**Foodprints**

**Understanding Connections Between Food Choices and Our Environment**

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**Chapter 2**

**Carbon Footprints of Foods**

**Section 1. Learning outcomes**

After this chapter you will be able to:

* Briefly describe the greenhouse effect and why it is leading to climate change
* Describe the major greenhouse gases
* Understand the reasons why certain food products have a higher carbon footprint than others
* Calculate the carbon footprint of a simple meal
* Put carbon footprints in the context of the reductions needed to reach Paris Climate targets
* Briefly describe the role of the cold chain in carbon footprints
* Understand how an estimate of the carbon footprint of a plastic package compares to the footprint for the ingredients.

**Section 2. Chapter Overview**

In the last chapter, we covered the planetary boundaries concept and the many connections between the various boundaries and foods. One of the boundaries that is currently being exceeded, climate change, has particularly strong ties with our food system. Foods vary widely footprint, the impact their production has on climate. In addition, processing, packing, and transportation of foods all have an impact on climate change.

This chapter will provide a brief background on climate change followed by an overview of the greenhouse gas emissions on various types of foods. We will then look at packaging and refrigerated transport.

**Section 3. Quick Primer on Climate Change**

Our planet is a habitable temperature due to a layer of gases that create a “greenhouse effect.”

When solar radiation in the form of visible and ultraviolet light passes through the atmosphere and is absorbed by the Earth, the surface temperature rises and the Earth emits infrared radiation. This radiation has a longer wavelength and will largely be absorbed by certain gases in the atmosphere termed greenhouse gases (GHGs). Important GHGs include carbon dioxide (CO2), water vapor, ozone (O3), nitrous oxide (N2O), methane (CH4), and halocarbons including chlorofluorocarbons (CFCs). The energy absorbed by GHG is then re-emitted in every direction, and the downward radiation warms the troposphere to a temperature that is on average supportive of Earth’s ecosystems.

The natural greenhouse effect has been amplified over the last several hundred years due to anthropogenic increases in the levels of GHGs. Each GHG has a characteristic global warming potential, which indicates the contribution a molecule of that gas will make toward warming, relative to a molecule of carbon dioxide. For example, over a 100 year period, one molecule of methane is 25 times more potent than a molecule of CO2. Nitrous oxide is 298 times more potent than carbon dioxide on a molecule by molecule basis, over the same timeframe. Even though carbon dioxide as potent of a GHG as methane and nitrous oxide, it is so abundant that it is the major contributor to anthropogenic warming (water vapor contributes the most to the natural greenhouse effect).

Trends and sources for the most significant anthropogenic GHGs are as follows:

* Carbon dioxide concentration has increased from 280 ppm to 389 ppm since 1750. Sources include deforestation and the burning of fossil fuels, the latter of which brings into the cycle carbon that has been sequestered for millions of years.
* Methane levels have risen 2.5 fold since the start of the industrial revolution. Sources include oil deposits, ruminant animals (cows, goats, and sheep), landfills, and rice cultivation.
* Nitrous oxide is produced in animal agriculture and chemical manufacturing. Car emissions and synthetic nitrogen fertilizer are also important sources. Since the start of the industrial revolution, levels of nitrous oxide have risen 18%.
* Ozone levels have increased by about 36% as a result of photochemical smog.

Some of the major impacts we are seeing include:

* The average temperature on the Earth has increased by roughly 1 degree C.
* Days of extreme heat occur with greater frequency.
* Higher sea surface temperatures have led to increases in the intensity, power, and possibly number of tropical storms.
* Droughts have intensified due to changes in precipitation patterns.
* Flooding has occurred due to heavy rain events along with land use change.
* Glaciers are retreating at high rates
* Sea levels are rising and will result in displacement of millions of people.

**Section 4. Carbon Footprint of Various Foods**

Foods vary in the GHG emissions embodied in their production. See Figure 1 for carbon footprints per gram of food (panel A) and per gram of protein (panel B) for selected foods.

In general, plant foods have a lower carbon footprint. This is because resources including land, fertilizer, and water are required for growing food of any kind, either crops for people or feed crops for livestock. If we eat the crops directly, we can calculate the footprint based on those resources. However, if we feed crops to animals, very little of the energy in the feed is converted to food for people. Most of the energy goes to sustaining the animal over its lifetime, or is lost in the manure.

Figure 1. Carbon footprints per gram of food (panel A) and per gram of protein (panel B) for selected foods. Data on the carbon footprint of foods are from Heller and Keoleian (2014). The USDA Food Composition Database was used to convert grams of food to grams of protein.

