Measuring Embodied Emission Flows for the Interdependent Economies within China

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Abstract

China's remarkable growth since its economic reform in 1978 brought significant socio-economic changes which led to uneven economic development between regions and labour migration from western China to Central and Eastern Coastal regions. China can be perceived as a group of disparate economies with distinct income, lifestyle and expenditure patterns rather than a homogenous entity. Urban population in newly formed mega-cities adapted energy-intense lifestyles, and the steadily growing demand for consumer products coupled with an inefficient heavy industry causes a drastic increase of Chinese emissions. Raw materials and production sites for intermediate goods are located in different regions than their final demand for consumption, causing a vast trade flow between regions in China. Following the concept of consumption-based emissions accounting we apply environmentally extended multi-regional input-output analysis (EE-MRIO) to eight economic regions in China to assess the emissions embodied in the trade meshwork between regions and sectors. We were able to identify sink and source regions of carbon emissions, with the two economic "powerhouses" in China, Central Region and East Coast, exporting large amounts of emissions, and regions like the South West and Beijing Tianjin importing emissions through trade. The construction sector is primarily responsible for emissions embodied in imports, followed by the electricity sector. We propose that policies aiming at reduction of carbon intensities should focus on these sectors, and also suggest a regional consumption-based emissions accounting approach to support policies in line with legally binding carbon reduction targets in the future.

Keywords: CO_2, China, trade, embodied emission, regional disparity.

Introduction

In the past decades China has undergone dramatic economic and social changes. Following a catch-up strategy to the leading economies in the world, for nearly 30 years the country achieved an average annual growth rate of 8.2% (Fei, 2007) and saw a quadrupling of its GDP in the past decade. China is about to overtake Japan to become the 2nd strongest economy after the US (Holland et al. 2010). Despite this remarkable performance of its economic engine, pace of growth and distribution of reform benefits have been uneven across Chinese regions (Feng et al., 2009; Guan and Hubacek, 2010). China can be perceived as a group of co-evolving, disparate economies rather than a homogenous entity. On one hand, China has fast-developing urban growth centres in the coastal areas and, on the other hand, backward rural areas that are each associated with distinct income, lifestyle and expenditure patterns (Hubacek and Sun, 2001). The gap in economic development and wealth of households is quickly widening between the fast growing east coast and less developed regions in the west. Chinese official statistics report that coastal provinces grew at an average of 10% between 1978 and 2008, whereas the western regions grew ‘only’ at a rate of 7.4%. As a result, 80% of labour migrants are moving from Central and Western regions to the East Coast and South Coast. This shift led to growth of mega-cities in provinces like Guangdong, Zhejiang and Jiangsu (Zhang 2004).

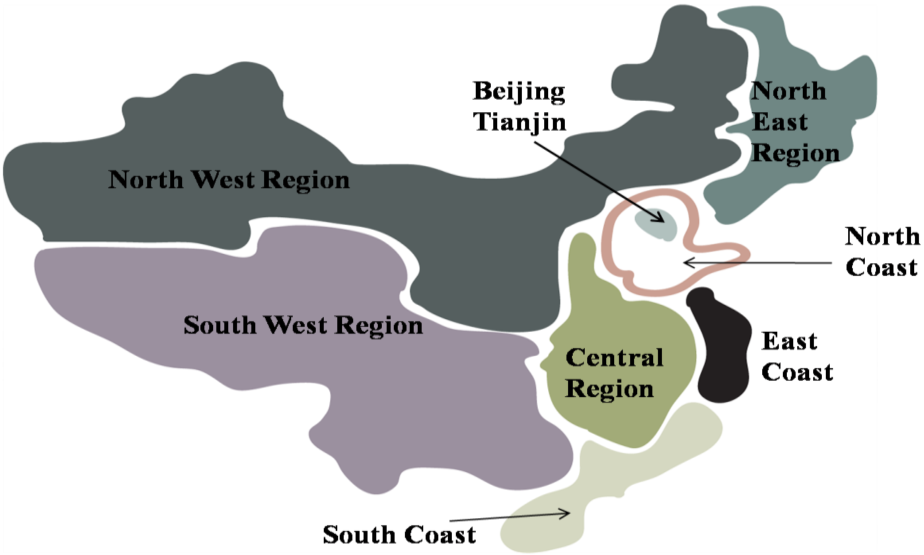

Fig. 1. Map of mainland China (not drawn to scale) showing eight economic regions used for this study

A drawback of the rapid economic growth is the threefold increase in CO_2 emissions that China has experienced since 1980. In 2007, the country overtook the US as the top emitter of annual CO_2 emissions (Guan et al. 2009). In China, 70% of energy consumption relies on the CO_2-intensive resource coal which is mined primarily in the Central region and North-West. China has a fast growing energy demand due to expansion of production of consumer goods to satisfy export demand on the one hand, and increasing domestic demand in urban areas with western lifestyles on the other (Guan et al., 2008; Peters et al., 2007). Demand growth in combination with the investment into intense heavy industry during the past decade causes

China to be locked into a pathway of coal dependence, now and in the future. This trend is continued with about approximately 1.5GW of coal-fired power stations being constructed weekly since 2005 (IEA 2008).

