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The Contribution of Chinese Exports to Climate Change

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Abstract: Within 5 years, China's CO2 emissions have nearly doubled, and China may already be the world's largest emitter of CO2. Evidence suggests that exports could be a main cause for the rise in Chinese CO2 emissions; however, no systematic study has analyzed this issue, especially over time. We find that in 2005, around one third of Chinese emissions (1700 Mt CO2) were due to production of exports, and this proportion has risen from 12% (230 Mt) in 1987 and only 21% (760 Mt) as recently as 2002. It is likely that consumption in the developed world is driving this trend. A majority of these emissions have largely escaped the scrutiny of arguments over "carbon leakage" due to the current, narrow definition of leakage. Climate policies which would make the developed world responsible for China's export emissions have both benefits and costs, and must be carefully designed to achieve political consensus and equity. Whoever is responsible for these emissions, China's

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rapidly expanding infrastructure and inefficient coal-powered electricity system need urgent attention.

Keywords: China; exports; Climate change

1 Introduction

Within a very short period of time, from 2002 to 2007, China's CO_2 emissions have almost doubled and it is now believed that China is the world's biggest emitter of CO_2 (Gregg et al., 2008). China faces increasing international pressure to curb its CO_2 emissions, but argues that "[t]he ramifications of limiting the development of developing countries would be even more serious than those from climate change." (Wu, 2007). China has several arguments for why it should not be required to limit its CO_2 emissions in the short term (National Development and Reform Commission, 2007). First, limits on China's CO_2 emissions would hamper economic development. Second, China has low per capita emissions, ranked 73rd in 2004, though this ranking is both higher than some developed countries and growing quickly (WRI, 2007). Third, historically China argues that it only contributes a small amount to cumulative emissions, which is true on a per-capita basis – ranking 92nd since 1900 – but not for absolute emissions – ranking fourth since 1990 (WRI, 2007). Finally, despite capital investments and household consumption dominating China's increasing CO_2 emissions (Peters et al., 2007), China has currently focused arguments towards the role of exports, claiming it should not be responsible for emissions attributable to the production of exports(McGregor, 2007). In 2005 exports accounted for a relatively large amount: 33% of China's GDP, increasing from 12% in 1987.

Despite several references to this issue (Ahmad and Wyckoff, 2003; IEA, 2007 p.290-291; Peters and Hertwich, 2008a; Peters et al., 2007; Wang and Watson, 2007), there have been no systematic studies on the contribution of exports to China's CO_2 emissions, and particularly how this has changed over time. Several studies have estimated the emissions embodied in China's exports (and imports), but few studies have focused on this as the primary issue. Ahmad and Wyckoff (2003) using a related method to ours, found that in 1997, 15% of China's emissions were embodied in exports and 3% of China's domestic emissions were imported. Peters *et al*. (2007) found that in 1997 25% of China's emissions were exported and 24% avoided by imports and in 2002 32% and 34%. However, Peters *et al*. (2007) did not adjust for imports in the production of exports, and thus their method differs slightly from what is used here. Wang and Watson (2007) estimated the emissions embodied in China's exports in 2004 as 23%, though they used a relatively simple method which fails to capture supply-chain effects. The most comprehensive study to date, Peters and Hertwich (2008a) considered the emissions embodied in trade for 87 countries and regions and found that in 2001 China exported 24% of its CO_2 emissions and imported 7% of China's domestic emissions. This study is the most similar methodologically to the analysis presented here and will be used to supplement the results.

We apply environmental input-output analysis (Leontief and Ford, 1972) to estimate the CO_2 emissions emitted in the production of exports in China from 1987 to 2005, representing the most recent data available. This method considers all the upstream supply-chain inputs necessary for the production of exports. The following section describes methods and data sources, followed by the results and a discussion of their relevance.

2 Methods and Data

2.1 Environmental Input-Output Analysis (EIOA)

The calculations are based on environmental input-output analysis (EIOA), (Miller and Blair, 1985; United Nations, 1999). This is a well-established method and is the basis of the System of National Accounts (Leontief, 1986). A summary of the method is shown here, but more detailed treatments are available elsewhere (Miller and Blair, 1985, United Nations, 1999).

