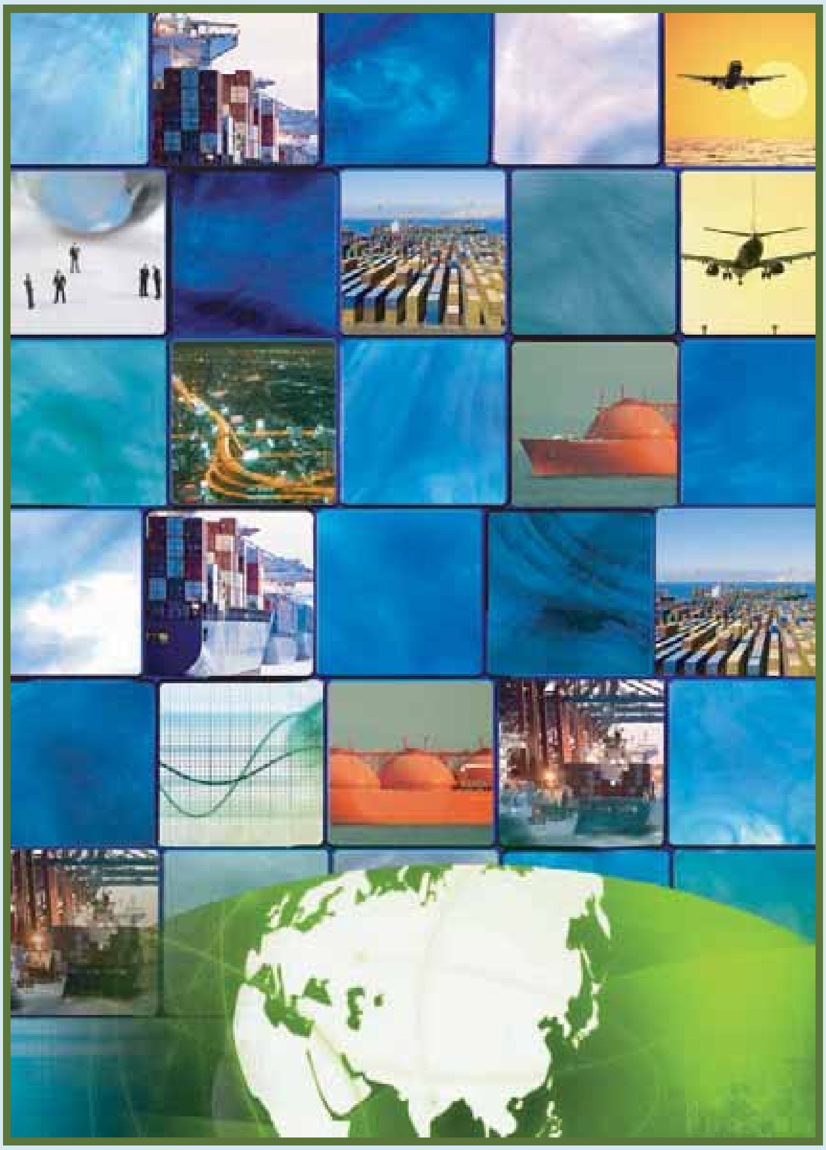
CARBON EMISSIONS EMBODIED IN INTERNATIONAL TRADE

An assessment from the Asian perspective



Institute for Global Environmental Strategies

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Preface

National economies are increasingly interacting with each other through international trade, foreign direct investment, capital flow and the spread of technology. In a supply chain of a product, not all of the stages, from the extraction of raw materials, production and process, transportation and distribution until the delivery to the end users, occur in the same country. The cooperation among various agents located in different countries to complete the supply chain of a product is a major characteristic of globalisation, a process by which a spatially interwoven and sophisticated network of business and trade has been formed.

In climate policy, there is a growing need to take account of international trade. Amid this trend, there are two concerns related to the relationships of climate policy and international trade, viz., international competitiveness and carbon leakage, which might influence the effectiveness of the climate policy and the participation of developing countries.

In recent years, there is a large body of literature focusing on emissions embodied in international trade to address these concerns. “Embodied emissions” has been used as an indicator to account for emissions emitted from each upstream stage of the supply chain of a product, which is used or consumed by the downstream stages or consumers, from “the cradle to the grave”. This indicator can help assess the impacts of international trade on the climate system.

In this context, the Institute for Global Environmental Strategies (IGES) initiated a research to assess embodied emissions in international trade, with particular focus on Asian countries. Many developing Asian countries, such as China, India and Southeast Asian countries, are growing fast owing mainly to their steadily increasing exports, which contribute greatly to their national emissions inventories. The participation of these countries in the future climate policy is of a great importance to achieve the stabilisation objective of the United Nations Framework Convention on Climate Change

(UNFCCC).

This research consists of two components, which are included in this report as two parts. Part I, conducted by the Economic Analysis Team of IGES, focuses on the assessment of emissions embodied in multilateral trade in Asian countries and different responsibility principles for the generation of national green house gas (GHG) inventories. Part II, conducted by the Kansai Research Centre of IGES, focuses on the analysis of emissions embodied in the bilateral trade between Japan and China.

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PART I

Carbon Emissions Embodied in International Trade: An assessment based on the multi-region input-output model

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ABSTRACT

The entry into force of the Kyoto Protocol to the United Nations Framework Convention on Climate Control (UNFCCC) divides parties into two groups by their obligations to mitigate domestic emissions. This division creates differences in the strictness of domestic climate policy, which are in favour of the conditions for creating the "heavens" of pollution. Current national GHG emissions accounting is based on territorial responsibility, or similarly producer responsibility, which contributes to make the conditions for creating the "heavens" of pollution mature. These situations lead to the concerns on global competitiveness and carbon leakage because carbon emissions embodied in international trade and associated global social costs are not taken into account. In addition, the equity of allocating full responsibility for emissions embodied in exports to the exporting countries is arguable. There is a need to consider other responsibility principles and take account of international trade.

Various policy measures have been suggested to address competitiveness and leakage concerns. Among others, the foremost policy option is to commit all emitting countries to reduce. Other measures include, e.g., border tax adjustment to level the international playing field. Part I of this report presents a policy option of national responsible emissions accounting adjusted by trade to address these issues.

The purpose of this research is (i) to assess and compare national emissions based on different principles of responsibility, including producer responsibility, consumer responsibility and shared producer and consumer responsibility based on value-added ratios; and (ii) to test the differences in the results calculated by different input-output models (the single-region input-output model and the multi-region input-output model). We conducted an empirical analysis for ten economies, including five ASEAN countries (Indonesia, Malaysia, the Philippines, Singapore and Thailand), mainland China, Taiwan and three OECD countries (Japan, the Republic of Korea and the USA).

The empirical analysis indicates that CO_2 embodied in multilateral trade among ten

selected economies is significant, accounting for 13% of the total national responsible emissions of ten economies. In terms of the trade balance of embodied CO_2, the USA (-464 Mt-CO_2), Japan (-191 Mt-CO_2) and Singapore (-13 Mt-CO_2) have a deficit while other economies, in particular China (452 Mt-CO_2), have a trade surplus. Our research indicates that carbon leakage occurs in a non-negligible way from developed economies to developing economies, which will undermine the efforts made in achieving the mitigation targets set by the Kyoto Protocol and should be properly considered by the UNFCCC.

This research demonstrates that a change from producer responsibility to consumer responsibility will greatly influence national emissions inventories. For example, the responsibility allocated by the two extreme methods, i.e., full producer responsibility vs. full consumer responsibility, could cause a change in the national emissions ranging from -525 to 543 Mt-CO_2 for different countries. This implies that trade adjustment to current national accounting to generate national responsible emissions accounts will influence the relationships between climate policy and international trade potentially and therefore can be considered as a complementary policy option, among others, to help address the carbon leakage concern. However, how consumer responsibility will influence carbon leakage and international competitiveness needs further assessment.

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1. Introduction

The greenhouse gas (GHG) concentrations in the atmosphere now stand at around 430 parts per million (ppm) CO_2 equivalent, compared with only 280 ppm before the Industrial Revolution (Stern, 2007). The stock is rising and emissions of carbon dioxide grew at an average annual rate of around 2.5% between 1950 and 2000, driven by increasing emissions from human activities including energy generation and land-use change. This will result in warming of the Earth's surface and atmosphere and may adversely affect natural ecosystems and humankind.

According to the Stern Review (Stern, 2007), North America and Europe have produced around 70% of CO_2 emissions from energy production since 1850. Though developing countries account for less than one quarter of cumulative emissions, over three quarters of future emissions growth will likely come from today's developing countries because of more rapid population and GDP growth than developed countries and an increasing share of energy-intensive industries. Therefore all nations have a responsibility to protect the climate system, which is a shared resource.

The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) entered into force on 16 February 2005. Thirty-seven industrialised countries and the European Community have committed to collectively reduce their GHG emissions to an average of 5% against 1990 levels over the period 2008-2012. According to the principle of "common but differentiated responsibilities" and national respective capabilities, the Protocol does not commit developing countries to do so. During the 15th meeting of the Conference of the Parties of the UNFCCC, the Copenhagen Accord was concluded on 18 December 2009 with signatories agreeing that deep cuts in global emissions are required. Though new reduction targets have yet to be established, industrialised countries will further strengthen emissions reduction initiated by the Protocol and developing countries will implement nationally appropriate mitigation actions.

To establish quantified national reduction targets and to monitor the progress made to achieving them requires an assessment of national GHG emissions. Methods such as the reference approach and sectoral approach, currently adopted by the UNFCCC to estimate national GHG inventories, "include all greenhouse gas emissions and removals taking place within national (including administered) territories and offshore areas over which the country has jurisdiction" (IPCC, 1996). These accounting methods are based on a principle of territorial responsibility (Eder and Narodoslawsky, 1999) or producer responsibility.

There are several advantages of accounting for national emissions based on the producer principle: (i) direct emissions generated from production are easier to be estimated and monitored; (ii) accounting for emissions within the boundary of national jurisdiction is compatible with the principle of sovereignty of states in international cooperation to address climate change which is endorsed by the UNFCCC; and (iii) producer responsibility is underpinned by the polluter-pays-principle which has been embraced by the OECD countries since 1974 (Neumayer, 2000).

However, there are also drawbacks in applying the principle of territorial responsibility. First, a region optimising its environmental strategy according to territorial responsibility is likely to relocate pollution-intensive production to regions with less stringent environmental regulation, the so-called "heavens" of pollution, and import the respective products. Some studies show that many countries become clean due to the out-sourcing of pollution (Rothman, 2000; Aldy, 2005; Cole and Elliott, 2005; Ekins, 2009; SERI et al., 2009; Weber and Peters, 2009). From the perspective of global sustainability, these countries would not be deemed sustainable (Pearce and Atkinson, 1993; Eder and Narodoslawsky, 1999; Proops et al., 1999).

Second, the Kyoto Protocol divides parties into two groups by their obligations to mitigate domestic emissions which creates differences in the strictness of domestic climate policy. Since emission reduction is costly, terms-of-trade will therefore be affected. Industries in countries which implement the reduction policy will face a competitive disadvantage compared to their international competitors that operate in countries which have not quantified reduction targets (Kemfert et al., 2004; van Asselt and Biermann, 2007; UNEP, 2009). As a consequence, carbon-intensive production will be pulled to countries that have less stringent climate policies along with other economic factors. Emissions reduced in Annex I countries through offshore carbon-intensive production and international trade will, however, generate elsewhere, in particular from developing countries. This potential trend of relocation has led to the concern of carbon leakage, which refers to an increase in CO_2 emissions in countries without climate policies due to emissions reduction in countries with climate policies in place. Carbon leakage can undermine the effectiveness of the Kyoto Protocol (Weber and Matthews, 2007; Peters and

Hertwich, 2008a) and become a central concern in the debates of climate change and international trade (Copeland and Taylor, 2005; World Bank, 2007; UNEP, 2009; van Asselt and Brewer, 2010).

Third, the equity of territorial GHG inventories has been argued by some major exporting countries. They produce goods that are consumed by other countries but carbon emissions are charged to their national emissions accounts. This is also argued as one of the barriers keeping developing nations from reduction commitments because many of them such as China, India and Southeast Asian countries, have experienced rapid economic development largely owing to the steady growth in exports, which contribute greatly to the increase in their territorial GHG emissions. Besides developing countries, open economies facing national CO_2 targets and having a big net export of CO_2 intensive goods, such as Denmark, are also concerned about a fairer responsibility principle (Munksgaard and Pedersen, 2001).

Against this background, international trade should be considered in future climate policy and there is a need to incorporate other principles of responsibility in assessing national emissions. In a large body of literature, "embodied emissions" is used as an indicator to account for emissions from each upstream stage of the supply chain of a product, which is used or consumed by the downstream stages or consumers, from "the cradle to the grave". Along with this is consumer responsibility proposed to address the driving forces of environmental pressures (Rose, 1990; Proops et al., 1993; Kondo et al., 1998; Eder and Narodoslawsky, 1999; Munksgaard and Pedersen, 2001; Lenzen et al., 2004; Peters and Hertwich, 2008a; Peters and Hertwich, 2008b). A national emissions inventory generated based on consumer responsibility includes emissions assessed based on producer responsibility plus emissions embodied in imports minus emissions embodied in exports. In addition, several articles proposed shared responsibility, including between exporting and importing countries (Kondo et al., 1998; Eder and Narodoslawsky, 1999; Peters, 2008), between production and consumption (Ferng, 2003;), or among upstream and downstream actors in a supply chain (Eder and Narodoslawsky, 1999; Bastianoni et al, 2004; Gallego and Lenzen, 2005; Lenzen et al., 2007).

Since the late 1990s, a large body of literature has emerged in estimating CO_2 emissions embodied in international trade. A clear message derived from these studies is that a significant amount of CO_2 is embodied in international trade. For example, CO_2 emitted inside Japan was estimated to be 1,115Mt-CO_2 in 1990[1], while carbon embodiments in the imports to Japan was 249Mt-CO_2, surpassing those embodied in Japan's exports (170Mt-CO_2) (Kondo et al., 1998). For Denmark, the CO_2 trade balance changed from a surplus of 0.5Mt in 1987 to a deficit of 7Mt in 1994 (Munksgaard and Pedersen, 2001). Norwegian household consumption-induced CO_2 emitted in foreign countries represented 61% of its total indirect CO_2 emissions in 2000 (Peters and Hertwich, 2006a). For the USA, the overall CO_2 embodied in US imports grew from a range of 0.5 to 0.8Gt-CO_2 in 1997 to a range of 0.8 to 1.8Gt-CO_2 in 2004, representing between 9-14% and 13-30% of US national emissions in 1997 and 2004, respectively (Webber and Mattews, 2007). At the multi-regional level, about 13% of the total carbon emissions of six OECD countries (Canada, France, Germany, Japan, UK and USA) were embodied in their manufactured imports in the mid-1980s (Wyckoff and Roop, 1994). More recent research (Peters and Hertwich, 2008a) shows that around 5.3Gt, out of 42Gt CO_2 equivalent of global GHG emissions in 2000, were embodied in the international trade of goods and services and Annex B countries were found to be net importers of CO_2 emissions.

However, most of previous works focus mainly on developed countries and few of them measure the impacts on the national GHG inventories of developing nations. As the participation of developing countries in the mitigation of global warming is critical in achieving the stabilisation objective set by the UNFCCC, there is a need for an assessment on embodied emissions for developing countries.

To calculate embodied emissions, many studies use input-output analysis, an analytical framework developed by Wassily Leontief in the late 1930s (Leontief, 1936 and 1941) to deal with the interdependence of industries. An input-output model is originally applied to predict the impacts throughout an economy induced by a change in one industry. Since the late 1980s, input-output analysis has been widely used in environmental studies to account for emissions embodied in finished goods. Three types of input-output models are usually applied to account for emissions embodied in the imports of a particular country: the single-region input-output (SRIO) model, the model of emissions embodied in bilateral trade (EEBT), and the multi-region input-output (MRIO) model.

By the SRIO model, domestic technical coefficients (Miller and Blair, 1985) and emission intensities are applied to calculate CO_2 multipliers for imports irrespective of countries of

[1] In the original paper, the authors use Mt-C as the unit for emissions accounting. The conversion factor from Mt-C to Mt-CO_2 is 44/12.

origin. This method is questionable because technologies and emission intensities vary from one country to another in producing similar products. In addition, summation of the results calculated by separate SRIO models at the global level will cause accounting errors.

As an improvement to the SRIO model, the EEBT model, which is established based on multiple SRIO models, emphasises emissions embodied in bilateral trade. Either regional input coefficients or regional technical coefficients (Miller and Blair, 1985), together with emission intensities in countries of origin are used to calculate CO_2 multipliers for imports, including both finished goods and intermediate products. However, treating the imports of intermediate commodities as exogenous variables fails to account for the interregional and inter-industrial feedback effects associated with the use of imported intermediate commodities (Miller, 1969; Round, 1979; Gillen and Guccione, 1980; Lenzen et al., 2004). In the case of using regional technical coefficients, the same kind of errors as mentioned above will occur at the global accounting level. In the case of using regional input coefficients, though accounting errors is not the question, the fairness of responsibility allocation will be another concern. For an extreme example, Country *r* produces 10-unit commodities, which are transshipped via Country *s* to Country *t*, where the commodities are finally consumed. Assume that the CO_2 multipliers of Country *r*, *s* and *t* are c_r, c_s and c_t, respectively, and $c_r < c_s$, $c_t < c_s$ and the transshipment via Country *s* contributes no more emissions. Based on the EEBT model, emissions embodied in the imports of 10-unit commodities to Country *s* from Country *r* will be $10c_r$, while emissions embodied in the imports of the same 10-unit commodities from Country *s* to Country *t* will be $10c_s$. Considering the balance of emissions embodied in trade, a negative amount of $10(c_r - c_s)$ (since $c_r < c_s$) will be allocated to the national inventory of Country *s*, while an amount of $10c_s$ will be charged to the national account of Country *t*. At the level of three countries, the total emissions from production are $10c_r$, which is equal to the total emissions assessed by consumer responsibility, i.e., 0 from Country *r*, $10(c_r - c_s)$ from Country *s* and $10c_s$ from Country *t*. However, the fairness of such allocation is arguable because it is rational to consider that $10c_r$ are charged to the national account of Country *t* rather than $10c_s$ ($>10c_r$).

In the MRIO model, a systematic and symmetric analytical framework, regional technical coefficients and emission intensities of countries of origin are used to estimate CO_2 multipliers for the imports of final commodities. Different from the EEBT model, intermediate commodities both produced domestically and imported are endogenously accounted for in CO_2 multipliers. The problems associated with other two models can be solved in the MRIO model.

The MRIO model is more appropriate and fairer to generate consumption-based national inventories at a multi-region level (Lenzen et al., 2004; Turner et al., 2007; Wiedmann et al., 2007).

In most existing literature, the SRIO model (e.g. by Kondo et al., 1998; Lenzen 1998; Munksgaard and Pedersen, 2001) and the EEBT (e.g. by Wyckoff and Roop, 1994; Nijdam et al., 2005; Peters and Hertwich, 2006b; Webber and Mattews, 2007; Peters and Hertwich, 2008a) are usually used. There are few studies which apply the MRIO model to account for emissions embodied in international trade (Weber and Matthews, 2007; Peters and Hertwich, 2007; McGregor et al., 2008). This is mainly due to the availability of data-intensive MRIO tables. A MRIO table is compiled based on SRIO tables and international trade data. Countries in a MRIO table are symmetrical to one another. Imports to each country are explicitly recorded by their source industry and by country of origin. In addition, the detailed use of imports by industries and by the final consumption is clearly documented. To generate such detailed and systematic accounts for each country in a MRIO table requires intensive data on international trade and compilation techniques to coordinate different presentations used in single-country IO tables and match different classification of sectors. These difficulties constrain the availability of MRIO tables compared to national input-output tables and therefore influence their extensive application.

In this context, the Institute for Global Environmental Strategies (IGES) initiated research on accounting for emissions embodied in international trade with particular focus on Asian developing countries. This research was supported by the IGES Strategy Fund in the fiscal year 2008. The purpose of this work was twofold. One was to assess and compare national emissions based on different principles of responsibility: (i) producer responsibility; (ii) consumer responsibility; and (iii) shared producer and consumer responsibility. The other was to test the differences in the results calculated by different input-output models: the SIRO model and the MRIO model. An empirical analysis was conducted for ten economies, including three OECD countries (Japan, ROK and USA), five ASEAN countries (Indonesia, Malaysia, the Philippines, Singapore and Thailand), China and Taiwan. The rest of world (ROW) apart from the ten selected economies was also considered. These economies are covered due to the availability of the MRIO table.

The results of this research could be used to inform negotiators to the UNFCCC the implications of international trade for climate policy. Though international trade has many impacts on climate policy, either positive or negative, it has yet to receive proper consideration in the process of setting up a post-2012 global climate regime. Part I of this report can be used to stimulate the concerns on the relationships between international trade and climate policy. From a technical point of view, if national emissions accounting based on consumer responsibility will be used for providing complementary information to current national emissions inventories, Part I of this report can indicate how different accounting methods could influence national emissions inventories and therefore help select an appropriate assessment method. From a specific country's standpoint, this research also provides breakdowns of sources and destinations of embodied emissions and trade balance of CO_2.

Part I of this report is organised as follows: Section 2 provides a brief overview on different principles of responsibility. Section 3 explains the methodology and responsibility principles applied in the empirical analysis. Section 4 presents the results of the empirical analysis. Section 5 provides policy implications and concludes Part I of this report.

2. Producer vs. Consumer Responsibility: An Overview

National economies are increasingly interacting with each other through international trade, foreign direct investment, capital flow and the spread of technology. In a supply chain of a product, not all of the stages, from the extraction of raw materials, production and process, transportation and distribution until the delivery to the end users, occur in the same country. The cooperation among various agents located in different countries to complete the supply chain of a product is a phenomenon of economic globalisation, a process by which a spatially interwoven and sophisticated network of business and trade has been formed. As a consequence of this process, countries are bound economically to each other. A change in one country will have propagating effects on other economies.

From an environmental perspective, owing to global trade people have access to cheaper and better quality goods that are not produced domestically. However, emissions and other environmental loads may be generated elsewhere, in particular in developing countries where the environmental requirements are generally low. The environmental costs caused by damage to the environment, productivity and public health are usually not included in the price of finished goods and passed on to the consumers. This raises the question of who is responsible for the external costs associated with the production of goods for consumption in other countries/regions, via international trade. The essence of this question is the allocation of responsibility for emissions between the producer and the consumer.

2.1 Producer responsibility

Producer responsibility is supported by the well-recognised polluter-pays-principle which can be dated back to the 1970s. The rationale behind this is that the producer benefits from income generated from production and emissions are the unfavourable by-products. There are many other reasons for adopting the principle of producer responsibility. First, the producer has the best knowledge, capacity and jurisdiction to incorporate environmental considerations into the design and manufacturing of a product and to conduct emission abatement. Second, the producer as a business entity is convenient for the government to regulate, monitor and take statistics. Third, allocating emissions responsibility to the producer can create a strong and direct incentive to emitters to reduce emissions from production, which is the final goal of any environmental policy. The current national emissions inventories (IPCC, 1996) are generated based on producer responsibility in which a nation is responsible for all emissions emitted within her borders.

A further principle in line with this is extended producer responsibility (EPR) that aims to impose accountability over the entire life cycle of products, in particular the post-consumer stage. EPR has been introduced as a policy concept to the Organisation for Economic Co-operation and Development (OECD) countries. Policy instruments such as product take-back mandate and recycling rate targets, advance recycling fees and landfill bans, etc. (Walls, 2006) are developed to require firms, which manufacture, import and/or sell products and packaging, to be financially or physically responsible for the products.

A major concern over the adoption of producer responsibility in environmental policy is the “pollution heaven hypothesis”, which is caused by the relocation of polluting production to countries/regions with less strict environmental requirements and the corresponding imports of pollution-intensive products by countries with strict environmental policy in place. In climate policy, this is related to the concern of carbon leakage from Annex I countries to non-Annex I countries. In the Kyoto Protocol, only a sub-set of all emitting countries commit to the binding mitigation targets which creates a gap in national implementation of climate policy among parties to the UNFCCC. This will trigger the mechanism for relocation and makes the "heavens" of pollution exist, in particular in developing countries.

Another argument is about the equity of this principle because the consumer, in particular residing in a country other than the producing country, also benefits from an improvement in living standards and should share the responsibility for emissions. In addition, the producer responsibility principle has little incentive to the consumer to conserve the environment.

2.2 Consumer responsibility

On average, a European consumes three times as many resources as an inhabitant of Asia and more than four times as much as an average African. Inhabitants of other rich countries consume up to ten times more than people in developing countries (SERI et al., 2009). In OECD countries, overconsumption is increasingly recognised as the driving force of many anthropogenic impacts on the environment and the climate system. Dated back to the early 1990s, sustainable consumption and production is defined as an important component of sustainable development in Agenda 21. In recent years the focus of environmental policy in Europe has shifted from industrial pollution control towards establishing more sustainable consumption patterns and a number of policy measures have been adopted in the European Union (EU), e.g., the Sustainable Consumption and Production Action Plan (2008) (Ekins, 2009). This trend leads to an increasing need for proper assessment on the environmental impacts of the products consumed by the households. Consequently, consumer responsibility has emerged as a principle for such assessment.

There are several reasons to use consumer responsibility in environmental policy. First, consumption is the driving force of economic growth and income generation which are obtained at the expense of environmental damage. In applying the systematic framework, driving force–pressure–state–impact–response (DPSIR) and life-cycle management to addressing environmental problems, it is necessary to take consumer responsibility into account. Second, the consumer benefits from consumption in terms of increasing living standards. According to the beneficial responsibility, the consumer should be responsible for the emissions embodied in the product that he/she consumed. Third, in the current model of demand-driven market, environmental awareness among consumers and the resulting boycott and selective purchasing have been demonstrated as effective pressure on big corporations and multinationals to improve their environmental performance. Therefore consumer responsibility could be used as a complementary policy tool of the dominant command-and-control measures. Fourth, consumer responsibility might help to discourage carbon leakage. Since this principle seems to be more beneficial and fairer to developing countries, it might help to encourage more participation from developing countries in mitigation regime.

