Direct and indirect energy consumption in China and the United States

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Abstract

Greenhouse gas reduction and energy consumption are becoming two important issues in both industrialized and developing countries, and policy makers are developing means to reduce total domestic energy use. We evaluate and compare the direct and the indirect energy consumption both in the People's Republic of China (China) and the United States of America (US) by looking at a series of hybrid energy input-output tables (1997, 2002, and 2007). We also apply structural decomposition analysis (SDA), to identify the factors causing energy intensity (energy consumption per unit of gross domestic product) to differ between the two countries, which lead to potential energy-saving options. Our results show that, besides the differences in direct energy consumption, huge differences also exist in indirect energy consumption between the two countries. Differences in indirect energy consumption are mainly due to differences in technology. Technological change and industrial-structure change are key factors to explain the inequality of energy intensity, while there is a significant trend towards the convergence of sectorial energy efficiency between the two countries.

Keywords: Input-output analysis, Structural decomposition analysis, Energy

Introduction

Climate change is now a major issue that is being widely discussed and debated throughout the world. As the largest two energy consumers in the world, the People's Republic of China (China) and the United States each accounted for 19.5% of the total global primary energy consumption in 2009 (BP, 2010). Therefore, both countries' energy policies are mainly directed at reducing the domestic consumption of fossil fuels. China aims to reduce its carbon intensity (carbon emission per unit of gross domestic product (GDP)) by 40-45% relative to 2005 levels by 2020, and launched a national low-carbon province and low-carbon city experimental project in five provinces and in eight cities (China's National Development and Reform Commission, 2010). The US government made clear that clean and renewable energy is central to the economic future in the United States (Levin, et al., 2011).

Energy is used by residents directly, and to produce goods and services consumed domestically as well as abroad. Therefore, energy consumption is mainly determined by a country's gross domestic income (product), industrial structure, and sectorial energy efficiency. Gross domestic income affects households' direct energy use and indirect energy use (energy embodied in nonenergy goods and services). Industrial structure and efficiency determine the amount of energy embodied in nonenergy goods and services.

One technique that analysts use to reveal differences in country performance is energy input-output (I-O) analysis. They use this technique to combine information available in input–output tables and energy-consumption datasets and to separate total energy consumption into various components. In recent decades, they have frequently used the energy I-O models for energy and environmental policy analysis (Gay and Proops 1993; Lenzen 1998; Labandeira and Labeaga 2002; Lenzen, Pade et al. 2004; Munksgaard, Wier et al. 2005; Wiedmann, Minx et al. 2006; Nässén, Holmberg et al. 2007; Liang, Fan et al. 2007; Druckman and Jackson 2009).

In both China and the United States, an increasing number of empirical studies emerged using this analytical framework, covering a wide range of topics from household consumption and final demand for energy, to energy embodied in goods and services, to impacts of energy-related policies (Lin and Polenske 1995; Liu, et al. 2009; Zhang, Mu et al. 2009; Chen and Zhang 2010; Liu, et al. 2010). We propose to apply an energy input-output framework to a between-country setting to evaluate the relative importance of the various determinants of energy use in both countries. We will identify where the main gains in energy-saving are likely to be found: should the country under observation focus on introducing more efficient technologies, or should it consider changing its final demand composition? Hence, our international comparison will provide energy-saving policy implications for the policy makers.

2 Theoretical Background

Using the basic Leontief model, we show that the total output of an economy, X, can be expressed as the sum of intermediate consumption, AX, and final consumption, Y (Leontief, 1936), as in Equations 1 and 2. In Equation 1, X is the $n \times 1$ total output vector, A is the $n \times n$ direct input coefficients matrix, describing the inter-industry relationships between all sectors of the economy, and Y is the $n \times 1$ final demand vector, which can be treated as exogenous to the system, for example, the level of total production can be determined by the final demand. In Equation 2, B is the Leontief inverse matrix , $(I - A)^{-1}$.

$$X = AX + Y \qquad (1)$$

$$X = (I - A)^{-1}Y = BY \qquad (2)$$

In this study, we use the hybrid unit, energy input-output analysis to combine the energy consumption information in the input-output tables (Miller and Blair, 2009; Liu, et al., 2009). We construct the energy input-output matrices following the same logic that analysts use to create the basic input-output tables for both countries (Equation 3).

$$E + Z = G \qquad (3)$$

E is the matrix of energy flow from energy producing sectors to all other sectors, which is a $c \times n$ matrix. c is the number of primary energy sectors. Z is the vector of final energy demand and G is the vector of total energy consumption, all measured in physical units, tonnes of standard oil equilibrium. We calculate direct primary energy intensities as ratios of direct energy consumption (in physical terms) to total inputs (in monetary terms), expressed in tonnes of standard oil equivalent per thousand US dollars (Equation 4). The total primary energy intensity of a product is equal to the total secondary energy intensity of that product plus any amount of energy lost in conversion or used for other purposes. Therefore, we calculate total primary energy intensities by multiplying direct primary energy intensities with the Leontief inverse matrix of the corresponding input-output table (Equation 5).

