LUND UNIVERSITY
School of Economics and Management

Master's Program in International Economics with a Focus on China

Sectoral Decomposition of Technology-adjusted CO_2 Emissions from International Trade in China 1999-2009

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In the context of increasing focus on the climate change China is being blamed for its large contribution to global CO_2 emissions, which have been produced within China's territory. However, increasing number of researches have started to argue that the developed countries should be held responsible for displacing their emissions by outsourcing pollution-heavy production to the developing countries. Using Multi-Region Input-Output (MRIO) analysis for 41 countries disaggregated into 35 sectors and Log-Mean Divisia Index (LMDI) decomposition, this academic research paper attempts to find out what are the driving forces of China's CO_2 emissions and whether China has become the "factory of the world" when different technologies between countries have been taken into account. The results indeed point to the existence of CO_2 emissions displacement to China and China becoming the "factory of the world". However compared to conventional accounting methods, the magnitude of displacement is lower in the case of technology-adjusted emissions embodied in trade, holding China accountable for its carbon-intense production process. The decomposition results point to the trade specialization effect as the largest contributor to China's emissions embodied in trade, which has mostly been caused by the electricity, gas and water supply sector.

Key words: CO_2 emissions, carbon leakage, multi-region input-output, LMDI decomposition, China

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1 Introduction

Under the United Nations Framework Convention on Climate Change (UNFCCC) China has reported of emissions up to 10,540 $MtCO_2$ compared to 5,334 $MtCO_2$ in the U.S. in 2014 (EDGAR, 2014). This makes China by far the largest CO_2 emitter in the world. In light of the recent increasing attention on the climate change and the actions to be taken to mitigate it, it becomes important to look into the issue more closely to provide more coherent policies and measures to effectively reduce global emissions. China emits the largest amount of CO_2 from its production but it is also clear that China has been producing goods for the global demand. The Intergovernmental Panel on Climate Change (IPCCC) uses the system of production (territory) based accounting, on which the major climate policies (Paris agreement, Kyoto protocol) have been based upon. However, in the globalized world, where the supply chains have become ever interlinked to satisfy demand, the need for a more fair sharing of responsibility for the emissions emitted from the production of the goods consumed becomes more evident. This is important since the production-based accounting reflected in the climate agreements, triggers the „carbon leakage“ problem, where the more developed countries tend to clean up their production by outsourcing the "dirty" industries to less developed ones, with often less stringent directives on climate change.

Therefore, this academic research paper will attempt to look closer into the emissions embodied in global trade and the share of the CO_2 emissions, which countries are accountable for. In order to provide more profound policy implications for China and to understand where the emissions come from, the emissions embodied in trade for China will be further decomposed into its driving factors by each sector. Henceforth, the main research question this thesis attempts to answer is:

What are the driving forces for China's CO_2 emissions embodied in international trade.

More detailed research questions covered in the thesis will involve:

1) Has China become "the factory of the world"? Does the carbon displacement argument hold in the case of China?
2) Does China's emission exports show any pattern of regional divide?
3) Which underlying factors can China's net technology-adjusted emissions be attributed to?

4) Which sectors have been the main driving forces of the underlying factors?

1.1 Aim and Scope

The purpose of this academic research paper is to look into the CO_2 emissions embodied in trade and its driving factors for China. The analysis will be based on a two-step approach, with first input-output analysis (IOA) involving 40 countries with a model developed for the Rest of the World (RoW). The emissions for these countries are evaluated based on 35 industries provided in the WIOD database. The second step will include a detailed decomposition analysis to further decompose the results from IOA into its sector based driving forces. The analysis will include the years from 1999 until 2009 in order to take into account the effect of China joining the World Trade Organization (WTO). It has to be noted that the WIOD database has been recently updated with the new 2016 release, which includes data for the years up to 2014. However, due to the lack of funding, the environmental satellite accounts (data on CO_2 emissions) have not been updated after 2009. Therefore, this study will be constrained to the year 2009 as the latest data available within WIOD. Methods to estimate CO_2 emissions for later years have been proposed by few researches, however, due to time constraints this approach was not followed through.

1.2 Outline of the Thesis

The structure of the thesis consists of eight sections, with introduction as the first part. The paper will continue with section 2, which will bring out theoretical background relevant to this research. Section 3 will provide a more detailed account of previous literature written on this topic. Section 4 will continue with background information about China's situation in the field of energy and thus emissions. Section 5 will describe the data used in the analysis, thus leading the paper to its empirical analysis part. The data description will be followed by section 6, which provides a detailed account of the methodologies used to conduct the analysis. Section 7 will provide the results obtained from the analysis and will continue with a discussion of the results, where the results will be analyzed in the context of raised hypotheses, theoretical background and previous literature. Finally, section 8 will provide concluding remarks and policy implications attributable to China emissions in international trade.

2 Theoretical Background

2.1 Environmental Kuznets' Curve

The recent debate on the climate change has focused much on the developing countries' uncontrolled pollution coming from the intense manufacturing sector and the lack of environmental regulations. These conditions, however, have precisely helped to pave the way for economic growth in these countries. The relationship between economic growth and environmental degradation has been described by the inverse U-shaped Environmental Kuznets' Curve (EKC) first introduced by Grossman and Kruger in their study of North American Free Trade Agreement (NAFTA) and air pollution in Mexico (1991). They were able to conclude by empirical tests that there exists an U-shaped relationship between air pollution and economic growth, similar to the one of inequality and growth proposed by Kuznet in 1955. Specifically, that the pollution increases in-line with GDP growth at low levels of income but eventually decreases after reaching certain level of national income (estimated to be somewhere between 4,000 and 5,000 in 1985 U.S. Dollars) (Grossman and Krueger, 1991).

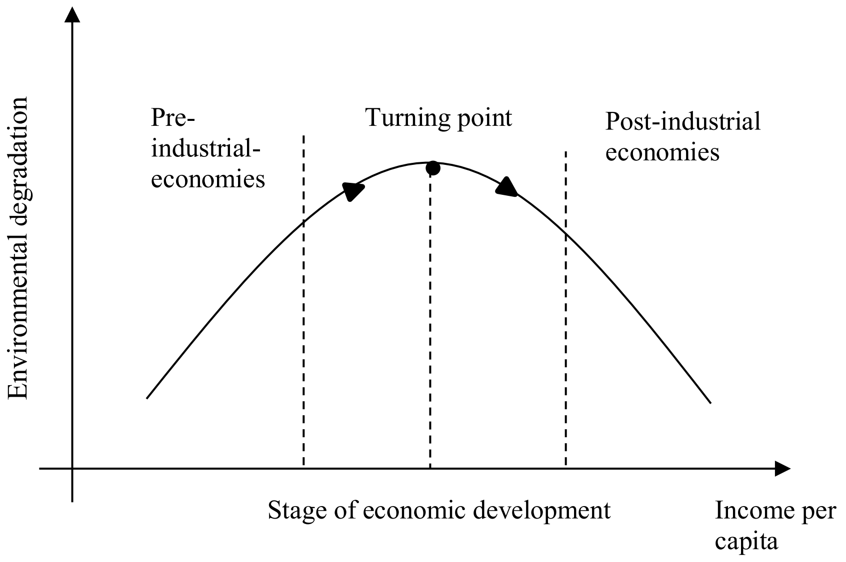


Figure 1. Environmental Kuznet's Curve. Source: Own construction based on Panayotou (1993)

Panayotou (1993) also proposed that environmental degradation follows a U-shaped path but tied the explanation more specifically to the country's structural change from rural to urban and from agriculture to industry (see figure 1). Degradation initially increases when a low-income country goes through the process of industrialization and levels off or eventually decreases afterwards when income per capita has reached a certain point. This first stage can be seen mostly in developed countries when they move from specializing in agriculture production to more carbon-intense manufacturing in cities. This is further intensified by the growth of these manufacturing industries, which leads to agglomeration in the cities with traffic congestions and higher demand for heating. The decreasing section from the U-curve arises when a country moves from relying on heavy industry and manufacturing towards less energy demanding sectors such as information technology and services or producing electronics, which is typical for developed countries. Thus, the author claims that environmental degradation is an inevitable part of countries path of development, however, the effect could be flattened or reduced by policy choices in the country (i.e. fewer environmentally harmful subsidies) (Panayotou, 1993).

The relationship between environmental degradation and economic growth through trade between countries has been less researched area. Grossman and Krueger (1991) decomposed the relationship into three underlying factors: scale, composition and technology. Proposing a connection between trade relationships and pollution, with increasingly liberalized trading relationships resulting in increased pollution. This also applies to energy sector, since more economic activity means a higher demand for energy and therefore higher combustion of fossil fuels. The composition effect involves the competitive advantage theory by Heckscher-Ohlin (1933), which hypothesizes that countries specialize in producing and trading goods that require inputs they are most endowed with. When these countries enjoy a competitive advantage in polluting industries (i.e. heavy industries) through less stringent environmental regulations, the prospects of the environment are reduced, also known as "environmental dumping". Lastly, the technology effect means that trade can simplify the transfer of cleaner production technology from more advanced countries to less advanced ones (Grossman and Krueger, 1991).

However, the EKC theory, and the empirical tests to prove its existence, have received criticism for their lack of solid empirical models and statistical quality. Stern (2003) termed previous literature in the field as "econometrically weak" and points out that there is no inevitability in the relationship between environmental degradation and growth and that the relationship is not as simple as previously pictured. He found evidence that the innovations in improving environmental conditions took place in both developing and already developed countries. Initiated by the high-income countries but adopted by the low-income countries fairly fast. Similar to the research of Grossman and Kruger (1991), he found that the decomposing emissions into its driving forces to be statistically more adequate method. Thus, in this thesis, countries' emissions will be looked from trade perspective and as proposed by Stern (2003) these emissions will be decomposed into their driving factors.

2.2 Pollution Haven Hypothesis and Carbon Leakage

To continue with the relationship between environmental degradation and growth, this section will introduce the phenomenon called pollution haven hypothesis (PHH). It contradicts the EKC theory by arguing that the decline in pollution production in high-income countries does not stem from the mere structural change of the economy and consuming less pollution intense goods, but is instead related to high-income countries' displacement of their pollution intense industries to low-income countries. This stems partly from the international trade theory and previously mentioned Heckscher-Ohlin model of comparative advantage and the importance of global value chains. Meaning that similar to low-wage advantage phenomenon and other benefits (lower electricity price, cost of raw material), more stringent environmental regulations in developed countries incentivizes them to outsource their polluting industries to developing countries with less regulated environmental policies (also known as the strong carbon leakage) (Mani and Wheeler, 1998). Thus, in effect the greenhouse gases are not being reduced in aggregate or global terms. Instead they are being displaced to less developed countries (i.e. China), resulting in an increase of emissions due to the more carbon-intense production processes that could have been avoided when produced in developed countries using their more clean production technology (Cole, 2004).

The PHH with carbon leakage will be further analyzed in the empirical analysis section, where the results of net exporting and net importing countries of emissions, based on the calculations from input-output tables and its environmental extensions, will be presented.

2.3 Accounting of Greenhouse Gases (GHG)

Since the greater necessity to restrict the emission of greenhouse gases (GHG) coming from mostly anthropogenic activities (fossil fuel combustion), the United Nations Framework Convention on Climate Change (UNFCCC), has committed developed countries (Annex-I) to provide national inventories of their emissions. These inventories have been used to monitor the development of emissions, and based on these, introduce international climate policies that ascribe specific targets to reduce emissions to its signed members. The Kyoto protocol and the Paris agreement are two treaties known to have ascribed such targets. More specifically, the Kyoto protocol has bound its signed members to 5% reduction in GHG emissions in the period of 2008-2012 (Peters and Hertwich, 2008). From the 1970s three different accounting methodologies have been determined to account for emissions countries are responsible for: territory-based, production-based and consumption-based. Territorial perspective takes into account the emissions produced within one country or within its jurisdictions. This approach has been in use also for major climate policies like the Kyoto Protocol and the Paris agreement. Production-based accounting is closely related to the territorial accounting but refers to emissions produced by "resident" companies regardless of their production location. That is, it allocates the emissions based on the national economic accounts, similar to national gross domestic product (GDP), which takes into account the gross value-added that is produced by all of its economic institutions (including international transportation and tourism) (Peters and Hertwich, 2008). Finally, the consumption-based accounting refers to emissions consumed within a country as goods and services regardless of the location of production. Thus, taking into account the emissions embodied in trade. Meaning that the responsibility of the emissions is shifted to the consumers of the produced emissions (EEA, 2013).

Following the EKC hypothesis, the emissions will eventually start to decrease in-line with the income growth. This assumes that environmental quality is a "normal" good, which means that there will be more investments in the environment, as the income rises. While the EKC theory puts emphasis on the production of emissions coming from composition changes and the accompanied reductions in the energy and resources used, it does not take into account the links between international trade and thus the consumption perspective. However, consumption is believed to be the dominating contributor to environmental degradation directly or indirectly. More specific, "*goods and services will not be produced, bought, sold and traded across* *borders, unless there is a demand for them*" (Rothman, 1998). Following the structural change of the developed countries, from carbon-intense industries to less carbon-intense industries such as electronics, ICT or services, these developed countries increasingly consume the goods produced in developing countries. Thus, in the process of measuring the progress of emissions reduction in context of climate treaties where only territorial or production based emissions have been taken into account, there exists a strong bias in favor of the developed countries that appear to follow the EKC model resulting in reduced emissions. The advantage of consumption-based methodology, however, is that it also accounts for international trade, and re-adjusts the responsibility of who should bear the costs associated with emissions. In this approach, the consumers are being held accountable for the emissions that have incurred from the production of the good.

3 Energy and Greenhouse Gases in China

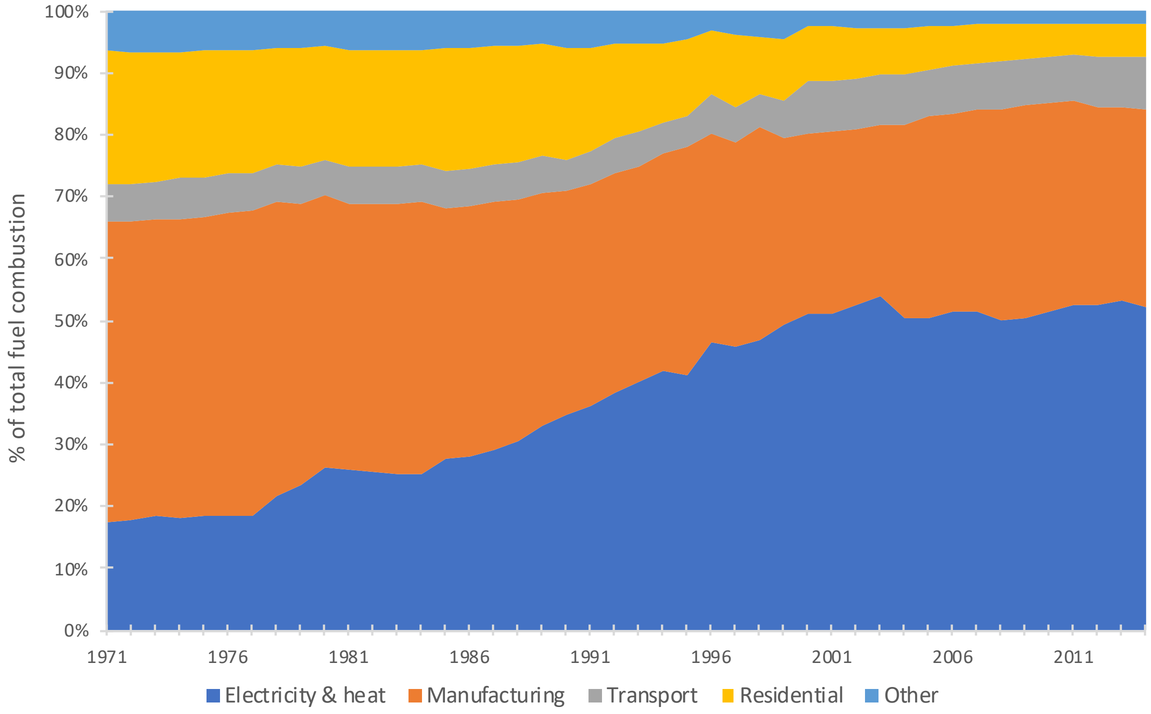


Figure 2. CO_2 emissions break-down by sector in China (as a % of total fuel combustion). Source: author's own construction based on World Bank, 2014.

