Energy Efficiency and Economic Development in China

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Abstract
China is now the world's second largest economy, and it is expected to overtake the United States to become the largest by 2020. What are the implications for the global environment and climate change if China surpasses the United States? There are major concerns with China's rapid rise because its economic and industrial structure is increasingly dependent on the consumption of energy, raw materials, and electricity. In 2010, China's GDP was approximately 40 percent of the United States' GDP, yet it was the world's largest polluter and the biggest consumer of energy and electricity. This implies that the energy efficiency of the Chinese economy measured by energy consumption per unit of GDP is about one-third of that of the United States and one-fourth that of the EU and Japan. If the Chinese economy continues to grow as fast as it has in the past, without changing its structure and improving energy efficiency, China's growth will cause severe damage to the global environment. This paper analyzes the evolution of energy efficiency in the Chinese economy and stresses the importance of transforming China's economic structure.

1. Introduction

China's economy is now in the stage of high energy-intensive growth. In 2010, China used 3.2 billion tons of coal equivalent (TCE), or roughly 20 percent of the world's total energy consumption, surpassing the United States to become the world's largest energy consumer. With domestic production of oil stagnating at 200 million tons annually, China has depended on oil imports for more than 50 percent of its total oil usage since 2009. If the current trends of oil production and demand continue, McKinsey (2009) estimates that China's oil imports will surpass 80 percent of its oil usage by 2030. As 80 percent of China's oil imports are shipped through the Malacca Strait, any serious regional conflict will endanger national energy security.

China's oil shortage is mitigated by the fact that more than 70 percent of China's energy is generated by coal, of which China has massive reserves. Nevertheless, given current consumption trends, China will be forced to depend on external supplies for more than 10 percent of its coal needs by 2030 (McKinsey & Company 2009). The fact is that China is becoming vulnerable not only to energy security but also to environmental problems. A 2007 joint study by the Chinese government and the World Bank concludes that 750,000 die prematurely in China every year as a result of diseases caused by air pollution (Walsh 2009).

China has been moving to address these problems. A primary target in China's 11th Five-Year Plan (FYP), 2006–10, was to improve energy efficiency by 20 percent, a rate of 3.7 percent per year (Oxford Analytica Daily Brief Service 2009). The just released 12th FYP (2011–15) aims to reduce GDP energy intensity by another 16–17 percent.

According to the National Bureau of Statistics, China's energy intensity declined 1.2 percent in 2006, 3.7 percent in 2007, 4.6 percent in 2008, 3.61 percent in 2009, and 4.01 percent in 2010 (Oxford Analytica Daily Brief Service 2009; NBS 2009, 2010). Hence, China achieved its 11th FYP targets, improving energy efficiency by 19.1 percent over the 5-year period. Data from the China Energy Statistical Yearbook, however, which measures energy efficiency in terms of total primary energy supply per thousand U.S. dollars of GDP (in 2000 prices), show the improvement in efficiency over the same 5-year period to be just 5.8 percent. This inconsistency between the data from two different sources is troubling. Fischer-Vanden et al. (2004) has in fact gone so far to suggest that the falling energy intensity in China might actually be the result of under-reported energy consumption, over-reported output, or both.

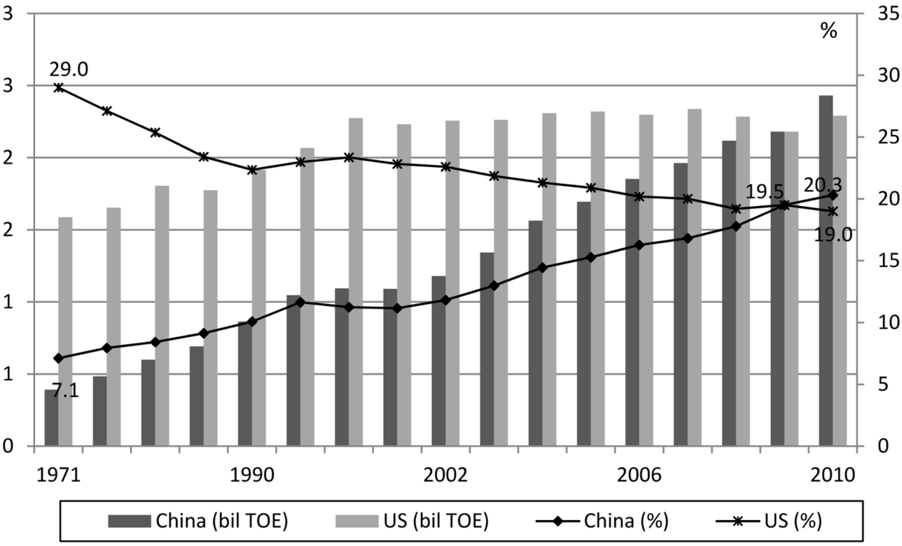
The objectives of this paper are to examine the key factors contributing to the rise in energy consumption in China and discuss the policy options to achieve energy efficiency targets that are compatible with China's growth.

2. Energy consumption and challenges in China

China's current energy situation involves three major challenges:

1. an increasing thirst for energy and reliance on imports;
2. an unbalanced mix of energy sources; and
3. a need to slow down energy consumption and increase energy efficiency.

