energies

Sources of China's Fossil Energy Use Change

Yawen HAN[1,2,4], Shigemi KAGAWA[*3] , Fumiya Nagashima[2] and Keisuke NANSAI[5]

[1] School of Earth Sciences and Resources, China University of Geosciences, Beijing. 29 Xueyuan Road, Haidian District, Beijing 100083, China
[2] Graduate School of Economics, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan
[3] Faculty of Economics, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan
[4] Research Center for Strategy of Global Mineral Resources, Chinese Academy of Geological Sciences, 26 Baiwanzhuang Street, Xicheng District, Beijing 100037, China
[5] National Institute for Environmental Studies of Japan, 16-2 Onokawa, Tsukuba, Ibaraki 305-0053, Japan
* Corresponding author: kagawa@econ.kyushu-u.ac.jp

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Table S1. Results of Industrial sectors classification.

Sectors of energy inventory	Sectors of Chinese MRIO	Aggregated sectors	No.
Farming, Forestry, Animal Husbandry, Fishery & Water Conservancy Logging and Transport of Wood and Bamboo	Agriculture	Agriculture	1
Coal Mining and Dressing	Coal mining	Coal mining	2
Petroleum and Natural Gas Extraction	Petroleum and gas	Crude oil	3
		Natural gas	4
Ferrous Metals Mining and Dressing Nonferrous Metals Mining and Dressing	Metal mining	Metal mining	5
Nonmetal Minerals Mining and Dressing Other Minerals Mining and Dressing	Nonmetal mining	Nonmetal mining	6
Food Processing Food Production Beverage Production	Food processing and tobaccos	Food processing and tobaccos	7

Tobacco Processing			
Textile Industry	Textile	Textile	8
Garments and Other Fiber Products Leather, Furs, Down and Related Products	Clothing, leather, fur, etc.	Clothing, leather, fur, etc.	9
Timber Processing, Bamboo, Cane, Palm & Straw Products Furniture Manufacturing	Wood processing and furnishing	Wood processing and furnishing	10
Papermaking and Paper Products Printing and Record Medium Reproduction Cultural, Educational and Sports Articles	Paper making, printing, stationery, etc.	Paper making, printing, stationery, etc.	11
Petroleum Processing and Coking	Petroleum refining, coking, etc.	Petroleum refining	12
		Coking products	13
Raw Chemical Materials and Chemical Products Medical and Pharmaceutical Products Chemical Fiber Rubber Products Plastic Products	Chemical industry	Chemical industry	14
Nonmetal Mineral Products	Nonmetal products	Nonmetal products	15
Smelting and Pressing of Ferrous Metals Smelting and Pressing of Nonferrous Metals	Metallurgy	Metallurgy	16
Metal Products	Metal products	Metal products	17
Ordinary Machinery Equipment for Special Purpose	General and specialist machinery	General and specialist machinery	18
Transportation Equipment	Transport equipment	Transport equipment	19
Electric Equipment and Machinery	Electrical equipment	Electrical equipment	20
Electronic and Telecommunications Equipment	Electronic equipment	Electronic equipment	21
Instruments, Meters Cultural and Office Machinery	Instrument and meter	Instrument and meter	22
Other Manufacturing Industry Scrap and waste	Other manufacturing	Other manufacturing	23
Electric Power, Steam and Hot Water Production and Supply	Electricity and hot water production and supply	Electricity and hot water production and supply	24
Gas Production and Supply	Gas and water production and supply	Oil gas production and supply	25

Tap Water Production and Supply		Coal gas production and supply	26
		Tap water production and supply	27
Construction	Construction	Construction	28
Transport, Storage, Postal & Telecommunications Services	Transport and storage	Transport and storage	29
Wholesale, Retail Trade and Catering Service	Wholesale and retailing	Wholesale and hotel	30
	Hotel and restaurant		
Other	Leasing and commercial services	Other services	
	Scientific research		31
	Other services		

Table S2. Energy grouping.

Energy groups	Items
Coal mining	Raw Coal, Cleaned Coal, Other Washed Coal
Crude oil	Crude Oil
Natural gas	Natural Gas
Petroleum refining	Gasoline, Kerosene, Diesel Oil，Fuel Oil, Other Petroleum Products
Coking products	Briquettes, Coke, Other Coking Products
Electricity and hot water production and supply	Heat, Electricity
Oil gas production and supply	Refinery Gas, LPG.
Coal gas production and supply	Coke Oven Gas, Other Gas

Table S3. Price deflaters for sectors.