$$e_i = \frac{\sum_{k=1}^{c} E_{k,i}}{X_i} \qquad (4)$$

$$\mathrm{L} = \hat{\mathrm{e}}\,\mathrm{B} \qquad (5)$$

Where e_i is the direct energy intensity of sector i, e is the $n \times n$ diagonal direct primary energy intensity matrix (e_i in the main diagonal and zeros elsewhere), and L is the $n \times n$ total energy-intensity matrix. Given the total primary energy intensity in each sector, we calculate the domestic energy impact to produce final demand Y, which includes households, government, and exports (Equation 6).

$$\mathrm{E}^{\mathrm{Y}} = \mathrm{L}\,\mathrm{Y} \qquad (6)$$

In general, the domestic energy use to produce final demand, which is the same as energy embodied in final demand(Equation 6), changes for a variety of reasons—such as, growth in final demand, changes in industrial structure, changes in technology, and energy efficiency improvement (Hoekstra and van der Bergh, 2003; Liu and Ang, 2007; Wood and Lenzen, 2009). In this paper, we apply the input-output Structural Decomposition Analysis (SDA) to obtain insight in the relative importance of the various factors that cause differences in energy embodied in final demand between China and United States. Since in this we express all monetary values in the same currency through the use of Purchasing Power Parities, we can subtract domestic energy use in one country (China) from that of any other country (the United States), thus, yielding the difference in energy embodied in final demand. To begin with, differences in the energy embodied in final demand (ΔE^{Y}) from sectors, between the United States (country t) and China (country $t-1$), can be expressed in terms of differences of total energy intensities and final demand as follows.

$$
\begin{aligned}
\Delta E^{Y} &= E_{t}^{Y} - E_{t-1}^{Y} \\
&= L_{t}Y_{t} - L_{t-1}Y_{t-1} \\
&= (L_{t} - L_{t-1})Y_{t} + L_{t-1}(Y_{t} - Y_{t-1}) \\
&= (L_{t} - L_{t-1})Y_{t} + L_{t-1}(Y_{t} - Y_{t-1}) = \Delta LY_{t} + L_{t-1}\Delta Y \\
&= (L_{t} - L_{t-1})Y_{t-1} + L_{t}(Y_{t} - Y_{t-1}) = \Delta LY_{t-1} + L_{t}\Delta Y
\end{aligned}
\qquad (7)
$$

From Equation 7, differences in the energy embodied in final demand (ΔE_{t}^{Y}) comprise the differences of total energy intensities ($\Delta \mathbf{L}$) and the differences of final demand (ΔY). Note that this structure decomposition is additive and non-unique, and it does not include interaction terms. We use the simple average of only two decomposition forms, the so-called polar forms (Dietzenbacher and Los, 1998), to solve the non-uniqueness problem as follows.

$$
\Delta E^{Y} = \frac{1}{2}(\Delta L)(Y_{t} + Y_{t-1}) + \frac{1}{2}(L_{t-1} + L_{t})\Delta Y \qquad (8)
$$

According to Equation 7, we further divide the differences in total energy intensities into the effects caused by differences in direct energy intensities (energy efficiency) and the effects caused by differences in the Leontief inverse (Equation 9). The Leontief inverse can be expressed in terms of the differences in the direct input-coefficients matrix $\mathbf{A}$ (i.e., the underlying technological difference) (Equation 10).

$$\begin{aligned} \Delta L &= e_t B_t - e_{t-1} B_{t-1} \\ &= \Delta e B_t + e_{t-1} \Delta B \\ &= \Delta e B_{t-1} + e_t \Delta B \\ &= \tfrac{1}{2} (\Delta e)(B_t + B_{t-1}) + \tfrac{1}{2}(e_t + e_{t-1})(\Delta B) \end{aligned} \tag{9}$$

$$\begin{aligned} \Delta B &= B_t - B_{t-1} \\ &= (I - A_t)^{-1} - (I - A_{t-1})^{-1} \\ &= B_t [(I - A_{t-1}) - (I - A_t)] B_{t-1} \\ &= B_t (A_t - A_{t-1}) B_{t-1} \\ &= B_t (\Delta A_t) B_{t-1} \end{aligned} \tag{10}$$

Similarly, we also decompose the difference of final demand into the different composition of final demand (the different consumption patterns of the various types of final demand users (among which the final consumers, investment, and exports) and the different level of final demand (the size of final demand itself) (Equation 11 and 12). F (Column vector) represents the structure of final demand with ratios of each sector's final demand to the total volume of final demand, Y_S . Hence, we obtain the following expression for the decomposition of the difference between two countries' energy embodied in final demand (Equation 13).

$$\mathrm{Y} = \sum Y_i \mathrm{Y} \ / \sum Y_i = \sum Y_i \mathrm{F} = Y_S \mathrm{F} \tag{11}$$

$$\begin{aligned}
\Delta \mathrm{Y} &= \mathrm{Y}_{\mathrm{t}} - \mathrm{Y}_{\mathrm{t}-1} \\
&= Y_{S,t}\mathrm{F}_{\mathrm{t}} - Y_{S,t-1}\mathrm{F}_{\mathrm{t}-1} \\
&= \Delta Y_S \mathrm{F}_{\mathrm{t}} + Y_{S,t-1}\Delta \mathrm{F} = \Delta Y \ \mathrm{F}_{\mathrm{t}-1} + Y_t \Delta \mathrm{F} \\
&= \tfrac{1}{2} (\Delta Y_S)(\mathrm{F}_{\mathrm{t}} + \mathrm{F}_{\mathrm{t}-1}) + \tfrac{1}{2} (Y_{S,t} + Y_{S,t-1})\Delta \mathrm{F}
\end{aligned} \tag{12}$$

