

Homework

Due: Friday 2/6/2004 at class time

In this homework problem, you are first going to evaluate how much carbon dioxide you are producing and emitting to the air in your typical activities of your life. Then, you will find what the total emission would be if each human being emitted the same amount as you, and compare it to the present human emissions to the atmosphere. Finally, you are going to compute by how much the carbon dioxide concentration in the atmosphere should be increasing every year given these emissions, and compare it to the measured annual increase.

If that sounds like an impossible challenge, don't worry! This homework problem will guide you along the way. In the end, you will see that it is not actually difficult to figure out by yourself how human activities must be affecting the atmosphere and its greenhouse effect.

1. The first thing you need to do is to collect your bills of electricity and natural gas heating in the house where you live. Being a freshman, I must assume you moved here in September. If you take your electricity bills for October, November and December, and add the kilowatt-hours (kWh) that were spent in all three months, you can then multiply by four to estimate how much you would spend in twelve months.

For natural gas, you can take the number of CCF (hundreds of cubic feet) spent in December, and multiply by six, and that is roughly how much you will spend during a year (in December you spend more than in most other months, of course, because it's cold, so that is why you multiply by six instead of twelve; if you have your bill for November, you probably want to multiply by twelve instead because November will reflect more like your average monthly gas usage).

Then, divide by the number of people living in your house to find out the number of kWh and CCFs spent per person.

You can also choose to do this for your parents' house, if you prefer, and find out how many kWh and CCF you spent in the last year, and divide by the number of people in the house.

Then, figure out how many gallons of gas you spent in driving. To estimate this, find how many miles you drove in a car over the last year, then divide by the number of miles per gallon that the car gets. You can estimate the mileage your car gets if you divide the number of miles you can typically drive between two successive fillings of your gas tank, by the number of gallons you get when you fill up your tank.

If you don't have a car, try to estimate how many miles you were driven in other cars, and divide by an estimate of the mileage (usually something like 18 miles per gallon for an SUV and 27 miles per gallon for a passenger car). If you usually car-pool with several people, you get to divide that by the number of people who are sharing the ride.

Next, estimate the number of miles you flew in airplanes over the last year.

2. Now, convert all these quantities to the pounds of CO₂ (carbon dioxide) you emitted during a year. You can use the following conversions:

- (a) Electricity: 1.97 pounds for every kWh used. (Note: the emissions for electricity occur at the power plant where the electricity that you consume is produced. This conversion is valid only for the state of Ohio. Other states will have somewhat different conversions because they have a different proportion of coal, natural gas, nuclear, hydroelectric, and other types of power plants. Because Ohio generates 88% of its electricity from coal, and coal produces the most carbon dioxide per kWh produced, most other states will have somewhat lower rates. But you can use the same rate as an approximation if you are using the electricity consumption of your previous house outside of Ohio).
- (b) Natural gas: 12.06 pounds for every CCF.
- (c) Gas for your car: 22.4 pounds for every gallon. If your house is heated from an oil tank instead of natural gas, use this same conversion to go from gallons of oil to pounds emitted.
- (d) Miles flown: commercial planes emit on average 0.7 pounds of CO₂ per mile for every passenger. So, multiply the number of miles you flew by 0.7.

Now, add up all the emitted pounds to find your total emissions.

3. Next, we convert the pounds of carbon dioxide emitted into metric tons of carbon. First, every molecule of carbon dioxide has two atoms of oxygen and one of carbon. Because the atomic masses of oxygen and carbon are 16 and 12, respectively (you can check it in your periodic table of the elements), the molecule of carbon dioxide has a total molecular weight of 44, and only 12 of that comes from carbon. So, multiply your total carbon dioxide emitted by 12 and divide by 44 to obtain the mass of carbon emitted.

Next, a pound is equal to 454 grams, and one metric ton is one million grams. So, multiply your emissions by 454, and then divide by 1 million, to obtain the number of metric tons of carbon you emitted.

Now, multiply this number by the present population of the United States. If every citizen emitted the same amount as you, this would be the emissions by the United States.