As originally formalized by Leontief in his groundbreaking work (Leontief, 1986), the total output of an economy, $\boldsymbol{x}$, can be expressed as the sum of intermediate consumption, $\boldsymbol{Ax}$, and final consumption, $\boldsymbol{y}$:

$$\boldsymbol{x} = \boldsymbol{Ax} + \boldsymbol{y} \tag{1}$$

where $\boldsymbol{A}$ is the economy's direct requirements matrix and $\boldsymbol{y}$ is the demand for which the supply chain output, $\boldsymbol{x}$, is to be derived. The matrix $\boldsymbol{A}$ describes the relationship between all sectors of the economy. In this study we used four separate final demand categories from each year's input-output table: household consumption, fixed capital investment, exports, and governmental consumption. When solved for total output, this equation yields:

$$\boldsymbol{x} = (\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{y} \tag{2}$$

When coupled with an environmental matrix, $\boldsymbol{F}$, which shows the environmental emissions caused by each sector in the model, normalized by the sector's economic output, $\boldsymbol{x} = (x_1\ x_2 \dots x_n)^T$, (where n is the number of sectors in the input-output table) the total amount of emissions can be calculated as:

$$\boldsymbol{f} = \boldsymbol{F}(\boldsymbol{I}-\boldsymbol{A})^{-1}\boldsymbol{y} \tag{3}$$

with $\boldsymbol{f}$ representing the sector-wise total supply chain emissions to meet the final demand $\boldsymbol{y}$.

This is the standard method for environmental IOA. However, this method is not sufficient for studies of trade as the direct requirements matrix $\boldsymbol{A}$ usually does not distinguish between domestically produced and imported products (United Nations, 1993). Thus, it is common to derive new requirements matrices and final demand vectors in which only domestic goods are included, $\boldsymbol{A_d}$ and $\boldsymbol{y_d}$:

$$\begin{aligned} s_i &= \frac{m_i}{x_i + m_i - e_i} \quad \text{for all } i \\ \boldsymbol{A}_d &= diag(\boldsymbol{s}) * \boldsymbol{A} \\ \boldsymbol{y}_d &= diag(\boldsymbol{s}) * \boldsymbol{y} \end{aligned} \tag{4}$$

where s_i is the share of imports in the supply of products and services to each sector, i. This method removes imported goods, $\boldsymbol{m}$, from the direct requirements table and from components of GDP other than exports, $\boldsymbol{e}$, (household consumption, capital investment, and government consumption). This method assumes that each economic sector and final demand category uses imports in the same proportions; for example, it assumes that industry, government, and households each consume the same share of domestically produced and imported software.

For each year, then, the emissions embodied in exports (or other GDP components) are calculated as:

$$\boldsymbol{f}_e = \boldsymbol{F}(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{y}_e \quad (5)$$

where $\boldsymbol{f_e}$ is total domestic emissions embodied in total exports $\boldsymbol{y_e}$.

There are different methods to treat the emissions embodied in trade depending on how intermediate imports are dealt with (Peters, 2008). In this paper we consider total exports (and imports) from China, thus the exports include both intermediate and final demand. If a global model is used, it is possible to consider trade in exports to final demand only. Both approaches are correct, but they do answer different questions. For Chinese policy at the national level, it is most relevant to analyze the total emissions in China regardless if they are exports for final consumers or as inputs into foreign industries. If one wants to analyze the global emissions to produce different products – such as in life-cycle assessment – then trade in intermediate products must be allocated differently.

In addition to this standard method, IOA usually requires some degree of country-specific manipulations depending on data availability.

2.3 Normalization

We follow standard procedures for normalization of the monetary IO table and the energy and emissions data,

$$\boldsymbol{A} = \boldsymbol{Z}\,\hat{\boldsymbol{x}}_{total}^{\boldsymbol{-1}} \quad (6)$$

where $\boldsymbol{A}$ is the inter-industry requirements matrix which represents the technology of the Chinese economy and ^ represents diagonalization. Because the energy data is more aggregated than the IOTs, it is necessary to map between the IO sectors and the energy sectors for each year. To normalize the total energy and emissions data, $\boldsymbol{T}$**,** we first aggregate the output to the sector classification used in the energy and emissions data and then normalize before disaggregating back to the IOT aggregation,

$$\boldsymbol{F} = \boldsymbol{T}\left(\boldsymbol{P}\boldsymbol{x}_{total}\right)^{-1}\boldsymbol{P} \tag{7}$$

where $\boldsymbol{P}$ represents the mapping between IO sectors and energy sector, constructed from the sector descriptions of the IOT and energy data. This procedure assumes that all IO sectors that map to the one energy sector have the same emission intensity. Since the IOT and energy intensities now have the same industry classification, we can perform the calculation for each year, as shown above in equation 5.

2.4 Approximation of Regional Responsibility

Since IOTs do not include information about the country of destination for exports, additional data were needed. This analysis was based on a previous study by one of the authors (GP) using the GTAP database (Peters and Hertwich, 2008a). Their methodology is similar as described in this paper, except that Peters and Hertwich (2008a) cover 87 countries and regions at a 57 sector resolution for a single year, 2001. The calculation done here is extended by including the bilateral time series from 1987-2002 from the GTAP database. The time series has some discontinuities in the early 1990's resulting from the break-up of the Former Soviet Union and different sector classifications in GTAP over time. Since the trade data is in current prices we consider trade shares, which assumes similar inflationary effects and efficiency improvements between countries and sectors over time. While this assumption does not hold in reality (IEA, 2007), it is satisfactory for the approximation of responsibility over the time investigated in this paper. The GTAP trade data only extended to 2002.

