Energy Policy ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

CO_2 emissions from the transport of China's exported goods

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ARTICLE INFO

Article history:
Received 17 February 2010
Accepted 10 May 2010

Keywords:
Air transport
Shipping
Trade

ABSTRACT

Emissions of greenhouse gases in many European countries are declining, and the European Union (EU) believes it is on track in achieving emission reductions as agreed upon in the Kyoto Agreement and the EU's more ambitious post-Kyoto climate policy. However, a number of recent publications indicate that emission reductions may also have been achieved because production has been shifted to other countries, and in particular China. If a consumption perspective is applied, emissions in industrialized countries are substantially higher, and may not have declined at all. Significantly, emissions from transports are omitted in consumption-based calculations. As all trade involves transport, mostly by cargo ship, but also by air, transports add considerably to overall emissions growth incurred in production shifts. Consequently, this article studies the role of transports in creating emissions of CO_2, based on the example of exports from China. Results are discussed with regard to their implications for global emission reductions and post-Kyoto negotiations.

1. Introduction

The Kyoto protocol is designed to lead to global reductions in greenhouse gas (GHG) emissions, based on the principle of common but differentiated responsibilities, which foresees a considerable decline in emissions in developed countries (Annex I), while allowing for further growth in developing countries (non-Annex I, for details see UNFCCC, 2009a). The European Union (EU) is currently leading global efforts to curb emissions, and has pledged to reduce its emissions by 8% by 2012 and 20% by 2020, compared to the base year 1990 (Euractiv, 2009). If other industrialized countries make comparable contributions and if developing countries also engage in adequate reductions, the EU is committed to increase its emission reductions by another 10% by 2020 (UNFCCC, 2010a). The European Union has also called on important emerging economies, including China, India, and Brazil, to commit themselves to emission reduction targets similar to those of the industrialized countries (European Parliament, 2009). After the failure of the Conference of Parties (COP) 15 meeting in Copenhagen in December 2009, the United Nations Framework Convention on Climate Change (UNFCCC) opened up for voluntary post-Kyoto emission pledges. By January 31st, 55 countries had submitted national pledges to limit or reduce global GHG by 2020 (UNFCCC, 2010b), though many of these are conditional, and it is thus as yet unclear into what global emission reductions these will translate.

Even though commitments as currently submitted to UNFCCC have been criticized as not being far-reaching enough to lead to stabilization at 2 °C average global warming by 2100 (cf. Allison et al., 2009), i.e. the consensus goal of the COP-15, a number of unconditional pledges at between 5–10% (Belarus) and 30–40% (Norway) nevertheless represent considerable mitigation challenges (referring to emission reductions by 2020 compared to 1990; UNFCCC, 2010a). The European Union is so far the only region in the world that has already initiated a process to cut emissions through an emissions trading scheme (the EU ETS), which ran through its first trading period in 2005–2007, and is now running in its second trading period (2008–2012) with an EU-wide CO_2 cap set at 2.08 Gt for the entire trading period. Notably, the EU ETS covers industrial emissions from some 10 000 large industrial plants (Euractiv, 2009), but emissions from sectors including transport, buildings, agriculture, and waste are not covered. According to a 2006 report, the EU ETS delivered emission reduction in the order of 2% in 2005 over 1990 levels in the 15 EU member states originally signed up to Kyoto (Commission of the European Communities, 2006), but the UNFCCC (2009b) reported more recently that emissions from all Annex I Parties and emerging economies had increased by 3.1% in the

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doi:10.1016/j.enpol.2010.05.030

Please cite this article as: Andersen, O., et al., CO_2 emissions from the transport of China's exported goods. Energy Policy (2010), doi:10.1016/j.enpol.2010.05.030

period 2000–2007. Even though the European Community reduced emissions by −4.3% over the period 1990–2007, reductions in the period 2000–2007 were just −0.26%. Globally, CO_2 emissions from the burning of fossil fuels have increased by 41% between 1990 and 2008 (Le Quéré et al., 2009).

This raises several questions. First, have emissions in the European Union declined over the period 1990–2007 because of a process of dematerialization, i.e. reduced emissions per unit of production/consumption or are there other factors that explain the decline in emissions? And secondly, do statistics by UNFCCC (2009b) provide a comprehensive emissions picture, given that the Kyoto protocol does not include international aviation (under the International Civil Aviation Organization—ICAO) and shipping (under the International Maritime Organization—IMO)? These questions are investigated in more detail in this article with a focus on the role of Chinese trade in global emissions of CO_2.

2. Approaches to emission calculations

An increasing number of publications are concerned with the calculation of emissions and their allocation between countries. With regard to emissions associated with the production of certain goods or a sector, the argument has been made that parts of the life cycle of the goods are often ignored, leading to omission of a share of emissions associated with consumption of the goods. For instance, Hertwich and Peters (2009) point out that the IPCC (2007) discusses emissions associated with the production of transportation fuels on a well to wheel (WTW) basis. The production of motor vehicles is not considered in the calculation of transport-related emissions, even though this might have added as much as 800 Mt CO_2 equivalents (CO_2e) in 2001 (Hertwich and Peters, 2009: p. 6414). Another issue regards the allocation of emissions from a climate policy point of view: if a car is produced in Japan, and then exported to France, how should emissions be allocated, to Japan as the producing country, or France as the consuming country (for further discussion see e.g. Bastianoni et al., 2004; Munksgaard and Pedersen, 2001; Peters and Hertwich, 2006, 2008). Most relevant in the context of this article is eventually that given the current structure of the Kyoto Protocol, neither Japan nor France would be responsible for emissions caused by transport of the car from Japan to France, as both shipping and aviation are not part of the agreement. Clearly, these and other issues relating to the formulation of policies to reduce greenhouse gas emissions are of considerable relevance in ongoing discussions of post-Kyoto frameworks (Peters and Hertwich, 2008; Aall and Hille, 2010).