Figure 1. Energy consumption (billion TOE) by China and the United States, 1971–2010



Source: *World Bank and BP Statistical Review of World Energy 2010 and 2011. http://data.worldbank.org/indicator/EG.USE.COMM.KT.OE/countries?page=4&display=default.*

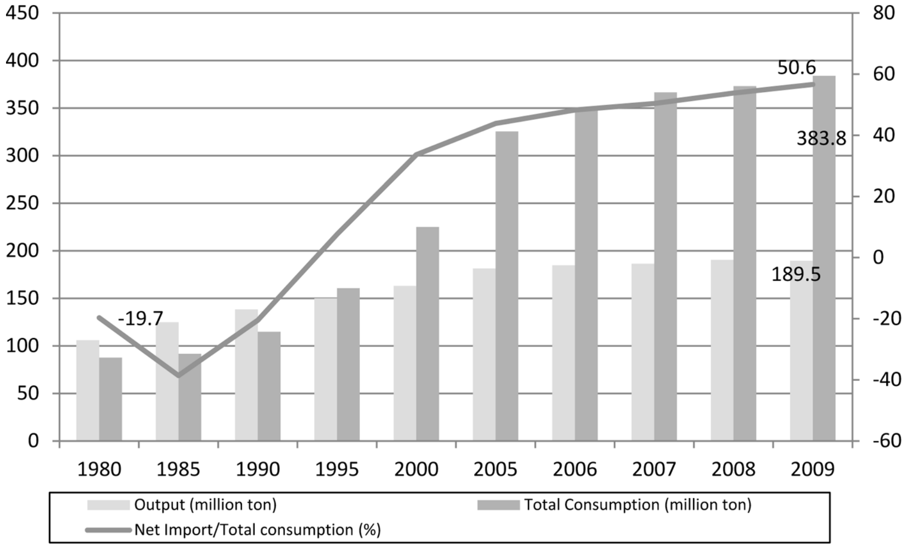
Note: *Billion TOE = billion ton of oil equivalent. China (percent) and United States (percent) represent energy consumption by China and the United States as a percent of world total. Data for 2009 and 2010 are from BP Statistical Review of World Energy. Data for other years are from the World Bank.*

The rising Chinese thirst for energy is captured in Figure 1, which shows the energy consumption by China and the United States over the period 1971–2009. China's energy consumption rose from 0.8 billion tons of oil equivalents (TOE) in 1971 to 2.8 billion TOE in 2010, which brought its share of world energy consumption from 7.1 percent to 20.3 percent. The corresponding world share of the United States declined from 29 percent to 19 percent. China's energy consumption will continue to grow phenomenally in the years to come because per capita energy consumption in 2008 was only 1.6 TOE per capita in China compared to 7.5 TOE in the United States. The two major factors that will accelerate a rise in per capita energy consumption in China are the high urbanization rate[1] and the high growth rate of per capita disposable income.

The demand for oil in China also increased enormously over the last decade. Figure 2 shows the changes in domestic oil production, total consumption, and

1 On average, urban residents consume 3.5 times more energy than their rural counterparts.

Figure 2. China's consumption of crude oil, 1980–2009



Source: *China Energy Statistical Yearbook, 2010.*

imports as a proportion to total demand over the past three decades. China was a net oil exporter until 1993. By 2010, China imported 239 million tons of oil, which accounted for more than 53 percent of the country's total oil consumption.[2] The rise in dependence on external oil supply inevitably exposes China to serious energy security problems. Rising oil prices have significantly raised the cost of oil imports for China. In 2010, China spent US$ 135 billion on oil imports, which was 50 percent higher than in 2009, but the amount of oil imported only rose by 17 percent.

The second challenge facing China is its highly unbalanced mix of energy sources. Because coal is the most abundant energy source within China's borders, coal consistently supplied more than 70 percent of the total energy used over the past 30 years, resulting in serious greenhouse gas (GHG) emissions and pollution. China's annual CO_2 emissions have grown almost 10 percent since 2000 and China became the world's biggest emitter of GHGs in 2006 (World Bank 2006). In 2010, CO_2 emissions in China reached 8.3 billion tons, accounting for 26 percent of the world's total (World Bank 2010).

2 The same ratio for the United States was also about 53 percent.

In 2009, hydro, wind, solar, and nuclear power generation constituted 7.8 percent of China's total energy mix compared with 14.3 percent in Brazil, 44.5 percent in France, 17.5 percent in Japan, and 11.8 percent in the United States (World Bank 2009). This explains why the GHG issue is increasingly serious in China, making the country subject to international criticism.

Equally worrisome is the fact that there has been a slowdown in improvement in sustainable production. The amount of CO_2 emissions for every one million RMB of GDP, measured in 2000 prices, declined from 668 tons in 1990 to 343 tons in 2000 and then to 309 tons in 2010; a decline of 49 percent and 10 percent in each respective decade.

The third and most serious challenge for China is how to control energy consumption and improve energy efficiency. The GDP elasticity of energy (electricity) consumption is the growth rate of energy (electricity) consumption divided by the GDP growth rate. When the GDP elasticity of energy (electricity) consumption is less than unity, it means that the economy is improving its energy (electricity) efficiency over time. If the opposite holds true, then the economic growth pattern could be unsustainable.

To examine the relationship between GDP and energy consumption in more detail, the post-reform period 1978–2010 is divided into three sub-periods: 1978–90, 1990–2000, and 2000–10. Table 1 reports the growth rates of GDP, energy, and electricity consumption, and the GDP elasticities of energy and electricity consumption over different economic development periods.

