# China's fossil fuel combustion, carbon dioxide emissions and international trade

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**Abstract:** China depends much on energy import and export. Thus, we have to split-up intermediate inputs into domestic parts and imported parts, in such way to reflect non-perfect substitution between these two different inputs. In light of this, a new hybrid model namely energy-environment-economy non-competitive input-output model (3ENCIOM) is constructed. Firstly, it reflects the feature of processing export in China; then, a new concept called carbon dioxide ($CO_2$) emissions of fossil fuel is developed, which enables more accurate calculation of $CO_2$ emissions. Some main conclusions are drawn: first and foremost, in 2007 China's $CO_2$ emissions are mainly due to the production for satisfying domestic demands; secondly, China is a net importer in terms of $CO_2$ emissions; thirdly, 30% $CO_2$ emissions can be ascribed to foreign consumers' demands; last but not least, $CO_2$ emissions by processing export production are very limited, in contrast, non-processing exports yield relatively large part of the emissions.

**Keywords**: energy-related $CO_2$ emissions of fuels; energy-environment-economy (3E) non-competitive input-output model; import and export

## 1. Introduction

Recently, Steve Davis published his research about global trade on Proceedings of National Academy Sciences (PNAS). By using global trade data, he estimated that the US and some developed countries had "imported" about one-third $CO_2$ emissions from other countries. In this sense, it would be plausible to consider that the argument about "rich countries" should take the lead to reduce emissions is reasonable. It is reported in his paper that roughly 22.5% China's emissions is generated to satisfy foreign consumers' demands, among which 7.8% emissions are due to the exports to the US. Moreover, his study indicates that Australia, France, Sweden, Switzerland and the UK have imported about one-third emissions from all over the world. Following this line, we would argue that China's emissions contain those part yielded by exports production, which are actually consumed by foreign countries and therefore should be ascribed accordingly. For instance, Weber et al.[1] shows that 33% production-related $CO_2$ emissions came from exports production while most part were generated for domestic demands production purpose in 2005. To some extent, the study of $CO_2$ emissions, specifically, embodied in imports and exports, has become a focus within both academia and policy community.

## 2. $CO_2$ emissions by fossil fuel combustion

The fossil fuel combustion-related $CO_2$ emissions are confined to those generated by fossil fuels, while other sources are exempted e.g. from logging, biological death, industry non-combustion procedure, exhaust gas, waste water and other castoff, atmosphere and ocean. According to IPCC (2007), global climate change is mainly caused by greenhouse gas emissions, where $CO_2$ is uppermost component in greenhouse gas. $CO_2$ emissions accounted to 76.7% in global greenhouse gas in 2004, in which fossil fuel combustion-related $CO_2$ emissions took 56.6%, i.e. fossil fuels are main emission source with contribution of 73.79% in overall $CO_2$ emissions. In contrast, energy consumption in household daily life only accounts for 10%. Therefore, this study naturally turns to the investigation of $CO_2$ emissions by production-related fossil fuels combustion, which is of importance.

There are many studies on investigating the relationship between trade and energy, which can mainly be grouped as follows: 1) the impact of international trade on energy consumption and the environment. Previous work analyzed and forecasted the impact of trade on energy consumption and emissions, and the main conclusion is that structure and technology are the most important determinants for energy consumption and emissions in trade (see for example, Battjes[2], Fieleke[3], Machado et al. [4], Rhee and Chung[5], Wyckoff and Roof[6] ). 2) the impacts of input-output (IO) technology on energy consumption and environment. Literature in this line, see for instance, Miller and Blair[7], Forssell[8][ 9], Gallego and Lenzen[10], Lenzen et al. [11], Rodrigues et al. [12], Suh and Kagawa[13], Turner et al. [14] and Wiedmann[15] and so forth.

Recently, Lau and Chen et al. [16][17] have developed a special input-holding-output table which makes explicit distinction between processing exports and non-processing counterparts. This table can be used to analyze the impact of processing trade to China’s foreign trade. What follows is the work by Lau et al. [18][19], Zhu[20] who calculated the domestic value-added content generated by performing respectively processing exports and non-processing exports. Peters et al. [21][22] reckoned China's $CO_2$ emissions in 2002, and according to their estimation production-related $CO_2$ emissions amounted to 95%. Pei[23] estimated exports' impact on environment by using the extended input-output table.