$$\begin{aligned}
\Delta \mathrm{E}_{\mathrm{t}}^{\mathrm{Y}} &= \tfrac{1}{4} (\Delta \mathrm{e}) (\mathrm{B}_{\mathrm{t}} + \mathrm{B}_{\mathrm{t}-1}) (\mathrm{Y}_{\mathrm{t}} + \mathrm{Y}_{\mathrm{t}-1}) \\
&+ \tfrac{1}{4} (\mathrm{e}_{\mathrm{t}} + \mathrm{e}_{\mathrm{t}-1}) (\mathrm{B}_{\mathrm{t}}(\Delta \mathrm{A}_{\mathrm{t}}) \mathrm{B}_{\mathrm{t}-1}) (\mathrm{Y}_{\mathrm{t}} + \mathrm{Y}_{\mathrm{t}-1}) \\
&+ \tfrac{1}{4} (\Delta Y_S)(\mathrm{L}_{\mathrm{t}-1} + \mathrm{L}_{\mathrm{t}}) (\mathrm{F}_{\mathrm{t}} + \mathrm{F}_{\mathrm{t}-1}) \\
&+ \tfrac{1}{4} (Y_{S,t} + Y_{S,t-1}) (\mathrm{L}_{\mathrm{t}-1} + \mathrm{L}_{\mathrm{t}})\Delta \mathrm{F}
\end{aligned} \tag{13}$$

The differences in the energy embodied in final demand between countries are decomposed into the effects caused by differences in primary energy efficiency in the first term on the right-hand side of Equation (13), the differences caused by different structures of intermediate inputs in the second term, the different level of final demand in the third term, and the different structures of final demand is the last term. In this decomposition, all the terms are multiplied by a Leontief inverse matrix, so that the measurements capture both direct and indirect impacts of each causal expression on the energy embodied in final demand and take account of the linkage through the induced intermediate demand.

3 Data sources and processing

Two sets of data are required in both China and the United States to apply the hybrid energy input-output model discussed above: input-outputdata for the interindustry flows and outputs measured in value terms and industry-specific estimates of the physical quantities of the different fuels consumed. Both are easily found for China and the United States, although the industrial classification systems used in the input-output tables and in the energy balance of the country are not the same. Therefore, our first task for this research is to make both systems compatible in both countries. Because the energy statistics are highly aggregated in both countries, we aggregate the input-output tables to make the systems compatible. With the uniform criteria for the classification of both countries' input-output tables, we aggregate the Chinese 1997(124 sectors), 2002 (123 sectors), and 2007 (135 sectors), as well as the United States 1997 (132 sectors benchmark table), 2002 (136 sectors benchmark table), and 2007 (65 sectors annual table) industry- by-industry input-output tables into 24-sector input-output tables.

To obtain an accurate evaluation of the industry-specific impacts of an energy policy, we calculate the energy consumption of each industry, including both direct combustion and the purchase of electricity and other intermediate inputs. To estimate the quantity of energy use in the energy input-output tables, we assume that every sector pays the same average price for each kind of energy product. However, we note that this is a poor assumption for some industries (e.g., the electricity-generation industry pays a lower average price for coal than other industries). For China's energy input-output tables, we obtain industrial energy-use data from the final-energy-consumption-by-industrial-sector tables (standard quantity) provided by the Chinese Energy Statistical Yearbook, and collect energy data for agriculture, electric utility, transportation, and services from energy-balance tables (standard quantity) and infer energy use for the other industries from the value data by assuming that all these sectors pay the same price for a tonne of coal, a kilowatt-hour of electricity, or a unit of any other commodity.

For the United States, we obtain energy use for the electric-utility industry, agriculture, transportation, and services on an end-use basis from the Annual Energy Review. For the U.S. industrial energy use, we collect the energy-consumption data for the manufacturing industries in the 2002 energy input-output table from the 2002 Manufacturing Energy Consumption Survey (MECS). For the 1997 and 2007 energy input-output tables, we use the 1998 and 2006 MECS data to estimate the quantities of energy used by the manufacturing sectors based on a calculation constrained by national quantities of the fuels in both years.

4. Results

To demonstrate what insights can be obtained from between-country energy input-output analysis, we apply the technique to analyze direct and indirect energy use in China and the United States over time.

4.1. Economic development and energy consumption in China and US

In the last three decades, economies of China and the United States, the largest developing and developed countries in the world, respectively, have experienced rapid growth. During the period from 1981 to 2009, the US gross domestic product (GDP) has increased from 3,103 billion Yuan to 14,119 billion US dollars at current prices (Figure 1), with an annual GDP growth rate of about 5%. China's economy has developed with a much higher annual growth rate (about 12%) compared with that of the United States In 1981, China’s GDP was only nine percent of the US GDP, but in 2009 China’s GDP was already 64% of that of the United States (Figure 1).