Sectors	Fixed base price index 2007=100	
	2007	2012
Agriculture	100	147.76
Coal mining	100	154.09
Crude oil	100	137.91
Natural gas	100	137.91
Metal mining	100	121.03
Nonmetal mining	100	130.29
Food processing and tobaccos	100	117.54
Textile	100	116.18
Clothing, leather, fur, etc.	100	109.79
Wood processing and furnishing	100	110.25
Paper making, printing, stationery, etc.	100	107.05
Petroleum refining	100	150.72
Coking products	100	150.72
Chemical industry	100	109.57
Nonmetal products	100	116.07
Metallurgy	100	103.43
Metal products	100	108.32

General and specialist machinery	100	106.29
Transport equipment	100	101.57
Electrical equipment	100	99.60
Electronic equipment	100	88.91
Instrument and meter	100	98.47
Other manufacturing	100	109.97
Electricity and hot water production and supply	100	111.97
Oil gas production and supply	100	121.38
Coal gas production and supply	100	121.38
Tap water production and supply	100	121.38
Construction	100	126.54
Transport and storage	100	106.41
Wholesale and hotel	100	125.78
Other services	100	117.47

Table S4. Abbreviation of each province.

Province	Abbreviation	Province	Abbreviation	Province	Abbreviation
Beijing	BJ	Zhejiang	ZJ	Hainan	HAN
Tianjin	TJ	Anhui	AH	Chongqing	CQ
Hebei	HB	Fujian	FJ	Sichuan	SC
Shanxi	SX	Jiangxi	JX	Yunnan	YN
Inner Mongolia	IM	Shandong	SD	Guizhou	GZ
Liaoning	LN	Henan	HEN	Shaanxi	SHX
Jilin	JL	Hubei	HUB	Gansu	GS
Heilongjiang	HLJ	Hunan	HUN	Qinghai	QH
Shanghai	SH	Guangdong	GD	Ningxia	NX
Jiangsu	JS	Guangxi	GX	Xinjiang	XJ

Supplementary method S1: Decomposition of the changes in the imported energy of China during 2007 to 2012

The change of the imported energy during 2007 to 2012 can be calculated by the following:

$$\Delta \mathbf{h} = \mathbf{h_{12}} - \mathbf{h}_{07} = \mathbf{M}_{12}\mathbf{L}_{12}\mathbf{f}_{12} - \mathbf{M}_{07}\mathbf{L}_{07}\mathbf{f}_{07} \quad \text{(S-1)}$$

Thus, the driving factors are final demand effect $\Delta\mathbf{h}_F$, Leontief effect $\Delta\mathbf{h}_L$ and import structure effect $\Delta\mathbf{h}_M$.

$$\Delta\mathbf{h}_F = \frac{\mathbf{1}}{6}(\mathbf{2M}_{07}\mathbf{L}_{07}\Delta\mathbf{f} + \mathbf{M}_{07}\mathbf{L}_{12}\Delta\mathbf{f} + \mathbf{M}_{12}\mathbf{L}_{07}\Delta\mathbf{f} + \mathbf{2M}_{12}\mathbf{L}_{12}\Delta\mathbf{f}) \quad \text{(S-2)}$$

$$\Delta\mathbf{h}_L = \frac{\mathbf{1}}{6}(\mathbf{2M}_{07}\Delta\mathbf{L}\mathbf{f}_{07} + \mathbf{M}_{07}\Delta\mathbf{L}\mathbf{f}_{12} + \mathbf{M}_{12}\Delta\mathbf{L}\mathbf{f}_{07} + \mathbf{2M}_{12}\Delta\mathbf{L}\mathbf{f}_{12}) \quad \text{(S-3)}$$

$$\Delta\mathbf{h}_M = \frac{\mathbf{1}}{6}(\mathbf{2}\Delta\mathbf{M}\mathbf{L}_{07}\mathbf{f}_{07} + \Delta\mathbf{M}\mathbf{L}_{07}\mathbf{f}_{12} + \Delta\mathbf{M}\mathbf{L}_{12}\mathbf{f}_{07} + \Delta\mathbf{M}\mathbf{L}_{12}\mathbf{f}_{12}) \quad \text{(S-4)}$$

The decomposition of Leontief effect $\Delta\mathbf{h}_L$ is the same with that of $\Delta\mathbf{d}_L$, we get

$$\Delta\mathbf{h}_L = \frac{\mathbf{1}}{6}(\mathbf{2M}_{07}\Delta\mathbf{L}\mathbf{f}_{07} + \mathbf{M}_{07}\Delta\mathbf{L}\mathbf{f}_{12} + \mathbf{M}_{12}\Delta\mathbf{L}\mathbf{f}_{07} + \mathbf{2M}_{12}\Delta\mathbf{L}\mathbf{f}_{12}) \quad \text{(S-5)}$$