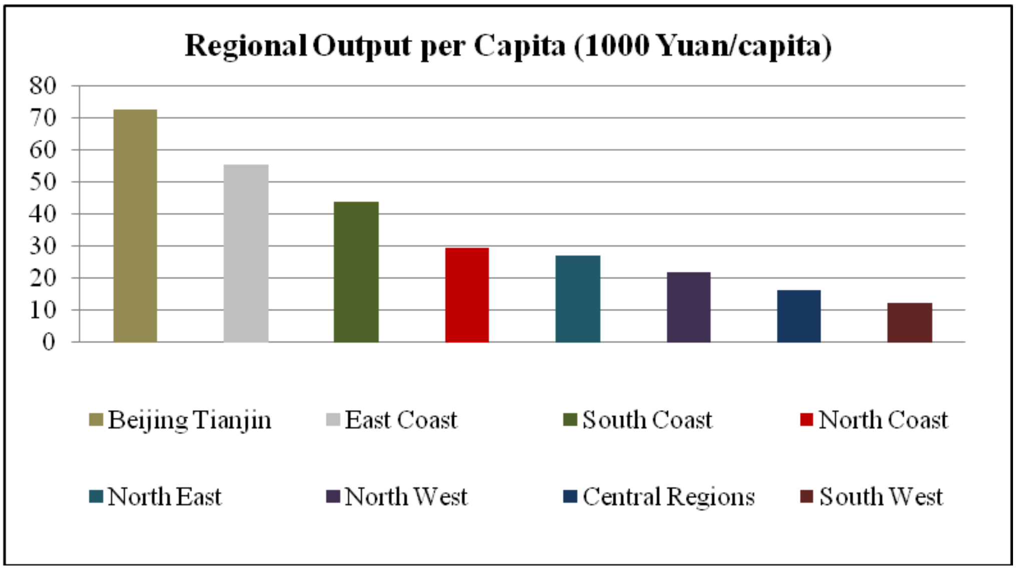

Fig. 2. Regional output per capita in the year 2002 for each region (own results)

Since the major economic reform in 1978, China has experienced a transition from a highly centralized planned economy to a market economy. The Central Government put considerable efforts into strengthening inter-regional economic linkages with the purpose of deepening the economic interdependency among them (Chen 1998). Hioki et al. (2005) show that the structure of spatial linkages and trade flows between sectors has undergone changes between 1987 and 1997. Most intraregional linkages in 1997 concentrated between North China, Central China and the Eastern and Central regions with service sectors taking an important role in this new setting. Ten years before, the "trade triangle" existed mainly between the heavy industries of North China, Central Coast and Central China[1].

Due to the mismatch of consumption and production activities across a large land mass, a vast amount of goods and products flow between sectors and regions, from production sites of intermediate- and final goods, to regions where these products are either processed, or consumed (Liang et al. 2006).Therefore, fast growing regions, like the Coastal region, are likely to affect in some way the emissions and energy consumption in other regions.

In the work presented we examine emissions and carbon intensities of 42 sectors in eight economic regions, in China, with a particular focus on contrasting the fast growing Coastal Region with the Central- and slower growing North West region. The latter two have experienced outmigration in the past (Zhang, 2004). A multi-regional input-output (MRIO) analysis with an environmentally extension is applied to regional input output data of the year 2002 in order to evaluate the emissions embodied in the underlying network of inter-

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[1] Hioki et al. (2005) use 7 economic regions in their study that differ slightly in provincial composition from our 8 region model.

regional and inter-sectoral trade flows of intermediate and final products. An analysis of emissions from a regional consumption perspective, in which emissions embodied in intermediate products are accounted to the region of final consumption, enables us to evaluate the environmental impact of growing demand for energy and consumption goods in the fast growing Coastal Region.

2. Literature review and methodology

Input-output analysis (IOA) is one of the most widely applied methods in economics and was developed by Professor Leontief in the late 1930's. Commonly referred to as the Leontief model, its fundamental purpose is to analyze the interdependence of industries in an economy (Miller and Blair, 2010). IOA is based around a set of sectors and industries with the aim to identify each input and subsequent uses of sectoral output separately. There have been numerous application of input-output analysis to economic-ecological problems. For example, Cumberland (1966) was the first to use IOA to identify environmental cost and benefits as a result of economic development. Daly (1968) and Isard (1972) developed similar approaches, but it was Walter (1973) who was the first to estimate the pollution content of trade between between countries using input-output analysis.

In our study we use a multi-regional input output model (MRIO) that we extend to an environmental output model in order to cover CO_2 emissions of regions. Environmentally extended input-output analysis (EE-IOA) is a useful method to attribute pollution or use of resources to final demand (Leontief and Ford, 1970; Miller and Blair, 2010). Single-region approaches fail to take into account that domestic and foreign production technology can differ significantly. Hence, products imported from a country with a different production structure embody different emissions and resource intensities. Multi-region input-output (MRIO) models offer a solution to this challenge by internalising the trade flow within intermediate demand between distinguished countries or regions (Miller and Blair, 2010). As a result, many studies investigating the geographic separation of consumption and production systems through inter-regional trade apply MRIO analysis.

The topic has gained renewed interest in the context of international climate policy. Investigating environmental pressures from a consumption perspective of one country could offer an alternative to production-based emissions accounting that is currently used by the UNFCCC (Peters and Hertwich, 2008, Wiedmann et al. 2007). The potential benefit of attributing emissions to the final consumer country would be that countries, such as China, with a strong emphasis on export of emission-intensive consumption goods become more open to international climate negotiations. Authors using this model to support the consumption-based accounting perspective include Hubacek et al. (2009), Lenzen et al (2004), Minx et al. (2008).

