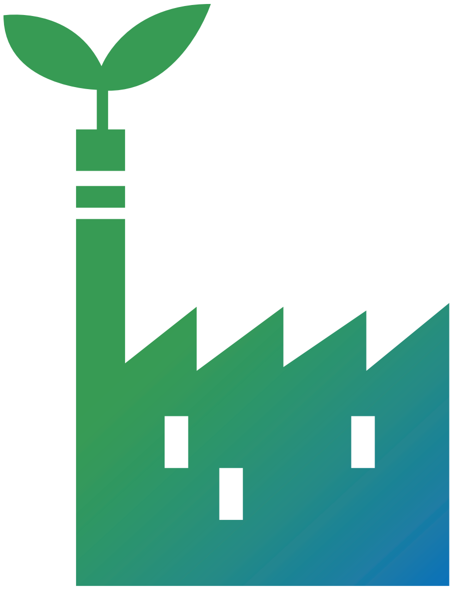

ENERGY MARKET CONSEQUENCES
OF AN EMERGING U.S. CARBON MANAGEMENT POLICY

Implications of Offshoring Carbon Emissions for Climate Policy

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ENERGY forum
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ENERGY FORUM MEMBERS

ABOUT THE STUDY:
ENERGY MARKET CONSEQUENCES OF AN EMERGING U.S. CARBON MANAGEMENT POLICY

Emerging energy and climate policies in the United States are accelerating the pace of technological changes and prompting calls for alternative energy and stricter energy efficiency measures. These trends raise questions about the future demand for fossil fuels, such that some energy-producing nations are reluctant to invest heavily in the expansion of production capacity. The abundance of shale gas resources in North America could allow the United States to utilize more gas in its energy mix as a means of enhancing energy security and reducing CO_2 emissions. However, this will only occur if U.S. policies promote and allow the benefits provided by natural gas to be realized. To examine these issues and changing trends in the U.S. energy and climate policy, the Baker Institute organized a major study investigating the North American and global oil and natural gas market consequences of emerging U.S. policies to regulate greenhouse gas emissions, as well as the potential role of alternative energy in the U.S. economy.

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Introduction

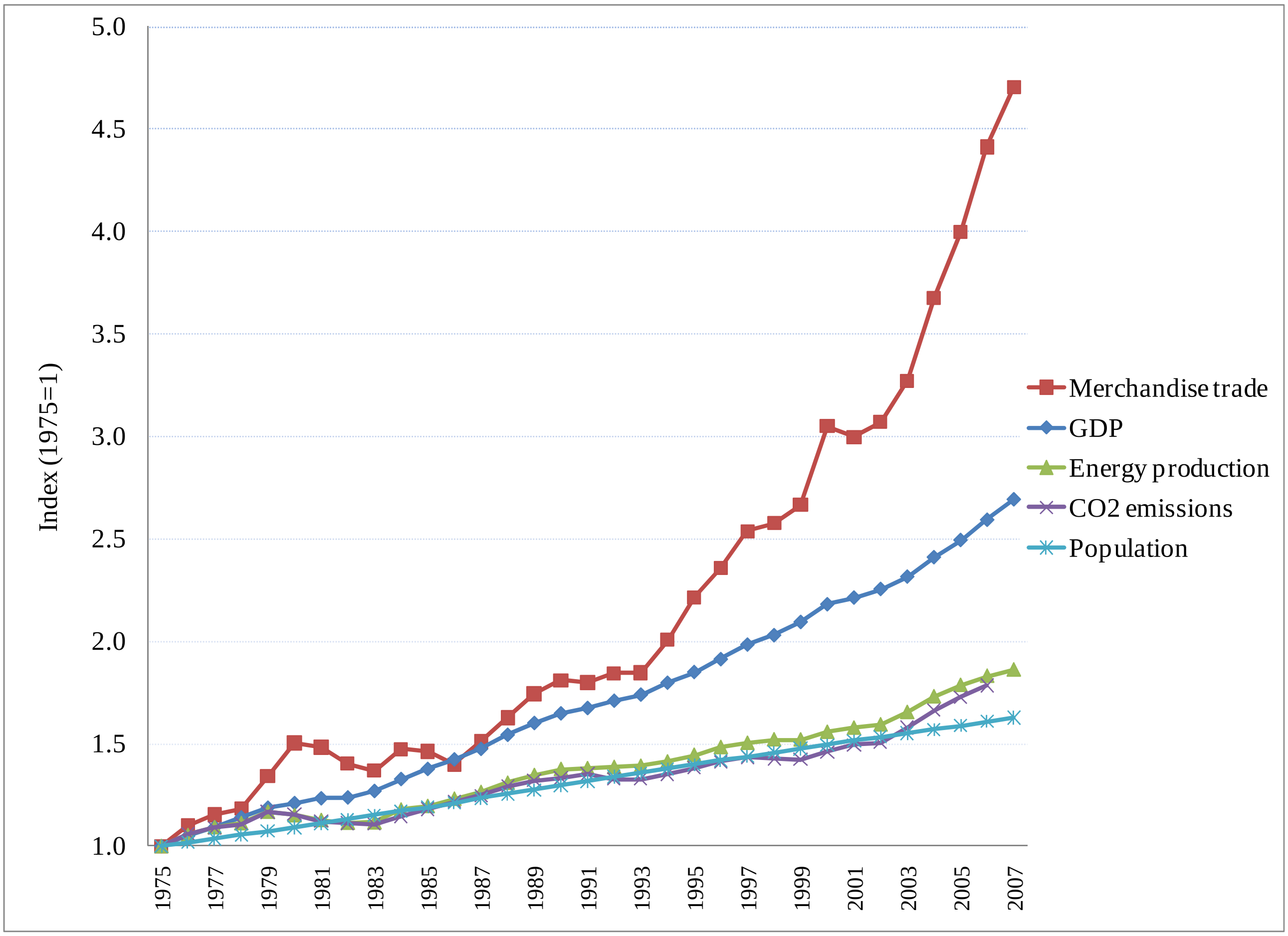
International trade in commercial commodities is a significant factor contributing to the growth of atmospheric carbon dioxide (CO_2) concentrations and future changes in the Earth's climate. China and the United States, as leading exporting and importing nations and top emitters of CO_2 emissions to the global atmosphere, are at the center of this emerging science and policy issue. This working paper examines the scientific basis for estimating CO_2 emissions associated with international trade and emerging policy perspectives on the consequences of these new findings for climate change negotiations. The weight of evidence reported in this analysis indicates that the globalization of trade represents an opportunity for gaining new perspectives on policies for addressing the challenge of reducing national and global CO_2 emissions.