For 2005 the destination of the emissions embodied in China's exports was approximated based on Chinese export data (total exports by country of destination) from the China Statistical Yearbook 2007 (National Bureau of Statistics, 2007b). Data for the years 2000, 2001, and 2002 were averaged to obtain approximate carbon intensities of total exports to each region; i.e., CO_2/yuan, which were then used for linear interpolation of embodied carbon in exports for 2003-2005 using total exports (data for 2000-2002 were rather similar in all regions, justifying the assumption that these carbon intensities would hold through to 2005, Table 1). For example, from 2000-2002, exports to the US were seen as relatively more carbon intensive than exports to the rest of the world. These relative factors from Table 1 were then used in combination with total exports to each region, Table 2, to approximate embodied CO_2 exported to each region in 2003-2005.

Table 1

Table 2

2.5 Data Sources

2.5.1 Input-Output Tables

We employed China's input-output tables (IOT) from Li and Xue (1998) for 1987, 1990 and 1995 with 30 sectors in constant 1990 prices. We obtained the input-output tables from the Chinese National Bureau of Statistics (NBS) for 1992 with 118 sectors (National Bureau of Statistics, 1996), 1997 with 124 sectors (National Bureau of Statistics, 1999), 2002 with 122 sectors (National Bureau of Statistics, 2006), and 2005 with 42 sectors (National Bureau of Statistics, 2007a), all at current prices. All the tables have the same final demand categories: household consumption, government expenditures, capitals investments, exports, imports, and "others". "Others" represents a balance specific to the Chinese IOT and was removed from the IOT (Peters et al., 2007, Supporting Information).

2.5.2 Energy and Emissions data

The CO_2 by industry sector for 1992, 1997, and 2002 were constructed in previous work by two of the authors (GP and CW) , and data for all other years were calculated using the same method (see Peters et al., 2006 for details). The emissions include both the combustion of fuels and industrial processes and were constructed using official Chinese energy statistics and the IPCC reference approach (IPCC, 1996). The energy and emissions data have 36 industry sectors.

3 Results

Fig. 1 shows a breakdown of China's CO_2 emissions from 1987 to 2005 into the four driving forces of GDP: household consumption, capital investment, government expenditure, and exports. Since imports have already been subtracted from production functions (equation 4), the sum of these four components equals total domestic CO_2 emissions, as opposed to total CO_2 emissions embodied in consumption.

Fig 1

We find that in 2005, 33% (1,700 Mt) of China's domestic CO_2 emissions were in the production of exports and this has steadily increased from 12% (230 Mt) in 1987. Interestingly, these figures mirror very closely the rise of exports as a percentage of GDP, meaning that exports are on average no more or less carbon-intensive than domestic consumption and investment. To put this figure into perspective, China's export emissions in 2005 (1,700 Mt) were similar to the combined emissions of Germany, France, and the UK (1850 Mt) (EIA, 2007).

A rise in exported CO_2, from only 21% (759 Mt) of domestic emissions, has occurred since 2002, mirroring both the overall steep increase in China's CO_2 emissions (keeping in mind potential undercounting in 2002) and the large increase in exports over this period, from 22% of GDP in 2002 to 33% in 2005. In most years the growth rate of the emissions from the production of exports is greater than the growth rate of total emissions, showing the particular importance of exports to China's growth in CO_2 emissions.

It is useful to breakdown the Chinese export emissions by commodity. Figure 2 shows a breakdown of the growth in these emissions by major commodity groups that China exports. Recently (in 2005), substantial fractions of total emissions were due to exports of electronics (22% of total), metal products (13%), textiles (11%), and chemical products (10%). It is clear that the large recent growth in export emissions is increasingly due to advanced products, much more so than previously, as the 1995 breakdown of export emissions was substantially different: 19% textiles, 13% electronics, 12% machinery, and 10% chemicals, and 7% metal products. Emissions embodied in primary product exports (including here: all mining, raw timber, raw chemicals, and basic metals) have decreased from around 20-24% in the early years of the analysis (1987-1992) to only 13% in 2002-2005 as the Chinese economy has developed into producing higher value-added items.

China also is a large importer and avoids domestic emissions by importing raw materials as well as final goods and services. The method utilized here (single-region EIOA) can be used to estimate the CO_2 emissions which would have occurred in China had all Chinese imports been made domestically (typically called "emissions avoided by imports", EAI). Table 4 shows this quantity, in million tonnes of CO_2 (Tg CO_2), as well as total Chinese emissions (total) and emissions embodied in exports (EEE) for comparison.