Several studies have been conducted where MRIO analysis has been applied to individual countries for detecting emissions embodied in interregional trade. Bertini and Paniccia (2008) constructed a 20 region input-output model for Italy in order to calculate global warming potential (GWP) from a consumption perspective. For the United Kingdom, Wiedmann et al. (2008) created a time series from 1992 to 2004 of carbon dioxide emissions embedded in trade between four regions. They used publicly available supply and use tables for each year and the tables were then coupled with those from three world regions. The authors were able to detect a significant increase in consumer CO_2 emissions and a widening gap between emissions stemming from production and consumption. Hubacek and Sun (2001) apply input-output analysis to land use change problems in China by assessing how economic changes since 1978 affects use of land on the reginal level. Later, Hubacek and Sun (2005) develop a hydrological input-output model representing water flows to determine how lifestyle changes in China affect water resources. In 2009, Hubacek et al. assess ecological and water footprints of different scenarios for urbanisation and lifestyle changes in China using Input-output analysis. Further work for MRIO analysis in a single country includes Minx et al. (2009) (UK), Norman et al. (2007) and Weber and Matthews (2007) for the United States.

For China, Zhang et al. (2004) use structural decomposition analysis (SDA) to investigate the energy related CO_2 emissions in China between 1991 and 2006. They show that economic activity has the largest positive effect in CO_2 emissions changes in all major economic sectors. Guan et al. (2008) assess the emissions driver of China from 1980 to 2030. They find that household consumption and capital investment will largely be responsible for increase in CO_2 emissions and efficiency gains can only partially offset this trend.

Most studies undertaken at the regional level of China, focus on a selected number of provinces or sectors only. Zhao and Michaelowa (2006) show the pattern of energy consumption and CO_2 emissions up to the year 2020 for the Yinzhou district in the Zhejiang province. Wang et al. (2005) take the Zaozhuang municipality of the Shandong province and forecast energy related emissions for the same year. Yang and Yu (2004) take six Chinese provinces and forecast the annual rural electricity growth up to the year 2010 on the basis of historical data for over 20 years. As a conclusion the paper gives a preferred order for future rural electricity investment: Jiangsu, Hebei, Henan, Shaanxi, Liaoning and Xinjiang from the most to the least developed province.

Liang et al. (2006) showed in a multi-regional input-output analysis of Chinese regions that population growth is an important driving force for additional energy requirement and likely to cause greater CO_2 emissions across all regions. The study concludes that improvements in energy end-use efficiency for each region could generate energy savings beyond regional borders. The work done by Liang et al (2006) is to our knowledge the only study that assesses the regional interrelation of emissions and energy requirement of trade flows in China.

Our work differs in the way that we assess the amount of interregional emissions embodied in imports and exportsof products ,and are therefore able to identify sink and source regions in China. Working with highly disaggregated regional economies consisting of 42 sectors enables us to determine sectors responsible for emissions import and export of respective regions. A regional consumption based emissions inventory for the whole economy of China has not been done before, and it holds important implications for future national climate policy design.

2.1 Methodology

The methodology applied for constructing the eight region model for our work is explained in detail in a separate paper (Guan et al. 2010).

In summary, we used input output tables provided by the National Bureau of Statistics in China [i]for the economy of 30 provinces, grouped them into eight economic regions, and used those to construct a multi-region input output model. In each region we created technical coefficient matrices and combined them endogenously with import matrices from the other regions into one large coefficient matrix. The technical coefficient describes the dependency of inter-sectoral flow and total output of a sector. We then extend the MRIO to account for emissions by introducing CO_2 multipliers to regional trade flow. This step is explained in detail in Peters (2008).

3. Results

We compared emissions stemming from production for regional domestic consumption with interregional emissions embodied in imports (EEI) and emissions embodied in regional exports (EEE). We found that all regions, except for East Coast and North East, have higher EEI than production emissions associated with domestic consumption (see figure 2). The total emissions embodied in imports for Central Region are 317.46 Mt of CO_2, in other words, all other regions combined produce this amount of emissions for production of intermediate or final goods for consumption in the Central Region. 144.98 Mt of CO_2 alone is imported from the East Coast. The East coast itself imports 210.44 Mt CO_2 from all other regions. It must be noted that the majority, 93.6 %, of emissions in the South West can be attributed to inter-regional emissions embodied in imports. The region only produces 18.18 Mt CO_2 within its own borders.

Central Region and East Coast are leading regions for exporting emissions to other regions in China (international exports are not accounted for in this figure). It is remarkable that for Central Region, the largest emitter, the exported emissions are more than double the emissions for domestic consumption. Beijing Tianjin and Southwest are regions with high emissions embodied in imports (sink), Central and East Coast regions of export (source) and emissions in the North-East originate mainly from production within its region. Overall, however, we observe a fast exchange of emissions between individual regions.

