

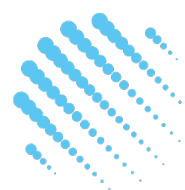
TPI CARBON PERFORMANCE ASSESSMENT OF FOOD PRODUCERS: DISCUSSION PAPER

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Simon Dietz, Eleanor Harvey, Valentin Jahn
and Agnes Norris Keiller

With contributions from: Robin Goon, Issam Jamaledine,
Vitaliy Komar and Philippa Lockwood



**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.

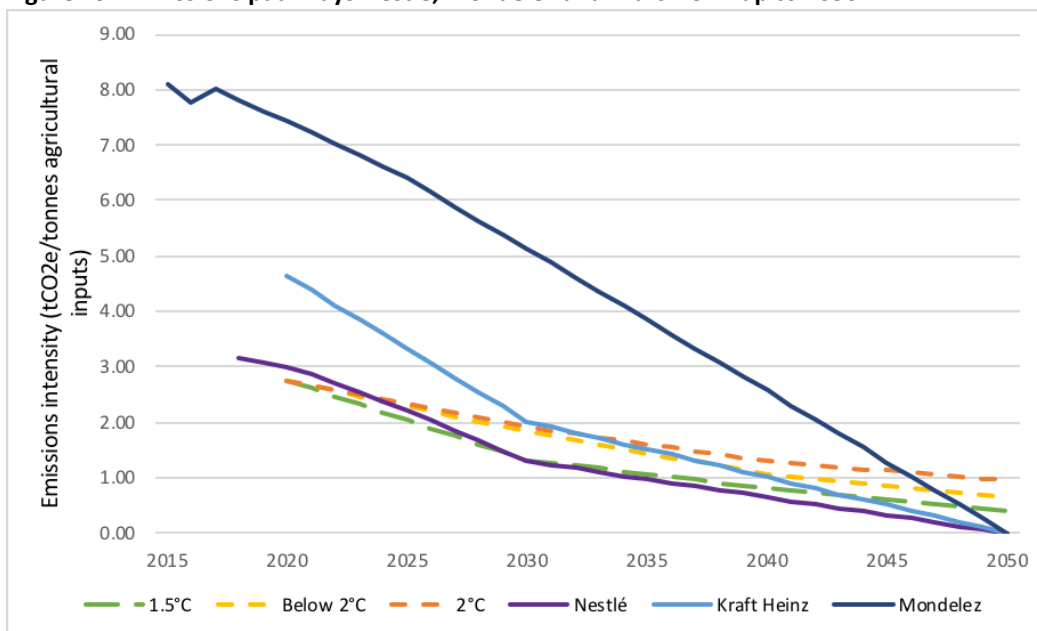
In developing a methodology for food producers' Carbon Performance, we have had to overcome unique challenges. The main challenge in producing low-carbon benchmark scenarios is that the Integrated Assessment Models (IAMs) used for food-sector emissions pathways do not provide emissions/production figures 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

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.

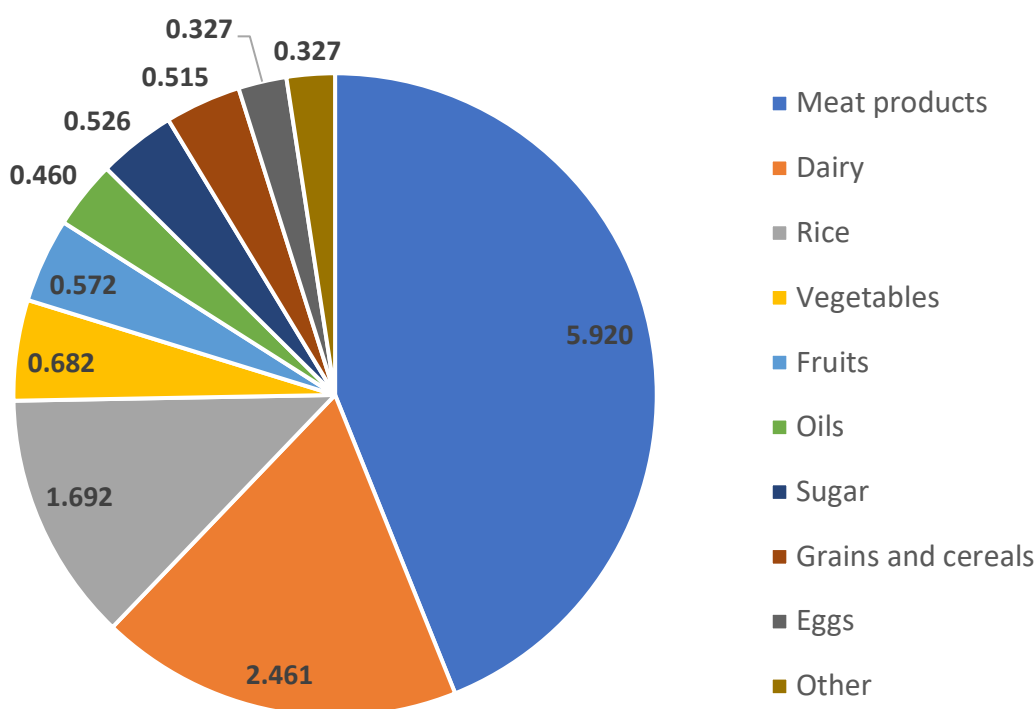
⁹ Poore and Nemecek (2018) [10] adjust milk quantities across different species to standardize the fat and protein content, which is an item that we may address in subsequent versions of the Benchmark.

