.6 |
| Potatoes | 1 kg soil free tuber | 0.5 |
| Poultry Meat | 1 kg fat and bone-free meat and edible offal | 7.5 |
| Rapeseed Oil | 1 liter of refined/filtered oil | 3.5 |
| Rice | 1 kg full grain white or brown rice | 3.7 |
| Root Vegetables | 1 kg of soil free tuber | 0.4 |
| Soybean Oil | 1 liter of refined/filtered oil | 3.9 |
| Soymilk | 1 liter of soymilk | 0.9 |
| Sunflower Oil | 1 liter of refined/filtered oil | 3.5 |
| Tofu | 1 kh tofu (16% protein) | 2.6 |
| Tomatoes | 1 kg of fresh fruit or vegetable | 0.7 |
| Wheat & Rye (Bread) | 1 kg bread (variable protein wheat) | 1.3 |
| Wine grapes | 1 liter of wine | 1.6 |

## Appendix D. Supplementary emissions factors used in this study.

| FAO item name | FAO Item Code | EF (Clune) | EF (Other source) | Other source |
|---|---|---|---|---|
| Cinnamon (cannella) | 693 | - | 0.87 | https://assets.wwf.org.uk/downloads/how_low_report_1.pdf |
| Soybeans | 236 | - | 1.3 | https://pubs.acs.org/doi/pdf/10.1021/acs.jafc.7b03310; https://link.springer.com/article/10.1007/s10584-014-1169-1/tables/4 |
| Cocoa, beans | 661 | - | 3.22 | https://www.sciencedirect.com/science/article/pii/S0959652607002429 |
| Milk, whole fresh goat | 1020 | | 4.94 | Authors' calculations using: https://www.fao.org/3/i3461e/i3461e04.pdf https://ec.europa.eu/jrc/sites/default/files/BISO-EnvSust-Food-and-Feed-Milk_141020.pdf https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7492176/ |
| Milk, whole fresh sheep | 982 | - | 5.66 | Authors' calculations using: https://www.fao.org/3/i3461e/i3461e04.pdf https://ec.europa.eu/jrc/sites/default/files/BISO-EnvSust-Food-and-Feed-Milk_141020.pdf https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7492176/ |
| Rye | 71 | 0.41 | - | |
| Fonio | 94 | 0.47 | - | |
| Millet | 79 | 0.47 | - | |
| Barley | 44 | 0.49 | - | |
| Grain, mixed | 103 | 0.50605689 | - | |
| Buckwheat | 89 | 0.53391128 | - | |
| Honey, natural | 1182 | 0.795 | - | |
| Sorghum | 83 | 0.88 | - | |
| Sesame seed | 289 | 0.88 | - | |
| Quinoa | 92 | 1.15 | - | |

| | | | | |
|---|---|---|---|---|
| Sunflower seed | 267 | 1.41 | - | |
| Oil, coconut (copra) | 252 | 2.1 | - | |
| Meat, duck | 1069 | 3.085 | - | |
| Oil, safflower | 281 | 3.525 | - | |
| Oil, sesame | 290 | 3.525 | - | |
| Milk, whole fresh buffalo | 951 | 3.75 | - | |
| Meat, bird nes | 1089 | 3.7745566 | - | |
| Meat, rabbit | 1141 | 4.7 | - | |
| Oil, groundnut | 244 | 4.717 | - | |
| Meat, turkey | 1080 | 6.04063592 | - | |
| Meat, goat | 1017 | 23 | - | |
| Meat, buffalo | 947 | 55.3956835 | - | |