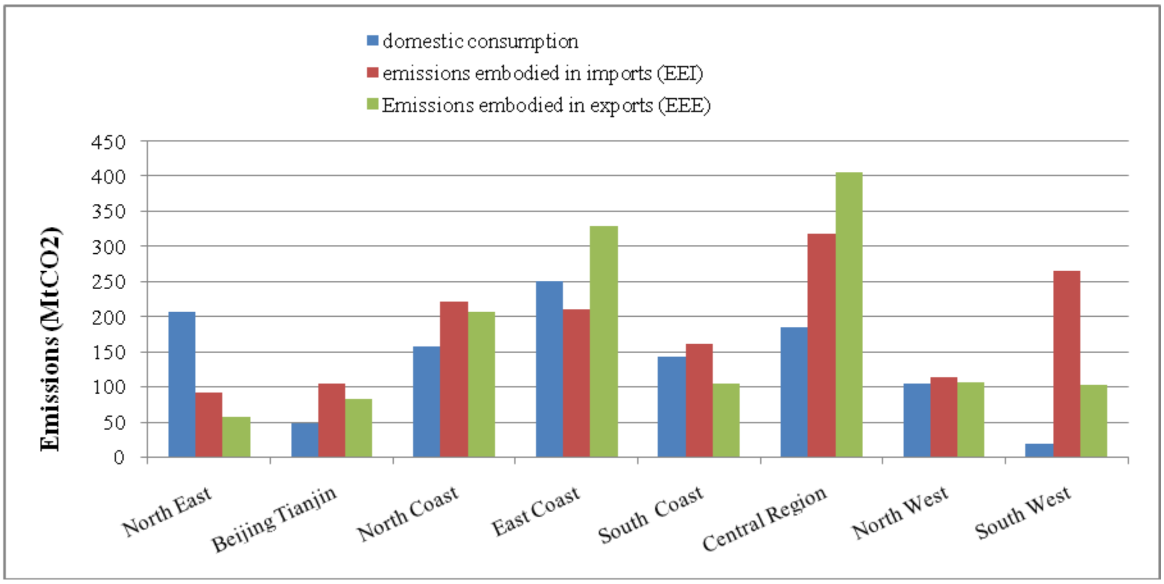

Fig. 3. Comparison of domestic consumption, EEI and EEE in eight economic regions in China.

Taking a closer look at final consumption categories in each region, including emissions embodied in international exports, we find that capital investment is the main driver of CO_2 emissions for both, interregional emissions embodied in imports as well as emissions produced for domestic consumption, shown in figure 3. This is followed by emissions embodied in exports to foreign countries of each region, except for the North West where urban households drive more emissions than exports. In the East coast and North West region about half (49%) of total demand-driven emissions can be attributed to activities related to capital investment; in the Central region investments make up 43%. Overall, urban households make up more emissions than rural households in all regions except for the South West and North Coast. Table 2 in Annex A shows this relationship in detail. The contribution of rural households to emissions from final consumption in Beijing-Tianjin is only 14.4%, whereas in the South-West it is 52.1%. We also found that the share of GDP and emissions between rural and urban households are nearly the same.

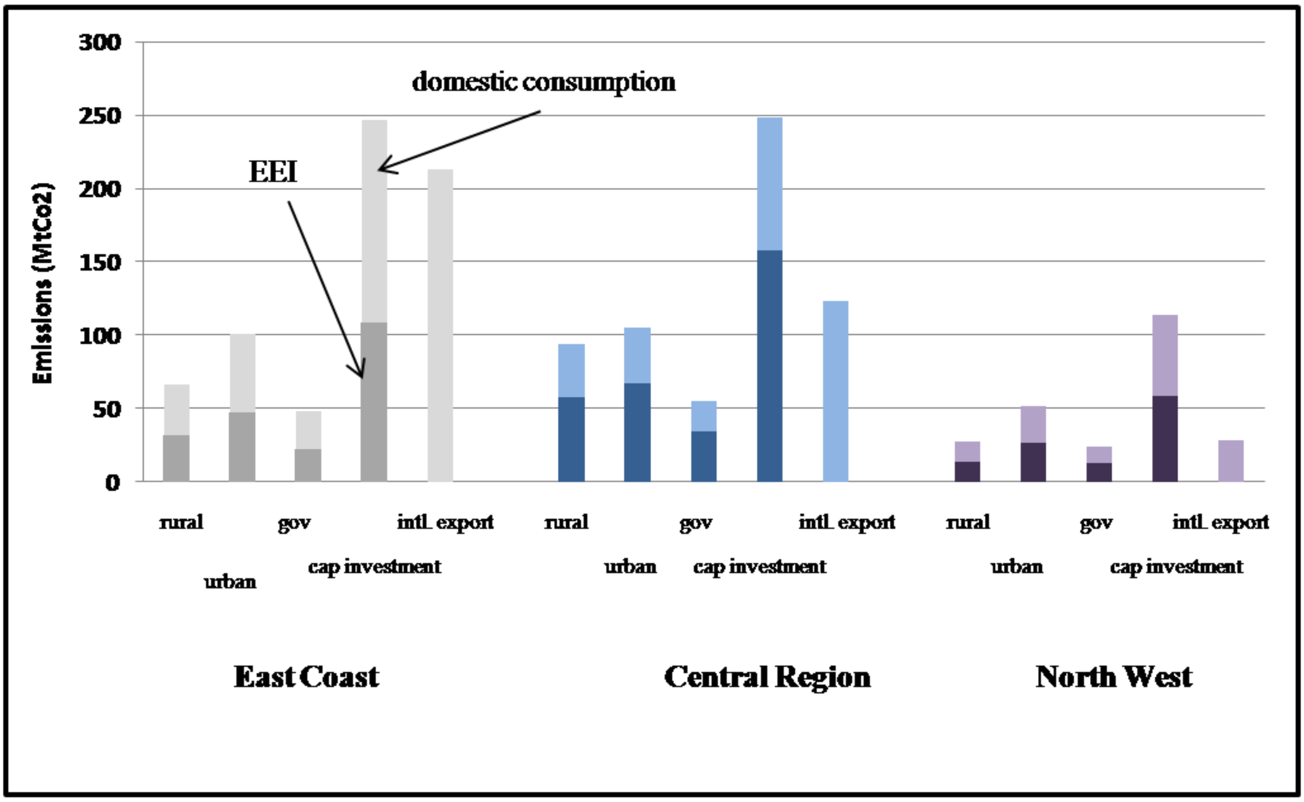

Fig. 4. Comparison of final demand categories, including emissions embodied in international exports for three Regions

We then analyse the emissions from East coast, North West and Central region that arise from the production of intermediate or final goods and products for export into all other regions to meet consumption of final demand categories. In contrast to Figure 2, we show the emissions arising through export of goods and products by the three regions in Figure 4. East coast produces a total of 350.47 Mt of CO_2 due to export of products into other regions. 144.98 Mt of CO_2 alone is embodied in exports to the Central region. The Central region itself produces a total of 433.37 Mt CO_2 to fulfil final demand of other regions, and North West produces 113.16 Mt CO_2 for export. Also, we see that a total of 24% of export emissions from East coast and Central region flow into the South-west region. The North-west transfers only 15% of total export emissions to the South-west. It can also be noted that the total export emissions from North-west are significantly lower than those of Central and East coast region.