Clearly, China avoids large amounts of emissions through its imports; in every year the avoided emissions are higher than the exported emissions. However, EAI is a biased measure for China, since China's carbon intensity is significantly higher than most

(Peters and Hertwich, 2008a; Peters et al., 2007). A better estimate of emissions embodied in imports can be calculated using a global model (usually limited to a single year), but this is beyond the scope of this paper. Peters and Hertwich estimated the emissions embodied in Chinese trade using a global model and found that 216 Mt of CO_2 was embodied in Chinese imports in 2001. This compares to 1170 Mt avoided by imports in 2002 estimated in this paper.

Table 3

The current focus on China mirrors the importance of trade in the environmental profile of many other countries. For example, in 2001, 22% of global CO_2 emissions were in the production of exports (Peters and Hertwich, 2008a). Countries vary widely in their relative shares of CO_2 in trade; most European countries have a high share of their domestic emissions in the production of exports (20-50%), the USA had 8%, Japan 15%, India 13%, South Korea 28%, and South Africa 45% (Peters and Hertwich, 2008a). A key explanatory variable for the share of emissions in the production of exports is size – in general, small countries have larger shares while large, and thus relatively self-sufficient, countries have lower shares. China does not fall into this categorization as it is a large country with a large share of exports. China’s exports thus play a more important role in its environmental profile compared to other countries.

A key question is whether the rapid growth of exports in China – or any other country – is at the expense of production in developed countries, loosely termed by many as "carbon leakage" (Metz et al., 2007) or the "pollution haven hypothesis (PHH)" (Rothman, 1998). The IPCC has placed low importance on carbon leakage since its definition of leakage only considers marginal emission changes in non-Annex I countries resulting *explicitly from climate policy* within Annex I countries (Peters and Hertwich, 2008b). It is unlikely that China's increased export emissions are due to current climate policy in Annex I countries; they are simply a byproduct of China's other advantages for production such as lower environmental standards and lower labor costs. Using the IPCC definition one would expect to find low levels of carbon leakage, and thus, the problem has been defined away. But the issue does remain: increased consumption in Annex I countries is met by expanded production in non-Annex I countries (Peters and Hertwich, 2008a; Rothman, 1998; Weber and Matthews, 2007). A stronger definition of carbon leakage considers increases in emissions in non-Annex I countries that might occur for reasons other than climate policy in Annex I countries. It is this latter type of "carbon leakage" that lies at the core of China's increased export emissions.

Indeed, large portions of recent Chinese export emissions go to the developed world, with approximately 27% to the US, 19% to the EU-27, and 14% to the remaining Annex B countries, mainly Japan, Australia, and New Zealand (Figure 3). While approximately 40% of China's export emissions go to the non-Annex B developing world, these flows are still important because Chinese exports to developing countries may displace either domestic production there or production from another trading partner which would have released less CO_2 for the same amount of products.

Fig. 3

This is because relative to production in most other countries, Chinese production is more polluting, due both to inefficient production systems and a coal-dominated electricity supply (Peters and Hertwich, 2008a; Peters et al., 2007; Weber and Matthews, 2007). The low-cost of Chinese production does benefit most consumers, but this benefit comes at the detriment of both the local Chinese environment (Streets et al., 2006) and the global environment due to the effects of climate change. Cheap production in China could be globally beneficial in terms of the environment as well, though, particularly in driving down the costs of environmental products like energy-efficient lighting or wind turbines. Any increased emissions from production of these products in China would likely be outweighed by the positive impacts of their use (see for example (Lenzen and Munksgaard, 2002)). Unfortunately, this potential benefit of cheap Chinese production has not yet materialized.

Recently, China reacted to both the increasing pollution caused by the production of exports and fears of resource security by raising export taxes on certain products (Ministry of Finance People's Republic of China, 2007). These export taxes were placed mostly on primary products such as raw metals and chemicals. However, as previously shown above, these products represent a small fraction of the emissions from China's exports—approximately 13% in 2005, even if all chemicals are included in this category (see fig. 2).

A more effective approach would use monetary or tax policy to discourage large-volume export commodities such as electronics (22% of exported CO_2 in 2005), machinery (19%), metal products (13%), and textiles (11%). However, since these higher value-added products contribute more to China's economic growth than primary products, this approach would lead to both higher costs to the Chinese economy through loss in competitiveness, as well as costs to consuming countries through increasing inflation. Thus, it is unlikely in the short term. However, over the longer term it is in the interest of both Western countries and China to lower the energy and carbon intensity of its production practices, as the advantages of producing in China are immense. Perhaps, then, cooperation on low-carbon research and development is the best avenue forward from both sides.

4 Uncertainties

While the results clearly show the importance and scale of the issue of Chinese exports and climate change, it is important to stress the many uncertainties in calculating and allocating such emissions (Weber and Matthews, 2007). Input-output analysis itself has many inherent uncertainties related to the calculation and balancing of the actual tables (which are outside the hands of IO practitioners), aggregation of unlike products into economic sectors, the assumption of proportionality and linearity, and many others (see Lenzen, 2001 for a detailed discussion). The "imports assumption" is particularly important here, as single region IOA is not able to correctly calculate the emissions embodied in China's imports, only emissions avoided by importing.