As mentioned in previous sections, economic growth in China is strongly linked to higher production of goods and thus energy demand in China. Agglomeration in the cities in search for better jobs in manufacturing, increases the demand for electricity and heat production among others. As visible from figure 2, one of the largest contributors to CO_2 emissions in China is the energy sector producing electricity and heat based on fuel combustion, accounting for 52% in 2014. Whereas the other major sources include manufacturing and transportation. Thus, this section will analyze the energy sector in China, with emphasis on its composition, security and relevant policies that have paved the way towards mitigating the degradation of the environment.

3.1 China’s Energy Sector Break-down

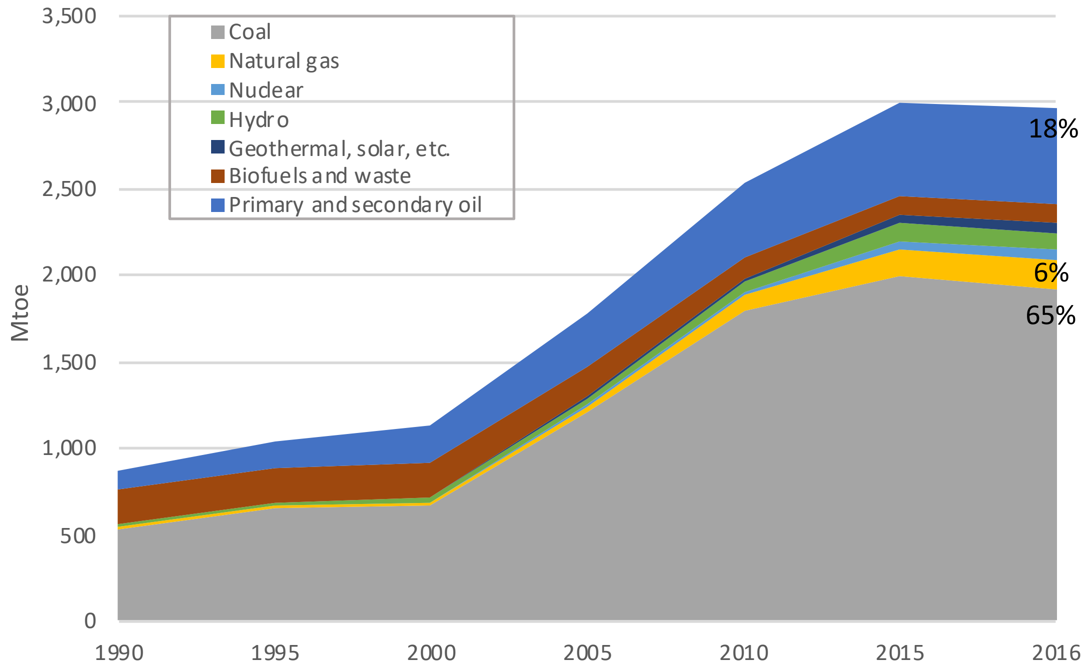


Figure 3. Energy supply by fuel in China in Mtoe from 1990 to 2016. Source: author’s own construction based on International Energy Agency, 2016d.

China’s energy mix has remained fairly constant throughout the years, whereas output has seen major rise coming from increasing energy demand since joining the World Trade Organization (WTO) in 2001 and opening up the country to trade. As seen from figure 3 Chinese energy sector has been mostly relying on burning coal, the most CO_2 intense energy resource. Coal took up more than half or more specifically 65% of the total energy supply (1,916 Mtoe) in 2016. Throughout the years coal share has increased fairly by 4% from 61% in 1990. Because of its significant role in China’s energy production, the Chinese government has heightened interest in the policy strategy for the coal industry, which has seen a lot of changes in order to support the industry’s development. For example the policy to encourage private coal mines in the 1990s to increase production and overcome energy shortages changed to encouraging large state-owned coal mines in order to reduce deaths related to unsafe private coal mines and inefficiencies (Wang *et al.*, 2011). Even more recently in 2018, after long pledging to clean up its environment and showing consistent efforts in this regard by suspending large coal mine constructions, the Chinese government has once again started to approve new coal mine projects for its increased energy demand (Reuters, 2019). Following coal in scale, oil has also increased its share over the years, increasing 5% from 1990 accounting up to 18% (545 Mtoe) in 2016. Oil is followed by natural gas with 5,8% (171 Mtoe) in 2016, biofuels 3,8% (113 Mtoe) and hydro 3,3% (100 Mtoe). Although still accounting for a negligible share in the supply mix, in recent years China has put more effort on renewable energy generation following the energy demand growth and climate change. In 2017 alone China increased its solar power capacity by 53 GW which accounted for over half of world's increase in capacity the same year (International Energy Agency, 2018).

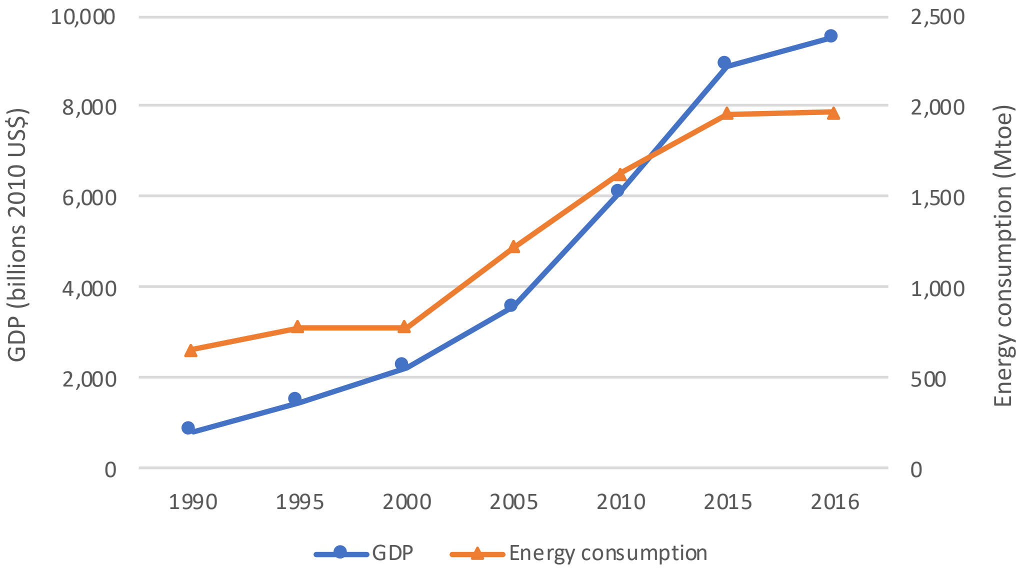


Figure 4. Energy consumption and GDP development in China. Source: The World Bank, 2016 And International Energy Agency, 2016c. Author's own construction.

The energy demand in China has experienced a tremendous spurge in-line with the country's economic growth. The intuition behind this coupled growth is quite straight-forward. China's rapid economic growth has come mostly from increased trade and manufacturing, which in turn requires an expansion in the energy used to meet the world's demand. Figure 4 shows the relationship between energy demand and economic growth in China, which have both seen similar growth paths. Since 2015, however, the trend has changed. China's energy consumption has decoupled from GDP growth, showing the increased efficiency in energy use. This could be partly attributed to reduced coal consumption in the country with the coal share in the energy consumption mix decreasing from 43% in 2010 to 38% in 2016. From energy demand composition, coal is still in the lead with a share of 36% in the mix (710 Mtoe), followed by oil with 25% (495 Mtoe), electricity with 23% (445 Mtoe) and natural gas with 6% (113 Mtoe). From the sectoral view industry has been by far the largest consumer of China's energy accounting for 55% followed by transport sector with 16,4% (International Energy Agency, 2016b). The large share of industry comes from the fact that it includes mining and quarrying, manufacturing, and electricity production as well as transportation.

3.1.1 GHG Emissions

CO_2 is the largest contributor to the greenhouse gases (GHG) accounting to 83,2% in 2012. Other gases include methane (CH_4) which accounts for 9,9% in the total GHG emissions, nitrous oxide (N_2O) – 5,4% and other fluorinated gases – 1,6%. Thus, in discussing emissions in China and emissions embodied in trade, CO_2 will be the main component measured due to data availability and its representativeness of overall GHGs (Sandalow, 2018).

The data on CO_2 emissions in China is not publicly available on yearly basis, which makes the research in this field more complicated compared to similar studies in other countries. The Chinese government has published its CO_2 inventories only for the years of 1994, 2005 and 2012. The gap in the data availability has been attempted to be filled by research institutes' own calculations based on the Intergovernmental Panel on Climate Change (IPCC) emission factors. The methodologies used by these institutions, however, have been criticized to be overestimated (Shan *et al*., 2018). From the data available it is evident that emissions in China have tripled since the turn of the century, while it has started to level off from 2015, in-line with the energy consumption in China. In 2017, China accounted for 28% (9,233 $MtCO_2$) of world's total emissions (BP, 2018a). Figure 2 shows the energy sources that are responsible for most of the CO_2 emissions from fuel combustion in China and their respective shares. Electricity and heat generation account for the largest part – 52% followed by manufacturing – 31%, transport – 8,6% and residential with 5,4%. The large share of electricity and heat production in CO_2 emissions comes from the fact that electricity is generated mostly by the use of coal, which accounts for 68% from total electricity generation (see figure 2). Other major sources of CO_2 emissions, which are not included in China are cement production, which by itself accounts for around 15% from all CO_2 emissions. Cement and steel production constitute large part of construction sector, which has been booming in recent years, with large increases in fixed asset investments and increasing magnitude of infrastructure projects underway (Lin and Zhang, 2016).

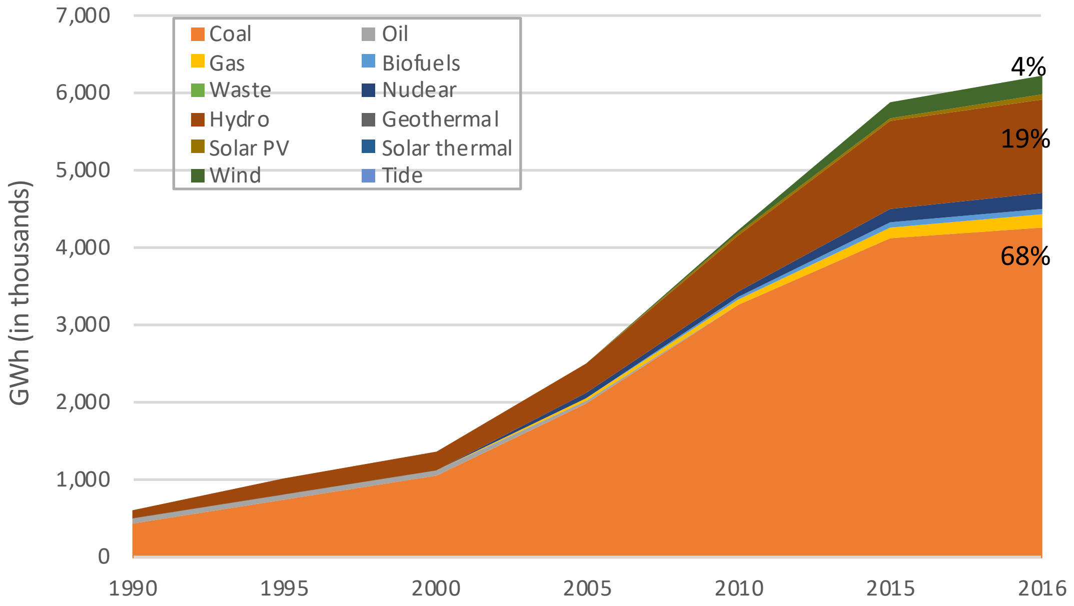


Figure 5. Electricity generation by fuel in China in GWh from 1990 to 2016. Source: author's own construction based on International Energy Agency, 2016a.

3.1.2 Energy Security

Energy is a highly strategic resource in China, considered as an important constituent to national security. While China's resources are quite vast, coupled with China's continuous economic growth and growing energy demand, China has not been able to be "self-sufficient" and meet its demand by solely relying on its own energy resources and production. Thus, China has shifted from net energy exporting country to net importer from 2009. Specifically, due to its scarcity, non-substitutability and history, oil has been the main source of energy insecurity in China. In order to satisfy the growing demand for oil from the rapid increase in the transport sector, the country became net importer of oil already in 1993. To illustrate the significance of it even further, the net import dependence of oil in 2009 reached 53,5%. The previous Chinese Communist Party (CCP) import hesitation in relation to national security has been substituted with the country's pledge for "import security" with many bilateral agreements and investments into foreign oil reserves. (Leung, 2011).

Even though China has huge reserves of coal and is the largest coal producer in the world holding 46% in 2018 (or 45% in 2009) (BP, 2018b), China still became a net importer of coal in 2009. This comes from the great regional disparity between the coal mines and the consumers in China. The coal reserves are located in China’s remote inland regions, especially in Inner Mongolia, Shaanxi and Shanxi. Yet, the largest consumers of coal are the coastal regions, making the transport of coal costly. Due to the higher cost from inland transport and availability of coal in many countries, China’s coastal regions have started to meet their demand by importing it from overseas, mainly from Australia and Indonesia. However, due to the imports’ low share in total coal consumption, it has not been a major security issue for the CCP compared to oil (Leung, 2011).

Natural gas, in terms of imports, has also a rather insignificant role in China’s energy security, since it accounted for only 5,7% in energy consumption by fuel in 2016 and is easily substitutable. Even though China’s natural reserves of natural gas are huge, reaching 5,5 trillion cubic meters, the extraction process has not been very successful. Thus the demand for natural gas has increased faster than its local supplies. China started importing natural gas after the establishment of the first Liquified Natural Gas (LNG) receiving terminal in Guangdong province in 2006 (Leung, 2011). The demand spurge has been especially remarkable in recent years (15% in 2017), when the national energy policies have shifted focus to emissions reduction through switching to low carbon energy resources, like natural gas. Specifically, in 2017, the consumption of natural gas was 91,2 billion cubic meters higher than the production (BP, 2018a).

3.2 Climate Policies and China

In order to tackle its large share in global CO_2 emissions and air pollution, the Chinese Government is committed to put more emphasis on relevant policy enforcement to set clear targets for climate change mitigation. This has also become more visible in the global stage, with its increasing role in the Paris Climate Agreement. The Air Pollution Prevention and Control Action Plan (APPCAP) introduced by the State Council in 2013 can be considered as a milestone in Chinese climate policies. It set clear targets to improve air quality in terms of PM2.5 and PM10 concentration by 2017 and there is evidence that it has been fairly effective, the changes mostly coming from the shift to cleaner energy, natural gas and electricity (Huang *et al.*, 2018).

The recent biggest step towards cleaner energy on a global level has been China's ratification of the Paris Climate Change Agreement introduced in 2015, with submitting their Intended Nationally Determined Contribution (INDC) papers. This was in stark contrast to China's previous stance in committing to international obligations in COP 21 meeting in Copenhagen in 2009. In its INDC paper China set to reduce its CO_2 emissions by 60-65% per unit of GDP by 2030 from the 2005 level and increase its carbon free energy contribution in energy consumption to 20% (Fang *et al*., 2019). The success of Paris Climate Change Agreement conference in 2015 can be traced back to the "New Normal" and its addressing 13th Five Year Plan. The "New Normal" essentially means slower economic growth due to lower global demand. The 13th Five Year Plan addressed the slower growth by adjusting its growth outlook and focus from heavy-industry and export-led growth towards more sustainable, ICT and services led growth, albeit at a lower rate (Hilton and Kerr, 2016).