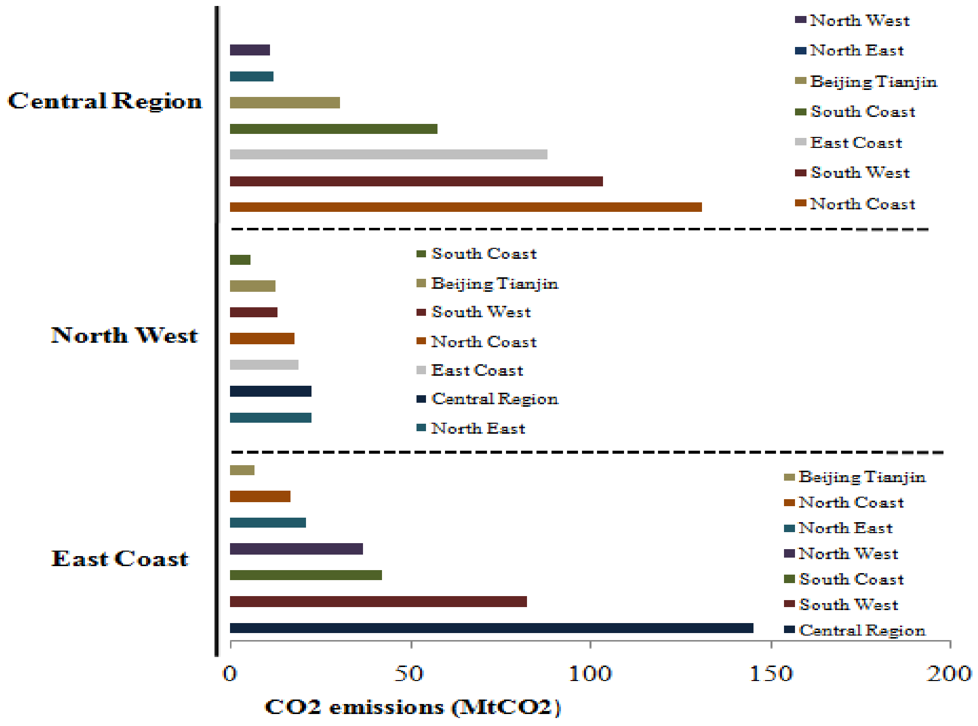

Fig. 5.: Emissions caused by East coast, North West and Central region due to trade flow to all other economic regions of China

3.1 Sectoral analysis

For the East coast, Central Region and North West we determined the ten highest emitting production sectors for direct and indirect emissions out of 42 sectors, they are listed in Annex A. We find that the electricity production and supply sector causes the highest amount of direct emissions per region. This sector contributes 68% to total direct emissions in the North West, and 54% and 60% in the Central and East Coast region, respectively. As a comparison, the non-metal mineral production sector, ranked number two for total direct emissions, causes only 9%, 19% and 15% of emissions in the three regions, respectively. This shows that mitigation policies have to target the electricity and power sector in order to be most effective. Other sectors mainly responsible for direct emissions are coal mining and petroleum processing & coking (Central Region), as well as metals smelting and pressing, chemicals, and transport and warehousing. The construction sector relies on imports of raw material and intermediate carbon-intense products such as steel. Thus, this sector is in all three regions the main contributor for indirect emissions, although its magnitude is not the same as the electricity sector. In comparison to the other sectors contributing to indirect emissions the construction sectors makes up 14% in the North-West, 12% in the Central region and 10% on the East coast. The electricity sector is actually the second main cause of indirect emissions in the Central and North West region.

Figure 5 shows the relative carbon intensity of the main contributing sectors, expressed in kgCO_2/billion Yuan, indexed to the national average of each sector. For example, carbon intensity of coal mining in the North West exceeds the national average intensity of that sector by a factor of close to 5 (492%). In the East Coast and Central Region carbon intensity of electricity production lies just slightly above the national average. Metal ore mining in the East coast and petroleum processing in the Central Region are sectors with very high carbon intensity when compared to the national average. Crude petroleum processing is ranked second in terms of carbon intensity in Central and North East region.

We see that processing sectors of raw material, like mining of metal ore and coal as well as crude petroleum processing have a high impact on carbon intensity of regions.