Since the 1980s, there is a growing literature on the estimation of emissions, energy, resources and ecological footprints embodied in household consumption (Denton, 1975; Herendeen, 1978; Common and Salma, 1992; Bicknell et al., 1998; Kondo et al., 1998; Lenzen, 1998; Ferng, 2001; Lenzen and Murray, 2001; Munksgaard and Pedersen, 2001; Hubacek and Giljum, 2003; Nijdam et al., 2005; Peters and Hertwich, 2006a; Peters and Hertwich, 2006b; Wiedmann et al., 2006; Zhou et al., 2006a and 2006b; Webber and Matthews, 2007; Mcgregor, 2008, etc.). In practice, consumer responsibility is used as the basis to generate national ecological footprints (Rees and Wackernagel, 2006; Wackernagel and Rees, 1996; WFF, 1998, 1999, 2000, 2002, 2004, 2006, 2008; Manfreda, 2004), an indicator used to reveal the overshoot of biological capacity at a global level. In addition, the consumer principle is applied to account for indirect GHG emissions categorised in Scope 2 and Scope 3 of the GHG Protocol to achieve carbon neutrality (DECC, 2009).

However, there are also drawbacks in using the principle of consumer responsibility. First, emissions accounting based on consumer responsibility is complicated and requires massive data on technology and international trade that is usually not available. Currently many studies use input-output analysis to assess national responsible emissions. However, highly aggregation of products into sectors will cause uncertainty in the results (Lenzen et al., 2004; Lenzen, 2007). Second, to generate effective pressure on the producer via consumer responsibility and therefore cause the change in production behaviour, it is necessary to have enough environmental awareness among consumers and available information on the environmental aspects of products. However, in many cases these conditions are not met. In addition, consumer pressure works as an indirect incentive to the producer to mitigate. Though many single cases demonstrate successfully, the effectiveness of such mechanism to ensure the achievement of global mitigation targets is still in question. Third, a big concern related to policy implementation based on consumer responsibility is territorial sovereignty. A country has political control over its jurisdiction however does not have the political power in other countries. To deal with this problem requires international cooperation.

2.3 Comparison of responsibility principles

Table I.1 provides a list of different responsibilities and their comparison. These responsibility principles are summarised into two distinct categories. One is territorial emissions accounting for only direct emissions from a nation's territory based on the polluter-pays-principle. The other is national responsible emissions accounting for both direct emissions and indirect emissions associated with production and consumption of a country based on beneficial principle. For the latter category, there are several allocating schemes to account for indirect CO_2 emissions based on different system boundary and different actors (e.g., producer and consumer). Table I.2 provides the implications of different responsibility principles for climate policy at both domestic level and the international level.

Table I.1 Responsibility for CO_2 emissions based on different principles

Responsibility	Literature	Description	System Boundary	Accounting Measurement	Principle
Territorial responsible CO_2 emissions	Eder and Narodoslawsky, 1999.	A nation is responsible only for CO_2 emissions occurred directly in its territory.	A nation's territory.	Direct emissions from production and consumption.	Assign responsibility to polluters based on polluter-pays-principle.
National responsible CO_2 emissions	Common and Salma, 1992; Proops et al., 1993; Kondo et al., 1998.	A nation is (fully or partly) responsible for both direct CO_2 emissions and indirect CO_2 emissions embodied in international trade.	The respective nation and all of its trading partners (both importing and exporting)	Different approaches to account both direct and indirect emissions.	Assign responsibility to force drivers (e.g., consumers) based on beneficial principle.
Unrestricted beneficial responsibility	Eder and Narodoslawsky, 1999.	A nation is responsible for all activities from which the inhabitants of the region obtain benefits.	Domestic consumers and all trading partners to satisfy domestic consumption.	Direct emissions from final consumption and indirect emissions embodied in the international trade to satisfy the final consumption in the country.	Consumer is the end of any supply chain and is assigned full responsibilities to all emissions occurred in the supply chain. A full consumer-based responsibility with full life-cycle perspective based on beneficial principle.
Unrestricted production-oriented responsibility	Eder and Narodoslawsky, 1999.	A nation is responsible for its production with extensions to the upstream production in the supply chain wherever they are located.	Domestic producers and all trading partners associated with upstream supply.	Direct emissions from domestic producers and emissions embodied in the international trade of intermediate commodities.	Producer-based responsibility expanded to upstream responsibility based on polluter–pays-principle and partial beneficial principle.
Shared producer and consumer responsibility	Lenzen et al., 2007; Gallego and Lenzen, 2005.	Responsibility divided into mutually exclusive and collectively exhaustive portions is assigned to the different actors in the full supply chain.	All actors (e.g., producers as only suppliers, producers as both suppliers and consumers, and final consumers) in the full supply chain no matter where they located.	Direct emissions and emissions embodied in all upstream productions are shared between producer and its immediate consumer based on different allocation ratio.	Based on both polluter–pays-principle and beneficial principle.

Source: the Authors.

Table I.2 Policy implications of different responsibility principles

	Annex I countries	Non-Annex I countries	Global climate policy
Territorial responsibility	With reduction commitments defined by the Kyoto Protocol, countries are likely (i) to transfer CO_2-intensive part of production chain to other countries, especially non-Annex I countries; and (ii) to import CO_2-intesive goods/services instead of producing by themselves. They could enjoy the benefit of less cost to attaining the binding reduction target without compromising their levels of consumption and living standard.	Without binding reduction commitments yet, countries are likely to generate income through exports of CO_2-intensive intermediate commodities and final goods and therefore increase their national GHG inventories. Countries with net carbon trade balance (carbon embedded in export is greater than carbon embedded in import) argue that their territorial CO_2 emissions should be attributed partly to their trading partners.	Carbon leakage issues: (i) CO_2 emissions associated with international transportation; and (ii) direct CO_2 emissions from production in non-Annex I countries embodied in the exports of intermediate commodities, final goods and services to Annex I countries. The reduction in Annex I countries through international trade only result in the relocation of emitting sources from Annex I countries to non-Annex I countries, but nothing to contribute to the global reduction. In addition, as technologies are less advanced and productions are dirtier in developing countries, this kind of global relocation of emitting sources via international trade would undermine global efforts to achieve mitigation target. Countries with net carbon balance in view of international trade question the fairness of territorial principle and refuse to participate in the binding reduction scheme.
Beneficial responsibility	They would consider the trade-offs among producing by themselves, importing from other countries and changing life style, etc.	To create income from export, they would improve their production to promote low carbon technologies.	Carbon leakage resulted from the relocation of CO_2-intesive production via international trade could be addressed. Technology transfer from Annex I countries to non-Annex I countries might happen when Annex I countries relocate CO_2-intensive production in non-Annex I countries. Fairer responsibility-sharing principle would encourage more non-Annex I countries' participation in global mitigation scheme.
Unrestricted beneficial responsibility	ibid.	ibid.	ibid. Problem: producers have less incentive to improve their production.
Unrestricted production-oriented responsibility	Relocation of CO_2-intensive production would take into account of upstream emissions and finally promote world-wide systematic life-cycle management of production.		Technological innovation would be promoted and emissions would be minimised in terms of systematic life-cycle management. Problems: (i) unsustainable life style could not be influenced substantially; and (ii) double counting.
Shared producer and consumer responsibility	All actors in the full supply chain no matter where they locate will be responsible for mutually exclusive portion of emissions. This would promote world-wide systematic life-cycle management, including both production and consumption. Life style change can also be expected.		Problem: the accounting system also requires international cooperation.

Source: the Authors.

3. An Empirical Analysis Focusing on Asia: Methodology

To fulfill the purpose of this research work, i.e., (i) to assess and compare national emissions based on different principles of responsibility; and (ii) to test the differences in the results calculated by different input-output models, we conduct an empirical analysis for ten economies, including nine in Asia and USA, an important trading partner with nine economies. They are five ASEAN countries (Indonesia, Malaysia, the Philippines, Singapore and Thailand), China and Taiwan and three OECD countries (Japan, ROK and USA). These economies are covered due to the availability of the MRIO table. The rest of the world (ROW) apart from the ten selected economies is also considered.

3.1 Multi-region input-output model

In this work, we apply the Asian International Input-Output Table 2000 (AIO 2000) developed by IDE-JETRO (2006) to calculate CO_2 embodied in multilateral trade (Zhou, 2009). AIO 2000 includes 24 sectors and ten regions in Asia and the Pacific. It is the Chenery-Moses type of MRIO (Miller and Blair, 1985; Chenery, 1953; Moses, 1955). To calculate embodied CO_2 we use the GTAP-E database which provides data on CO_2 emissions from combustion of six types of fuels from 60 sectors (including capital goods, households and government) in 87 regions for 2001. By aggregating and matching sectors from 60 in GTAP-E (Dimaranan, 2006) to 24 in AIO 2000 (see Appendix I.A) and using sectoral outputs from the GTAP database, intensities of CO_2 emissions are calculated for 24 sectors in 2001 (see Appendix I.B). These are used for calculating embodied emissions.

The framework of AIO 2000 is illustrated by the simplified two-sector and two-region case (Table I.3), in which intra-regional and interregional trade of both intermediate and final goods among two regions are made explicit by bivariates indicating the source and destination sectors and regions. For the full framework of AIO 2000, please see Appendix I.C.

The supply-demand relations based on AIO 2000 could be generalized as follows:

$$X = AX + F + E$$

Or at the regional level,

$$\begin{pmatrix} X^1 \\ X^2 \\ \vdots \\ X^n \end{pmatrix} = \begin{pmatrix} A^{11} & A^{12} & \cdots & A^{1n} \\ A^{21} & A^{22} & \cdots & A^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A^{n1} & A^{n2} & \cdots & A^{nn} \end{pmatrix} \begin{pmatrix} X^1 \\ X^2 \\ \vdots \\ X^n \end{pmatrix} + \begin{pmatrix} \sum_s F^{1s} \\ \sum_s F^{2s} \\ \vdots \\ \sum_s F^{ns} \end{pmatrix} + \begin{pmatrix} E^{1ROW} \\ E^{2ROW} \\ \vdots \\ E^{nROW} \end{pmatrix} \quad \text{(I.1)}$$

with X^r : total output of region *r*; $A^{rs} = X^{rs} / X^s$: transaction coefficient matrix representing ratios of trade from *r* to *s* to the total input of *s*; F^{rs} : final demand of *s* supplied by *r*; E^{rROW} : exports from *r* to .

Table I.3 Simplified framework of AIO 2000 in a two-sector and two-region case

		Intermediate Demand				Final Demand		Export to *ROW*	Total Output
		s1r1	*s2r1*	*s1r2*	*s2r2*	*r*1	*r*2		
Supply	*s1r1*	x_{11}^{11}	x_{12}^{11}	x_{11}^{12}	x_{12}^{12}	f_1^{11}	f_1^{12}	e_1^{1ROW}	x_1^1
	s2r1	x_{21}^{11}	x_{22}^{11}	x_{21}^{12}	x_{22}^{12}	f_2^{11}	f_2^{12}	e_2^{1ROW}	x_2^1
	s1r2	x_{11}^{21}	x_{12}^{21}	x_{11}^{22}	x_{12}^{22}	f_1^{21}	f_1^{22}	e_1^{2ROW}	x_1^2
	s2r2	x_{21}^{21}	x_{22}^{21}	x_{21}^{22}	x_{22}^{22}	f_2^{21}	f_2^{22}	e_2^{2ROW}	x_2^2
Import from *ROW*		m_1^{ROW1}	m_2^{ROW1}	m_1^{ROW2}	m_2^{ROW2}				
Value-added		v_1^1	v_2^1	v_1^2	v_2^2				
Total input		x_1^1	x_2^1	x_1^2	x_2^2				

Note: *s1, s2, r1, r2*: sector 1, sector 2, region 1 and region 2, respectively; x_{ij}^{rs} : transaction of intermediate goods from sector *i* in *r* to sector *j* in *s,* where *i, j* =1, 2 representing two sectors and *r, s* = 1, 2 representing two regions; f_i^{rs} : final demands of *i* in *s* supplied from *r*; e_i^{rROW} : exports of *i* from *r* to *ROW*; m_j^{ROWs} : imports of *j* from *ROW* to *s*; x_i^r : total output of sector *i* in *r*; v_j^s : value added of sector *j* in *s*.

Eq. I.2 and Eq. I.3 are derived to indicate the final demand-induced production, based on the MRIO model and the SRIO model, respectively. B^{rs} is the Leontief multiplier derived from the MRIO model representing production in *r* induced by the per unit final output in *s*.

$$\begin{pmatrix} X^1 \\ X^2 \\ \vdots \\ X^n \end{pmatrix} = \begin{pmatrix} B^{11} & B^{12} & \cdots & B^{1n} \\ B^{21} & B^{22} & \cdots & B^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ B^{n1} & B^{n2} & \cdots & B^{nn} \end{pmatrix} \left[\begin{pmatrix} \sum_s F^{1s} \\ \sum_s F^{2s} \\ \vdots \\ \sum_s F^{ns} \end{pmatrix} + \begin{pmatrix} E^{1ROW} \\ E^{2ROW} \\ \vdots \\ E^{nROW} \end{pmatrix} \right] \quad \text{(I.2)}$$

$$\begin{pmatrix} X^1 \\ X^2 \\ \vdots \\ X^n \end{pmatrix} = \begin{pmatrix} (I-A^{11})^{-1} & 0 & \cdots & 0 \\ 0 & (I-A^{22})^{-1} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & (I-A^{nn})^{-1} \end{pmatrix} \times \left[\begin{pmatrix} \sum_{s\neq 1} A^{1s}X^s \\ \sum_{s\neq 2} A^{2s}X^s \\ \vdots \\ \sum_{s\neq n} A^{ns}X^s \end{pmatrix} + \begin{pmatrix} F^{11} + \sum_{s\neq 1} F^{1s} \\ F^{22} + \sum_{s\neq 2} F^{2s} \\ \vdots \\ F^{nn} + \sum_{s\neq n} F^{ns} \end{pmatrix} + \begin{pmatrix} E^{1ROW} \\ E^{2ROW} \\ \vdots \\ E^{nROW} \end{pmatrix} \right] \quad \text{(I.3)}$$

The system boundary for calculating the multipliers using the SRIO model (See Appendix I.D) and the MRIO model (See Appendix I.E) is different. By the MRIO model, intermediate inputs from ten regions are internalised in the multiplier calculation, while by the SRIO model only domestic intermediate inputs are internalised while the imports of intermediate goods from other nine regions are treated exogenously similarly to imported final goods.

Treating the imports of intermediate commodities as exogenous variables in the SRIO model fails to account for the inter-regional and inter-industrial feedback effects associated with the use of imported intermediate commodities (Miller, 1969; Lenzen et al., 2004; Peters, 2008; Peters and Hertwich, 2006a). In addition, the fairness of responsibility allocation will be another concern, in particular in the case of exports from one country to another country via the transshipment of a third country (see an example in the introduction section).

3.2 Two responsibility allocation schemes

Taking international trade into account, national responsible emissions are calculated based on two responsibility allocation schemes, viz., (i) consumer responsibility (Scheme I); and (ii) shared producer and consumer responsibility based on the ratio of value added (Gallego and Lenzen, 2005; Lenzen, 2007; Lenzen et al., 2007) (Scheme II). For Scheme I, both models of MRIO and SRIO are applied.

Given c^r (row vector with each element representing CO_2 emissions per unit industrial output in *r*), national territorial emissions, C^r_{prod}, is estimated as follows, in which producers are taking full responsibility:

$$C^r_{prod} = c^r X^r + C^r_{hh} \quad \text{(I.4)}$$

C_{hh}^{r} represents direct emissions from regional households. According to this accounting method, the amount of national emissions is influenced by factors such as sectoral carbon intensity, national production output and the share of carbon intensive sector in national economy. In this case emissions embodied in trade are not taken into account.

Scheme I: Consumer responsibility

Under Scheme I, we calculate using both models of MRIO and SRIO. By the MRIO model (SchI-MRIO), national responsible emissions include four parts: (i) emissions embodied in the final demands supplied domestically ($P1_M$); (ii) emissions embodied in the final demands provided by imports from other nine regions ($P2_M$); (iii) emissions embodied in imports (miscellaneous of intermediate and final goods) from *ROW* (regions other than ten regions) ($P3_M$); and (iv) direct emissions from regional households ($P4$).

$$C_{con\_M}^{s} = \underbrace{\left(\sum_r c^r B^{rs}\right) F^{ss}}_{P1_M} + \underbrace{\sum_{n \neq s} \left[\left(\sum_r c^r B^{rn}\right) F^{ns}\right]}_{P2_M} + \underbrace{C_{im}^{s}}_{P3_M} + \underbrace{C_{hh}^{s}}_{P4} \tag{I.5}$$

C_{im}^{s} (Eq. I.6) are emissions embodied in imports from *ROW* to *s*, which is calculated using emission coefficients and multipliers of *ROW*.

$$C_{im}^{s} = c^{w} B^{w} M^{ROWs} \tag{I.6}$$

with c^{w}: row vector indicating sectoral carbon intensity of *ROW*; B^{w}: Leontief multiplier for *ROW* derived from GTAP database; M^{ROWs}: imports from *ROW* to *s*.

Emissions embodied in the total exports of region *s* calculated using multi-regional multipliers includes two parts: (i) emissions embodied in exports to other nine regions ($P5_M$); and (ii) emissions embodied in exports to *ROW* ($P6_M$)

$$P5_M = \sum_{n \neq s} \left[\left(\sum_r c^r B^{rs}\right) F^{sn}\right] \tag{I.7}$$

$$P6_M = \left(\sum_r c^r B^{rs}\right) E^{sROW} \tag{I.8}$$

with E^{sROW} : exports from region *s* to *ROW*.

National trade balance of CO_2 is shown in Eq. I.9.

$$C^s_{tb\_M} = (P5_M + P6_M) - (P2_M + P3_M) \tag{I.9}$$

Using the SRIO model under Scheme I (SchI-SRIO), national responsible emissions, $C^s_{con\_S}$ (Eq. I.10), also includes four parts, $P1_S$, $P2_S$, $P3_S$ and $P4$. World average sectoral CO_2 intensity $c^{\overline{w}}$ and world input-output multiplier $B^{\overline{w}}$, derived from the GTAP database, are applied to estimate imports from other nine regions as well as from *ROW* (regions other than the ten regions).

$$C^s_{con\_S} = \underbrace{\left[c^s\left(I - A^{ss}\right)^{-1}\right]F^{ss}}_{P1_S} + \underbrace{\sum_{n\neq s}\left[\left(c^{\overline{w}} B^{\overline{w}}\right)\left(A^{ns} X^s + F^{ns}\right)\right]}_{P2_S} + \underbrace{c^{\overline{w}} B^{\overline{w}} M^{ROWs}}_{P3_S} + \underbrace{C^s_{hh}}_{P4} \tag{I.10}$$

Similarly, emissions embodied in total exports calculated using single-region multipliers also includes two parts $P5_S$ and $P6_S$.

$$P5_S = \sum_{n\neq s}\left[C^s\left(I - A^{ss}\right)^{-1}\left(A^{sn} X^n + F^{sn}\right)\right] \tag{I.11}$$

$$P6_S = \left[C^s\left(I - A^{ss}\right)^{-1}\right] E^{sROW} \tag{I.12}$$

National trade balance of CO_2 calculated by the SRIO model is shown in Eq. I.13.

$$C^s_{tb\_S} = (P5_S + P6_S) - (P2_S + P3_S) \tag{I.13}$$

According to the consumer responsibility, factors influencing total national emissions may include a mixture of levels of sectoral carbon intensity, multiplier, level of consumption, share of carbon intensive consumption in total consumption, and trade, etc.

Scheme II: Shared producer and consumer responsibility

Under Scheme II, emissions emitted from one sector are shared at a defined ratio (based on value-added) between this sector ($C1$) and its downstream demands, including both intermediate demands of downstream producers ($C2$), and final consumers and exports ($C3$) (Lenzen et al., 2007; Lenzen, 2007). These are calculated using the MRIO model (see Eq. I.14).

$$cX = c(AX + F + E) = \underbrace{c[(I-\alpha)(AX+F+E)]}_{C1\text{: upstream producer}} + \underbrace{c(\alpha AX)}_{\substack{C2\text{: downstream}\\ \text{producer}}} + \underbrace{c[\alpha(F+E)]}_{\substack{C3\text{: final consumers}\\ \text{and exports}}} \qquad \text{(I.14)}$$

α is a diagonal matrix with each element α_i^r on the diagonal representing the ratio of non-factor external inputs in sector *i* in region *r* to *i*'s total external inputs. $(1-\alpha_i^r)$ is therefore the factor inputs as a ratio to the total external inputs, defined as follows (Eq. I.15):

$$1-\alpha_i^r = v_i^r / \left(x_i^r - a_{ii}^{rr} x_i^r\right) \qquad \text{(I.15)}$$

with v_i^r: value added of sector *i* in *r*, representing factor inputs; $\left(x_i^r - a_{ii}^{rr} x_i^r\right)$ being the total external inputs in sector *i* in *r*.

The supply and demand relations derived from Eq. I.14 using the MRIO model is shown in Eq. I.16:

$$cX = \left[c(I-\alpha A)^{-1}\right] \times \left\{\left[(I-\alpha)(AX+F+E)\right] + \alpha F + \alpha E\right\} \qquad \text{(I.16)}$$

$c(I-\alpha A)^{-1}\left[(I-\alpha)(AX+F+E)\right]$ is the portion shared by the upstream producer (*S1*) while $c(I-\alpha A)^{-1}\alpha F$ and $c(I-\alpha A)^{-1}\alpha E$ are the portions shared by the final consumer (*S2*) in ten regions and exports to *ROW* (*S3*), respectively.

4. An Empirical Analysis Focusing on Asia: Results

4.1 National responsible emissions adjusted by trade

National responsible CO_2 emissions are calculated with trade adjustment based on SchI-MRIO (Eq. I.5), SchI-SRIO (Eq. I.10) and SchII-MRIO (Eq. I.16). These accounts are then compared with the current national accounts estimated based on producer responsibility (Eq. I.4). The focus is put on emissions embodied in multilateral trade among ten economies. Trade between each region and ROW is also calculated, but with less priority.

In Table I.4 (SchI-MRIO), national responsible CO_2 emissions indicate that changes to current national emissions vary from -525Mt-CO_2 (China) to 543Mt-CO_2 (USA). By percentage, these changes range from -25% (Malaysia) to 42% (Singapore).

Table I.4 National responsible emissions (SchI-MRIO, 2000)

(in Mt-CO_2)

Region	$P1_M$	$P2_M$	$P3_M$	$P4$	$C^s_{con\_M}$	C^r_{prod}	Difference [1]	Difference (%)[2]
IDN	133	4	25	53	215	273	-58	-21%
MYS	47	7	19	15	88	118	-30	-25%
PHL	36	3	11	17	67	69	-2	-3%
SGP	36	7	38	4	85	60	25	42%
THA	92	6	25	21	144	155	-11	-7%
CHN	2,252	9	79	311	2,651	3,176	-525	-17%
TWN	94	14	46	56	210	217	-7	-3%
ROK	267	11	76	88	442	435	7	2%
JPN	862	82	189	310	1,443	1,179	264	22%
USA	4,318	163	659	1,105	6,245	5,702	543	10%
Total	8,137	306	1,167	1,980	11,590	11,384	206	2%

Note: IDN: Indonesia; MYS: Malaysia; PHL: the Philippines; SGP: Singapore; THA: Thailand; CHN: China; TWN: Taiwan; ROK: the Republic of Korea; JPN: Japan; USA: the United States of America.

1. Equals to $C^s_{con\_M} - C^r_{prod}$;

2. Equals to $(C^s_{con\_M} - C^r_{prod}) / C^r_{prod} \times 100\%$.

In Table I.5 (SchI-SRIO), national responsible emissions adjusted by trade show changes to current national emissions ranging from -518Mt-CO_2 (China) to 322Mt-CO_2 (USA) or from -23% (Indonesia) to 42% (Singapore) in terms of percentage change.

Table I.5 National responsible emissions (SchI-SRIO, 2000)

(in Mt-CO_2)

Region	$P1_S$	$P2_S$	$P3_S$	$P4$	$C^s_{con\_S}$	C^r_{prod}	Difference	Difference (%)
IDN	128	11	19	53	211	273	-62	-23%
MYS	42	30	15	15	102	118	-16	-14%
PHL	33	11	9	17	70	69	1	1%
SGP	29	24	28	4	85	60	25	42%
THA	84	21	20	21	146	155	-9	-6%
CHN	2,214	68	65	311	2658	3,176	-518	-16%
TWN	82	47	38	56	223	217	6	3%
ROK	240	47	63	88	438	435	3	1%
JPN	769	107	155	310	1341	1,179	162	14%
USA	4,205	163	551	1,105	6,024	5,702	322	6%
Total	7,826	529	963	1,980	11,298	11,384	-86	-1%

Comparing two calculation results, $(\sum_s C^s_{con\_M} - \sum_s C^s_{con\_S})$ for ten regions indicates 2.6% of total consumption-based emissions, i.e. $\sum_r C^r_{prod}$. However, $(C^s_{con\_M} - C^s_{con\_S}) / C^r_{prod}$ at national level, is considerable, e.g. up to -12% for Malaysia. These are caused mainly by different emission multipliers (multi-region multipliers, single-region multipliers or multipliers of *ROW*) applied to imports and exports, and the way treating intermediate demands and the impacts of feedback effects.

Under Scheme II (Eq. I.16), the focus is placed on responsibility shared among ten economies (Table I.6). Changes range from a decrease of -327Mt-CO_2 (China) to an increase of 386Mt-CO_2 (USA). Changes in terms of percentage exhibit a range from -18% (Malaysia) to 38% (Singapore).