The international climate change policy community is currently grappling with the design of a successor policy framework to the Kyoto Protocol that expires in 2012. Given the large disparities in wealth and emissions between rich and poor nations, one certainty is that international policies to reduce CO_2 emissions will not be applied in a globally uniform fashion, and differentiation of commitments and targets among countries is inevitable. We conclude that the particularly contentious and complex challenge of apportioning CO_2 emissions generated from internationally traded energy intensive commodities will require a dialogue on fundamental issues related to who should bear the responsibility for these emissions—the producer or consumer?

The Growth of Carbon Embodied in International Trade

For the past several decades, growth in international trade has outpaced the growth of global gross domestic product (GDP), energy consumption, and world population (See Figure 1). This surge of economic globalization has resulted in a dynamic shifting in the geographic patterns of production and consumption of consumer goods, fossil fuels use, and CO_2 emissions.

Figure 1: Growth of Global Trade in Goods, Gross Domestic Product (GDP), Energy Use, CO_2 Emissions, and Global Population, 1975-2007



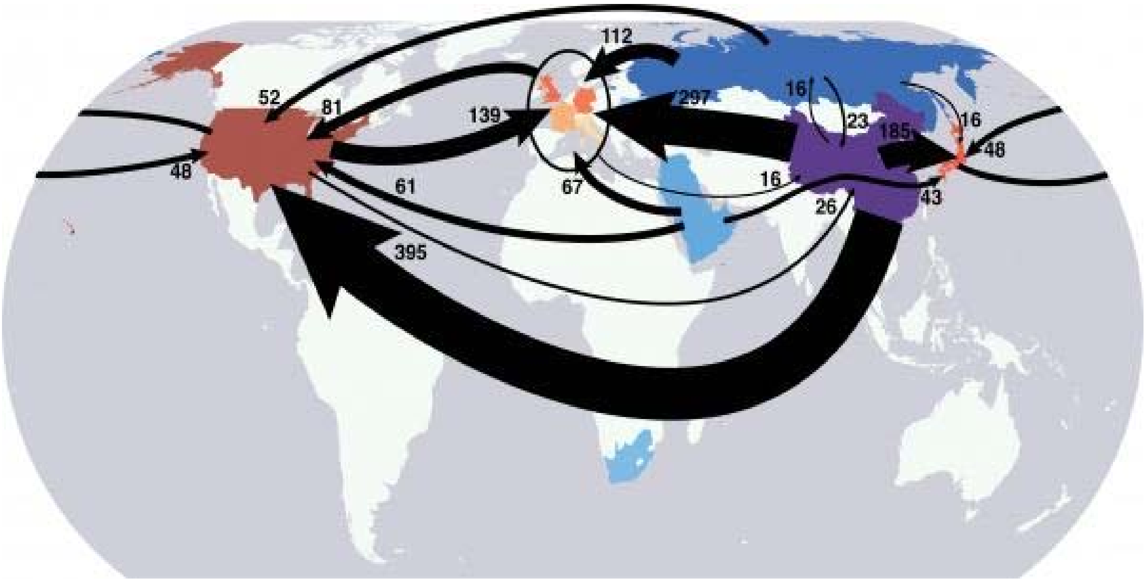
Source: World Development Indicators, World Bank[1]

Economic globalization reflects the logic of increasing the production of consumer goods at the lowest possible costs while maintaining the qualities and quantities that buyers demand. Estimating the net benefits and costs of economic globalization is a contentious and widely debated topic. One, perhaps unintended, consequence of economic globalization has been a shifting of the burden of additional CO_2 emissions and other environmental pollutants from developed to developing countries. The large-scale geographical separation of material production and consumption raises fundamental policy questions concerning country-level responsibility for emissions, and, ultimately, may undermine broader sustainable development goals.

The growth in internationally traded commodities has required increased fossil fuel energy inputs and, consequently, has resulted in increased CO_2 emissions. Manufacturing technologies, materials, and the type of fuels used determine the quantities of CO_2 emitted to the atmosphere during the production of commercial commodities. The emissions generated during the manufacturing and distribution of an exported commodity are most often known as “embodied carbon in trade.” The terms “embedded carbon in trade” and “virtual carbon in trade” have also been used in the same context.

A state-of-the-art analysis of embodied carbon in international trade recently published in the *Proceedings of the National Academy of Sciences* (PNAS) reported that in 2004 the embodied carbon in commodities imported for consumption in the U.S. would be equivalent to transferring approximately 11% of U.S. national CO_2 emissions to the exporting countries, which is equivalent to 2.4 metric tons of CO_2 per American citizen.[2] In other words, the American gets the benefit of the purchased goods while the exporting country gets credited with the CO_2 emissions. The PNAS study estimated embodied carbon in trade across 57 industry sectors and 113 countries or regions (See Figure 2).

Figure 2: Interregional Movements of Embodied Carbon in Trade in 2004



Net exporting countries are purple and blue, while the dominant net importing countries are red and orange.
Source: Davis and Calderia (2010)[2]
(The units are ($MtCO_2$ /yr) or million metric tons of CO_2 per year.)