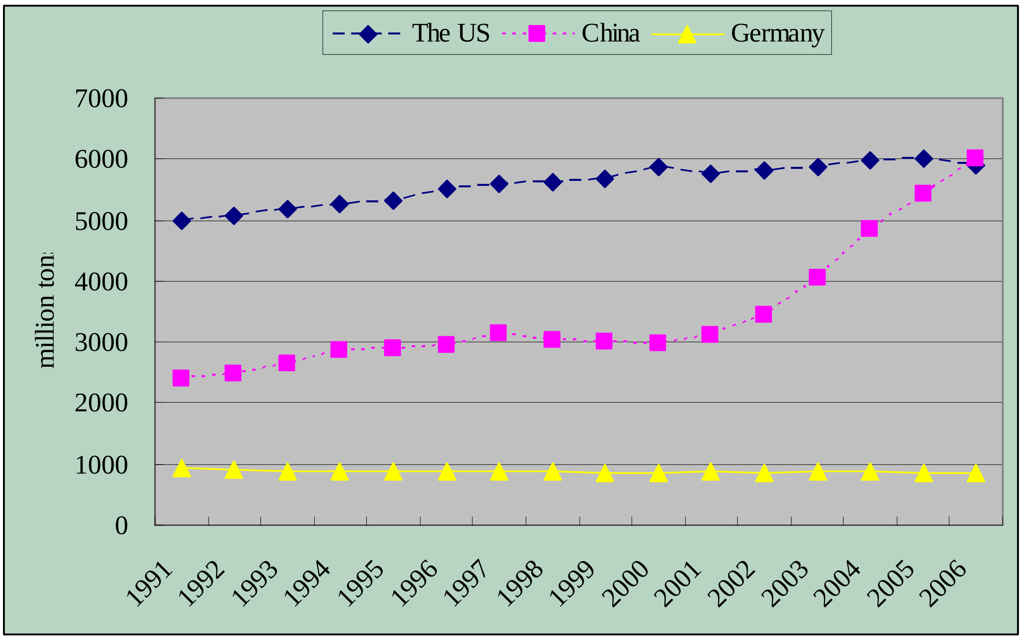


Figure .1. $CO_2$ emissions in the US, China and Germany (Million tons)

Source: *World Resources Institute*, Report various years.

## 3. The development of energy-environment-economy (3E) non-competitive input holding output model

Input-holding-output technique was proposed by Professor Xikang Chen based on basic input-output technology founded by Leontief. IHO model has the merit that not only the relationship between input and output is taken into account, but also the quantity relationship among holding, input and output. Later on, Chen proposed the extended non-competitive input-holding-output model that captures China's processing trade feature. In this model the production is divided into three parts: those for domestic demands (D), processing exports (P), and non-processing exports and other production of foreign-invested enterprises (N).

Table 1. Energy-environment-economy (3E) non-competitive input-output table

| Input \ Output | | | | Intermediate Consumption: Domestic (E, NE) | Intermediate Consumption: Exports Processing (E, NE) | Intermediate Consumption: Exports Non-processing (E, NE) | Intermediate Consumption: Subtotal | Final Consumption: Consumption | Final Consumption: Capital Formation | Final Consumption: Export | Final Consumption: Others | Final Consumption: Subtotal | Gross Output |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Input | Domestic product | Domestic | E | $X_E^{DD}$ $\begin{pmatrix}E^{DD}\\C^{DD}\end{pmatrix}$ | $X_E^{DP}$ $\begin{pmatrix}E^{DP}\\C^{DP}\end{pmatrix}$ | $X_E^{DN}$ $\begin{pmatrix}E^{DN}\\C^{DN}\end{pmatrix}$ | | $F_E^{DC}$ $\begin{pmatrix}E^{DC}\\C^{DC}\end{pmatrix}$ | $F_E^{DI}$ | 0 | | $F_E^{D}$ | $X_E^{D}$ $\begin{pmatrix}E^{D}\\C^{D}\end{pmatrix}$ |
| Input | Domestic product | Domestic | NE | $X_R^{DD}$ | $X_R^{DP}$ | $X_R^{DN}$ | | $F_R^{DC}$ | $F_R^{DI}$ | 0 | | $F_R^{D}$ | $X_R^{D}$ |
| Input | Domestic product | Exports Processing | E / NE | 0 | 0 | 0 | | 0 | 0 | $F^{PE}$ | | $F^{P}$ | $X^{P}$ |
| Input | Domestic product | Non-processing | E | $X_E^{ND}$ $\begin{pmatrix}E^{ND}\\C^{ND}\end{pmatrix}$ | $X_E^{NP}$ $\begin{pmatrix}E^{NP}\\C^{NP}\end{pmatrix}$ | $X_E^{NN}$ $\begin{pmatrix}E^{NN}\\C^{NN}\end{pmatrix}$ | | $F_E^{NC}$ $\begin{pmatrix}E^{NC}\\C^{NC}\end{pmatrix}$ | $F_E^{NI}$ | $F_E^{NE}$ | | $F_E^{N}$ | $X_E^{N}$ $\begin{pmatrix}E^{N}\\C^{N}\end{pmatrix}$ |
| Input | Domestic product | Non-processing | NE | $X_R^{ND}$ | $X_R^{NP}$ | $X_R^{NN}$ | | $F_R^{NC}$ | $F_R^{NI}$ | $F_R^{NE}$ | | $F_R^{N}$ | $X_R^{N}$ |
| Input | Imports | | E | $X_E^{MD}$ $\begin{pmatrix}E^{MD}\\C^{MD}\end{pmatrix}$ | $X_E^{MP}$ $\begin{pmatrix}E^{MP}\\C^{MP}\end{pmatrix}$ | $X_E^{MN}$ $\begin{pmatrix}E^{MN}\\C^{MN}\end{pmatrix}$ | | $F_E^{MC}$ $\begin{pmatrix}E^{MC}\\C^{MC}\end{pmatrix}$ | $F_E^{MI}$ | | | $F_E^{M}$ | $X_E^{M}$ $\begin{pmatrix}E^{M}\\C^{M}\end{pmatrix}$ |
| Input | Imports | | NE | $X_R^{MD}$ | $X_R^{MP}$ | $X_R^{MN}$ | | $F_R^{MC}$ | $F_R^{MI}$ | | | $F_R^{M}$ | $X_R^{M}$ |
| Input | Subtotal | | | | | | | | | | | | |
| Input | Value-added | | | $V^D$ | $V^P$ | $V^N$ | | | | | | | |
| Input | Total Input | | | $(X^D)^T$ | $(X^P)^T$ | $(X^N)^T$ | | | | | | | |
| Holding | Labors | | | $L^D$ | $L^P$ | $L^N$ | | | | | | | |
| Environment | $CO_2$ emissions | | | $Q^D$ | $Q^P$ | $Q^N$ | | | | | | | |