A number of recent studies have sought to quantify the magnitude of differences implied in production- versus consumption-based approaches to national emission inventories. For instance, a study by Li and Hewitt (2008) assessed the amount of CO_2 embodied in trade between the UK and China in 2004. They concluded that through trade with China, the UK "reduced" its emissions by approximately 11% in 2004, compared with a situation where the same type and volume of goods were produced in the UK. Less efficient production processes in China resulted in an additional 117 Mt of CO_2, corresponding to another 19% of national UK emissions (555 Mt CO_2 in 2004). A more recent study by Helm et al. (2007), which considered all trade between the UK and other countries, concluded that the UK may not have seen a 12.5% decline in national emissions in the period 1990–2005, rather than a 19% increase, when emissions embedded in international aviation, international shipping, and imports are considered. Notably, the UK appears to have reduced carbon intensive production (rather importing these goods), and increased low-carbon production: Helm et al. (2007) suggest that the UK imported 130 Mt CO_2e from China, at a greenhouse gas intensity of 4.140 t CO_2e/$m (year 2000 prices) in 2006, while exports totalled 4.2 Mt CO_2e in 2006, at an energy intensity of 458 t CO_2e/$m.

Similar figures have been found in other consumption-focused input–output analyses on embedded emissions, with for instance the Swedish Environmental Protection Agency estimating that consumption-related emissions in Sweden in 2003 were 33% higher than official UNFCCC figures (Naturvårdsverket, 2008). In the case of Denmark, Munksgaard et al. (2005) found that the Danish economy imported some 11 Mt CO_2 of shadow emissions, with imported emissions being 0.8 Mt CO_2 greater than those embedded in exports. These findings would be confirmed by data provided by the Worldwide Fund for Nature (WWF, 2008), which found that on a consumption basis, emissions in Denmark were 20% higher than in UNFCCC inventories. Imports accounted for about half of this. Yet another study of Norwegian emissions including shipping and aviation found that emissions embodied in production in Norway are in the order of more than 97 Mt CO_2e, but consumption-related emissions are in the order of less than half, about 43 Mt CO_2e (Aall and Hille, 2010). Norway's role as a high gross emitter can largely be explained with the country's large fleet of ships, which mostly run on behalf of other nations, causing emissions of 50 Mt CO_2e. Likewise, production of oil and gas for domestic purposes accounts for 13 Mt CO_2e, but the country's exports of oil and gas products cause emissions of more than 900 Mt CO_2e in other countries when these fossil fuels are burned. These examples indicate the relevance of allocation approaches distinguishing consumption and production, as these determine whether a country is growing or declining in emissions.

China has now turned into one of the leading producing and exporting countries in the world, and is – together with the USA – the biggest emitter of GHG (UNSD, 2009, see also Guan et al., 2009). Since 1990, emissions related to energy use in China have grown from 2.2 to 6.1 Gt CO_2 in 2007, 28% of this from industry (IEA, 2009, see also Guan et al., 2009). By 2020, emissions are expected to grow to 9.6 Gt CO_2 in the IEA Reference Scenario. Production for export is clearly an important factor in this growth. For instance, Shui and Harriss (2006) find that US emissions in the period 1997–2003 would have been 3–6% higher if goods imported from China had been produced in the US (not considering transports). Vice versa, 7–14% of China's emissions of CO_2 in 2003 were a result of producing exports for US consumers, corresponding to 720 Mt CO_2. Movements of production are reflected in China's emission growth, which is a result of increasing domestic consumption as well as production for export (RCSD and CASS, 2005). The Research Centre for Sustainable Development and the Chinese Academy of Social Sciences suggest that:

> China is becoming a major manufacturing base for the world. Since China is at the lower end of the international division of labour, the majority of the country's imports are high value-added products and services, while exports are mostly products from energy intensive manufacturing industries. As the intensity of embedded energy of its imports is generally lower than that of its exports it causes an international mismatch of energy demand [...]. Under such an import and export structure and given the expectation of inevitable growth in import and export volumes, it would be difficult to buck the trend of energy demand transfer from other countries to China in short and medium term.
>
> (RCSD and CASS, 2005: p. 15)

An analysis of flow of emissions through international trade suggests that emissions embodied in Chinese production are in

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the order of 3.3 Gt CO_2, while consumption in China corresponds to 2.7 Gt CO_2, resulting in a trade balance of 585 Mt CO_2 embodied and exported from China in 2001 (Peters and Hertwich, 2008). More generally, Peters and Hertwich (2008) conclude that emissions exceeding 5.3 Gt CO_2 are embodied in international trade among 87 major countries in 2001.

The above findings suggest that through trade, emissions are shifted in between countries, with in particular emission-intense production apparently being moved to emerging economies. Most important in the context of this paper, however, is that none of the publications on these issues have provided a detailed analysis of the role of transport in production/consumption-based comparisons of emissions, even though reference to transport is for instance made in Peters and Hertwich (2008) and Hertwich and Peters (2009). As all trade is dependent on transports, this article seeks to quantify actual emissions embedded in transports of goods produced in China.