Another point to notice from the graph is that products from ruminant animals like cows, sheep, and goats, have a higher footprint than other animal products. This is because ruminants produce methane as part of their natural digestion.

A lot of people wonder about the sustainability of grass-fed beef. To address this, it is necessary to consider what aspect of sustainability we are interested in. See Figure 2 for a compilation of various studies of the carbon footprints of different sources of protein. Every dot represents a separate carbon footprint estimate. You can see that pasture raised beef, “Beef extensive,” is on par with beef produced in a more confined system, “Beef intensive”. This is because when the animals are eating grasses, which are the natural diet, they produce methane naturally. If part of their diet is switched to corn, for example, they will actually produce somewhat less methane. (The corn would have its own carbon footprint for its production, which is factored in.) Grass-fed beef has other benefits, including more humane treatment of the animals, but unfortunately it is no “free lunch” with respect to climate.



Figure 2. From Nijdam et al. (2012) of life cycle analysis estimates of the carbon footprint of various protein sources. Points show individual estimates while the bars show the range.

Table 1 gives average carbon footprint of foods for a number of common foods in g CO2-eq/g food. These numbers include average GHG emissions embodied in transport for the United States, which explains the high carbon footprint of asparagus, which is frequently air transported from other countries, including Peru.

Method of production can make a big difference in carbon footprint. For example, hot house tomatoes have a carbon footprint that is 18 times that for field produced tomatoes (5.3 g CO2-eq /g for hothouse, versus 0.3 g CO2-eq /g for field produced).

**Table 1. Carbon footprints of common foods. Data from Heller and Keoleian (2014), Heller et al. (2013), and Meier and Christen (2013).**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Food** | **g CO2-eq/g** | **Food** | **g CO2-eq/g** | **Food** | **g CO2-eq/g** |  | **g CO2-eq/g** |
| Added sugar | 0.96 | Collards | 0.33 | Lima Beans | 0.73 | Rye Flour | 0.36 |
| Almond butter | 1.17 | Corn Products | 0.66 | Lime | 0.5 | Salmon | 3.83 |
| Almond milk | 0.7 | Corn tortilla | 0.66 | Maitake Mushroom | 0.73 | Scallions | 0.39 |
| Almonds | 1.17 | Crab | 11.74 | Mango | 0.97 | Sesame seeds | 1.17 |
| Apple | 0.36 | Cranberries | 0.33 | Margarine | 1.36 | Shiitake Mushroom | 0.73 |
| Applesauce, unsweetened | 0.36 | Cream Cheese | 1.92 | Milk | 1.34 | Shrimp | 11.74 |
| Apricots | 0.36 | Crimini Mushroom | 0.73 | Morel Mushroom | 0.73 | Skim milk | 1.34 |
| Artichokes | 0.73 | Cucumber | 0.66 | Mozzarella cheese | 9.78 | Snap Beans | 0.73 |
| Asparugus | 8.87 | Cumin Seeds | 2.6 | Mushrooms | 0.73 | Sour Cream | 2.6 |
| Avocado | 1.27 | Cured Fish | 4.11 | Mustard Greens | 0.33 | Soybeans | 0.78 |
| Banana | 1.32 | Dried Fruit | 1.03 | Mustard Seeds | 1.17 | Soymilk, plain | 0.23 |
| Barley Products | 0.6 | Egg | 3.54 | Oat Products | 0.47 | Soymilk, unsweetened | 0.17 |
| Beef | 26.45 | Eggplant | 1.3 | Okra | 0.73 | Soymilk, vanilla | 0.23 |
| Bell peppers tricolor | 0.88 | English muffin | 0.58 | Olive oil | 1.63 | Soyrizo | 1.5 |
| Black Beans | 0.78 | Escarole & Endive | 1.46 | Onion | 0.39 | Spinach | 0.13 |
| Blueberries | 0.33 | Flaxseed, ground | 1.36 | Orange | 0.5 | Spinach baby | 0.13 |
| Broccoli | 0.4 | Flour, white | 0.58 | Orange juice | 1.03 | Squash | 0.09 |
| Brown Rice | 1.14 | Fresh and Frozen Fish | 3.83 | Oyster Mushroom | 0.73 | Strawberries | 0.35 |
| Brown sugar | 0.96 | Fresh and Frozen Shellfish | 11.74 | Papaya | 0.97 | Strawberries, frozen | 1.03 |
| Brussel Sprouts | 0.33 | Frozen Fruit | 1.03 | Peaches | 0.36 | Sugar | 0.96 |
| Butter | 11.92 | Frozen yogurt, soft | 3.1 | Peanut butter | 1.94 | Sweet Corn | 0.73 |
| Cabbage | 0.12 | Fruit Juices | 1.03 | Peanuts | 1.94 | Sweet Potatoes | 0.33 |
| Canned Fish & Shellfish | 4.11 | Garlic | 0.33 | Pear | 0.29 | Tahini | 0.8 |
| Canned Fruit | 1.05 | Grapefruit juice | 1.03 | Pineapple | 0.31 | Tofu | 0.84 |
| Cantaloupe | 0.27 | Grapes | 0.29 | Plum | 0.36 | Tomato, field | 0.3 |
| Carrot | 0.53 | Head Lettuce | 1.08 | Pork | 6.87 | Tomato, hothouse | 5.3 |
| Cauliflower | 0.39 | Honeydew | 0.27 | Pork chorizo | 6.87 | Total Cheese | 6.58 |
| Celery | 0.73 | Ice cream vanilla | 1.8 | Portabella Mushroom | 0.73 | Total Tree Nuts | 1.17 |
| Chanterelle  Mushroom | 0.73 | Kale | 0.33 | Potato | 0.21 | Total Wheat Flours | 0.58 |
| Cheddar  Cheese | 9.78 | Kidney beans | 0.78 | Poultry | 5.05 | Turnip Greens | 0.33 |
| Cherries | 0.36 | Kiwi | 0.6 | Pumpin seeds | 1.17 | Veal | 7.8 |
| Chia seeds | 1.17 | Lamb | 22.9 | Pumpkin, canned | 0.09 | Vegan butter | 1.17 |
| Chicken Breast (Water & Sea Salt) | 5.06 | Lard & Beef Tallow | 11.92 | Radishes | 0.33 | Walnuts | 1.17 |
| Chickpeas | 0.78 | Legumes | 0.78 | Raspberries | 0.33 | Watermelon | 0.27 |
| Citrus | 0.5 | Lemon | 0.5 | Red Lentils | 0.78 | White Mushroom | 0.73 |
| Coconut milk drink | 0.7 | Lentils | 0.78 | Rice | 1.14 | White Rice | 1.14 |
| Coconut milk, canned | 1.17 | Lettuce, Romaine | 1.03 | Rolled oats | 0.47 | Whole Milk | 1.34 |
| Cod | 3.83 | Light & heavy cream | 3.77 | Romaine & leaf lettuce | 1.08 | Yogurt, plain lowfat | 2.02 |