Superscript *D, P, N, M* denote domestic products, processing exports and non-processing exports and others, and imports;

*DD* means inputs and use within domestic products;

*DP* means domestic products used for processing exports production;

*DN* means domestic products used for non-processing exports production;

Subscript *E, R* means energy and non-energy sectors in production;

$X^D$ $X^P$ $X^N$ $X^M$ denote column vectors of gross outputs or imports;

$F^D$ $F^P$ $F^N$ $F^M$ denote column vectors of final demands;

$E^D$ $E^N$ $E^M$ denote column vectors of energy consumption;

$C^D$ $C^N$ $C^M$ denote column vectors of $CO_2$ emissions;

$X^{DD}$ $X^{DP}$ $X^{DN}$ denote intermediate input matrix for domestic products;

$X^{ND}$ $X^{NP}$ $X^{NN}$ denote intermediate input matrix for exports non-processing;

$X^{MD}$ $X^{MP}$ $X^{MN}$ denote intermediate input matrix for imports;

$F^{DC}$ $F^{DI}$ denote column vectors of consumption and capital formation for domestic products;

$F^{MC}$ $F^{MI}$ denote column vectors of consumption and capital formation for imports;

$F^{NC}$ $F^{NI}$ $F^{NE}$ denote column vectors of consumption, capital formation and exports for exports non-processing;

$F^{PE}$ denote column vectors of exports for exports processing;

$V^D$ $V^P$ $V^N$ denote row vectors of value-added;

$L^D$ $L^P$ $L^N$ denote row vectors of employment labors;

$Q^D$ $Q^P$ $Q^N$ denote row vectors of energy and $CO_2$ emissions.

To be clear, production for domestic demands means production activity that is exercised to satisfy domestic demands by enterprises; processing exports contain the production of processing with customer's imports (PCM) and processing with imported materials (PIM); non-processing exports production include the ordinary exports and the production by foreign-invested enterprises which is to meet the demand by domestic consumers. It is assumed that imports are only used as intermediate inputs to domestic production, rather than direct exporting. On the other hand, the production of domestic products and ordinary exports would not consume processing exports, which are only served as direct exports. For illustration, we show the energy-environment-economy (3E) non-competitive input-output model in Table 1.

### 3.1. Definitions of various coefficients

In row-wise of 3ENCIOM (see Table 1), the equations showing relationships of D、P、N and

M may be summarised as follows:

$$C^{DD} + C^{DP} + C^{DN} + C^{DC} = C^{D} \tag{1}$$

$$C^{ND} + C^{NP} + C^{NN} + C^{NC} = C^{N} \tag{2}$$

$$C^{MD} + C^{MP} + C^{MN} + C^{MC} = C^{M} \tag{3}$$

$$X^{DD} + X^{DP} + X^{DN} + F^{D} = X^{D} \tag{4}$$

$$F^{P} = X^{P} \tag{5}$$

$$X^{ND} + X^{NP} + X^{NN} + F^{N} = X^{N} \tag{6}$$

$$X^{MD} + X^{MP} + X^{MN} + F^{M} = X^{M} \tag{7}$$

For column-wise, equations are given by:

$$\mu X^{DD} + \mu X^{ND} + \mu X^{MD} + V^{D} = (X^{D})^{T} \tag{8}$$

$$\mu X^{DP} + \mu X^{NP} + \mu X^{MP} + V^{P} = (X^{P})^{T} \tag{9}$$

$$\mu X^{DN} + \mu X^{NN} + \mu X^{MN} + V^{N} = (X^{N})^{T} \tag{10}$$

Where， $\mu = (1,1,\cdots,1)$ .