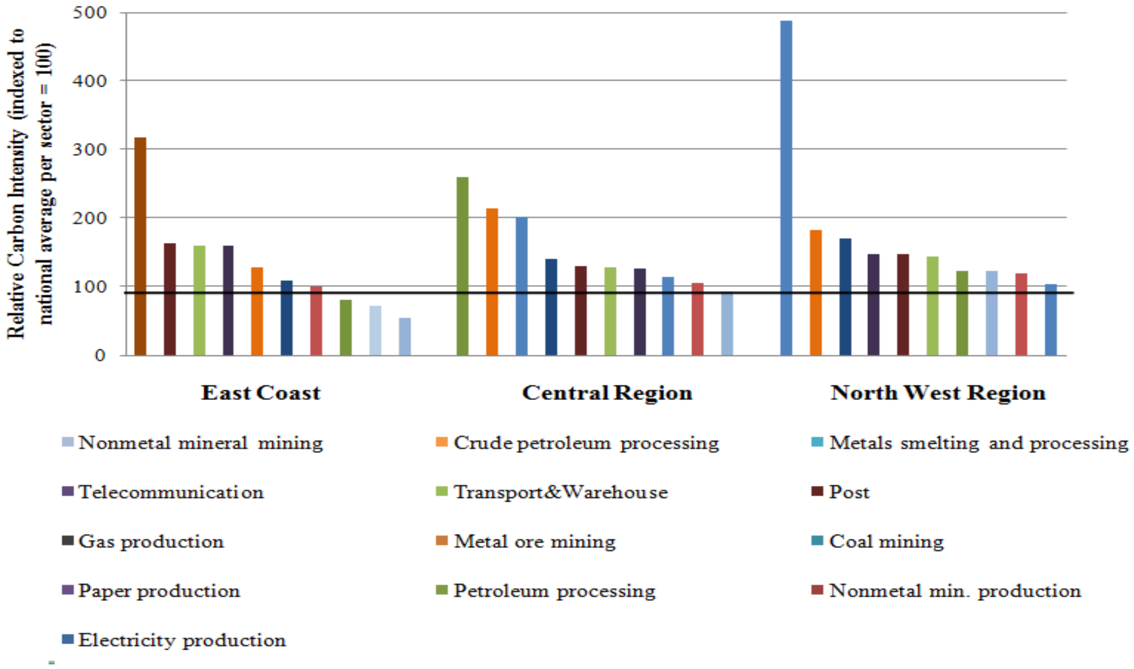

Figure 6. Relative carbon intensity indexed to the national average of each sector

3.2. Emissions stemming from interregional trade flows between sectors

Finally, we analysed in more detail three sectors in each region holding the highest interregional emissions embodied in imports. The majority of imported emissions (76%) in the construction, electricity and machinery and equipment sector of the East coast region stem from Central, South West and North West region. 29% of total indirect emissions of these three sectors in the East Coast are to be attributed to imports of the construction sector from the Central region.

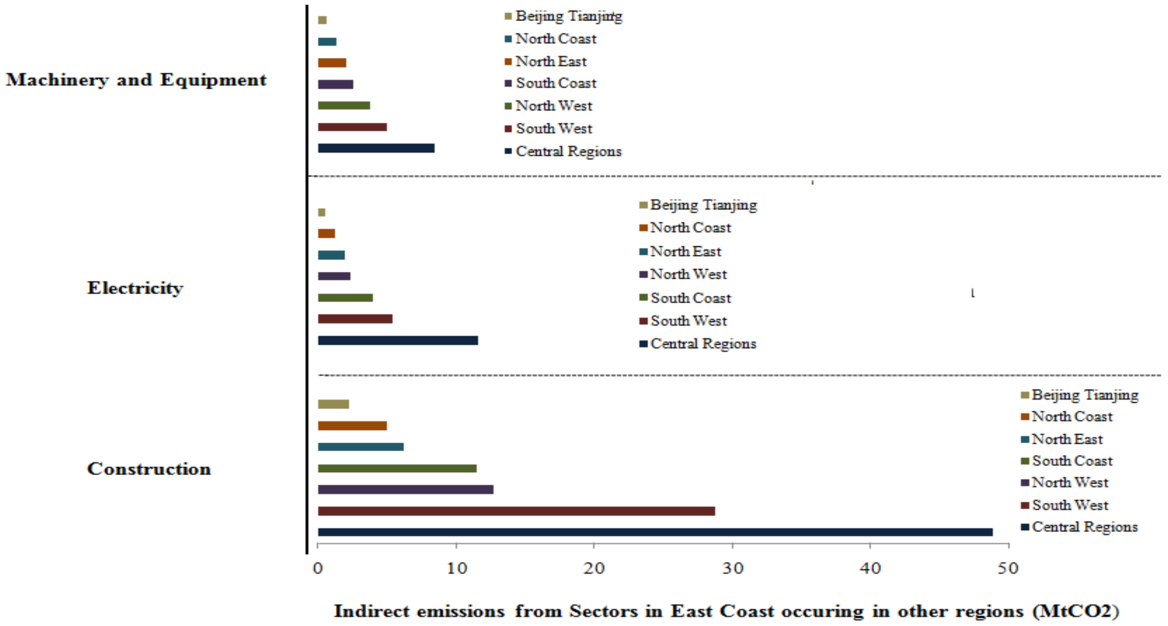

Fig.7: Interregional emissions of three sectors in East Coast

Emissions embodied in imports of the North West occur mainly in Central Region, North East and South Coast. They share 57.1% of total imported emissions (among the top three sectors), and the Central Region alone shares 19.9%. Interestingly, products imported from Central Region into the construction sector of North West hold 8.95 Mt of CO_2, whereas those imported by the construction sector in the East Coast hold 46.37 Mt of CO_2.

