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PERSPECTIVES

Your personal choices in transportation and food are important for lowering carbon emissions

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HIGHLIGHTS

- Express energy use and carbon emissions in understandable numbers.
- Normalize energy use to daily food energy using “D”.
- Ratio carbon emissions to those from daily food using “C”.
- Based on the entire country China emitted 22.5 C and the US emitted 43.9 C (2022).
- Personal choices such as the car you drive, food you eat, and home heating lower C.

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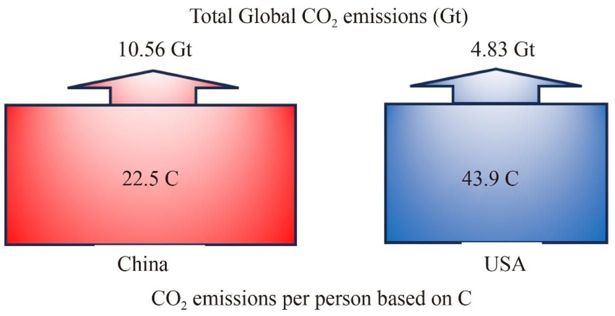
GRAPHIC ABSTRACT



ABSTRACT

There is a global need to reduce greenhouse gas emissions to limit the extent of climate change. A better understanding of how our own activities and lifestyle influence our energy use and carbon emissions can help us enable changes in activities that can lead to reductions in carbon emissions. Here we discuss an approach based on examining carbon emissions from the perspective of the unit C, where 1 C is the CO_2 from food a person would on average eat every day. This approach shows that total CO_2 emissions in China, normalized by the population, is 22.5 C while carbon emissions for a person in the US is 43.9 C. A better appreciation of our own energy use can be obtained by calculating carbon emissions from our own activities in units of C, for example for driving a car gasoline or electric vehicle a certain number of kilometers, using electricity for our homes, and eating different foods. With this information, we can see how our carbon emissions compare to national averages in different countries and make decisions that could lower our personal CO_2 emissions.

1 Introduction

The three most important contributors for your personal carbon emissions, and likely for anyone in the world, are home heating/cooling, transportation, and food. When you own a home and control the rooftop and the land around your home, you have many ways to reduce your carbon emissions. You can improve the building insulation, get solar panels to make your own electricity, and install highly efficient heat pumps instead of using electricity directly for heating. However, many people live in multi-story buildings with little control over the building heating and cooling systems. Therefore, in these multi-occupant units, there is not a lot you can do to reduce carbon emissions through structural changes. You can reduce energy use by turning the thermostat up or down, using less hot water, choosing energy efficient appliances, and turning off unused devices, but those are likely relatively smaller contributions to your overall personal carbon emissions. In single homes the cost of

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installing a large number of photovoltaic panels or large capital investments in the infrastructure may also be prohibitive. However, you should not feel powerless in your lifestyle choices to make significant reductions in your own carbon emissions because you can make careful and informed decisions on methods of transportation and your food choices! Before we explain why these two topics are important, it is important to have a more tangible understanding of numbers used to quantify energy and carbon emissions.

Typically, the available information on energy use and carbon emissions focuses on large-scale users (states or countries) and uses really big numbers that do not have any intrinsic connection to our daily lives. For example, the US Energy Information Agency (EIA) reported that the US consumed 100.3 quads of energy in 2022 (Lawrence Berkeley National Laboratory, 2023). Even if you know that a quad is short for a quadrillion BTU, that 1 quadrillion means 10^{15} of something, and that the BTU stands for British Thermal Units, the size of the number makes it difficult to comprehend this amount of energy. Also, we really don't have any context for what a BTU means as it is not commonly used (except by energy specialists), and energy units vary for different applications making it difficult to compare amounts of energy used for different purposes. We might discuss home heating in units of therms or cubic meters of natural gas, or electricity in kilowatt hours, or gasoline for a car in liters (volume, not energy units) but you cannot directly sum them for a total amount. Even though some people can make these unit conversions it is unlikely that total energy use is ever calculated. Instead, you are more likely to know how much was paid for these energy services rather than the energy amounts.