3.3 Trade Balance and Trade Specialization in China

Since 1978 China has opened up its economy to the world accompanied with economic restructuring making a shift towards socialist market economy Chinese style. Import substitution was gradually lifted and tariffs eased. China shifted its focus on catching up with the West with the aim of foreign technology transfer to the country. China was a good outsourcing destination for foreign companies due to its low wage advantage. The biggest contributor to China's growth has been its accession to WTO in 2001, with the promise to abolish all trade tariffs still in place (Caporale *et al*., 2015). Since then China has enjoyed the export-led growth, which has resulted in positive trade balance since the early 1990s (see figure 6). Chinese trade was badly hit by the Global Financial Crisis (GFC), when the trade balance dropped from U.S. $759 billion to U.S $571 billion (UN Comtrade, 2018). Even though the trade picked up fast after the GFC, showing increasing trend already in 2010, the more recent figures since 2015 show a different trend. Specifically, the world demand from China has started to show signs of cooling down, thus reflecting in the surplus of trade balance, which has been declining ever since.

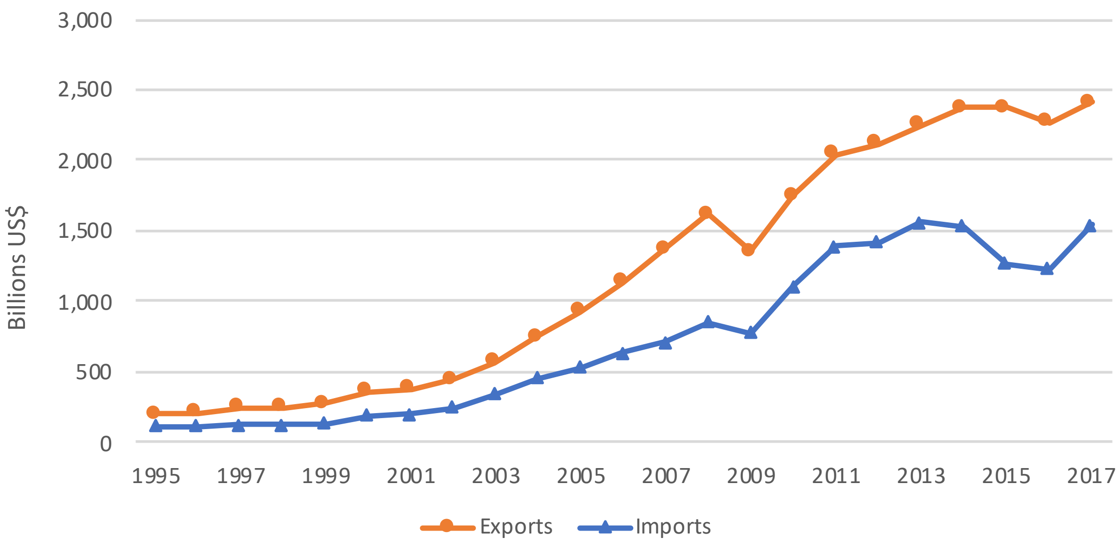


Figure 6. China's balance of trade, 1995-2017. Source: author's own construction based on UN Comtrade, 2018.

China has been long known for their comparative advantage in labor-intense manufacturing industry, which, consistent with trade theory, used to account for the largest part in their exports. Following Finger and Kreinin (1979) export similarity assumption, countries on a similar development level export comparable products. However, China's export basket has started to show more similarities with Germany or Japan than with its should-be competitors in labor-intense sector – Vietnam or Indonesia. This means that China has climbed up its value-chain ladder with technological upgrading being the key driver behind this shift. In other words, labor-intense exports have been replaced by technology-intense machinery, such as broadcasting equipment, parts of data processing equipment, etc. (seeTable A. Products exported by China, 2017 (% of total exports) (Schott, 2006).

The major trading partner for Chinese exports worth U.S. $2,4 trillion in 2017 was the United States, accounting for 20% of its total exports, followed by Hong Kong with 11% and Japan with 6,5%. If the European Union countries are taken separately then Germany has the largest share with 4,5% coming after Japan. With regards to imports, ASEAN countries are the largest partners for China. Other parts of Asia takes 9,8% of the imports worth US $1,5 trillion, followed by South Korea with 9,7%, Japan with 8,8%, United States with 8,7% and Germany with 6,2% (UN Comtrade, 2018).

4 Literature Review

The academic literature in the field of environmental economics is quite extensive, with the groundwork laid by Noble Prize economist Leontief (1970). He developed the input-output analysis framework together with satellite accounts for the environment to be applied to environmental studies. Since then the literature has grown tremendously fueled by the growing concern about increasing CO_2 emissions and about ways to reduce them. The debate about who should take responsibility for emissions started already in early 1990s, with Proops *et al.*, (1993) and Munksgaard and Pedersen (2001) following their lead. In their empirical study on electricity trade, Munksgaard and Pedersen (2001) argued for the shared responsibility between consumers and producers. Especially since the world has become increasingly interconnected through international trade and production and consumption are spatially separated. Their argument relied on Denmark's electricity trading with Norway, where during the Kyoto protocol's base year in 1990 Denmark imported electricity generated by hydropower from Norway in large volumes, thus reducing Denmark's CO_2 emissions considerably and, which was then used to set future targets for emissions reduction. In parallel to the debate between consumer and producer responsibility, another debate between different models to account for emissions embodied in trade had emerged. Since then studies from Lenzen *et al.*, (2004), Lenzen *et al.*, (2007) etc. have emerged, applying different methods and datasets for CO_2 emission embodied in trade studies. These are in broad terms categorized into studies using Single-Region Input-Output (SRIO) and Multi-Region Input-Output (MRIO) method. In this paper, however, the focus will be on MRIO, due to the use of this method in the empirical analysis of this research. Following MRIO, studies that have gone further from IO analysis to decompose the emissions into their underlying factors will be elaborated upon, i.e. the effects from trade balance, trade specialization, energy intensity etc.

4.1 Multi-Region Input-Output Analysis

The MRIO model has its roots from Inter-Region Input-Output (IRIO) model applied as early as 1951 by Isard (1951), which was mostly intended for regional analyzes with technological differences within the U.S. regions. The first examples of the MRIO literature emerged already in the 1990s (Imura and Tiwaree, 1994; Battjes *et al*., 1998) but started to see more consistency in the 2000s (Lenzen *et al*., 2004). In recent years more studies have emerged using the MRIO approach, especially since the publication of harmonized MRIO tables or World Input-Output Tables (WIOT), which have been conducted by different research institutes. Besides the availability of harmonized tables, another advantage of MRIO over other methods is its distinction between trade in intermediate and final consumption, which allows for more detailed country analyzes.

Among the more recent studies Davis and Caldeira (2010), Peters *et al.* (2011) and Boitier (2012) have used the MRIO methodology to study the emissions embodied in trade using the consumption-based perspective. Their research has found evidence that global emissions transfer follows a trend of regional divergence. That is, more emissions from developed countries are being transferred to developing countries. More specifically, Davis and Caldeira (2010) used global economic data of 113 countries, disaggregated into 57 industries from 2004 to study the consumption-based CO_2 emissions. They found that in 2004 23% of global CO_2 emissions were traded internationally and show that this mostly follows the pattern of exports from China and other emerging markets to consumers in wealthy countries, like Switzerland, Sweden, the UK, etc., proving the existence of weak carbon leakage and regional distinction of developed (Annex-I) and developing countries (non-Annex-I). Following Davis and Caldeira (2010), Peters *et al.* (2011) applied similar approach and database to study the growth in CO_2 emissions in international trade but looked into the trends over time making use of time-series data of 1990-2008. They found that the emissions coming from production of traded goods increased from 4,3 $GtCO_2$ in 1990 to 7,8 $GtCO_2$ in 2008 and that the developed countries have increased their consumption-based emissions faster than their territorial emissions. Resulting in 11% of global emissions growth from 1990 being consumed by the developing countries, compared to 3% reduction from territorial accounting. Boitier (2012) studied production- and consumption-based CO_2 emissions for six aggregated regions (EU-15, EU-12, EU-27, OECD, BRIC and Rest of the World (RoW)) for the period of 1995-2009. Similar to the previous studies, the author found that the world can be divided into two: CO_2-consumers (i.e. the developed countries: EU-27, EU-15, OECD) and CO_2-producers (i.e. the developing countries: BRIC, RoW). More specifically, the results point to the increasing trend in the gap between developed and developing countries from 1$GtCO_2$ of emissions in 1995 to 2,25 $GtCO_2$ in 2008, which raises questions about the effectiveness of the climate change policies.

In relation to the climate policies, which are undermined by the carbon leakage problem, Sakai and Barrett (2016) studied the volume of emissions in trade that could be taxed by the Border Carbon Adjustment (BCA) – a border tax levied on imported emissions to address the carbon leakage. Using the MRIO model for 2017, they found that 5,3 $GtCO_2$ (approximately 17,9% of global emissions) was imported to Annex-I countries, whereas 3,5 $GtCO_2$ (11,8%) was exported from Annex-I countries to the rest of the world. According to their analysis of emissions together with trade regulations and tariff rates, consistent with the results from Jakob *et al.* (2014), they found that putting a price on emissions embodied in imports or BCAs to be an ineffective policy tool for reducing carbon leakage. Specifically, in the case of China, they argued that a tariff as low as 1,2% does little to protect the domestic industries and competition. Instead, close international cooperation is suggested together with a mix of emissions abating policies (i.e. state's aid on sensitive industries, free but output-based allocation of allowances for emission-intense industries, wider implementation of carbon abatement policies like Clean Development Mechanism, etc.).

4.1.1 Technology-adjusted Emissions Embodied in Trade

Following the shift in literature from production-based accounting (PBA) to consumption-based accounting (CBA) due to concerns in fair division of responsibility in global emission abatement, new concerns over the effectiveness of CBA approach have emerged. The major criticism includes the CBA's effectiveness, practicability, political incompatibility and carbon efficiency differences between countries (Afionis *et al.*, 2017; Kander *et al.*, 2015; Liu, 2015). First, the issue of effectiveness covered in Liu (2015) argues that essentially both, the PBA and CBA serve the same goal: the reduction of global emissions from reducing production. This can be directly linked to PBA but also indirectly to CBA, since it will put pressure on consumers, who consequently will put pressure on producers to reduce emissions. Thus, arguing that PBA is more effective together with environmental policies on carbon emission reduction. Second, there has been a lot of criticism around the complex nature of CBA calculations and inconsistencies within the provided datasets. Meaning that CBA approach not only relies on statistical assumptions from PBA but also on the modeling assumptions of CBA (sectoral carbon intensities in international trade) (Afionis et al., 2017). Third, the political incompatibility seems to be the biggest obstacle in adopting the CBA approach, since it requires extensive international cooperation in reaching carbon emissions abatement policies. Adopting CBA perspective would assume that developed countries would be willing to take responsibility for emissions they have no control over and likewise that developing countries are willing to let their domestic production (technology) choices be influenced by developed countries. (Afionis et al., 2017). Lastly, Kander *et al.* (2015) argue that under CBA approach all export related emissions are shifted to consumers and thus, neglects the measures taken by countries to increase carbon efficiencies or cleaner technology in their export industries. Henceforth, a country that has energy-intense production for exports but uses relatively clean energy mix in producing it, would consequently have lower carbon content compared to its trading partners and therefore be perceived as carbon importer. While the carbon leakage argument found under CBA results in decreased carbon emissions domestically, and an increase of emissions abroad, the net export or imports, however, may be caused by the differences in carbon intensities among the trading partners. In the case of exporting with cleaner technology there will not be any increase in emissions abroad, and this should be taken into account when assigning responsibility over emissions under CBA (Jiborn et al., 2018).

In light of the differences in technological efficiencies in export industries Kander *et al.* (2015) have introduced a new approach to accounting for emissions embodied in trade, namely the technology-adjusted CBA or TCBA, where carbon intensities of country's exports are adjusted to the world average. They used MRIO analysis to calculate TCBA for 40 countries. In contrast to the results from previous CBA analyzes (Davis and Caldeira, 2010; Boitier, 2012), their results do not show any clear regional disparity between developed (Annex-I) and developing countries (non-Annex-I). Also, the results for Europe show TCBA to be lower than PBA, which show that some of the difference can be attributed to the differences in carbon intensities between the trading countries. In the case of China, TCBA was lower than in PBA but higher than CBA, which means that China is still net exporter of emissions embodied in trade, however, under TCBA it is held accountable for its carbon intensity.

4.1.2 Decomposition Studies

To continue with the weaknesses in CBA approach, Jakob and Marschinski (2013) argue that focusing only on the net emissions from CBA approach does not provide an accurate picture of the factors causing higher emissions in the producing country and, therefore developing climate policies in attempt to reduce global emissions based on CBA approach would be premature. Especially since without international trade these emissions could end up being higher. Instead, Jakob and Marschinski (2013) propose that a more detailed analysis should be conducted to see the real contribution to emissions embodied in trade. More specifically, a decomposition that would divide the emissions embodied in trade into its driving forces. The authors applied Laspeyres index decomposition to IO analysis results from Davis and Caldeira (2010) to divide the emissions into its four driving forces: 1) trade balance; 2) trade specialization; 3) energy intensity; and 4) carbon intensity. Their results point to the conclusion that the widely applied Heckscher-Ohlin (HO) trade theory, where countries specialize and trade based on their comparative advantage, does not provide an accurate picture. Especially since factor productivity of the production differs among countries. Also, basing policies on the conventional net exports and imports would not lead to desired effects since the effect can come from the unbalanced scale of trading. Especially in the case of the U.S. where under the CBA they would be held accountable for their emission imports. Whereas, the decomposition results show that around 45% of this comes from their trade deficit with China.

Xu and Dietzenbacher (2014) also conduct a decomposition analysis based on their IO analysis results of 40 countries in 1995-2007. They, however, apply the structural decomposition analysis (SDA) to decompose emissions embodied in trade into five underlying factors: 1) emission intensity; 2) changes in trade structure of intermediate goods; 3) changes in production technology; 4) changes in trade structure of final goods; and 5) changes in the level of final demand. They found that the increase in global emissions embodied in trade and the uneven division between developed and developing countries can be attributed to the change in trade structure. The changes in the world trade structure of intermediate goods has reduced U.S. emissions embodied in exports by 11% showing world's declining dependence on U.S. intermediate production, which holds true for many other developed countries. In contrast, increase in global dependence on emerging markets (i.e. China and India) have increased their emissions embodied in exports (EEE) share by 45%. More specifically, in the case of China, the results show that from 1995-2007 the EEE has increased by 207% of which the foreign trade structure plays the largest role, accounting to 119%, closely followed by the foreign trade structure of final goods that accounted for 95% of EEE. Implying that China has become the "world factory" by world's production shift to China.

Following Jakob and Marschinski (2013) argument provided above, Jiborn *et al.* (2018) emphasize the need for decomposition analysis to separate the effects of scale and composition of exports relative to imports from the carbon intensity effect. They argue that the four factor decomposition applied by Jakob and Marschinski (2013) is not sufficient coming from the definition of trade specialization. Thus, based on previous work by Kander *et al.* (2015) and commentary by Domingos *et al.* (2016), they propose a technology-adjusted balance of emissions embodied in trade (TBEET) be used to see whether the displacement controversy holds true. In other words, they cancel out the differences in carbon intensities between trading partners by adjusting relative carbon intensities of country's exports and imports to the world average in each sector. Furthermore, they apply Laspeyres index decomposition, similarly to Jakob and Marschinski (2013), to calculate the contributions of two factors: trade balance and composition of exports and imports to TBEET. The results show that in the case of Sweden, BEET is negative for the whole period under study, whereas with TBEET it is positive, however, diminishing over time. For the case of the UK, however, TBEET was negative over the study period, similar to the BEET. The more detailed decomposition results show that for the UK, trade specialization was the major contributor to negative TBEET, thus emphasizing the fact that the UK has increased the imports of more carbon-intense products compared to its exports. For Sweden, however, in contrast to BEET, the results from TBEET show specialization to be negative, which were offset by positive trade balance, thus resulting in positive TBEET.

Baumert *et al.* (2019), extend the methodologies developed by Jiborn *et al.* (2018) to 40 countries and look at the TBEET from more global perspective. Their results show that if global trade is taken into account while adjusting for world average carbon intensities, the carbon leakage effect is much smaller than under conventional systems. For example, China's TBEET is still found to be positive but less so than its BEET, implying higher carbon intensities than the world average. For the EU-27, however, TBEET was throughout the period positive, whereas under BEET it was negative. Also, their results point that there is no clear distinction between developed countries being outsourcers of emissions and developing countries being the insourcers of emissions. Especially since, China and Russia are the only developing economies that clearly show positive TBEET, whereas in Brazil and Indonesia it fluctuates around zero.