Table I.6 National responsible emissions (SchII-MRIO, 2000)

(in Mt-CO_2)

Region	*S1*	*S2*	$P3_M$	*P4*	National emissions	C^r_{prod}	Difference	Difference (%)
IDN	131	41	25	53	250	273	-23	-8%
MYS	45	18	19	15	97	118	-21	-18%
PHL	30	12	11	17	70	69	1	1%
SGP	29	12	38	4	83	60	23	38%
THA	79	24	25	21	149	155	-6	-4%
CHN	1,891	568	79	311	2,849	3,176	-327	-10%
TWN	86	26	46	56	214	217	-3	-1%
ROK	197	78	76	88	439	435	4	1%
JPN	658	193	189	310	1350	1,179	171	15%
USA	3,097	1,227	659	1,105	6,088	5,702	386	7%
Total	6,243	2,199	1,167	1,980	11,589	11,384	205	2%

Note: *S1*: emissions shared by the region as a producer; *S2*: emissions shared by the region as a final consumer (Eq. I.16); national emissions equal to ($S1+S2+P3_M+P4$).

4.2 Multilateral trade balance of embodied emissions

Table I.7 presents sources and destinations of embodied CO_2 in multilateral trade (SchI-MRIO). Rows read CO_2 embodied in exports and columns read CO_2 embodied in imports. As a reference, the last three rows show CO_2 embodied in imports and exports and trade balance of CO_2 under SchI-SRIO Singapore, Japan and the USA have trade deficits, while the other countries have trade surpluses in terms of embodied CO_2. Among ten economies, the USA has the largest trade deficit (-464Mt-CO_2) followed by Japan (-191Mt-CO_2), while China has the largest trade surplus (452Mt-CO_2). In the case of SchI-SRIO, USA, Japan, Singapore, Taiwan, ROK and the Philippines have trade deficits and the other economies have trade surpluses of CO_2.

Table I.7 Sources and destinations of embodied emissions (SchI-MRIO, 2000)

(in Mt-CO_2)

Region	IDN	MYS	PHL	SGP	THA	CHN	TWN	KOR	JPN	USA	ROW
IDN	133.2	0.8	0.2	0.6	0.4	0.2	0.6	0.4	2.6	6.4	32.4
MYS	0.3	47.2	0.3	1.8	0.6	0.5	0.9	0.4	3.5	6.7	27.8
PHL	0.0	0.1	36.5	0.0	0.1	0.1	0.1	0.1	1.5	4.1	9.3
SGP	0.1	0.8	0.3	35.7	0.3	0.3	0.4	0.3	1.1	2.9	25.6
THA	0.3	0.5	0.2	0.5	91.8	0.3	0.4	0.2	3.1	5.3	31.3
CHN	1.3	2.0	0.4	1.9	2.0	2,252.2	3.6	4.8	51.6	103.6	369.1
TWN	0.3	0.5	0.3	0.2	0.4	2.1	94.4	0.4	3.1	8.3	50.2
ROK	0.3	0.3	0.3	0.3	0.2	1.4	1.0	267.5	4.0	9.8	77.1
JPN	0.5	1.0	0.4	0.8	0.9	1.7	2.6	1.6	861.9	15.4	55.2
USA	0.4	1.0	0.5	0.9	0.8	2.3	4.1	2.6	11.3	4,318.5	333.8
ROW	25	19	11	38	25	79	46	76	189	659	
$P2_M + P3_M$	29	26	14	45	31	88	60	87	271	822	
$P5_M + P6_M$	45	43	15	32	42	540	66	95	80	358	
$C^s_{tb\_M}$	16	17	1	-13	11	452	6	8	-191	-464	
$P2_S + P3_S$	30	45	20	52	41	133	85	110	262	714	
$P5_S + P6_S$	93	60	19	27	49	699	81	109	100	391	
$C^s_{tb\_S}$	63	15	-1	-25	8	566	-4	-1	-162	-323	

Table I.8 indicates the responsibility of emissions shared by an economy as an upstream producer (*S1* in Table I.6) and the destinations of trade for which the responsibility is shared between two trading partners. Table I.9 presents the source countries from which embodied emissions are shared by an economy as a consumer (*S2* in Table I.6).

Table I.10 indicates the bilateral trade balance of embodied CO_2 (SchI-MRIO). The USA and Japan have trade deficits of CO_2 in the bilateral relations with all other eight economies and ROW, while China has a trade surplus of CO_2 in relation with all other nine economies and ROW. In particular, the Sino-USA trade surplus of CO_2 is considerably large (101Mt-CO_2).

Table I.8 Destinations with which embodied emissions is shared by an economy as an upstream producer (SchII-MRIO, 2000)

(in Mt-CO_2)

Region	IDN	MYS	PHL	SGP	THA	CHN	TWN	KOR	JPN	USA	Total
IDN	103.7	0.7	0.4	0.3	0.6	2.2	1.4	4.4	13.5	4.2	131
MYS	0.2	37.5	0.3	1.3	0.4	0.7	0.5	0.4	1.8	2.2	45
PHL	0.0	0.2	25.5	0.0	0.1	0.2	0.3	0.2	1.2	2.6	30
SGP	0.1	0.3	0.1	26.9	0.1	0.2	0.1	0.1	0.2	0.5	29
THA	0.2	0.4	0.1	0.2	73.9	0.4	0.3	0.2	1.3	1.9	79
CHN	0.9	0.8	0.3	0.8	1.0	1,844	1.8	3.4	15.1	23.5	1,891
TWN	0.2	0.4	0.2	0.2	0.3	3.3	74.5	0.3	1.7	4.3	86
ROK	0.2	0.3	0.2	0.2	0.2	2.4	0.6	187.1	2.4	3.6	197
JPN	0.3	0.7	0.2	0.6	0.7	2.1	1.5	1.4	644.0	6.0	658
USA	0.4	0.8	0.4	0.7	0.6	2.1	2.1	2.5	8.6	3,079	3,097

Table I.9 Source countries with which embodied emissions is shared by an economy as a consumer (SchII-MRIO, 2000)

(in Mt-CO_2)

Region	IDN	MYS	PHL	SGP	THA	CHN	TWN	KOR	JPN	USA
IDN	40.2	0.2	0.0	0.2	0.1	0.1	0.2	0.1	0.8	2.0
MYS	0.1	16.8	0.1	0.5	0.3	0.2	0.5	0.1	1.1	2.0
PHL	0.0	0.0	11.0	0.0	0.0	0.0	0.0	0.0	0.5	1.3
SGP	0.0	0.2	0.1	10.0	0.1	0.1	0.1	0.1	0.3	0.7
THA	0.1	0.1	0.0	0.1	22.2	0.1	0.1	0.0	0.8	1.3
CHN	0.3	0.5	0.1	0.4	0.5	565.9	0.9	1.1	11.3	25.4
TWN	0.1	0.2	0.1	0.0	0.1	0.7	22.6	0.1	0.9	2.6
ROK	0.1	0.1	0.1	0.1	0.1	0.4	0.3	75.3	1.3	2.9
JPN	0.1	0.2	0.1	0.1	0.2	0.3	0.5	0.3	173.3	2.6
USA	0.1	0.2	0.1	0.2	0.2	0.5	0.9	0.6	2.6	1,186.5
Total	41	18	12	12	24	568	26	78	193	1,227

Table I.10 Bilateral trade balance of embodied emissions (SchI-MRIO, 2000)

(in Mt-CO_2)

Region	IDN	MYS	PHL	SGP	THA	CHN	TWN	ROK	JPN	USA	ROW	Trade Balance
IDN	0.0	0.5	0.2	0.5	0.1	-1.1	0.3	0.1	2.1	6.0	7.4	16
MYS	-0.5	0.0	0.2	1.0	0.1	-1.5	0.4	0.1	2.5	5.7	8.8	17
PHL	-0.2	-0.2	0.0	-0.3	-0.1	-0.3	-0.2	-0.2	1.1	3.6	-1.7	1
SGP	-0.5	-1.0	0.3	0.0	-0.2	-1.6	0.2	0.0	0.3	2.0	-12.4	-13
THA	-0.1	-0.1	0.1	0.2	0.0	-1.7	0.0	0.0	2.2	4.5	6.3	11
CHN	1.1	1.5	0.3	1.6	1.7	0.0	1.5	3.4	49.9	101.3	290.1	452
TWN	-0.3	-0.4	0.2	-0.2	0.0	-1.5	0.0	-0.6	0.5	4.2	4.2	6
ROK	-0.1	-0.1	0.2	0.0	0.0	-3.4	0.6	0.0	2.4	7.2	1.1	8
JPN	-2.1	-2.5	-1.1	-0.3	-2.2	-49.9	-0.5	-2.4	0.0	4.1	-133.8	-191
USA	-6.0	-5.7	-3.6	-2.0	-4.5	-101.3	-4.2	-7.2	-4.1	0.0	-325.2	-464
ROW	-7.4	-8.8	1.7	12.4	-6.3	-290.1	-4.2	-1.1	133.8	325.2	0.0	155

5. Conclusions and Policy Implications

The entry into force of the Kyoto Protocol to UNFCCC divides parties into two groups by their obligations to mitigate domestic emissions. This division creates differences in the strictness of domestic climate policy, which are in favour of the conditions for creating the "heavens" of pollution. Contrarily, current national GHG accounting is based on territorial responsibility, or similar producer responsibility, which contributes to make the conditions for creating the "heavens" of pollution mature. These situations lead to the concerns on global competitiveness and carbon leakage because carbon emissions embodied in international trade and associated global social costs are not taken into account. In addition, the equity of allocating full responsibility for emissions embodied in exports to the exporting countries is also arguable.

Various policy measures have been suggested to address competitiveness and leakage concerns. Among others, the foremost policy option is to commit all emitting countries to reduce. Based on the results of the 15th meeting of the Conference of the Parties of the UNFCCC held in Copenhagen, to conclude an international agreement on full participation in emission reduction will remain an intractable challenge. Other measures (Neuhoff, 2008) include: (1) the free allocation of tradable emission allowances and expanding the scope and coverage of a scheme or state aid to mitigate the carbon costs imposed by the emissions trading scheme implemented in the EU; (2) trade measures at the border that discussed in the US and the EU to level up the international playing field; and (3) measures creating a similar carbon price through the conclusion of international (sectoral) agreements. Part I of this report presents national responsible emissions accounting adjusted by trade to help address these issues.

Our research indicates that CO_2 embodied in multilateral trade among ten selected economies is significant. It accounts for about 1,473 Mt-CO_2 or 13% of the total national responsible emissions of ten economies (11,590 Mt-CO_2, under SchI-MRIO). At a national level, it could reach as high as 53% (Singapore). The results from the empirical analysis also indicate that carbon leakage occurs in a non-negligible way from developed economies to developing economies. This will undermine the efforts made in achieving the mitigation targets set by the Kyoto Protocol and should be properly considered by the UNFCCC.

This research demonstrates that a change from producer responsibility to consumer responsibility will greatly influence national emissions inventories. For example, responsibility allocated by the two extreme methods, i.e., full producer responsibility vs. full consumer responsibility, could cause a change in national emissions from –525 to 543 Mt-CO_2 (SchI-MRIO). For different countries the influence will be different. In general, the national emissions inventories in countries with net exports of emissions will increase and in an opposite way, the national emissions inventories in countries with net imports of emissions will decrease. This clue implies that trade adjustment to current national accounting to generate national responsible emissions accounts influence the current relationships between climate policy and international trade potentially and therefore can be considered as a complementary policy option, among others, to help address the carbon leakage concern. The comparison of advantages and disadvantages of different policy options to address the issue of embodied carbon and competitiveness and carbon leakage concerns is included in our future research agenda. In addition, how consumer responsibility will influence carbon leakage and international competitiveness needs further assessment (Zhou et al., 2010)

To conduct trade adjusted national emissions accounting, more data is required including bilateral trade and carbon intensity by sector/product and by country. Rarely is the latter one transparent nor is it provided by countries or by authoritative international organisations. Information on geographical identity, energy intensity and carbon intensity of tradable goods are important to inform environmentally-conducive purchasing decisions and should be addressed through the collaboration between global climate regime and international trade regime.

In allocating emission responsibility associated with international trade, full producer responsibility and full consumer responsibility are two extremes. Shared producer and consumer responsibility lie between them and can work as direct incentives to help change the environmental behaviours of both actors. In this paper the ratio of added value in total external inputs is used to define shares. However, this is only one of the alternative ratios, such as the proportion of imports to exports. Further study is necessary to help select a fair, effective and robust ratio for sharing responsibilities between upstream producers and downstream consumers.

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Appendix I.A Sector Classification

	Sector definition in AIO 2000	Sector code in GTAP Data Base 6
1	Paddy	pdr
2	Other agricultural products	wht, gro, v_f, osd, c_b, pfb, ocr
3	Livestock and poultry	ctl, oap, rmk, wol
4	Forestry	frs
5	Fishery	fsh
6	Crude petroleum and natural gas	oil, gas
7	Other mining	coa, omn
8	Food, beverage and tobacco	cmt, omt, vol, mil, pcr, sgr, ofd, b_t
9	Textile, leather and related products	tex, wap, lea
10	Timber and wooden products	lum
11	Pulp, paper and printing	ppp
12	Chemical products	crp
13	Petroleum and petro products	p_c
14	Rubber products	crp
15	Non-metallic mineral products	nmm
16	Metal products	i_s, nfm, fmp
17	Machinery	ele, ome
18	Transport equipment	mvh, otn
19	Other manufacturing products	omf
20	Electricity, gas, and water supply	ely, gdt, wtr
21	Construction	cns
22	Trade and transport	trd, otp, wtp, atp
23	Services	cmn, ofi, isr, obs, ros, dwe
24	Public administration	osg

Appendix I.B Carbon Intensities of 24 Sectors

(in kg/10^3 US$[1])

	IDN	MYS	PHL	SGP	THA	CHN	TWN	ROK	JPN	USA
1	1.58	15.01	2.40	0.04	63.77	132.87	215.10	315.57	140.41	1048.49
2	68.59	17.44	20.77	0.09	266.78	157.53	341.46	474.04	199.37	282.77
3	122.10	1.96	14.93	0.00	158.53	199.59	15.92	698.27	29.86	129.49
4	619.08	62.24	398.39	0.83	150.15	342.39	660.65	262.47	316.30	85.27
5	1048.67	107.17	483.73	0.16	1740.43	520.00	0.00	3372.10	1298.38	778.68
6	1645.06	0.05	13708.34	20362.47	0.99	1627.47	2720.06	619.37	23.05	714.71
7	564.96	2527.90	490.85	122.80	191.33	821.43	307.15	415.76	214.13	9.47
8	111.07	163.78	116.60	3.51	135.46	203.05	203.13	143.46	33.59	84.21
9	245.89	192.93	123.21	5.23	77.33	88.74	496.29	279.77	115.15	59.08
10	12.88	76.57	56.28	2.74	56.52	110.37	10.10	148.40	5.64	57.37
11	462.37	395.70	671.03	6.37	341.31	351.84	286.23	476.12	118.21	165.43
12	708.53	32.93	181.56	18.65	525.58	459.50	336.83	155.71	15.15	222.56
13	2262.61	3963.40	0.06	0.00	0.02	45.30	0.00	0.00	0.00	594.06
14	708.53	32.93	181.56	18.65	525.58	459.50	336.83	155.71	15.15	222.56
15	5986.40	453.09	1193.32	8.15	1023.63	1122.33	729.77	742.31	378.33	523.85
16	1260.65	249.14	149.38	10.06	310.18	685.06	577.23	135.15	177.65	180.27
17	53.12	29.04	2.94	3.09	27.30	65.65	28.10	22.70	11.48	21.97
18	22.34	108.93	0.96	4.05	8.59	118.40	27.27	98.17	1.12	33.44
19	373.32	175.54	5.61	14.77	73.01	14.93	62.68	243.33	46.48	15.58
20	9908.56	5753.85	2399.03	19460.36	5323.57	17701.69	2972.71	1794.26	658.12	6615.91
21	92.36	175.76	74.33	0.00	60.02	55.52	68.27	64.30	14.91	8.00
22	1502.79	1028.27	1281.42	0.57	889.22	550.96	804.17	1376.60	292.76	384.65
23	59.73	18.47	68.12	0.19	9.88	62.77	20.71	101.85	35.96	16.85
24	75.18	54.63	75.78	0.68	12.18	232.94	58.09	198.27	109.56	26.93

Note 1: US$ at 2000 value.

Appendix I.C Framework of AIO 2000 Table

Code	Intermediate Demand (A)										Final demand (F)										Export (L)			Statistical Discrepancy (QX)	Total Outputs (XX)
	Indonesia (AI)	Malaysia (AM)	Philippines (AP)	Singapore (AS)	Thailand (AT)	China (AC)	Taiwan (AN)	Korea (AK)	Japan (AJ)	U.S.A. (AU)	Indonesia (FI)	Malaysia (FM)	Philippines (FP)	Singapore (FS)	Thailand (FT)	China (FC)	Taiwan (FN)	Korea (FK)	Japan (FJ)	U.S.A. (FU)	Export to Hong Kong (LH)	Export to EU (LO)	Export to R.O.W. (LW)		
Indonesia (AI)	A^{II}	A^{IM}	A^{IP}	A^{IS}	A^{IT}	A^{IC}	A^{IN}	A^{IK}	A^{IJ}	A^{IU}	F^{II}	F^{IM}	F^{IP}	F^{IS}	F^{IT}	F^{IC}	F^{IN}	F^{IK}	F^{IJ}	F^{IU}	L^{IH}	L^{IO}	L^{IW}	Q^{I}	X^{I}
Malaysia (AM)	A^{MI}	A^{MM}	A^{MP}	A^{MS}	A^{MT}	A^{MC}	A^{MN}	A^{MK}	A^{MJ}	A^{MU}	F^{MI}	F^{MM}	F^{MP}	F^{MS}	F^{MT}	F^{MC}	F^{MN}	F^{MK}	F^{MJ}	F^{MU}	L^{MH}	L^{MO}	L^{MW}	Q^{M}	X^{M}
Philippines (AP)	A^{PI}	A^{PM}	A^{PP}	A^{PS}	A^{PT}	A^{PC}	A^{PN}	A^{PK}	A^{PJ}	A^{PU}	F^{PI}	F^{PM}	F^{PP}	F^{PS}	F^{PT}	F^{PC}	F^{PN}	F^{PK}	F^{PJ}	F^{PU}	L^{PH}	L^{PO}	L^{PW}	Q^{P}	X^{P}
Singapore (AS)	A^{SI}	A^{SM}	A^{SP}	A^{SS}	A^{ST}	A^{SC}	A^{SN}	A^{SK}	A^{SJ}	A^{SU}	F^{SI}	F^{SM}	F^{SP}	F^{SS}	F^{ST}	F^{SC}	F^{SN}	F^{SK}	F^{SJ}	F^{SU}	L^{SH}	L^{SO}	L^{SW}	Q^{S}	X^{S}
Thailand (AT)	A^{TI}	A^{TM}	A^{TP}	A^{TS}	A^{TT}	A^{TC}	A^{TN}	A^{TK}	A^{TJ}	A^{TU}	F^{TI}	F^{TM}	F^{TP}	F^{TS}	F^{TT}	F^{TC}	F^{TN}	F^{TK}	F^{TJ}	F^{TU}	L^{TH}	L^{TO}	L^{TW}	Q^{T}	X^{T}
China (AC)	A^{CI}	A^{CM}	A^{CP}	A^{CS}	A^{CT}	A^{CC}	A^{CN}	A^{CK}	A^{CJ}	A^{CU}	F^{CI}	F^{CM}	F^{CP}	F^{CS}	F^{CT}	F^{CC}	F^{CN}	F^{CK}	F^{CJ}	F^{CU}	L^{CH}	L^{CO}	L^{CW}	Q^{C}	X^{C}
Taiwan (AN)	A^{NI}	A^{NM}	A^{NP}	A^{NS}	A^{NT}	A^{NC}	A^{NN}	A^{NK}	A^{NJ}	A^{NU}	F^{NI}	F^{NM}	F^{NP}	F^{NS}	F^{NT}	F^{NC}	F^{NN}	F^{NK}	F^{NJ}	F^{NU}	L^{NH}	L^{NO}	L^{NW}	Q^{N}	X^{N}
Korea (AK)	A^{KI}	A^{KM}	A^{KP}	A^{KS}	A^{KT}	A^{KC}	A^{KN}	A^{KK}	A^{KJ}	A^{KU}	F^{KI}	F^{KM}	F^{KP}	F^{KS}	F^{KT}	F^{KC}	F^{KN}	F^{KK}	F^{KJ}	F^{KU}	L^{KH}	L^{KO}	L^{KW}	Q^{K}	X^{K}
Japan (AJ)	A^{JI}	A^{JM}	A^{JP}	A^{JS}	A^{JT}	A^{JC}	A^{JN}	A^{JK}	A^{JJ}	A^{JU}	F^{JI}	F^{JM}	F^{JP}	F^{JS}	F^{JT}	F^{JC}	F^{JN}	F^{JK}	F^{JJ}	F^{JU}	L^{JH}	L^{JO}	L^{JW}	Q^{J}	X^{J}
U.S.A. (AU)	A^{UI}	A^{UM}	A^{UP}	A^{US}	A^{UT}	A^{UC}	A^{UN}	A^{UK}	A^{UJ}	A^{UU}	F^{UI}	F^{UM}	F^{UP}	F^{US}	F^{UT}	F^{UC}	F^{UN}	F^{UK}	F^{UJ}	F^{UU}	L^{UH}	L^{UO}	L^{UW}	Q^{U}	X^{U}
Freight & Insurance (BF)	BA^{I}	BA^{M}	BA^{P}	BA^{S}	BA^{T}	BA^{C}	BA^{N}	BA^{K}	BA^{J}	BA^{U}	BF^{I}	BF^{M}	BF^{P}	BF^{S}	BF^{T}	BF^{C}	BF^{N}	BF^{K}	BF^{J}	BF^{U}					
Import from HK (CH)	A^{HI}	A^{HM}	A^{HP}	A^{HS}	A^{HT}	A^{HC}	A^{HN}	A^{HK}	A^{HJ}	A^{HU}	F^{HI}	F^{HM}	F^{HP}	F^{HS}	F^{HT}	F^{HC}	F^{HN}	F^{HK}	F^{HJ}	F^{HU}					
Import from EU (CO)	A^{OI}	A^{OM}	A^{OP}	A^{OS}	A^{OT}	A^{OC}	A^{ON}	A^{OK}	A^{OJ}	A^{OU}	F^{OI}	F^{OM}	F^{OP}	F^{OS}	F^{OT}	F^{OC}	F^{ON}	F^{OK}	F^{OJ}	F^{OU}					
Import from R.O.W.	A^{WI}	A^{WM}	A^{WP}	A^{WS}	A^{WT}	A^{WC}	A^{WN}	A^{WK}	A^{WJ}	A^{WU}	F^{WI}	F^{WM}	F^{WP}	F^{WS}	F^{WT}	F^{WC}	F^{WN}	F^{WK}	F^{WJ}	F^{WU}					
Duties & taxes (DT)	DA^{I}	DA^{M}	DA^{P}	DA^{S}	DA^{T}	DA^{C}	DA^{N}	DA^{K}	DA^{J}	DA^{U}	DF^{I}	DF^{M}	DF^{P}	DF^{S}	DF^{T}	DF^{C}	DF^{N}	DF^{K}	DF^{J}	DF^{U}					
Value added (VV)	V^{I}	V^{M}	V^{P}	V^{S}	V^{T}	V^{C}	V^{N}	V^{K}	V^{J}	V^{U}															
Total inputs (XX)	X^{I}	X^{M}	X^{P}	X^{S}	X^{T}	X^{C}	X^{N}	X^{K}	X^{J}	X^{U}															

Source: IDE-JETRO (2006).