The large numbers and units used to quantify CO_2 emissions present similar challenges as those for energy. For example, the US emitted 4.83 Gt of CO_2 from fossil fuels in 2022, and China emitted 10.56 Gt (Energy Institute, 2023). Even if you know that a giga tonne is 10^9 t or 10^{12} kg, these numbers remain difficult to comprehend or connect to our individual activities. Large numbers and these units may be appropriate for describing global emissions, but they lack a tangible connection to CO_2 emissions resulting from our own daily activities. Thus, for both CO_2 emissions and energy use, we are currently faced with large numbers that are difficult to relate to our personal lives. Thus, for both carbon emissions and energy use, we are currently faced with large numbers that are difficult to relate to in terms of activities in our own lives.

2 Express energy use based on D, and carbon emissions based on C

One way to better understand the amounts of energy you use every day is to compare it to the amount of energy in your food. The average man needs more energy than the average women (due to differences on average in larger body mass and height), and people all have different levels of activities, but around the world everyone can relate to the average energy needed from food each day no matter your language or the units you typically use for that food energy. Let us define an average amount of energy to fuel a person as 2000 kilocalories (kcal) per day, or 2000 kcal/cap-d (Energy Institute, 2023). We could then use kcal as a way to quantify our energy use but the calorie or kcal units are a problem for several reasons. First, 2000 kcal is really 2000000 calories, and social scientists inform us that it is difficult for a person to understand something when it is as large as a million. Second, in the US, the food energy is expressed in Calories (capital C) where 1 Calorie equals 1 kcal, making calorie and kcal terminology confusing. Third, some countries use kilojoules (kJ) or megajoules (MJ) for food energy, where 1 megajoule is one million joules. So, we conclude units of calories or joules may be familiar for food energy, but they could be difficult to use as a basis for understanding other energy uses because these units would require using very large numbers (millions or more of calories or joules).

To more clearly express energy use to something we are familiar with, we introduce the unit of D and define 1 D as the energy needed to "fuel" a person, on average, per day, so that 1 D equals 2000 kcal per capita (per person, abbreviated cap) per day, or 1 D = 2000 kcal/cap-d (Logan, 2019; Logan, 2022). Using this D definition we can examine amounts of energy (renewable or fossil-fuel derived) that we use relative to that amount of food energy and avoid dealing with large numbers or mixtures of units. For example, if you used 1 L of gasoline per day that contains 9.33 kWh of energy, and you convert the units to kcal to obtain 8030 kcal/cap-d, you would use 4.0 D (8030 kcal/cap-d divided by 2000 kcal/cap-d). If you take all the energy consumed by China in 2022 (159.4 EJ) (Lawrence Berkeley National Laboratory, 2023), and divide it by the number of people in China (1.41 billion) relative to food energy (World Bank, 2023) you would calculate (Logan, 2022) that on average energy use was 37.1 D. That means that the average energy use attributed to a person in China would be 37.1 times more energy than that in the food they eat every day. In the US, this same calculation of total energy consumption produces 95.9 D, while for India it is 11.9 D, showing how much energy use varies for people in different countries. The benefits of quantifying energy use using this approach based on D is that anyone, anywhere, can understand the numbers in units of D since they are related to the daily energy for food for a person, and no other units (such as kWh or kcal) are needed. D can theoretically have a minimum of zero if you did not use any energy sources for any activity relative to the energy in your food (i.e., zero energy used divided by 2000 kcal/cap-d).