**Section 5: Active learning: Sandwich calculation by hand.**

**What is the carbon footprint of a sandwich?**

You can work through making two different sandwiches using the per serving carbon footprint numbers. You can calculate a carbon footprint for a “comfort food”—something you might enjoy if you weren’t considering carbon footprint at all. The second sandwich should be something you would enjoy if you were trying to have a low carbon footprint.

Here is some information about the carbon footprint of a list of sandwich ingredients. For each row, the first number (middle column) comes from a review scientific papers on the carbon footprint of foods by Heller and Keoleian (2014). The column on the right takes into account the size of servings so the numbers are more convenient to use.

Table 2. Carbon footprint of sandwich ingredients in g CO2-eq / g food and g CO2-eq / serving.

|  |  |  |
| --- | --- | --- |
| **Food** | **g CO2-eq/g food** | **g CO2-eq / serving** |
| 1 bagel (98g) | 0.42 | 41 |
| 1 Slice of Bread (50g) | 0.42 | 21 |
| Hummus (15g = 1 tbsp) | 1.3 | 20 |
| 1 Slice of Cheese (28.35g)\* | 9.78 | 277 |
| 1 Slice of Ham (28.35g) \* | 6.87 | 195 |
| 1 Slice of Roast Beef (28.35g)\* | 26.45 | 750 |
| 1 Slice of Chicken/Turkey (28.35g)\* | 5.06 | 143 |
| 1 Slice of Tomato (20.5 g) | 0.3 | 6 |
| 1 Piece of Lettuce (9g) | 1.03 | 9 |
| Peanut butter (16g = 1 tbsp) | 1.94 | 31 |
| Jelly (20 g = 1 T) | 0.35 | 27 |
| Hamburger patty | 26.45 | 2,645 |
| Black bean patty | 0.78 | 78 |

* Note: a deck of cards size of meat = 3 ounces = 3 slices

For example, a peanut butter and jelly sandwich might look like:

|  |  |  |  |
| --- | --- | --- | --- |
| Food | # of servings | Carbon Footprint per serving  (g CO2-eq/ serving) | Carbon footprint contribution  (g CO2-eq) |
| Slice of bread | 2 | 21 | 42 |
| Peanut butter | 3 | 31 | 93 |
| Jelly | 2 | 27 | 54 |
|  |  |  |  |
|  |  |  |  |
| Total | | | =189 (g CO2-eq) |