3. Methodology and data

To define workable system boundaries, this article is limited to the transport of exported goods between China and receiving countries. No further transport within the importing countries after entry into port is included. Moreover, only sea and air transports are included, as rail transport is of negligible importance. Calculations were split into two sets, one for sea transport and one for air transport. These are explained stepwise in the following, with more detailed explanations being provided in subsequent sections.

3.1. *Sea transport*

Data for exports and imports of goods were derived from the statistics of the Chinese Ministry of Commerce (CMC, 2009). The data were allocated to main ship types after weight-based statistics had been converted to volumes, based on an assessment of goods mainly transported with bulk carriers and product tankers. Shares of the total exports/imports between different world regions were estimated based on statistics from the Ministry of Commerce (China) on export markets and the origin of imports. Based on the capacity of various ship types and a fixed load factor, the number of trips necessary to transport goods to/from each region/country was derived. The duration of journeys were then calculated based on average speed and distances, as a basis for calculation of tank to wheel (TTW) fuel use in a given year for all ship types, also considering their respective engine power, port-, manoeuvring-, and hauling times.

In the calculation of ship emissions, two approaches can be distinguished. The first calculates fuel consumption and related CO_2 emissions using a top-down approach based on aggregate level of fuel use. The second calculates emissions using an activity-based bottom-up approach. This method calculates fuel use and emissions directly, i.e. based on engine loads, together with information on sailing times and emission factors (cf. Maes et al., 2007). IMO (2008) concludes that activity-based estimates using detailed activity data (for different ship sizes and types) provide a better basis for projections of global fuel consumption and CO_2 emissions from international shipping than fuel statistics, due to an apparent under-reporting of marine bunker sales.

Emission factors and assumptions on fuel type are the same as applied in Whall et al. (2002). In this study, emission factors for five different engine types and three different fuel types were derived. This was repeated for three different activities: (i) “at sea” (or cruising), (ii) “in port” (includes time spent hotelling, loading, and unloading), and (iii) “manoeuvring”. The underlying sources connected to emissions factors were mostly based on Lloyds Register Engineering Services data and Swedish Environmental Research Institute (IVL). These data were combined by use of data from the Lloyd’s Marine Information Service (LMIS) database with information regarding the typical engine types used and fuel use by vessel category.

To calculate WTT emissions, the life cycle database ProBas (www.probas.umweltbundesamt.de) was used. This is a process-based database for materials, products, and energy chains. Calculations also consider the Chinese oil mix, based on the assumption that most oil is bunkered in China. Finally, indirect emissions are calculated on the basis of EcoInvent data for operation, production, and maintenance of the ships, as well as construction and operation of ports (Spielmann et al., 2007). The construction of ports is integrated over 100 years.

3.2. *Air transport*

Data for volumes of goods transported by air were derived from China Aviation Statistics and the General Administration of Civil Aviation of China. The calculation of TTW fuel use was based on average DEFRA (2008) factors for cargo flights as well as passenger flights also carrying cargo. Emission factors for “long-haul flights” and “short-haul flights” were applied for various world regions/countries that statistics of the Chinese Ministry of Commerce encompasses, i.e. “long-haul flights” include Europe, USA, Latin America, Canada, and Asia other than Southeast Asia, while “short-haul flights” include Japan, Korea, Southeast Asia, and the rest of the world (Table 10). WTT emissions of CO_2 were calculated based on ProBas for the Chinese jet fuel mix. Indirect emissions were calculated based on EcoInvent data for airports and intercontinental freight aircrafts.

3.2.1. *Allocation of commodities to ship type*

For sea transport export and import, volumes as provided by statistics from China’s Ministry of Commerce (2009) were used and allocated to amounts of imported/exported commodities by main ship type. Data from January to October 2008 were extrapolated to cover 12 months, i.e. the whole of 2008, based on January–October monthly averages. Table 1 shows different commodity categories of exported goods, their calculation basis, and extrapolated amounts in tonnes[1] for 2008, as well as main ship types assumed used for their transport. Imported volumes of goods and ship type are similarly shown in Table 2.

A calculation of CO_2 emissions solely based on weight of goods (in tonnes) for sea transport is likely to be misleading because a ship loaded with heavy goods is not consuming proportionally more fuel than a ship loaded with light goods, because in the latter case, more ballast water is used. For container ships the total number of containers handled in Chinese export and import harbours is used as the basis (UNCTAD, 2008: p. 92). For other ships, volume-based calculations are used, except for the two commodity types *crude oil* and *auto and chassis*. Crude oil is transported in dedicated tankers, where capacity in tonnes refers to one specific product only, and automobiles are mainly transported with dedicated roll-on/roll-off ships, with capacity in terms of car equivalent units (CEUs). For the other categories in Tables 1 and 2 it is thus necessary to convert from tonnes to m^3 to obtain volumes on goods transported at sea. The conversion is carried out based on assumptions shown in Table 3.

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[1] In this article we consistently use the metric unit *tonne* (equalling 1000 kg), instead of the imperial unit ton (equalling 2240 lb).

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Table 1
Main commodities exported from China in 2008.