Defining direct input coefficient as:

$$a_{ij}^{DD} = X_{ij}^{DD} / X_{j}^{D}, i, j = 1, 2, \cdots, n \tag{11}$$

Where, $a_{ij}^{DD}$ indicates direct consumption in the $i\,th$ sector per unit product for domestic demands in the $j\,th$ sector. Direct input coefficients matrix of D can be expressed as:

$$A^{DD} = [a_{ij}^{DD}] \equiv [X_{ij}^{DD} / X_{j}^{D}] \tag{12}$$

$$\begin{bmatrix} (I - A^{DD}) & -A^{DP} & -A^{DN} \\ 0 & I & 0 \\ -A^{ND} & -A^{NP} & (I - A^{NN}) \end{bmatrix} \begin{bmatrix} X^{D} \\ X^{P} \\ X^{N} \end{bmatrix} = \begin{bmatrix} F^{D} \\ F^{P} \\ F^{N} \end{bmatrix}$$

So,

$$\begin{bmatrix} X^{D} \\ X^{P} \\ X^{N} \end{bmatrix} = \begin{bmatrix} (I - A^{DD}) & -A^{DP} & -A^{DN} \\ 0 & I & 0 \\ -A^{ND} & -A^{NP} & (I - A^{NN}) \end{bmatrix}^{-1} \begin{bmatrix} F^{D} \\ F^{P} \\ F^{N} \end{bmatrix}$$

$$\bar{X} = (I - \bar{A})^{-1}\bar{F} \tag{13}$$

$$\bar{X} = \bar{B}\bar{F} \tag{14}$$

Where,

$$\bar{X} = \begin{bmatrix} X^D \\ X^P \\ X^N \end{bmatrix}, \quad \bar{A} = \begin{bmatrix} A^{DD} & A^{DP} & A^{DN} \\ 0 & 0 & 0 \\ A^{ND} & A^{NP} & A^{NN} \end{bmatrix}, \quad \bar{F} = \begin{bmatrix} F^D \\ F^P \\ F^N \end{bmatrix}$$

In the extended model, there is

$\bar{B} = (I - \bar{A})^{-1} = \begin{bmatrix} (I - A^{DD}) & -A^{DP} & -A^{DN} \\ 0 & I & 0 \\ -A^{ND} & -A^{NP} & (I - A^{NN}) \end{bmatrix}^{-1}$ denoted extended Leontief inverse matrix, or equivalently extended total requirements coefficient matrix.

By block matrixes, it reads,

$$\begin{bmatrix} (I - A^{DD}) & -A^{DP} & -A^{DN} \\ 0 & I & 0 \\ -A^{ND} & -A^{NP} & (I - A^{NN}) \end{bmatrix}^{-1} = \begin{bmatrix} B^{DD} & B^{DP} & B^{DN} \\ B^{PD} & B^{PP} & B^{PN} \\ B^{ND} & B^{NP} & B^{NN} \end{bmatrix}$$

Table 2. Direct input coefficients summary table

| | $D$ | $P$ | $N$ |
|---|---|---|---|
| $D$ | $A^{DD}$ | $A^{DP}$ | $A^{DN}$ |
| $E^{DD}$ | $H^{DD}$ | $H^{DP}$ | $H^{DN}$ |
| $P$ | $A^{PD} = 0$ | $A^{PP} = 0$ | $A^{PN} = 0$ |
| $N$ | $A^{ND}$ | $A^{NP}$ | $A^{NN}$ |
| $E^{ND}$ | $H^{ND}$ | $H^{NP}$ | $H^{NN}$ |
| $M$ | $A^{MD}$ | $A^{MP}$ | $A^{MN}$ |
| $E^{MD}$ | $H^{MD}$ | $H^{MP}$ | $H^{MN}$ |
| $V$ (Value-added) | $A_V^D$ | $A_V^P$ | $A_V^N$ |
| $L$ (Labor) | $A_L^D$ | $A_L^P$ | $A_L^N$ |
| $Q$ ($CO_2$) | $W^D$ | $W^P$ | $W^N$ |

Table 3. Total requirements coefficients summary table

| | D | P | N |
|---|---|---|---|
| D | $B^{DD}$ | $B^{DP}$ | $B^{DN}$ |
| $E^{DD}$ | $\overline{H}^{DD}=H^{DD}B^{DD}+H^{DN}B^{ND}$ | $\overline{H}^{DP}=H^{DD}B^{DP}+H^{DP}+H^{DN}B^{NP}$ | $\overline{H}^{DN}=H^{DD}B^{DN}+H^{DN}B^{NN}$ |
| P | $B^{PD}=0$ | $B^{PP}=I$ | $B^{PN}=0$ |
| N | $B^{ND}$ | $B^{NP}$ | $B^{NN}$ |
| $E^{ND}$ | $\overline{H}^{ND}=H^{ND}B^{DD}+H^{NN}B^{ND}$ | $\overline{H}^{NP}=H^{ND}B^{DP}+H^{NP}+H^{NN}B^{NP}$ | $\overline{H}^{NN}=H^{ND}B^{DN}+H^{NN}B^{NN}$ |
| M | $B^{MD}=A^{MD}B^{DD}+A^{MN}B^{ND}$ | $B^{MP}=A^{MD}B^{DP}+A^{MP}+A^{MN}B^{NP}$ | $B^{MN}=A^{MD}B^{DN}+A^{MN}B^{NN}$ |
| $E^{MI}$ | $H^{MD}=H^{MD}B^{DD}+H^{MN}B^{ND}$ | $H^{MP}=H^{MD}B^{DP}+H^{MP}+H^{MN}B^{NP}$ | $H^{MN}=H^{MD}B^{DN}+H^{MN}B^{NN}$ |
| V | $B_V^D=A_V^DB^{DD}+A_V^NB^{ND}$ | $B_V^P=A_V^DB^{DP}+A_V^P+A_V^NB^{NP}$ | $B_V^N=A_V^DB^{DN}+A_V^NB^{NN}$ |
| L | $B_L^D=A_L^DB^{DD}+A_L^NB^{ND}$ | $B_L^P=A_L^DB^{DP}+A_L^P+A_L^NB^{NP}$ | $B_L^N=A_L^DB^{DN}+A_L^NB^{NN}$ |
| W | $\overline{W}^D=W^DB^{DD}+W^NB^{ND}$ | $\overline{W}^P=W^DB^{DP}+W^P+W^NB^{NP}$ | $\overline{W}^N=W^DB^{DN}+W^NB^{NN}$ |