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 IAMs¹⁰. 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 3¹³. 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 N₂O¹⁴. 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 data¹⁵ [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]

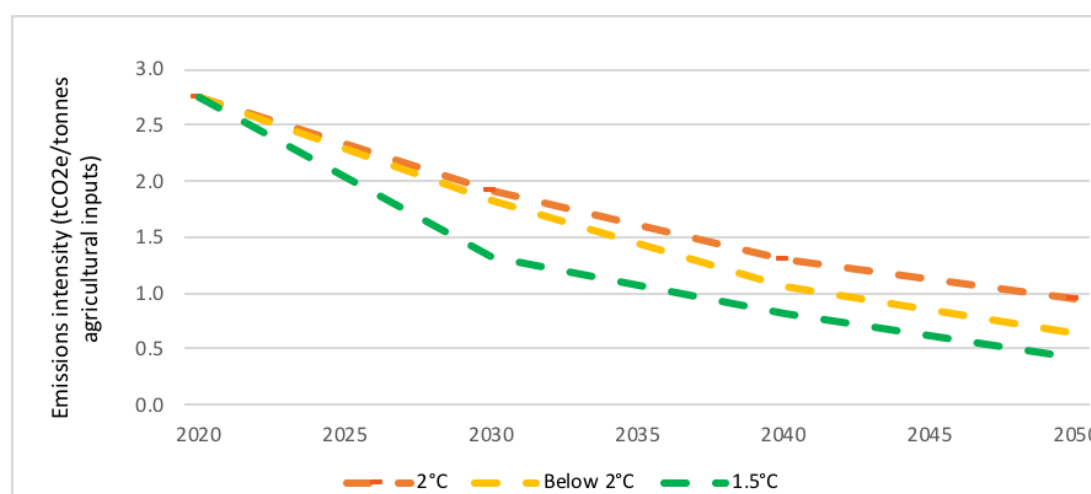
- AFOLU CO₂ is entirely attributable to food processors. As the vast majority of AFOLU CO₂ emissions are due to land use change¹⁶ [27], this inclusion is justified by agriculture’s major role in driving land conversion. [28], [29]