Appendix I.D Carbon Multipliers of 24 Sectors Calculated by the SRIO Model

(in kg/10^3 US$)

	IDN	MYS	PHL	SGP	THA	CHN	TWN	ROK	JPN	USA
1	99.82	215.27	62.40	0.04	174.18	1363.87	310.41	378.36	198.13	1048.49
2	218.45	281.73	123.75	348.60	434.22	1337.86	474.89	606.68	266.06	662.16
3	487.22	660.37	232.88	383.50	615.74	1057.07	326.57	1194.82	187.80	740.16
4	813.81	377.01	520.40	0.83	245.88	1075.80	830.22	365.79	409.17	257.77
5	1288.27	1155.60	654.30	1109.82	1972.38	1423.01	112.06	3596.92	1420.05	1022.52
6	2004.24	79.44	13818.42	20362.47	116.37	3467.10	2842.71	619.37	115.36	1021.05
7	805.15	3105.32	665.02	1089.88	467.43	3935.89	405.65	608.53	317.83	446.08
8	594.66	908.15	420.90	287.62	646.68	1526.09	466.20	714.71	203.72	500.15
9	1020.90	688.24	291.64	293.63	704.74	1487.56	945.54	641.61	244.96	441.24
10	747.93	549.76	408.89	352.30	406.37	2208.89	195.67	465.21	137.59	387.68
11	1178.09	968.38	987.52	326.29	712.57	2653.00	548.35	973.16	257.80	530.74
12	1457.89	808.06	492.67	617.91	1099.96	3870.98	593.34	479.57	146.97	667.73
13	2920.29	4423.62	103.63	97.52	98.54	2390.50	60.70	54.80	30.28	1292.59
14	1232.74	535.50	326.96	431.62	1052.18	2663.91	588.77	430.65	138.99	590.01
15	7198.90	1599.89	1856.05	596.20	1874.11	4674.91	1043.79	1231.44	548.82	1072.82
16	2347.15	696.84	519.98	455.10	764.52	4632.84	974.30	482.95	378.27	597.17
17	735.48	258.29	131.12	188.18	282.21	2138.44	223.64	240.48	135.21	245.59
18	661.65	402.35	389.15	270.84	302.65	2188.89	246.91	420.48	131.09	298.98
19	1154.85	615.80	183.11	444.28	529.78	2282.96	364.44	593.33	177.60	318.01
20	11794.58	6520.00	3036.89	21999.86	6539.42	20918.44	2999.72	2103.75	749.27	7491.32
21	1230.44	734.77	344.83	223.48	671.10	2537.59	430.08	375.75	158.42	295.92
22	2021.79	1397.94	1546.08	201.95	1138.80	1910.43	866.59	1543.86	351.40	603.30
23	498.47	275.00	281.28	365.70	443.01	1523.06	90.05	279.11	97.05	186.55
24	512.67	399.73	205.88	317.52	469.49	1739.45	140.86	346.59	164.23	286.41

Appendix I.E Carbon Multipliers of 24 Sectors Calculated by the MRIO Model

(in kg/10^3 US$)

	IDN	MYS	PHL	SGP	THA	CHN	TWN	ROK	JPN	USA
1	116.31	283.42	83.83	0.04	242.02	1381.21	332.83	394.88	214.29	1048.49
2	234.54	347.50	170.94	477.31	482.84	1354.49	510.10	638.49	282.19	672.09
3	505.35	746.54	272.97	544.26	654.83	1069.44	385.20	1255.80	219.88	753.24
4	827.02	417.92	564.90	0.83	262.29	1091.98	860.13	382.38	418.28	272.37
5	1300.35	1207.32	695.57	1298.22	2022.50	1438.02	185.91	3652.03	1453.33	1030.04
6	2011.94	109.17	13856.49	20362.47	139.80	3486.37	2864.82	619.37	126.85	1029.53
7	819.60	3198.06	726.21	1189.34	503.49	3966.16	464.50	636.57	341.05	457.21
8	623.42	1036.18	472.64	545.92	720.84	1548.82	560.00	795.08	243.27	512.02
9	1137.17	963.11	544.90	505.50	848.55	1551.16	1077.96	794.77	310.74	491.90
10	785.42	658.39	522.37	558.91	503.26	2265.08	315.45	594.97	201.98	411.99
11	1246.76	1172.88	1153.87	471.28	844.92	2744.63	654.13	1075.97	283.45	542.43
12	1562.63	1002.11	721.30	793.03	1267.81	3924.90	794.82	664.13	211.39	686.57
13	2995.48	4513.09	173.41	396.29	201.03	2428.59	203.09	195.48	111.54	1304.14
14	1338.34	710.40	616.53	637.09	1166.37	2729.86	724.07	581.95	190.04	626.85
15	7254.21	1774.91	2074.70	863.44	1983.67	4714.69	1208.11	1329.86	594.29	1096.51
16	2456.90	980.91	806.00	727.94	953.99	4681.68	1155.96	648.59	436.74	626.33
17	845.97	506.38	308.38	422.95	528.24	2206.32	411.81	373.98	184.33	289.57
18	726.10	574.73	634.25	446.32	446.03	2235.84	359.13	526.06	171.48	337.05
19	1300.30	818.04	377.26	652.95	688.86	2354.79	514.14	714.57	231.83	342.13
20	11819.37	6565.22	3165.72	22137.62	6565.83	20945.41	3004.88	2210.71	813.67	7498.07
21	1313.46	922.93	469.70	409.90	791.52	2582.01	531.83	441.72	190.19	320.51
22	2044.15	1434.48	1595.66	278.45	1170.09	1934.97	887.63	1580.28	359.73	609.29
23	515.66	323.98	322.00	430.76	486.19	1548.80	108.95	303.03	107.75	192.66
24	533.06	472.35	229.07	420.03	506.47	1763.00	166.74	373.66	172.40	294.97

References

Aldy, J.E., 2005. An environmental Kuznets curve analysis of US state-level carbon dioxide emissions. Journal of Environment and Development 14, 48-72.

Bastianoni, S., Pulselli, F.M., Tiezzi, E., 2004. The problem of assigning responsibility for greenhouse gas emissions. Ecological Economics 49, 253-257.

Bicknell, K.B., Ball, R.J., Cullen, R., Bigsby, H.R., 1998. New methodology for the ecological footprint with an application to the New Zealand economy. Ecological Economics 27(2), 149-160.

Chenery, H. B., 1953. Regional Analysis. In Chenery, H. B., Clark, P. G. and Pinna, V. C. (Ed.), The Structure and Growth of the Italian Economy, 97-129. U.S. Mutual Security Agency, Rome.

Cole, M.A., Elliott, J.R., 2005. FDI and the capital intensity of "dirty" sectors: a missing piece of the pollution Haven puzzle. Review of Development economics 9, 530-548.

Common, M.S., Salma, U., 1992. Accounting for changes in Australia carbon dioxide emissions. Energy Economics 14 (30), 217-225.

Copeland, B.R., Taylor, M.S., 2005. Free trade and global warming: a trade theory view of the Kyoto Protocol. Journal of Environmental Economics and Management 29, 205-234.

Denton, R.V., 1975. The energy cost of goods and services in the Federal Republic of Germany, Energy Policy 3, 279-284.

Department of Energy and Climate Change (DECC), 2009. Guidance on Carbon Neutrality. UK.

Dimaranan, B. V., 2006. Global Trade, Assistance, and Production: GTAP 6 Data Base, 2-8, 2-9. Center for Global Trade Analysis, Purdue University, West Lafayette.

Eder, P., Narodoslawsky, M., 1999. What environmental pressures are a region's industries responsible for? A method of analysis with descriptive indices and input-output models. Ecological Economics 29, 359-374.

Ekins, P., 2009. Resource Productivity, Environmental Tax Reform and Sustainable Growth in Europe. Anglo-German Foundation for the Study of Industrial Society, London.

Ferng, J.J., 2001. Using composition of land multiplier to estimate ecological footprints associated with production activity. Ecological Economics 37, 159-172.

Ferng, J.J., 2003. Allocating the responsibility of CO_2 over-emissions from the perspectives of benefit principle and ecological deficit. Ecological Economics 46, 121-141.

Gallego, B., Lenzen, M., 2005. A consistent input-output formulation of shared producer and consumer responsibility. Economic Systems Research 17, 365-391.

Gillen, W.J., Guccione, A., 1980. Interregional feedbacks in input-output models: Some formal results. Journal of Regional Science 20, 134-138.

Herendeen, R.A., 1978. Input-output techniques and energy cost of commodities. Energy Policy 6, 162-165.

Hubacek, K., Giljum, S., 2003. Applying physical input-output analysis to estimate land appropriation (ecological footprint) of international trade activities. Ecological Economics 44, 137-151.

Institute of Developing Economies, Japan External Trade Organization (IDE-JETRO), 2006. Asian International Input-Output Table 2000, Volume 1, Explanatory Notes. IDE-JETRO, Tokyo.

IPCC, 1996. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Vol.2 Workbook, pp.Overview.5. URL.http://www.ipcc-nggip.iges.or.jp/public/gl/guideline/ overwb.pdf.

Kemfert, C., Lise, W., Tol, R.S.J., 2004. Games of climate change with international trade. Environmental and Resource Economics 28, 209-232.

Kondo, Y., Moriguchi, Y., Shimizu, H., 1998. CO_2 emissions in Japan: influences of imports and exports. Applied Energy 59 (2-3), 163-174.

Lenzen, M., 1998. Primary energy and greenhouse gases embodied in Australian final consumption: an input-output analysis, Energy Policy 26. 495-506.

Lenzen, M., 2007. Aggregation (in-)variance of shared responsibility: A case study of Australia. Ecological Economics 64, 19-24.

Lenzen, M., Murray, J., Sack, F., Wiedmann, T., 2007. Shared producer and consumer responsibility – Theory and practice. Ecological Economics 61, 27-42.

Lenzen, M. Murray, S.A., 2001. A modified ecological footprint method and its application to Australia. Ecological Economics 37, 229-255.

Lenzen, M., Pade, L.L., Munksgaard, J., 2004. CO_2 multipliers in multi-region input-output models. Economic Systems Research 16, 391-412.

Leontief, W., 1936. Quantitative input-output relations in the economic system of the United States. Review of Economics and Statistics 18, 105-125.

Leontief, W., 1941. The Structure of American Economy: 1919-1929. Oxford University Press, New York.

McGregor, G.P., Swales, J.K., Turner, K., 2008. The CO_2 'trade balance' between Scotland and the rest of the UK: Performing a multi-region environmental input-output analysis with limited data. Ecological Economics 66, 662-673.

Miller, R.E., 1969. Interregional feedbacks in input-output models: Some experimental results. Western Economic Journal 7, 41-51.

Miller, R.E., Blair, P.D., 1985. Input-Output Analysis: Foundations and Extensions, 49-52. Prentice-Hall, Inc., New Jersey,

Monfreda, C., Wackernagel, M., Deumling, D., 2004. Establishing national natural capital accounts based on detailed ecological footprint and biological capacity accounts. Land Use Policy 21, 231–246.

Moses, L. N., 1955. The stability of interregional trading patterns and input-output analysis, American Economic Review 45, 803-832.

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

Neuhoff, K., 2008. Tackling Carbon: How to Price Carbon for Climate Policy. Climate Strategies, Cambridge. UK.

Neumayer, E., 2000. In defence of historical accountability for greenhouse gas emissions. Ecological economics 33, 185-192.

Nijdam, D.S., Wilting, H.C., Goedkoop, M.J., Madsen, J., 2005. Environmental load from Dutch private consumption. Journal of Industrial Ecology 9, 147-168.

Pearce, D.W., Atkinson, G., 1993. Capital theory and the measurement of sustainable development: an indicator of weak sustainability. Ecological Economics 8, 103-108.

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

Peters, G.P., Hertwich, E.G., 2006a. The importance of imports for household environmental impacts. Journal of Industrial Ecology 10, 89-109.

Peters, G.P., Hertwich, E.G., 2006b. Structural analysis of international trade: environmental impacts of Norway. Economic Systems Research 18, 155-181.

Peters, G.P., Hertwich, E.G., 2007. The application of multi-regional input-output analysis to industrial ecology: Evaluating trans-boundary environmental impacts. In: Suh, S. (Ed.), Handbook of Input-Output Analysis for Industrial Ecology. Springer, Dordrecht.

Peters, G.P., Hertwich, E.G., 2008a. CO_2 embodied in international trade with implications for global climate policy. Environmental Science & Technology 42, 1401-1407.

Peters, G.P., Hertwich, E.G., 2008b. Post-Kyoto greenhouse gas inventories: Production versus consumption. Climatic Change 86, 51-66.

Proops, J.L.R., Atkinson, G., v. Schlotheim, B.F., Simon, S., 1999. International trade and the sustainability footprint: a practical criterion for its assessment. Ecological Economics 28, 75-97.

Proops, J.L.R., Faber, M., Wagenhals, G., 1993. Reducing CO_2 Emissions: A Comparative Input-output-Study for Germany and the UK. Springer, New York.

Rees, W., Wackernagel, M., 1996. Urban ecological footprints: why cities cannot be sustainable – and why they are a key to sustainability. Environmental Impact Assessment Review 16, p.228.

Rose, A., 1990. Reducing conflict in global warming policy: the potential of equity as a unifying principle. Energy Policy 18, 927-935.

Rose, A., Stevens, B., Edmonds, J., Wise, M., 1998. International equity and differentiation in global warming policy. Environmental and Resource Economics 12, 25-51.

Rothman, D.S., 2000. Measuring environmental values and environmental impacts: going from the local to the global. Climate Change 44, 351-376.

Round, J.I., 1979. Compensating feedback effects in interregional input-output models. Journal of Regional Science 19, 145-155.

Stern, N., 2007. The Economics of Climate Change: The Stern Review. Cambridge University Press, Cambridge, United Kingdom.

Sustainable Europe Research Institute (SERI), Global 2000, Friends of the Earth Europe, 2009. Overconsumption? Our use of the world's natural resources.

Turner, K., Lenzen, M., Wiedmann, T., Barrett, J., 2007. Examining the global environmental impact of regional consumption activities – Part 1: A technical note on combining input-output and ecological footprint analysis. Ecological Economics 62, 37-44.

United Nations Environment Programme (UNEP), 2009. Climate and Trade Policies in a Post-2012 World. UNEP, Geneva.

van Asselt, H., Biermann, F., 2007. European emissions trading and the international competitiveness of energy-intensive industries: a legal and political evaluation of possible supporting measures. Energy Policy 35, 497-506.

van Asselt, H., Brewer, T., 2010. Addressing competitiveness and leakage concerns in climate policy: An analysis of border adjustment measures in the US and the EU. Energy Policy 38, 42-51.

Wackernagel, M., Rees, W.E., 1996. Our Ecological Footprint: Reducing Human Impact on the Earth. New Society Publishers, Gabriola Island, BC.

Walls, M., 2006. Extended Producer Responsibility and Product Design. Resources for the Future, Discussion Paper 06-08. Washington, D.C.

Weber, C.L., Matthews, H.S., 2007. Embodied environmental emissions in U.S. International trade 1997-2004. Environmental Science & Technology 41, 4875-4881.

Weber, C.L., Peters, G.P., 2009. Climate change policy and international trade: Policy considerations in the US. Energy Policy 37, 432-440.

World Wildlife Fund (WWF), 1998, 1999, 2000, 2002, 2004, 2006, 2008. Living Planet Report. Global FootprintNetwork, UNEP World Conservation Monitoring Center. WWF, Gland, Switzerland. http://www.panda.org/about_our_earth/all_publications/living_planet_report/linving_planet_report_timeline/, accessed on 10 July 2009.

Wiedmann, T., Lenzen, M., Turner, K., Barrett, J., 2007. Examining the global environmental impact of regional consumption activities – Part 2: Review of input-output models for the assessment of environmental impact embodied in trade. Ecological Economics 61, 15-26.

Wiedmann, T., Minx, J., Barrett, J., Wackernagel, M., 2006. Allocating ecological footprints to final consumption categories with input-output analysis. Ecological Economics 56, 28-48.

World Bank, 2007. International Trade and Climate Change. World Bank, Washington, DC.

Wyckoff, A.W., Roop, J.M., 1994. The embodiment of carbon in imports of manufactured products. Energy Policy 22 (3), 187-194.

Zhou, X., Imura, H., Shirakawa, H., 2006a. Who is responsible for what: regional Ecological

Footprint calculation for China with special emphasis on interregional dependency. Third World Congress of Environmental and Resource Economist, 3-7 July 2006, Kyoto, Japan.

Zhou, X., Shirakawa, H., Imura, H., 2006b. Study on China's regional ecological footprint and identification of "brown sectors" and "brown paths". Environmental Systems Research 34, 497-505.

Zhou, X., 2009. How does trade adjustment influence national inventory of open economies? Accounting for embodied carbon emissions based on multi-region input-output model. Environmental Systems Research 37, 255-262.

Zhou, X., Shirakawa, H., Pan, H.T., 2010. Can consumer responsibility help address carbon leakage concerns? Games of participation vs. non-participation in a global mitigation regime (Paper submitted). The Fourth Congress of Environmental and Resource Economist, 28 June – 2 July, 2010, Montreal, Canada.

PART II

Analyses of CO_2 Emissions Embodied in Japan-China Trade

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ABSTRACT

CO_2 embodiment in international trade has raised a lot of discussions in currently emerging literature. Most of the literature provides a direct quantitative estimation of the amount of embodied CO_2 emissions, which certainly help better understand the environmental separation between domestic consumption and global production. Part II of this report examines a new area within this topic: the carbon content of Japan-China trade, which has enormous global importance due to the large volume of trade between the two economies. Besides identifying the displacement of CO_2 emissions between the two countries by using traditional input-output (IO) modelling, this study analyses the impact of the bilateral trade to global overall CO_2 emissions through a comparison of the actual base case and an assumed no trade scenario. The linkages between the comparative advantage in trade and production's carbon-intensities are also monitored at the sector level. Since the latest Asian international IO table is for 2000, from which the Japan-China IO table could be compiled, Part II of this report only provides a time series analyses for the period of 1990-2000. CO_2 emissions embodied in the exported goods from Japan to China were continuously increasing during the study period due to the increase of export volume. Reversely, the exported CO_2 emissions from China to Japan greatly increased in the first half of the 1990s but reduced in the second half of the decade. This may be attributable to the fast improvement of energy efficiency in China during 1995-2000. Nevertheless, there was a displacement of CO_2 emissions from Japan to China. The comparison indicates that the bilateral trade was beneficial for reducing the global CO_2 emissions probably due to the composition of the trade with each country exporting the goods with environmentally comparative advantage. The analyses at sector level find a significant but not perfect correlation between emissions intensities in the two countries. Chinese industry is much more carbon intensive than Japanese counterparts on average. There is a small but significant correlation between comparative advantage in the bilateral trade and carbon emission intensity in 1990. In terms of opportunities for CO_2 emissions reduction, an important policy message is that many sectors of Chinese industry could benefit from studying Japanese technologies for the production with lower carbon emissions. From the perspective of public policy, this

study confirms the importance to adopt certain economic measurements like carbon tax to limit CO_2 emissions.

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Abbreviations and Acronyms

BEET	Balance of Emissions Embodied in the Trade
CIF	Cost, Insurance and Freight
COP	Conference of Parties
CSY	Chinese Statistical Yearbook
CTS	Chinese Trade Statistics
GDP	Gross Domestic Product
GTAP	Global Trade Analysis Project
IEA	International Energy Agency
IDE/JETRO	Institute of Developing Economies, Japan External Trade Organization
IO	Input-Output
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
METI	Ministry of Economy, Trade and Industry
MITI	Ministry of International Trade and Industry
MRIO	Multiregional Input-Output
NBS	National Bureau of Statistics
OECD	Organization for Economic Cooperation and Development
R.O.W	Rest of the World
SNA	System of National Account
SYFT	Statistical Yearbook of Foreign Trade
3EID	Embodied Energy and Emission Intensity Data for Japan Using Input-Output Tables
UNFCCC	United Nations Framework Convention on Climate Change

1. Introduction

CO_2 embodiment refers to CO_2 emitted at all phases in a good's manufacturing process, from the mining of raw materials through the distribution process, to the final product for the consumer. The fast growing volume of CO_2 embodiment in the international trade of goods has raised discussions on several important questions for future climate change agreements. One of them is whether the emission responsibilities shall be allocated at the point of manufacturing, which is currently performed, or at the point of consumption. This question has particular implications for the developing countries like China, which is experiencing significant economic growth driven by increases in exports and energy use. There may be a large economic cost associated with the participation of global climate regime for the countries that have a large share of exports in carbon intensive production (Peters and Hertwich, 2008a). If the climate regime has inadequate participation, there is a risk that production will be increasingly shifted to nonparticipating countries (Peters et al., 2007).

The embodied carbon in trade may become a negotiating issue for China and other rapidly developing countries due to the pressure to curb CO_2 emissions, while there is still a lack of good research results to academically support this kind of discussion. With increasing global production, a lot of low cost mitigation options may be located outside of the country of consumption. However, very few proposals have been assessed on whether trade underlying some of the concerns with the Kyoto Protocol. Overall, there may be three aspects for the research of carbon embodied in trade. One is the direct quantitative estimation of the amount to provide a better understanding of the environmental separation between domestic consumption and global production. The second is the analysis of carbon leakage which can reveal the extent of the shifted pollution rather than the abated. The third issue is whether the trade adjusted carbon emission inventories could help eliminate carbon leakage and mitigate global CO_2 emissions.

In order to have a better understanding of the current development of quantitative analysis on carbon embodied in trade, the first aspect of researches mentioned above, Part II of this report gives a thorough overview of the related literatures emerging in recent years. However, due to the lack of data for developing economies, most of the studies analysed the carbon content of the trade flows among the member countries of the Organization for Economic Cooperation and Development (OECD). Based on certain assumptions, a few other studies looked into the cases between selected pair of developing countries and developed countries, such as China-US and China-UK cases, etc. After outlining the major findings of these quantitative analyses, the calculation methodologies adopted were classified and described. The preconditions for the use of the categorised approaches, including available data sources and study assumptions, were discussed to assist their proper applications for the analyses in this study.

As the major component, Part II of this report quantitatively analysed CO_2 emissions embodied in a new bilateral case in this field: Japan-China trade. The quantifications were conducted by practicing two optional approaches. One is to directly calculate CO_2 emissions embodied in the traded goods between the two countries. Another is to assume a no-trade scenario and compare total CO_2 emissions of each country in this case with those in actual case. The first method identifies whether one country is a net importer of carbon from another. The second method may find whether the bilateral trade could reduce or increase global CO_2 emissions in total. Although this study is trying to provide a time series of observation, only the period of 1990-2000 is covered by analysing the cases of three separated years, 1990, 1995 and 2000. This is mainly due to data availability of cross-country input-output (IO) tables.

The structure of Part II is arranged as follows. Section 2 outlines the necessity for the quantitative analyses of CO_2 emissions embodied in trade. An overview of previous studies measuring CO_2 embodiments in trade, especially those literatures concerned with the trade of Japan or China, is conducted in section 3. Section 4 lists the main objectives of this study. The calculation methodologies are identified and discussed in section 5. Section 6 describes in detail the data sources and procedures for database construction necessary for this study. The next section 7 shows the quantification results and related discussions. Lastly, Part II of this report provides some policy implications of this study, and proposals for further discussions in section 8. The industrial sector classifications and converter examples of different classifications are listed in the annexes.

2. Rationale of Quantitative Analyses of CO_2 Embodiment in Trade

The international framework to tackle climate change problem beyond 2012, the post-Kyoto regime, has been intensively discussed. The current negotiation process summarised that the framework should address the actual benefits both globally and individually for each country.

The importance of comprehensive strategies for reducing the intensities of energy consumption and CO_2 emissions at the country and industrial sector levels should be addressed. The widely adopted principle for accounting CO_2 emissions is production based (IPCC, 2008). The Intergovernmental Panel on Climate Change (IPCC) authorised methodology presents that a country only takes the responsibility for CO_2 emissions derived from the internal combustion of fossil fuels. Almost all the discussions so far are based on this measurement approach for national CO_2 inventory. However, it has been recently argued whether the production based measurement standard of CO_2 emissions could effectively encourage the emissions reduction efforts (Peters and Hertwich, 2008a). For instance, Helm et al. (2008) found that UK's CO_2 emissions have fallen by 15% since 1990 based on IPCC measurement, whereas they have risen by 19% in the same period if using consumption-based measurement.

The difference between the two measurements can be traced back to the principle of CO_2 emission responsibilities. The consumption-based measurement corresponds to the 'beneficiary pays principle' while the production based measurement follows the traditional 'polluter pays principle'. The differences in the accounting principles have substantial impacts on the cooperation in implementing coherent reduction policies across countries. Theoretically, the consumption based measurements have more attractive features than production based quantification (Peters and Hertwich, 2008b). It is said that the consumption based measurements are important for allocating the reduction of CO_2 emissions from the viewpoint of equity. They have the advantages of avoiding carbon leakage, increasing the options for mitigation, encouraging environmental comparative advantage, addressing competitiveness concerns and inevitably speeding up technology diffusion (Peters and Hertwich, 2008a).

The consumption-based measurement calculates CO_2 emissions generated for producing the goods consumed inside a region regardless of the place of production. Naturally, international trade, the imports and exports of goods, is taken into account as the most important factor for this approach. However, a detailed and systematic global analysis by the consumption-based principle is still lacking. There is seldom information on consumption-based CO_2 emissions available across the regions and industrial sectors. The comparative advantage of the principle of consumption-based responsibility and the absence of relevant academic data create the basic rationale for quantitatively estimating the CO_2 embodiment in international trade. This quantification can help the countries to be aware of their actual contributions to global CO_2 emissions by commodities consumption. The analysis of energy intensities at sector level and trade balance among the trade partners can identify the opportunities for reducing total CO_2 emissions, and thus have great implications for CO_2 mitigation policies in the changing and obviously integrating world economies. Due to the difference of CO_2 emission intensities and self-sufficiency ratio, the disaggregated regions and sectors need to be considered in the measurement.

3. Literature Review

3.1 Overview of the literature from a global perspective

The literature aimed at quantitatively analysing CO_2 embodiment in international trade and to discuss its policy implications were fast emerging in the past few years. The adopted analytical methodologies shared a common principle by using IO modelling with consideration of the feasibility. Due to the shortcoming of the quantification approaches themselves and far insufficiency of necessary data, these studies indicated high diversity in boundary and estimation accuracy. Despite the significant differences and unavoidable deficiencies in the study boundary and analytical approaches, several meaningful messages have been shared by these emerging quantitative estimations. The common findings may provide useful implications for international climate change regime and are thus summarised as follows.

3.1.1 The major developed countries are net importers while developing countries as a whole are net exporters of CO_2 emissions

A common conclusion from the literature on trade and environment is that developed countries displace a significant amount of their environmental load onto the lower income economies. For instance, both Japan and the U.S. have displaced effectively part of the environmental burden of their consumption onto the rest of the world (Muradian et al., 2002). The literature analysing CO_2 embodiment in trade have given clear evidence that the major developed countries are net CO_2 importers, while developing countries as a whole and a number of developed countries with rich resources are net exporters of carbon. Wyckoff and Roop (1994) showed that 13% of total carbon emissions caused by the consumption of the six largest OECD countries were due to carbon embodied in imports. Chung and Rhee (2001) found that Korean exports to Japan were more carbon intensive than Japanese exports to the Republic of Korea. Another analysis focused solely on Japanese trade, showed that Japan was once a net exporter of embodied CO_2

emissions in 1975, while switched to be a net importer of CO_2 before 1990 (Kondo and Moriguchi, 1998).