The method's inherent limitations are compounded with large data uncertainties in both economic and particularly energy data. For example, several authors have questioned the legitimacy of the official Chinese energy statistics for certain years, especially from around 1996 to 2004 (Sinton, 2001; Streets et al., 2001; Wu, 2007). During this period, Chinese coal consumption first declined and then rose precipitously, creating substantial variation in the energy intensity of the economy. There is still significant controversy over whether the 1996-2000 decline in energy intensity was real or a factor of under-reporting to data collection agencies (Peters et al., 2007), though recent satellite data seems to suggest some level of under-reporting (Akimoto et al., 2006). We utilize the raw data from the Chinese statistical agencies despite these issues (though we use data revised for the third time after release, such as using data released in 2005 for year 2002), though we note that this may cause an underestimation of China's export emissions in 2000 and 2002.

Thus, in the face of such large uncertainties in both method and data, the calculated emissions embodied in exports must be regarded as approximate. However, the scale and trend of the numbers are unlikely to be affected extremely in any one direction by these uncertainties, with the exception of the potential underestimation of coal consumption in 2000 and 2002.

5 Discussion: Who is responsible for China's emissions?

It is clear Chinese exports are currently responsible for large amounts of greenhouse gas emissions; our estimate for 2005 (1700 Mt CO_2) represents 6% of global CO2 emissions from fossil fuels (EIA, 2007). This staggering statistic begs the question of who should be responsible for the emissions resulting from the production of China's exports (Munksgaard and Pedersen, 2001). There are, of course, many arguments from both sides of the issue.

On the one hand, while China's economic development benefits from export growth, so do the consumers in developed countries, and it can be argued that they should be held at least somewhat responsible for emissions occurring because of their demand for low-priced goods. If these consumers were to become partially responsible for China's export emissions (Peters, 2008), perhaps China would be more willing to play an active role in post-Kyoto climate commitments. In general, recognizing the role the international trade plays in greenhouse gas emissions may open new opportunities, and is possibly a precondition for political agreement (Peters and Hertwich, 2008a).

However, if others become responsible for China's export emissions, then who is responsible for China's imported carbon emissions? China itself imports many products, including many components of the final products it exports, and it avoids greenhouse gas emissions by doing so. As shown above, in all years analyzed, no matter how they are counted the total emissions embodied in China's imports are substantial, and if China does not want to be held responsible for its exported emissions, it must be held at least responsible for what it imports.

Although one-third of China's CO_2 emissions result from the production of exports, it is important to keep track of the remaining two-thirds of emissions. Capital expenditure necessary for building up infrastructure and production capacities has been responsible for between 32-37% of China's CO_2 emissions since 1987 (see above Fig. 1). Of course, at least part of these emissions could be indirectly attributed to exports because much of the infrastructure improvements occurring are for export production. However, data were not available to allocate China's capital expenditures by different sectors to domestic or export markets.

The importance of exports and capital goods can also be shown by the fact that household consumption is responsible for a decreasing portion of emissions, from 45% in 1987 down to 28% in 2005. This drop in household consumption's share in total emissions mirrors the overall drop in private consumption share in China, possibly due to high savings rates caused by peculiarities of the labour and market and social system (Modigliani and Cao, 2004) and especially due to low household incomes caused by an underdeveloped financial sector (Aziz and Cui, 2007). Nevertheless, household consumption is widely seen as the future driver of China's economy, and thus its future CO_2 emissions (Aziz and Cui, 2007; IEA, 2007).

Whoever is responsible for emissions to produce Chinese exports, inefficient and coal-dominated electricity production is at the core of China's CO_2 emissions, accounting for 44% of China's total emissions in 2005. It is clear that urgent improvements are needed in this sector. Increasing efficiencies, installing more renewable power, and overcoming the financial and technological hurdles involved with new technologies such as carbon capture and sequestration (CCS) should be the first priority of China and its export partners alike. Allowing Kyoto parties to count the incremental cost of CCS within the framework of the Clean Development Mechanism could be a crucial first step (de Coninck, 2008), as this would allow some of the importers of China's carbon-intensive goods to invest in lowering the carbon intensity of Chinese exports.

References

Ahmad, N., Wyckoff, A., 2003. A. Carbon dioxide emissions embodied in international trade of goods. Organisation for Economic Co-operation and Development. OECD, Paris.

Akimoto, H., Ohara, T., Kurokawa, J.-i., Horii, N., 2006. Verification of Energy Consumption in China during 1996-2003 by Using Satellite Observational Data. Atmospheric Environment, 40, 7663-7667.

Aziz, J., Cui, L., 2007. Explaining China's Low Consumption: The Neglected Role of Household Income. IMF Working Paper No. 07/181.

de Coninck, H., 2008. Trojan Horse or Horn of Plenty? Reflections on Allowing CCS in the CDM. Energy Policy, 36, 929-993.