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 CO₂

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

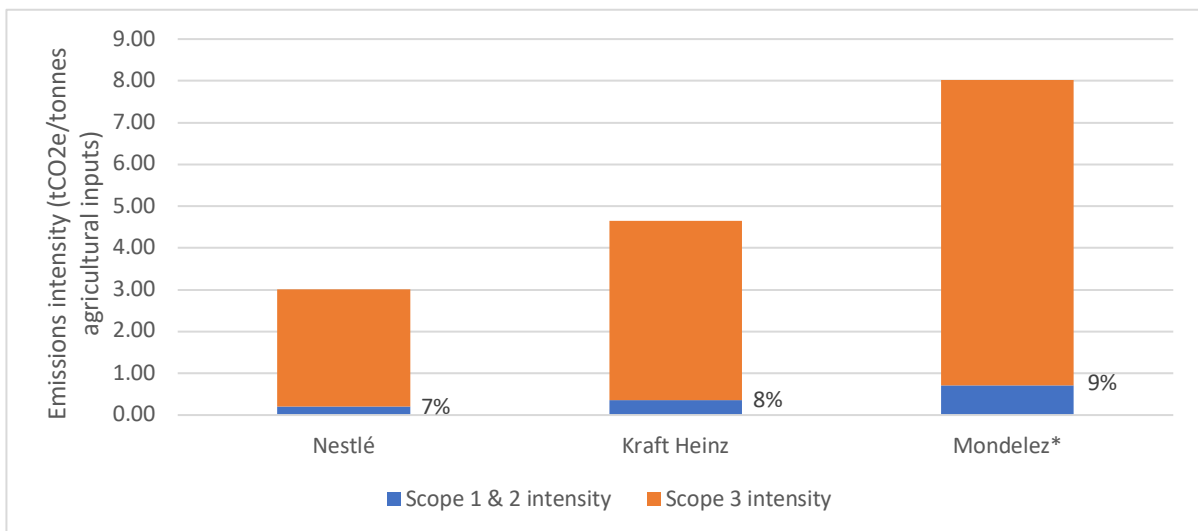
5.2. Company Performance

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 tCO₂e/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:

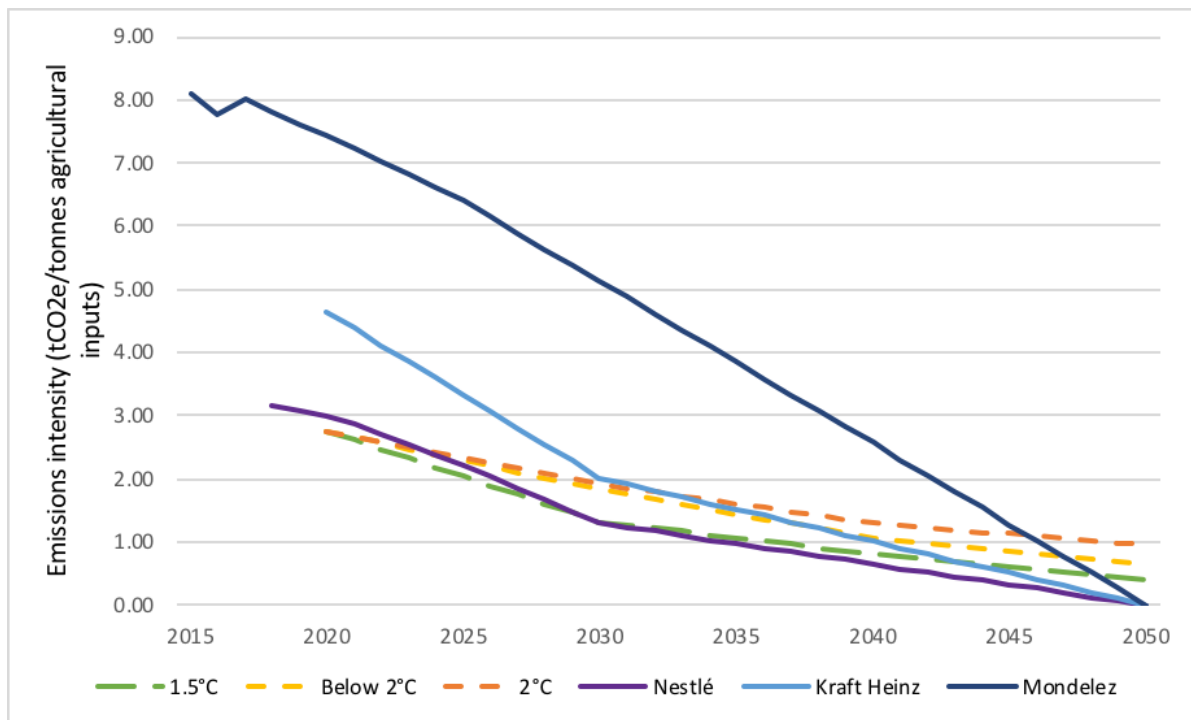
- Nestlé's path to decarbonisation commits the company to net zero by 2050, with their target covering Scope 1, 2, and 'more than 80%' of its Scope 3 emissions. The company also sets interim targets of a 20% reduction from a 2018 baseline by 2025, and a 50% reduction from the same baseline by 2050.
- 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 CO₂ 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 ratio¹⁹.

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 constant²⁰.

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.