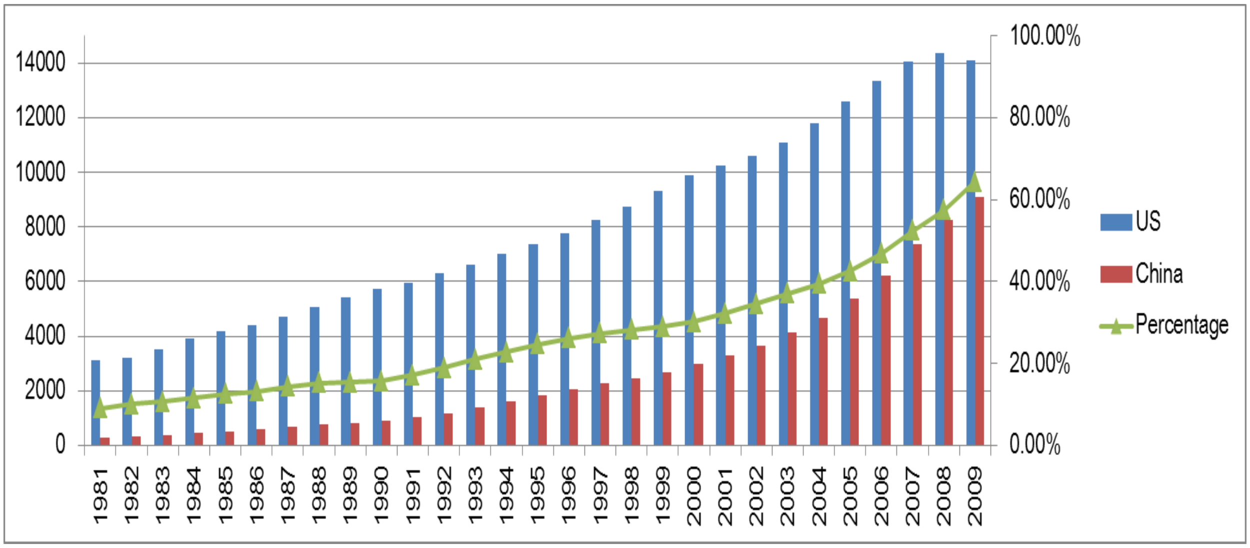

Figure 1: PPP GDP of China and US

Note: Percentage here refers to the ratio of China's PPP GDP to that of the United States. PPP GDP is gross domestic product converted to US dollars using purchasing power parity rates.

Date source: World Bank

Both China and U.S. economic growth were accompanied with a relatively rapid increase of fossil-fuel consumption as well as GHG emissions. Driven by the relatively rapidly increasing GDP, the rate of growth of China's energy consumption was significantly faster than the speed of the US energy consumption (Figure 2). In 1981, China's primary energy consumption was 411 million tonnes oil equivalent, which was about 24% of that in the United States. In 2009, although China and the United States still have huge differences in GDP and population sizes, their energy consumption was very similar. China's primary energy consumption was 2,177 million tonnes oil equivalent, which was only five million tonnes oil equivalent less than that of the United States. China and U.S. energy consumption each accounts for 19.5% of the world's total energy consumption in 2009 (BP, 2010).

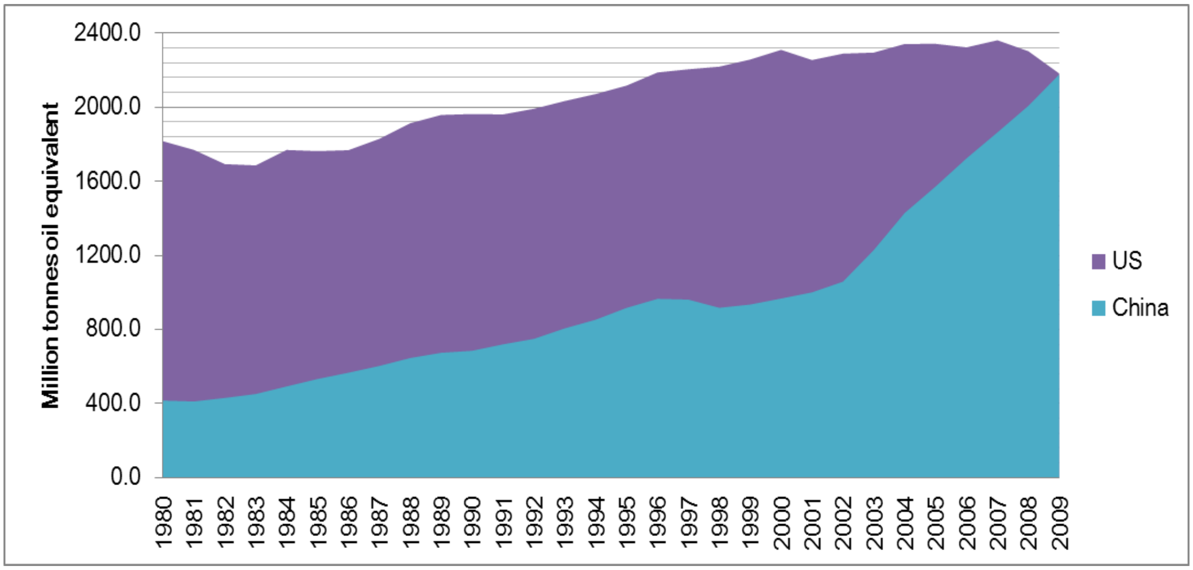

Figure 2: China and U.S. primary energy consumption, 1980-2009

Source: BP Historical data, http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622

From the perspective of per capita energy use, China has had a slight increase, while the United States has a relatively constant value during the last three decades. China's per capita energy use has increased from 597 kilograms (kg) of oil equivalent in 1981 to 1,611 kg of oil equivalent in 2009, while the U.S. per capita energy use was 7,647 kg of oil equivalent in 1981 and 7,104 kg of oil equivalent in 2009. A significant difference exists between China and the U.S. per capita energy use, although the ratio of China's per capita energy use to that of the United States has increased from 8% to 24% from 1981 to 2009 (Figure 3).