# Appendix E. Agricultural production conversion factor calculations.

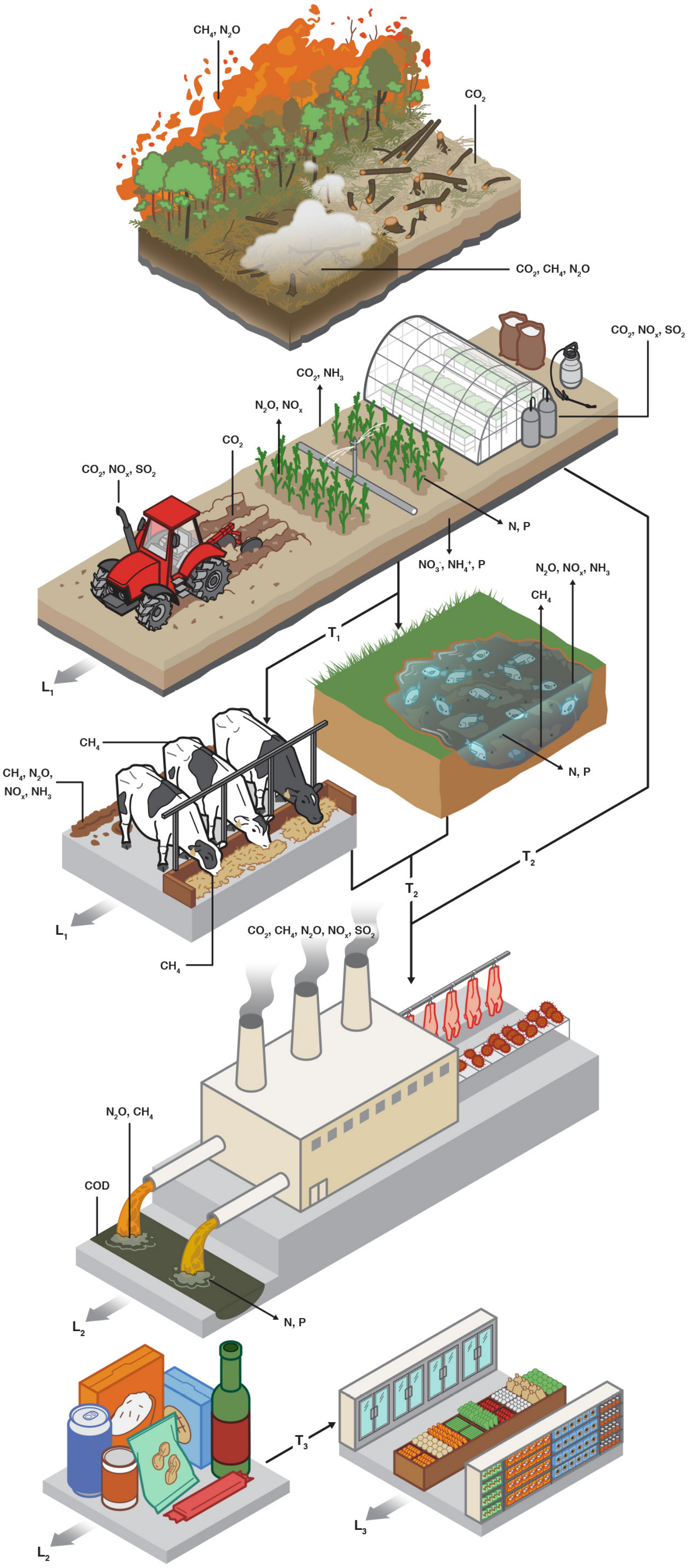
**Table E1. Agricultural production conversion factor calculation by commodity: crops**

| Product | Models | Dry matter share | Factor to apply | FAOSTAT production 2010 | Factor weight (share of production across modelled crops) | |
|---|---|---|---|---|---|---|
| | | | | | IMAGE; REMIND-MAgPIE | MESSAGE-GLOBIOM |
| Temperate cereals (wheat, rye, oats, barley, triticale) | IMAGE; REMIND-MAgPIE | 0.89 | 1 | 960614319 | 0.16 | 0.00 |
| Rice | MESSAGE-GLOBIOM; IMAGE; REMIND-MAgPIE | 0.89 | 1 | 499709669 | 0.08 | 0.08 |
| Maize | MESSAGE-GLOBIOM; IMAGE; REMIND-MAgPIE | 0.87 | 1 | 1141359868 | 0.19 | 0.19 |
| Tropical cereals (millet, sorghum) | IMAGE; REMIND-MAgPIE | 0.895 | 1 | 85695849 | 0.01 | 0.00 |
| Pulses | IMAGE; REMIND-MAgPIE | 0.91 | 1 | 50273736 | 0.01 | 0.00 |
| Temperate roots and tubers | IMAGE; REMIND-MAgPIE | 0.25 | 0.25 | 403982633 | 0.07 | 0.00 |
| Tropical roots and tubers | IMAGE; REMIND-MAgPIE | 0.33 | 0.33 | 464734169 | 0.08 | 0.00 |
| Sunflower | MESSAGE-GLOBIOM; IMAGE; REMIND-MAgPIE | 0.923 | 1 | 56020665 | 0.01 | 0.01 |
| Soybean | MESSAGE-GLOBIOM; IMAGE; REMIND-MAgPIE | 0.91 | 1 | 336329392 | 0.06 | 0.06 |
| Groundnut | MESSAGE-GLOBIOM; IMAGE; REMIND-MAgPIE | 0.91 | 1 | 49544191 | 0.01 | 0.01 |
| Rapeseed | MESSAGE-GLOBIOM; IMAGE; REMIND-MAgPIE | 0.923 | 1 | 71838655 | 0.01 | 0.01 |
| Sugarcane | MESSAGE-GLOBIOM; IMAGE; REMIND-MAgPIE | 0.32 | 0.32 | 1955307695 | 0.32 | 0.33 |
| Barley | MESSAGE-GLOBIOM | 0.89 | 1 | 158462601 | 0.00 | 0.03 |
| Dry beans | MESSAGE-GLOBIOM | 0.91 | 1 | 26095060 | 0.00 | 0.00 |
| Cassava | MESSAGE-GLOBIOM | 0.33 | 0.33 | 299028225 | 0.00 | 0.05 |
| Chickpea | MESSAGE-GLOBIOM | 0.91 | 1 | 14184449 | 0.00 | 0.00 |
| Cotton | MESSAGE-GLOBIOM | 0.935 | 1 | 45377342 | 0.00 | 0.01 |
| Millet | MESSAGE-GLOBIOM | 0.9 | 1 | 28333094 | 0.00 | 0.00 |
| Potatoes | MESSAGE-GLOBIOM | 0.25 | 0.25 | 354812093 | 0.00 | 0.06 |
| Sorghum | MESSAGE-GLOBIOM | 0.89 | 1 | 57362755 | 0.00 | 0.01 |
| Sweet potatoes | MESSAGE-GLOBIOM | 0.33 | 0.33 | 91490303 | 0.00 | 0.02 |
| Wheat | MESSAGE-GLOBIOM | 0.89 | 1 | 764980821 | 0.00 | 0.13 |