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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
	Jajoba 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 , [ii] https://www.diva-portal.org/smash/get/diva2:943348/FULLTEXT01.pdf [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 , [ii] https://www.diva-portal.org/smash/get/diva2:943348/FULLTEXT01.pdf [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_carca ss_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, mangosteen s, 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	
	Watermelons	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.

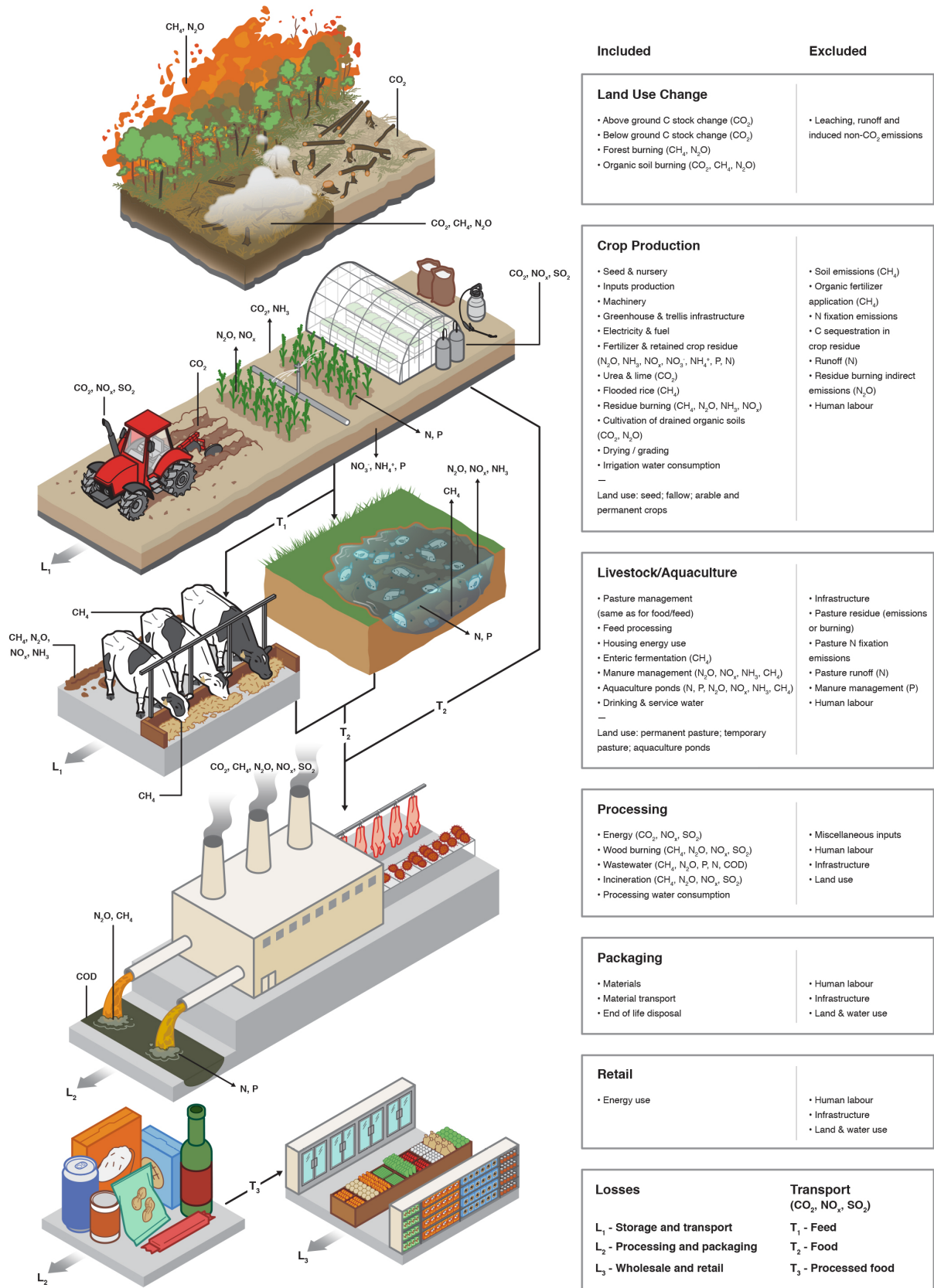
Table E1. Agricultural production conversion factor calculation by commodity: crops

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).



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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