Nevertheless, net exporters of embodied carbon include both middle income developing countries with emerging economies and a few developed countries with resource and energy intensive exports. Tolmasquim and Machado (2003) indicated that Brazil had a net export of about 7% of the country's carbon emissions in the 1990s. Qi et al. (2008) revealed that China was a carbon exporting nation during 1997– 2006 with the net carbon export accounting for about 0.5%-2.7% of total carbon emissions during 1997– 2004. The proportion increases rapidly after 2004 and reached to 10% in 2006. An OECD study estimated that in 1995 net carbon exports from China and Russia were roughly equal to net carbon imports of the OECD as a whole, which was about 5% of OECD domestic emissions *(*Ahmad and Wyckoff, 2003). Although the OECD as a whole is a net carbon importer, individual countries vary widely. Ahmad and Wyckoff (2003) found the net carbon exports from Australia, Canada, the Czech Republic, Denmark, Finland, Netherlands, Norway, and Poland, the balanced carbon trade in Hungary, and the net carbon imports from other countries including the U.S., Japan, Republic of Korea and all the large European economies. Other studies, which analysed individual country cases, reached similar results indicating significant net carbon exports from Australia (Lenzen, 1998), Norway (Peters and Hertwich, 2006), and Sweden (Kander and Lindmark, 2006) and approximately balanced carbon trade in Denmark (Munksgaard et al., 2005).

3.1.2 International trade may provide opportunities for global CO_2 reduction

In theory, environmental effects of trade can be decomposed into three kinds: composition, scale, and technique effects. The composition and technique effects encourage the optimisation of resource allocation in a wider scope and the diffusion of cleaner technologies, resulting in the improvement of production efficiency. Trade also leads the countries to scale up their manufacturing capacities with comparative advantages (Grossman and Krueger, 1991). The multi-layer effects of trade may cause positive or negative impacts on the environment (Beghin et al., 2002; Anderson and Strutt, 2000). The possibly controversial results mirrored the complexity of the topic of CO_2 embodiment in trade.

Some estimation studies provided evidence that international trade could reduce global CO_2 emissions in certain conditions. Hayami and Nakamura (2002) obtained encouraging results that the bilateral trade of Japan and Canada reduced the emissions in both countries. Japan exported many manufactured goods which it produced very efficiently with low carbon emissions, while Canada exported energy and resource intensive products like paper products and coal. Canada can produce these products with relatively low emissions due to its abundant natural resources which create a comparative advantage and allow more efficient production. This can also attribute to Canada's extensive use of hydroelectric power which means lower carbon emissions from electricity generation than in Japan and most other countries.

3.1.3 The importance of carbon taxes and other limitations on CO_2 emissions are most addressed

The theory of comparative advantage suggests that each country would specialise in the production of goods for which its production costs are relatively low. Such a specialisation pattern maximises the aggregate social welfare. If every country specialised in the production of goods for which its emissions intensity is lower, the globally aggregate emissions would be minimised. However, the parallel is far from perfect in reality. There were few economic incentives for minimising the carbon emissions in the past. The ability to emit CO_2 freely might increase the comparative advantage of manufacturing. This could account for the positive correlation between comparative advantage and emissions, as occurs in US-China trade (Shui and Harriss, 2006).

By indicating the noticeable change of carbon emissions embodied in international trade, most of the available literature underlined the importance of energy and greenhouse gas policies that have been recently debated (Peters and Hertwich, 2008b; Dimaranan, 2006). They suggested that assigning responsibility for pollution based on consumption, rather than production, increases the share of climate problems attributable to the richest countries. Globalisation shifts but does not necessarily reduce the worldwide total amount of CO_2 emissions. From the perspective of public policy, carbon taxes and other possible limitations on CO_2 emissions should be employed. In the absence of carbon taxes or other related limitations, the developing economies, which rely on a comparative advantage in energy use and carbon intensive production, would have little incentive to shift away from the traditional model. The comparative advantage of developed countries in trade is also not necessarily concentrated in the sectors with lower carbon emission intensities. In this circumstance, energy intensive production could be a commercially profitable strategy. National and regional policies to raise the costs of carbon emissions are required to make a lower carbon emission path worldwide. As a result, several countries in Europe have adopted carbon taxes as part of their strategies to meet

Kyoto Protocol commitments, such as Denmark, Sweden, Norway, Finland, Italy, Netherlands, and UK (Hoerner and Bosquet, 2001). Since their adoption, carbon taxes have proven to be largely effective. For example, Denmark's carbon tax policy, which includes using revenue from the tax to finance energy efficiency investment, resulted in the reduction of carbon dioxide emissions by 4% between 1992 and 2000. Finland's carbon tax, enacted in 1990, was credited with reducing CO_2 emissions by 7% in 1998 (Brown, 2003). Because of these success, carbon taxes are likely to become increasingly common as part of national efforts to reduce CO_2 emissions.

3.1.4 Consumption based CO_2 reduction should be discussed for future global climate policy framework

The significant imbalance of CO_2 embodiment in international trade may have a strong impact on the participation and effectiveness of global climate policies (Peters and Hertwich, 2008b). From the viewpoint of social welfare and equity, the international framework of CO_2 emissions reduction shall be based on consumption since this measurement represents the consumption magnitude domestically and is fairer than the production based approach. As an agreement achieved in COP13 (the 13th Conference of Parties) held in December of 2007, the Bali Roadmap summarised a new negotiation process for the international framework on climate change, and also addressed the real benefits not only at the global level but also at the country level. From a practical viewpoint for carbon leakage, consumption-based approach is more preferable to encourage developed countries to transfer clean technologies for improving energy efficiency and lowering carbon intensity in developing countries. Therefore, consumption-based CO_2 reduction should be also discussed for future global climate policy framework. If countries could take binding commitments as a coalition, instead of as individual countries, the impact of trade to CO_2 emissions might be substantially reduced. Adjusting emission inventories for trade can provide a more consistent description of a country's environmental pressures.

3.2 Overview of the literature from the Chinese perspective

The embodied CO_2 emissions in internationally traded goods of China have attracted considerable attention in several researches. E.g., Jiang (2008) explored the conception of embodied carbon and its possible impacts on trade policy and climate negotiations. Li et al. (2008) pointed out that international trade would cause "carbon leakage", and the huge trade surplus of China has caused a remarkable increase of Chinese CO_2 emissions. Despite of similar

focuses on this topic, inconsistent aspects might be summarised from present studies.
The research subjects of most studies focused on both import and export, including the products in multilateral trade of China (Li et al., 2008; Pan and Chen, 2007; Qi et al., 2008; Wang et al., 2007; Wang and Watson, 2007; Wang and Watson, 2008). Some other studies mainly focused embodied CO_2 emissions in the exports from China (Liu et al., 2008; Zhou and Yang, 2006). Quite a few studies observed the bilateral trade between China and another country (Li and Hewitt, 2008; Shui and Harris, 2006). Major findings from above listed studies are summarised in Tab.1. Most studies applied an IO model as analytical methodology to describe how energy flows and how much a sector or a product consumes (Li et al., 2007; Pan and Chen, 2007; Qi et al., 2008). Several researchers used an IO table after certain deformations. E.g., Li and Sun (2008) constructed an energy IO table and analysed both trade of energy products and energy contents in trade. Besides an IO model, a few simplified approaches were developed. Liu et al. (2008) applied LCA (life cycle assessment) method by considering different production processes and energy consumption behind the goods. Zhou and Yang (2006) calculated energy consumption coefficient of one importing or exporting sector by using the weighted average of selected typical products. The reviewed studies covered a time period ranging from one year to eighteen years with a time span from 1987 to 2006. However, the results of different studies did show an obvious change with time series although different methods and data sources were used for estimations.

Different data sources and methodologies resulted in various findings in current studies. Most studies confirmed that China was a net exporter of embodied CO_2 emissions during the studied period and the Chinese trade surplus was accompanied with an ecological deficit (Liu et al., 2008; Luo, 2008; Pan and Chen, 2007; Qi et al., 2008; Wang et al., 2008; Zhou and Yang, 2006). The two studies on bilateral trade gave similar results. Shui and Harris (2006) found that about 7%-14% of China's CO_2 emissions were attributable to the exports to the U.S. and US-China trade had increased global CO_2 emissions by 720 Mt. Li and Hewitt (2008) found that China-UK trade reduced UK's CO_2 emissions by approximately 11% in 2004 and resulted in an additional 117 Mt of CO_2 to global CO_2 emissions in the same year, accounting for 0.4% of global emissions.

Due to the poor data availability and simplification of methodology, some of this literature is limited to certain shortcomings. For example, Luo (2008), Wang et al. (2008) and Wang and Watson (2007) used CO_2 emission intensity per unit of GDP as the intensity of importing or exporting goods, which led to undervaluation of the energy-intensive sectors and products and the embodied emissions in exports. Like further analysis in Wang et al. (2008), CO_2 emissions in exports might be underestimated about 50% since the average CO_2 intensity of the secondary industry is evidently higher than that of total industries. In some studies (Wang et al., 2007; Zhou and Yang, 2006), emission intensity of importing goods was not differentiated from exporting goods, assuming that imports are produced by using domestic technologies. This caused the emission intensity of certain goods imported from developed countries to be overestimated.

A few totally opposite conclusions can be deduced although similar data sources and methods were used. China was regarded as a net importer of embodied CO_2 emissions in a few studies (Wang et al., 2007; Li et al., 2008; Li et al., 2007). This result needs to be further scrutinised. E.g., in Li et al. (2008), the constructed mixed energy IO table was not accurate due to the lack of strict theoretical derivation. The assumption of technology level in Li et al. (2007) neglected the continuously technical development progress.

In summary, studies on energy and CO_2 emissions embodied in trade between China and other countries have been carried out by adopting different methodologies and provided various conclusions. These studies may be used as references in data selection, method simplification, etc.

Table II.1 Results of studies concerning with CO_2 emissions embodied in China's trade

Study	Language	Subjects	Year of estimate	Journals	Methodology	Research results			Data sources
						Exports	Imports	Net	
(Wang et al., 2007)	Chinese	trade of China	1997	International Trade Issues (2007)	IO	26.83% (energy)[a]	28.25% (energy)[a]	net importer(energy)[a]	Chinese IO table
(Hu, 2007)	Chinese	trade of China	1992 and 1997	Tsinghua University [D] (2007)	IO	net importer in 1992 and net exporter in 1997 (energy)[a]			CSY
(Zhou and Yang, 2006)	Chinese	export of China	2002 and 2003	Advances in Earth Science (2006)	weighted average	net export of 188 Mt and 247 Mt respectively (energy)[a]			CSY
(Li and Hewitt, 2008)	English	China-UK trade	2004	Energy Policy (2008)	IO	reduced UK CO_2 emissions approximately 11% and resulted in an additional 117 Mt of CO_2 emissions, accounting for 0.4% of global total			CSY,UN Comtrade
(Wang and Watson, 2008)	English	trade of China	2004	Climate Policy (2008)	intensity per unit GDP	1,490 Mt (CO_2)[b]	381 Mt (CO_2)[b]	1,109 Mt (23%) (CO_2)[b]	IEA
(Liu et al., 2008)	Chinese	export of China	2005	China Industrial Economics (2008)	LCA	14.4% (CO_2)[b]	NA	NA	CSY,CCY
(Weber et al., 2008)	English	export of China	1987-2005	Energy Policy (2008)	IO	12% in 1987, 21% as recently as 2002, 1/3 in 2005 (CO_2)[b]			Chinese IO tables, NBS
(Wu et al., 2007)	English	trade of Taiwan	1989-2001	Ecological Economics (2005)	IO	export level increased industrial CO_2 emissions			NA
(Li and Sun, 2008)	Chinese	trade of China	1991-2005	World Economy Study (2008)	IO	the energy content in import and export of non-energy product is far more than that of the direct trade of energy products			CSY
(Li and Hewitt, 2007)	English	trade of China	1996-2004	Energy Policy (2007)	IO	net importer except for the year from 1997 to 1999			CSY, SYFT

Cont. Table II.1

Study	Language	Subjects	Year of estimate	Journals	Methodology	Research results			Data sources
						Exports	Imports	Net	
(Shui and Harriss, 2006)	English	China-US trade	1997-2003	Energy Policy (2006)	IO	reduced 3%-6% of US emissions and increased about 7%-14% of China's emission, and increased global emissions by 720 Mt			US Census Bureau, EIA and CSY
(Wang et al., 2008)	Chinese	trade of China	1997-2006	China's Energy (2008)	intensity per unit GDP	19.2%-36.6% $(CO_2)^b$	11.36% in 2006 $(CO_2)^b$	25.27% in 2006 $(CO_2)^b$	CSY
(Luo, 2008)	Chinese	trade of China	1997-2006	Tsinghua University[D] (2008)	NA	NA	NA	7.7%-17.5% (energy)[a]	CSY
(Qi et al., 2008)	Chinese	trade of China	1997-2006	China Population, Resources and Environment (2008)	IO	NA	NA	12.11%-29.28% $(CO_2)^b$	CSY,EIA
(Pan and Chen, 2007)	Chinese	trade of China	2000-2006	WWF Report	IO	25.5%-46.6% (energy)[a]	16% in 2002 (energy)[a]	150Mt $(CO_2)^b$	CSY, CTS

Notes: a. The amount of import or export of energy or the percentage that the import or export accounts for the Chinese total primary energy consumption;

b. The amount of import or export of CO_2 or the percentage that the import or export accounts for the Chinese total CO_2 emissions;

CSY: Chinese Statistical Yearbook;

SYFT: Statistical Yearbook of Foreign Trade;

NBS: National Bureau of Statistics;

CTS: Chinese Trade Statistics.

3.3 Overview of literature from the Japanese perspective

Several international publications have observed CO_2 emissions embodied in the trade related to Japan. The main findings from these studies are summarised in Table II.2.

Table II.2 Results of studies on emissions embodied in Japan's trade

Study	Year	Domestic production (Mt CO_2)	Domestic consumption (Mt CO_2)	CO2 emissions embodied in:			Data source
				Exports (%)	Imports (%)	Net (%)	
(Kondo and Moriguchi, 1998)	1990	1,114.7Mt	1,155 Mt	170.1 Mt (15.2%)	1975: 115.9 Mt 1980: 150 Mt 1985: 132.7 Mt 1990: 209.4 Mt	NA	Japan IO table
(Ahmad and Wyckoff, 2003)	1995	1,100 Mt	1,287 Mt	102 Mt (9.3%)	289 Mt (26.3%)	-187 Mt (-17%)	OECD, IEA
(Nakano et al., 2009)	1995	1,098 Mt	1,377 Mt	NA	NA	-279 Mt (-25.4%)	OECD, IEA
	2000	1,159 Mt	1,471 Mt			-312 Mt (-26.9%)	
(Peters and Hertwich, 2008)	2001	1,291Mt	1,488.8 Mt	187 Mt (14.5%)[a]	384 Mt (29.8%)[a]	-197.5Mt (-15.3%)[a]	GTAP data
(Hayami and Nakamura, 2007)	1990	NA	NA	2.832Mt[b]	5.44Mt[c]	NA	1990 and 1995 Canadian and Japan IO tables
	1995			1.562Mt[b]	6.96Mt[c]		
(Ackerman et al., 2007)	1995	1,052 Mt[d]	NA	NA	NA	6.7Mt (0.64 %)[e] -31.7Mt (-3.01%)	Japan–US IO model 1995, OECD's energy balance sheet of 1995-1996
(Chung and Rhee, 2001)	1990	1,030 Mt	NA	16.39%	NA	NA	Korean Office of Statistics, MITI, etc.

Notes: a. Percentage of national production-based total emissions, which is different from UNFCCC values;

b. Production-based emissions for each commodity sector resulting from Japanese exports to Canada alone;

c. Production-based emissions for each commodity sector resulting from Canadian exports to Japan alone;

d. Excluding non-industrial emission;

e. Embodied emissions in Japan-US trade only.

Japan has been confirmed as a net importer of CO_2 emissions since the beginning of the 1990s. The amounts of CO_2 embodied in imports to and exports from Japan were estimated by using IO tables, assuming that the imported commodities have the same CO_2 emission intensities as the similar types of Japanese products (Kondo and Moriguchi, 1998). Until 1985, the amount of CO_2 embodied in exports had been larger than that in its imports in Japan, but by 1990 the situation had reversed. This is because the Japanese government has adopted the policy of expanding domestic final demands since 1985. Ahmad and Wyckoff (2003) estimated that CO_2 emissions generated to satisfy Japan's domestic demand amounted to over 1,287 Mt of CO_2 in 1995, 187 Mt higher than emissions generated by the production. Emissions generated for domestic consumption in OECD countries as a whole in 1995 were 5% higher than emissions related to production. This ratio was 17% for Japan, which reflects Japan's significant use of nuclear power leading to relatively low embodied emission values. Nakano et al. (2009) pointed out similarly that consumption-based CO_2 emissions amounted to 14,037 Mt of CO_2, which was 16.1% (1,949 Mt) higher than the 12,088 Mt generated by production within OECD countries in 2000. This difference exceeded 26.9% for the Japanese case, where consumption-based emissions increased 94 Mt CO_2 during 1995 to 2000. The carbon trade deficit of Japan is -279 Mt and -312Mt of CO_2 for 1995 and 2000 respectively. Peters and Hertwich (2008b) summarised that Japan is a net importer of embodied pollution despite a substantial trade surplus because its imports are much more energy and carbon intensive than its exports.

The bilateral trade between Japan and Canada was found to reduce the emissions in both countries (Hayami and Nakamura, 2007). Japan exported many manufactured goods, which it produced very efficiently with low carbon emissions, while Canada exported energy and resource intensive products like paper products and coal. Canada can produce these products with relatively low emissions due to its abundant natural resources which create a comparative advantage and allow more efficient production. This can also attribute to Canada's extensive use of hydroelectric power which means lower carbon emissions from electricity generation than in Japan and most other countries. Ackerman et al. (2007) indicated that the US has a more carbon-intensive economy than Japan. Industry as a whole is more than twice as carbon-intensive in the US as in Japan. US exports to Japan are more carbon-intensive, per unit, while US imports from Japan are much larger in volume. (Chung and Rhee, 2001) quantified total CO_2 emissions of Japan and the Republic of Korea for 1990 by using an IO table. The differences in CO_2 emission between the two countries are decomposed into their components and effects of international trade on domestic CO_2 emissions are analysed for both countries. It showed that Japan's total emissions in 1990 were 1,030 Mt of CO_2. The Republic of Korea's total emission was about 23% of Japan's. Electric and heat supply, iron and steel, and road freights transport were major emitting sectors in both the Repubic of Korea and Japan. Korean exports to Japan were more emission intensive than the reverse. 16.39% of Japan's CO_2 emissions were attributable to Japanese demand from other countries.

4. Objectives of this Study

This study examines a new area within this topic: the carbon content of Japan-China trade. The massive volume of trade flows between these two large world economies is of enormous global importance in terms of both economy and environment. The major objectives of this study are to determine three questions:

(i) Whether one country is a net importer or a net exporter of CO_2 emissions from another?
(ii) Whether the Japan-China trade could reduce or increase globally overall CO_2 emissions during the study period?
(iii) Whether comparative advantage in trade of the two countries is more or less associated with carbon-intensive productions?

As mentioned earlier, since the latest available cross-country IO table is for the year 2000 between the two countries, this study covers the period of 1990-2000 and analyses the cases of three separate years: 1990, 1995 and 2000.

5. Methodologies for Quantitative Calculations

A number of tools and methodologies were developed to calculate the embodied CO_2 emissions in products among which life cycle assessment (LCA) is a production based analytical tool. LCA was empirically applied to specific stages of the full life cycle of products, usually not covering emissions during the use and final disposal stages. As a bottom-up method, LCA calculations examine the production processes of specific product and need a large amount of preliminary data. The level of detailed data and technological information required are not available in nearly all the developing countries due to insufficient data collection and weak statistics institutions. Therefore, this study does not consider the possible application of this method.

Conversely, the top-down method using IO analysis has often been applied to estimate embodied energy, CO_2 emissions, pollutants and land appropriation from international trade activities (Costanza, 1980; Wyckoff and Roop, 1994; Machado et al., 2001; Ferng, 2003; Shui and Harriss, 2006). IO analysis was originated by Leontief (1941) and then was extended to interregional and international trade applications in early contributions by Isard (1951), Chenery (1953), and Moses (1955). This approach can analyse the embodied CO_2 emissions in imports and exports of a country as a whole, whereas it has some difficulties to quantify in detail at the sector level (Treloar et al., 2001).

IO tables are usually expressed in the value added by sector and each sector spans a number of different products with different CO_2 emission coefficients. The sector CO_2 emission coefficients are usually averaged by the ratios of all the products in each sector. This kind of quantitative estimation inevitably generates particular uncertainties. Even for the implemented researches using certain forms of IO modeling, the available IO tables greatly determine the level of detail and accuracy of these studies. For the ideal case, a worldwide multiregional IO (MRIO) model is required to relate different countries' exports and imports and assign CO_2 emission factors based on their net consumption of goods and services. This would distinguish the CO_2 emission intensities among different trading partners, as well as among different goods. The approach using MRIO model to do a full analysis is a data intensive and time consuming process which makes it infeasible in most cases. A few other methods, applying the principle of IO analysis, were practically adopted to simplify the estimation based on the available sources of data and certain reasonable assumptions.

The quantification methodologies used in this study also follow the principle of using IO modelling based on careful identification of available data sources. A direct quantification of carbon embodiments in the traded goods, by multiplying the volume of the trade at sector level with corresponding embodied CO_2 emission coefficients, is adopted to determine whether one country is a net importer or exporter of carbon to another. Scenario comparison of the actual case with the assumed no-trade case is applied to find whether the bilateral trade helps reduce or increase the total global CO_2 emissions. Regression analysis is employed for observing the linkage of trade comparative advantage and carbon intensive productions between the two countries. The approaches of this study are described in details as follows.

5.1 Quantification of CO_2 embodiments in bilateral trade

CO_2 embodiments in bilateral trade can be directly determined by quantifying the domestic CO_2 emissions in one country during the production of goods for exporting to another country. Two steps are necessary for this kind of quantification. The first step is to prepare a vector of embodied CO_2 emission intensity. The following step is to multiply CO_2 emission intensity with the volume of exports and sum up the results at sector level to achieve the total CO_2 embodiments in trade.

5.1.1 Preparation of vector of embodied CO_2 emission coefficients by sector

The treatment of imports in the IO tables has a significant effect to the basic IO model, regardless of whether the table is compiled by producer price or purchaser price. If assuming CO_2 emissions related to the production of imported products to be identical as those of the same domestic products, the following Eq. II.1 can be given.

$$e = d(I - A)^{-1} \qquad \text{(II.1)}$$

Where; e is embodied CO_2 emission coefficient vector; d is direct CO_2 emission coefficient vector; A is intermediate input coefficient matrix; and I is a unit matrix with the same dimension as matrix A.

$(I - A)^{-1}$, called "Leontief's Inverse Matrix", or simply "Inverse Matrix", is a fundamental matrix for IO analysis which identifies the ripple effects among different economic sectors. This method has been widely used since it is difficult to make accurate estimations of CO_2 emissions for the imported products.

However, this method may provide quite different values from reality for this study since the primary products of petroleum, coal, iron ore and aluminum, etc., are produced domestically in small quantities in Japan. An alternative approach, involving the calculation of embodied CO_2 emissions for solely domestic production activities while excluding the inputs from the imported products, is applied in this study. By defining an import coefficient (m_i), representing percentage of imported products with respect to total intermediate demand and domestic final demand of sector i, as expressed in Eq. II.2 , the equation for calculating embodied CO_2 emission intensity vector e can be deduced into Eq. II.3.

$$m_i = \frac{M_i}{\sum_{j=1}^{n} a_{i,j} X_j + F_i} \qquad \text{(II.2)}$$

Where; M_i is the imports of sector i; n is the number of sectors in IO table; and F_i is domestic final demand of sector i.

$$e = d\left[I - (I - M)A\right]^{-1} \qquad \text{(II.3)}$$

Where; M is a diagonal matrix of import coefficient (m_i).

5.1.2 Calculation of embodied CO_2 emissions in bilateral trade

The explicit modelling of embodied CO_2 emissions requires a decomposition of the standard IO analysis framework into domestic and traded components (Peters and Hertwich, 2008b). The total production-based CO_2 emissions occurring in country *r* can be expressed as Eq. II.4.

$$Em_r = d_{rr}\left[I - (I - M)A_{rr}\right]^{-1}\left(y_{rr} + \sum_{s} e_{rs}\right) \qquad \text{(II.4)}$$

Where d_{rr}: A row vector with each element representing direct CO_2 emissions per unit of industry output; A_{rr}: The matrix of intermediate input coefficients of domestically produced products demanded by domestic industrial sectors; y_{rr}: The products produced and consumed domestically; e_{rs}: The exports from country r to country s; I: The unit matrix.

The linearity assumption of IO analysis allows Eq. II.4 to be decomposed into emission components for domestic demand on domestic production and embodied emissions from country *r* to country *s*, as expressed by Eq. II.5. Another useful quantity is the balance of emissions embodied in bilateral trade (BEET), which represents a country's trade balance of CO_2 emissions with another. BEET can be derived by Eq. II.6.

$$Em_{rs} = d_{rr}\left[I - (I - M)A_{rr}\right]^{-1} e_{rs} \qquad \text{(II.5)}$$

$$Em_{r}^{BEET} = Em_{rs} - Em_{sr} \qquad \text{(II.6)}$$

This method is transparent and can sum up CO_2 emissions embodied in the imports and exports of a specific bilateral trade. As mentioned earlier, it only considers domestic production activities and excludes the inputs from imported products. In the simplest cases, several studies used the trade balance data in total for an individual economy which did not give due consideration to the differences of CO_2 intensities at sector level (Helm et al., 2008; Hoshino and Sugiyama, 2008; Li et al., 2007; Luo et al., 2009; Qi et al., 2008; Wang and Watson, 2007). These quantification results inevitably indicate certain uncertainties. In order to avoid the shortcomings of the previous researches, this study practiced the use of trade data from IO tables and prepared the emission coefficients accordingly at a medium level of industrial sector classification.