Japan's imported goods were equivalent to nearly 18% of domestic emissions and European nations reduced their CO_2 emissions 20-50% as a result of importing commodities rather than manufacturing the goods within their national territories. Most of the imports to wealthy countries were produced in developing countries. Small wealthy nations, such as Switzerland, avoided the largest quantities of CO_2 emissions by importing goods. On the flip side, nearly one-quarter of China's CO_2 emissions, for instance, were dedicated to making goods for export and consumption in wealthy countries.

An estimated 23% of total global CO_2 emissions—or 6.2 billion metric tons of CO_2—were traded internationally as commodities in 2004, with most of the exported commodities originating from low-income countries for the consumption of middle- and high-income countries. China was identified as the largest exporter of embodied carbon emissions, followed by Russia, the Middle East, South Africa, Ukraine, and India. The largest trade flows of embodied carbon emissions were from China to the United States, Europe, and Japan. The embodied carbon flows from Russia to Europe and from countries in the Middle East to the United States and the European Union (EU) were also significant, as was the trade between United States and the EU.

Imports from Russia, China, and India were significantly higher in CO_2-per-U.S. dollar spent than imports from European countries. The reason for these differences can arise from a combination of the larger fraction of coal in the producer country energy mix, the lower energy efficiency of manufacturing, and the market valuation of the products being exported.

Figure 2 illustrates that Chinese exports to the U.S. in 2004 resulted in 395 million metric tons of CO_2/year ($MtCO_2$/yr) of CO_2 emissions in China. Thus, the U.S. was, in effect, "offshoring" the 395 $MtCO_2$/yr of carbon emissions associated with commodities produced in China and subsequently consumed in the U.S. The carbon intensity of manufacturing in China is higher than in the U.S., so that in addition to the U.S. reducing its inventory of domestic CO_2 emissions by importing Chinese commodities, net global CO_2 emissions were also increased. The consideration of embodied carbon emissions as a factor contributing to climate change adds to the complex and growing list of factors associated with economic globalization and the environment.[3]

Methodologies for Determining the Embodied Carbon Content of Goods and Services in International Trade

The European Union (EU) was a leader in recognizing the potential environmental consequences of international trade. The goal of moving toward a more sustainable consumption and production of all consumer goods is a key objective in the European Union Sustainable Development Strategy.[4] This strategy recommends changes in the way products and services are designed, produced, used, and disposed of. It is inclusive in identifying the need for attention to both producer and consumer behaviors. However, as is often the case with broad policy statements, the absence of mandatory quantifiable targets, deadlines, and other implementation details weakens the ability of this strategy to achieve its fundamental objective of reducing the impacts of material production and consumption.[5] The lack of implementation details in the EU strategy on sustainable consumption and production are due, in part, to the absence of widely accepted standard methods for quantifying environmental effects, including CO_2 emissions associated with international trade.

Methodologies for estimating embodied carbon resulting from the production and consumption of commercial commodities had been primarily of interest to academic researchers until recently, when the issue was recognized as relevant to international negotiations on the mitigation of global warming. A variety of methodologies has been utilized, or is under development, for quantifying the embodied carbon associated with the life cycle of commercial products. The study of embodied carbon is related to broader research areas known as industrial ecology, life cycle assessment, and carbon footprinting.

A life cycle assessment of a product attempts to document the potential environmental and health factors associated with that product from its origins to final disposal or, in the more popular term often used, from cradle-to-grave. Life cycle assessments are one component of quantifying the role of embodied carbon in international trade. Methodologies for assessing embodied carbon in internationally traded products also require economic input-output models for quantifying trade flows. The integration of a life cycle assessment model with an economic input-output model is required to derive estimates of embodied carbon in traded products. This paper offers a brief review of state-of-the-art methodologies used for estimating embodied carbon in international trade. References to recent and ongoing methodological developments are provided in the following paragraphs for readers wishing a deeper understanding of methodologies.

The challenge of designing an analytical framework for quantifying the impacts of traded goods requires consideration of the economic, environmental, spatial, and temporal dimensions of the entire life cycle of a product. Currently, there is not a standard analytical methodology capable of providing comprehensive assessments of embodied carbon international trade. At the global and regional scales, the most common input-output methods for economic studies of trade flows use aggregated categories of products. This limitation derives from standard protocols for the reporting of international trade data. Detailed product life cycle assessments are typically focused at the micro level of material composition, manufacturing methods, use, and disposal of individual products. A marriage of these two analytical frameworks is used to achieve an estimate of embodied carbon in international trade.

A public website maintained by Carnegie Mellon provides a comprehensive overview of the current The Economic Input-Output Life Cycle Assessment (EIO-LCA) methodology and on-line tools needed to evaluate the comprehensive environmental impacts associated with the life cycle of a commercial commodity.[6] The EIO-LCA models available on the website were initially applied to the U.S. More recently, the EIO-LCA software tools have been applied to assessments in Canada, Germany, Spain, and, most recently, to studies of international trade.

A team of European research institutions recently published a state-of-the-art assessment of methodologies for the measurement of embodied carbon in internationally traded products and services.[7] The project, titled “The Environmental Impacts of Trade” (EIPOT), had the goal of specifying an environmental accounting method to quantify and assess the transnational environmental impacts of traded goods and services. Questions addressed by the EIPOT project were: What are the environmental impacts associated with growing trade between nations? Is it possible to quantify the extent of these impacts and to create “environmental trade balances?” And what are the most quantitative approaches to do this? The goals of the EIPOT project focused on (a) putting forward a flexible range of compatible methods that could address a range of research and policy questions and (b) directing attention to limitations in the areas of data and functionality.