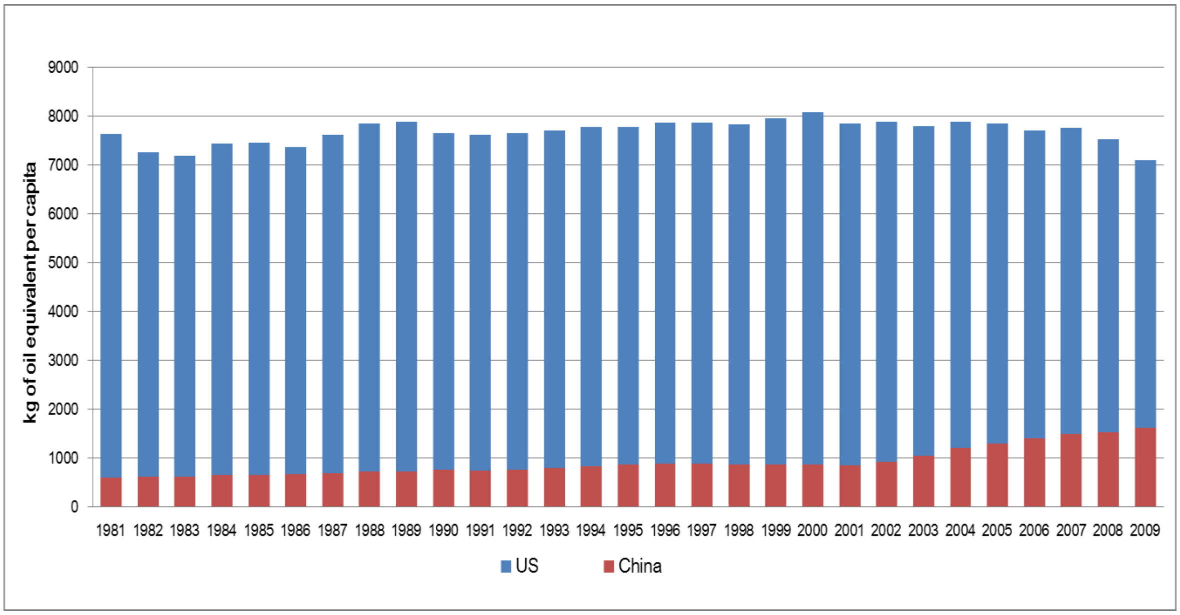

Figure 3: China and United States per capita primary energy consumption, 1981-2009

Data source: World Bank and BP

From the trend of China's economic growth and per capita energy use increase, it is obvious that China's energy consumption will surpass that of the United States in the near future. However, China has been following consistently a strategy of Export- Led Growth (ELG) and the net exports from China to the rest of world have grown rapidly. The energy embodied in China's exports represents that the energy used domestically for producing goods consumed abroad (Liu et al., 2010). Therefore, it is important to determine the energy embodied in the final demand (household consumption, investment, and exports) for both China and the United States.

4.2. Energy intensities

Both China and the United States have experienced a decrease in energy intensity as a whole (energy use per unit GDP) from 1981 to 2009. In 1981, China's energy intensity was 1,098 kg of oil equivalent per thousand US dollars GDP (constant 2005 PPP).

During the period from 1981 to 2009, it has decreased by about 76% (260 kg of oil equivalent per thousand US dollars GDP in 2009). The US energy intensity has decreased from 290 to 170 kg of oil equivalent per thousand US dollars GDP during this period.

Table 1: China and U.S. direct primary energy intensity for 24 sectors, 1997, 2002, 2007

		China			US		
		1997	2002	2007	1997	2002	2007
1	Agriculture	26	43	49	102	97	93
2	Oil and gas extraction	224	186	148	216	143	82
3	Other mining	434	343	323	155	112	52
4	Food, beverage and tobacco	78	60	61	41	38	36
5	Textile	117	108	102	46	45	55
6	Wood products and furniture	119	109	106	72	68	57
7	Paper products	201	116	92	126	84	67
8	Printing and related activities	40	34	22	19	17	16
9	Petroleum and coal products	2,396	1,910	1,221	1,047	566	236
10	Chemical products	476	367	196	291	256	171
11	Plastics and rubber products	92	60	50	39	36	33
12	Nonmetallic mineral products	727	613	287	210	201	193
13	Primary metals	710	457	283	207	180	146
14	Fabricated metal products	72	64	46	35	28	24
15	Machinery	87	50	30	16	13	12
16	Electronic products	29	18	14	11	10	7
17	Electrical equipment	68	63	25	25	24	18
18	Transportation equipment	111	64	32	15	14	14
19	Miscellaneous manufacturing	135	88	45	16	10	9
20	Utilities	3,451	2,418	1,910	3,042	2,065	1,749
21	Construction	53	47	36	86	65	38
22	Transportation	702	468	360	299	283	238
23	Wholesale and retail trade	42	35	28	21	20	19