To better understand amounts of CO_2 emissions we take a similar approach by defining the CO_2 emitted per person every day from activities that released CO_2 from energy use from fossil fuels relative to the CO_2 emitted from the oxidation of their "fuel" by consuming their 1 D of "fuel" of food (Logan, 2022). While the amount of CO_2 you release again depends on your food energy consumption (it might be 0.8 D or 1.2 D depending on your age, weight, activity level and other factors), and conversion of different foods (broadly in terms of protein, fat, and carbohydrates) a person on average releases about 2 pounds (lb) of CO_2 (0.9 kg) per day. Thus, we calculate CO_2 emissions from using a fossil fuel, for example to power our car or electricity for our home, relative to the CO_2 each one of us emits just from eating food every day (not including energy to obtain or prepare that food). For example, 1 person using 1 L of gasoline per day would release 2.4 kg (5.3 lb) per day of CO_2, or 2.7 C (2.4 kg/cap-d divided by 0.9 kg/cap-d). If we take all the CO_2 emissions from fossil fuels used in China in 2022 (10.56 Gt) (Energy Institute, 2023), and divide by the number of people relative to their food CO_2 emissions, you get 22.5 C, while for the US (4.83 Gt) you have 43.9 C. When accounting for population differences between China and the US, on average there are less carbon emissions per person in China compared to the US. We calculated that for a person in China CO_2 emissions are 22.5 times those that would occur just from eating food every day to sustain all other activities in China, while in the US it results in 43.9 times as much CO_2 emissions. Note that the C value has a minimum of 0, not 1, since C refers to the fossil fuel carbon emissions for activities related to producing and transporting the food, not the carbon in the food itself. The carbon released from eating food was taken from the environment and returned to the environment, while the carbon in fossil fuels was previously removed from natural carbon cycles. In some countries that have very low fossil fuel use and carbon emissions, C can be less than 1, for example, Chad (0.36 C) and Somalia (0.18 C). Renewable energy sources (wind, solar, hydro, geothermal, and biomass) are assumed to have no associated carbon emissions with their use here. However, a more thorough analysis could add in the CO_2 emissions associated with the machinery and other activities enabling the use of these energy sources.

3 Think about your personal energy use and CO_2 emissions in terms of D and C

If you find out that a person in China on average produces 22.5 C, it really doesn't tell you what portion of that C you are personally responsible for based on your own lives. Many people believe that their own energy consumption and carbon emissions are small relative to others, but it can be difficult to imagine how your personal lifestyle, if adopted by everyone, would compare to energy use by industries. For example, concrete and steel production produce a lot of the global CO_2 emissions (13% of total emissions), but because most consumers likely do not buy those directly for their own use (although they may be sold in products you do purchase), you likely do not have any direct contribution to carbon emissions from concrete and steel. But if everyone were to reduce their energy use based on choices that depend on fossil fuels then global emissions could be substantially reduced. To see how this is possible, we can compare the D and C numbers based on things that we personally do and compare those to the average values for people around the world.

The three things that most likely matter in your own life relative to your carbon emissions are: transportation, home energy use, and energy used to put food on your table. Many people do not know how to rank these by the amount of energy used, on average, by a person every day. In the US, for example, the ranking is Car > Food > Home. Many people tend to think that their home uses more energy per person than the energy in the gasoline for their car. It is important when trying to reduce carbon emissions that you gain a better understanding of your personal energy use and how that translates into carbon emissions. Below, we examine the magnitude of these D and C numbers and look at how they vary based on choices of cars and food.

4 The mass of CO_2 emitted by driving a car can be a big C for you (if you drive one)

In China, on average a person driving a car will use 9.2 D of energy and emit 5.9 C (5.3 kg/cap-d), assuming 11,700 km/yr (Statistica, 2023) and a fuel efficiency of 14 km/L (33 miles per gallon, mpg). Therefore, if you drive a car with 5.9 C of emissions that is 27% (5.9/22) of the total emissions of an average person in China based on your driving choices. In the US, this increases to 21 D and 14 C due to higher annual mileage and lower average vehicle fuel efficiencies (Logan, 2022). For the US, this amounts to ~29% of the carbon emissions by a person. This shows how important your choices are for driving. But how much could you reduce your emissions from driving?