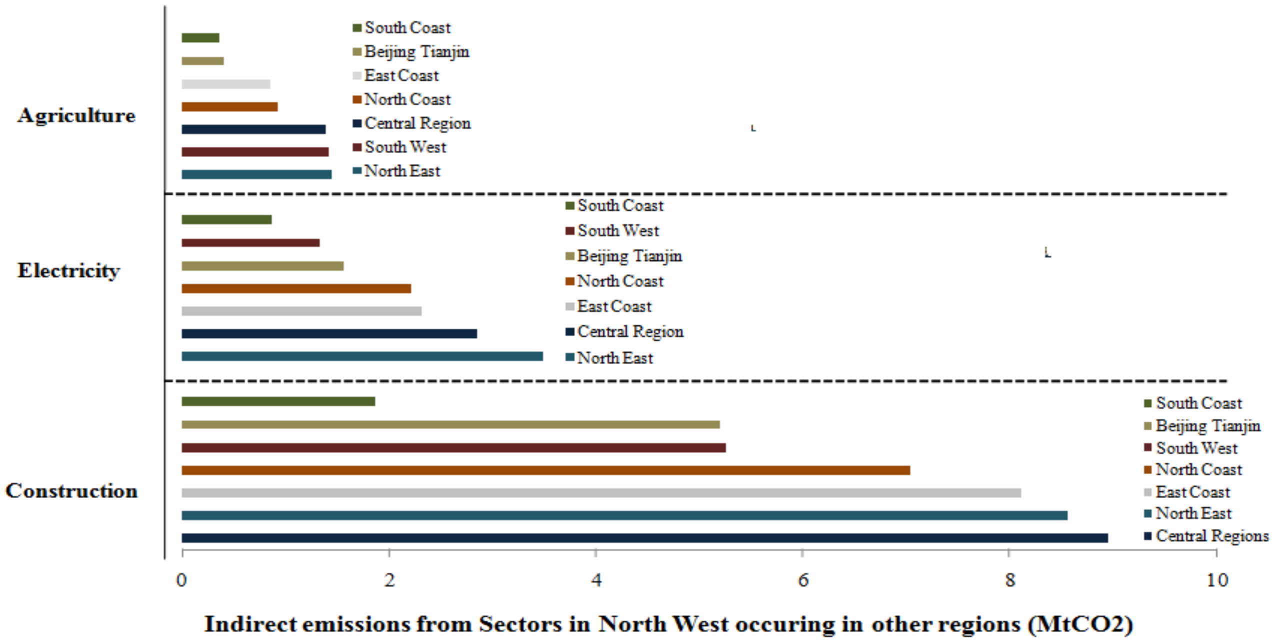

Fig. 8. Interregional emissions of three sectors in North West.

More than half, i.e. 58% of the embodied emissions of the Central Region are imported from the North Coast, South West and East Coast, with nearly 30% stemming from the North Coast alone. 20% of total indirect emissions can be attributed to imports of the construction sector.

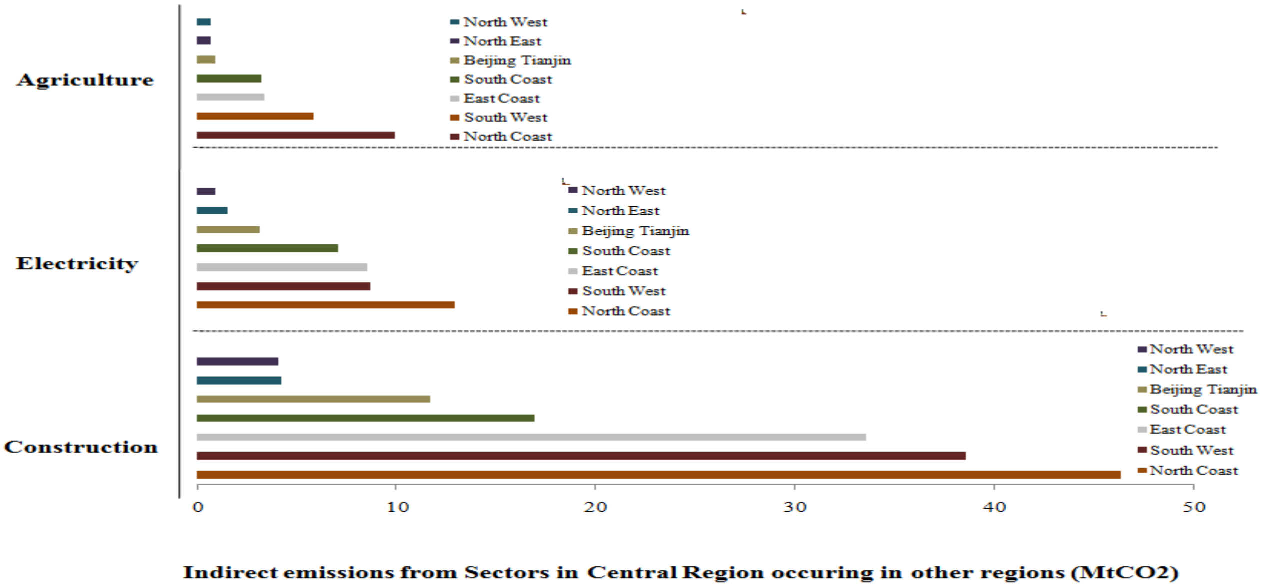

Fig. 9. Interregional emissions of three sectors in Central region

In summary, our results show that there exist a fast flow of emissions embodied in trade of products between regions and sectors in China. At the centre of this trade, holding the highest amount of emissions in exports are Central Region and the East Coast, whereas the South West and Beijing Tianjing are main importers of emissions. Most emissions embodied in sectoral trade stem from the construction and electricity sector.

4. Conclusion

Given the spatial economic disparity in China and migration fluxes from Western and Central Regions to the East Coast this paper estimated and assessed the amount of emissions generated by the trade linkages between China's regions.

A main finding is that all regions, except for North East and East Coast, have more emissions embodied in imports than stemming from domestic production. We were able to identify strong source regions, Central and East Coast that are largely responsible for emissions embodied in exports, as well as sink regions with a high fraction of emissions embodied in imports, like the South West. We link this finding to strategic policies implemented by the Central Government. One strategy of the 9th five year plan (1996-2000) was to deepen economic interdependencies between regions by enhancing cooperation and to strengthen relationships based on comparative advantage of each area (Hioki et al. 2005).