Liu *et al.* (2017) studied the emissions embodied in China's exports and net exports during 2002-2011 by applying temporal and spatial decomposition analysis to all GHGs (CO_2, CH_4, N_2O, NO_x and SO_2). In order to see the underlying factors of emissions in China, they applied three factor (trade specialization, trade balance and emission intensity) index decomposition analysis or more specifically the Log-Mean Divisia Index (LMDI) decomposition analysis to their results from emissions embodied in trade calculated through the SRIO model. They found that production of exports had a significant impact on emissions in China. In the spatial decomposition, it was found that emission intensity had declined quite drastically, however in comparison with its major trading partners the gap remained. Furthermore, the results pointed that China had higher specialization effect in pollution-intense goods in it imports compared to exports, which contradicts the results from Baumert *et al.* (2019).

4.1.3 Research Contribution

In light of the literature reviewed above, this academic research paper will attempt to contribute to these existing researches in the field by conducting a two-step analysis. Namely the input-output analysis (IOA) and the decomposition of the results from the previous step. This paper deviates from previous works by using different methodologies in the IOA and decomposition analysis. The current research will build upon Baumert *et al.* (2019) in the derivation of technology-adjusted balance of emissions embodied in trade (TBEET) but decomposing the results based on all 35 sectors using the Log-Mean Divisia Index (LMDI) decomposition instead of Laspeyres index decomposition analysis to allow for the detailed sectoral view. Moreover, the decomposition analysis will be based upon the spatial decomposition method described by Liu *et al.* (2017), but deviates from the analysis in the methodology used for IOA, the specific sectoral view and the technology-adjusted approach.

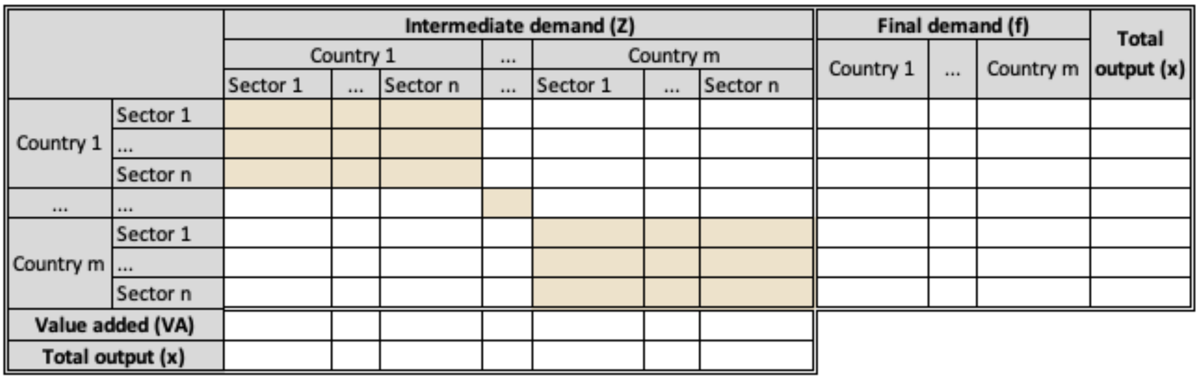
5 Data

Input-output analysis (IOA) requires an extensive amount of data. This is illustrated by the fact that in total approximately 27 million input-output data was analyzed for the purpose of this paper. Data for the IOA and the following decomposition was gathered from the World Input-Output Database (WIOD) (Timmer *et al.*, 2015). The database contains yearly input-output tables from 1995-2009 for 27 EU countries and 13 other major countries, including a model for Rest of the World (RoW), thus in total 40 countries and RoW. The WIOD tables are intended to show trade flows in monetary terms (denoted in millions of U.S. dollars) between these 41 countries, which are disaggregated into harmonized 35 sectors. This paper will conduct a time-series analysis of CO_2 emissions over 10 year period from 1999-2009 in order to see the effect of China joining the WTO in 2001. The database provides also other satellite tables connected to the IO tables. Specifically, the environmental accounts tables for different environment related indicators, such as energy use, CO_2 emissions, emissions to air, land use, materials use and water use, as well as socio-economic accounts tables, which include data on employment, capital stocks, gross output and value added. For the purpose of this paper, the IO tables combined with environmental accounts data will be used. It has to be noted that the WIOD database has released an update for the years from 2010 to 2014, however due to the lack of funding, the environmental accounts tables have not been updated since 2009 (Timmer *et al.*, 2015). Thus, constraining the analysis of this academic research to the years from 1999-2009.

In recent years there has been an increase in the number of different sources for input-output tables by different research institutes. Some examples are the EXIOPOL, the OECD/WTO value added database, the Asian Development Bank multi-region input-output tables (ADB-MRIO), the IDE Jetro Asian International Input-Output Tables (AIIOT) and the Eora MRIO database. The WIOD was chosen for its transparent methodology, providing already well-constructed tables available for the public, and its disaggregation to 35 sectors, which are homogenous throughout all tables. Eora, for example, covers wider range of years, 187 countries and is disaggregated into more sectors. However, due to the complexity of these tables and the data quality issues arising from the inclusion of countries with less statistical quality and transparency, Eora tables were not used. Since other databases (ADB-MRIO, IDE) are constructed for certain benchmark years then these databases are less suitable for time-series analysis (Timmer et al., 2015).

5.1 World Input-Output Tables for IOA

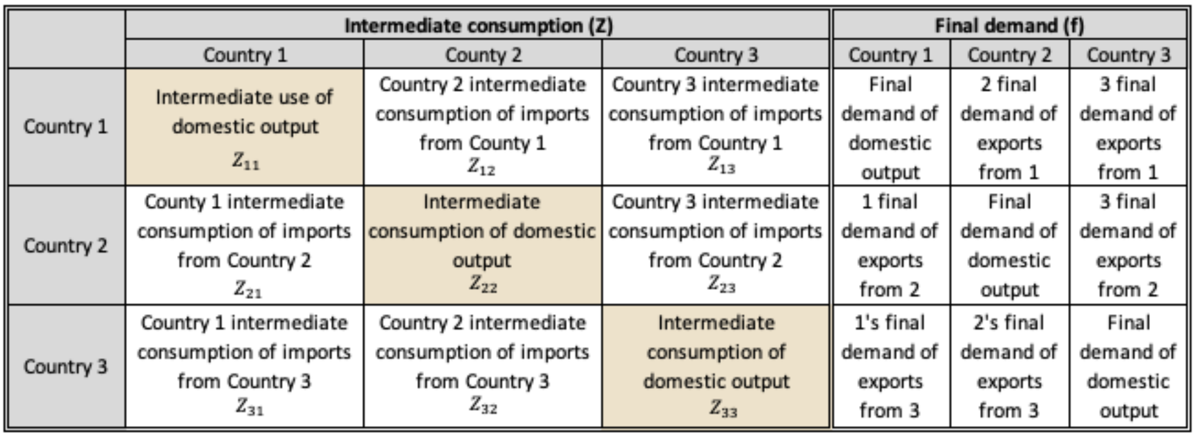
All world input-output tables (WIOTs) have a similar structure to show monetary flows throughout global supply chains. Essentially they combine national input-output tables with bilateral international trade flows. In construction of the WIOD, official data from published national supply and use tables (SUTs) have been used. The countries were chosen based on the data availability and the attempt to cover large part of global economy. With the 40 countries, the WIOD covers approximately 85% of the world's GDP calculated in 2008 constant prices.
The IO tables are constructed as symmetrical industry-by-industry matrix tables for 41 countries including the model for Rest of the World (RoW), which differentiate between intermediate (Z) and final (f) demand (see figure 7). The sum of all rows equal the total output in respective industry in a country (x) and similarly, the sum of all columns equal the total output of a certain industry in a country.



		Intermediate demand (Z)							**Final demand (f)**			**Total output (x)**
		Country 1			...	Country m			Country 1	...	Country m	
		Sector 1	...	Sector n	...	Sector 1	...	Sector n				
Country 1	Sector 1	▨	▨	▨								
	...	▨	▨	▨								
	Sector n	▨	▨	▨								
...	...				▨							
Country m	Sector 1					▨	▨	▨				
	...					▨	▨	▨				
	Sector n					▨	▨	▨				
Value added (VA)												
Total output (x)												

Figure 7. WIOT table construction. Source: author's own construction based on Timmer *et al*. (2015).

Figure 8 shows the simplified three country model of WIOT with an explanation on the interlinkages between countries. The value for Z_{11} denotes the intermediate use of domestic output (also marked as beige in the figures 7 and 8), whereas the value of Z_{21} denotes the intermediate use by country 2 of imports from country 1. Similarly with final demand, the value for f equals the final use of domestic output, whereas f_{21} denotes the final use by 2 of exports from 1. The full WIOD IO table for one year includes a 1435x1435 intermediate demand matrix, a 1435x205 final demand matrix and in addition, the value added and total output rows (column). The environmental satellite accounts tables have been also provided by the WIOD to allow for environmentally extended input-output analysis. These include the CO_2 and other environmental accounts data disaggregated by the 35 industries used in the WIOT on each country through the years of 1995-2009.



	Intermediate consumption (Z)			Final demand (f)		
	Country 1	County 2	Country 3	Country 1	Country 2	Country 3
Country 1	Intermediate use of domestic output Z_{11}	Country 2 intermediate consumption of imports from County 1 Z_{12}	Country 3 intermediate consumption of imports from Country 1 Z_{13}	Final demand of domestic output	2 final demand of exports from 1	3 final demand of exports from 1
Country 2	County 1 intermediate consumption of imports from Country 2 Z_{21}	Intermediate consumption of domestic output Z_{22}	Country 3 intermediate consumption of imports from Country 2 Z_{23}	1 final demand of exports from 2	Final demand of domestic output	3 final demand of exports from 2
Country 3	Country 1 intermediate consumption of imports from Country 3 Z_{31}	Country 2 intermediate consumption of imports from Country 3 Z_{32}	Intermediate consumption of domestic output Z_{33}	1's final demand of exports from 3	2's final demand of exports from 3	Final demand of domestic output

Figure 8. WIOT interlinkages explained. Source: author's construction based on Timmer et al. (2015).

5.2 Assumptions Made Under WIOD Construction

In order to compile the WIOTs, extensive amount of data is derived from different statistical offices and databases, thus indicating a set of assumptions made in the process. Furthermore, certain limitations of the WIOTs have to be elaborated upon, so that any conclusions derived from the use of the data will take these limitations into consideration. Thus, following Timmer *et al.* (2015) the section below will describe these limitations and assumptions made.

1) Import proportionality assumption – in the construction of WIOT tables through national supply tables, it is assumed that the shares of country-of-origin in imports are proportional to all uses of this product. In other words, if Sweden imports 10% of its semi-conductors from Japan, it is assumed that 10% all intermediate and end-uses of semi-conductors in Sweden come from Japan.
2) Technological homogeneity assumption – in production of a good in a specific sector, it is assumed that all companies within that sector use similar production technology.
3) Rest of the World aggregation into one group – in order to include the whole world trade and not exclude rather significant part (15%) of the global GDP, the remaining countries

were modelled into RoW. However, when treated as a single group, the flows of imports and exports within this group and also the country-of-origin remains unknown. Thus, this classification can lead to some inconsistencies in the global import and export flows. As explained by Su and Ang (2010), spatial aggregation can lead to under- or overestimation of the results depending on whether a certain region has a low or high emission intensity and consequently leads to reduced representativity of the situation.

5.2.1 Limitations

Moreover, the construction of WIOTs involve certain limitations, which could affect the data reliability. For one, in order to construct a harmonized table from supply and use tables of different countries, the harmonization required a currency conversion to U.S. dollars. In the WIOD market exchange rates were used for this purpose. However, Rodrik (2008) have found that in certain countries currencies are undervalued, especially noticeable in the developing countries (i.e. China). This trend of undervaluation has historically been one of the driving forces of its economic growth from the export sector. Thus, this could give rise to errors in the results for other importing countries. Andersson (2018) provides an alternative method that could have been used to mitigate this over/undervaluation risk. Specifically, he used the rate from the difference of the actual exchange rate of a country and a long-term equilibrium exchange rate from the World Development Indicators. He argues, however, that this undervaluation in case of China has limited effect on the exported CO_2 emissions.

Second, the WIOD IO tables are based on national supply and use tables, which are usually published in an interval of few years and used as reference since the technical coefficients are slow to change and the surveying is expensive for the statistical offices. However, since the WIOD's aim was to provide a database where a time-series analyses could be made, the remaining years outside the official supply and use tables had to be estimated (Dietzenbacher *et al.*, 2013).

Third, the supply and use tables from different countries are far from homogenous. Most notably there are vast differences between the sectoral disaggregation, for example with some countries having 65 (Sweden) and some 71 (U.S.). Thus, harmonizing these tables into coherent

35 industries inherently indicates that some industries had to be aggregated. Meaning that some industries might have been combined with industries that could show significant impacts.

5.3 Decomposition Data

To see more detailed results, the second analysis step, the LMDI decomposition, will be based on the IOA. Meaning that the data needed for the decomposition, will be calculated in the first IOA stage. In order to see the sectoral contributions to TBEET, sector specific technology-adjusted emissions embodied in exports (TEEE), sector specific technology-adjusted emissions embodied in imports (TEEI), aggregate sector specific exports and aggregate sector specific imports for China were used. The decomposition will include only the data for China, since the analysis attempts to focus on the China's emissions embodied in trade and its underlying factors. The specific methodology, how these were calculated will be further elaborated upon in the next methodology section.

5.3.1 Limitations

First major downside for the LMDI decomposition is that it is unable to handle negative or zero values. Even though often said that it is unlikely to have negative values in the IO data, it can happen. Zero values, however, are a more common case. Meaning that some sectors of a country can have zero trade with other countries. With this in mind and as suggested by Ang and Liu (2007) the zero values were replaced by a very small number equivalent to 10^{-16}, which would in the end have almost no effect on the results. Negative values, however, are more serious issue. These cannot be easily replaced as it can affect the data. This comes from the mathematical form of LMDI that uses natural logarithms to decompose the aggregate value to its underlying driving forces. In this paper two very small negative values (-0,005) in real estate and healthcare sectors were encountered and were similarly set to a small positive number in a manner stated above. This transformation was undertaken due to its small impact on the overall results and to allow for the continuation of the decomposition analysis without omitting the sectors.

Second limitation or rather a precaution for data preparation and analysis in decomposition is inflation. This becomes especially important in time-series analyzes where monetary values are used. Not taking inflation into account could inflate the results from the analysis thus leading to bias or overestimation. Since the WIOD tables have been constructed in current prices, measures to mitigate inflation have been proposed by different authors (Gasim, 2015; Xu and Dietzenbacher, 2014; Dong *et al.*, 2010). The WIOD does, however, include tables from 1995-2009 also in previous year prices, which makes the combination of tables in current year and previous year prices to the decomposition as one solution to mitigate the inflation bias. The analysis can be thus conducted via the rolling base-year approach from year 1995-1996, 1996-1997, etc., allowing for more precise results from the inflation perspective but also from the decomposition perspective, since the yearly fluctuations will be visible. The WIOD tables in previous year's prices have been deflated row-wise using the output deflators from National Accounts (Xu and Dietzenbacher, 2014). Thus, when WIOD tables in previous year's prices are not available the double deflation method could be applied, which in principle uses the same methodology as in WIOD. While the double deflation method has been well acknowledged method, also used by the United Nations, the process is quite time consuming, especially when more than few countries have been involved.

As noted by Gasim (2015) and Xu and Dietzenbacher (2014), the inflation bias is important especially for the emission intensity effect due to industries being measured in emissions per dollar of output. However, since the emission intensity effect has been cancelled out in the calculation of TBEET used in the decomposition then the inflation risk has been partially reduced. In the case of this analysis inflation has not been taken into account due to time constraints, however it could lead to some bias and overestimation in the results.

6 Methodology

The empirical analysis in this research paper includes a two-step analysis approach. Meaning that in order to analyze the underlying driving forces of China's TBEET the sectoral input from IOA is required. This section will therefore explain the methodologies used in the two-step analysis in detail starting from the first input-output analysis (IOA) and then proceeding with the decomposition analysis.