Where, $B^{DD}$, $B^{DP}$ and $B^{DN}$ give total requirements coefficient matrices in D per unit final demands by D, P and N; $B^{PD}$, $B^{PP}$ and $B^{PN}$ stand for total demand coefficient matrices in P per unit final demands by D, P and N; $B^{ND}$, $B^{NP}$ and $B^{NN}$ are similarly defined, i.e. total demands coefficient matrices in N per unit final demands by D, P and N. To summarise，we collect all the coefficients and put them together in Tables 2 and 3.

**3.2. Model set-up**

The final demands, by different purposes, can be divided into four categories: domestic final demands $F^D$; final demands produced by non-processing exports and others $(F^N - F^{NE})$; processing exports $F^P$ and non-processing exports $F^{NE}$.

By basic input-output formula, we have $X=(I-A)^{-1}F=BF$

Fossil fuel combustion-related $CO_2$ emissions for final demands can be defined as

$$C = WB(F^D + (F^N - F^{NE}) + F^P + F^{NE}) \quad (16)$$

So, $C^{FD} = (\overline{W}^{DD} + \overline{W}^{ND})F^D = [(W^{DD}B^{DD} + W^{DN}B^{ND}) + (W^{ND}B^{DD} + W^{NN}B^{ND})]F^D$

$$C^{NNE} = (\overline{W}^{DN} + \overline{W}^{NN})(F^N - F^{NE})$$
$$= [(W^{DD}B^{DN} + W^{DN}B^{NN}) + (W^{ND}B^{DN} + W^{NN}B^{NN})](F^N - F^{NE})$$

$$C^{FP} = (\overline{W}^{DP} + W^{PP} + \overline{W}^{NP})F^P$$
$$= [(W^{DD}B^{DP} + W^{DP} + W^{DN}B^{NP}) + W^{PP} + (W^{ND}B^{DP} + W^{NP} + W^{NN}B^{NP})]F^P \quad (15)$$

$$C^{FN} = (\overline{W}^{DN} + \overline{W}^{NN})F^{NE}$$
$$= [(W^{DD}B^{DN} + W^{DN}B^{NN}) + (W^{ND}B^{DN} + W^{NN}B^{NN})]F^{NE}$$

## 4. Empirical results

The energy, environmental and economic statistics are taken from four main sources: extended input-output tables of 2002 and 2007 (Preliminary table) from National Bureau of Statistics; China's Energy Statistical Yearbooks, 2008 and 2009. The emissions for both fossil fuel combustion and industrial processes were calculated using the IPCC 2006 reference approach.

1) Calculation of $CO_2$ emissions. Peters et al. calculated $CO_2$ emissions up to 3406.3 million tons in 2002 by industrial fuels combustion. However, the estimation by *World Resources Institution* was reported to be 3440.6 million tons in the very year. The results in this paper based on 3ENCIOM are roughly 2700 million tons, since only fossil fuel combustion is taken into consideration which accounts for 78% of gross emissions (73.79% from IPCC report for 2004). Table 4 shows the $CO_2$ emissions reckoned by using 3ENCIOM for all sectors in 2007.

$CO_2$ emissions of fossil energy were 4696.7 million tons, in which 81% emissions can be ascribed to industrial production. If the proportion of fossil fuel combustion-related $CO_2$ emissions in 2002 were used, the number would have been 6022.65 million tons in 2007. In our estimation, the household emissions only account for 4.43%, while 95.5% of 4489.56 million tons are yielded for production. So, in this paper we focus on production-related emissions. In Table 4, there are some sectors with most emissions: *Thermal power production and supply*, *Ferrous metal smelting* *and pressing*, *Transport, storage and post services*, *Nonmetallic mineral products*, *Chemical materials and products*, *Petroleum and nuclear processing*, all together they take 75% emissions.