The EIPOT project final report recommends an environmentally extended multi-region input-output (EE-MRIO) framework integrated with a system of economic and environmental accounts (SEEA) as the components for assessments of embodied carbon in international trade flows. Specific policy and research questions can then be addressed by building upon the EE-MRIO structure, using various forms of hybrid modeling.[7] The main elements of this carbon accounting framework included: monetary input-output tables for countries engaged in relevant trade in a resolution of at least 100 economic sectors; detailed, bilateral trade datasets for goods and services in monetary (and possibly physical) units; and complete tables of carbon accounts derived through a process analysis and/or life cycle assessment.

Economic input-output models have been used for more than 70 years and will be familiar to most readers of this working paper. Comprehensive life cycle assessment and analysis methodologies are a much more recent development associated with the still emerging field of industrial ecology. A basic introduction to the life cycle assessment and analysis is available to readers as an appendix to this document.

China-U.S. Trade: A Case Study of International Trade as a Source of Enhanced Global CO_2 Emissions

Fueled by a rapidly growing industrial economy, China has become a major merchandise supplier serving consumers worldwide. According to the Congressional Research Service, total China-U.S. trade expanded from $5 billion in 1980 to $409 billion in 2008.[8] China was the United States’ second largest trading partner, its third largest export market, and its number one source of imports. About 12% of total U.S. trade was with China. This economic relationship was under stress due to a number of issues including the large and growing U.S. trade deficits during the period of our study. China’s failure to fully implement its World Trade Organization (WTO) trade commitments, its refusal to adopt a floating currency system, and other practices were deemed unfair or harmful to U.S. interests. This section of our paper documents the emerging role of China-U.S. trade as a factor in determining interregional and global CO_2 emissions.

The growth of China-U.S. trade during the period 1999-2008 is documented below in Table 1. The double-digit increase in the growth of U.S. exports to and imports from China during the years 2000 through 2007 is a remarkable and sustained pace of growth in international trade. The additional data necessary for implementing an assessment of embodied carbon in this China-U.S. trade is the composition of products being imported and exported by each nation. Tables 2 and 3, which also follow, provide data on U.S./China export/import trade as reported in broad categories by federal agencies. Two important factors to note are the commodity categories of trade flowing between China and the U.S. and very general descriptions of the composition of trade flows. Both of these characteristics add uncertainties to the life cycle assessment methodologies used for determining embodied carbon.

Table 1: China's Trade with the United States ($ billion)

	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
US Exports	13.1	16.3	19.2	22.1	28.4	34.7	41.8	55.2	65.2	71.5
% change	-8	24.4	18.3	15.1	28.5	22.2	20.6	32.1	18.1	9.5
US Imports	81.8	100	102.3	125.2	152.4	196.7	243.5	287.8	321.5	337.8
% change	14.9	22.3	2.2	22.4	21.7	29.1	23.8	18.2	11.7	5.1
Total	94.9	116.3	121.5	147.3	180.8	231.4	285.3	343	386.7	409.2
% change	11	22.6	21.4	21.2	22.8	28	23.3	20.2	12.7	5.8
US Balance	-68.7	-83.7	-83	-103.1	-124	-162	-201.6	-232.5	-256.3	-266.3

Note: US exports reported on FOB basis; imports on a general customs value, CIF basis

Sources: US International Trade Commission, US Department of Commerce, and US Census Bureau

Table 2: Top US Exports to China in 2008 ($ billion)

HS#	Commodity Description	Volume	% Change*
85	Electrical machinery & equipment	11.4	6.8
84	Power generation equipment	9.7	10.0
12	Oil seeds & oleaginous fruits	7.4	76.2
88	Air & spacecraft	5.1	-29.0
39	Plastics & articles thereof	3.8	6.6
90	Optics & medical equipment	3.7	12.9
72, 73	Iron & steel	3.3	18.5
47	Pulp & paperboard	2.3	11.2
76	Aluminum & articles thereof	2.1	16.6
29	Organic chemicals	2.1	-0.8

*Percent change over 2007

Sources: US International Trade Commission, US Department of Commerce, and US Census Bureau

Table 3: Top US Imports from China 2008 ($ billion)

HS#	Commodity Description	Volume	% Change*
85	Electrical machinery & equipment	80.3	4.7
84	Power generation equipment	65.1	1.7
95	Toys & games	27.2	4.0
61, 62	Apparel	24.0	0.1
94	Furniture	19.4	- 4.7
72, 73	Iron & steel	14.8	24.7
64	Footwear & parts thereof	14.5	2.4
39	Plastics & articles thereof	8.9	8.2
42	Leather & travel goods	7.4	2.1
87	Vehicles other than railway	6.4	4.9

*Percent change over 2007

Sources: US International Trade Commission, US Department of Commerce, and US Census Bureau

The global importance of China-U.S. trade has inspired numerous independent studies of embodied carbon in trade between China and the U.S. We compare these studies here to provide insights into uncertainties associated with estimates of the magnitude of CO_2 embodiment in traded products. Most of the studies reviewed below addressed the following questions: How much of China's national CO_2 emissions were emitted to meet final consumer demand for commodities in the U.S.? What quantity of CO_2 emissions did the U.S. avoid emitting by trading with China? What were the impacts of China-U.S. trade on global CO_2 emissions?