EIA, 2007. International Energy Annual 2005. Energy Information Administration.

Gregg, J.S., Andres, R.J., Marland, G., 2008. China: Emissions pattern of the world leader in CO2 emissions from fossil fuel consumption and cement production. Geophysical Research Letters, 35, L08806.

IEA, 2007. World Energy Outlook 2007. International Energy Agency, Paris.
IPCC, 1996. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (3 volumes). Intergovernmental Panel on Climate Change.

Lenzen, M., 2001. Errors in Conventional and Input-Output based Life-Cycle Inventories. Journal of Industrial Ecology, 4, 127-148.

Lenzen, M., Munksgaard, J., 2002. Energy and CO2 life-cycle analyses of wind turbines - review and applications. Renewable Energy, 26, 339-362.

Leontief, W., 1986. Input-Output Economics, second ed. Oxford University Press, New York.

Leontief, W., Ford, D., 1972. Air pollution and the economic structure: empirical results of input-output computations, in: Brody, A., Carter, A.P. (Eds.), Input-Output Techniques. North Holland, Amsterdam, pp. 9-30.

Li, Q., Xue, T., 1998. Sectoral analysis of China's economic development: comparable input-output tables. China Statistics Press, Beijing.

McGregor, R., 2007. China takes stand on climate, Financial Times, Beijing.

Metz, B., Davidson, O., Bosch, P., Dave, R., Meyer, L. (Eds.), 2007. Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Miller, R.E., Blair, P.D., 1985. Input-Output Analysis: Foundations and Extensions. Prentice-Hall, Englewood Cliffs, New Jersey.

Ministry of Finance People's Republic of China, 2007. Announcement of further adjustment on custom tariff from January, 1st 2008, Beijing.

Modigliani, F., Cao, S., 2004. The Chinese Saving Puzzle and the Life-Cycle Hypothesis. Journal of Economic Literature, 42, 145-170.

Munksgaard, J., Pedersen, K.A., 2001. CO_2 accounts for open economies: Producer or consumer responsibility? Energy Policy 29, 327-334.

National Bureau of Statistics, 1996. 1992 Input-Output Table of China China Statistics Press, Beijing.

National Bureau of Statistics, 1999. 1997 Input-Output Table of China China Statistics Press, Beijing.

National Bureau of Statistics, 2006. 2002 Input-Output Table of China China Statistics Press, Beijing.

National Bureau of Statistics, 2007a. 2005 Input-Output Table of China China Statistics Press, Beijing.

National Bureau of Statistics, 2007b. China Statistical Yearbook 2007. China Statistical Press, Beijing.

National Development and Reform Commission, 2007. China's National Climate Change Programme. National Development and Reform Commission People's Republic of China.

Peters, G.P., 2008. From production-based to consumption-based national emission inventories. Ecological Economics, 65, 13-23.

Peters, G.P., Hertwich, E.G., 2008a. CO_2 Embodied in International Trade with Implications for Global Climate Policy. Environmental Science and Technology, 42, 1401-1407.

Peters, G.P., Hertwich, E.G., 2008b. Trading Kyoto Nature Reports Climate Change, 2, 40-41.

Peters, G.P., Weber, C., Liu, J., 2006. Construction of Chinese Energy and Emissions Inventory. Norwegian University of Science and Technology, Trondheim.

Peters, G.P., Weber, C.L., Guan, D., Hubacek, K., 2007. China's growing CO_2 emissions - a race between increasing consumption and efficiency gains. Environmental Science and Technology, 41, 5939-5944.

Rothman, D.S., 1998. Environmental Kuznets Curves-real progress or passing the buck? A case for consumption-based approaches. Ecological Economics, 25, 177-194.

Sinton, J.E., 2001. Accuracy and Reliability of China's Energy Statistics. China Economic Review, 12, 372-383.

Streets, D., Yu, C., Bergin, M., Wang, X., Carmichael, G., 2006. Modeling Study of Air Pollution Due to the Manufacture of Export Goods in China's Pearl River Delta Environmental Science and Technology, 40, 2099-2107.

Streets, D.G., Jiang, K., Hu, X., Sinton, J.E., Zhang, X.-Q., Xu, D., Jacobsen, M.Z., Hansen, J.E., 2001. Recent Reductions in China's Greenhouse Gas Emissions. Science, 294, 1835-1837.

United Nations, 1993. Handbook of National Accounting: Integrated Environmental and Economic Accounting. Studies in Methods, United Nations, New York.

United Nations, 1999. Handbook of input-output table compilation and analysis. Studies in Methods Series F, No 74. Handbook of National Accounting, United Nations, New York.

Wang, T., Watson, J., 2007. Who owns China's carbon emissions? Tyndall Centre for Climate Change Research, Sussex, United Kingdom.