Table 4. $CO_2$ emissions in all sectors in 2007 (Million tons)

| Sectors | Emissions | Share | Sectors | Emissions | Share |
|---|---|---|---|---|---|
| 1 | 131.50 | 2.80% | 24 | 154.36 | 3.29% |
| 2 | 30.35 | 0.65% | 25 | 5.45 | 0.12% |
| 3 | 16.56 | 0.35% | 26 | 3.56 | 0.08% |
| 4 | 0.00 | 0.00% | 27 | 3.74 | 0.08% |
| 5 | 1581.24 | 33.66% | 28 | 2.75 | 0.06% |
| 6 | 138.08 | 2.94% | 29 | 355.42 | 7.57% |
| 7 | 81.40 | 1.73% | 30 | 929.68 | 19.79% |
| 8 | 72.86 | 1.55% | 31 | 45.34 | 0.97% |
| 9 | 16.52 | 0.35% | 32 | 10.80 | 0.23% |
| 10 | 109.24 | 2.33% | 33 | 26.12 | 0.56% |
| 11 | 6.59 | 0.14% | 34 | 12.88 | 0.27% |
| 12 | 2.75 | 0.06% | 35 | 18.57 | 0.40% |
| 13 | 9.70 | 0.21% | 36 | 6.48 | 0.14% |
| 14 | 34.75 | 0.74% | 37 | 5.98 | 0.13% |
| 15 | 11.96 | 0.25% | 38 | 0.92 | 0.02% |
| 16 | 1.98 | 0.04% | 39 | 5.83 | 0.12% |
| 17 | 33.41 | 0.71% | 40 | 0.75 | 0.02% |
| 18 | 4.85 | 0.10% | 41 | 63.23 | 1.35% |
| 19 | 2.45 | 0.05% | 42 | 384.19 | 8.18% |
| 20 | 7.53 | 0.16% | 43 | 52.81 | 1.12% |
| 21 | 30.73 | 0.65% | 44 | 74.01 | 1.58% |
| 22 | 1.23 | 0.03% | Rural | 98.50 | 2.10% |
| 23 | 1.03 | 0.02% | Urban | 109.61 | 2.33% |

In Table 5, $CO_2$ emissions for domestic demands production are accounted of 71.34%, while non-processing exports take 26.81%. It would consume many domestic products to satisfy domestic demands production, while much less for exports production case. In consequence, we see that it yields more $CO_2$ emissions when domestic products are produced than exports do. The domestic and imported products used for production of non-processing exports generate 95.57% and 71.86% $CO_2$ emissions of their total inputs, respectively. Thus, the domestic demands should be held most responsibility for $CO_2$ emissions while the exports take a relatively minor position. Given that, it is worth noting that emissions by exports production are still non-trivial, taking proportion of 28.66%. In other words, there is nearly 30% $CO_2$ emissions are yielded due to the production to satisfy foreign consumers' demands. Hence, this part should be ascribed to foreign countries that consume these products.

Table 5. $CO_2$ emissions and share by different production mode in 2002 (Million tons)

| | D | P | N |
|---|---|---|---|
| D | 1788.93 | 4.56 | 307.17 |
| % | 85.16% | 0.22% | 14.62% |
| P | 0 | 0 | 0 |
| % | 0.00% | 0.00% | 0.00% |
| N | 0.00 | 12.34 | 265.93 |
| % | 0.00% | 4.43% | 95.57% |
| M | 10.57 | 29.82 | 103.14 |
| % | 7.37% | 20.77% | 71.86% |
| Emissions | 1799.51 | 46.71 | 676.24 |
| % | 71.34% | 1.85% | 26.81% |

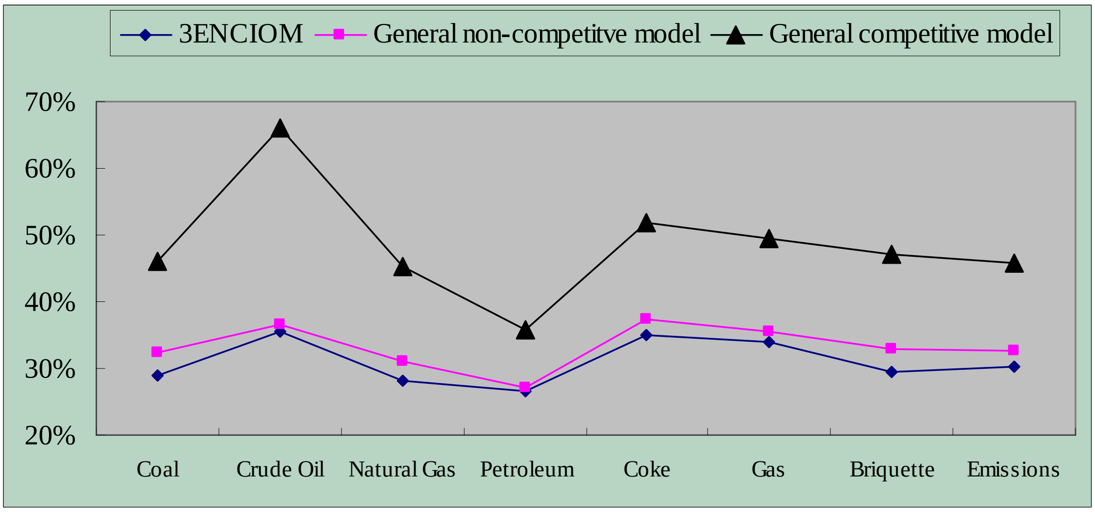


Figure 2. The shares of $CO_2$ emissions yielded by exports production using different table in 2007[1]