The GDP elasticity of energy was 0.6 in 1978–90, 0.4 in 1990–2000, and 0.8 in 2000–10. The surge in energy consumption was particularly pronounced in 2001–06 to produce a GDP-energy elasticity of 1.3 and a GDP-electricity elasticity of 1.6. The global financial crisis in 2008 reduced China's GDP energy and electricity intensity. The government's 4 trillion RMB stimulus package and massive bank lending from the second half of 2009 triggered a new round of infrastructure and industrial expansion in China, however. The demand for energy and electricity rocketed to a new high. The first half of 2011 had GDP growing at 9.6 percent and electricity consumption at 12.6 percent, producing a GDP elasticity of electricity consumption of 1.31. The result was widespread shortage of electricity across the country because of this increase in the inefficient use of electricity.

To explore the issue of energy efficiency further, Table 2 compares the energy and electricity consumption per unit of GDP in different countries for the 2002–08 pe-

Table 1. GDP growth and energy consumption

Year	Annual growth (percent) Energy consumption	Electricity consumption	GDP	GDP elasticity of Energy consumption	Electricity consumption
1985	8.1	9.0	13.5	0.6	0.7
1990	1.8	6.2	3.8	0.5	1.6
1995	6.9	8.2	10.9	0.6	0.8
2000	3.5	9.5	8.4	0.4	1.1
2001	3.3	9.3	8.3	0.4	1.1
2002	6.0	11.8	9.1	0.7	1.3
2003	15.3	15.6	10.0	1.5	1.6
2004	16.1	15.4	10.1	1.6	1.5
2005	10.6	13.5	11.3	0.9	1.2
2006	9.6	14.6	12.7	0.8	1.2
2007	8.4	14.4	14.2	0.6	1.0
2008	3.9	5.6	9.6	0.4	0.6
2009	5.2	7.2	9.1	0.6	0.8
2010	5.9	13.1	10.3	0.6	1.3
Average annual growth rate (percent)					
1978–2010	5.6	9.2	9.9	0.6	0.9
1978–90	4.7	6.8	8.4	0.6	0.8
1990–2000	4.0	8.0	10.4	0.4	0.8
2001–06	11.5	14.3	8.9	1.3	1.6
2000–10	8.4	12.0	10.5	0.8	1.1

Source: *NBS, China Statistic Year Book 2010.*

Note: *The starting period for electricity consumption was 1980.*

Table 2. Energy and electricity consumption for US$ 1,000 GDP in 2000 prices

Country or area	TPES/GDP (TOE/US$ 1,000) 2002	2005	2008	Electricity consumption/GDP (kWh/US$ 1,000) 2002	2005	2008
World average	0.31	0.32	0.30	450	460	460
OECD total	0.20	0.20	0.18	350	340	330
Non-OECD Total	0.75	0.70	0.65	850	860	850
BRIC						
China	**0.86**	**0.89**	**0.81**	**1,070**	**1,123**	**1,250**
India	1.07	0.83	0.75	870	810	780
Russia	2.16	1.86	1.60	2,700	2,370	2,130
Brazil	0.31	0.29	0.29	520	510	500

Source: *NBS, China Energy Statistical Yearbook, 2010.*

Note: *TPES = total primary energy supply; TOE = ton oil equivalent; kWh = kilowatt hour; BRIC = Brazil, Russia, India, and China.*

riod. China's energy (electricity) efficiency is constantly well below the world average. In 2008, China consumed 4.5 times as much energy and 3.8 times as much electricity to produce the same amount of GDP as the OECD average. China's energy (electricity) efficiency is only one-third (40 percent) of the level achieved by Brazil. India's energy efficiency was lower than China's in 2002 (1.07 versus 0.86), but it outperformed China by 2008 (0.75 versus 0.81). It is very shocking that electricity efficiency declined sharply in China, from 1,070 kWh in 2002 to 1,250 kWh in 2008

Table 3. Composition of GDP by industries in the world's major economies (percent) in 2009

2009	Agriculture	Industry	Services	Exports/GDP
BRIC				
Brazil	6	25	69	11
China	11	46	43	27
Russian	5	33	62	28
India	18	27	55	20
Developed countries				
France	2	19	79	23
Germany	1	26	73	41
Italy	2	25	73	24
Spain	3	26	71	23
UK	1	21	78	28
United States	1	22	77	11
Japan	1	28	71	13
Singapore	0	26	74	221
Average	1.6	24.1	74.5	23.3

Source: *The World Bank.*

Note: *The average figure is calculated based on all developed nations listed in the table. The average exports of goods and services figure does not take Singapore into account.*

for every US$ 1,000 of GDP, whereas electricity efficiency increased significantly in Russia, India, and Brazil over the same period.

3. Factors responsible for high energy demand and low energy efficiency in China

China's soaring demand for energy results from several factors that are central to the structure of the Chinese economy, and thus are quite clear. First, China is reliant on the fast expansion of the secondary industry, and particularly heavy industry. In addition, in recent years China has increased its exports of energy-intensive products such as automobiles, machinery, and steel. Finally, the relocation of energy-intensive industries from the coastal region to the inland areas reduces the overall energy efficiency of the Chinese economy. All these factors result in high energy demand and low energy efficiency in the Chinese economy.