About a quarter of export emissions of Central Region and East Coast flow to the least developed regions, the South West region. We found that a main part of these emissions stem from the construction sector, but electricity sector and machinery and equipment contribute as well. We see this flux of emissions as a direct result of the Western Development Program in China which aims at improving infrastructure and urbanisation of provinces of western China. A general trend we observe is that less developed regions export intermediate products and raw materials to wealthier regions, namely Central Region and East Coast. The emissions of regions with a considerable lower GDP output are partially driven by the consumer intense lifestyle and carbon intense production industry of more developed regions in China.

As somewhat expected we find that the electricity sector is the highest emitting sector, but this picture is dampened when comparing its carbon intensity with those of the other 42 sectors. Products stemming from sectors in which raw materials are mined or processed show much higher carbon intensity than the electricity sector. We find this concerning, in particular when considering the expected further increase of energy demand in China and continuing investment into heavy industry, which will ultimately lead to further extraction of raw materials and mining of coal. The IEA (2008) forecasts that primary energy demand (MtOe) in China will increase by 48% in 2020, compared to 2006 levels. We propose a that policies on improving energy intensities and emissions should include mining and processing sectors that cater to the heavy industry, specifically in source regions like North East, North Coast and South West. China's white paper on National Climate Change Policies (2007) mentions the dissemination and development of energy conservation technologies in key sectors like the iron and steel industry, oil and petrochemical industry as well as building and construction sector (NDRC, 2007). Our findings add to Liang's et al. (2006) recommendation to improve energy end-use efficiency in all Chinese regions in the way that we regard it as important to reduce carbon intensity of energy extraction and raw material processing industry.

In the current debate of climate change and global mitigation efforts China inherits a special role. Due to its uneven spread of economic development, leaving behind large rural areas where citizens continue to live below the poverty line (The World Bank 2010), the country is considered a developing country and has no mandatory mitigation target under the Kyoto protocol. During the Copenhagen summit in December 2009 China has shown signals to open up towards consideration of a binding emissions reduction target from 2020 onwards.

Our presented work fits into the broader frame of ongoing post-Kyoto climate policy discussions. It gains in relevance when China decides to accept a binding mitigation target at some point in the future, as this would inform the range of possibilities China would have in order to implement such a national target in the most effective way. Our work holds implications for designing pathways to an effective reduction of CO_2 emissions in China in a scenario where the country does commit to a national reduction target. If the common duty of achieving such a national goal were to be shared by individual regions in the form of regional reduction targets, we argue that allocation of reduction obligation according to regional consumption-based emissions accounting would give the more developed Eastern Coastal and Central region stronger responsibility of reducing emissions. Thus, this scheme would actually take into consideration the high disparity of economic development in China by putting a heavier burden on consumer- and production intense regions, and taking away emissions reduction responsibilities from less developed regions. In a global context, a consumption-based approach has been discussed by many authors (see for example Peters and Hertwich

2007), reasoning that countries like China, exporting consumption goods which embody emissions to high developed countries, may potentially become more open to accept mitigation targets if these emissions embedded in trade would be allocated to the country of final consumption, rather than the country of production (Wiedmann et al. 2007). Future work should build on this idea, and examine the potential of a regional cap-and trade model for China as a means to reduce emissions in a cost-effective way.

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Annex A:

Table 1. Ten sectors of highest direct and indirect emissions in three regions of China.

East Coast

Sector	direct emissions		indirect emissions
Electricity	397.76	Construction	203.7
Nonmetal mineral products	99.57	Machinery and equipment	55.9
Metals smelting	37.28	Electricity	48.32
Transport&warehousing	35.85	Wearing apparel, leather, furs, down and related products	38.9
Chemicals	31.69	Chemicals	38.39
Petroleum processing	16.22	Textile goods	36.76
Telecommunication	40.49	Electric equipment and machinery	34.29
Agriculture	40.23	Electronic and telecommunication equipment	30.85
Textile goods	15.15	Public administration and other sectors	30.85
Wholesale and retail trade	4,26	Manufacture of food products and tobacco processing	24.20

Central Region

Sector	direct emissions		indirect emissions
Electricity	495.68	Construction	222.01
Nonmetal mineral products	170.95	Electricity, steam and hot water production and supply	64.85
Coal mining and processing	61.64	Nonmetal mineral products	42.05
Petroleum processing and coking	51.63	Machinery and equipment	37.72
Metals smelting and pressing	46.81	Manufacture of food products and tobacco processing	36.56
Transports# and warehousing	35.09	Agriculture	36.20
Agriculture	25.00	Education	25.68
Machinery and equipment	9,48	Public administration and other sectors	24,36
Telecommunication and IT services	9,32	Health services and social welfare	23.89
Chemicals	9,19	Transports# and warehousing	19.67

North West Region

Sector	direct emissions		indirect emissions
Electricity	213.96	Construction	87,57
Nonmetal mineral products	28.49	Electricity, steam and hot water production and supply	26,56
Petroleum processing and coking	13.13	Agriculture	15,19
Transports# and warehousing	12,98	Wholesale and retail trade	10,84
Metals smelting and pressing	12,73	Public administration and other sectors	10,63
Coal mining and processing	11,81	Transports# and warehousing	9,99
Agriculture	6,80	Manufacture of food products and tobacco processing	9,77
Construction	5,06	Machinery and equipment	7,98
Crude petroleum and natural gas products	4,87	Education	7,35
Telecommunication and IT services	2,70	Nonmetal mineral products	6,05

Table 2. Rural and urban household as contributors to total household consumption.

Proportion of rural households to total household (urban+rural)		
Region	CO2 emissions (%)	GDP output (%)
North East	32,8	34,4
Beijing Tianjin	14,40	15,34
North Coast	52,2	50,86
East Coast	39,5	39,67
South Coast	34,1	36,12
Central Region	47,1	49,52
North West	34,6	35,62
South West	52,1	54,82

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