Weber, C., Matthews, H.S., 2007. Embodied Environmental Emissions in U.S. International Trade 1997-2004. Environmental Science and Technology, 41, 4875-4881.

WRI, 2007. Climate Analysis Indicators Tool (CAIT) Version 5.0. World Resources Institute, Washington, DC.

Wu, C., 2007. Action plan aims to cut gas emissions, China Daily.

Table 1: Relative carbon intensity of exports to each region, 2000-2002, as % of embodied emissions/% value of trade. Annex B refers to the Annex B countries of the Kyoto Protocol.

	CO_2/yuan
United States	1.28
European Union (EU-27)	1.02
Economies in Transition	0.86
Rest of Annex B	0.90
Non-Annex B Countries	0.91

Table 2: Total export share to each region from 2003-2005 (see Figure 3 for country definitions).

	2003	2004	2005
US	0.21	0.21	0.21
EU27	0.18	0.18	0.19
EIT	0.02	0.02	0.02
Rest of B	0.17	0.16	0.15
Non-B	0.42	0.43	0.43

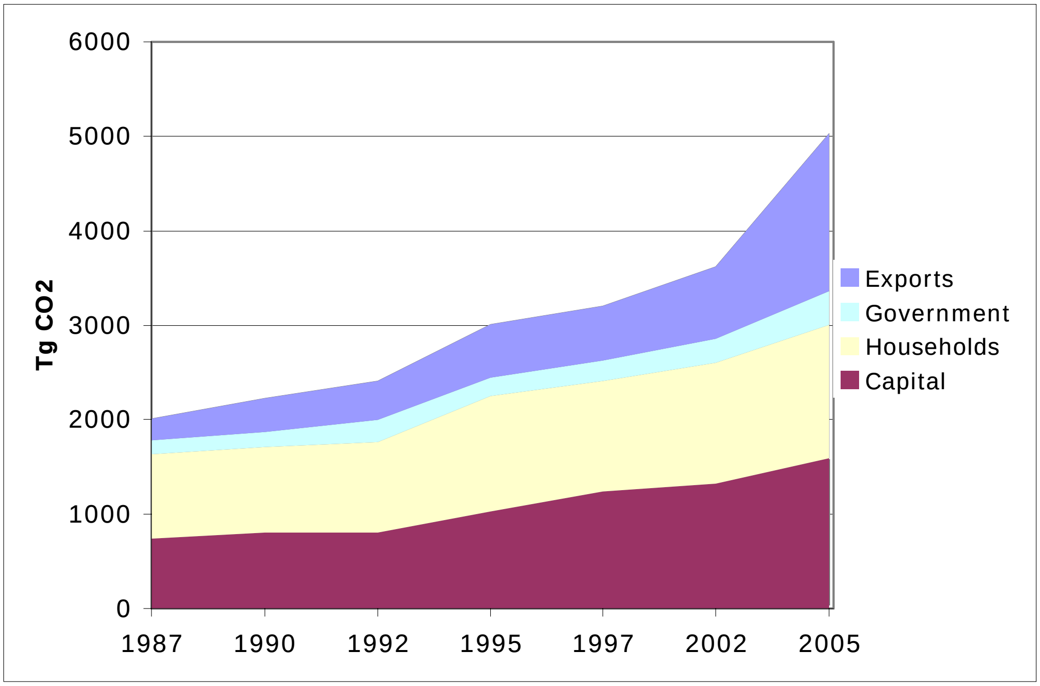

Fig. 1: China's total domestic CO2 emissions, divided by driving demand: exports, governmental consumption, household consumption, and capital investment.