3.1 Economic and industrial structures

China's economy is heavily skewed toward manufacturing. In 2009, for example, the manufacturing industry was responsible for 46 percent of China's GDP. For the developed economies, this share is less than 25 percent (Table 3). The agricultural sector is responsible for over 10 percent of China's GDP, compared with less than 3 percent for developed countries, and the service sector accounts for only 43 percent of China's GDP, compared with over 70 percent for most developed economies. China's economic structure suggests that the more energy-intensive industries (i.e., agriculture and manufacturing), are more dominant than the energy-efficient

Table 4. Total industrial output value and its composition, 1965–2009 (2000 constant prices)

	Industrial output value (trillion yuan)			Percentage (percent)	
	Total	**Light industry**	**Heavy industry**	**Light industry**	**Heavy industry**
1978	42	18	24	43.1	56.9
1980	52	24	27	47.2	52.8
1985	97	46	51	47.4	52.6
1990	239	118	121	49.4	50.6
1995	919	435	484	47.3	52.7
2000	857	341	516	39.8	60.2
2005	2,516	783	1,733	31.1	68.9
2006	3,165	949	2,217	30.0	70.0
2007	4,052	1,196	2,855	29.5	70.5
2008	5,073	1,454	3,619	28.7	71.3
2009	5,483	1,615	3,868	29.5	70.5
Growth rate (percent)					
1978–2009	17.0	15.6	17.8	−1.2	0.7
1978–90	15.5	16.8	14.4	1.1	−1.0
1990–2000	13.6	11.2	15.6	−2.1	1.8
2000–09	22.9	18.9	25.1	−3.3	1.8

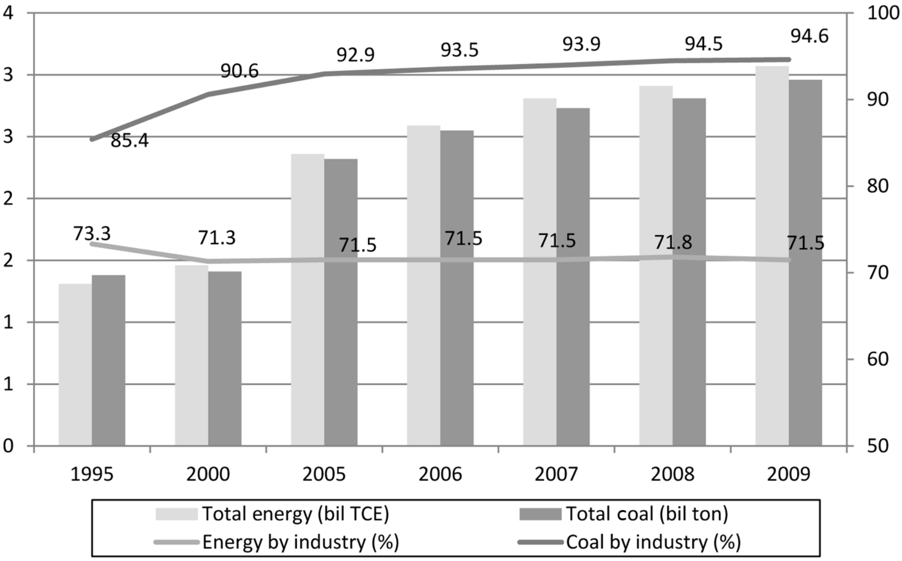
Source: *NBS, China Industry Economy Statistical Yearbook, 2010.*

services industry relative to all the other major economies in the world. Even in comparison with other BRIC economies, the Chinese economy is far more dominated by the industrial sector.

The industrial sector can be further divided into two subsectors: heavy and light industries. The composition and structural changes within the industrial sector explain why the Chinese economy becomes more energy intensive over time. Table 4 shows the industrial output values and their composition by the two subsectors for the period 1978–2009. In 1990, light industry accounted for 49 percent of the total industrial output value but this share declined to 29.5 percent by 2009. On average, industrial output value grew rapidly at 13.6 percent per year during 1990–2000 and 22.9 percent per year during 2000–09. The output value of the heavy industry increased faster at 15.6 percent and 25.1 percent, respectively, during the same periods. As heavy industry is more energy intensive than light industry (in general), its more rapid growth raises the energy intensity of the Chinese economy on the whole.

Figure 3 shows that during 2000–09, total energy consumption in China increased 106.7 percent—from 1.5 to 3.1 billion TCE. Over the same period, energy consumption by the industrial sector increased 111.2 percent from 1.04 to 2.2 billion TCE. Measured by coal consumption, the industrial sector's share rose by almost 10 percentage points from 1995, to 95 percent by 2009. In 2009, the industrial sector contributed only 46 percent of GDP but was responsible for over 71 percent of total energy and 95 percent of total coal consumption, indicating that this sector is highly energy inefficient in terms of units of added value.

Figure 3. Energy and coal consumption by the industrial sector, 1995–2009



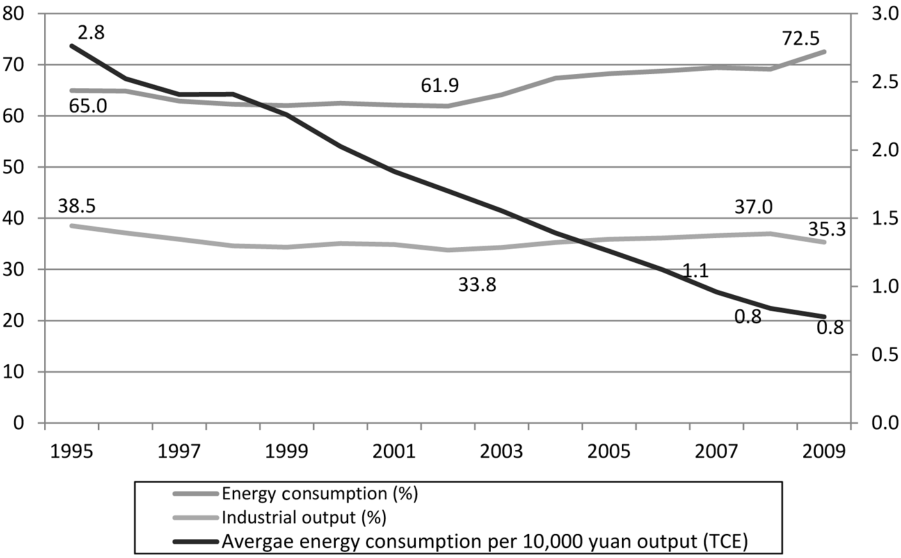
Source: *NBS, China Industry Economy Statistical Yearbook, 2010.*