5.2 Scenario analysis of CO_2 emissions with and without trade

The scenario comparison approach was adopted to analyse the CO_2 emission impact of bilateral trade between a selected pair of countries (Ackerman et al., 2007). Considering two countries 1 and 2, with X as the vector of total output, A as the intermediate input coefficient matrix, F as the final demand vector, and L as the export to the other countries, the familiar one region IO model can be extended to a cross country format as expressed by Eq. II.7. The solution will be given by equation (8). The model's estimations of total output vector can be multiplied by the direct carbon coefficients to obtain CO_2 emissions of each sector classified by IO table. This provides the 'base case' for scenario analysis, indicating actual conditions in a selected year.

$$\begin{pmatrix} X_1 \\ X_2 \end{pmatrix} = \begin{pmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{pmatrix} \cdot \begin{pmatrix} X_1 \\ X_2 \end{pmatrix} + \begin{pmatrix} F_{11} \\ F_{21} \end{pmatrix} + \begin{pmatrix} F_{12} \\ F_{22} \end{pmatrix} + \begin{pmatrix} L_1 \\ L_2 \end{pmatrix} \qquad \text{(II.7)}$$

$$\begin{pmatrix} X_1 \\ X_2 \end{pmatrix} = \begin{pmatrix} I - A_{11} & -A_{12} \\ -A_{21} & I - A_{22} \end{pmatrix}^{-1} \cdot \begin{pmatrix} F_{11} + F_{12} + L_1 \\ F_{21} + F_{22} + L_2 \end{pmatrix} \qquad \text{(II.8)}$$

A natural way to measure the effects of a bilateral trade is to set matrix blocks A_{12} and A_{21}, which represent one country's inputs into another country's intermediate production processes, to be zero. Then recalculate out the total output which would be required in order to satisfy the same final demand under this assumption. Accordingly, two scenarios can be defined to measure CO_2 emission effects of the bilateral trade of two countries like Japan and China. Scenario 0 (S0) is the actual base case as defined by Eq. II.8. Scenario 1 (S1) is a 'no trade' scenario, where each country produces the goods domestically which are now imported from another country, leaving all the trade that flows with other countries unchanged. Extended from Eq. II.8 of the base case, scenario 1 can be expressed by Eq. II.9. The difference of CO_2 emissions between the base case S0 and the assumed S1 represents the emissions attributable to the bilateral trade. If the total CO_2 emissions are smaller in S1 than S0, the bilateral trade would increase the globally overall emissions. On the contrary, the bilateral trade helps to reduce the global emissions.

$$\begin{pmatrix} X_1 \\ X_2 \end{pmatrix} = \begin{pmatrix} I - A_{11} - A_{21} & 0 \\ 0 & I - A_{12} - A_{22} \end{pmatrix}^{-1} \cdot \begin{pmatrix} F_{11} + F_{21} + L_1 \\ F_{12} + F_{22} + L_2 \end{pmatrix} \qquad \text{(II.9)}$$

It shall be noted that this measurement excludes the foreign emissions actually created by other country's exports to these two countries. The principal drawback of this approach is the difficulty of developing the necessary and detailed data on international transactions which are irregular and increasingly dynamic. In spite of the obvious time lag problem, a few international IO tables have been prepared. For instance, the Institute of Developing Economies, Japan External Trade Organization (IDE/JETRO) constructed the Japan-China IO table for the year 1985 and then developed several bilateral IO tables for Japan and a few other Asian countries for 1990. Asian International IO tables, covering nine Asian countries and the U.S., were constructed for the years 1985, 1990, 1995 and 2000 (Tamamura, 1994). The Japanese government, MITI (the Ministry of International Trade and Industry, now named Ministry of Economy, Trade and Industry, METI), developed the Japan-US international IO table in details of 175 sectors for the years 1990, 1995 and 2000 (Ackerman et al., 2007). The Global Trade Analysis Project (GTAP) compiled the necessary dataset which can be used for multiregional IO analysis. The GTAP provides data for 87 countries and 57 industrial sectors with the latest version 6 for 2001 (Dimaranan, 2006). The compilation of these international IO tables took a lot of time, efforts, and personnel resources, especially when the table was developed on the basis of material flow survey of imported goods (Tamamura, 1994).

For the scenario analysis in this study, the Japan-China 1990 IO table with 89 sectors is directly used. For the years 1995 and 2000 the cross country IO tables are prepared by compiling the data from the Asian international IO table of the same years with 78 and 76 sectors respectively.

6. Sources of Data and Databases Construction

6.1 Cross-country IO tables

6.1.1 Japan-China 1990 IO table

Nowadays, domestic IO tables are commonly compiled and used for various purposes of analyses in numerous countries of the world. In China the construction of benchmark IO tables is conducted every five years. The 1987 China IO table is the first national IO account based on full data and SNA (System of National Accounts) framework. In Japan, benchmark tables were compiled every five years since 1955 and the latest version is the 2005 table. The national IO tables are different in structure from country to country, which causes the difficulty to construct cross-country IO table in uniform. Fortunately, 1990 international IO table for China and Japan, compiled by IDE/JETRO, provides comprehensive information for the comparison of economic structures between the two countries in 1990 and also for the comparison of their inter-industrial interdependencies (IDE, 1997). The format of the Japan-China 1990 IO table is shown in Fig. II.1. The table indicates the distribution structure of goods in each sector when reading in a row-wise direction. In a column-wise direction, the table shows inputs needed for the production of commodities in the sector as the same way as nationally domestic IO table. The Japan-China 1990 IO table has three kinds of sector classifications. The most detailed includes 89 sectors whose definitions are listed in the annexed Table II.A1.

			INT. DEMAND			FINAL DEMAND					EXPORT TO R.O.W.		
			China	Japan		China	Japan						
			AC001 … AC089 AC900	AJ001 … AJ089 AJ900	ET900	FC001 … FC004 FC900	FJ001 … FJ004 FJ900	FX900	GC900	GJ900	LH001 … LW001 LX900	QX001	XX600
INT. INPUTS	China	AC001 … AC089 AC900	**A^{CC}**	**A^{CJ}**		**F^{CC}**	**F^{CJ}**				**L^{C}**		**X^{C}**
	Japan	AJ001 … AJ089 AJ900	**A^{JC}**	**A^{JJ}**		**F^{JC}**	**F^{JJ}**				**L^{J}**		**X^{J}**
		BF001											
	R.O.W.	CW001 … CW089 CW900	**A^{WC}**	**A^{WJ}**		**F^{WC}**	**F^{WJ}**						
	Tariff	DT001											
	Total	ET900											
Value added		VV001 … VV004 VV900	**V^{C}**	**V^{J}**									
Total Input		XX600	**X^{C}**	**X^{J}**									

Fig. II.1 The format of Japan-China 1990 IO table

The first column indicates the intermediate input structure of industries domestically in China. A^{CC} depicts the domestic inputs of goods and services within China. A^{JC} represents the flow of goods and services from the industries of Japan to the industries of China. It is evaluated at the producers' price. The BF vector is for international freight and insurance of the imported goods from Japan. A^{WC} is the import matrix from the rest of the world (R.O.W.) rather than Japan. It is valued at the price of CIF (Cost, insurance and freight). The import duties and commodity taxes levied on A^{JC} and A^{WC} are shown by DT vector. V^{C} is the value added of industries in China and X^{C} is the sum of this column, total input of the industries in China. The second column similarly shows the input structure of industries in Japan. A^{CJ} is the import matrix from China to Japan. A^{JJ} represents the domestic flow of goods among industries within Japan. Other parts of column can be read similarly to the column of China. The third and fourth columns show the final demand of the two countries. F^{CC} depicts the domestic final demand within China and F^{JC} represents the final demand of China for commodities produced in Japan. It is also evaluated at the producers' price. Final demand goods imported from the R.O.W. are put into F^{WC}. The exports of China and Japan to the other countries (L^{C}, L^{J}) are divided into 14 countries of destinations (Hongkong, Singapore, Indonesia, etc., and the R.O.W.).

6.1.2 Asian international IO tables of 1995 and 2000

The project on "Industrial Interdependencies in the Asia-Pacific Region" was launched by IDE/JETRO in 1998 in order to integrate 1995 IO tables of ten countries in the region. The Asian International IO tables 1995 and 2000 are designated to depict the industrial network extended over the ten countries and regions, namely, China, Indonesia, Korea, Malaysia, Taiwan, the Philippines, Singapore, Thailand, Japan and the U.S., and gives a picture of intermediate input composition and output distribution of each domestic industry as well as foreign countries' industries (IDE, 2001; IDE, 2006). The whole picture of Asian international IO Table is demonstrated in Fig. II.2.

Code	Intermediate Demand (A)										Final demand (F)										**Export (L)**			Statistical Discrepancy (OX)	Total Outputs (XX)
	Indonesia (AI)	Malaysia (AM)	Philippines (AP)	Singapore (AS)	Thailand (AT)	China (AC)	Taiwan (AN)	Korea (AK)	Japan (AJ)	U.S.A. (AU)	Indonesia (FI)	Malaysia (FM)	Philippines (FP)	Singapore (FS)	Thailand (FT)	China (FC)	Taiwan (FN)	Korea (FK)	Japan (FJ)	U.S.A. (FU)	Export to Hong Kong (LH)	Export to EU (LO)	Export to R.O.W. (LW)		
Indonesia (AI)	A^{II}	A^{IM}	A^{IP}	A^{IS}	A^{IT}	A^{IC}	A^{IN}	A^{IK}	A^{IJ}	A^{IU}	F^{II}	F^{IM}	F^{IP}	F^{IS}	F^{IT}	F^{IC}	F^{IN}	F^{IK}	F^{IJ}	F^{IU}	L^{IH}	L^{IO}	L^{IW}	Q^{I}	X^{I}
Malaysia (AM)	A^{MI}	A^{MM}	A^{MP}	A^{MS}	A^{MT}	A^{MC}	A^{MN}	A^{MK}	A^{MJ}	A^{MU}	F^{MI}	F^{MM}	F^{MP}	F^{MS}	F^{MT}	F^{MC}	F^{MN}	F^{MK}	F^{MJ}	F^{MU}	L^{MH}	L^{MO}	L^{MW}	Q^{M}	X^{M}
Philippines (AP)	A^{PI}	A^{PM}	A^{PP}	A^{PS}	A^{PT}	A^{PC}	A^{PN}	A^{PK}	A^{PJ}	A^{PU}	F^{PI}	F^{PM}	F^{PP}	F^{PS}	F^{PT}	F^{PC}	F^{PN}	F^{PK}	F^{PJ}	F^{PU}	L^{PH}	L^{PO}	L^{PW}	Q^{P}	X^{P}
Singapore (AS)	A^{SI}	A^{SM}	A^{SP}	A^{SS}	A^{ST}	A^{SC}	A^{SN}	A^{SK}	A^{SJ}	A^{SU}	F^{SI}	F^{SM}	F^{SP}	F^{SS}	F^{ST}	F^{SC}	F^{SN}	F^{SK}	F^{SJ}	F^{SU}	L^{SH}	L^{SO}	L^{SW}	Q^{S}	X^{S}
Thailand (AT)	A^{TI}	A^{TM}	A^{TP}	A^{TS}	A^{TT}	A^{TC}	A^{TN}	A^{TK}	A^{TJ}	A^{TU}	F^{TI}	F^{TM}	F^{TP}	F^{TS}	F^{TT}	F^{TC}	F^{TN}	F^{TK}	F^{TJ}	F^{TU}	L^{TH}	L^{TO}	L^{TW}	Q^{T}	X^{T}
China (AC)	A^{CI}	A^{CM}	A^{CP}	A^{CS}	A^{CT}	$\mathbf{A^{CC}}$	A^{CN}	A^{CK}	$\mathbf{A^{CJ}}$	A^{CU}	F^{CI}	F^{CM}	F^{CP}	F^{CS}	F^{CT}	$\mathbf{F^{CC}}$	F^{CN}	F^{CK}	$\mathbf{F^{CJ}}$	F^{CU}	L^{CH}	L^{CO}	L^{CW}	Q^{C}	$\mathbf{X^{C}}$
Taiwan (AN)	A^{NI}	A^{NM}	A^{NP}	A^{NS}	A^{NT}	A^{NC}	A^{NN}	A^{NK}	A^{NJ}	A^{NU}	F^{NI}	F^{NM}	F^{NP}	F^{NS}	F^{NT}	F^{NC}	F^{NN}	F^{NK}	F^{NJ}	F^{NU}	L^{NH}	L^{NO}	L^{NW}	Q^{N}	X^{N}
Korea (AK)	A^{KI}	A^{KM}	A^{KP}	A^{KS}	A^{KT}	A^{KC}	A^{KN}	A^{KK}	A^{KJ}	A^{KU}	F^{KI}	F^{KM}	F^{KP}	F^{KS}	F^{KT}	F^{KC}	F^{KN}	F^{KK}	F^{KJ}	F^{KU}	L^{KH}	L^{KO}	L^{KW}	Q^{K}	X^{K}
Japan (AJ)	A^{JI}	A^{JM}	A^{JP}	A^{JS}	A^{JT}	$\mathbf{A^{JC}}$	A^{JN}	A^{JK}	$\mathbf{A^{JJ}}$	A^{JU}	F^{JI}	F^{JM}	F^{JP}	F^{JS}	F^{JT}	$\mathbf{F^{JC}}$	F^{JN}	F^{JK}	$\mathbf{F^{JJ}}$	F^{JU}	L^{JH}	L^{JO}	L^{JW}	Q^{J}	$\mathbf{X^{J}}$
U.S.A. (AU)	A^{UI}	A^{UM}	A^{UP}	A^{US}	A^{UT}	A^{UC}	A^{UN}	A^{UK}	A^{UJ}	A^{UU}	F^{UI}	F^{UM}	F^{UP}	F^{US}	F^{UT}	F^{UC}	F^{UN}	F^{UK}	F^{UJ}	F^{UU}	L^{UH}	L^{UO}	L^{UW}	Q^{U}	X^{U}
Freight & Insurance (BF)	BA^{I}	BA^{M}	BA^{P}	BA^{S}	BA^{T}	BA^{C}	BA^{N}	BA^{K}	BA^{J}	BA^{U}	BF^{I}	BF^{M}	BF^{P}	BF^{S}	BF^{T}	BF^{C}	BF^{N}	BF^{K}	BF^{J}	BF^{U}					
Import from HK (CH)	A^{HI}	A^{HM}	A^{HP}	A^{HS}	A^{HT}	A^{HC}	A^{HN}	A^{HK}	A^{HJ}	A^{HU}	F^{HI}	F^{HM}	F^{HP}	F^{HS}	F^{HT}	F^{HC}	F^{HN}	F^{HK}	F^{HJ}	F^{HU}					
Import from EU (CO)	A^{OI}	A^{OM}	A^{OP}	A^{OS}	A^{OT}	A^{OC}	A^{ON}	A^{OK}	A^{OJ}	A^{OU}	F^{OI}	F^{OM}	F^{OP}	F^{OS}	F^{OT}	F^{OC}	F^{ON}	F^{OK}	F^{OJ}	F^{OU}	◀ Valued at C.I.F.				
Import from R.O.W. (CW)	A^{WI}	A^{WM}	A^{WP}	A^{WS}	A^{WT}	A^{WC}	A^{WN}	A^{WK}	A^{WJ}	A^{WU}	F^{WI}	F^{WM}	F^{WP}	F^{WS}	F^{WT}	F^{WC}	F^{WN}	F^{WK}	F^{WJ}	F^{WU}					
Duties & taxes (DT)	DA^{I}	DA^{M}	DA^{P}	DA^{S}	DA^{T}	DA^{C}	DA^{N}	DA^{K}	DA^{J}	DA^{U}	DF^{I}	DF^{M}	DF^{P}	DF^{S}	DF^{T}	DF^{C}	DF^{N}	DF^{K}	DF^{J}	DF^{U}					
Value added (VV)	V^{I}	V^{M}	V^{P}	V^{S}	V^{T}	V^{C}	V^{N}	V^{K}	V^{J}	V^{U}															
Total inputs (XX)	X^{I}	X^{M}	X^{P}	X^{S}	X^{T}	X^{C}	X^{N}	X^{K}	X^{J}	X^{U}															

Note: Each cell of A** and F** represents a matrix of 78*78 and 78*4 dimension for 1995, and a matrix of 76*76 and 76*4 dimension for 2000, respectively.

Fig. II.2 The schematic image of the 1995 and 2000 Asian international IO table

Column-wise, each cell in the table shows input composition of the industries in respective countries. For example, A^{II} shows the input compositions of Indonesia industries with domestically produced goods and services. A^{MI} shows input compositions of Indonesian industries for the goods and services imported from Malaysia. The transaction values are all given at producers' price of the countries of origin. International freight and insurance paid by Indonesian industries, as an example, for the imported transactions are all recorded in the row vector BA^{I}. HA^{I} and WA^{I} are input compositions of Indonesian industries imported goods and services from Hong Kong and the R.O.W., and they are given in CIF value. Import duties and import sales taxes levied on all Indonesian imports are recorded in the row vector DA^{I}. The value added items of Indonesian industries are shown in V^{I}. The bottom of the column gives X^{I}, the gross inputs of Indonesian industries. The 11th column from the left side of the table indicates the composition of the goods and services that have flowed into final demand sectors of Indonesia. F^{II} and F^{MI}, for example, are the inflow into Indonesia final demand sectors of goods and services domestically produced and of those imported from Malaysia, respectively.

The first row of the table shows the output distributions of the commodities produced by Indonesian domestic industries to Malaysian industries, to the industries of the Philippines, and so on. F^{II} is the distribution of Indonesian goods and services to final demand sectors of Indonesia, and F^{IM} is to the final demand sectors of Malaysia, and so on. LH^{I}, LE^{I}, LF^{I}, LG^{I} and LW^{I} are Indonesia's exports to Hong Kong, UK, France, Germany and the R.O.W. Q^{I} is the statistical discrepancies and X^{I} shows the gross outputs of Indonesian industries.

The columns and rows for other countries can be read in the same manner. The data used for analysing CO_2 emissions embodied in Japan-China trade in 1995 and 2000 can be easily obtained from the corresponding international Asian IO tables. E.g., the intermediate input coefficient matrix and volume of final demand are directly achieved from the table as areas marked by green color. The imports from other countries, except for the two countries under study, are obtained by aggregating the intermediate inputs and final demand from the countries covered by the table, HK, EU and the R.O.W., as marked in yellow in the column. Similarly, the exports to the other countries are achieved by summing up the intermediate inputs and final demands to the countries covered in the table and the exports to specifically listed HK, EU and the R.O.W., as marked in blue in the row.

The sector classification in the Asian 1995 and 2000 tables includes 78 and 76 sectors in the most details respectively. Their exact definitions are listed in the annexed Table II.A2-A3.

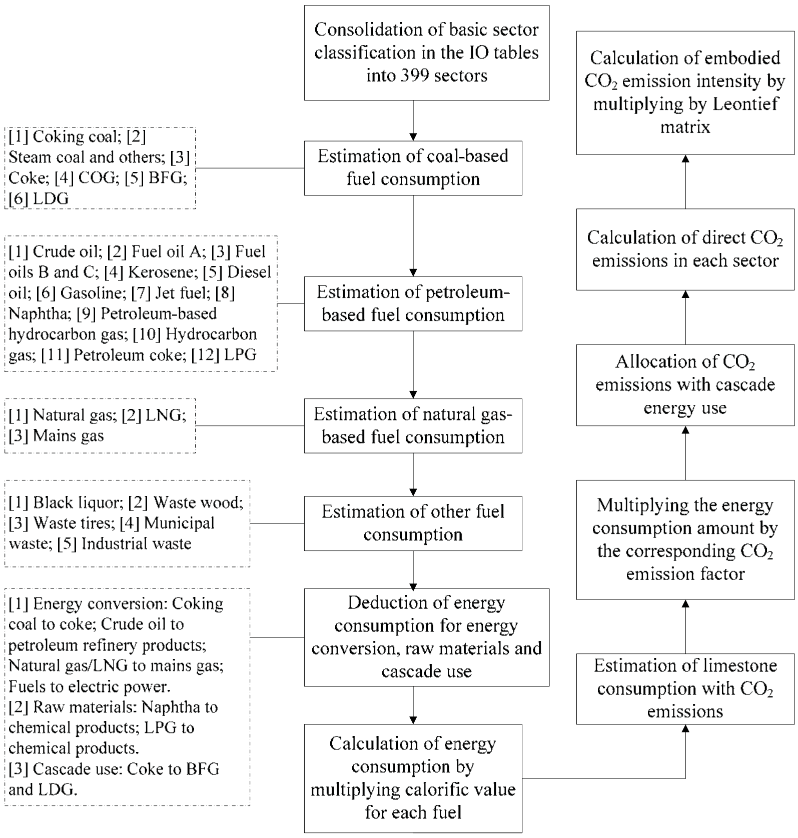
6.2 Preparation of CO_2 emission coefficients of Japan

6.2.1 Data sources of direct CO_2 emission coefficients of Japan

Stored at National Institute for Environmental Studies (NIES) of Japan are data obtained during studies on structural analysis of CO_2 emissions and life cycle inventory analyses. The results for the period of 1975-1990 were compiled as "Carbon Dioxide Emission Intensity Based on IO Analysis" (Kondo and Moriguchi., 1997) and published in 1997 by Center for Global Environmental Research (CGER), NIES. Since then, NIES has been collaborating with the Graduate School of Energy Sciences at Kyoto University in adding data on emissions of air pollutants to the intensity database. After the release of the "1995 IO Table" in Japan (MCAG, 1995), the energy consumption and CO_2 emission intensities for 1995 were compiled and entitled "Energy Consumption and Carbon Dioxide Emission Intensities Based on IO Analysis: 95 (β Edition)". The quality of the database was improved by taking into account the results of questionnaire surveys and extensive dialogues with the users. The main improvement of 2002 data book, which is entitled "Embodied Energy and Emission Intensity Data for Japan Using IO Tables (3EID)", over the β Edition is more accurate estimates for fuel consumption and changes in calorific value and CO_2 emission factors for individual fuels (Nansai et al., 2002).

The calculation process for CO_2 emission intensity in 3EID is shown in Fig. II.3. The first step is to consolidate certain sectors to convert the original domestic IO table into a perfectly square matrix, e.g., 399 rows and 399 columns for 1990. The gross consumption, expressed as the physical amount for each sector of six coal-based, 12 petroleum-based, three natural gas-based fuels and five other fuels, is estimated (totally 26 types of energy). The net contribution to environmental burden is set for a combination of each fuel type and sector to exclude fuel consumption that is converted into another fuel type, namely secondary energy, or used as feedstock, which isn't a direct cause of the burden. Consumption of fuels contributing to environmental load is obtained by multiplying the gross fuel consumption by the net contribution rate and calorific value for each type of fuel. CO_2 emissions are calculated by multiplying the obtained energy consumption for each type by its corresponding CO_2 emission factor. CO_2 emissions from limestone are also estimated as an emission source additional to fossil fuel. Lastly, energy consumption and CO_2 emissions by sources are summed up for each sector in the domestic IO table. They are treated as direct CO_2 emissions for each sector.

In 3EID, a producer price-based CO_2 emission intensity data file consists of Worksheets A through E, showing the rationale used to calculate CO_2 emission intensity. An overview of the preparation process and data entered in each Worksheet is shown in Fig. II.4. The worksheet D2 is used for the preparation of the CO_2 emission coefficient vector by the sector classification of international IO tables.



Note: COG: Coke oven gas; BFG: Blast furnace gas; LDG: Linz donawitz gas; LPG: Liquefied petroleum gas; LNG: Liquefied natural gas)

Fig. II.3 Calculation process for CO_2 emission intensity of each sector in 3EID

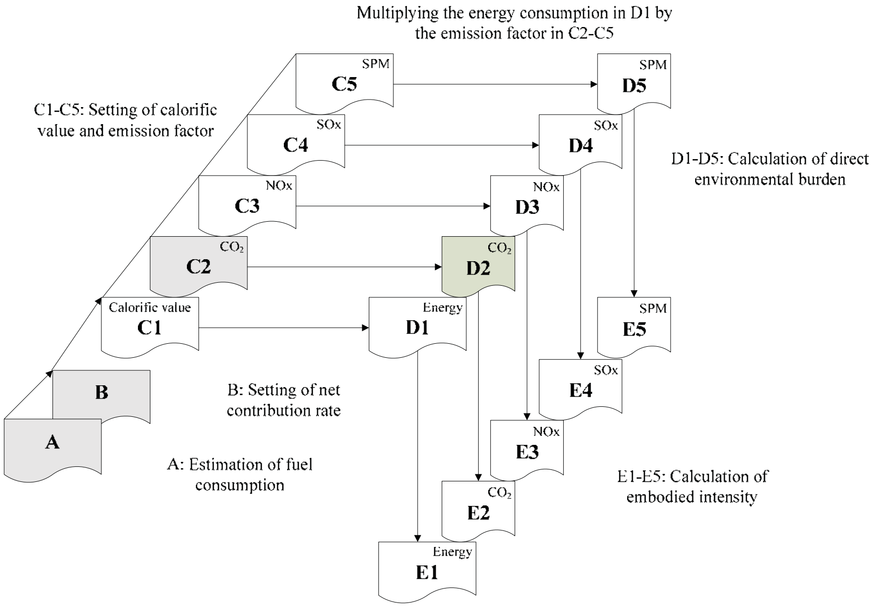


Fig. II.4 Composition of worksheets in embodied intensity data files

6.2.2 Construction of CO_2 emission coefficient vector of Japan

The direct CO_2 emission coefficients, well compiled in datasheet D2 of 3EID for 1990, 1995 and 2000, are used to construct CO_2 emission intensity vector according to the classification of sectors in international IO tables. Fortunately, good converters between the sector category in the international IO tables and corresponding Japanese domestic IO tables are available. The examples of the sector converters for the three defined years are listed in Table II.A4-A6 in the annexes. The number of sectors in the international and Japanese domestic IO tables is listed in Table II.3.

Table II.3 Comparison of sector number of international IO tables and Japan domestic IO tables

Year	Sector number in international IO table	Sector number in Japan domestic IO table
1990	89	407
1995	78	399
2000	76	401

Usually, one sector in the international IO table covers one or several sectors in the Japan domestic IO table. By repeatedly using Eq. II.10, the direct CO_2 emission coefficients by sector classification of international IO table are calculated. Accordingly, direct CO_2 emission coefficient vector of Japan can be constructed with the same sector definition in international IO tables.

$$I^i = \frac{\sum_{j=1}^{n}(X_J^j \times I_J^j)}{\sum_{j=1}^{n} X_J^j} \qquad \text{(II.10)}$$

Where; I^i is the direct CO_2 emission coefficient of sector i in international IO table, I_J^j is the direct CO_2 emission coefficient of sector j in Japan IO table which is covered by sector i of international IO table, X_J^j is the total output of sector j in Japan IO table.