Fill in the empty tables below to design two sandwiches—one with a high carbon footprint and one w a lower one.

|  |  |  |  |
| --- | --- | --- | --- |
| Food | # of servings | Carbon Footprint per serving | Carbon footprint contribution |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
| Total | | | = |

|  |  |  |  |
| --- | --- | --- | --- |
| Food | # of servings | Carbon Footprint per serving | Carbon footprint contribution |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
| Total | | | = |

**Section 6. Putting carbon footprint numbers in context**

From the sandwich activity, it can be estimated that the difference between a typical high and low CF sandwich is around 3,000 g CO2-eq. While this helps us understand the relative difference between two foods, but we don’t know how to conceptualize whether these numbers are significant, b/c we are not used to thinking in terms of CO2-eq. An interesting way to put this in perspective is to consider the Paris Climate Accord. To meet the Paris Climate targets, the US would need to reduce GHG emissions by 447 million metric tonnes per year. This sounds like a big number, and it is, but if we divide that number by the population of the US and the number of days in a year, we come up with 3,660 g CO2-eq per day, which is similar to the difference between two sandwiches!

**Section 7. Guacamole example for understanding packaging and refrigerated transp**ort.

Imagine you would like to make guacamole at home. When you arrived at the store, you would notice that almost all of the ingredients you need would be found in bins or shelves, unrefrigerated at the store:

* Avocados
* Limes
* Garlic
* Red onion or shallot
* Salt
* Tomatoes

The one exception would be cilantro, which you may or may not like to add to your guacamole.



The carbon footprint for a large bowl of guacamole (for the ingredients alone) would be as follows (using conversions from Heller and Keoleian, 2014, which include average values for production and transport to a store or facility):

Table 1. Carbon footprints of ingredients needed for a large bowl of guacamole.

|  |  |
| --- | --- |
| Ingredient | Carbon Footprint  g CO2-equivalents |
| 3 avocados | 572 |
| 3 garlic cloves | 3 |
| 2 limes | 67 |
| 1 tomato | 37 |
| **Total** | **678** |

When you buy a prepackaged guacamole, you also need to consider the energy in processing, packaging, refrigerated transport, and in-store refrigeration.

First, let’s consider refrigerated transport.  There is a great paper by Tassou et al. (2009) that compares the carbon footprint of various types of trucks carrying food at different temperatures.

In the paper, they give values for g CO2 per pallet per km (these values are for the energy required for transportation and cooling, but exclude refrigerant leakage):

Table 2. Transportation carbon footprint (g CO2 per pallet per km) for ambient, chilled, and frozen foods on vehicles.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Ambient | Chilled | Frozen |
| Med. rigid truck | 88 | 106 | 112 |
| Lg. rigid truck | 85 | 102 | 108 |
| City articul. | 56 | 69 | 73 |
| 32 T artic. | 51 | 61 | 65 |
| 38 T artic. | 48 | 58 | 61 |

The paper also mentions a couple of other studies that indicate the greenhouse gas emissions are approximately 20% higher for the chilled and frozen scenarios if you do consider refrigerant leakage.

So, to send the same amount of chilled guacamole 1500 miles (assuming the pallet numbers and payload weights given in the paper for each type of truck, and assuming the 20% higher emissions with leakage), we would have to tack on **210 g CO2-equivalents** for a large articulated truck (38 T) or **570 g CO2-equivalents** for a medium sized truck per bowl of guacamole.

Next, what about the plastic container?  To make a 1 L plastic bottle requires about **270 g CO2-equivalents** (Gleick and Cooley, 2009).  Assuming around the same amount of plastic for a fairly good-sized container of guacamole, we have a total of **480 to 840 additional g CO2-equivalents**, **just for the packaging and refrigerated transport of our bowl of guacamole.**This analysis does not take into account the energy to make the guacamole, or to keep it cold in the store.

In general, eating foods closer to their natural state and making things from scratch is preferable, since processing, the food miles associated with various processing steps, refrigerated transport, and packaging can really make a difference!

If you are in a hurry, though, go ahead and grab those pre-packaged healthy foods—relying on climate-friendly ingredients is still the best way to keep your footprint low! In fact, a study on food miles by Weber and Matthews (2008) found switching out beef and dairy for foods with a lower carbon footprint **just one day per week** was as effective as eating locally seven days a week in reducing greenhouse gas emissions!!

**Section 8. Cited References**

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