Commodity	Volume Jan.–Oct.	Unit	Assumptions	Whole year (t)	Main ship type
Corn	21	10 000 t	–	252 000	Bulk carrier
Coal	3828	10 000 t	–	45 900 000	Bulk carrier
Crude oil	310	10 000 t	–	3 720 000	Crude oil tanker
Finished oil	1376	10 000 t	–	16 512 000	Products tanker
Cotton yarns	49	10 000 t	–	588 000	Container ship
Cotton woven fabrics	682 408	10 000 m	1 m wide and 0.2 kg/m^2 (TYTC 2004)	1 637 779	Container ship
Plastics	604	10 000 t	–	7 248 000	Container ship
Footwear	686 818	10 000 pairs	0.7 kg/pair (UNSHOD 2002)	5 769 271	Container ship
Steel	5312	10 000 t	–	63 744 000	Container ship
Video recorders	14 780	10 000 sets	5 kg/set	886 800	Container ship
TV sets	4390	10 000 sets	9 kg/set	474 120	Container ship
Cameras	10 639	10 000 cameras	0.3 kg/camera	38 300	Container ship
Computers and parts	121 306	10 000 sets	5 kg/set	7 278 360	Container ship
Wireless telephones and accessories	44 310	10 000 sets	0.3 kg/set	159 516	Container ship
Motor vehicles (other than autos)	1041	10 000 vehicles	Mainly light 2-wheelers, 150 kg/vehicle	1 873 800	Container ship
Bicycles	4982	10 000 bicycles	15 kg/bicycle	896 760	Container ship
Cars and chassis	58	10 000 cars	1000 kg/car	696 000	Roll-on/roll-off ship
			Total	**157 674 707**	

Table 2
Main commodities imported to China in 2008.

Commodity	Volume Jan.–Oct.	Unit	Assumptions	Whole year (t)	Main ship type
Cereal and flour	136	10 000 t	–	1 632 000	Bulk carrier
Soybean	3082	10 000 t	–	36 984 000	Bulk carrier
Edible vegetable oil	656	10 000 t	–	7 872 000	Container ship
Rubber (natural+synthetic)	254	10 000 t	–	3 048 000	Container ship
Pulp	826	10 000 t	–	9 912 000	Container ship
Iron ore	37 669	10 000 t	–	452 028 000	Bulk carrier
Aluminium oxide	377	10 000 t	–	4 524 000	Bulk carrier
Crude oil	15 115	10 000 t	–	181 380 000	Crude oil tanker
Finished oil	3328	10 000 t	–	39 936 000	Products tanker
Plastics	1513	10 000 t	–	18 156 000	Container ship
Paper and chipboard	306	10 000 t	–	3 672 000	Container ship
Steel	1347	10 000 t	–	16 164 000	Container ship
Unwrought copper and copper product	213	10 000 t	–	2 556 000	Container ship
Unwrought aluminium and aluminium product	76	10 000 t	–	912 000	Container ship
Computers and parts	45 598	10 000 sets	5 kg/set	2 735 880	Container ship
Wireless telephones and accessories	1625	10 000 sets	0.3 kg/set	5850	Container ship
Cars and chassis	34	10 000 cars	1000 kg/car	408 000	Roll-on/Roll-off ship
			Total	**781 925 730**	

3.2.2. *Regional shares of export and import*

Regional shares of export and imports are based on monetary value statistics by China's Ministry of Commerce. This encompasses statistics on export markets[2] and import sources,[3] supplemented with more detailed shares between countries[4] (Table 4).

3.2.3. *Assumptions on number of containers shipped*

Export and import figures provided by CMC are total figures, including goods that are transported by aeroplanes. To obtain net figures for container transport, amounts transported by air were therefore subtracted. Data provided by UNCTAD (2008: p. 92) on the number of 20-ft equivalent units (TEU)[5] handled at Chinese ports were used as the basis for calculation of the number of trips made by container ships. Estimated combined export and import were 139.1 million TEU in 2007. According to the statistics of Customs, China's total import and export between January and November 2008 amounted to US$ 2 378 billion, up 20.9% on a year-to-year basis. Of this, export was US$ 1317 billion and import US$ 1061 billion, up 19.3% and 22.8%, respectively (China Statistics, 2008). Based on this, 20% growth between 2007 and 2008 is assumed. This results in 166.9 million TEU in 2008. The calculated import share, derived from Table 2 above, is subtracted from the total to estimate exports.

3.2.4. *Assumptions on sea distances*

Average trip lengths are calculated from CSGN (2010). The calculation basis and distances are shown in Table 5.

Assumptions on average capacities of ships in operation from/to China are shown in Table 6. Capacities are adjusted for average annual utilization rates (IMO, 2008: p. 91) for various ship types.

Table 7 shows main engine (ME) and auxiliary engine (AE) power of the ships, as used in the calculations. Data for the ME are the average values of the relevant ship types in IMO (2008: p. 30–31). AE values are calculated on the basis of average

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[2] Export Markets by Continents/Regions (2008/01–10) http://english.mofcom.gov.cn/aarticle/statistic/ie/200901/20090105999738.html. Accessed 14 February 2010.

[3] Import Sources by Continents/Regions (2008/01–10) http://english.mofcom.gov.cn/column/print.shtml?/statistic/ie/200901/20090105999742. Accessed 14 February 2010.

[4] http://english.mofcom.gov.cn/table/200810statistics.doc. Accessed 14 February 2010.

[5] One TEU represents cargo capacity of a standard container 20 ft long, 8 ft wide, and 8 ft high.