Switching to an electric car and powering that car with solar photovoltaic panels could remove that 5.9 C. However, in China switching to electricity from the grid might not lower your CO_2 emissions as much as you might expect due to the high proportion of coal used for electricity production in China. If we assume that you drive a Tesla Model 3, you can reduce your CO_2 emissions to 4.2 C, and achieve a 29% reduction in carbon emissions based on national grid energy sources in China. This calculation includes a 7% loss of energy in the transmission lines to your charging station, and a 15% energy loss when charging the battery on the car (Logan, 2022). The total CO_2 emissions resulting from charging your car could be lower or higher depending on the amount of renewable electricity in the grid at that time, your proximity to the power source, as well as charging stations and charging rates.

To put the carbon emissions that result from driving a car in perspective, compare the mass of the 5.9 C of gaseous CO_2 waste from the fuel for driving every day to the mass of solid waste a person produces every day in China. The typical mass of municipal solid waste produced per person in China is about 1.1 kg/d (World Bank Group, 2019). That is only about 21% of the gaseous CO_2 "trash" (5.3 kg/d) that you would put into the atmosphere every day from the gasoline used for driving your car. The mass of the CO_2 produced is much greater than that of original gasoline due to combustion of the gasoline (~2 hydrogen atoms per 1 carbon) to CO_2 (2 oxygen atoms per carbon), or a mass increase of ~3.7 times. Also, these carbon emissions for the car do not include all of the greenhouse gas emissions that go into extracting the oil, transporting it and refining it into gasoline. On a global average, those emissions can add another 15%−40% to the total CO_2 equivalent.

5 Is it better to eat locally or make different food choices?

You probably know that it is better to eat less red meat to reduce carbon emissions. But how much better? Let us compare the amounts of CO_2 emissions, in units of C, if you ate a portion of beef every day compared versus chicken in the US. This C calculation will include all greenhouse gas emissions, converted to equivalent CO_2 emissions, from producing, processing, and transporting the food. Therefore, this C is not the carbon in the food, but instead all the emissions needed to get this food to your table. Assuming a beef serving of 3 ounces (85 g, 180 kcal, produced from a beef herd) per day, the associated greenhouse gas emissions would be 6.6 C, compared to 0.87 C for a 4 ounce (113 g, 187 kcal) serving of chicken (Fig. 1), from start (farming) to finish (your table) (Ritchie and Roser, 2020). Most of the carbon emissions occur at the farm. Transport of beef in the US is only on average 0.7% of the total emissions, and thus eating beef produced locally or in another state does not appreciably change the total emissions. For chicken or other poultry the energy used for transport is about the same as that for beef, but because it has a much smaller C transport will be 5.5% of the overall carbon emissions. Also, note that these servings are based on recommended amounts. If you dine in the US most restaurants would serve a hamburger that is 8 oz, and therefore the total would be 17.6 C per serving!

If you make more deliberate food choices based on the amounts of C in a serving, you can really lower your carbon emissions. For example, a serving of farmed fish is 1.2 C (4 oz, 113 g, 233 kcal), while for a serving of tofu is between 0.24 C (3 oz, 85 g, 80 kcal) and 0.48 C (160 kcal serving). These comparisons highlight how specific food choices can often matter more than transport distances, particularly for high C foods such as red meat. As the total carbon emissions per serving are reduced, for example eating tofu instead of beer, transport plays a larger role. Thus, for locally grown crops and vegetables which may have low C values for production, shipping distances can matter more for the overall total emissions.