**Table E2. Agricultural production conversion factor calculation by commodity: livestock products**

| Product | Models | Dry matter share | Factor to apply | FAOSTAT production 2010 | Factor weight (share of production across modelled livestock products) | | |
|---|---|---|---|---|---|---|---|
| | | | | | IMAGE | REMIND-MAgPIE | MESSAGE-GLOBIOM |
| Bovine meat | MESSAGE-GLOBIOM; IMAGE | 0.39 | 0.39 | 67915624 | 0.06 | 0.00 | 0.06 |
| Bovine milk | MESSAGE-GLOBIOM | 0.54 | 0.54 | 708264265 | 0.00 | 0.00 | 0.62 |
| Small ruminant meat | MESSAGE-GLOBIOM; IMAGE | 0.65 | 0.65 | 15550194 | 0.01 | 0.00 | 0.01 |
| Small ruminant milk | MESSAGE-GLOBIOM | 0.54 | 0.54 | 30684320 | 0.00 | 0.00 | 0.03 |
| Pig meat | MESSAGE-GLOBIOM; IMAGE; REMIND-MAgPIE | 0.59 | 0.59 | 109635731 | 0.10 | 0.10 | 0.10 |
| Poultry meat | MESSAGE-GLOBIOM; IMAGE; REMIND-MAgPIE | 0.25 | 0.25 | 123630097 | 0.11 | 0.11 | 0.11 |
| Eggs | MESSAGE-GLOBIOM; IMAGE; REMIND-MAgPIE | 0.767 | 0.767 | 84363316 | 0.07 | 0.07 | 0.07 |
| Ruminant meat | REMIND-MAgPIE | 0.595 | 0.595 | 83465818 | 0.00 | 0.07 | 0.00 |
| Milk | IMAGE; REMIND-MAgPIE | 0.54 | 0.54 | 738948585 | 0.65 | 0.65 | 0.00 |
| Bovine meat | MESSAGE-GLOBIOM; IMAGE | 0.39 | 0.39 | 67915624 | 0.06 | 0.00 | 0.06 |

## Appendix F. Agricultural production conversion factor calculations (taken from Poore & Nemecek, 2018, Supplementary Materials).