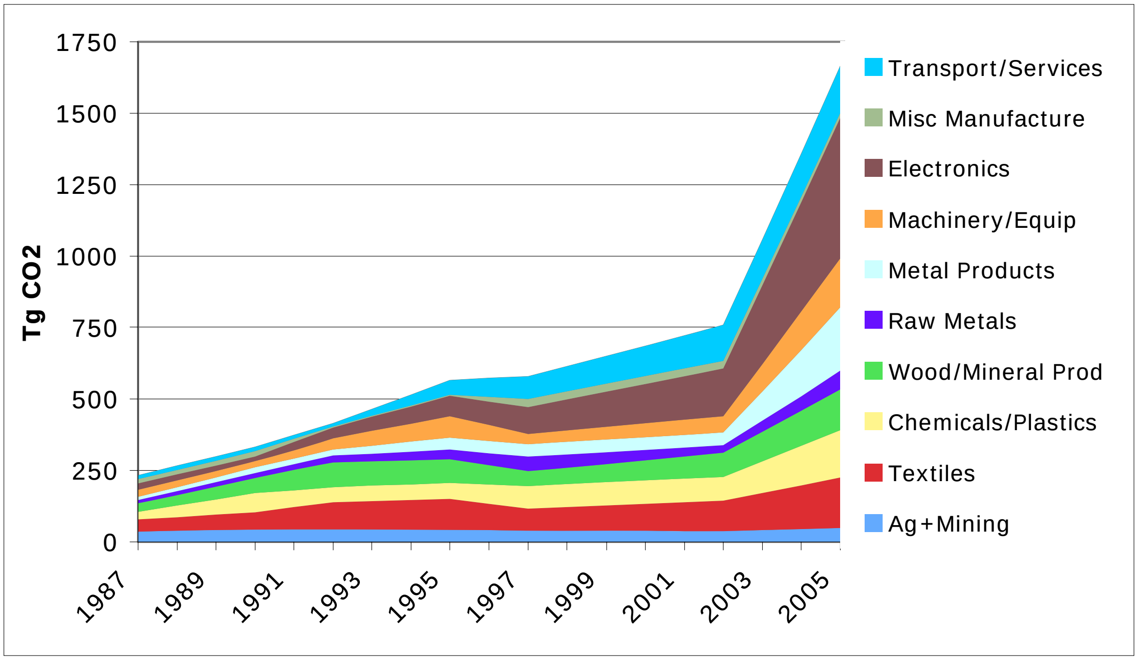

Figure 2: Chinese export emissions by major commodity group (Tg CO2).

Table 3: Total CO2 emissions, emissions embodied in exports (EEE), and emissions avoided by imports (EAI). All values in Tg CO_2. The emissions avoided by imports are different to the actual emissions embodied in imports (see text). *The actual emission embodied in imports for 2001 was estimated to be 216 Mt CO_2 (see text).

	1987	1990	1992	1995	1997	2002	2005
Total	2010	2230	2410	3010	3210	3620	5030
EEE	230	360	420	570	580	760	1670
EAI	390	420	560	710	700	1170*	2200

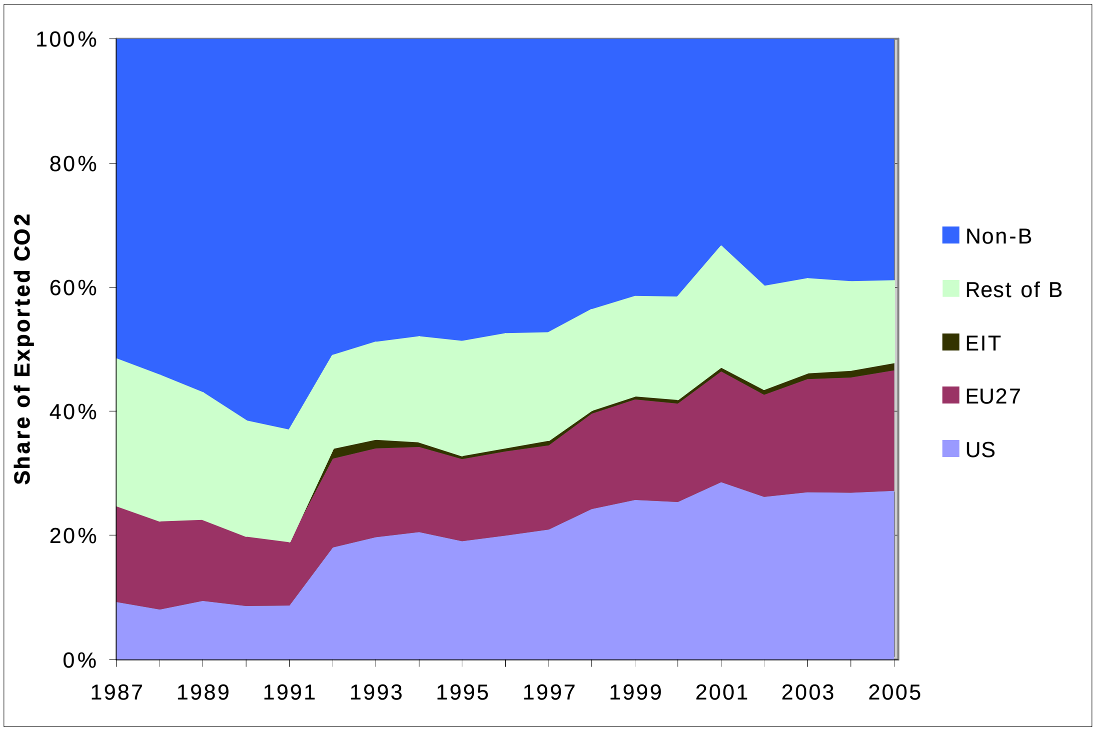

Figure 3: Region of destination for Chinese CO_2 emissions embodied in exports by year. EU27 does not include any economies in transition (EIT), and "Rest of B" represents all remaining Annex B countries which do not fall into another group. The dips and peaks represent changes in trade *shares*, even though growth continued. Annual variations can represent both realistic changes and also errors in the trade data. The dip in the early 1990's relates to political boundary changes and a merging of different datasets.