24	Other services	38	29	25	36	33	22

Source: Authors

The direct primary energy intensities by sector for China and the United States in 1997, 2002, and 2007, which are expressed in tonnes oil equivalent per thousand US dollars total output at current price, are presented in Table 1. As presented in Table 1, except for agriculture, the direct primary energy intensities of the other 23 sectors have decreased continuously from 1997 to 2002 and from 2002 to 2007 in China. The rise of agriculture sector's direct primary energy intensity in China is mainly caused by increasing use of agricultural machinery. The decrease of other 23 sectors' direct primary energy intensities can be considered as the improvement in energy efficiency in these sectors. For US, all 24 sectors have decreased their primary energy intensity during the period from 1997 to 2007, which means an overall improvement in energy efficiency. By comparing the sectoral direct energy intensities between the two countries in these three years, we find China only has relative smaller direct primary energy intensities in agriculture and construction, because these two sectors use less machinery and more labor in China than these two sectors in US. China's other 22 sectors all have relative bigger direct primary energy intensities than those of US's.

Table 2 provides the total primary energy intensities of all 24 industries in China and the United States for 1997, 2002, and 2007, which are expressed in tonnes of oil equivalent per thousand US dollars final demand at current prices. For China, just like its direct primary energy intensities, with the exception of agriculture, the total primary energy intensity for the other 23 sectors decreased from 1997 to 2002 and from 2002 to 2007. For the United States total primary energy intensities for all 24 sectors decreased from

1997 to 2002 and from 2002 to 2007. China's sectorial total primary energy intensities are larger than those for the United States, which indicates that to produce the same amount of final demand, more energy is required in China than in the United States.

Table 2: China and the United States total primary energy intensities for 24 sectors, 1997. 2002, 2007

		China			US		
		1997	2002	2007	1997	2002	2007
1	Agriculture	269	346	399	424	408	378
2	Oil and gas extraction	602	457	348	477	335	185
3	Other mining	951	754	672	387	279	151
4	Food, beverage and tobacco	212	205	164	107	93	91
5	Textile	319	279	245	169	154	194
6	Wood products and furniture	327	304	286	266	178	158
7	Paper products	796	502	421	364	261	234
8	Printing and related activities	114	94	77	42	38	36
9	Petroleum and coal products	3,998	2,418	1,282	2,246	1,338	539
10	Chemical products	1,405	1,068	689	656	566	399
11	Plastics and rubber products	290	223	190	90	83	79
12	Nonmetallic mineral products	1,912	1,664	934	434	413	401
13	Primary metals	1,723	1,384	918	428	402	379
14	Fabricated metal products	243	235	170	74	60	55
15	Machinery	259	153	112	35	29	30
16	Electronic products	97	64	57	24	23	15
17	Electrical equipment	230	201	100	59	56	41
18	Transportation equipment	386	184	92	51	39	39
19	Miscellaneous manufacturing	272	178	88	33	23	19.3
20	Utilities	7,460	6,432	5,086	5,097	3,649	2,962
21	Construction	159	143	132	177	146	97
22	Transportation	1,889	1,076	780	650	571	483
23	Wholesale and retail trade	123	87	59	75	70	49
24	Other services	170	140	133	117	94	77

Source: Authors

We also calculated each sector’s indirect primary energy intensity for China and the United States, which is the difference between total primary energy intensity and direct primary energy intensity and represents the energy embodied in the intermediate inputs for each sector. Almost all sectors in China and the United States have relatively larger indirect primary energy intensities compared with their direct primary energy intensities. One unique case is the utilities sector. It has relative larger indirect primary energy intensity in China, while having a relatively smaller indirect primary energy intensity in the United States, compared with its direct primary energy intensity (Figure 4). The reason is because the geographical distribution of electricity-generating plants and their raw-fuel suppliers, coal mines, is mismatched in China, as 67 percent of all proven recoverable coal reserves occur in the north and northwest of China (mainly in the provinces of Shanxi, Shaanxi, and Inner Mongolia) while the electricity consumption mainly occurs in the south and southeast of China. The indirect energy intensity of one electricity generating plant is negatively associated with its spatial accessibility to coal resources through the national transportation network because of transportation-caused energy consumption.