| | Included | Excluded |
|---|---|---|
| **Land Use Change** | • Above ground C stock change ($CO_2$)<br>• Below ground C stock change ($CO_2$)<br>• Forest burning ($CH_4$, $N_2O$)<br>• Organic soil burning ($CO_2$, $CH_4$, $N_2O$) | • Leaching, runoff and induced non-$CO_2$ emissions |
| **Crop Production** | • Seed & nursery<br>• Inputs production<br>• Machinery<br>• Greenhouse & trellis infrastructure<br>• Electricity & fuel<br>• Fertilizer & retained crop residue ($N_2O$, $NH_3$, $NO_x$, $NO_3^-$, $NH_4^+$, P, N)<br>• Urea & lime ($CO_2$)<br>• Flooded rice ($CH_4$)<br>• Residue burning ($CH_4$, $N_2O$, $NH_3$, $NO_x$)<br>• Cultivation of drained organic soils ($CO_2$, $N_2O$)<br>• Drying / grading<br>• Irrigation water consumption<br>—<br>Land use: seed; fallow; arable and permanent crops | • Soil emissions ($CH_4$)<br>• Organic fertilizer application ($CH_4$)<br>• N fixation emissions<br>• C sequestration in crop residue<br>• Runoff (N)<br>• Residue burning indirect emissions ($N_2O$)<br>• Human labour |
| **Livestock/Aquaculture** | • Pasture management (same as for food/feed)<br>• Feed processing<br>• Housing energy use<br>• Enteric fermentation ($CH_4$)<br>• Manure management ($N_2O$, $NO_x$, $NH_3$, $CH_4$)<br>• Aquaculture ponds (N, P, $N_2O$, $NO_x$, $NH_3$, $CH_4$)<br>• Drinking & service water<br>—<br>Land use: permanent pasture; temporary pasture; aquaculture ponds | • Infrastructure<br>• Pasture residue (emissions or burning)<br>• Pasture N fixation emissions<br>• Pasture runoff (N)<br>• Manure management (P)<br>• Human labour |
| **Processing** | • Energy ($CO_2$, $NO_x$, $SO_2$)<br>• Wood burning ($CH_4$, $N_2O$, $NO_x$, $SO_2$)<br>• Wastewater ($CH_4$, $N_2O$, P, N, COD)<br>• Incineration ($CH_4$, $N_2O$, $NO_x$, $SO_2$)<br>• Processing water consumption | • Miscellaneous inputs<br>• Human labour<br>• Infrastructure<br>• Land use |
| **Packaging** | • Materials<br>• Material transport<br>• End of life disposal | • Human labour<br>• Infrastructure<br>• Land & water use |
| **Retail** | • Energy use | • Human labour<br>• Infrastructure<br>• Land & water use |

| **Losses** | **Transport** ($CO_2$, $NO_x$, $SO_2$) |
|---|---|
| $L_1$ - Storage and transport | $T_1$ - Feed |
| $L_2$ - Processing and packaging | $T_2$ - Food |
| $L_3$ - Wholesale and retail | $T_3$ - Processed food |

[10]

## Appendix G. Company disclosures as of 25th November 2022.

| Company Metadata | | | Emissions Data | | | Production/Input Data | | Data Sources |
|---|---|---|---|---|---|---|---|---|
| **Company** | **Market Cap ($billion)** | **Sourced Commodities** | **Discloses Scope 3 purchased goods and services (PGS)** | **Scope 3 from agricultural inputs and PGS distinct?** | **Upstream Scope 3 includes land-use change emissions?** | **Production** | **Input** | |
| **Nestlé** | 313.47 | Coffee, wheat, dairy, soybeans, palm oil, cocoa | ✓ | ✓ | ✓ | ✓ | ✓ | CDP 2014-2021; Consolidated Environmental Performance Indicators 2020; Net Zero Roadmap 2021; Sustainability Report 2020 |
| **Mondelez International Inc.** | 76.31 | Cocoa, wheat, dairy, coffee, corn products, oils, sugar, sweeteners | ✓ | | ✓ | ✓ | | CDP 2014-2021; Annual Report 2013-2020; ESG Report 2019-2021 |
| **Danone** | 39.82 | Milk, sugar, corn, palm oil | ✓ | | | ✓ | | CDP 2014-2021; Integrated Annual Report 2021 and 2019; Environmental Data 2021; Methodology Note 2021 |
| **General Mills** | 35.09 | Oats, wheat, cattle products, palm oil, sugar | ✓ | ✓ | | | | CDP 2014-2021; Global Responsibility Report 2022 |
| **Archer Daniels Midland (ADM)** | 25.27 | Corn, palm oil, cotton, rice, soy | ✓ | | | ✓ | ✓ | CDP 2014-2021; Corporate Sustainability Report 2021 |
| **McCormick & Co** | 21.59 | Dairy, pepper, capsicums, onion, vanilla, garlic, salt | ✓ | | | ✓ | | CDP 2014-2021; Purpose-led Performance Report 2021 |
| **Hershey Company** | 20.61 | Cocoa, sugar, timber, dairy, palm oil | ✓ | ✓ | ✓ | | | CDP 2013-2017 and 2019; 2022 Proxy Statement and 2021 Annual Report 2021; ESG Report 2021 |
| **Kraft Heinz** | 20.24 | Dairy, meat, coffee, nuts, tomatoes, potatoes, oils, sugar, corn, wheat | ✓ | ✓ | | ✓ | | CDP 2016-2021; ESG Report 2021 |
| **Kerry Group PLC** | 19.31 | Palm oil, dairy, soy, coffee, cocoa | ✓ | | | ✓ | | GRI Sustainability Report 2021 |
| **Tyson Foods Inc** | 17.72 | Cattle products, pork, animal feed | | | | ✓ | | CDP 2016-2021; Sustainability Report 2021 |

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Title photo: Irewolede, “Sunset over Limuru tea farm”, 2021 via Unsplash:, link

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