Shui and Harriss published a pioneering study on embodied carbon in China-U.S. trade for the years 1997-2003.[9] The EIO-LCA methodology referenced above was used for the analysis. The results of their study indicated that 7-14% of China's CO_2 emissions were a result of manufacturing of products for export to the U.S. If the same products had been manufactured in the U.S., the U.S. national CO_2 emissions inventory would have increased by 3-6%. From 1997-2003, there was a very consistent ratio in which one unit of carbon avoided in the U.S. was associated with about 1.4 units of carbon emitted in China. For instance, in 2003, the U.S. avoided 357 $MtCO_2$ from importing Chinese goods, while the products China imported to the U.S. led to the emissions of 497 $MtCO_2$, or 1.39 times as much CO_2 as the U.S. would have produced. These results are explained by the higher carbon intensity of manufacturing in China that increases the carbon embodiment per unit of product when compared to manufacturing the same product in the U.S. The importing of products from China allows the U.S. to increase consumption without increasing the U.S. national inventory of CO_2 emissions. The higher carbon intensity of manufacturing in China compared to manufacturing similar products in the U.S. also resulted in a net increase of total global CO_2 emissions. To illustrate the potential importance of CO_2 emissions associated with international trade, Shui and Harriss also noted that during the period 1997-2003, the net "additional" global CO_2 emissions resulting from China-U.S. trade amounted to 720 $MtCO_2$.

Guo et al. investigated the role of carbon embodied in China-U.S. trade for the year 2005.[10] The results indicated that the U.S. avoided 190.1 $MtCO_2$ as a result of consuming imported goods from China, while the emissions in China's imports were 705.38 $MtCO_2$. These findings indicate that every unit of carbon avoided in the U.S. is associated with an increase of over 3.7 units in

China, a *vastly* different finding than the conclusion of the Shui and Harriss paper and much more troubling from a climate perspective if true. The paper's analysis by 13 sectors (11 with emissions) shows the sources that account for this tremendous difference: the ratio of embodied to avoided emissions is over 10 in sectors for Primary Metals, Fabricated Metal Products, and Non-Metallic Mineral Products, and the ratio is over three in four others. Similarly, the authors calculate a ratio of almost 3.7 for Chinese imports of U.S. goods, 178.62 $MtCO_2$ emitted and 48.7 Mt saved. These authors estimate that the net impact of China-U.S. trade was an increase in global CO_2 emissions by 385.3 $MtCO_2$. This net impact on global CO_2 emissions reflects significant differences in the carbon intensity of production of goods and variations in the life cycle carbon intensity of specific commodity categories in China and the U.S. Embodied carbon in chemical, fabricated metal products, non-metallic mineral products, and transportation equipment sectors was estimated to have contributed an 88% share of the increase in global emissions.

Studies by Xu et al. focused on eastbound trade (from China to the U.S.) from 2002-2007.[11] These authors calculated that China's exports to the U.S. consumed about 12-17% of China's energy consumption and were responsible for 8-12% of China's total CO_2 emissions. Because avoided emissions in the U.S. are not addressed, it is impossible to calculate a ratio between carbon avoided in the U.S. and emitted in China. However, the difficulty in calculating emissions is shown again, as the authors calculate that China exported goods with 486 Mt of embodied CO_2 to the U.S. in 2007, over 30 percent less than the calculation in the paper by Guo et al. (The numbers from the Xu et al. and Shui and Harriss papers better correspond with each other.) In an important further consideration, these authors estimated that exported products also accounted for 10-15% of sulfur dioxide (SO_2) and 8-12% of nitrogen oxides (NOx) emissions in China, contributing to local and regional air pollution. In addition to noting the need for improvements in data for input-output and lifecycle calculations, Xu et al. noted that differences in labor inputs, working conditions, and pay should be considered in future, more comprehensive assessments of international trade.

China's World Trade

Yunfeng and Laike used the EIO-LCA model, with an updating of CO_2 emissions factors, to estimate embodied carbon in all of China's international exports for 1997-2007.[12] Their results indicated that 26.5% of China's annual CO_2 emissions were produced as a result of the manufacture of exported goods in 2007. The embodied carbon in imported goods was equivalent to 9.1% of China's 2007 CO_2 emissions. These results implied that, in 2007, the rest of the world avoided emitting approximately 593 $MtCO_2$ through importing Chinese products.

In a similar effort, Lin and Sun adopted the methods of a 2003 study by the Organisation for Economic Co-operation and Development (OECD) to estimate the total carbon embodied in Chinese international trade.[13,14] This study estimated that 1,024 $MtCO_2$ were avoided globally by consuming countries as a result of Chinese international exports in 2005. The significant differences between the Lin and Sun and Yunfeng and Laike estimates of avoided carbon emissions in countries consuming China's exports in 2005 and 2007 reflect the issue of uncertainties associated with different methodologies and data used for estimating embodied carbon in trade.

China became the world leader in annual CO_2 emissions in 2006 when it exceeded U.S. CO_2 emissions. It is expected that China's CO_2 emissions will continue to grow.[15,16] The International Energy Agency has forecast that China's total emissions in 2015 will increase to between 8.1 and 9.5 billion metric tons of CO_2, further widening the gap between their emissions and those of the U.S. China also became the second largest international exporter of commodities, behind the U.S. in 2010. There is no doubt that China will demand consideration of embodied carbon as an issue in determining producer versus consumer responsibility for CO_2 emissions. China's energy intensity (amount of energy consumed per unit of GDP) and carbon intensity (amount of energy-related carbon emissions per unit of GDP) increased during the period of the studies reported here. The most important driver was the growth of coal-based energy and carbon-intensive industries responding to global economic growth in demand for consumer goods and urban expansion.[17]

China-U.S. trade may offer an opportunity to create a collaboration that could dramatically accelerate the decarbonization of global manufacturing and trade. The combination of the rate and scale of China's economic development, and the sophistication of U.S. research and development capabilities, could be crafted into an arrangement for large-scale experimentation and deployment of clean energy technologies. This collaboration could also provide advances in strategies for the sharing of intellectual property between developing and developed countries.

In 2009, it was announced that China would export the first wind turbines destined for use in a U.S. wind farm, a project valued at $1.5 billion. The United States currently produces less than 10% of the world's solar cells, and is likely to also look to Asia for photovoltaic technologies and for hybrid and electric vehicle technologies. America will remain a center for fundamental research and innovation, and should be prepared to take risks that encourage the globalization of manufacturing and marketing of clean technologies and other environmentally friendly consumer goods.