$\frac{\mathbf{1}}{6}(\mathbf{2M}_{07}\Delta\mathbf{L}_G\mathbf{f}_{07} + \mathbf{M}_{07}\Delta\mathbf{L}_G\mathbf{f}_{12} + \mathbf{M}_{12}\Delta\mathbf{L}_G\mathbf{f}_{07} + \mathbf{2M}_{12}\Delta\mathbf{L}_G\mathbf{f}_{12})$ (Trade effect $\Delta\mathbf{h}_T$) Technology effect

$$+\frac{1}{6}(2\mathbf{M}_{07}\Delta\mathbf{L}_W\mathbf{f}_{07}+\mathbf{M}_{07}\Delta\mathbf{L}_W\mathbf{f}_{12}+\mathbf{M}_{12}\Delta\mathbf{L}_W\mathbf{f}_{07}+2\mathbf{M}_{12}\Delta\mathbf{L}_W\mathbf{f}_{12})\ \text{(Non-energy input effect}\ \Delta\mathbf{h}_G)$$

$$+\frac{1}{6}(2\mathbf{M}_{07}\Delta\mathbf{L}_C\mathbf{f}_{07}+\mathbf{M}_{07}\Delta\mathbf{L}_C\mathbf{f}_{12}+\mathbf{M}_{12}\Delta\mathbf{L}_C\mathbf{f}_{07}+2\mathbf{M}_{12}\Delta\mathbf{L}_C\mathbf{f}_{12})\ \text{(Energy composition effect}\ \Delta\mathbf{h}_C)$$

$$+\frac{1}{6}(2\mathbf{M}_{07}\Delta\mathbf{L}_E\mathbf{f}_{07}+\mathbf{M}_{07}\Delta\mathbf{L}_E\mathbf{f}_{12}+\mathbf{M}_{12}\Delta\mathbf{L}_E\mathbf{f}_{07}+2\mathbf{M}_{12}\Delta\mathbf{L}_E\mathbf{f}_{12})\ \text{(Energy level effect}\ \Delta\mathbf{h}_E\ )$$

Supplementary method S2: Constructing hybrid MRIO tables of China

1. Adjustment of Chinese monetary MRIO

In order to compile hybrid MRIO tables, the monetary flows in the energy rows of monetary MRIO table should be replaced with physical flows. In the published Chinese monetary MRIO tables, there are five energy sectors:

a. Coal mining,
b. Petroleum and gas,
c. Petroleum refining, coking (etc.),
d. Electricity and hot water production and supply,
e. Gas and water production and supply.

Some energy sectors can produce more than on kind of energy products. Hence, we distribute Petroleum and gas to Crude oil and Natural gas; distribute Petroleum refining, coking (etc.) to Petroleum products and Coking products; distribute Gas and water production and supply to Oil gas production and supply, Coal gas production and supply and Water production and supply through the consideration of "Output value" as the weight factors. Finally, we get Chinese monetary MRIO tables with 8 energy sectors:

a. Coal mining,
b. Crude oil,
c. Natural gas,
d. Petroleum refining,
e. Coking products,
f. Electricity and hot water production and supply,
g. Oil gas production and supply,
h. Coal gas production and supply.

The output value is estimated by the product of the current prices of the energy goods and the according yields. We collect the energy prices from Win.d database[1], provincial primary energy yields from provincial energy balance table[2,3], and the secondary energy yields from provincial energy inventory of CEADs[4].

2. Adjustment of Chinese provincial energy inventory

Chinese provincial energy inventory provides energy consumption by 20 energy types. In order to be consistent with the 8 energy sectors of monetary MRIO, we classify the 20 energy types into the corresponding 8 energy groups (Table S1) according to the definition of each energy sector [5]. The unit of the energy consumption is converted to the standard coal equivalent. The conversion factors from physical units to coal equivalent can be obtained from the China energy statistical yearbook [6].

Here, we get the provincial energy inventory by 8 energy types and it provides the final energy consumption of 45 industrial sectors as well as consumer sectors: urban and rural, and the energy input and output in the process of transform. We consider both energy input of the transform and final energy consumption when calculating the energy consumption of a specific sector. At the same time, we need distribute the original five energy sectors into the 8 energy sectors we have defined. Here, we set the provincial energy inventory of Tianjin as an example.