4. Compare this to the true annual CO₂ emissions by the United States, which are 1.5 Gigatons (or 1.5 billion tons). Do you produce more or less than the average American?

In asking this question, there are some things to consider. When you computed your emissions, you included only the carbon emitted from your heating and electricity spent at home, your car, and your flights. But if you use public transportation, buses and trains also spend gas and electricity. When you buy food, natural gas was required to make the fertilizers, the tractors and other machinery used to grow the food consumed oil, some more oil was used to transport the food, and electricity to refrigerate it. In general, when you buy any product, the company that produced it emitted some CO₂ to make the product. The university where you study also needs to heat its buildings and consume electricity. Comment on how you think this affects your estimate of your

contribution to CO₂ emissions, and the comparison to the total emissions by the United States. Think also if your emissions are representative of the average person living in the United States. Are there people whose activities probably emit a lot more, or a lot less?

5. Now, we are going to see if the total world emissions are indeed large enough to modify the composition of the atmosphere of the Earth. The United States contributes 25% of the world emissions, so the total emissions are four times larger than those from the US: 6 Gigatons of carbon every year.

- (a) To compare that with the total carbon dioxide that was naturally present in the atmosphere before the industrial revolution, we first compute the total mass of the atmosphere. For this, the first quantity we need to know is the density of air near the surface of the Earth. This density is 1.2 kilograms for every cubic meter of air. You have some experience of this if you ever played with a balloon. If you had a balloon as big as 1 cubic meter, filled with a gas much lighter than air (like helium), the balloon would be able to pull up a weight close to 1.2 kilograms (or a bit more than 2 pounds). A normal size balloon of half a cubic foot pulls up a weight of about an ounce (a cubic foot is about 35 times smaller than a cubic meter).

- (b) To know the mass of the atmosphere, we just need to multiply the density of air by the volume of the atmosphere. We are going to use an altitude of 8 kilometers, or 8000 meters, for the atmosphere. Even though we know the atmosphere extends to much higher altitude, its density rapidly drops above 8 kilometers. All the air that is above 8 kilometers is roughly the same that the air that is “missing” below 8 kilometers if we assume a constant density (when in reality the density drops as we go to higher altitude).

Now we need to multiply this height by the total surface of the Earth. The surface of a sphere is 4π times the radius squared. The radius of the Earth is 6370 kilometers, or 6370000 meters. Taking the radius in meters, figure out the surface of the Earth in meters squared, and then multiply by the height in meters to obtain the volume of the atmosphere in cubic meters. Now, multiply this volume by the density to obtain the mass in kilograms.

Finally, divide this mass by 1000 to obtain it in metric tons, and divide again by one billion to obtain it in gigatons.

- (c) What we have obtained is the total mass of the atmosphere. To figure out the mass of the carbon in the atmosphere, we need to know that the carbon dioxide content used to be 270 parts per million by volume before the industrial revolution. It is now 370 parts per million. Using the present concentration, we multiply the mass of the atmosphere by 370 and then divide by a million. And we need to do something else: because the average air molecule has 29 atomic masses (an average of the nitrogen and oxygen molecules), but the carbon in CO₂ has only 12 atomic masses, and we are trying to figure the *mass* of carbon in the atmosphere (not the fraction of volume taken by the carbon dioxide), we need to multiply this mass by 12 and divide by 29. This is the present mass of carbon (the reservoir) in the atmosphere.

6. Now, compare the 6 Gigatons of present human annual emissions with the size of the reservoir. If we add this rate of emissions over 50 years, are we increasing the atmospheric carbon in a substantial way?

Roughly, we can consider that the total emitted over human history is equivalent to 6 Gigatons of carbon emitted annually over 50 years (before 1950, emissions were much lower than at present). So, how does that compare with the total increase of atmospheric carbon dioxide, from 270 parts per million to 370 parts per million by volume, over the industrial revolution? Comment on how the processes of the carbon cycle described in class affect this comparison.