6.3 Calculation of CO_2 emission coefficients of China

The international IO tables and Chinese energy consumption matrix prepared for 1990, 1995 and 2000 were used for calculating energy and CO_2 emission coefficients for China. Since the emission coefficients for each year were calculated using the same method, the calculations are described only for the case of the year 2000. The calculation procedure for CO_2 emission intensities is shown in Fig. II.5.

Based on the data from the Chinese Yearly Energy Statistical Yearbook and the China Energy Data Book compiled by the Lawrence Berkeley National Laboratory, valid data was sorted out to construct an energy consumption matrix consisting of 37 rows and 16 columns, which describes the consumption of 16 types of energy by 37 sectors of Chinese classification at medium level. As there are 76 sectors in the 2000 international IO table, the 37 sectors in the energy data matrix were decomposed into 76 sub-sectors correspondingly by the definition of sector in either classification. The sector comparison and converter examples for each year are shown in annexed Table II.A7-A10.

After the sector decomposition and coordination, energy consumptions by the 76 sectors were calculated by using gross intermediate input at the sector level in the 2000 international IO table. This is because the total intermediate input of each sector can reflect the amount of resources and energy used by the sector. The energy consumptions of Chinese classified sectors were therefore split into the energy use of the sectors in the international IO table by the relative ratios of gross intermediate inputs. For instance, sector 24-nonmetal mineral products in Chinese energy matrix can be divided into AC0038 (cement and cement products), AC0039 (glass and glass products) and AC004（other non-metallic mineral products）in the 2000 international IO table. Energy use of these three sectors was calculated by multiplying the proportion of the relative value of the total intermediate input of each sector with each type of energy use of sector 24. It should be noted that there is one exception for the residential sector considering that for residential sector, gross output may reflect energy consumption more reasonably than gross intermediate input. The value of the gross output of each sub-sector in the residential sector was used for splitting the energy consumption data. In this way, the energy consumption matrix with 76 sectors by the international IO table classification was achieved.

Regarding the 16 types of energy, the CO_2 emission factor of each was calculated by multiplying its average calorific value with carbon content based on an assumption of 100% oxidation rate. CO_2 emissions were quantified by multiplying the obtained energy consumption of each fuel with the corresponding CO_2 emission factor. CO_2 emissions by fuel type were added together to get the total emissions of each sector in international IO table. As the last step, the emissions of per unit value of output of each sector, emission coefficients, were obtained by dividing the total CO_2 emissions by the gross output of the sector.

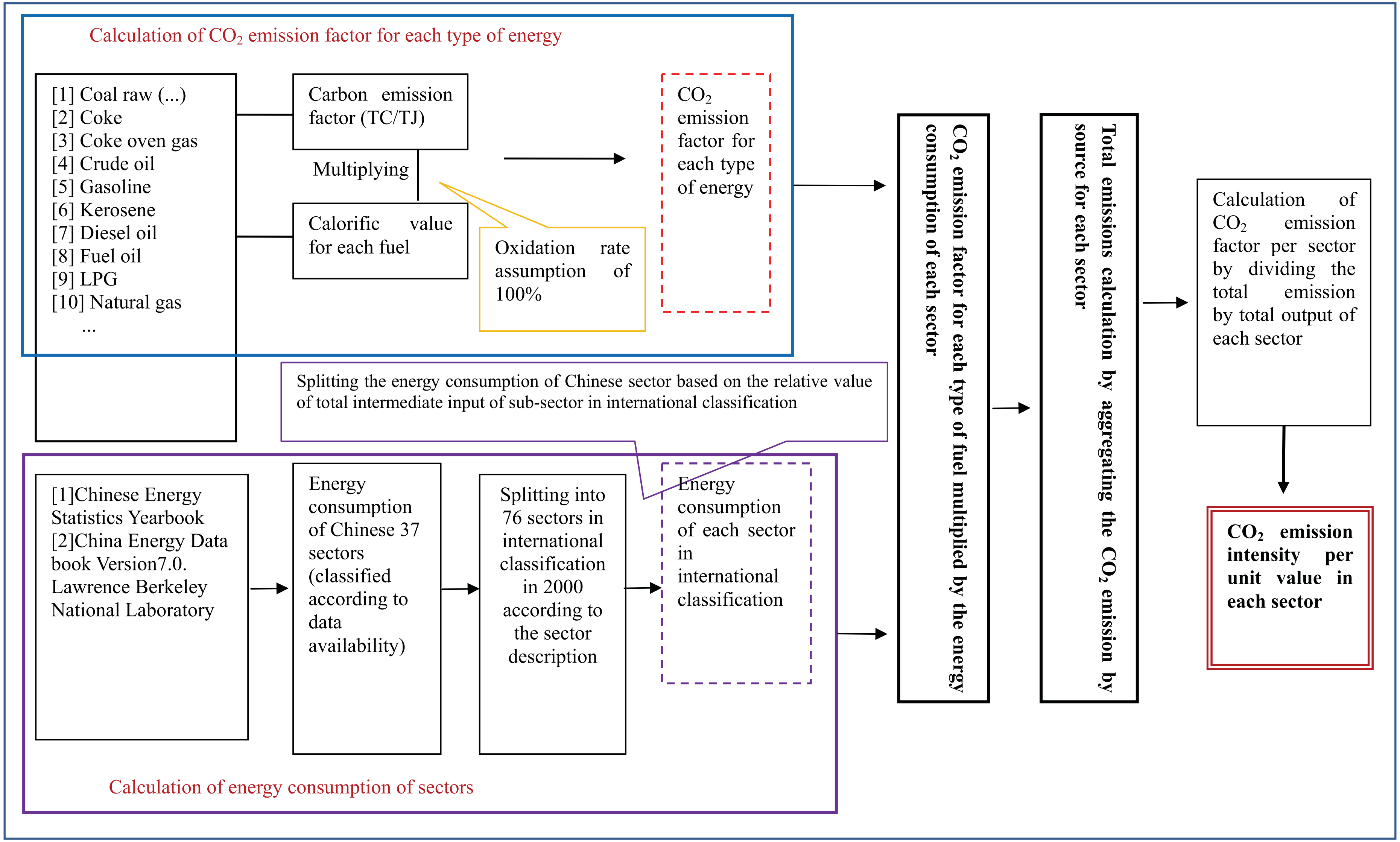


Fig. II.5 Calculation process for direct CO_2 emission intensity in each sector for China

7. Results and Discussions

7.1 Embodied CO_2 emissions in Japan-China trade

CO_2 emissions embodied in Japan-China trade are calculated by using the methodology explained in section 5.1. The aggregated results are listed in Table II.4. CO_2 emissions embodied in the exported goods from China to Japan were 43.52 Mt of CO_2 in 1990. This amount increased to 58.81 Mt in 1995 and then decreased to 44.01 Mt of CO_2 in 2000. The ratio of the exported CO_2 emissions from China to Japan in China's total emissions fluctuated from 1.5% to 2.0%. Meanwhile, CO_2 emissions embodied in the exported goods from Japan to China continuously increased from 4.49 Mt in 1990 to 10.8 Mt in 1995 and then reached 16.3 Mt of CO_2 by 2000. This amount accounted for 0.43%-1.35% of Japanese total emissions. CO_2 emissions embodied in the exports from China to Japan were larger than the reverse flow of emissions. There was a displacement of CO_2 emissions of Japan to China in the 1990's. This result is consistent with other previous studies which concluded that China is a giant carbon exporting country to major OECD countries like Japan and the U.S. (Kondo and Moriguchi, 1998; Ahmad and Wyckoff, 2003; Shui and Harriss, 2006).

Table II.4 Traded amount of CO_2 emissions in Japan-China trade during 1990-2000

Year	Traded amount of carbon emission (in Mt of CO_2)		
	From China to Japan	From Japan to China	Balance of China with Japan
1990	43.52 (1.9%)	4.49 (0.43%)	39.03
1995	58.81 (2.03%)	10.8 (0.9%)	48.01
2000	44.01 (1.48%)	16.3 (1.35%)	27.71

Note: Ratio of embodied emissions in country's total emissions is listed in the parenthesis. The total emissions are from IEA data referring to CO_2 emissions from the consumption of fossil fuels.

CO_2 emissions embodied in the exported goods from Japan to China were continuously increasing during 1990-2000 probably due to the increase of export volume (see Table II.5). The proportion of this amount to Japanese total emissions in the same year appeared as a similar increasing trend. However, although the export volume from China to Japan also increased dramatically in the same period, embodied CO_2 emissions from China to Japan increased in the first half of the 1990's while they decreased in the second half of the decade. The different pattern indicated the complexity of this topic. Actually, there is a complex relationship between trade and its environmental effects. Embodied CO_2 emissions are determined by three aspects of trade: total volume, composition and carbon intensities of traded goods (Grossman and Krueger, 1991). The general composition of traded goods between the two countries seemed to be relative stable. CO_2 emission intensities of Japanese industrial sectors also remained stable during the study period. CO_2 emissions embodied in Japanese exports were thus more determined by the trade volume. For the Chinese side, carbon intensities of industrial sectors more strongly affected embodied CO_2 emissions in the exports. The carbon intensity of the Chinese economy overall has decreased significantly during 1995-2000 (as listed in Table II.7). This may provide an explanation to some extent for the decrease of embodied emissions in the exports from China to Japan in the same period. It is not controversial for some researchers to find that trade development would cause negative environmental impacts (Beghin et al., 2002), while some others got quite a different conclusion through case studies (Anderson and Strutt, 2000).

Table II.5 Volume of Japan-China trade during 1990-2000

Year	Trade volume (in Mill. USD)	
	Export from China to Japan	Export from Japan to China
1990	11323.07	7183.69
1995	31704.78 (2.8)	27611.58 (3.84)
2000	44903.98 (3.96)	34467.21 (4.80)

Note: Data in the parenthesis is the times of export volume to that of 1990.

7.2 Results of scenario analysis

Using the compiled Japan-China IO tables and corresponding CO_2 emission coefficient vectors, the total CO_2 emissions in Japan and China were estimated. This provides the 'base case' for the comparison, representing the actual conditions for the defined three individual years. The aggregated results of the two scenarios, S0 with trade and S1 with no bilateral trade, are listed in Table II.6. The base case estimation in 1990 amounted to 1617.96 Mt of CO_2 in China, and 908.42 Mt in Japan. The industrial sectors included in the IO calculations shared most but not all of the emissions of both countries. China's total emissions in 1990 were 2293.39 Mt of CO_2 equivalents, while the Japanese total was 1053.77 Mt. Thus the IO model base case in this study accounted for 70.5% of China's overall emissions and 86.2% of Japan's emissions in total. The ratios of the IO model base case in the country's overall emissions were 68% and 94.9% for China and Japan respectively in 1995. The ratios were 57% and 90.5% for China and Japan in 2000 respectively.

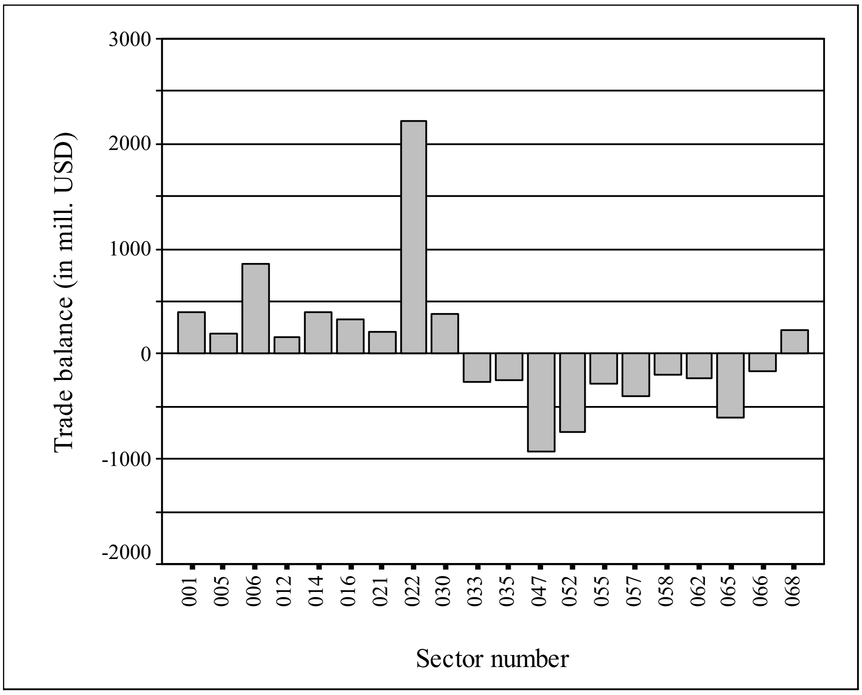
Table II.6 Total CO_2 emissions in the base case and assumed no trade scenario

Year	China (in Mt of CO_2)		Japan (in Mt of CO_2)	
	Base case	Change of S1 from base case	Base case	Change of S1 from base case
1990	1617.96	6.9 (0.43%)	908.42	-0.07 (-0.01%)
1995	1973.71	24.58 (1.25%)	1063.11	-0.7 (-0.07%)
2000	1690.22	32.9 (1.99%)	1089.65	-3.51 (-0.32%)

Note: Data in the parenthesis is the ratio of the change amount to the total emissions in base case.

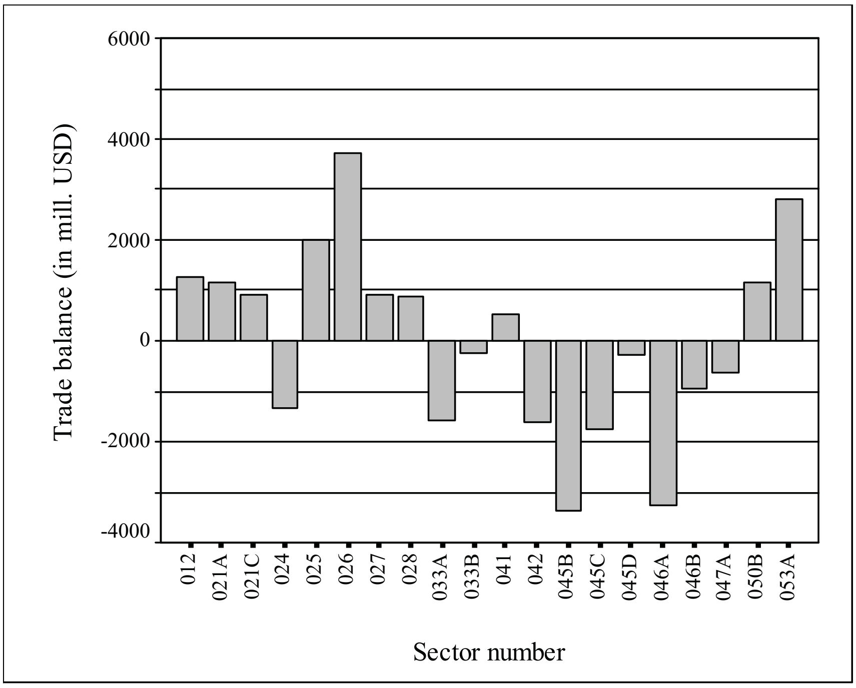
Comparing the base S0 result with the emissions in S1, the bilateral trade was beneficial for China to reduce CO_2 emissions while increased very slightly for Japanese overall emissions. E.g., the bilateral trade helped China to reduce 6.9 Mt of CO_2 emissions in 1990, which accounted for 0.43% of China's emissions in base case. In the same year, the bilateral trade slightly increased 0.07 Mt of CO_2 emissions for Japan, or 0.01% of Japan's base case's emissions. Therefore a net global CO_2 emission reduction of 6.83 Mt could be attributable to China-Japan trade in 1990. Similarly, for the year of 1995, 23.88 Mt of CO_2 emissions were avoided due to the bilateral trade. This amount increased to 29.39 Mt in 2000.

It shall be addressed that the difference between S1 and the base case is a purely domestic and single country measurement. It equals to the domestic emissions created if manufacturing the imports domestically minus the domestic emissions generated by producing the goods for exports. It does not measure the foreign emissions actually created by other countrie's exports to the two countries. This result might be explained by the composition of the trade goods between the two countries. Fig. II.6-8 summarises the top ten sectors with trade surpluses/deficits of China to Japan for 1990, 1995 and 2000 individually. In general, the basic trade composition between the two countries was not changed dramatically. China was exporting more primary materials and products to Japan, such as agricultural and food products, textile products and clothes, etc. Whereas, Japan was exporting chemical products, machinery equipments and electronic products, etc. to China during 1990-2000. Thus each country was exporting the goods with comparative advantage to one another, which possibly lead to global CO_2 emission reduction.



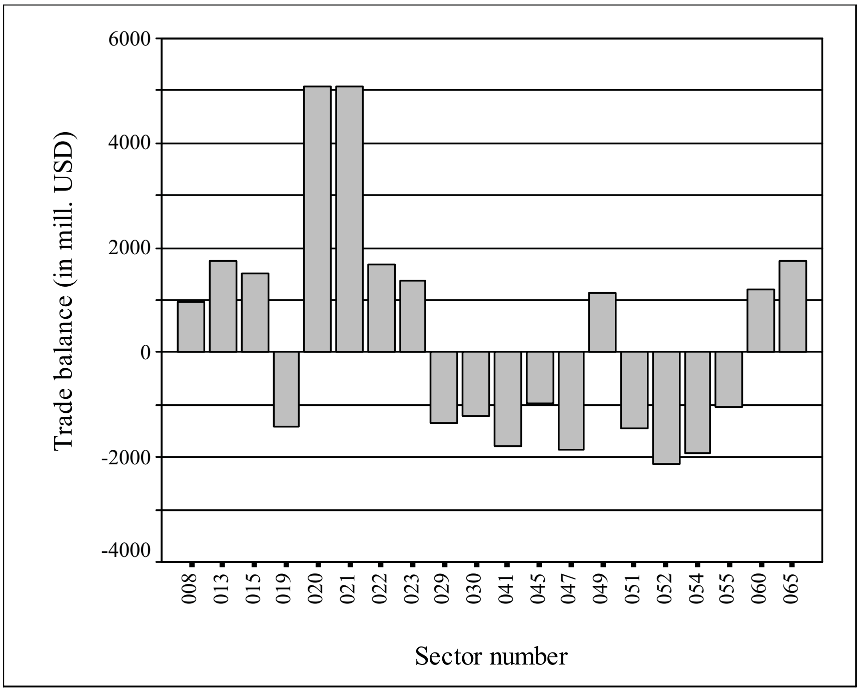
Top 10 sectors with trade surplus		Top 10 sectors with trade deficit	
No.	Description	No.	Description
001	Agriculture	033	Organic chemical products
005	Coal mining	035	Other chemical products
006	Crude oil and natural gas	047	Iron and steel
012	Slaughtering and meat processing	052	Special industrial machinery and equipment
014	Fish products	055	Other machinery
016	Other food industry	057	Road transport machinery
021	Textile industry	058	Shipbuilding
022	Clothing industry	062	Other electrical machinery and parts
030	Coal products and petroleum refinery	065	Other elect. equipment and communication machinery
068	Other manufacturing goods	066	Equipment, instrument and other machinery equip.

Fig. II.6 Major sectors with trade surpluses/deficits of China to Japan in 1990



Top 10 sectors with trade surplus		Top 10 sectors with trade deficit	
No.	Description	No.	Description
012	Crude petroleum and natural gas production	024	Weaving and dyeing
021A	Fish products	033A	Synthetic resins and fiber
021C	Other food products	033B	Other basic industrial chemicals
025	Knitting	042	Iron and steel
026	Wearing apparel	045B	Specialised industrial machinery
027	Other made-up textile products	045C	Ordinary industrial machinery
028	Leather and leather products	045D	Heavy electric machinery
041	Other non-metallic mineral products	046A	Electronics and electronic products
050B	Other manufacturing products	046B	Other electric machinery and appliance
053A	Wholesale and retail trade	047A	Motor vehicles

Fig. II.7 Major sectors with trade surpluses/deficits of China to Japan in 1995



Top 10 sectors with trade surplus		Top 10 sectors with trade deficit	
No.	Description	No.	Description
008	Crude petroleum and natural gas	019	Weaving and dyeing
013	Fish products	029	Synthetic resins and fiber
015	Other food products	030	Basic industrial chemicals
020	Knitting	041	Iron and steel
021	Wearing apparel	045	General machinery
022	Other made-up textile products	047	Specialised machinery
023	Leather and leather products	051	Semiconductors and integrated circuits
049	Television sets, radios, audios and communication equipment	052	Other electronics and electronic products
060	Other manufacturing products	054	Lighting fixtures, batteries, wiring and others
065	Wholesale and retail trade	055	Motor vehicles

Fig. II.8 Major sectors with trade surpluses/deficits of China to Japan in 2000

7.3 National overall difference in CO_2 emission intensity

As indicated in Table II.7, China has a much more carbon-intensive economy than Japan by any means during the study period of 1990-2000. China's average was 1833.3 kg CO_2 per 1000 USD of shipments in 1990, while the corresponding average of Japan was 159.7 kg CO_2 per 1000 USD of outputs. This means that the carbon intensity of the Chinese economy as a whole was 11.5 times of that of Japan in 1990. This situation did not change much in the first half of the 1990's. The economy's carbon intensity of China was still about 9.5 times of that of Japan by 1995. However, during the second half of the 1990's, the carbon intensity of China was reduced dramatically to 532.9 kg CO_2 per 1000 USD of shipments by average in 2000. It was about 4.2 times of that of Japan. During 1990-2000, nearly all the induced CO_2 emission intensities at the industrial sector level of Japan were smaller than that of China.

Table II.7 Overall CO_2 emission intensity in the two countries during 1990-2000

Year	Overall carbon intensity (kg CO_2/1,000 USD)		China/Japan
	China	Japan	
1990	1833.3	159.7	11.48
1995	1053.1	110.6	9.52
2000	532.9	126.6	4.21

7.4 CO_2 emission intensities by sector

In addition to analysing the total CO_2 emissions embodied in the bilateral trade, the pattern of CO_2 emissions by sector was examined. By defining I_C^i as CO_2 emission intensity of sector *i* in China (induced CO_2 emissions of sector *i*/total shipments value of sector *i*), and I_J^i as the corresponding CO_2 emission intensity of sector *i* in Japan, linear regressions were conducted for the industrial sectors with emission coefficients in both countries. The results for 1990, 1995 and 2000 are listed in Table II.8. Logarithms were used to reduce the influence of outliers. The regression coefficients of 0.414, 0.314 and 0.437 are significantly less than 1. This means that the variance of induced CO_2 emission intensity by sector is larger in Japan than that in China.

Table II.8 Regression results of CO_2 emission intensity by sector in the two countries

Year	Regression results of CO_2 emission intensity by sector in the two countries *(with t statistics in parentheses below the coefficients)*
1990	$\ln\left(I_C^i\right) = 1.75 + 0.414\ln\left(I_J^i\right)$, or equivalently, (19.5) (6.0) $I_C^i = 5.75 {I_J^i}^{0.414}$, with adjusted r^2=0.34, N=68
1995	$\ln\left(I_C^i\right) = 1.17 + 0.314\ln\left(I_J^i\right)$, or equivalently, (7.7) (3.6) $I_C^i = 3.22 {I_J^i}^{0.314}$, with adjusted r^2=0.14, N=71
2000	$\ln\left(I_C^i\right) = 0.64 + 0.437\ln\left(I_J^i\right)$, or equivalently, (5.1) (5.7) $I_C^i = 1.9 {I_J^i}^{0.437}$, with adjusted r^2=0.30, N=75

7.5 CO_2 emission intensity and trade balance by sector

The familiar theory of comparative advantage suggests that each country will specialise in the production of goods for which its production cost is relatively lower, and that such a pattern of specialisation maximises aggregate welfare. Similarly, if each country specialised in the production of goods for which its emission intensity is lower, the aggregate emissions would be minimised. However, the parallel case is far from complete. There was no economic incentive for minimising CO_2 emissions in both countries during 1990-2000 since CO_2 emissions were unregulated and costless. Plausible *a priori* theories are available to explain either positive or negative relationships between comparative advantage and emission intensity. The improvement of energy efficiency reduces costs for fuel consumption, lowers CO_2 emissions and production costs simultaneously, which suggests that comparative advantage in trade might be negatively correlated with CO_2 emission intensity, like the case of Japan-Canada trade (Ahmad and Wyckoff, 2003). From another viewpoint, the possibility to emit CO_2 without cost might be a free resource which could be substituted for other costly resources. This could account for a positive correlation between comparative advantage and CO_2 emissions, as the case of US-China trade (Shui and Harriss, 2006).

In order to answer the question of whether CO_2 emission intensity positively or negatively correlated to a comparative advantage in bilateral trade, another explanatory variable was added to include the trade balance of the two countries. If defining B^i as expressed by Eq. II.11, then it can be recognised as China's trade surplus or deficit coefficient with Japan in sector *i*. As a fraction of the total volume of bilateral trade in the sector, it ranges from 1, if the bilateral trade only consists of China's exports, to -1, if the bilateral trade is only China's imports.

$$B^i = (Ex_C^i - Ex_J^i)/(Ex_C^i + Ex_J^i) \qquad \text{(II.11)}$$

Where: Ex_C^i is China's export to Japan in sector *i*, and conversely for Ex_J^i .

The regression results of CO_2 emission intensity and trade coefficient defined above are listed in Table II.9. The logarithm of B^i can not be used since it takes on negative values for some sectors. The result indicates that China's trade balance to Japan is significantly and negatively correlated with the CO_2 emission intensity in 1990. However, the results are not significant for the regressions for 1995 and 2000.