6.1 Input-Output Analysis

The input-output analysis (IOA) has been widely used analytical framework for studying interdependencies of industries in an economy. Introduced by Leontief in late 1930s, the analytical tool has been since then constantly improved and extended to give the framework a greater detail in the analysis of an economy. In principle, the IOA is a set of linear equations, that characterize the movement of a product through an economy and makes use of specific economic trade data for a certain economy. The economic data is incorporated into interindustry transaction table described in the previous section (see figure 7), where the rows indicate the flows of produced goods in an economy (producer) and columns the demand or inputs needed from a particular sector to produce an output (purchaser) (Miller and Blair, 2009).

If the economy consists of *n* sectors, then the way by which sectors sell their products to other sectors (intermediate demand) and to final consumption (final demand) through an economy can be depicted as follows:

$$\begin{pmatrix} x_1 \\ \vdots \\ x_i \\ \vdots \\ x_n \end{pmatrix} = \begin{pmatrix} z_{11} & \cdots & z_{1j} & \cdots & z_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ z_{i1} & \cdots & z_{ij} & \cdots & z_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ z_{n1} & \cdots & z_{nj} & \cdots & z_{nn} \end{pmatrix} + \begin{pmatrix} f_1 \\ \vdots \\ f_i \\ \vdots \\ f_n \end{pmatrix} \qquad (6.1)$$

Where x_i denotes the total production (output) of sector *i* and z_{ij} the intermediate sales to sector *j* (including itself, when i=j) and f_i the total final demand for sector *i*'s product.

From here on the column vectors will be denoted with lowercase letters (i.e. x or f) and matrices with upper-case letters (i.e. Z). Therefore, *(6.1)* can be summarized by the following formula:

$$x = Z_i + f \tag{6.2}$$

The relationship between inputs and outputs is defined by the technical coefficient or a_{ij}, which describes the amount of good i needed to produce one unit of good j or more illustratively, a ratio of steel input to train output, which can be written as:

$$a_{ij} = \frac{z_{ij}}{x_j} \tag{6.3}$$

It has to be noted that Leontief's input-output model assumes that there are constant returns to scale, which means that if output increases by two the inputs needed to produce this output increase by two as well. The flows between sector's input and output are thus fixed. The technical coefficient matrix will be from here on denoted as A.
Reformulating equation *(6.3)*, by substituting z_{ij} with $a_{ij}x_j$ the relationship from *(6.2)* can be written as:

$$\begin{pmatrix} x_1 \\ \vdots \\ x_i \\ \vdots \\ x_n \end{pmatrix} = \begin{pmatrix} a_{11}x_1 & \cdots & a_{1j}x_j & \cdots & a_{1n}x_n \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ a_{i1}x_1 & \cdots & a_{ij}x_j & \cdots & a_{in}x_n \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ a_{n1}x_1 & \cdots & a_{nj}x_j & \cdots & a_{nn}x_n \end{pmatrix} + \begin{pmatrix} f_1 \\ \vdots \\ f_i \\ \vdots \\ f_n \end{pmatrix} \tag{6.4}$$

When equation *(6.4)* is rearranged, the final demand can be expressed as:

$$(I - A) * x = f \tag{6.5}$$

where I is the identity matrix, with ones in the main diagonal and zeros in all other fields. Equation *(6.5)* can be solved for output *x* by taking the inverse of *(I—A)*. Thus, the whole output required to produce one final demand is described by:

$$x = (I - A)^{-1} * f \tag{6.6}$$

$(I - A)^{-1}$ (also denoted as L in rest of the paper) is described as the Leontief inverse or the total requirements matrix. Showing the increase of output in all sectors due to an increase in final demand (Miller and Blair, 2009).

6.1.1 Environmentally Extended IOA

As mentioned in the previous section the input-output tables have been also extended to allow for more detailed analysis of an economy. One of these extensions is environmental accounts, which allows for identification of carbon dioxide generation through interindustry activity on a global scale. Thus, in the context of this paper and more specifically in the context of the analysis of CO_2 emissions embodied in international trade of China, the CO_2 data was combined with the IOA. Emissions generated in a certain economy can be thus found via the total output equation for final demand in *(6.6)* by multiplying it with emission intensity vector *d*:

$$E = \hat{d} * L * f \tag{6.7}$$

Where *E* is the total emissions generated directly and indirectly in an economy in the production process of final output and $\hat{d}$ a matrix diagonalization of direct emission intensities. The emissions embodied in exports and imports are then calculated by summing up all the emissions embodied in trade from country *i* to country *j* – denoted by e_{ij} or conversely by e_{ji} for imports:

$$EEE_i = \sum_{i \neq j}^{n} e_{ij} \tag{6.8}$$

$$EEI_i = \sum_{i \neq j}^{n} e_{ji} \tag{6.9}$$

The balance of emissions embodied in trade is then calculated by subtracting found emissions embodied in imports from emissions embodied in exports:

$$BEET_i = EEE_i - EEI_i \tag{6.10}$$

6.1.2 Technology-adjusted Balance of Emissions Embodied in Trade

In order to show the technology-adjusted emissions, the effects from different energy intensities for different countries has to be cancelled out. This is done by replacing $\hat{d}$ from equation *(6.7)* with the world average CO_2 intensities in each sector, which are then denoted by $\widehat{d^{WA}}$:

$$E = \widehat{d^{WA}} * L * f \tag{6.11}$$

The element ${e_{ji}}^{WA}$ shows now the emissions embodied in trade when the technology to produce the final good would be exactly the same in each country. Consequently, the technology-adjusted emissions embodied in imports, exports and the balance for country i are calculated similarly to equations *(6.8 - (6.10*:

$$TEEI_i = \sum\nolimits_{i \neq j}^{n} e_{ji}{}^{WA} \tag{6.12}$$

$$TEEE_i = \sum\nolimits_{j \neq i}^{n} e_{ji}{}^{WA} \tag{6.13}$$

$$TBEET_i = TEEE_i - TEEI_i \tag{6.14}$$

6.2 Decomposition of TBEET

As argued by Jakob and Marschinski (2013), calculating emissions embodied in trade does not give the full picture of the driving factors behind the emissions embodied in trade. Thus, a further decomposition is necessary. The decomposition has been conducted using an index decomposition analysis (IDA) method, which has been a widely used method primarily for energy consumption analyzes but since the 1990s has also become widely used in CO_2 emission decomposition analyzes. It was named index decomposition analysis in order to clarify the difference between structural decomposition analysis (SDA), which instead of aggregate industry data uses IO tables (Ang, 2015). Thus, IDA is considered more easily applicable compared to SDA, which is also more time consuming analysis. The specific formula formulation process for IDA is described in detail by Ang (2005) and more recently in Ang (2015). Following Liu *et al.* (2017) the IDA identity for the decomposition for three-factor approach for emissions embodied in exports and imports can respectively be written as:

$$TEEE = \frac{E_i}{GDP_i} * \frac{\frac{TEEE_i}{Ex_i}}{\frac{E_i}{GDP_i}} * Ex_i = Sp_i * Ex_i \tag{6.15}$$

$$TEEI = \frac{E_i}{GDP_i} * \frac{\frac{TEEI_i}{Im_i}}{\frac{E_i}{GDP_i}} * Im_i = Sp_i * Im_i \tag{6.16}$$

Where E_i is the total emissions, $\frac{E_i}{GDP_i}$ emission intensity, Sp the degree of specialization in pollution-intensive products, Ex_i total exports and Im_i total imports.

Under IDA methodology, the LMDI decomposition method was chosen instead of Laspeyres index because of its ease of use, near perfect decomposition leaving no residuals and the possibility of adding sub-sectors for sectoral analysis. In this case 35 sub-sectors from the IOA have been decomposed into two underlying factors. However, LMDI has the limitation of being able to handle only positive numbers due to the logarithmical function involved, which were elaborated upon in the section of data description (Ang, 2005).

Since the energy intensity effect has been cancelled out by calculating technology-adjusted balance of emissions in trade with energy intensity set as world average, then the IDA identity will not include the energy intensity effect. Instead the TBEET have been decomposed into two major factors: trade balance (scale effect) and trade specialization (composition effect), thus the LMDI decomposition of the TBEET can be described as:

$$\begin{aligned} TBEET = TEEE - TEEI = {} & Sp_i * Ex_i - Sp_i * Im_i \\ = {} & \Delta Sp_i + \Delta TB_i \end{aligned} \qquad (6.17)$$

where the change in trade specialization (ΔSp_i) and trade balance (ΔTB_i) effects are described respectively as (where $Sp_{w/i}$ denotes world's specialization besides country i):

$$\Delta Sp_i = \frac{TEEE - TEEI}{lnTEEE - lnTEEI} * \ln\left(\frac{Sp_i}{Sp_{w/i}}\right) \qquad (6.18)$$

$$\Delta TB_i = \frac{TEEE - TEEI}{lnTEEE - lnTEEI} * \ln\left(\frac{Ex_i}{Im_i}\right) \qquad (6.19)$$

7 Empirical Analysis

7.1 Results

This section will attempt to bring out the main results that could be drawn from the extensive data analysis. Since the analysis included the data analysis of 27 million, the detailed results with the comparison of the BEET and the TBEET for all 41 countries will be presented in a table format which can be found in the appendix (see Table D. BEET and TBEET results for all 41 countries, including RoW ($MtCO_2$). It has to be noted, however, that even though the analysis included the years 1999-2009, the graphical depictions will mostly be limited to four years (1999, 2002, 2005 and 2009) to save space. Also, in the presentation of decomposition results, in order to better show the effect of major contributors to the China's overall TBEET, some less relevant sectors with relatively insignificant contribution have been omitted. With this academic paper taking a two-step methodology approach with the IOA as the first step and the sectoral decomposition for the second step, the results will follow the same sequence. Meaning that the overall IOA results from the perspective of China will be elaborated on first and then the paper will move on to more specific sectoral decomposition results for China to show the underlying reasons behind China's net emission contribution to its TBEET.

7.1.1 Emissions Displacement

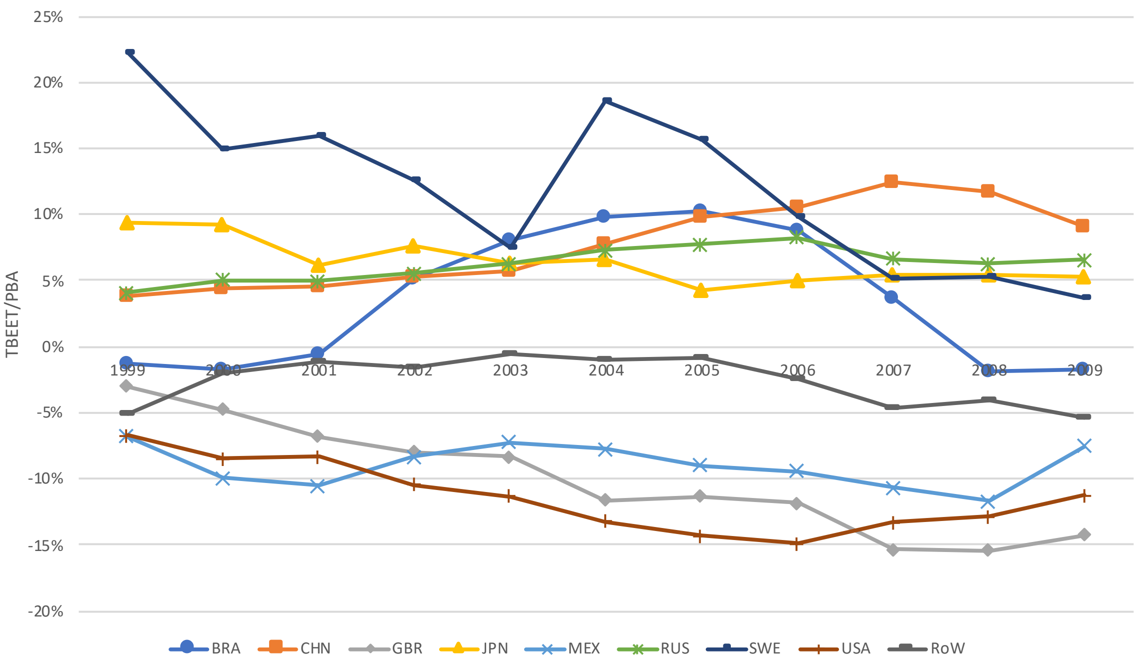


Figure 9. China compared to other major global economies, normalized to % from PBA.

To understand whether the developed countries show a trend of (weak) carbon leakage that has been absorbed by China, figure 9 depicts the results of technology-adjusted balance of emissions embodied in trade (TBEET) normalized to the percentage of PBA through the years of 1999 to 2009 for eight countries and RoW. Negative values mean that a country is a net insourcer of emissions. More specifically, that a country imports more emissions from abroad than it exports. And conversely, positive values mean that a country is a net outsourcer of emissions or that a country exports more emissions than it imports. As visible on the graph, all countries included in the graph have mostly declining trend of net emissions as a percentage of PBA except China. This implies that China has indeed become the "factory of the world". Clearly, the USA strikes out with the largest amount of emissions embodied in its trade of -565 $MtCO_2$ which means that the USA is a net insourcer of emissions. For the rest of the countries, however, there is no clear trend that would divide the world into two: developed and developing countries. Which means, there is no clear trend showing that all developed countries are cleaning up their production by outsourcing the carbon intense production to developing countries. From the table 3 in the appendix it is visible that the other major net emission insourcers in 2009 were RoW (-292 $MtCO_2$), which includes mostly other developing countries, the UK (-79 $MtCO_2$), India (-49 $MtCO_2$), France (-35 $MtCO_2$), Mexico (-32 $MtCO_2$), Canada (-29 $MtCO_2$), Australia (-25 $MtCO_2$) and Indonesia (-17 $MtCO_2$). While the net emissions from trade of the U.S., the U.K. and Mexico have shown large negative TBEET throughout the time period between 1999 to 2009, then for the rest the TBEET turned negative since either 2002 or 2004. This could imply the effect from China joining the WTO in 2001.

From the developed countries Australia, Austria, Belgium, Germany, Denmark, Finland, Ireland, Luxembourg, the Netherlands and Sweden and many others show positive TBEET, which indicates that they are conversely net outsourcers of carbon emissions. Meaning that their exports and domestic production include more emissions than their imports. From developing countries China's result is in stark contrast from the USA's. Implying that compared to USA's large negative TBEET, China exhibits a large positive TBEET. More specifically, China leads the world's TBEET in net outsourcing of emissions by far with the net emissions accounting to 613 $MtCO_2$ in 2009. China's negative TBEET showed an increasing trend from 1999 up to 2008, with an impact from the Global Financial Crisis (GFC). China is followed by Russia and Korea in this regard showing 105 $MtCO_2$ and 94 $MtCO_2$ respectively in net emissions embodied in trade in 2009. The TBEET for Russia and Korea have stayed relatively stable from 1999 to 2009, with some increases and decreases. To be precise, even though Russia is now considered as a developed country then in 2009, when the last data was extracted, it was still considered as a developing country. Thus, Russia is here still categorized as a developing country.