In addition to the decarbonization of international trade, advances in the life cycle assessment tools and methodologies discussed above will also address the need for certified standards on carbon labeling of commercial goods and for implementing voluntary and formal markets for carbon offsets. Deepening globalization will ensure a need to address both human well-being and the carbon dimension of trade to confront the climate change challenge.

Connecting the Science of Embodied Carbon in Trade to Global Climate Change and Trade Policies

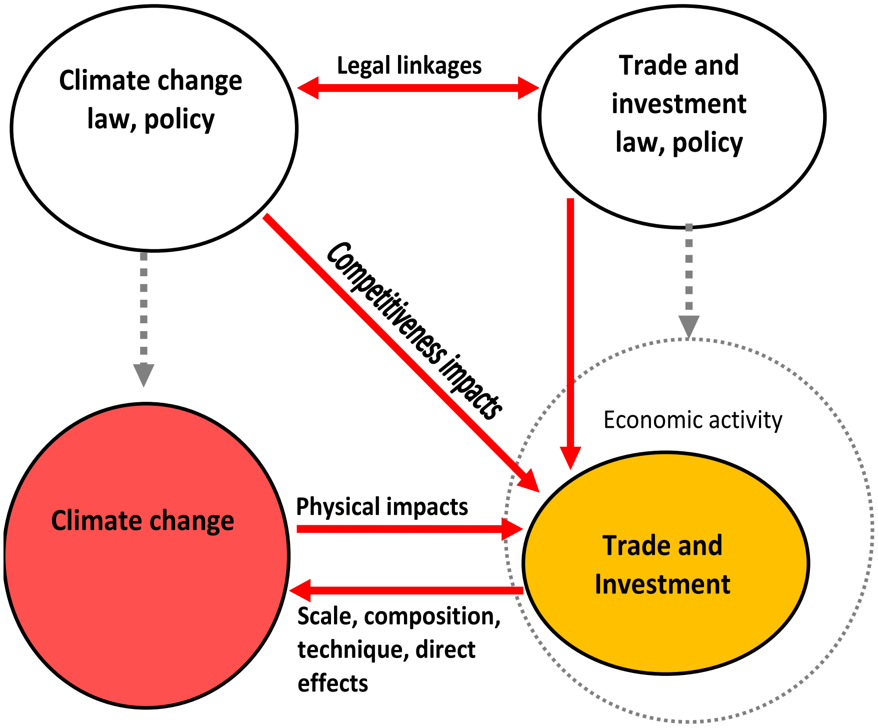
A comparative analysis of production-based versus consumption-based CO_2 emission inventories illustrates that economic globalization is undermining the utility of the national emissions inventory methodologies used by the Intergovernmental Panel on Climate Change (IPCC) to allocate responsibility for CO_2 emissions.[18] The United Nations Framework Convention on Climate Change (UNFCCC)/Kyoto Protocol process has based negotiations on CO_2 emissions that originate within national boundaries (i.e., national emissions inventories). Developing countries that are large emitters, such as China and India, have recently argued national emission inventories do not represent a true measure of consumption, the fundamental culprit of growth in global climate change. They recommend that consideration must be given to consumption-based measures of CO_2, especially the emissions generated during the manufacturing of a commodity in a developing country that is subsequently exported for use or consumption in a developed country.

Chinese officials have noted the “common but differentiated responsibility” criteria declared in Article 3 of the UNFCCC as a basis for their concerns. China’s President Hu Jintao, who spoke at the G-8 meeting held in summer 2008 in Japan, stated that, “…as a result of changes in international division of labor and manufacturing location, China faces mounting pressure of international transferred emissions.”[19] At a meeting in Washington, D.C., in March, 2010, with top U.S. climate policymakers and their counterparts from China, the EU, Japan, and Mexico, Mr. Gao Li, who heads the climate change department of the Chinese National Development and Reform Commission, told the gathering that his country was “at the low end of the production line for the global economy. We produce products and these products are consumed by other countries, especially the developed countries.” Gao Li estimated that the carbon emitted in China during the manufacturing of exports for the United States and other countries accounted for some 15% to 25% of his country’s total emissions. He said that, “This share of emissions should be taken by the consumers, not the producers.” Then, he noted that this would be a “very important item” in reaching a fair post-Kyoto global agreement on greenhouse gas reductions.[20]

The opponents of attributing embodied carbon emissions to the consumer country, which include the EU’s chief climate negotiator Artur Runge-Metzger, doubt that asking importers to accept responsibility for embodied carbon in purchased goods would work. In addition to the logistical difficulties involved in regulating embodied carbon emissions in the country of destination, Runge-Metzger has noted that importing countries would then “like to have jurisdiction and legislative powers in order to control and limit emissions in the exporting country and I’m not sure whether my Chinese colleagues would agree on that particular point.”[20]

Embodied carbon in international trade is an emerging issue that adds to an already long list of trade and environment issues.[2] The diagram in Figure 3 offers a conceptual framework for how issues of climate change and trade might interact in the context of the already very complex WTO and UNFCCC agendas.

Figure 3: Influence of Climate Issues on Global Trade and Investment Policy



Source: Cosby (2008)[21]

In the case of the top two global traders and CO_2 emitters—the U.S. and China—the embodied carbon of their trade flows is likely to remain a significant issue. Chinese scholars and policymakers have stated that, in addition to China's vigorous domestic efforts to reduce CO_2 emissions associated with manufacturing for international trade, a new international framework is needed that would allocate the responsibility for CO_2 emissions associated with embodied carbon in imports to consumer nations. These arguments come on top of previous concerns, including China's low per-capita emissions of CO_2 and the long-term cumulative contributions of CO_2 to the global atmosphere by the U.S. and other wealthy nations.