2) Analysis and comparison. It is possible to conduct various estimations by using different input-output tables, such as ordinary competitive, non-competitive or extended non-competitive table. Figure 2 illustrates $CO_2$ emissions caused by exports by applying different tables. The results would be overestimated in different magnitude when calculated by normal competitive and non-competitive table. Applying extended non-competitive table of 2007, we get 30.52% emissions by manufacturing exports (higher than Steve Davis' estimation 22.5%). However, this figure would be 32.55% if calculated by non-competitive table, which is an overestimation of 8%.

[1] The primary energy and secondary energy are distinguished, so there is no emissions from thermal power and heat any more in this setting.

The share would even be 45.8% if calculated by competitive table, which is overstated by 52%. Apparently, the competitive table would yield the largest exaggeration. Taking into account of emissions from different energy types (coal, gas, electricity etc.), there is 35.5% $CO_2$ emissions due to crude oil in producing exports, but 66% and 36.5% in other tables, which would be overestimated by 85.8% and 2.7%, respectively. Other types are generally overstated by 10%.

3) Emissions embodied in imports and exports. Since 1997, China has become a net direct import country of energy. Specifically, net direct imports of energy were quickly increasing from 14.52 million *tce* to 246.06 million *tce* from 2001 to 2007. Figure 3 shows the direct and indirect import and export of energy consumption and emissions. China is still a net (direct and indirect) import country of energy. By 3ECNIOM, it is estimated that the net direct import of energy in production-related is 238.3 million *tce*, and 497.6 million tons net direct import of emissions. Though indirect imports of energy and emissions are smaller than those of export, total energy consumption and emissions are still net import, precisely, 139.24 million *tce* of energy consumption and 324.9 million tons of emissions.

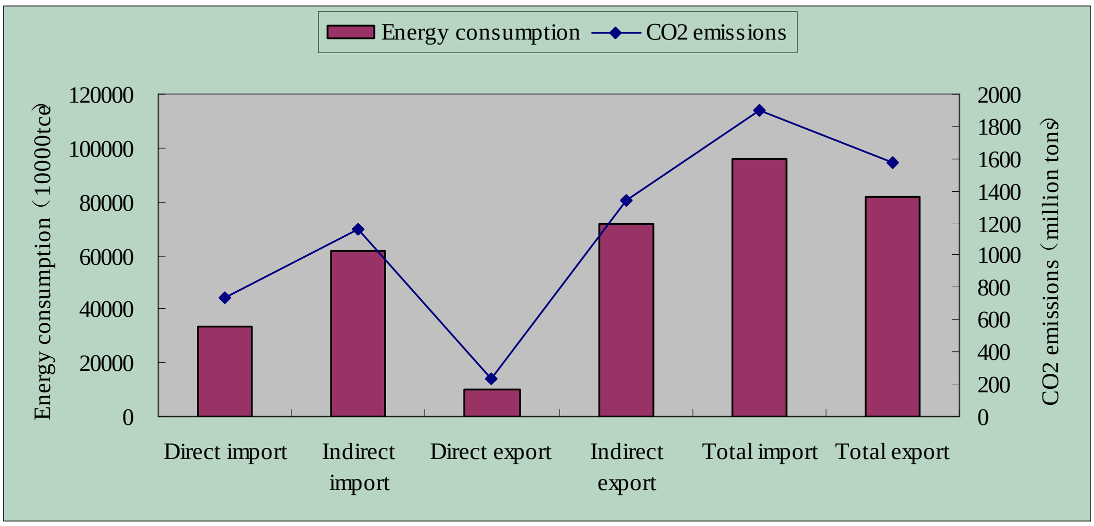


Figure 3. Energy consumption and emissions of imports and exports in 2007

Table 6 illustrates indirect emissions embodied in import and export in all sectors. The mode of processing export yields less emissions than others, which accounts for 6.11%. However, there are 25% emissions yielded by non-processing export and import. Obviously, processing export yields very limited $CO_2$ emissions and worthwhile to promote from such aspect. By industry, main emission sectors are *Electronic and telecommunication equipment* and *Wholesale, retail trade* *services, accommodation and food serving services*, total of those emissions account for 60% in indirect emissions of processing export. For non-processing export, main emitting sectors are *Ferrous metal smelting and pressing*, *Textile, Transport, storage and post services, Chemical materials and products* and *General and special industrial machinery*, and in total they account for 56% of indirect emissions of non-processing export. For imports, main emitting sectors are *Chemical materials and products*, *Ferrous metal smelting and pressing*, *General and special industrial machinery* and *Electronic and telecommunication equipment*, and they account for 50% of indirect emissions of imports.