The energy input and output in transform process in Tianjin include Thermal Power, Heating Supply, Coal Washing, Coking, Petroleum Refineries, Gas Works and Briquettes, seven categories in total. We only consider the input (The value of the energy input is positive and the value of the output is negative). The energy input to the Thermal Power and Heating Supply are added to the final energy consumption in Electricity and hot water production and supply; energy input to the Coal Washing

are added to the final energy consumption in Coal mining; energy input to Coking, Petroleum Refineries, and Briquettes are added to the final energy consumption in Petroleum refining, coking (etc.); energy input to Gas Works are added to the final energy consumption in Gas production and supply. Thus, we get the total energy consumption in 45 industrial sectors by 8 energy types.

When distributing the 5 energy sectors in provincial energy inventory into 8 energy sectors, we allocate the energy consumption of Petroleum and gas to Crude oil and Natural gas based on value of output as weight factor. For instance, the energy consumption of Petroleum and gas in Tianjin in 2007 is showed at Table S7. The weight factor of Crude oil is 0.984 and the weight factor of Natural gas is 0.016 (According to the author's calculations). Thus, energy consumption of Crude oil and Natural gas can be estimated (Table S5)

Table S5. Energy consumption of Petroleum and gas and its distribution in Tianjin (10^4 tonnes).

Energy sectors	Coal	Crude oil	Natural gas	Electricity and heat	Petroleum products	Coal products	Oil based gas	Coal based gas
Petroleum and gas	10.29	16.71	13.42	14.19	2.65	0.00	0.17	0.00
Crude oil	10.13	16.44	13.21	13.96	2.61	0.00	0.167	0.00
Natural gas	0.16	0.27	0.21	0.23	0.04	0.00	0.003	0.00

Similarly, energy consumption of sector Petroleum refining, coking (etc.) are allocated to Petroleum refining and Coal products. We suppose Petroleum refining consumes crude oil, natural gas, petroleum products and oil based gas while Coal products consumes coal, coal products and coal based gas. The allocation of electricity and heat consumption is weighted by the yields of Coal products and Petroleum refining in the region. For example, the coal products produced in Tianjin are 3.269 million tons of standard coal equivalents, and the petroleum products are 10.909 million tons of standard coal equivalents[4]. It can be seen that the weight of electricity and heat allocated to Coking products is 0.23, and the weight assigned to Petroleum refining is 0.77. The energy consumptions of sectors Coking products and Petroleum refining are showed in Table S6.

Table S6. Energy consumption of Petroleum refining, coking (etc.), and its distribution in Tianjin (10^4 tonnes).

Energy groups	Coal mining	Crude oil	Natural gas	Electricity and heat	Petroleum products	Coal products	Oil based gas	Coal based gas
Petroleum refining, coking (etc.),	414.77	1323.17	0.00	55.80	204.54	0.00	46.33	6.52
Petroleum products	0.00	1323.17	0.00	42.97	204.54	0.00	46.33	0.00
Coal products	414.77	0.00	0.00	12.83	0.00	0.00	0.00	6.52

Energy consumption of Gas production and supply is allocated to sectors Oil gas production and supply and Coal gas production and supply. It is assumed that Coal gas production and supply consumes only coal-based energy, while Oil gas production and supply consumes only oil/natural gas-based energy. The distribution of electricity and heat is distributed according to the physical quantity of coal-based gas and oil-based gas produced in the region. Still taking Tianjin as an example, the oil based gas produced in Tianjin is 1.20 million tons of standard coal equivalent, and the coal based gas is 0.08 million tons of standard coal equivalent [4].It can be seen that the weight of electricity allocated to Oil gas production and supply is 0.93, and the weight assigned to Coal gas production and supply is 0.07. Thus, the consumptions of various types of energy by Oil gas production and supply and Coal gas production and supply are showed in Table S7.

Table S7. Energy consumption of Gas and water production and supply, and its distribution in Tianjin (10^4 tonnes).

Energy groups	Coal mining	Crude oil	Natural gas	Electricity and heat	Petroleum products	Coal products	Oil based gas	Coal based gas
Gas production and supply	0.14	0.00	0.00	0.97	0.05	0.00	0.00	0.00
Oil gas production and supply	0.00	0.00	0.00	0.90	0.05	0.00	0.00	0.00
Coal gas production and supply	0.14	0.00	0.00	0.07	0.00	0.00	0.00	0.00

By analogy, we have treated the energy inventory table of each province with the above-mentioned way. After that we can get the consumption of 8 types of energy in industrial departments (including 8 energy departments) and 2 living departments in 30 provinces (cities).