Table II.9 Regression results of CO_2 emission intensity and trade balance by sector

Year	Regression results of CO_2 emission intensity by sector with the trade balance (with *t* statistics in parentheses below coefficients)
1990	$\ln(I_C^i) = \underset{(20.7)}{1.85} + \underset{(6.9)}{0.475}\ln(I_J^i) - \underset{(-2.1)}{0.142}B^i$, with adjusted r^2=0.44, N=65
1995	$\ln(I_C^i) = \underset{(11.8)}{1.44} + \underset{(6.9)}{0.531}\ln(I_J^i) - \underset{(-0.8)}{0.072}B^i$, with adjusted r^2=0.46, N=62
2000	$\ln(I_C^i) = \underset{(6.9)}{0.84} + \underset{(6.7)}{0.582}\ln(I_J^i) - \underset{(-0.6)}{0.05}B^i$, with adjusted r^2=0.5, N=63

8. Summary and Policy Implications

The study began by asking whether Japan-China trade increases or decreases global CO_2 emissions and whether one country displaces part of its emissions onto another. The answer is that Japan-China trade helped to reduce global carbon emissions while it shifted part of the carbon burden associated with Japan's consumption onto China. The analyses at the sector level found a significant but not perfect correlation between emissions intensities in the two countries. Chinese industry was much more carbon intensive than its Japanese counterparts on average. Additionally, there is a small but significant correlation between comparative advantage in the bilateral trade and carbon emission intensity for 1990. The sectors that emit more carbon per thousand dollars of sales are less likely to be successful exporters. This could be a reflection of the nature of the two economies and the long-standing absence of any prices or disincentives for CO_2 emissions. This might, in part, be a distorted reflection of price differences between the two countries in certain sectors. E.g., higher prices per physical unit of products with the same technological level imply lower carbon emissions per thousand dollars of sales.

One important policy message, in terms of opportunities for CO_2 emission reduction, is that many sectors of Chinese industry could benefit from studying Japanese technologies for the production with lower carbon emissions. From the perspective of public policy, this study underscores the importance of giving a certain kind of limitation on CO_2 emissions, like carbon taxation or other economic measurements. In the absence of carbon taxes or other regulations, the Chinese economy has naturally continued to rely on its traditional experience and comparative advantage in energy-using, carbon-intensive productions. The absence of carbon taxes has meant that Japan's comparative advantage in trade is not necessarily concentrated in the lowest emission sectors. As long as energy is cheap and emissions are free, energy-intensive production can be commercially profitable strategies. Policies that raise the cost of energy use and carbon emissions at the national and even the global level will be required in order to make a more sustainable low CO_2 emission path attractive for industry in China, Japan and elsewhere.

Actually, the Chinese government has begun to adjust the export tax rebate policy from several years ago. The export tax rebate is a kind of refunded tax to the exporters after departure of the exporting goods declaration by domestic value-added tax or consumption tax which has been paid in the pre-export production and distribution. This policy promoted national economy development effectively since the first tax system revolution in 1994. In 2005 and 2007, the policy adjustment targeted the three-intensive (energy, pollution and resources) products by reducing or even canceling the export tax rebate. As a result, export of these products decreased and the same for their trade surplus. But in early 2009, the policy adjustment was reversed as a reaction to the international economic crisis to help the enterprises that rely on exporting. As the most relevant policy to this study, embodied CO_2 emissions in traded goods, the modifications of export tax rebate policy played an active role in controlling carbon intensive product exports and optimising the industrial structure in China. However, there are still some defects of this policy, e.g., the lack of unity in policy implementation, the frequent change of rebate rate resulting in instability of the policy environment and definite cost increases.

Limited by the available data sources, this study inevitably has certain shortcomings which shall be addressed by future studies. The obvious time lag of cross country IO tables determines the possible time span for the quantitative analyses. The study can only update to the year 2000 since the latest Asian international IO table is for 2000. Similar quantification shall be followed up to observe the change and potential reasons for the embodied CO_2 emissions once a new version of the international IO table has been developed. The analyses in this study were conducted at a scale of tens of industrial sectors due to the medium level of sector classifications in the provided international IO tables. The converters between the sector classifications in the IO table and the databases of energy consumption sheet are not given clearly, which might affect the accuracy of carbon emission coefficients at the sector level. These limitations definitely cause certain discrepancies of the quantification results in this study. Much more detailed analyses shall be carried out for individual industrial sectors to identify the opportunities of reducing CO_2 emissions in total by using comparative advantage of both cost and environmental impacts of production for trade. Regarding the public policy for CO_2 emissions mitigation, the feasibility for introducing certain limitations to carbon emissions such as carbon tax needs to be discussed for Asian countries. The design of the policy framework and monitoring of the acceptability of the firms to the proposed policy measures are essential from future perspective.

Annexes

Table II.A1 Sector classification of Japan-China 1990 IO table (89 sectors)

Code	Description	Code	Description	Code	Description
001	Agriculture	031	Basic chemical materials	061	Electric machinery for daily use
002	Forestry	032	Chemical fertilizer and pesticides	062	Other electric machinery and parts
003	Animal husbandry	033	Organic chemical products	063	Electronic computer
004	Fishery	034	Chemical products for daily use	064	Electronic equipment for daily use
005	Coal mining	035	Other chemical products	065	Other electronic equipment and communication machinery
006	Crude oil and natural gas	036	Medicine	066	Equipment, instrument and other machinery equipment
007	Iron ore mining	037	Chemical fiber	067	Repair of machinery
008	Non-ferrous metal mining	038	Rubber products	068	Other manufacturing goods
009	Other ore mining	039	Plastic products	069	Construction
010	Tap water production and supply	040	Cement	070	Railway transportation
011	Food and oil industry	041	Cement products and special cement	071	Road transportation
012	Slaughtering and meat processing	042	Bricks, tiles, lime and other building materials	072	Water transportation
013	Dairy products	043	Glass products	073	Air transportation
014	Fish products	044	Ceramics	074	Pipeline
015	Sugar refinery	045	Fire-clay products	075	Communication
016	Other food industry	046	Other non-metallic mineral products	076	Trade
017	Liquors	047	Iron and steel	077	Restaurant
018	Non-alcoholic beverage	048	Non-ferrous metal	078	Real estate
019	Tobacco	049	Metallic products	079	Public service
020	Feed processing	050	Boiler and turbine	080	Service for household
021	Textile industry	051	Metal processing machinery	081	Health and medical services
022	Clothing industry	052	Special industrial machinery and equipment	082	Education
023	Leather industry	053	Agricultural, forestry and animal husbandry machinery	083	Social welfare service
024	Wood processing and plywood	054	Machinery for daily use	084	Cultural arts and broadcasting services
025	Furniture and wooden products	055	Other machinery	085	Science research institute
026	Pulp and paper	056	Railway transport machinery	086	Other general services
027	Printing	057	Road transport machinery	087	Banking and insurance
028	Stationery and educational articles	058	Ship building	088	Public administration
029	Electricity, steam and hot water	059	Other transport machinery	089	Unclassified
030	Coal products and petroleum refinery	060	Electric generation and electric machinery		

Table II.A2 Sector classification of Asian 1995 IO table (78 sectors)

Code	Description	Code	Description	Code	Description
001	Paddy	023	Spinning	045A	Agricultural machinery and equipment
002	Cassava	024	Weaving and dyeing	045B	Specialized industrial machinery
004	Sugar cane and beet	025	Knitting	045C	Ordinary industrial machinery
005	Oil palm and coconuts	026	Wearing apparel	045D	Heavy Electric machinery
006	Fiber crops	027	Other made-up textile products	045E	Engines and turbines
007A	Other grain	028	Leather and leather products	046A	Electronics and electronic products
007B	Other food crops	029	Timber	046B	Other electric machinery and appliance
008	Other commercial crops	030A	Wooden furniture	047A	Motor vehicles
009	Livestock and poultry	030B	Other wooden products	047B	Motor vehicles and bicycles
010	Forestry	031	Pulp and paper	048A	Aircraft
011	Fishery	032	Printing and publishing	048B	Shipbuilding
012	Crude petroleum and natural gas production	033A	Synthetic resins and fiber	048C	Other transport equipment
013	Copper ore	033B	Other basic industrial chemicals	049	Precision machines
014	Tin ore	034	Chemical fertilizers and pesticides	050A	Plastic products
015A	Iron ore	035A	Drugs and medicine	050B	Other manufacturing products
015B	Other metallic ore	035B	Other chemical products	051	Electricity, gas and water supply
016	Non-metallic ore and quarrying	036	Refined petroleum and its products	052A	Building construction
017	Oil and fats	003	Natural rubber	052B	Other construction
018	Milled rice	037	Tires and tubes	053A	Wholesale and retail trade
019	Other milled grain and flour	038	Other rubber products	053B	Transportation
020	Sugar	039	Cement and cement products	054A	Telephone and telecommunication
021A	Fish products	040	Glass and glass products	054B	Finance and insurance
021B	Slaughtering, meat products and dairy products	041	Other non-metallic mineral products	054C	Education and research
021C	Other food products	042	Iron and steel	054D	Other services
022A	Beverage	043	Non-ferrous metal	055	Public administration
022B	Tobacco	044	Metal products	056	Unclassified

Table II.A3 Sector classification of Asian 2000 IO table (76 sectors)

Code	**Description**	**Code**	**Description**	**Code**	**Description**
001	Paddy	027	Pulp and paper	053	Household electrical equipment
002	Other grain	028	Printing and publishing	054	Lighting fixtures, batteries, wiring and others
003	Food crops	029	Synthetic resins and fiber	055	Motor vehicles
004	Non-food crops	030	Basic industrial chemicals	056	Motor cycles
005	Livestock and poultry	031	Chemical fertilizers and pesticides	057	Shipbuilding
006	Forestry	032	Drugs and medicine	058	Other transport equipment
007	Fishery	033	Other chemical products	059	Precision machines
008	Crude petroleum and natural gas	034	Refined petroleum and its products	060	Other manufacturing products
009	Iron ore	035	Plastic products	061	Electricity and gas
010	Other metallic ore	036	Tires and tubes	062	Water supply
011	Non-metallic ore and quarrying	037	Other rubber products	063	Building construction
012	Milled grain and flour	038	Cement and cement products	064	Other construction
013	Fish products	039	Glass and glass products	065	Wholesale and retail trade
014	Slaughtering, meat products and dairy products	040	Other non-metallic mineral products	066	Transportation
015	Other food products	041	Iron and steel	067	Telephone and telecommunication
016	Beverage	042	Non-ferrous metal	068	Finance and insurance
017	Tobacco	043	Metal products	069	Real estate
018	Spinning	044	Boilers, Engines and turbines	070	Education and research
019	Weaving and dyeing	045	General machinery	071	Medical and health service
020	Knitting	046	Metal working machinery	072	Restaurants
021	Wearing apparel	047	Specialized machinery	073	Hotel
022	Other made-up textile products	048	Heavy electrical equipment	074	Other services
023	Leather and leather products	049	Television sets, radios, audios and communication equipment	075	Public administration
024	Timber	050	Electronic computing equipment	076	Unclassified
025	Wooden furniture	051	Semiconductors and integrated circuits		
026	Other wooden products	052	Other electronics and electronic products		

Table II.A4 Sector converter example of 1990 Japan-China IO table and Japan domestic table

Sector classification in Japan-China 1990 IO table		**Sector classification in Japan 1990 domestic IO table**	
Code	Description	Code	Description
033	Organic chemical products	2029-02	Inorganic pigments
		0231-01	Petrochemical basic products
		2031-02	Petrochemical aromatic products
		2032-01	Aliphatic intermediates
		2032-02	Cyclic intermediates
		2039-02	Methane derivative
		2039-04	Plasticizers
		2039-05	Synthetic Dyes
		2039-09	Other industrial organic chemicals
		2072-01	Paint, varnish and lacquer
		2072-02	Printing ink
		2079-02	Gelatin and adhesives

Table II.A5 Sector converter example of 1995 Asian IO table and Japan domestic table

Sector classification in Asian 1995 IO table		**Sector classification in Japan 1995 domestic IO table**	
Code	Description	Code	Description
042	Iron and steel	261101	Pig iron
		261102	Ferroalloys
		261103	Crude steel (converters)
		261104	Crude steel (electric furnaces)
		262201	Steel pipes and tubes
		262301	Cold-finished steel
		262302	Coated steel
		263101	Cast and forged steel
		263102	Cast iron pipes and tubes
		263103	Cast and forged materials (iron)
		264901	Iron and steel shearing and slitting
		264909	Other iron or steel products

Table II.A6 Sector converter example of 2000 Asian IO table and Japan domestic table

Sector classification in Asian 2000 IO table		**Sector classification in Japan 2000 domestic IO table**	
Code	Description	Code	Description
030	Basic industrial chemicals	202101	Industrial soda chemicals
		202902	Compressed gas and liquefied gas
		202909	Other industrial inorganic chemicals
		203101	Petrochemical basic products
		203102	Petrochemical aromatic products (except synthetic resin)
		203201	Aliphatic intermediates
		203202	Cyclic intermediates
		203301	Synthetic rubber
		203901	Methane derivatives
		203902	Oil and fat industrial chemicals
		203903	Plasticizers
		203909	Other industrial organic chemicals

Table II.A7 Sector classification in Chinese energy consumption matrix

Code	Description	Code	Description
1	Agricultural	19	Raw chemical materials and chemical products
2	Coal mining and dressing	20	Medical and pharmaceutical products
3	Petroleum and natural gas extraction	21	Chemical fiber
4	Ferrous metals mining and dressing	22	Rubber products
5	Nonferrous metals mining and dressing	23	Plastic products
6	Nonmetal mineral mining and dressing	24	Nonmetal mineral products
7	Other minerals mining and dressing	25	Smelting and rolling of ferrous metals
8	Logging and transport of wood and bamboo	26	Smelting and rolling of nonferrous metals
9	Food, beverage, and tobacco processing	27	Metal products
10	Textile industry	28	Machinery, electric equipment, electronic manufacturing
11	Garments and other fiber products	29	Other manufacturing industry
12	Leather, furs, down, and related products	30	Electric power, steam, and hot water production & supply
13	Timber processing, bamboo, cane, palm, and straw products	31	Gas production & supply
14	Furniture manufacturing	32	Tap water production & supply
15	Papermaking and paper products	33	Construction
16	Printing and record medium reproduction	34	Transportation
17	Cultural, educational, and sports articles	35	Commercial
18	Petroleum processing and coking	36	Residential

Table II.A8 Sector converter example of 1990 Japan-China IO table and Chinese sector classification

Sector classification in Japan-China 1990 IO table		**Sector classification in China 1990 energy matrix**	
Code	Description	Code	Description
AC040	Cement	24	Nonmetal mineral products
AC041	Cement products and special cement		
AC042	Bricks, tiles, lime and other Building Materials		
AC043	Glass products		
AC044	Ceramics		
AC045	Fire-clay products		
AC046	Other non-metallic mineral products		

Table II.A9 Sector converter example of 1995 Asian IO table and Chinese sector classification

Sector classification in Asian 1995 IO table		**Sector classification in China 1995 energy matrix**	
Code	Description	Code	Description
AC017	Oil and fats	9	Food, beverage, and tobacco processing
AC018	Milled rice		
AC019	Other milled grain and flour		
AC020	Sugar		
AC021A	Fish products		
AC021B	Slaughtering, meat products and dairy products		
AC021C	Other food products		
AC022A	Beverage		
AC022B	Tobacco		

Table II.A10 Sector converter example of 2000 Asian IO table and Chinese sector classification

Sector classification in Asian 2000 IO table		Sector classification in China 2000 energy matrix	
Code	Description	Code	Description
AC012	Milled grain and flour	9	Food, beverage, and tobacco processing
AC013	Fish products		
AC014	Slaughtering, meat products and dairy products		
AC015	Other food products		
AC016	Beverage		
AC017	Tobacco		

References

Ackerman, F., Ishikawa, M., Suga, M., 2007. The carbon content of Japan-US trade. Energy Policy 35(9), 4455-4462.

Ahmad, N., Wyckoff, A., 2003. Carbon dioxide emissions embodied in international trade of goods. STI Working Paper. Paris: OECD Directorate for Science, Technology and Industry, 15.

Anderson, K., Strutt, A., 2000. Will trade liberalization harm the environment? The case of Indonesia to 2020. Environmental and Resource Economics 17(3), 203-232.

Beghin, J.B., Bowland, S.D., Roland-Holst, D., van der Mensbrugghe, D., 2002. Trade integration, environmental degradation and public health in Chile: assessing the linkages. Environment and Development Economics 7, 241-267.

Brown, L.R., 2003. Shifting taxes, plan B: Rescuing a planet under stress and a civilization in trouble. New York: W.W. Norton & Co.

Chenery, H.B., 1953. Regional analysis. In: Chenery H, Clark P, eds. The Structure and Growth of the Italian Economy. Rome: United States Mutual Security Agency, 97-129.

Chung, H.S., Rhee, H.C., 2001. Carbon dioxide emissions of Korea and Japan and its transmission via international trade. International Economic Journal 15(4), 117-136.

Costanza, R., 1980. Embodied energy and economic valuation. Science 210 (4475), 1219-1224.

Dimaranan, B.V., 2006. Global trade, assistance, and production: The GTAP 6 database. West Lafayette: Center for Global Trade Analysis, Purdue University.

Ferng, J.J., 2003. Allocating the responsibility of CO2 over-emissions from the perspective of benefit principle and ecological deficit. Ecological Economics 46(1), 121-141.

Grossman, G.M,, Krueger, A.B., 1991. Environmental impacts of a North American Free Trade Agreement. . National Bureau of Economic Research, Inc.

Hayami, H., Nakamura, M., 2002. CO2 emission of an alternative technology and bilateral trade between Japan and Canada: Relocating production and an implication for joint implementation. Discussion Paper 75, Keio Economic Observatory. Tokyo: Keio University.

Helm, D., Smale, R., Phillips, J., 2008. Too good to be true: The UK's climate change record. http://www.dieterhelm.co.uk/publications/ carbon_record_2007.pdf.

Hoerner, J.A., 2001. Bosquet B. Environmental tax reform: The European experience. Washington DC: Center for a Sustainable Economy, 11-27.

Hoshino, Y., Sugiyama, D., 2008. Quantifications of CO2 embodiment in trade. Discussion Paper, SERC08002. Japan: Central Research Institute of Electric Power Industry.

Hu, C.L., 2007. Analysis of energy flow in the international trade. Tsinghua University [D] (in Chinese).

IDE (Institute of Developing Economies), 1997. International input-output table China-Japan 1990. IDE Statistical Data Series No.76, Institute of Developing Economies, Japan External Trade Organization.

IDE (Institute of Developing Economies), 2001. Asian international input-output table 1995. IDE Statistical Data Series No.82, Institute of Developing Economies, Japan External Trade Organization.

IDE (Institute of Developing Economies), 2006. Asian international input-output table 2000–Volume 1: Explanatory notes. IDE Statistical Data Series No.89, Institute of Developing Economies, Japan External Trade Organization.

IPCC, 2008. 2006 IPCC guidelines for national greenhouse gas inventories. http://www.ipcc-nggip.iges.or.jp/public/2006gj/index.htm.

Isard, W., 1951. International and regional input-output analysis: A model of a space-economy. Review of Economics and Statistics 33 (4), 318-328.

Jiang, K.J., 2008. Embedded carbon in traded goods. Presentation in trade and climate change seminar, June 18-20, 2008. Copenhagen, Denmark.

Kander, A., Lindmark, M., 2006. Foreign trade and declining pollution in Sweden: a decomposition analysis of long-term structural and technological effects. Energy Policy 34(13), 1590-1599.

Kondo, Y., Moriguchi, Y., 1997. Carbon dioxide emission intensity based on the input-output analysis. National Institute for Environmental Studies, Center for Global Environmental Research, CGER-D016-'97.

Kondo, Y., Moriguchi, Y., Shimizu, H., 1998. CO2 emissions in Japan: Influences of imports and exports. Applied Energy 59(2-3), 163-174.

Lenzen, M., 1998. Primary energy and greenhouse gases embodied in Australian final consumption: An input-output analysis. Energy Policy 26(6), 495-506.

Leontief, W.W., 1941. The Structure of American Economy, 1919-1929: An Empirical Application of Equilibrium Analysis. Cambridge: Harvard University Press.

Li, H., Zhang, P.D., He, C.Y., Wang, G., 2007. Evaluating the effects of embodied energy in international trade on ecological footprint in China. Ecological Economics 62(1),136-148.

Li, K.W., Sun, W., 2008. Energy content of import and export trade in China. World Economy Study 168(2), 3-7 (in Chinese).

Li, L.P., Ren, Y., Tian, C.X., 2008. Analyzing responsibilities for Chinese carbon emissions from the international trade perspective. Environment Protection 392 (3B), 62-64 (in Chinese).

Li, H., Zhang, P.D., He, C.Y., Wang, G., 2007. Evaluating the effects of embodied energy in international trade on ecological footprint in China, Ecological Economics 62(1),136-148.

Li, Y., Hewitt, C.N., 2008. The effect of trade between China and the UK on national and global carbon dioxide emissions. Energy Policy 36, 1907-1914.

Liu, Q., Zhuang, X., Jiang, K.J., Han, W.K., 2008. Energy and carbon embodied in main exporting goods of China. China Industrial Economics 245(8), 46-55 (in Chinese).

Luo, S.P., 2008. Analysis of embodied energy in China's international trade. Tsinghua University[D] (in Chinese).

Luo, S.P., Wang, C., Chen, J.N., 2009. Analysis of embodied energy in China's international trade. Journal of Tsinghua University (Sci & Eng), in press (in Chinese).

Machado, G., Roberto, S., 2001. Ernst W. Energy and carbon embodied in the international trade of Brazil: An input-output approach. Ecological Economics 39(3), 409-424.

MCAG, 1995. 1995 input-output tables (in Japanese). Management and Coordination Agency Government of Japan.

Moses, L.N., 1955. The stability of interregional trading patterns and input-output analysis. American Economic Review 45(5), 803-826.

Munksgaard, J., Pade, L.L., Minx, J., Lenzen, M., 2005. Influence of trade on national CO2 emissions. International Journal of Global Energy Issues 23(4), 324-336.

Muradian, R., O'Connor, M., Martinez-Alier, J., 2002. Embodied pollution in trade: Estimating the environmental load displacement of industrialized countries. Ecological Economics 41(1), 51-67.

Nakano, S., Okamura, A., Sakurai, N., Suzuki, M., Tojo, Y., Yamano, N., 2009. The measurement of CO2 embodiments in international trade: Evidence from the harmonized input-output and bilateral trade database. OECD Science, Technology and Industry Working Papers, 2009/3, OECD Directorate for Science, Technology and Industry.

Nansai, K., Moriguchi, Y., Tohno, S., 2002. Embodied Energy and Emission Intensity Data for Japan Using Input-Output Tables (3EID)—Inventory Data for LCA. CGER Report. National Institute for Environmental Studies, Japan.

Pan, J.H., Chen, Y., 2007. The embodied energy and embodied carbon emissions analysis in Chinese import-export trade, in WWF (ed.), "Climate change international regimes: Chinese issues research", Chapter 3, pp25-44, Chinese Environmental Science Press, Beijing (in Chinese).

Peters, G.P., Hertwich, E.G., 2006. Pollution embodied in trade: The Norgwegian case. Global Environmental Change 16, 379-387.

Peters, G.P., Hertwich, E.G., 2008a. Post-Kyoto greenhouse gas inventories: Production versus consumption. Climate Change 86(1-2), 51-66.

Peters, G.P., Hertwich, E.G., 2008b. CO2 embodied in international trade with implications for global climate policy. Environmental Science & Technology 42(5), 1401-1407.

Peters, G.P., Weber, C.L., Guan, D., Hubacek, K., 2007. China's growing CO2 emissions—A race between increasing consumption and efficiency gains. Environmental Science & Technology 41(17), 5939-5944.

Qi, Y., Li, H.M., Xu, M., 2008. Accounting embodied carbon in import and export in China. China Population, Resources and Environment 18(3), 8-13 (in Chinese).

Shui, B., Harriss, R.C., 2006. The role of CO2 embodiment in US-China trade. Energy Policy 34(18), 4063-4068.

Tamamura, C., 1994. Conceptual framework and compilation procedure of bilateral IO table. Asian International IO Series No. 34. Tokyo: Institute of Developing Economies.

Treloar, G.J., Love, P.E.D., Holt, G.D., 2001. Using national input-output data for embodied energy analysis of individual residential buildings. Construction Management and Economics 19(1), 49-61.

Tolmasquim, M.T., Machado, G., 2003. Energy and carbon embodied in the international trade of Brazil. Mitigation and Adaptation Strategies for Global Change 8, 139-155.

Wang, N., Zhang, J., Wang, Z., Chen, X.D., 2007. Research on international trade of China based on energy consumption. International Trade Issues (8), 9-15 (in Chinese).

Wang, T., Watson, J., 2007. Who owns China's carbon emissions? Tyndall Center for Climate Change Research, Tyndall Briefing Note, 23.

Wang, T., Watson, J., 2008. China's carbon emissions and international trade: implications for post-2012 policy. Climate policy 8, 577-587.

Wang, Z.P., Li, Y., Li, D.G., 2008. A primary analysis on the impact of import-export trade on China's CO_2 emissions. China's Energy 30(3), 14-17 (in Chinese).

Weber, C.L., Peters, G.P., Guan, D.B., 2008. Hubacek K. The contribution of Chinese exports to climate change. Energy Policy 36, 3572-3577.

Wu, J.H., Chen, Y.Y., Huang, Y.H., 2007. Trade pattern change impact on industrial CO_2 emissions in Taiwan. Energy Policy 35, 5436-5446.

Wyckoff, A.W., Roop, J.M., 1994. The embodiment of carbon in imports of manufactured products: Implications for international agreements on greenhouse gas emissions. Energy Policy 22(3), 187-194.

Zhou, Z.T., Yang, D.G., 2006. Virtual energy-A new visual angle to analyze the hyper normal growth rate of energy consumption in China. Advances in Earth Science (21), 320-323 (in Chinese).

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