3.2 Fast expansion of energy-intensive industries and products

There are over 40 industrial subsectors in China, but eight sub-sectors are responsible for 35 percent of total industrial output value and 60 percent of energy consumption over the period 1995–2009 (Table 5). These subsectors are non-metallic mineral products; petroleum, coking, nuclear fuel; paper and paper products; ferrous metals; metal products; textile; non-ferrous metals; and chemical products. They consistently account for more than 60 percent of industrial energy demand, a share that is increasing in recent years (Figure 4). From 1995 to 2009, their industrial output share declined from 39 percent to 35 percent, but their energy consumption share rose from 65 percent to 73 percent (Figure 4, Table 5). These figures suggest that these eight industrial subsectors are far more energy-intensive than the other industrial subsectors, presenting a serious challenge to China's industrial policy, which is geared toward these energy-consuming and polluting industries.

It is encouraging to note that average energy consumption for each unit of output has declined over the past decade (Figure 4). To produce 10,000 RMB of output in these eight key industries, these industries consumed an average of 0.8 TCE in 2009, representing a decline of 76 percent from the 1995 levels. Nonetheless, the decline in

Figure 4. Industrial production and energy consumption of eight key industries to total



Source: *China Industry Economy Statistical Yearbook, 1996–2010; China Energy Statistical Yearbook, 1996–2010.*

energy intensity measured by gross industrial output value is somewhat misleading. This is because the share of value-added in gross output value declines over time, implying that the decline in energy intensity is overestimated relative to energy consumption per unit of value-added. It needs to be stressed that we can only measure energy intensity based on gross industrial output value because there is a lack of matching data for both industrial value-added and energy consumption.

Another factor triggering the fast expansion of China's heavy industry is increased internal consumption and external demand. As mentioned earlier, higher living standards not only increase per capita ownership of electrical appliances, but also allow Chinese residents to purchase more energy intensive products, such as motor vehicles and houses. This in turn accelerates the production of these products and the development of the automobile and real estate industries.

Table 6 lists the outputs of key energy intensive industrial products over the period 1978–2009. It shows that the production of motor vehicles experiences the fastest growth over the past decade. Total output increased by almost seven times from 2000 to 2009, with China surpassing the United States to become the world's biggest automobile producer and consumer. Meanwhile, the production of real

Table 5. Industrial outputs of eight key industries and their energy consumption, 1995–2009

Energy consumption/10,000 yuan	1995	2000	2005	2009
Non-metallic mineral products	4.4	3.7	2.6	1.3
Petroleum, coking, nuclear fuel	2.8	1.6	1.1	0.7
Paper, paper products	2.1	1.4	0.9	0.6
Ferrous metals	5.1	4.0	2.0	1.6
Metal products	0.6	0.5	0.4	0.2
Textile	0.8	0.6	0.5	0.3
Non-ferrous metals	2.1	1.9	1.0	0.7
Chemical products	4.2	2.5	1.6	0.9
GIOV (billion yuan)	5,424	8,567	22,887	46,443
GIOV of 8 industries (billion yuan)	2,090	3,006	8,219	16,412
Eight industries in total (percent)	**38.5**	**35.1**	**35.9**	**35.3**
Energy use of 8 industries in total (percent)	**65.0**	**62.5**	**68.3**	**72.5**

Source: *China Industry Economy Statistical yearbook, 1996–2010; China Energy Statistical Yearbook, 1996–2010.*

Note: *GIOV = gross industrial output value. All the values are measured in 2000 prices.*

Table 6. Output of key energy intensive industrial products, 1978–2009

	Home refrigerators (mil sets)	Chemical fertilizers (mil tons)	Motor vehicles (mil)	Pig iron (mil tons)	Crude steel (mil tons)	Cement (mil tons)
1978	0	8.7	0.1	34.8	22.1	65.2
1980	0	12.3	0.2	38.0	27.2	79.9
1985	1.4	13.2	0.4	43.8	36.9	146.0
1990	4.6	18.8	0.5	62.4	51.5	209.7
1995	9.2	25.5	1.5	105.3	89.8	475.6
2000	12.8	31.9	2.1	131.0	131.5	597.0
2005	29.9	51.8	5.7	343.8	377.7	1,068.8
2006	35.3	53.5	7.3	412.5	468.9	1,236.8
2007	44.0	58.3	8.9	476.5	565.6	1,361.2
2008	47.6	60.1	9.3	470.7	584.9	1,400.0
2009	59.3	63.9	13.8	552.8	694.1	1,644.0
Average annual growth rate (percentage)						
1978–2009	28.0	6.6	15.7	9.3	11.8	11.0
1978–90	53.1	6.6	10.9	5.0	7.3	10.2
1990–2000	10.7	5.4	14.9	7.7	9.8	11.0
2000–09	**18.6**	**8.0**	**23.5**	**17.3**	**20.3**	**11.9**

Source: *NBS, China Statistical Yearbook, various issues (1980–2010).*

estate–related products (that is, all other products in Table 6) increased substantially since 2000.