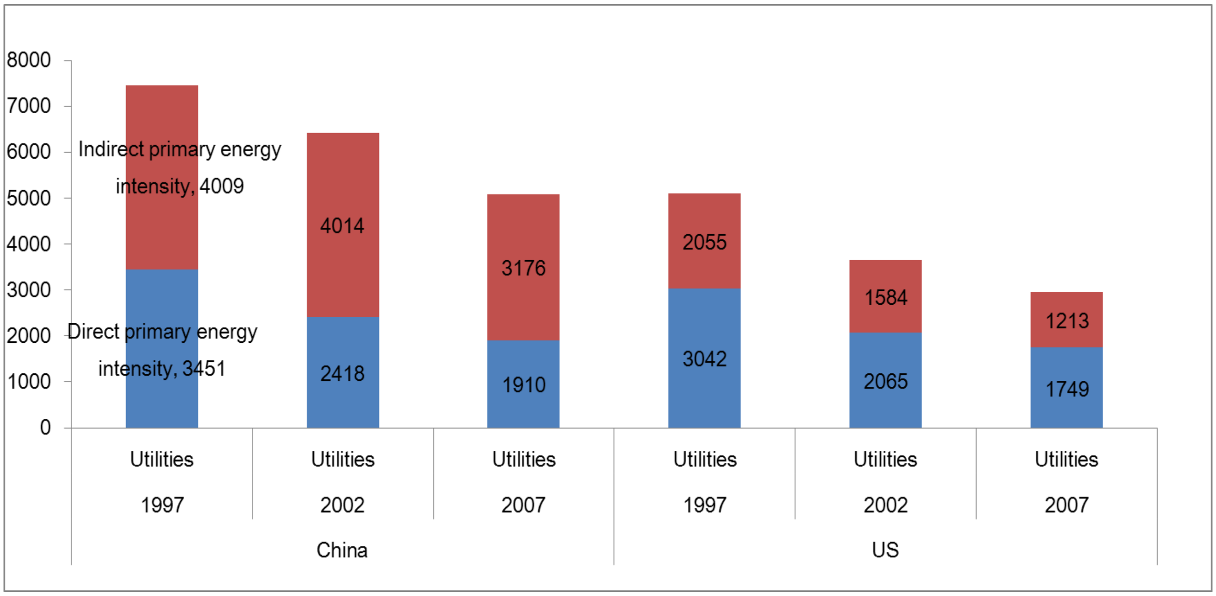

Figure 4: China and U.S. direct and indirect primary energy intensities for Utilities, 1987, 2002, 2007

Source: Authors

4.3. Structural decomposition analysis results

Based on between-country SDA, we evaluate the relative importance of the factors that cause these differences between two countries' energy embodied in final demand in 1997, 2002 and 2007. However, the decomposition equation we use in this paper (Equation 13) is at the sectoral level. In order to derive the importance of that factor in explaining the difference in aggregate energy embodied in final demand, we add up all sectoral differences in energy use caused by a specific decomposition factor. The results are shown in Table 3 and Figure 5. For each of the three years' comparisons, the three columns in Table 3 depict how much higher domestic energy use is in the China (or lower in case of a negative number) because of intercountry differences in each of the four decomposition factors.

Table 3: SDA results of differences in the energy embodied in final demand between China and U.S., 1997, 2002, 2007

Differences (Million tonne of oil equivalent)		1997	2002	2007
T	Energy embodied in final demand	1,058	1,093	384
e	Direct primary energy intensities	-205	-261	-140
A	Structure of intermediate inputs	-500	-770	-541
s	Level of final demand	1,817	2,166	1,098
F	Structure of final demand	-53	-43	-33

Note: The symbol T is used to denote the difference between US and China's energy embodied in final demand. The explanatory factors (the e, A, s and F rows) show the increase in China's domestic energy use if it would have been endowed with, respectively, US primary energy intensities (e), US intermediate inputs structure (A), US final demand level (s), US final demand structure (F).

Source: Authors

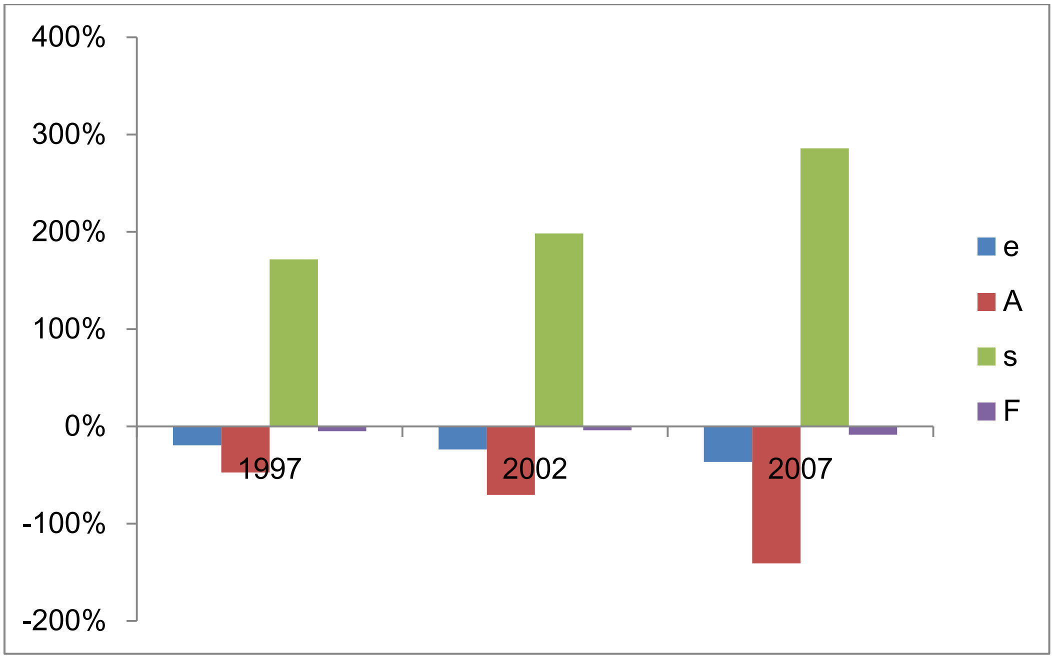

Figure 5: SDA results of differences in the energy embodied in final demand between China and U.S., 1997, 2002, 2007 (percent)

Source: Authors

The difference of the energy embodied in final demand between China and the United States during the period from 1997 to 2002 increased slightly from 1,058 to 1093 million tonne of oil equivalent, but decreased by 709 million tonne of oil equivalent from 2002 to 2007 (Table 3). Differences in the direct primary energy efficiency and the structure of intermediate inputs all decreased difference of the energy embodied in final demand between two countries. The relative importance of final demand structure is fairly limited. The difference in the level of final demand is the only factor that positively contributed to the difference of the energy embodied in final demand between China and the United States.