In addition to the Chinese call for the allocation of responsibility for embodied carbon in imported goods to the consuming country, three additional policy options relevant to the embodied carbon issue are: the liberalization of trade in environmental goods for climate change mitigation and adaptation, border tax adjustments based on the carbon content of imported goods, and clean technology transfer and intellectual property rights.

Trade between developed and developing countries will be an important channel for the diffusion of environmental technologies needed to mitigate and adapt to climate change.[22] Major considerations being discussed include: 1) reducing trade barriers in a manner that enhances the availability of climate-friendly commodities; 2) insuring that the benefits of trade liberalization accrue to poorer developing countries; and 3) addressing issues in cases where intellectual property rights might act as a barrier to the trade of environmentally friendly technologies and products.

Trade liberalization alone will not result in greater access to emerging climate-friendly technologies and goods if costs are kept high by licensing fees or royalty payments. A 2007 World Bank report called for smarter trade as an adjunct to freer trade and proposed bundling trade liberalization with packages of technical and financial assistance. The report estimated that the removal of tariffs for four basic clean energy technologies (wind, solar, clean coal, and efficient lighting) in 18 developing countries would result in trade gains of up to 7%. The removal of non-tariff barriers would further increase trade by as much as 13%.[23]

The definition of what constitutes an environmental commodity has been a difficult issue to resolve in discussions on liberalizing trade. The greenhouse gas mitigation potential associated with the 153 specific environmental technologies was submitted to the WTO’s Committee on Trade and Environment Special Session on environmental commodities in 2005. The impact on mitigation of greenhouse gas emissions would be relatively small for most countries, and almost exclusively due to renewable electricity generation technologies. The current list is tilted toward marketing goods that WTO members currently export, and preventing the liberalization of trade for technologies where developing country members would like to establish their own industries. A question has been raised as to whether it is better to import such goods more cheaply, thereby fostering greater environment improvement, or to encourage domestic industries with the consequence of delaying mitigation of greenhouse gases.

The World Bank proposed two alternatives in an effort to dislodge the current stalemate on liberalization of climate-friendly goods: 1) WTO members representing a minimum share of trade in climate-friendly goods could sign up via a sub-category to a larger negotiated package or independent of it, as their circumstances permitted or 2) Regional Trade Agreements (RTAs) may offer a vehicle for increasing markets in environmental goods and services, noting the constraints that their limited membership may entail. Clearly, further work is needed on liberalizing of trade in climate-friendly technologies, goods, and services in order to make progress on the mitigation of greenhouse gases.

There have been numerous proposals and studies related to the design of border tax adjustments. A border tax adjustment based on the carbon content of imported goods would be a trade measure that aims to level the economic playing field between domestic producers facing climate change measures and foreign producers facing few or none. In the case of a border tax, imported goods would be charged a fee equivalent to the carbon tax paid if the product had been produced domestically. Such a scheme might also rebate the paid tax funds to companies manufacturing exported goods, ensuring that they are not disadvantaged in international markets.

The reaction to a border tax adjustment scheme will be highly contentious and, at the very least, result in challenges to the WTO process. A recent study suggests that the imposition of a border tax could lead to substantial tariff rates on imports from developing countries.[24] Chinese imports into the U.S. could be subject to an average tariff rate of 10.3% if carbon was taxed at $50 per ton of CO_2. The authors concluded that border taxes on embodied carbon will be trade distorting in the sense that the volume and composition of international trade will change with significant losses in efficiency and welfare in developing countries. While reducing global emissions could be welfare-producing, developing countries could end up financing a global public good even though they have historically made minimal contributions to the source of the problem.

Is Embodied Carbon in Trade Relevant to Climate Policy Formulation?

The debate on how to measure and utilize information on embodied carbon started well over a decade ago. In a 1994 study of the carbon embodied in the manufactured imports of the six largest OECD countries between 1984 and 1986, researchers warned that policies predicated on the reduction of greenhouse gas emissions at home might not be effective if imports were contributing significantly to domestic consumption.[14]

A working paper recently published by the Stockholm Environment Institute provides an important reminder that "China's success in trade is based on labor costs, not on embodied CO_2 emissions; there is literally no correlation between the amount of CO_2 emissions emitted per unit of product and revealed comparative advantage within the Chinese economy today." The paper concludes that since comparative advantage in international trade is not related to embodied carbon in commodities, and many countries do not place a price on carbon, a border tax would likely do little harm to developing country exporters.[25] However, current news of unrest and protests by workers in the manufacturing sector indicates that labor costs may rise in the next few years, reducing to some degree China's comparative economic advantage. Looking further ahead, labor-intensive manufacturing will likely move to other countries with low labor costs as China places emphasis on financial, information, and management services.

The ongoing climate change negotiations addressing a post-Kyoto policy framework for CO_2 and other greenhouse gas inventories provide an opportune time to consider the importance of a role for embodied carbon and consumption-based accounting in rethinking climate policy. Proponents for using a country's economic activity, instead of national territory, as the basis for estimating emissions argue that this approach will reduce concerns about carbon leakage, reduce emission responsibilities for some developing countries, increase options for mitigation, encourage environmental comparative advantage, address some competitiveness concerns, and encourage the diffusion of low-carbon technologies.[26]

Progress on linking the science of embodied carbon to policy formulation will require a deeper understanding of interactions between the carbon cycle and the underlying consumption needs and wants of the global population. The significance of embodied carbon in trade appears to be a potential game changer for restructuring climate change policy development. In contrast to the past emphasis on national CO_2 inventories, where the focus was on emissions generated within national territorial boundaries, future policy strategies must now additionally consider whether to address the fundamental responsibilities associated with embodied carbon driven by consumer consumption. Just as it is important to understand CO_2 as an influence on the physical climate system, it is also important to consider human needs and wants for consumption as a set of cultural, economic, and equity issues that often trump environmental considerations.