External demand boosts the production of energy-intensive products further. Rising demand drives the expansion of production capacity of the Chinese companies and underpins a substantial rise in international prices of many minerals and metals. Table 7 presents the export values of key energy intensive industrial products over 1995–2009. Tough economic conditions worldwide during the 2008 global financial crisis reduced China's exports by 13.9 percent in 2009, so the growth rate analysis here is based on the period prior to 2008. Growth rates of all four energy-intensive products are higher than the growth of total exports. For example, during 2005–08, China's exports rise by 23.4 percent per year whereas the exports of rolled steel,

Table 7. Exports of key energy intensive industrial products by China (billion US$)

	1995	2000	2005	2008
Total exports	62.1	249.2	762.0	1,430.7
Coke and semi-coke	0.7	0.9	2.3	5.8
Rolled steel	2.2	2.2	13.1	63.4
Rolled aluminium	0.1	0.3	2.0	6.4
Motor Vehicles	n./a.	0.2	1.9	8.9
Average annual growth rate (percentage)	**1995–2008**	**1995–2000**	**2000–08**	**2005–08**
Total exports	27.3	32.0	45.8	23.4
Coke and semi-coke	17.9	6.0	46.3	35.4
Rolled steel	29.6	0.4	55.9	69.3
Rolled aluminium	35.2	20.5	53.5	48.3
Motor vehicles	n./a.	n./a.	59.3	67.1

Source: *NBS, China Statistical Yearbook, various issues (1996–2010).*

Note: *Exports dropped in 2009 due to the world financial crisis but recovered sharply in 2010 and 2011.*

rolled aluminium, and motor vehicles are up by 69.3 percent, 48.3 percent, and 67 percent, respectively. In 2008, China exported about 59 million tons of steel and 640,000 units of motor vehicles. It is obvious that controlling energy consumption requires appropriate adjustment of China's export mix. China should reposition itself toward the higher value-added end of the international production chain rather than acting as a world factory for low-value and polluting products.

3.3 Relocation of industrial production from the coastal to the inland regions

Energy efficiency of economic activities varies significantly across the country. Due to the 2008 global financial crisis and rising labor and land costs, many traditional manufacturing industries have relocated from the coastal to the inland areas. As energy efficiency is significantly lower in the inland areas than in the coastal regions, this industrial relocation reduces the overall energy efficiency of China's industrial production. Table 8 compares the energy consumption per unit of GDP production among the three large regions in China (East [coastal], Central, and West) to illustrate this point.

From 1990 to 2009, energy and electricity consumption per unit of GDP declined by 53 percent and 25 percent, respectively, across the whole country. On average for the whole country, 1.9 TCE of energy and 1,892 kWh of electricity were required to produce 10,000 RMB of GDP measured in 2000 prices in 1990. For the same amount of output, only 1.37 TCE of energy and 1,427 kWh of electricity were required in 2009.

The variation in the amount of energy and electricity to produce the same amount of GDP shows significant divergence between regions. For example, to produce 10,000 yuan of GDP in 1990, the 2.6 TCE of energy and 1,822 kWh of electricity in the East were much lower than the 3.27 TCE and 1,973 kWh in the West. In 2009, to

Table 8. Energy production and consumption by region, 1990–2009

		1990	1995	2000	2005	2006	2007	2008	2009
Energy production (share of national total, percent)									
Coal production	East	21.0	24.9	18.1	15.9	14.9	13.8	12.1	11.9
	Central	57.7	57.0	58.3	59.2	58.8	60.0	61.5	60.9
	West	21.3	18.2	23.6	24.9	26.2	26.3	26.4	27.3
Power generation	East	47.1	49.9	48.4	48.4	48.0	46.3	43.7	43.9
	Central	35.0	32.3	32.9	33.2	33.1	34.8	36.4	35.6
	West	17.9	17.7	18.7	18.4	18.9	19.0	19.9	20.6
Energy consumption (TCE/10,000 yuan of GDP) at 2000 prices									
TCE/GDP	East	2.60	1.76	1.34	1.28	1.25	1.24	1.20	1.15
	Central	3.15	2.49	1.70	1.83	1.80	1.75	1.65	1.58
	West	3.27	2.90	2.11	2.15	2.09	2.04	1.93	1.86
	All China	**2.90**	**2.15**	**1.55**	**1.55**	**1.52**	**1.49**	**1.43**	**1.37**
Electricity consumption (kWh/10,000 yuan of GDP) at 2000 prices									
kWh/GDP	East	1,822	1,459	1,312	1,379	1,382	1,416	1,369	1,324
	Central	1,953	1,738	1,387	1,521	1,589	1,589	1,517	1,459
	West	1,973	2,014	1,852	1,861	1,898	1,929	1,827	1,794
	All China	**1,892**	**1,624**	**1,408**	**1,482**	**1,507**	**1,533**	**1,473**	**1,427**

Source: *NBS, National Statistical Yearbook, various issues (1991–2010) and China Energy Statistical Yearbook, 2010.*
Note: *TCE = tons of coal equivalent. "East" includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, and Guangdong. "Central" includes Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan, Guangxi, and Hainan. "West" includes Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang. GDP value is calculated at 2000 constant prices.*

produce the same amount of GDP, only 1.15 TCE and 1,324 kWh was required in the East, compared with 1.86 TCE and 1,794 kWh in the West. On average, the eastern region was 62 percent more energy efficient and 35 percent more electricity efficient than the western region in 2009. This implies that any shift of industrial production from the East to the West reduces China's overall energy or electricity efficiency significantly.