From Table 3 and Figure 5, we can observe some general patterns. First, China's production is generally more energy-intensive than that of the United States, which is caused by China's relative higher sectoral energy intensities. Technological difference plays a more important role in explaining the difference of energy embodied in final demand between China and U.S, while there is a significant trend towards the convergence of sectorial energy efficiency as well as technology between the two countries. Second, gross domestic product in the United States is higher than China, and hence energy use in China would increase substantially if it would have the same level of final demand.

4.4. Energy embodied in final demands

Based on Equation (6), we discuss the impact of final demand on energy consumption for China and the United States, to attain a comprehensive and in-depth understanding of the relationship of final demand and domestic energy consumption. As presented in Figure 5, China's domestic consumption (including households and government consumption) accounts for about 50% of China's energy requirement, about one-third of China's energy is used to produce products consumed abroad, and about 20% of China's energy is used for investment. For the United States, more than 80% of its total energy consumption is used for producing goods and services consumed domestically, and less than 20% of its total energy consumption is used for exports and investment.

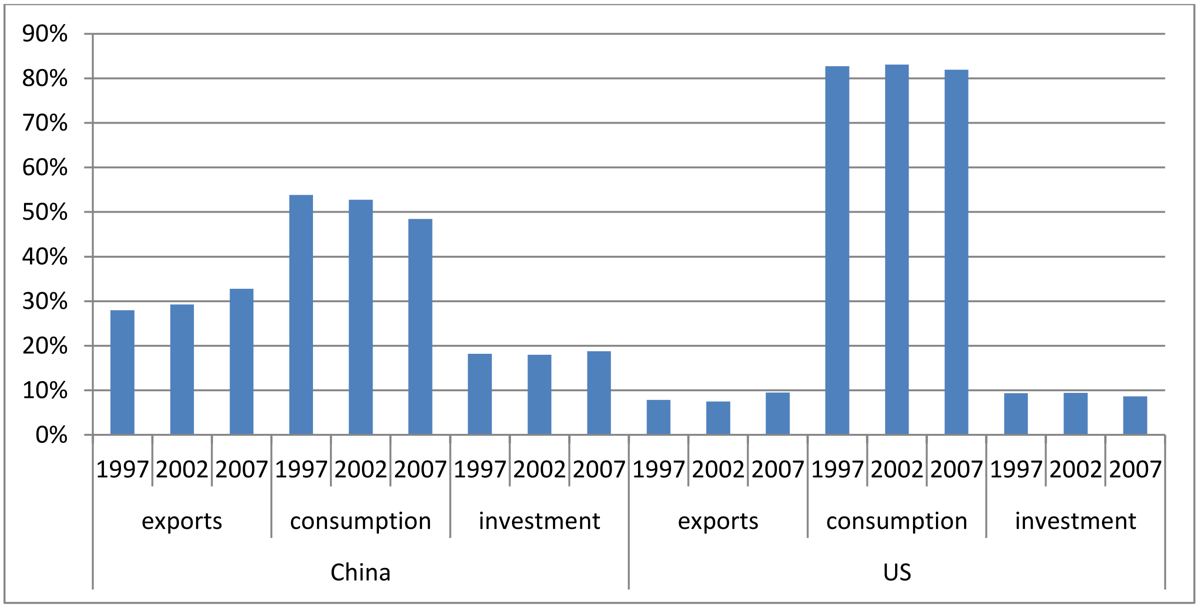

Figure 5: China and U.S. direct and indirect primary energy intensities in the Utility sector, 1997, 2002, 2007

Source: Authors

China and the United States are at different development stages. China's economic growth is largely driven by exports and investment, while in the United States, growth is mainly driven by domestic consumption. If we take the energy embodied in international trade into consideration, the U.S. consumption of China's goods increases China's energy consumption, while reducing its domestic energy consumption, and vice versa. From a global perspective, the U.S. consumption of China's goods would increase global energy consumption due to the relatively larger sectorial energy intensities in China.

5. Conclusion

Using an energy input-output framework, we analyzed energy consumption in China and the United States, two important energy-consuming countries in the world. First, based on a consistent set of 1999, 2002, and 2007 input–output tables for China and the United State, we evaluated energy intensity inequality, because it is a determinant of energy consumption disparities between countries. Second, we have applied between-country SDA to both countries' energy embodied in final demand. Third, we studied the impact of different final demand compositions on energy consumption.

Our results show that sectoral energy efficiency as well as the technological factor (intermediate-input structure) is primarily responsible for changes in direct energy intensities and indirect energy intensities, respectively. We also find that China can substantially reduce the amount of energy consumed by improving energy efficiency, intermediate input structure as well as final demand structure. A large part of China's energy consumption is due to the production of exports as well as investment, while for the United States, a major part of energy is used to fulfill domestic goods and services consumption. Therefore, it can be concluded that China's energy policy should focus on stimulating the adoption of energy saving technologies and reducing the energy intensity of its intermediate and final demand structure.

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