7.1.2 China's Exports to and Imports from Main Trading Partners

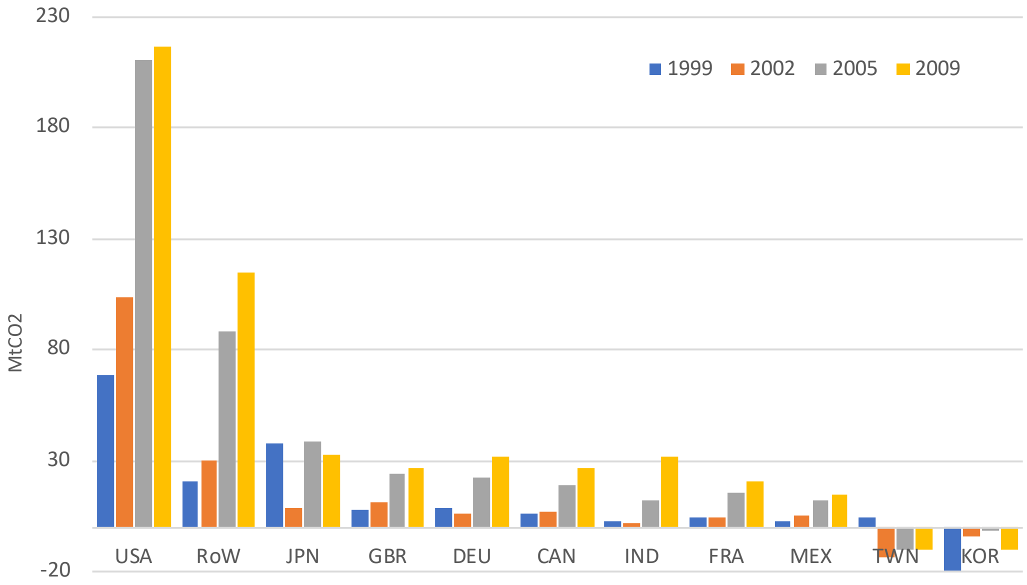


Figure 10 shows the largest contributors to China's TBEET. The graph focuses on four years (1999, 2002, 2005 and 2009) to show the results comparatively through years but so that the results could be presented in visually acceptable manner. Since China exhibits a large surplus in emissions embodied in trade the graph shows mostly the countries that have contributed to that surplus. Taiwan and Korea (on the right-hand side), however, have been included as the main source of China's emission imports that due to their magnitude should be included. Thus, from the graph above it is visible that USA, RoW, Japan, Germany, UK, Canada, France, India, Mexico, Taiwan and Korea are the major contributors to China's net emissions embodied in trade. More specifically it is visible that again the U.S. takes the lead, being the largest contributor by far with the net emissions exported increasing throughout the years, reaching 217 $MtCO_2$ in 2009. The Rest-of-World (RoW) has shown steady increase in China's TBEET, accounting to 56 $MtCO_2$ in 2009. RoW, which is the model for other countries not included in the WIOD but consisting mostly of other developing or Non-Annex I countries, shows that their share in China's net emissions exported have gained importance. More specifically, in 2005 RoW showed a notable increase from 2002, accounting 193%. Contribution from Japan has shown some interesting fluctuations. Specifically, in 2002 Japanese positive impact dropped significantly compared to 1999 (-77%) but then increased again to reach roughly the same volume as in 1999. Severing diplomatic and consequently trade relations between the two countries in the early 2000s could explain the significant drop, which then restored to the original level. The U.K., Germany, Canada, India, France and Mexico all show constantly increasing levels of net emissions from trade. Germany and India, however, exhibit two exceptions, with net emissions slightly decreasing in 2002 from 1999. The largest source of China's emission imports with noticeable magnitude has been from Taiwan and Korea, with net emissions peaking in 2002 accounting to -13 $MtCO_2$, which has declined down to -10 $MtCO_2$ in 2009. This result is not surprising considering the two countries' proximity and historical (political) connections. The trend for Taiwan has not been negative throughout the years. In 1999, however, Taiwan's contribution to China's net emissions was positive, accounting up to 4 $MtCO_2$. In the case of Korea, the TBEET showed initially a relatively large negative effect, accounting to -20 $MtCO_2$, but has declined ever since, with the lowest level of 2 $MtCO_2$ in 2005 to 10 $MtCO_2$ in 2009.

7.1.3 Driving Force Analysis for TBEET

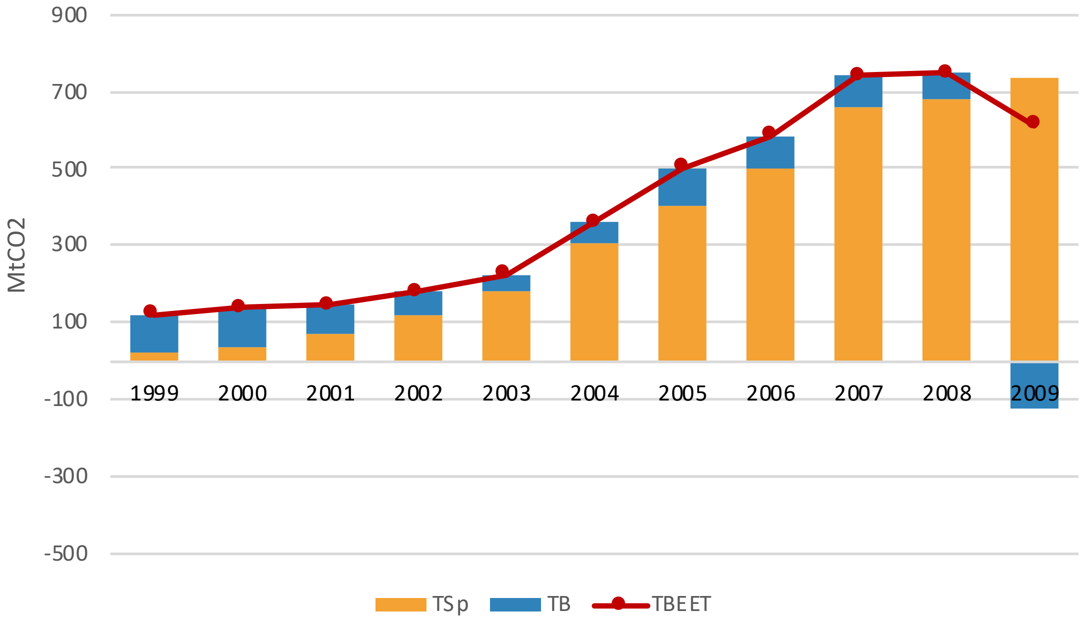


Figure 11. LMDI decomposition results from TBEET.

In the following section the results from the decomposition of China's TBEET are presented. As the effects from different technological carbon intensities between countries has been cancelled out in this case, the TBEET was decomposed into two factors: trade balance (TB) that shows the scale effect and trade specialization (TSp) which shows the composition of China's trade. The former was calculated as China's exports divided by its imports and the latter by the carbon intensity of its exports divided by carbon intensity of its imports, which would then give insight into China's specialization on carbon intense goods. Figure 11 shows these two effects from China's total TBEET through the years of 1999 to 2009. As it is visible from the figure above, China's TBEET has shown increasing trend up to 2008. It could be without further examination considered as the straight-forward effect from China joining the WTO in 2001, which led to the dismantling of trade barriers and tariffs, thus increasing China's trade surplus. However, the decomposition results point to another direction. That is, since 2002 the main contributor to China's TBEET has been the trade specialization effect. Meaning that China's large surplus in its net emissions embodied in trade comes mostly from the specialization on producing carbon intense goods. This is not only surprising from China's increasing positive trade balance point of view but also from its industry point of view. Especially since it has been widely discussed in Western media that it is the cheap labor intense goods like textiles, toys, shoes etc., which China produces for the world. Since 2007, however, the trend has reversed, starting to show a declining trend. This could be attributed to the effect from the Global Financial Crisis (GFC), which brought along the decline in global demand and which was also evident from China's declining trade surplus. The trade balance effect from the GFC is clearly visible also from the decomposition results with a larger negative trade balance effect driving down the TBEET after 2007.

7.1.4 Sector-based Decomposition of TBEET

In order to see the reasons behind China's TBEET coming mostly from trade specialization effect it is important to show the decomposition in sectoral view. That is to show the exact industries that contribute to the TBEET as either trade balance or trade specialization effect. In this section due to large amounts of data and lack of good visual methods to present them, the sectoral data will be presented in four graphs by year (1999, 2002, 2005 and 2009). Also, even though the decomposition involved all 35 sectors included in the WIOD, the graphs will present the 18 most significant sectors that contributed to TBEET including both, the trade balance (blue) and trade specialization effect (orange).

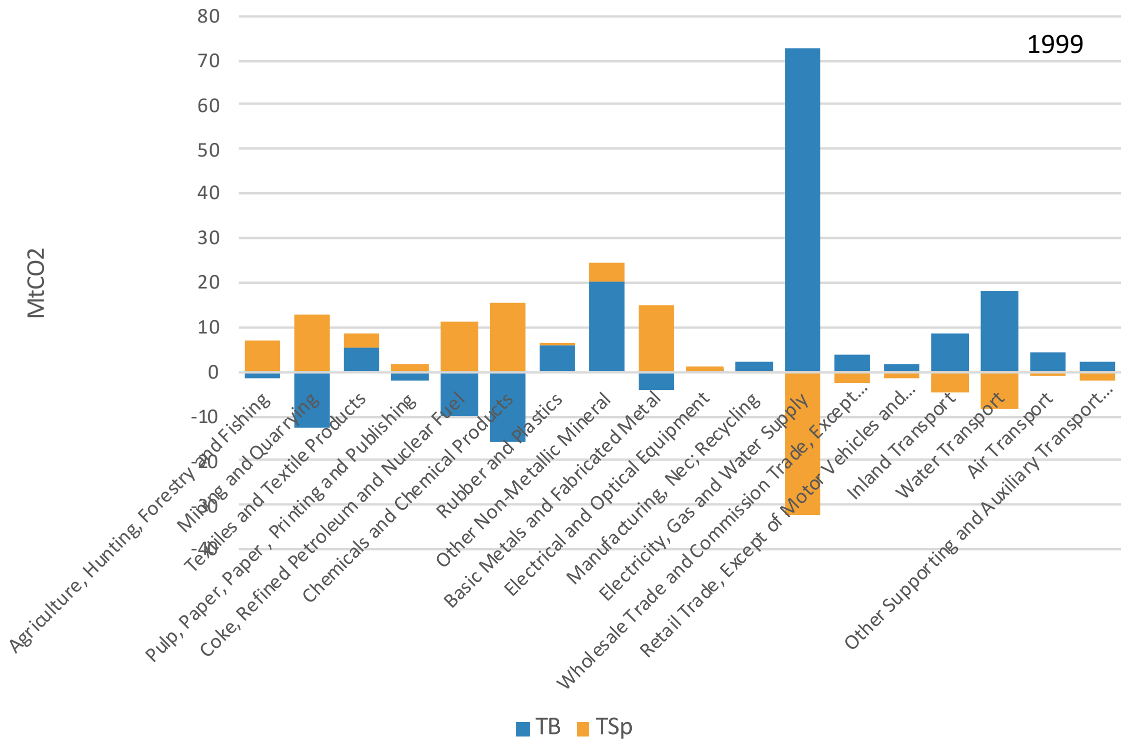


Figure 12. Sector-based decomposition results for 1999.

It is clear from the sectoral decomposition that trade balance was the major driving force of TBEET in 1999, which was visible also in figure 11. Electricity, gas and water supply sector were the single biggest contributor to driving up the trade balance effect, accounting to 73 $MtCO_2$, with a significant offsetting specialization effect of -32 $MtCO_2$. Meaning that the volume of electricity, gas and water exports outpaced the imports and that China imported more carbon intense electricity and gas from abroad than it exported. Other notable sectors contributing to the positive TBEET were other non-metallic minerals sector, with trade balance as the major contributor (20 $MtCO_2$), basic metals and fabricated metals sector, with specialization effect as major contributor (15 $MtCO_2$) and water transport sector, with trade balance being the largest effect (18 $MtCO_2$), however, offset slightly by specialization effect (7 $MtCO_2$). In the case of chemicals and chemical products sector, the positive specialization effect is rather significant (15 $MtCO_2$), however, it is mostly offset by the negative trade balance effect (-16 $MtCO_2$). Leaving overall contribution to China's TBEET minimal. The same is visible for coke, refined petroleum and nuclear fuel, and mining and quarrying sectors, where relatively significant specialization effects have been almost completely offset by their negative trade balance effects.

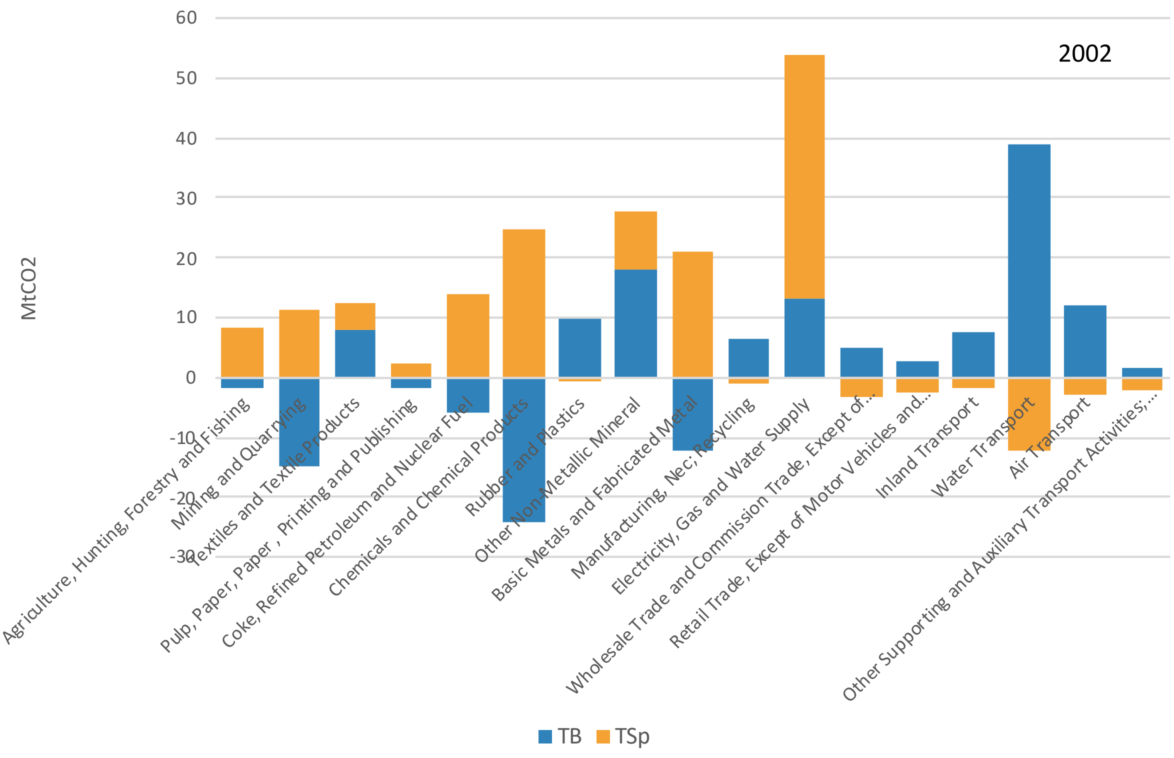


Figure 13. Sector-based decomposition results for 2002.

The sectoral picture in 2002 is a lot more diverse. The increasing trade specialization result can once again be attributed to the electricity, gas and water supply sector, with 41 $MtCO_2$ coming from the trade specialization effect and 13 $MtCO_2$ from the trade balance effect. This is, however, in stark contrast with the results from 1999, with major trade balance effect switched to major trade specialization effect. The latter could be entirely due to China's electricity supply, which is generated mostly from burning coal (see figure 5). Similar trend as for 1999 continues with the chemicals and chemical products sector with a large trade specialization effect accounting to 24,5 $MtCO_2$ but which was offset by the large negative trade balance effect of almost equal magnitude (-24,5 $MtCO_2$). The other non-metallic minerals sector has the second largest contribution to the TBEET, with largest part (18 $MtCO_2$) coming from the trade balance effect. Basic metals and fabricated metals sector also shows significant contribution to the TBEET, with relatively large trade specialization effect of 21 $MtCO_2$, while it is partly offset by the trade balance effect of -12 $MtCO_2$. The mining and quarrying sector displays large effects from the trade specialization and especially from its large negative trade balance, which however also offsets its overall TBEET, similar to 1999. The large increase of the water transport sector compared to 1999 has to be noted, with the overall net emissions increase of 177% from 1999 to 2002. The largest contribution came from the trade balance effect accounting for 39 $MtCO_2$, while it was offset by the trade specialization effect of -12 $MtCO_2$.