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Table 3
Assumptions made in weight to volume conversion.

Commodity	Specific gravity (tonnes/m^3)	Basis/reference
Corn	0.72	The value for both "corn, ground" and "corn, on the cob" in Reade (2006) http://www.reade.com/Particle_Briefings/spec_gra2.html#
Coal	0.83	The specific gravity of "Coal, Bituminous, broken" (ibid.) http://www.reade.com/Particle_Briefings/spec_gra2.html#C
Finished oil	0.88	The specific gravity of "Oil, petroleum" (ibid.) http://www.reade.com/Particle_Briefings/spec_gra2.html#O
Cereal and flour	0.59	The value for "Flour, wheat" (ibid.) http://www.reade.com/Particle_Briefings/spec_gra2.html#F
Soybean	0.75	The value for "Soybeans, whole" (ibid.) http://www.reade.com/Particle_Briefings/spec_gra2.html#S
Iron ore	5.05	The average value for hematite in Mechanical Engineering Dictionary (MED) (2006).
Aluminum oxide	1.52	"Weight Per Cubic Foot And Specific Gravity" in Reade (2006) http://www.reade.com/Particle_Briefings/spec_gra2.html#A.

Table 4
Regional shares of China's export and import.

World region/country	Export (%)	Import (%)
Europe	24.0	14.6
USA	17.7	7.0
Latin America	5.1	6.4
Canada[a]	1.5	1.1
Japan	8.0	13.2
Korea	5.3	10.0
Southeast Asia[b]	8.0	10.4
Asia rest[c]	25.1	28.7
Rest[d]	5.3	8.6
Sum	100.0	100.0

[a] After subtracting the USA percentage in the statistics from the North America percentage.

[b] Statistics category ASEAN (Association of Southeast Asian Nations), comprises Indonesia, Malaysia, the Philippines, Singapore, Thailand, Brunei, Cambodia, Laos, Myanmar, and Vietnam.

[c] After subtracting the percentage for ASEAN, Korea, and Japan from the Asia percentage.

[d] Mainly Oceania and Africa.

Table 5
Average voyage length from/to China.

World region/country	Calculation basis	Length (km)
Europe	A distance of 11 000 nautical miles between Japan and Europe (source: personal communication with cargo handler) minus the distance Osaka–Shanghai	19 000
USA	Shanghai–San Francisco	10 000
Latin America	Shanghai–Lima	17 000
Canada	Shanghai–Vancouver	9 000
Japan	Osaka–Shanghai	1 200
Korea	Seoul–Shanghai	800
Southeast Asia	Shanghai–Singapore	3 700
Asia rest	Hong Kong amounts to 15–17% of total export, or above 60% of the category "Asia rest", justifying a low average distance	2 000
Rest	An estimate based on average distances China–Africa and China–Australia	9 000

percentage of ME power (ibid.), using the ratio of main to auxiliary installed engine power derived from Maes et al. (2007: p. 55).

Assumptions made on average speed are derived from Maes et al. (2007: p. 54). Calculations also include emissions from port time, manoeuvring, and hauling, based on estimates for Belgium (ibid.). ME and AE do not always run at full load. A load factor is applied to adjust for this (Table 8).

Average correction factors from Maes et al. (2007) are included to compensate for the loss of efficiency when operating engines at lower than optimal load. For ME this is 0.92, while a factor of 0.88 is used for AE. CO_2 emission factors were derived from Maes et al. (2007, Table 9).

3.2.5. *Assumptions on air transport*

Calculations of amounts of goods transported from/to China by air are based on a ratio of 2:1 of export to import at the largest Chinese airport handling cargo, Shanghai Pudong International Airport (PACTL, 2009), in 2008. This ratio is applied to all Chinese international air cargo. International cargo throughput was based on China Aviation Statistics for 2007. In total, air transport of international goods to and from Chinese airports amounted to 133.7 billion tkm in 2007, according to General Administration of Civil Aviation of China.[6] In 2008, the number of tkm was 5% lower at 127 billion tkm. There has thus been a decrease in air transport even though total imports and exports have increased by 20%.

For calculation of CO_2 emissions for air transport of goods, updated 2008 factors from DEFRA (2008) were used. These factors are average for dedicated cargo flights and passenger flights, which also carry cargo. Table 10 shows factors by world region/country.

3.2.6. *Assumptions on gross direct emissions*

The above sections focused on the calculation of emissions of CO_2 from TTW energy use. Emissions connected to the production and distribution of these fuels need to be added to obtain WTW emissions.

3.2.7. *Well to tank emissions from sea transport*

For sea transport, ProBas was used to derive WTT emissions. Assuming that a major share of bunker fuels is tanked in China, a specific estimate becomes necessary. This is done by applying the known raw oil mix, consisting of import mix and domestic oil production in China. China's imported oil comes from two major sources, including OPEC countries accounting for 63% and Russia, accounting for 8% (period January–June 2008). Sudan, Oman, and Yemen are assumed to have similar exploration and production patterns as OPEC countries, accounting for 25.1%. Kazakhstan, accounting for 2.7% of imports, is assumed to have similar production patterns as Russia.[7] Overall, a 90% share of imported OPEC oil and a 10% share of Russian oil are assumed.

ProBas contains an estimate for raw oil delivered to pipeline for raw oil from OPEC countries and Russia. These estimates include energy requirements and emissions to air for producing

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[6] http://www.caac.gov.cn/English/Data/200709/t20070928_8227.html. Accessed 09 February 2010.