6 Virtual carbon dioxide emissions

The calculation of the average C for a person in a country has so far in this Perspective only been based on fossil fuel emissions by that country and its population. However, calculating an average based on national fossil fuel use neglects the emissions that occurred in another country to produce those items. Therefore, the average C calculation for a country should include the carbon emissions associated with international trade. For example, China manufactures a lot of goods and then exports them to other countries around the world. When these products are used in these other countries there is no

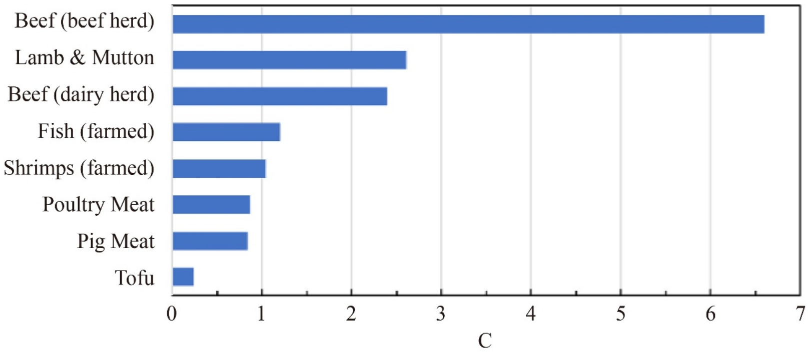

Fig. 1 Comparison of carbon emissions based on the daily C unit for portions of different foods.

direct accounting for the CO_2 that was emitted to make that product in the country where it was used. This can be referred to as “virtual carbon” as there were “no emissions” for those items where they were used. An analysis of materials shipped out of China in 2014 indicated that carbon emissions for all exports totaled 1369 Mt of CO_2 (Godin and Landberg, 2022), or 3.0 C based on the population of China in that year. This exported C is about 15% of the total fossil fuel emissions for China that amounted to 20.3 C. Thus, you could consider that China’s internal C is really 20.3 minus 3.0, or 17.3 C.

Countries that import goods should add in the virtual carbon in imports when assessing their total carbon emissions. For example, the transport of goods into the US was 3.3 C of virtual carbon. Adding this to the total emissions for a person in the US in 2014 (49.7 C) would increase the carbon emissions by about 7%. Many European countries have far lower C values for their production than the US, but when you add in their imported virtual carbon some countries can have substantially increased C values. For example, Austria’s emissions would be increased by 44% (9.2 C imported versus 21 C produced) by including this virtual carbon. Belgium would increase their C value by 75% (22.0 C imported versus 29.3 C produced), resulting in a total of 51 C which is on par with the USA with imports (51 C) when considering both released and virtual carbon. Some economists, like Dieter Helm, have advocated putting a tax on these imported goods based on carbon emissions, a move that might help to better identify the amounts of CO_2 contributed by imported goods (Helm, 2020).

7 Outlook

Many countries are increasing their production of renewable electricity but globally this change needs to occur in all countries and at a faster rate. Using the D and C approach it is possible to see how substantial changes to energy use can be made by everyone choosing to make decisions that consider energy use and carbon emissions. Individuals can help drive faster global reductions in carbon emissions through their own actions, for example, by choosing food that has low carbon emissions, avoiding food waste, and avoiding using cars that use gasoline or diesel fuels. These actions can then be taken up by others, leading to widespread reductions in carbon emissions. Food choices are an easy and important starting point.

Other changes that a person can make will require some way to understand how electricity they use was produced. The D and C approach could make it easier to compare carbon emissions from cars with internal combustion engines to emissions from electric vehicles due the C value associated with electricity generation at power plants. The D and C approach for cars in China makes it apparent that coal use needs to be phased out due its resulting high C values for electricity generation by a power plant. People do not need to stop energy consumption, but they should try to lower the C value associated with that D. For example, D could remain constant or even increase when a C value approached zero if there was sufficient renewable energy available. Virtual carbon must also be included in calculations by implementing policies that address virtual carbon in consumer products and international trade. Significant reductions in emissions can only be achieved through a combination of personal choices, setting national goals, and cooperating internationally to address both energy needs and carbon emissions.

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Conflict of Interests Bruce Logan is an advisory board member of *Frontiers of Environmental Science & Engineering*, Wulin Yang is a youth editoral board member of *Frontiers of Environmental Science & Engineering*. The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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