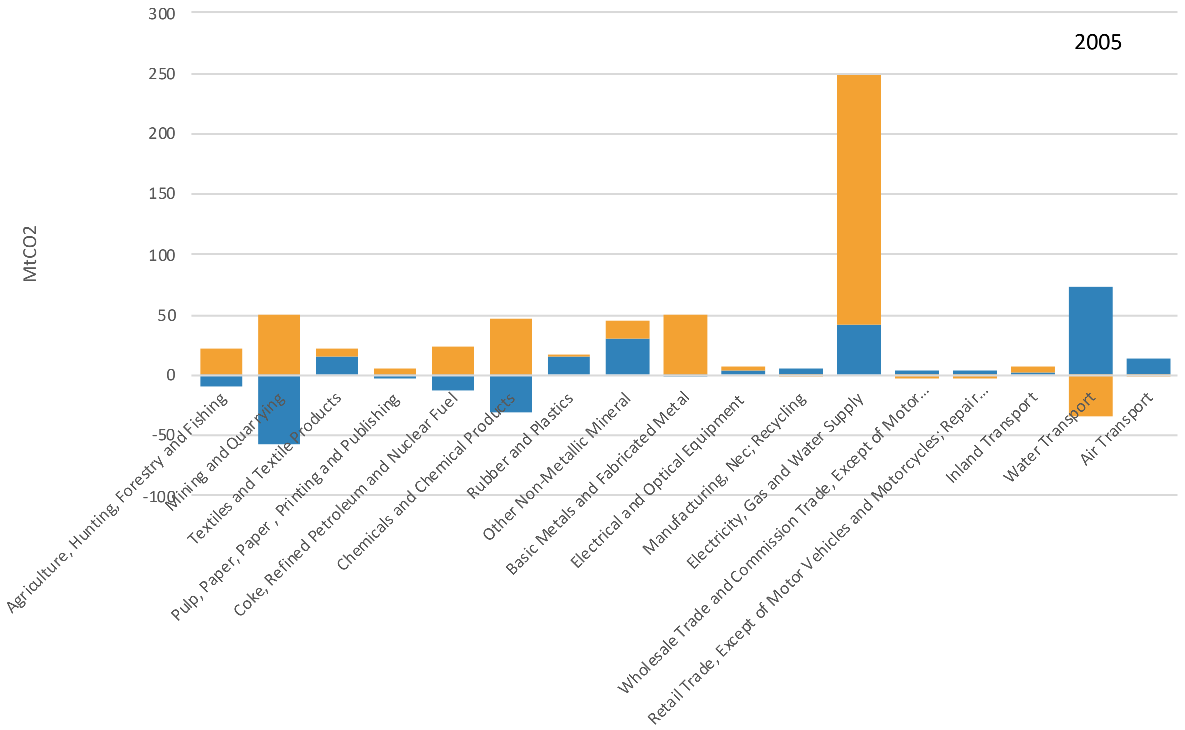


Figure 14. Sector-based decomposition results for 2005.

In 2005 the overall tendencies have remained the same but have increased in magnitude. Meaning that the electricity, gas and water supply sector still single-handedly led the contribution to China's TBEET. The tremendous increase of 362% in TBEET from 2002 led to the trade specialization effect accounting up to 208 $MtCO_2$ and trade balance adding 41 $MtCO_2$ to it. The mining and quarrying sector also displayed a significant increase in magnitude of both trade balance (284%) and trade specialization (343%) effect but the trade specialization effect have similar to previous years been offset by trade balance resulting in overall negative impact of 7 $MtCO_2$ on TBEET. The basic metals and fabricated metals sector has reduced its negative effect from trade balance significantly from -12 $MtCO_2$ in 2002 to -1 $MtCO_2$ in 2005, while the trade specialization effect has increased from 21 $MtCO_2$ to 49 $MtCO_2$.

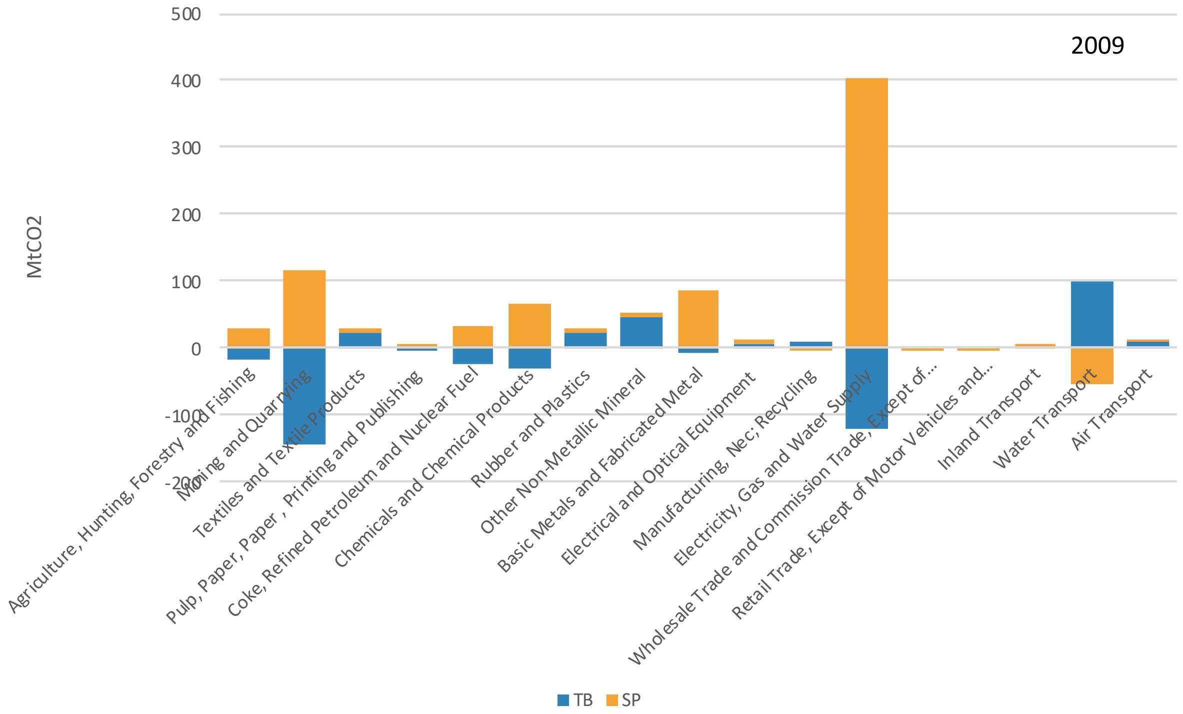


Figure 15. Sector based decomposition results for 2009.

In 2009, the increasing negative effects from trade balance compared to previous years have to be emphasized, which has resulted in an overall negative trade balance effect for 2009 and consequently diminished China's TBEET (see figure 11). This effect is the result of a notable change in the trade balance effect for the electricity, gas and water supply sector, which has turned to negative accounting for -121 $MtCO_2$, while in 2005 it contributed to positive TBEET with 41 $MtCO_2$. This has further resulted in the overall contribution increase of only 13% from

208 $MtCO_2$ in 2005 to 283 $MtCO_2$ in 2009, even though the specialization effect for the sector has increased tremendously (94%) from 208 $MtCO_2$ in 2005 to 404 $MtCO_2$. 13% is relatively small compared to the increase from the years 2002 to 2005, which accounted to 362%. The mining and quarrying sector has displayed a similar trend. With both increases in specialization effect and counterbalancing negative trade balance effect, which, however, has increased faster than the increase in specialization (a decrease of 153% from -57 $MtCO_2$ in 2005 to -143 $MtCO_2$ in 2009 compared to an increase of 132% from 50 $MtCO_2$ in 2005 to 115 $MtCO_2$ in 2009). The negative trend could be attributed to the lower demand levels from global markets resulting from the financial crisis, thus reduced exports of the sector but it could also mean that China has started to import significantly more compared to its exports. The latter indicating an increase in its production costs.

Following the results from TBEET decomposition, it can be concluded that the domination of trade specialization over trade balance as the driving force for China's net emissions embodied in trade can be attributed to three main sectors: electricity, gas and water supply, basic metals and fabricated metals, and chemicals and chemical products. As these industries are relatively carbon intense it shows that China has increased its carbon intense industry export from 1999 to 2009. While it has been widely argued that it has been China's labor-intense textiles industry that has led its increasing exports, it has had significantly smaller effect on the TBEET compared to the previously mentioned carbon-intense industries. More specifically, the textiles industry share has indeed showed an increasing trend in the trade balance effect over time but has remained moderate accounting 4,5 $MtCO_2$ in 1999 and 19 $MtCO_2$ in 2009. Similar effect is visible for the rubber and plastics sector, which despite its significant increase in the contribution to the TBEET of 359% from 7 $MtCO_2$ in 1999 to 30 $MtCO_2$ in 2009, the overall contribution has remained also moderate compared to the main three sectors mentioned above. In the case of electrical and optical equipment that has seen a recent surge in China's exports (see table 1 first four rows), the contribution has indeed increased tremendously, from 0,9 $MtCO_2$ in 1999 to 14 $MtCO_2$ in 2009 (1411%), with the largest hike in 2006 (from 7 $MtCO_2$ in 2005 to 11 $MtCO_2$ in 2006). The effect, however, disappears in comparison to the largest contributors to the TBEET.

7.2 Discussion

The discussion section of the academic research will focus on the joint analysis of different parts of the paper but mostly the sections of theoretical background, literature review and energy background in the context of the raised research questions. Thus, the discussion part will follow the sequence of the four questions raised in the introduction part.

The first two research question raised were concerned about whether or not China has become the "factory of the world" and if there was a visible distinction between the countries to which China has been exporting its technology-adjusted emissions. The EKC theory discussed in the second section of this research paper proposes that as countries develop and reach a certain stage in their income, the economy will go through a compositional change towards less carbon intense sectors like services, indicating the decoupling of income and emissions. The theory was used to show that as countries grow and coupled with the increased knowledge and empathy towards the environment, at some higher stage in their growth countries will become more carbon efficient by shifting its production to more clean industries. Pointing to the conclusion that economic growth is the solution to our environmental problems. This conclusion might be satisfied in the case of the UNFCCC territory-based accounting methodology, where the results indeed show a decreasing level of emissions for developed countries. In the case of emissions accounting where trade relationships or the consumers of emissions from trade are taken into account, or more specifically the technology-adjusted balance of emissions, EKC theory fails. Although it is difficult to draw conclusions based on 10 years, there are signs that when trade is taken into account the emissions are higher, indicating that carbon leakage or displacement does take place between countries. This can be concluded based on the results from the IOA, where some countries under the PBA accounting have shown decreasing emissions but under the CBA they continue to increase. More specifically, under PBA China's emissions are much higher than they would be if the CBA would be taken into account, leading to large negative BEET (see figure 16). Which consequently points to the fact that China exports significantly more emissions to the world than it consumes itself or in other words that the large production of emissions is for the global demand. Also, adjusting for technological differences between countries removes the bias of different production technologies, providing us with more clear understanding of who should take the responsibility, since the technology effect can bias the results. For example in the case of Nordic countries, especially in the case of Sweden and Finland, where under the BEET they are net importers of emissions implying that they have specialized on relatively clean industries domestically and displaced carbon-intense production elsewhere. This, however, does not show the effect of relatively clean production technology for these countries, making their exports less carbon intensive and thus leading them being net importers of emissions. Under technology-adjusted BEET China has remained a large exporter of emissions, however, less so than under BEET. Pointing to China's carbon-intense production technologies, which it should be held accountable for. Therefore, it is clear that China has indeed become the "factory of the world" by producing goods for global consumption. Moreover, even though a clear regional division was visible under BEET, also noted by Davis and Caldeira (2010), TBEET did not show the same tendencies, which is also illustrated by the mixture of developed and developing countries as the main contributors to China's TBEET. These results are in line with other authors' results, namely Boitier (2012), Baumert *et al.* (2019) and Jiborn *et al.* (2018).

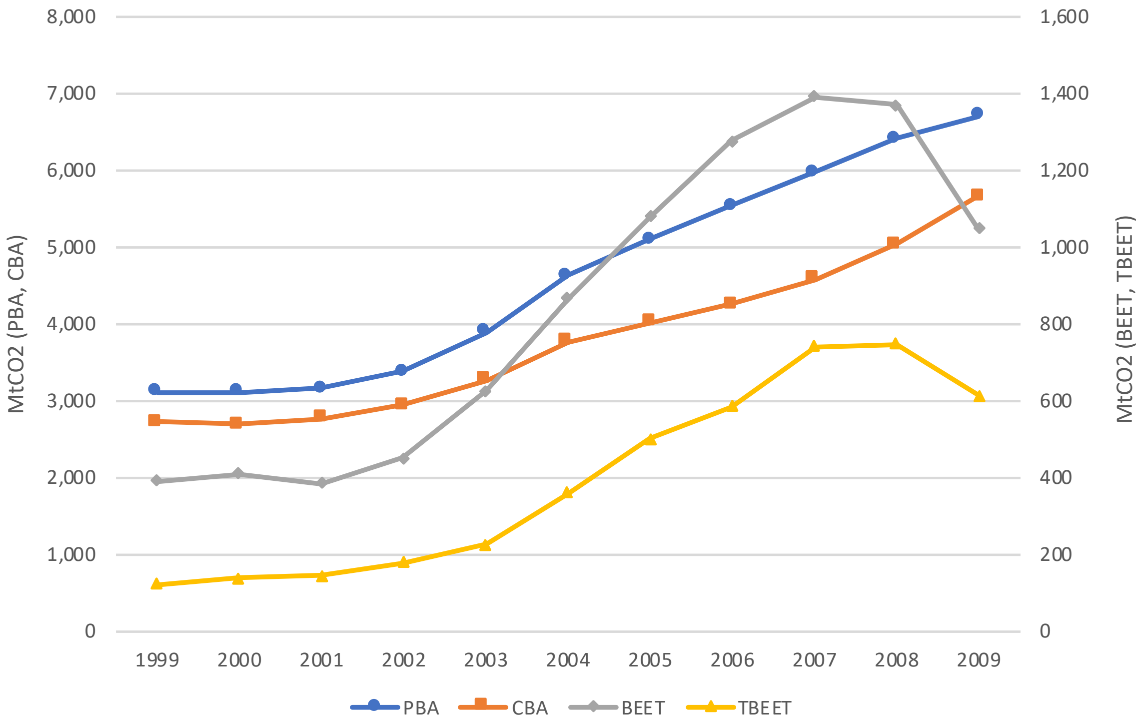


Figure 16. Results for CBA, PBA, BEET and TBEET for China.

The question of the main underlying driving forces was raised as the third research question to be able to see the factors that have contributed to the IOA results, providing insights based on which more specific policy implications could be drawn. In other words, what factors are responsible for China's large net surplus of emissions, especially when the technological differences between countries have been cancelled out. Following China's large trade surplus with its trading partners and especially with the U.S. it can be concluded based on the results of the analysis that China's positive net emissions embodied in trade have not come from the large exports of goods compared to its imports. Instead, China's positive balance of emissions embodied in trade are the result of increased specialization in exports of carbon-intense goods. Even in the context of China joining the WTO in 2001 and its consequent hike in exports, the trade balance contribution remains small, showing major contribution only during the years 1999-2001. Also, since China has been known for its low-cost labor advantage to specialize in labor-intense industry exports like textiles or footwear, the major specialization effect of carbon-intense goods on net emissions is rather contradictive. This would suggest that China's competitive advantage following the Heckscher-Ohlin (HO) theory has shifted from labor-intense industries towards more carbon-intense heavier industry. Even though different methodologies were used in the decomposition analysis, the results are largely in line with previous work by Baumert *et al.* (2019), with slight differences in the final year. As a fascinating fact, Liu *et al.* (2017) come to different conclusion based on same decomposition methodology. The paper mentioned above did, however, use data based on SRIO model instead of the MRIO model, which was used in this case. Furthermore, their results from the SRIO analysis were decomposed into three factors, including the effects from technological differences to the decomposition. Thus, in their three-factor decomposition analysis it was found that the contribution from trade balance was the largest.