Table 6. $CO_2$ emissions caused by imports and exports (Million tons)

| Sectors | Processing | Non-Pro. | Import | Sectors | Processing | Non-Pro. | Import |
|---|---|---|---|---|---|---|---|
| 1 | 0.00% | 0.73% | 0.49% | 18 | 1.36% | 7.71% | 14.24% |
| 2 | 0.00% | 0.35% | 8.90% | 19 | 0.38% | 5.16% | 1.20% |
| 3 | 0.00% | 0.00% | 0.12% | 20 | 1.15% | 23.75% | 14.92% |
| 4 | 0.00% | 0.00% | 0.00% | 21 | 3.45% | 5.64% | 1.28% |
| 5 | 0.47% | 0.97% | 0.15% | 22 | 1.57% | 6.84% | 11.80% |
| 6 | 0.89% | 0.79% | 2.05% | 23 | 1.86% | 2.83% | 4.03% |
| 7 | 0.21% | 0.32% | 0.58% | 24 | 5.80% | 5.77% | 5.59% |
| 8 | 0.02% | 0.00% | 0.00% | 25 | 36.50% | 2.85% | 10.37% |
| 9 | 0.00% | 0.00% | 0.00% | 26 | 5.69% | 0.94% | 2.85% |
| 10 | 0.00% | 0.58% | 1.54% | 27 | 0.23% | 1.39% | 1.39% |
| 11 | 0.05% | 0.16% | 8.69% | 28 | 0.00% | 0.00% | 0.00% |
| 12 | 0.30% | 0.31% | 0.48% | 29 | 0.00% | 0.88% | 0.43% |
| 13 | 0.67% | 1.32% | 1.23% | 30 | 3.88% | 8.06% | 2.25% |
| 14 | 2.98% | 9.32% | 0.90% | 31 | 23.49% | 2.08% | 0.34% |
| 15 | 2.74% | 4.29% | 0.51% | 32 | 0.00% | 3.26% | 2.40% |
| 16 | 2.13% | 2.16% | 0.29% | Subtotal | 273.74 | 1064.96 | 1165.955 |
| 17 | 4.16% | 1.56% | 1.00% | Share | 6.11% | 23.77% | 25.89% |

## 5. Conclusion

For China in 2002, Weber et al. reported that 21% emissions are due to exports production. In contrary, this percentage is estimated to 12.6% by Pei who applied extended input-output model, and he argued that emissions by exports were overestimated by no less than 60% if ordinary IO model is used. However, this paper indicates that the magnitude of overestimation is about 10%. The reason would be related to the different data used for energy consumption estimation.

To conclude, we get the following main results:

Firstly, processing export is a low-emission type. This paper shows that only 1.85% emissions can be ascribed to processing export production, given that processing export plays dominant role in exports for China. What's more, processing export is a low-consumption, low-emission, and low-pollution production mode.

Secondly, export takes important position for emissions, but the most responsibility should be held by domestic consumption. Given that, there is nearly 30% $CO_2$ emissions are generated due to the production to satisfy foreign consumers' demands. Undoubtedly, this part should be ascribed to foreign countries that consume the exports.

Thirdly, energy-related $CO_2$ emissions are not identical concepts to total emissions. Peters et al. considered that $CO_2$ emissions generated by production and household were equal to total emission. In fact, energy-related $CO_2$ emissions of fuels take roughly 80% of the total emissions.

Fourthly, magnitude of overestimation by using general non-competitive model is not larger than by using extended input-output model. This paper concludes that the degree is only 9% rather than 60%. Moreover, basic energy data of Peters et al. research is energy using, the number of which is larger than that of energy consumption.

Finally and most importantly, though indirect imports of energy and emissions are smaller than those of exports, in total energy consumption and emissions are still net import. In other words, from the perspective of net imports, energy consumption and $CO_2$ emissions in China are still dedicated to satisfy domestic demands instead of foreign consumers.

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Appendix: Sector classifications

| | Sectors | | Sectors |
|---|---|---|---|
| 1 | Coal mining and washing | 17 | Papermaking and paper products |
| 2 | Crude oil mining | 18 | Chemical materials and products |
| 3 | Natural gas mining | 19 | Nonmetallic mineral products |
| 4 | Hydro and Nuclear Power production and supply | 20 | Ferrous metal smelting and pressing |
| 5 | Thermal power production and supply | 21 | Metal products |
| 6 | Petroleum and nuclear processing | 22 | General and special industrial machinery |
| 7 | Coking | 23 | Transport equipment |
| 8 | Steam and Hot water production and supply | 24 | Electric equipment and machinery |
| 9 | Gas production and supply | 25 | Electronic and telecommunication equipment |
| 10 | Agriculture | 26 | Instruments, meters, cultural and office machinery |
| 11 | Ferrous metal ore mining | 27 | Other manufacturing products |
| 12 | Non-ferrous metal ore mining | 28 | Water production and supply |
| 13 | Food processing and manufacturing | 29 | Construction |
| 14 | Textile | 30 | Transport, storage and post services |
| 15 | Wearing apparel | 31 | Wholesale, retail trade services, accommodation and food serving services |
| 16 | Sawmills and furniture | 32 | Other services |

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