[7] http://www.chinaoilweb.com/UploadFile/docs/Attachment/2009-9-2767140777.pdf. Accessed 09 February 2010.

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Table 6
Average capacities of ships used from/to China.

World region/country	Container ship (TEU)	Bulk carrier[a] (m^3)	Roll-on/roll-off ship (CEU)	Crude oil tanker (t)	Products tanker (m^3)
Europe	7000	147 550	5600	141 714	72 215
USA	7000	147 550	5600	141 714	72 215
Latin America	7000	147 550	5600	141 714	72 215
Canada	7000	147 550	5600	141 714	72 215
Japan	2800	32 175	1750	49 633	10 725
Korea	2800	32 175	1750	49 633	5005
Southeast Asia	1750	18 590	1750	18 543	1287
Asia rest	1750	18 590	1750	31 805	5005
Rest	4550	52 910	5600	49 633	28 600

[a] Based on the estimate that 1 t equals 40 ft^3. http://www.answers.com/topic/long-ton. Accessed 14 February 2010.

Table 7
Engine power of ships sailing from/to China (kW).

World region/country	Container ship		Bulk carrier		Roll-on/roll-off ship		Crude oil tanker		Products tanker	
	ME	AE	ME	AE	ME	AE	ME	AE	ME	AE
Europe	68 477	13 695	17 224	3789	13 137	2890	24 610	5906	12 644	4805
USA	68 477	13 695	17 224	3789	13 137	2890	24 610	5906	12 644	4805
Latin America	68 477	13 695	17 224	3789	13 137	2890	24 610	5906	12 644	4805
Canada	68 477	13 695	17 224	3789	13 137	2890	24 610	5906	12 644	4805
Japan	34 934	6987	8209	1806	7971	1754	12 726	3054	4640	1763
Korea	34 934	6987	8209	1806	7971	1754	12 726	3054	2691	1023
Southeast Asia	21 462	4292	6436	1416	7971	1754	7889	1893	1320	392
Asia rest	21 462	4292	6436	1416	7971	1754	10 529	2527	2691	1023
Rest	55 681	11 136	9912	2181	13 137	2890	12 726	3054	8482	3223

Table 8
Average speed, port time, time used for manoeuvring and hauling, engine load factors, and correction factors.

Factors	Container ship	Bulk carrier	Roll-on/roll-off ship	Crude oil tanker	Products tanker
Speed (km/h)	37.0	26.2	30.9	25.9	26.9
Lay time (h)	19.5	86.5	16.8	30.0	55.7
Time used for manoeuvring and hauling (h)	0.6	1.1	2.3	1.0	2.7
ME load at port (%)	0	0	0	20	0
AE load at port (%)	20	10	70	60	60
ME load during manoeuvring and hauling (%)	20	20	20	20	20
AE load during manoeuvring and hauling (%)	60	40	40	40	40
ME load during cruising (%)	80	80	80	80	80
AE load during cruising (%)	50	30	30	30	30

Table 9
CO_2 emission factors for ships (g CO_2/kWh).

Operation modes	Container ship	Bulk carrier	Roll-on/Roll-off ship	Crude oil tanker	Products tanker
At port	710	706	723	754	710
During manoeuvring and hauling	696	688	724	754	710
During cruising	631	624	659	689	645

1 TJ of energy from raw oil (in 2000). By weighing these two raw oil inputs together, an estimate for the Chinese oil import mix can be derived. In addition, domestic Chinese oil production needs to be considered. ProBas contains an estimate for Chinese heavy oil products from refinery, based on domestic oil production. The estimate is for the year 1995. Chinese domestic production is assumed to make up 95% of imported oil.[8] This can be used to calculate the Chinese domestic raw oil to import mix ratio. To complete the estimate, an identical energy requirement relative to raw oil as for Chinese heavy oil products is assumed, which is exclusively based on domestic oil production.

Consequently, it requires 1508 TJ of energy to produce 1 TJ of energy in heavy oil products in China, resulting in an energy efficiency of 66.3%. Total emissions of CO_2 for the same energy amount are estimated to be 30.2 t. Since 27 027 l fuel goes into 1 TJ of energy from heavy oil products, this gives an energy requirement of 55.8 MJ/l with WTT emissions of 1.12 kg CO_2/l of bunker oil.

3.2.8. *Well to tank emissions from air transport*

Assumptions on the oil mix as detailed above are identical for aviation bunkers. Producing 1 TJ of energy in jet fuel requires

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[8] http://www.reuters.com/article/pressRelease/idUS59261+21-Sep-2009+PRN20090921. Accessed 09 February 2010.

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Table 10
CO_2 emission factors for air transport.

World region/country	Emissions (kg CO_2/tkm)
Europe	0.61
USA	0.61
Latin America	0.61
Canada	0.61
Japan	1.32
Korea	1.32
Southeast Asia	1.32
Asia rest	0.61
Rest	1.32

Table 11
Tank to wheel emissions of CO_2 from transport of China's exported, imported, and net exported goods in 2008 (million tonnes).