The aim of the fourth and the most specific research question proposed in the introduction of this academic research was to understand which sectors are the reasons behind the major contribution of specialization effect. This is a more detailed view of the previously discussed factor decomposition, providing proof of which sectors specifically are behind China's positive TBEET. Or in other words, which sectors have contributed to China's trade specialization in carbon-intense goods the most. The results provided over four years (1999, 2002, 2005 and 2009) point to similar results with increasing magnitude over the years. Specifically, that the electricity, gas and water supply sector has been the single largest contributor to the positive TBEET and to the specialization effect. This is not surprising considering the energy mix in electricity generation in China, where coal constitutes a large part (68% in 2016). This might indicate that the HO competitive advantage theory for China has changed from light-industry to heavy carbon intense industry. The main contributor is followed by the basic metals and fabricated metals sector, however, in significantly smaller magnitude. The other notable sectors with large increases in magnitude through the years have been the mining and quarrying, and chemicals and chemical products sectors, which, however, have been offset by one of the effects making the overall TBEET effect relatively insignificant. Even though China has started to export more electrical and optical equipment in recent years, this does not yet show in the data, since last results are from 2009 and the sector could have gained importance in later years. As pointed out in the results section, textiles and rubber industries have seen large increases in emissions throughout the period in the trade balance effect, however, the contribution is relatively small compared to the electricity, gas and water production sector. Similar results have come up in previous literature (Su and Thomson, 2016), making the electricity production and chemicals the major contributors, but it has to be noted that the aim and methodologies used have differed significantly.

8 Conclusion

8.1 Summary

The effectiveness of climate change policies in recent years has been challenged by the accumulation of research on the topic of carbon leakage, as studied by the application of the consumption-based accounting system. The results have long suggested that the developing world and more specifically that China has become the "factory of the world" and that the developed countries are to be held accountable for their increased consumption of these goods. However, different countries differ in the carbon intensity and productivity level of their production technologies, which leads to biased results under the CBA and should be taken into account. The consumption-based accounting is the preferred option for China, since all the export related emissions, which exceed the import related emissions by far, are passed on as the responsibility of the consumer, while China is not held responsible for its carbon intense production. The results show that, given the condition of the technology-adjusted balance of emissions embodied in trade, China still remains the net exporter of emissions but despite it, is still held accountable for its above world-average carbon intensity. Based on the decomposition results, one might conclude that the driving force of China's exported emissions has shifted, from a large trade surplus towards specialization in global export of carbon-intense goods. This implicates that establishing trade barriers on Chinese exports, will not prove to be as effective compared to implementing tariffs on the imported carbon content from China. Furthermore, the electricity supply sector is found to be solely liable for the specialization effect. This fact points to the necessary changes needed to be made in China's electricity generation mix. Even though one of the counterarguments for the CBA has been its political incompatibility, in the ever globalized world and interdependent supply-chains, a closer global cooperation would help reduce dependency on products produced with carbon-intense production. This can be done either by increasing exchange of clean technology between China and countries with high proportion of renewable energy in their production or by China's increased policy focus on subsidizing renewable energy consumption.

8.2 Practical Implications

Through the decomposition and more detailed sectoral view, implications on what should be focused on when constructing national policies on climate change can be drawn. That is, due to the results of this study pointing to a high-carbon specialization in the exporting sector, China should focus on reducing the carbon content of its production technologies. Due to the fact, that the main cause for China's large surplus in the balance of emissions is caused by the exports of electricity, with a highly polluting production process, it is therefore of interest to subsidize the use of renewable energy in order to increase its use as a production method. Furthermore, as mentioned in the section above, in the context of climate crisis on the global level, countries should look for more cooperation in joint mitigation rather than passing the responsibility to producers of emissions. This would mean increased cooperation on the knowledge and technology of more carbon efficient production.

8.3 Future Research

As one limitation, this study analyzed the driving forces of technology-adjusted balance of emissions embodied in trade without taking inflation into account. Thus, future research should be conducted with the inclusion of inflation to create comparative results. This would infer combining two sets of databases available on WIOD (tables in current year prices and tables in previous years' prices) or double deflating the values in current prices using national deflator indicators for each country, when WIOD tables are not used for the analysis. Furthermore, cost-benefit analyzes on China's incorporation of renewable energy in electricity generation would further help to narrow the focus on renewable energy in China.

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Appendices

Appendix A

Table A. Products exported by China, 2017 (% of total exports)

Product name	**%**	**Product name**	**%**
Transmit-receive apparatus for radio, tv, etc.	9,60	Monolithic integrated circuits, digital	12
Computer data storage units	4,30	Petroleum oils, oils from bituminous minerals, crude	9,40
Parts and accessories of data processing equipment	3,70	Iron ore, concentrate, not iron pyrites, unagglomerate	3,70
Monolithic integrated circuits, digital	3,00	Soya beans	2,40
Parts of line telephone/telegraph equipment	2,30	Gold in unwrought forms non-monetary	2,40
Toys	1,30	Medium sized cars	2,20
Color television receivers/monitors/projectors	1,10	Optical devices, appliances and instruments	1,60
Static converters	0,86	Copper ores and concentrates	1,60
Parts for radio/tv transmit/receive equipment	0,80	Fixed wing aircraft, unladen weight > 15,000 kg	1,50
Oils petroleum, bituminous, distillates, except crude	0,79	Parts of line telephone/telegraph equipment	1,30

Source: UN Comtrade, 2018.

Appendix B

Table B. List of countries covered in WIOD

Annex-I	**Non-Annex-I**
Australia	Brazil
Austria	China
Belgium	India
Bulgaria	Indonesia
Canada	Mexico
Cyprus	Republic of Korea (South Korea)
Czech republic	Rest of the world
Denmark	
Estonia	
Finland	
France	
Germany	
Greece	
Hungary	
Ireland	
Italy	
Japan	
Latvia	
Lithuania	
Luxembourg	
Malta	
The Netherlands	
Poland	
Portugal	
Romania	
Russia	
Slovakia	
Slovenia	
Spain	
Sweden	
Turkey	
United kingdom	
United states	
(Taiwan)	

Source: WIOD (Timmer et al., 2015).

Appendix C

Table C. List of sectors covered in WIOD

1	Agriculture, Hunting, Forestry and Fishing	S1
2	Mining and Quarrying	S2
3	Food, Beverages and Tobacco	S3
4	Textiles and Textile Products	S4
5	Leather, Leather and Footwear	S5
6	Wood and Products of Wood and Cork	S6
7	Pulp, Paper, Paper , Printing and Publishing	S7
8	Coke, Refined Petroleum and Nuclear Fuel	S8
9	Chemicals and Chemical Products	S9
10	Rubber and Plastics	S10
11	Other Non-Metallic Mineral	S11
12	Basic Metals and Fabricated Metal	S12
13	Machinery, Nec	S13
14	Electrical and Optical Equipment	S14
15	Transport Equipment	S15
16	Manufacturing, Nec; Recycling	S16
17	Electricity, Gas and Water Supply	S17
18	Construction	S18
19	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	S19
20	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	S20
21	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	S21
22	Hotels and Restaurants	S22
23	Inland Transport	S23
24	Water Transport	S24
25	Air Transport	S25
26	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies	S26
27	Post and Telecommunications	S27
28	Financial Intermediation	S28
29	Real Estate Activities	S29
30	Renting of M&Eq and Other Business Activities	S30
31	Public Admin and Defence; Compulsory Social Security	S31
32	Education	S32
33	Health and Social Work	S33
34	Other Community, Social and Personal Services	S34
35	Private Households with Employed Persons	S35

Source: WIOD (Timmer et al., 2015).

Appendix D

Table D. BEET and TBEET results for all 41 countries, including RoW (MtCO$_2$)

Country		**PBA**		**CBA**		**BEET**		**TBEET**	
		1999	**2009**	**1999**	**2009**	**1999**	**2009**	**1999**	**2009**
Australia	AUS	350	405	348	453	2	-48	5	-25
Austria	AUT	62	64	94	95	-32	-30	-1	25
Belgium	BEL	132	121	132	146	0,06	-25	28	6
Bulgaria	BGR	48	46	34	38	14	9	5	5
Brazil	BRA	282	323	297	370	-15	-48	-3	-6
Canada	CAN	512	529	457	555	56	-26	28	-29
China	CHN	3,099	6,696	2,707	5,651	391	1,044	121	613
Cyprus	CYP	7	8	10	11	-3	-3	-2	-3
Czech	CZE	107	109	99	97	8	11	10	13
Germany	DEU	912	817	1,109	958	-197	-141	8	87
Denmark	DNK	76	87	69	64	7	23	25	33
Spain	ESP	295	300	344	371	-49	-71	-9	4
Estonia	EST	16	16	15	12	1	3	0,5	1
Finland	FIN	63	62	71	70	-8	-8	10	2
France	FRA	424	386	532	547	-108	-162	27	-35
United	GBR	591	559	702	659	-111	-100	-18	-79
Greece	GRC	98	110	116	139	-18	-29	-4	-11
Hungary	HUN	59	53	67	58	-8	-5	-1	-0,07
Indonesia	IDN	280	393	239	380	41	12	7	-17
India	IND	968	1,643	897	1,595	71	48	6	-49
Ireland	IRL	42	426	49	59	-6	-16	7	12
Italy	ITA	470	425	582	545	-112	-120	31	-7
Japan	JPN	1,185	1,102	1,381	1,270	-196	-168	112	58
Republic of	KOR	441	584	384	499	57	85	69	94
Lithuania	LTU	15	15	21	19	-6	-5	-1	-1
Luxembourg	LUX	6	5	8	8	-2	-3	1	4
Latvia	LVA	8	8	10	11	-2	-2	-1	-1
Mexico	MEX	357	427	379	450	-22	-24	-24	-32
Malta	MLT	2	3	3	4	-1	-1	-1	0,1
Netherlands	NLD	196	205	205	210	-9	-5	45	59
Poland	POL	331	317	311	291	20	25	-3	5
Portugal	PRT	66	61	77	71	-11	-10	-8	-7

Romania	ROM	92	91	819	96	10	-5	5	-4
Russia	RUS	1,517	1,598	889	1,224	629	375	62	11
Slovakia	SVK	42	36	33	37	9	-1	5	6
Slovenia	SVN	15	18	18	20	-3	-3	-1	-1
Sweden	SWE	62	58	84	81	-22	-24	14	2
Turkey	TUR	202	296	233	315	-31	-19	-5	-4
Taiwan	TWN	240	314	222	211	17	103	19	34
United States	USA	5,357	5,025	5,893	5,670	-537	-644	-362	-565
Rest-of-World	RoW	4,111	5,494	3,934	5,487	177	7	-206	-292

Source: Own calculations based on (Timmer et al., 2015).

Appendix E

Table E. Specific IOA results for China, 1999-2009 (MtCO$_2$)

China	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Domestic	2,278	2,210	2,258	2,377	2,654	3,072	3,283	3,498	3,764	4,155	4,736
PBA (incl. households)	3,099	3,101	3,150	3,377	3,894	4,623	5,083	5,524	5,962	6,398	6,696
CBA (incl. households)	2,707	2,691	2,767	2,927	3,269	3,758	4,005	4,251	4,573	5,032	5,651
EEE	539	565	593	727	910	1,180	1,394	1,644	1,771	1,883	1,516
EEI	147	192	208	240	293	327	334	335	378	365	430
TEEE	262	312	337	407	502	678	826	932	1,122	1,174	1,067
TEEI	141	176	194	229	277	318	326	350	381	428	454

Source: Own calculations based on WIOD (Timmer et al., 2015).

Appendix F

Table F. TBEET decomposition results for 35 sectors, 1999-2009 (MtCO2)

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
S1	TB	-1	-10	-13	-14	-18	-9	-10	-13	-14	-18	-15
	TSp	7	23	28	30	32	19	23	28	30	32	29
S2	TB	-1	-57	-74	-97	-113	-50	-57	-74	-97	-113	-143
	TSp	13	50	67	89	93	44	50	67	89	93	115
S3	TB	1	2	2	2	1	1	2	2	2	1	1
	TSp	0	2	3	4	5	1	2	3	4	5	4
S4	TB	6	16	20	24	24	13	16	20	24	24	22
	TSp	3	7	8	8	7	6	7	8	8	7	6
S5	TB	1	1	1	1	1	1	1	1	1	1	1
	TSp	0	1	1	1	1	1	1	1	1	1	1
S6	TB	1	1	2	2	2	1	1	2	2	2	2
	TSp	1	1	1	1	2	1	1	1	1	2	2
S7	TB	-3	-3	-3	-3	-4	-3	-3	-3	-3	-4	-4
	TSp	4	6	6	7	8	4	6	6	7	8	8
S8	TB	-10	-12	-21	-21	-22	-10	-12	-21	-21	-22	-24
	TSp	21	23	28	31	30	21	23	28	31	30	32
S9	TB	-30	-31	-31	-29	-20	-30	-31	-31	-29	-20	-31
	TSp	36	46	57	67	64	36	46	57	67	64	66
S10	TB	12	15	18	20	23	12	15	18	20	23	22
	TSp	1	2	6	8	9	1	2	6	8	9	9
S11	TB	23	31	38	42	54	23	31	38	42	54	46
	TSp	12	14	14	17	14	12	14	14	17	14	7
S12	TB	0	-1	23	27	43	0	-1	23	27	43	-6
	TSp	33	50	56	75	65	33	50	56	75	65	85
S13	TB	-2	-1	-1	0	1	-2	-1	-1	0	1	0
	TSp	2	2	3	3	3	2	2	3	3	3	3
S14	TB	2	3	5	7	8	2	3	5	7	8	8
	TSp	3	4	6	8	8	3	4	6	8	8	7
S15	TB	0	0	0	0	1	0	0	0	0	1	0
	TSp	0	1	1	1	1	0	1	1	1	1	1
S16	TB	4	5	8	9	11	4	5	8	9	11	9
	TSp	-1	-1	-1	0	-1	-1	-1	-1	0	-1	-1
S17	TB	21	42	-7	-16	-41	21	42	-7	-16	-41	-121
	TSp	153	208	257	356	375	153	208	257	356	375	404

S18	TB	0	0	0	0	0	0	0	0	0	0	0
	TSp	0	0	0	0	0	0	0	0	0	0	0
S19	TB	0	0	0	0	0	0	0	0	0	0	0
	TSp	0	0	0	0	0	0	0	0	0	0	0
S20	TB	5	4	4	4	4	5	4	4	4	4	5
	TSp	-3	-3	-3	-3	-2	-3	-3	-3	-3	-2	-3
S21	TB	3	4	4	3	4	3	4	4	3	4	4
	TSp	-3	-3	-3	-3	-4	-3	-3	-3	-3	-4	-4
S22	TB	2	2	1	1	1	2	2	1	1	1	1
	TSp	-1	-1	0	1	11	-1	-1	0	1	1	1
S23	TB	4	3	3	1	-2	4	3	3	1	-2	0
	TSp	2	5	6	10	11	2	5	6	10	11	7
S24	TB	58	73	90	104	105	58	73	90	104	105	100
	TSp	-26	-34	-40	-51	-53	-26	-34	-40	-51	-53	-54
S25	TB	12	13	13	12	13	12	13	13	12	13	11
	TSp	-2	-1	1	2	2	-2	-1	1	2	2	2
S26	TB	3	3	3	2	2	3	3	3	2	2	2
	TSp	-3	-3	-3	-2	-2	-3	-3	-3	-2	-2	-2
S27	TB	0	0	0	0	0	0	0	0	0	0	0
	TSp	0	0	0	0	1	0	0	0	0	1	0
S28	TB	-1	-1	-1	0	0	-1	-1	-1	0	0	-1
	TSp	1	1	1	1	1	1	1	1	1	1	1
S29	TB	-4	-1	-1	-2	-7	-4	-1	-1	-2	-7	-7
	TSp	4	1	1	2	7	4	1	1	2	7	7
S30	TB	0	0	1	1	1	0	0	1	1	1	0
	TSp	-1	-1	-1	0	-1	-1	-1	-1	0	-1	-1
S31	TB	0	0	-1	-1	-1	0	0	-1	-1	-1	-1
	TSp	0	0	0	0	0	0	0	0	0	0	0
S32	TB	0	0	0	0	0	0	0	0	0	0	0
	TSp	0	0	0	0	0	0	0	0	0	0	0
S33	TB	-1	-1	-1	0	0	-1	-1	-1	0	0	0
	TSp	1	1	1	0	0	1	1	1	0	0	0
S34	TB	2	1	1	0	0	2	1	1	0	0	0
	TSp	-1	0	0	1	1	-1	0	0	1	1	1
S35	TB	0	0	0	0	0	0	0	0	0	0	0
	TSp	0	0	0	0	0	0	0	0	0	0	0
TOTAL		361,0	361	500	582	740	756	359	500	582	740	746

Source: Own calculations based on WIOD (Timmer et al., 2015).