The turning point in the spatial distribution of industrial production took place in 2005. Before 2005, the eastern region tended to grow faster than the inland regions. After 2005, the inland regions outperformed the eastern region in both GDP growth and industrial production. In particular, the most energy-consuming and polluting industries moved more quickly from the eastern to the inland regions after 2005, as shown in Tables 9 and 10. From 2005 to 2009, the share of national output accounted for by the eastern region declined and output by the central and western regions increased in all the most energy-consuming and polluting sub-industries, reaching a 6-percentage-point decline in the eastern region's share for metal products.

During the past two decades, the eastern region alone produced almost 60 percent of China's GDP and 70 percent of China's industrial output value but consumed less than 50 percent of the country's total energy. During the period from 2005 to 2009,

Table 9. GDP, production, and energy consumption of 8 key industries by region, 1990–2009

		As percent of national total				Average annual growth, percent		
	Region	**1990**	**2000**	**2005**	**2009**	**1990–09**	**2000–09**	**2005–09**
GDP	East	49.9	56.8	59.1	57.6	17.6	16.0	15.6
	Central	33.7	29.7	27.8	28.9	15.8	15.5	17.5
	West	16.9	13.6	13.2	13.5	15.4	15.8	17.2
Industrial output value	East	61.1	69.5	72.2	67.7	17.6	22.5	23.3
	Central	27.0	21.1	19.1	22.8	15.9	23.9	30.9
	West	11.9	9.4	8.7	9.5	15.7	23.1	28.3
Energy consumption	East	44.4	49.0	48.9	48.3	7.3	9.9	7.6
	Central	36.6	32.5	32.9	33.3	6.3	10.4	8.2
	West	19.0	18.5	18.3	18.4	6.7	10.0	8.1
Electricity consumption	East	47.7	52.9	55.0	53.4	10.0	11.9	9.4
	Central	34.8	29.2	28.5	29.6	8.5	11.9	11.2
	West	17.6	17.9	16.5	17.0	9.2	11.2	11.1

Source: *NBS, China Industry Economy Statistical Yearbook, 1991–2010.*

Note: *"East" includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang , Fujian, Shandong, and Guangdong. "Central" includes Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan, Guangxi, and Hainan. "West" includes Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang. Growth rates of GDP and industrial outputs are in current prices.*

Table 10. GDP, production, and energy consumption of 8 key industries by region, 1990–2009

		Share in national total percent			Average annual growth percent	
Energy-consuming industries	**Regions**	**2000**	**2005**	**2009**	**2000–09**	**2005–09**
Non-metallic mineral products	East	64.0	64.7	58.7	22.4	25.1
	Central	25.9	23.8	30.9	26.0	36.9
	West	10.1	8.6	10.3	23.9	34.5
Petroleum, coking, and nuclear fuel	East	66.7	64.2	61.0	18.0	14.2
	Central	25.5	23.1	23.7	18.2	16.5
	West	7.8	12.7	15.3	28.4	21.1
Paper and paper products	East	73.4	76.9	71.6	19.8	16.6
	Central	19.8	18.1	21.9	21.4	24.5
	West	6.8	5.1	6.5	19.6	26.4
Ferrous metals	East	64.1	67.8	66.1	28.1	17.9
	Central	24.4	23.2	24.5	27.7	20.3
	West	11.4	9.1	9.5	25.0	20.0
Metal products	East	85.8	88.1	82.0	22.2	22.9
	Central	10.4	8.8	12.6	25.4	36.9
	West	3.8	3.1	5.4	27.5	43.6
Textiles	East	78.9	85.7	81.6	18.5	14.6
	Central	16.4	11.1	14.5	16.4	24.1
	West	4.6	3.3	4.0	15.9	21.8
Non-ferrous metals	East	40.9	48.8	46.9	30.3	25.7
	Central	32.6	32.2	37.6	30.4	31.9
	West	21.7	19.0	15.4	23.5	20.5
Chemical materials and chemical products	East	67.6	71.8	69.8	23.4	21.7
	Central	22.3	18.7	21.0	22.1	26.3
	West	10.1	9.6	9.2	21.6	21.2

Source: *China Industry Economy Statistical Yearbook, 1991–2010.*

Note: *"East" region includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, and Guangdong. "Central" region includes Shanxi, Inner Mor. Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan, Guangxi, and Hainan. "Western" region includes Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang.*

industrial output value of the eastern region rose by 23.3 percent annually while the same ratios for the central and western regions were 30.9 percent and 28.3 percent, respectively. Relocating companies and manufacturing activities from the eastern to the central and western regions has inevitably caused more energy consumption per unit of GDP and industrial production. As the share of GDP and industrial production generated by the eastern region declined from 2005, it resulted in rising inefficiency in energy and electricity consumption for the whole country.

The factors that generate China's challenges in terms of energy efficiency and the environment are deeply ingrained in the structure and development of China's economy. A focus on secondary industry to lead development, and in particular heavy industry, makes transformation of the system difficult. Further, a regional move out of expensive coastal cities by heavy industry increases the inefficiency of energy use, while also increasing costs to transport energy into the consuming coastal areas. Yet there are specific policy measures that can be adopted to directly combat these difficulties.