Transport type	Export	Import	Net export
Container ship	120.88	70.22	50.66
Bulk carriers	1.48	3.52	−2.04
R/O ships	0.27	0.13	0.14
Crude oil tanker	0.17	7.93	−7.75
Products tanker	0.81	1.93	−1.13
Air transport	67.71	38.51	29.19
Total	**191.32**	**122.24**	**69.08**

about 0.37 TJ more energy (21.2%) in China than producing the same quantity in Germany. This is because Chinese domestic oil production is much more energy demanding than that of imported oils. Total emissions of CO_2 are estimated to be 30.789 t for 1 TJ of energy in jet fuel in China 2000, resulting in energy requirements of 50.2 MJ/l and WTT emissions of CO_2 of 1.02 kg/l kerosene.

3.2.9. *Assumptions on indirect emissions*

Indirect emissions from production and maintenance of transport infrastructure include ships, harbours, aeroplanes, and airports. For ships we have derived our estimates from EcoInvent 2.0 (Spielmann et al., 2007), assuming that 83% of the total life-cycle CO_2 emissions are from operation of the ship, 2% from production, 0.01% from maintenance of the ship, 0.01% from constructing port facilities, and 15.07% from port operation. For air transport we have used the EcoInvent factor for "transport aircraft intercontinental freight" with the aeroplane type "long haul flight", which assumes indirect emissions of 24.5 g CO_2/tkm from airports and aeroplanes.

4. Results

Table 11 shows TTW emissions of CO_2 from transport of China's exported, imported, and net exported goods (exports minus imports).

WTT emissions from sea transport are calculated from the total sea transport TTW CO_2 figures in Table 11. The total (net export) is 39.88 Mt CO_2. To obtain the amount of consumed bunker fuels we have divided this by 3.15 kg CO_2/kg fuel, and applied a density of 0.9 kg/l oil. We then obtain the figure of 14.068 billion l of bunker fuels. Thus, with 1.12 kg CO_2/l fuel (see section above), this results in WTT emissions of 15.76 Mt CO_2.

For air transport we have also applied the factor of 3.15 kg CO_2/kg fuel, but with a density of 0.8 kg/l. At a factor of 1.02 kg CO_2/l kerosene, WTT emissions add up to 11.82 Mt CO_2.

Table 12
Well to wheel emissions from transport of China's net exported goods in 2008.

Transport mode	CO_2 (Mt)
Sea transport	55.64
Air transport	41.01
Total	**96.65**

Table 13
Indirect emissions from transport of China's net exported goods in 2008.

Life cycle stage	CO_2 (Mt)
Ship production	1.34
Harbour operation/maintenance	10.10
Air transport	2.07
Total	**13.53**

Table 14
Summary of emissions of CO_2 from transport of China's net exported goods in 2008 (Mt).

Transport mode	WTT	TTW	Indirect	Total
Sea transport	15.76	39.88	11.46	67.10
Air transport	11.82	29.19	2.07	43.09
Total	**27.57**	**69.08**	**13.53**	**110.18**

Well-to-wheel emissions are obtained by adding WTT and TTW emissions (Table 12). Indirect emissions are shown in Table 13. The main results are summarised in Table 14.

4.1. *Uncertainties*

There are two major sources of uncertainty in the article, both leading to an underestimation of emissions from China's exported goods. The first source of uncertainty is connected to the fact that a share of imported raw materials/goods is actually used to produce the goods that are later on exported. Emissions embodied in these export-production related imports should thus be deducted from total import-related emissions. However, it has not been possible to assess the magnitude of these emissions, and the results presented consequently need to be seen as conservative.

Second, Hong Kong is China's second most important export market after the USA (see also Wang and Watson, 2007). Although Hong Kong has been part of China for more than a decade, Hong Kong still has an independent trading system, and transports of goods from China to Hong Kong are thus classified as exports. A considerable share of these exports is however moved on to other countries after processing in Hong Kong. These exports from Hong Kong are not captured in statistics focusing on "China's" exports, consequently underestimating China's exports. To complicate this even further, re-imports from Hong Kong to China are again classified as imports to China, leading to an overestimate of import volumes.

More specifically, with regard to direct emissions from ships, we used a detailed activity-based method considering different ship types, and based on their average handling capacity of TEU, CEU, t, and m^3. An alternative approach is to calculate this by

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using t/km for all ship types. If calculated on a tkm basis considering main commodities[9] exported from China, direct CO_2 emission per tkm amounts to 166.47 g CO_2 for container ships, 3.67 g CO_2 for bulk carriers, 5.23 g CO_2 for crude oil tankers, 5.61 g CO_2 for product tankers, and 44.36 g CO_2 for R/O ships.

In comparison, ProBas assumes direct CO_2 emissions from "Überseeschiffe" in the order of 7.4 g CO_2/tkm, and for "Übersee-Frachter" 8.58 g CO_2/tkm. Ecoinvent distinguishes two ship categories, "transoceanic freight ships" and "transoceanic tankers", with emissions of 8.82 and 4.54 g CO_2/tkm, respectively. In the estimates provided in this article, emissions connected to container ships and R/O are relatively high because these transport primarily voluminous and lightweight materials, such as clothes and consumer electronics. All other estimates provided in this article are in line with estimates derived from Probas and Ecoinvent.

Finally, with regard to the potential problem of using 15 years old data for Chinese refineries, data have been validated against the German LCA-database ProBas, and two estimates provided by DeLucchi (2005). The estimates by DeLucchi include gas leaks and flares from production of raw materials, drilling, extraction, and transport of raw oil, as well as fuel production in oil refineries. The estimates from ProBas include emissions from the whole production chain, as well as emissions from process heat and electricity used in refineries and emissions from material used in refineries, such as cement and steel.