In addition, we notice that energy consumed by sectors in each province comes from 30 provinces of China and imports. Therefore, we should separate the import portion of energy consumption from the total consumption. From the energy balance sheet[2,3], we can obtain the import volume of each energy in each province. We assume that the energy k imported to the province is consumed by each sector according to the proportion of energy k consumption of each sector in this province. Thus, the import portion of energy k consumed in sectors of certain province can be calculated. Finally, we use the total energy consumption of each sector minus the part of the energy consumption from import, and then we get the part of domestically produced the energy consumption.

In summary, we can obtain the energy produced by the domestic energy sector k consumed in the industrial sector or the living sector j of the province s, TE_{kj}^{s}, as well as import energy k consumed in the industrial sector or the living sector j of the province s, $IMTE_{kj}^{s}$.

In order to be consistent with the form of the MRIO table, we also considered the inventory changes. From the energy balance sheet[2,3], we can obtain the inventory changes of different energy types in a province. Since the energy comes from domestic and import, the inventory change is also distributed to the inventory brought from the domestic production and the inventory brought from the import. The weight is the proportion of domestic energy (summation of the province's primary energy production, recycling energy and transfer from other provinces) and imported energy (imported energy and the amount of fuel for Chinese ships and planes got in foreign countries). From this we can get $TE_{kj_V}^{s}$, $IMTE_{kj_V}^{s}$, representing the inventory changes in province s produced by the domestic energy sector k and the inventory changes in province s produced by the import energy k. j_V signified inventory change.

3. Compile the hybrid MRIO

The adjusted monetary MRIO tables and provincial energy inventory though include the same 8 energy sector, there are still differences in the non-energy sectors. In order to maintain consistency, we aggregated the sectors in monetary MRIO table and provincial energy inventory into the same 31 industrial sectors including the 8 energy sectors (Table S1).

TE_{kj}^{s} is domestically produced energy provided by energy sector k and inputted to industrial sector j of province s. In order to compile the hybrid MRIO tables, physical energy input from sector k in province r to certain sector j of province s: E_{kj}^{rs} should be identified.

$$E_{kj}^{rs}=TE_{kj}^{s} * \frac{Z'^{rs}_{kj}}{\sum_{r=1}^{30} Z'^{rs}_{kj}} \quad \text{(S-6)}$$

Here, Z'^{rs}_{kj} denotes monetary input from energy sector k of province r to sector j of province s. This figure can be obtained from our new built monetary MRIO by 30 provinces and 31 sectors (including 8 energy sectors). When j represents living sectors: rural sector j_R, urban sector j_U and inventory changej_V, TE_{kj}^{s} and $IMTE_{kj}^{s}$ can be regarded as final demand of province s for energy sector k. Thus,

$$E_{kj_R}^{rs}=TE_{kj_R}^{s} * \frac{f_{kj_R}^{rs}}{\sum_{r=1}^{30} f_{kj_R}^{rs}} \quad \text{(S-7)}$$

$$E_{kj_U}^{rs}=TE_{kj_U}^{s} * \frac{f_{kj_U}^{rs}}{\sum_{r=1}^{30} f_{kj_U}^{rs}} \quad \text{(S-8)}$$

$$E_{kj_V}^{rs}=TE_{kj_S}^{s} * \frac{f_{kj_S}^{rs}}{\sum_{r=1}^{30} f_{kj_S}^{rs}} \quad \text{(S-9)}$$

$f_{kj_R}^{rs}$, $f_{kj_U}^{rs}$ and $f_{kj_V}^{rs}$ is monetary final demand of rural sector, urban sector and inventory change in province s for energy sector k of province r which are also available in new built monetary MRIO.

Moreover, we also need to obtain the amount of energy of each province's energy sector that is exported abroad, which is available from the provincial energy balance sheet[2,3]. We assume that imported energy will not be exported again.

Finally, we get the physical flows from energy sector k of province r or import to industrial sector, living sector, inventory change j of province s or export. If we replace the energy rows in the monetary MRIO table with the physical flows we can get hybrid MRIO tables.

In addition, we use $\mathbf{M} = (m_{kj}^{s})$ to signify import of energy k needed to produce unit output of sector j of province s:

$$m_{kj}^{s} = (\frac{IMTE_{kj}^{s}}{x_j^s})$$

where x_j^s means the output of sector j of province s.

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