

Methods:

Carbon footprints

GHG intensities of common animal and alternative protein products were obtained from academic and gray literature. When possible, values were made to represent production emissions per kilogram of product from the cradle-to-farm gate, and the contribution of retail, consumer use, and transportation stages was subtracted from the reported carbon footprint. For example, the system boundary for Morningstar products and the Impossible Sausage included stages past the farm gate and those emissions, which were related to transportation to retail outlets, were identified and eliminated from the total carbon footprint.

Formulation (Sheet titled “Composition of Alternative Meats”)

I used the nutritional content of each alternative protein product and the nutritional content of common alternative protein ingredients to estimate the contribution of each ingredient to the product’s formulation.

If the first ingredient listed after water was a protein ingredient, then the protein content of the alternative protein product was used to estimate the amount (in grams) of key protein ingredients like soy protein concentrate or isolate, pea protein, rice protein and wheat gluten. For example, the first ingredient listed after water for the Impossible Burger (IB) was soy protein concentrate. It was assumed that all 19g of protein in the IB came from soy protein concentrate which is 70% protein. To meet the protein level in the IB, about 27 grams of soy protein concentrate would be needed. For products that contain multiple protein ingredients, an assumption was made about the protein contributed by each of the ingredients, depending on the order they were listed in on the nutritional label. For the Beyond Burger, it was assumed that 80% of the protein content came from pea protein while 20% of the protein content came from rice protein. The amount in grams of the key protein ingredient was then multiplied by the ingredient’s fat content to estimate the total amount of fat that was contributed by the oil ingredients. For the IB which has 27 g of soy protein concentrate, 0.11 g of IB’s fat is coming from this ingredient since 0.40% of soy protein concentrate is fat. The 0.11g fat contribution of soy protein concentrate is then subtracted from the total fat of the IB. The unsaturated and saturated fat content in each product was then used to determine the contribution of each key oil ingredient like coconut oil, sunflower oil, and canola oil. For products that contain multiple oil ingredients, an assumption was made about the fat contributed by each of the oil ingredients, depending on whether it was a key source of unsaturated or saturated fat (or both). For the Impossible Burger, it was assumed that the remaining fat content was evenly contributed by both sunflower and coconut oil, for example.

If the first ingredient listed after water was a flour ingredient, then the carbohydrate content was used to estimate the amount of soy or wheat flour in grams. The amount in grams of the flour ingredient was multiplied by the ingredient’s protein content to determine the remaining contributions of the protein ingredients to the total protein content of the product. If there were multiple protein ingredients, then an assumption was made about the protein contribution of each ingredient. For the Morningstar Original Chik Patties, it is assumed that 75% of the remaining

protein content was from soy protein concentrate and 25% was from soy protein isolate based on the order in which ingredients were listed on the nutritional label. For Morningstar Sausage patties, the remaining protein content was attributed equally to wheat gluten and soy protein concentrate.

I allocated 1-2% of the ingredient formulation towards ingredients that would have a carbon opportunity cost but were listed as making up less than 2% of the product's formulation. This includes cocoa butter, potato starch, and soy protein isolate (in some cases).

For mycoprotein-based products, Quorn reports the percentage of mycoprotein in the formulation. The contributions of the remaining ingredients were split evenly for Quorn Meatless Pieces and Quorn Beef Mince. For Quorn Sausages, the contributions of oil ingredients, wheat protein, and pea fiber were made identical to the average contribution across other products with similar ingredients, except for onion, whose contribution was equivalent to the remaining amount of product formulation leftover after determining the contribution of other ingredients.

The contribution of water is assumed to be the remaining product composition that is not accounted for by the other key ingredients.

The media formulation for cultivated meat was used to determine the COC of the product, and the contribution of each ingredient to the media composition was obtained from an anticipatory life cycle analysis.

Carbon Opportunity Cost (Sheet titled "Composition of Alternative Meats")

Each key ingredient in the alternative protein product was assigned a carbon opportunity cost (COC) value from the Carbon Benefits Calculator (CBC). The COC for the most similar crop or the highest COC of multiple similar crops from the CBC was assigned to each key ingredient. The highest COC value was chosen to produce a more conservative climate benefit for alternative protein products. The COC for water was assumed to be 0.

For conventional animal products, COCs were assigned from the CBC and then converted so that the units would be on a retail weight basis.

For cultivated meat, the production of amino acids, recombinant proteins, and growth factors involve glucose and other crop inputs. Most glucose in the US is derived from maize, so for any media components that are sugars or are processed with glucose as an input, the COC of maize grains (or other crop inputs when specified) multiplied by the sugar content of maize was used. The common salt solution used in cell media includes a sugar-derived ingredient, so the maize grains was used. Since HEPES (buffering agent) is synthesized chemically in a lab, the COC was assumed to be 0.

Total Climate Impact (Sheet titled "Climate Impact")

The total climate impact was equivalent to the COC and carbon footprint associated with each conventional animal and alternative protein product. The total climate impact was also calculated on a per kg protein basis by dividing the protein content in the given animal or alternative protein product from the total climate impact, and the value was also adjusted by the

protein digestibility of each product by dividing the digestibility of associated with the conventional meat animal product or a key alternative protein ingredient. No protein digestibility for soy milk was found, so the protein digestibility of soybeans was used.

For cultivated meat, the average protein content and digestibility of conventional animal protein were used to determine climate impact on a per kg protein basis.

Limitations

A key limitation of the analysis was the lack of information on the specific contributions of ingredients to the product formulation. Companies have not published data on the percentage or weight of soy protein concentrate, soy protein isolate, pea fiber or other ingredients. The contribution of a key ingredient to the COC of the entire product could be overestimated or underestimated, which would also impact the overall carbon footprint of the alternative protein product.

Another key limitation is the lack of data on the carbon opportunity costs of many of the ingredients. Ingredients like wheat gluten, textured wheat protein, or rice protein require additional processing from the crops that they are derived from. This may lead us to underestimate COCs, as there may be losses in production, storage, and processing. If the true COC of these ingredients is much higher, then the carbon footprint of these products is being underestimated by current calculations. However, by using the highest COC values for ingredients when available, we are able to produce a more conservative COC estimate for the entire alternative protein product.

For cultivated meat, it is likely that the COC is overestimated since upstream production processes of key serum ingredients are being used to determine the individual COCs of cultivated meat ingredients.