# Accounting for carbon dioxide emissions: A matter of time

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Carbon dioxide emissions in one country can support consumption of goods and services in another country; countries and their $CO_2$ emissions are linked together by international trade. The study of $CO_2$ emissions embodied in international trade was largely opened up by Peters and Hertwich (1). In PNAS, Peters et al. (2) introduce a dimension into this field of study, and that dimension is time. It is not often that one team of researchers has done so much to introduce a field of inquiry and then expand it so rapidly, giving us insights into the challenges and potential solutions to the energy/carbon/climate problem we all face.

On any typical day, we engage in a wide range of activities that are supported by $CO_2$ emissions, either directly or indirectly. When we drive our cars to work, $CO_2$ comes out of the tailpipe—a waste product resulting from the reaction of gasoline with atmospheric oxygen inside of an internal combustion engine. So, how much $CO_2$ was released to the atmosphere to get us to work this morning? Counting just the $CO_2$ that comes out of the tailpipe would fail to consider the fact that $CO_2$ was emitted to extract, refine, and transport that gasoline to us. The automobile is composed of steel and rubber, aluminum and plastic; $CO_2$ was released to supply the energy needed to manufacture each of these materials. Furthermore, the factories that produced the automobile had machines of various sorts, and the energy it took to make these machines likely produced $CO_2$ emissions as well. Furthermore, the workers in factories that made all of these things may have driven cars to get themselves to work. What part of their $CO_2$ emissions was emitted to facilitate our morning commute?

Very quickly, we see that nothing exists in isolation, and that to understand how much $CO_2$ emission can be related to any particular action, we must have a reasonable accounting system that allocates total emissions to specific actions. Accounting systems are not facts of nature, but conventions constructed by people. (How much of the factory worker's $CO_2$ emission while commuting to work should be attributed to our consumptive pleasure versus their own consumptive pleasure? How much of the emissions from the authors' morning commute should be attributed to you, the reader?)

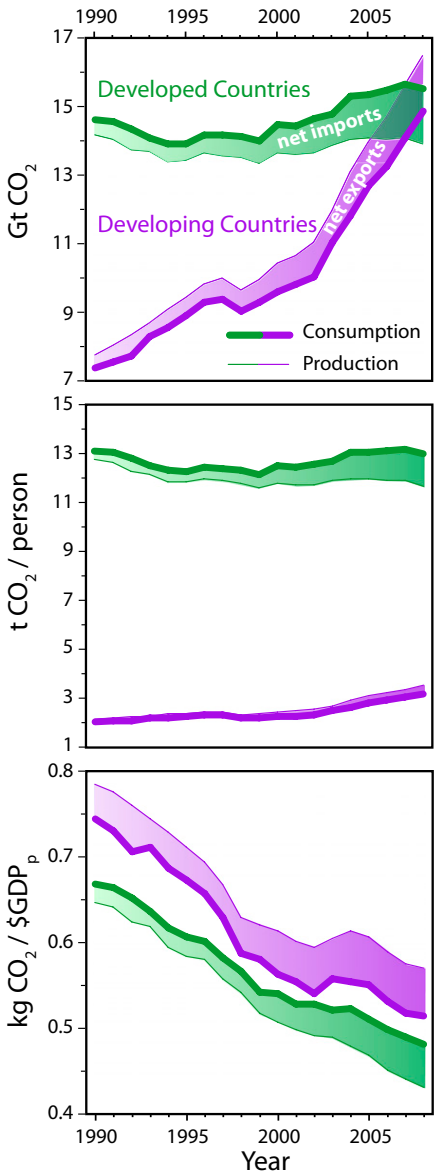


**Fig. 1.** Consumption-based and production-based accounting of $CO_2$ emissions by Peters et al. (2), divided into industrialized and industrializing countries (detailed in the text). (*Top*) $CO_2$ emissions to support consumption in developed countries exceeds $CO_2$ emissions to support consumption in developing countries, despite the fact that more $CO_2$ emissions are produced within the territory of developing countries. (*Middle*) On a per-capita basis, there is great disparity in consumption emissions between developed and developing countries. (*Bottom*) Consideration of a consumption-based perspective produces less of a difference in carbon intensity of economic activity (adjusted for purchasing power parity) between developed and developing countries.

Accounting systems can be more or less useful for various purposes, but they are not right or wrong. If we want to attribute $CO_2$ emissions to the consumption of particular goods or services, we must have an accounting system that conforms with our intuitions about how responsibility should be shared among participants in complex systems.

We do not have enough information about the world to map out the complex web that links specific goods and services with specific $CO_2$ emissions, but enough data do exist to map out these webs for broad product categories at the level of countries (or collections of small countries). At this level of detail, we can ask questions like: How much of the consumption in the United States was supported by $CO_2$ emitted in other countries? Peters and colleagues have been pioneers in the effort to quantify these international transfers, often referred to as "carbon emissions embodied in international trade." It is important to distinguish between carbon embodied in international trade (i.e., $CO_2$ that was released to the atmosphere to support the production of goods and services that are internationally traded) from actual carbon in international trade, such as is found in internationally traded fossil fuels, foodstuffs, or plastics.