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Appendix: Brief Tutorial on Life Cycle Assessment

The following tutorial is highly edited from the PRé Consultants website located at http://www.pre.nl/. This material is not intended to be an endorsement of the PRé Consultants and their products. The PRé Consultants are a leader in the field of life cycle analysis education and applications. We acknowledge their important contributions to the advancement of life cycle assessment.

Life cycle assessment (LCA) is an evolving set of concepts and tools for the quantitative characterization interactions between a product and the environment from the origin of the basic materials used for product generation to the end-of-life disposal or recycling process. It is also known as life cycle analysis.

There are two main steps in an LCA: (1) a materials emissions flow inventory and (2) an assessment of what the impacts of raw material depletions and uses are. This is referred to as the impact assessment step. LCA provides a primary input for designing product/process improvements in a manner that reduces environmental impacts.

The LCA methodology is described in detail by the Society of Environmental Toxicology and Chemistry (www.setac.org). In SETAC's Code of Practice, it is recommended that the LCA be split into five stages:

1. Planning
    - Statement of objectives
    - Definition of the product and its alternatives
    - Choice of system boundaries
    - Choice of environmental parameters
    - Choice of aggregation and evaluation method
    - Strategy for data collection
2. Screening
    - Preliminary execution of the LCA

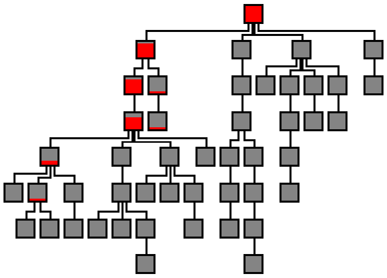
- Adjustment of plan

3. Data collection and data treatment
    - Measurements, interviews, literature search, theoretical calculations, database search, qualified guessing
    - Computation of the inventory table
4. Evaluation
    - Classification of the inventory table into impact categories
    - Aggregation within the category (characterization)
    - Normalization
    - Weighting of different categories (valuation)
5. Improvement assessment
    - Sensitivity analysis
    - Improvement priority and feasibility assessment

The first stage in a life cycle assessment is to map a product's life cycle from the processes required to produce each basic material input to the product development to the final composition of the disposal products.

A product's life cycle can be presented as a process tree with each box representing a process that forms a part of the life cycle. Every process will have defined inputs and outputs of materials.

Figure 1: The Process Tree Diagram



Process inputs can be divided into two kinds:

1. Inputs of raw materials and energy resources (environmental input)
2. Inputs of products, semi-finished products or energy, which are outputs from other processes (economic input)

Similarly, there are two kinds of outputs:

1. Outputs of emissions (environmental output)
2. Outputs of a product, a semi-finished product or energy (economic output)

With information about each process and a process tree of the life cycle, it is possible to draw up a life cycle inventory of all the environmental inputs and outputs associated with the product. The result is a table of impacts. Each impact is expressed as a particular quantity of a substance. The table below displays an example of a small part of the table of impacts for the production of two materials. A complete table can have hundreds of rows.

Table 1: An Example of Gaseous Emissions from the Production of 1 kg of Polyethylene and 1 kg of Glass

Emission	**Polyethylene**	**Glass**	**Unit**
CO_2	1.792	0.4904	kg
NOx	1.091	1.586	g
SO_2	0.987	2.652	g
CO	670.0	57.00	mg

Table 1 does not provide an immediate answer to a question such as whether 1 kg of polyethylene is more or less environmentally friendly than 1 kg of glass. There are many remaining impacts to assess prior to completing a comprehensive life cycle assessment.

The inventory process seems simple enough in principle. In practice, it is subject to a number of practical and methodological problems. They are as follows:

System Boundaries

In breaking the life cycle down into processes, it is not always clear how far one should go in including processes belonging to the product concerned. In the production of polyethylene, for example, oil has to be extracted; this oil is transported in a tanker; steel is needed to construct the tanker, and the raw materials needed to produce this steel also have to be extracted. For practical reasons, a line must be drawn. For example, the production of capital goods is usually excluded.

Processes that Generate More than One Product

One example is the electrolysis of salt to produce chlorine. The environmental effects of the electrolysis process cannot be ascribed entirely to chlorine alone, as caustic soda and hydrogen are also produced. A suitable allocation rule is needed here, for instance allocation on mass basis or economic value of the products.

Avoided Impacts

When a disposal process generates a profitable output, such as energy generation at a municipal waste incineration plant, it does not only cause impacts. It also saves impacts as it is no longer necessary to produce the energy or the material in a normal way.

To allow for this, *avoided impacts* are introduced. These are equivalent to the impacts that would have occurred in actual production of the material or energy. The avoided impacts of a process are deducted from the impacts caused by other processes.

Geographical Variations

An electrolysis plant in Canada may use much less environmentally detrimental electricity than an identical plant in the United States, as hydroelectric power is abundantly used in Canada.

Data Quality

Publications on environmental process data are often incomplete or inaccurate. Moreover, the data are subject to obsolescence; there are many cases where processing industries have cut emissions by 90% during the last 10 years. The use of obsolete data can therefore cause distortions.

Choice of Technology

A distinction can be made between *worst, average,* and *best* (or *modern*) technology. Before starting to collect data it is important to be aware of which type of technology you are interested in.

Despite these problems, it is often quite feasible to carry out an impact inventory. It is unreasonable, however, to treat the results as an absolute truth. Factors such as the choice of technology and system boundaries, data quality, and other factors have to be taken into account when interpreting them. This is why there always seems to be disagreement among experts about the environmental soundness of a product.

For further introductory materials on life cycle assessments see:

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