Table 15
Emission of CO_2e/MJ from different products from different refineries.

Refinery	Source	Product	g CO_2/MJ
China 2010	DeLucchi	Low sulphur diesel	12.4
China 2010	DeLucchi	Gasoline	17.7
Generic	ProBas	Heavy oil	20.9
EU 2010	ProBas	Diesel	8.3
Germany 2000	ProBas	Heavy oil	10.2

As shown in Table 15, the estimate for CO_2 emissions associated with production of gasoline in China 2010 from DeLucchi is about 2.13 times higher than the estimate for diesel in EU 2010. The estimate for low sulphur diesel in China 2010 from DeLucchi is about 1.5 times higher than the estimate for diesel in EU 2010. This suggests that for comparable products, emissions from Chinese conventional oil products may be 1.5–2 times higher than European ones. The estimate for production of heavy oil in China is 2.9 times higher than the ProBas generic estimate for heavy oil. This suggests that the 1995 emission data for Chinese heavy oil could be somewhat higher than other emission data for Chinese oil products.

5. Discussion and conclusions

The results indicate that emissions associated with transports of goods are considerable. In the case of China, total emissions associated with import and export transports exceed 300 Mt CO_2, with net export of emissions, i.e. the emissions associated with goods exported by China minus those imported by China amounting to 110 Mt CO_2. This indicates the scale of emissions associated with globalization of production and growth in transport. For comparison, annual emissions from for instance Sweden and Denmark are in the order of 65 and 67 Mt CO_2e, respectively (all values for 2007; UNFCCC, 2009b). Notably, this paper also finds that transport-related emissions are comparably high due to the lower efficiency of bunker fuel production in China.

As the calculations in this paper indicate, results pose a challenge for allocation of emissions between countries and in particular China, because a greater share of emissions is embedded in exports than imports, making China a major exporter of "shadow" emissions. Considering this, many countries that have seen slightly declining emissions in recent years may, on a consumption basis including transports, in fact have grown in emissions. This confirms findings of earlier publications showing that shifts in production from industrialized countries to emerging economies have been going along with shifts in emissions between nations and an overall increase in emissions per unit of production. This paper consequently adds to the debate of the role of transports, which have so far not been specified in more detailed analyses, particularly with regard to shipping and airfreight (e.g. Hertwich and Peters, 2009; Wang and Watson, 2007). Ultimately, the results suggest that in order to understand the importance of transports, their entire life cycle should be considered, and their contribution to global emissions of GHG be assessed based on a consumer perspective. This is likely to reveal considerable underreporting in national GHG inventories in industrialized countries, and indicates the need for a better understanding and recognition of emissions associated with various life cycle stages of transport.

From a climate policy point of view, findings are relevant because they indicate the magnitude of emissions not allocated in policy making, a problem that increases rapidly with globalization of production. Notably, international aviation and shipping are not covered by the Kyoto Protocol, nor were they explicit topics of post-Kyoto negotiations at COP-13 in Bali, Indonesia (December 2007), COP-14 in Poznan, Poland (December 2008), or COP-15 in Copenhagen (December 2009). The situation thus remains that emissions from international aviation and shipping are not accounted for by any nation, while IMO and ICAO, the organizations in charge of addressing emissions from shipping and aviation, have made limited progress on identifying and implementing strategies for mitigation. As the European Union has planned to achieve average greenhouse gas emission reductions by 10% in those sectors not covered by the ETS, including transport, buildings, agriculture, and waste (Euractiv, 2009), the question arises on consequences climate policy will have for global trade and allocation of emission burdens. It appears likely that should emissions from transport be properly accounted for in national greenhouse gas inventories on a consumption basis, many of the countries claiming to have achieved emission reductions – while also presenting ambitious future reduction targets – would in fact be identified as growing in emissions.

More generally, it is suggested that transport-focused emission inventories can make a considerable contribution to understanding emissions, and to design mitigation policies (cf. Peters and Hertwich, 2008). Emission inventories as currently used by the UNFCCC do not distinguish between production and consumption, nor do they adequately capture emissions from transports. As freight transports have grown considerably in recent years, and often based on the environmentally most problematic transport mode, the aircraft (Neiberger, 2009), there is a need to better understand the mechanisms that create growth in emissions (cf. Guan et al., 2009). Clearly, there is a trend for high-consuming societies to import goods from emerging countries (Peters and Hertwich, 2008; Aall and Hille, 2010), but these shifts in production have received little attention in policy debates. It is thus concluded in line with discussions by various authors

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[9] This calculation is based on total exported goods from China. We have multiplied the amount of exported goods for each region by the total kilometres travelled per ship type as given in table 1. For container ship we have subtracted 7 568 333 t from the numbers given in Table 1 because of allocation to air transport.

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(e.g. Lenzen et al., 2007; Munksgaard and Pedersen, 2001; Peters and Hertwich, 2008) that greenhouse gas emission inventories should be designed on a consumption basis to adhere to global climate justice principles, i.e. averaged per capita emissions, which the Kyoto Agreement is ultimately about. Findings as presented in this article would also emphasize that emissions associated with transport of freight should be considered in such inventories as they make a significant contribution to overall emissions. Overall, given the size of emissions from transports, and shipping and aviation more generally, global climate policy should include these within the framework of coming post-Kyoto agreements.

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