Peters and Hertwich (1) and Hertwich and Peters (3) described reasonable accounting methodologies that others, including ourselves, have applied to static cases, such as analysis of a particular year. For example, we used their methods to estimate that, in 2004, 19% of the $CO_2$ emitted to support production of goods and services consumed in the United States was emitted outside US territorial borders, whereas 28% of China's territorial $CO_2$ emissions supported production of goods and services consumed outside of China (4). Furthermore, some emissions in the United States supported consumption in other countries, while emissions in other countries helped support consumption in China.

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Peters et al. (2) take a major step forward by bringing the time dimension into this accounting problem. They focus on the period extending from 1990 to 2008. How have international transfers of embodied carbon varied over time? The analysis of Peters et al. (2) considers 113 countries and regions, and 57 economic sectors, for a total of 6,641 ledger entries for each year, but the results are most startling when we aggregate this detailed analysis into two categories: "developed countries" and "developing countries."

Here, we will use the terms "developed" and "developing" to refer to Annex B and non-Annex B countries, respectively. Under the United Nations Framework Convention on Climate Change, Annex B countries are the developed countries that took on emissions commitments with the Kyoto Protocol. Annex B countries include the United States, most of Europe, Russia, Japan, and Australia (http://unfccc.int/kyoto_protocol/items/3145.php). Non-Annex B countries can therefore be characterized as encompassing the developing countries, including rapidly industrializing countries such as China and India.

We replot estimates from Peters et al. (2) dividing the data into just two categories (Fig. 1). As reported by Peters et al. (2), in developed countries, territorial emissions of $CO_2$ have decreased from 14.2 Gt $CO_2$ in 1990 to 13.9 Gt $CO_2$ in 2008—a 2% reduction in territorial $CO_2$ emissions during this 18-y period. In contrast, in the developing countries, territorial emissions have more than doubled over this period, from 7.7 Gt $CO_2$ in 1990 to 16.4 Gt $CO_2$ in 2008 (a 113% increase over a period of 18 y). This contrast is truly amazing—during the past two decades, $CO_2$ emissions from the developed countries have been decreasing at the same time $CO_2$ emissions from the developing countries has more than doubled.

It is well known, however, that many of the goods and services consumed in developed countries were produced in developing countries. How would consideration of these $CO_2$ emissions embodied in trade affect the picture? When a nation outsources production of goods and services, it effectively outsources $CO_2$ release to the atmosphere.

According to Peters et al. (2), in 2008, approximately 16% of $CO_2$ emissions in developed countries supported production of products consumed in developing countries, whereas approximately the same fraction of $CO_2$ emissions in developing countries supported consumption of goods and services in developed countries. As there is now a greater amount of emissions coming from developing countries, this means that there is a net transfer of embodied emissions from developing to developed countries. In 1990, 0.4 Gt $CO_2$ were emitted in developing countries to subsidize consumption in developed countries. By 2008, this subsidy increased to 1.6 Gt $CO_2$.

**Consideration of international trade reverses the decreasing trend in emissions in developed countries.**

Taking these flows in international trade into account, Peters et al. (2) estimate that consumption-based emissions in the industrialized world increased from 14.5 to 15.5 Gt $CO_2$/y between 1990 and 2008 (a 7% increase) while consumption-based emissions from developing countries doubled (from 7.4 to 14.8 Gt $CO_2$/y between 1990 and 2008). Thus, consideration of international trade reverses the decreasing trend in emissions in developed countries, turning a 2% decrease into a 7% increase. Peters et al. (2) wryly note that this difference is larger than the emissions reductions commitments made under the Kyoto Protocol.

We have plotted the production and consumption emission estimates of Peters et al. (2) broken down by developed and developing world and in per-capita and per-dollar gross domestic product terms (Fig. 1). In terms of consumption emissions, developed countries are still responsible for more emissions than developing countries. However, in terms of territorial (i.e., production) emissions, developing countries now emit more $CO_2$ than developed countries. However, on a per-capita basis, it is quite apparent that the average individual in developed countries is responsible for much more $CO_2$ emission than is his or her counterpart in developing countries. The amount of $CO_2$ emitted per dollar GDP is often called "the carbon intensity of economic activity." Relative to production-based accounts, consumption-based accounts tend to increase estimated carbon intensities in developed countries and decrease carbon intensities in developing countries, but developed countries still have a lower overall carbon intensity of economic activity. The carbon intensity of both developing countries and developed countries appears to be improving at similar rates, with carbon intensity of economic activity in developing countries now lagging behind that in developed countries by less than half a decade.

So, what do we learn from this analysis? The focus on territorial emissions of $CO_2$ and other greenhouse gases has perhaps led us to underemphasize the role of consumption of goods and services in driving these emissions. It is important to look at all drivers of emissions, as everyone along the supply chain has a vested interest in our fossil-fueled global economy. Those who mine coal or pump oil benefit from selling the fuel. Those who use the fossil fuel to produce a good or service benefit from relatively low costs and a high degree of reliability. And those who consume goods and services benefit by being able to buy those products at lower prices. Just as we all have an interest in the benefits that accrue from continued use of fossil fuels, we all have an interest in the environmental risk reduction that would come with a transition to a carbon-neutral economy.

Policies aimed at achieving reductions in greenhouse gas emissions must account for international trade, so that these policies do not simply offshore carbon-intensive industries. Better data collection and additional analysis would allow a more complete understanding of how our actions relate to emissions of greenhouse gases, both domestically and abroad. Eventually, we may even be able to say how much carbon we were responsible for emitting when we drove to work this morning.


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