4. Conclusions and policy implications

We propose six policies to control the surging energy consumption and to ensure sustainable economic growth. The first policy measure is for China to accelerate the pace of its economic structure transformation. Instead of focusing on a single target of achieving certain levels of aggregated GDP growth, more attention should be paid to value-added and job creation in different industries. China should reduce its reliance on heavy industry and devote more resources to support the development of the "strategic emerging industries" including computers, mobile phones, hybrid vehicles, and biomedicines, as stated in China's 12th FYP.

The second policy measure to control energy consumption and promote sustainable economic growth is for China to change its export structure, which has been dominated by low-quality cheap energy-intensive products, and has accounted for at least one-third of the energy consumed by China (Walsh 2009). As China's comparative advantages in these products dries up, there is the need to shift its production chain toward the higher value-added end. In the coming decade, China should focus more on research and technological innovation, developing a series of high-tech (and low-energy-intensive) products such as high-resolution TVs, computers, computer software, mobile phones, high-value garments and clothing, medicines, and so forth, to restructure its export portfolio.

The third policy measure is to reform the pricing system. To protect the households and, to a lesser extent, industrial and commercial enterprises, China sets strict restrictions on the consumer prices of primary energy products, such as coal and crude oil. This means that energy prices in China do not fully reflect environmental impacts, resources scarcity, and supply and demand imbalances (Chai et al. 2009). Such low energy prices foster the growth of energy intensive industries, reduce pressure to improve energy efficiency, and encourage wasteful consumption.

In China, coal prices are influenced by the market but wholesale power prices paid to generators are still set by the government with some variations according to age, efficiency, and location of power plants. As a result, coal mining companies and crude oil producers make substantial profits, but power generators and oil refiners suffer tremendous losses. Pressure from the international market has forced China to raise its domestic energy and electricity prices closer to the global level. Nevertheless, they are still distorted by subsidies, quotas, and other forms of state control (The Economist 2007). Such a dual pricing system leads to various problems. Instead of selling domestically, power generators and oil refiners export at a profit, causing an internal energy shortage. Moreover, rising energy prices do not affect end users, encouraging waste and undermining the government's energy conservation efforts. Finally, artificially low energy prices lose their potential to stimulate domestic exploration and production. This hinders China's long-term energy plan. To overcome these problems, the Chinese government has to fully liberalize its energy pricing system, allowing free-market competition to promote efficiency.

The fourth policy measure to help curb energy consumption is to increase public awareness and enforce tougher standards on building design. Residential houses and commercial offices are a large source of energy consumption and carbon emissions, responsible for over 40 percent of final energy consumption worldwide. Hence, enhancing building energy efficiency is one of the quickest and cleanest ways to mitigate climate change. Locating residential and commercial housing near public transportation systems—for example, transit-oriented development (TOD) and pedestrian-oriented development—can also improve energy efficiency. Many cities throughout the world use TOD, including Vancouver, Denver, Montreal, San Francisco, and Hong Kong (Olympic City, etc.).

Improving building energy efficiency has the potential to realize energy saving for businesses and consumers. For example, among all types of energy consumption in the real estate industry, space heaters account for the largest percentage (Lang 2004). In north China alone, residential heating consumes over 30 percent of total real-estate energy consumption. Compared with countries in Western Europe or North America, which have similar weather conditions, however, each unit of construction area of Chinese residential buildings consumes two to three times more energy for heating (Wu 2008). Therefore, China still has a huge potential to save energy by improving building energy efficiency.

The fifth policy measure is to ensure energy security. The government should provide more financial support for domestic energy exploration and production, and for mass transit construction.

The sixth policy is to diversify the country's energy sources. Because it is hard to transform China's coal-based energy consumption structure, another way to improve its energy efficiency is to adjust its energy structure via technological change and management advancement (Chai et al. 2009). More emphasis should therefore be placed on cleaner and more renewable sources, such as natural gas, nuclear power, hydro power, and solar and wind power.

In fact, China has considered the issue of developing renewable resources as a national strategy for a long time. For example, China's Renewable Energy Law implemented in February 2005 (Zhang et al. 2009) targets the country's abundant renewable resources, especially wind and hydropower. Wind energy utilization, especially onshore grid-connected wind power generation, has been used in China for over 30 years (Han et al. 2009). The country is now the global leader in total power capacity from renewable energy, including wind turbines and solar photovoltaic) cells (Martinot 2010).

Rising utilization of renewable resources helps rebalance energy supply between different regions. Fossil fuels, such as coal, oil, and natural gas are mainly located in the Shanxi, Inner Mongolia, Shaanxi, Heilongjiang, and Xinjiang provinces, whereas the exploitable potential of hydropower resources, solar energy and wind farms are distributed in the Southwest (Sichuan and Yunnan), Northwest (Qinghai and Xinjiang), Northeast (Liaoning and Jilin), East (Hebei and Jiangsu), and West (Gansu) (Zhang, Liorb, and Jin 2011). Each of the provinces should devote more efforts to developing energy resources wherever there is comparative advantage. This not only diversifies the overall energy supply structure but also has the potential to save transportation-related costs and reduce reliance on importing energy.

Nevertheless, the development of renewable resources in China still faces many challenges, such as technology development, transmission constraints, market barriers, policy development, and restructuring. For example, it is estimated that about one-third of the wind generation capacity was not connected to the national grid in recent years due to the relatively small scale of energy produced compared to the coal-fired power plants (Wang, Yin, and Li 2010). Moreover, convincing the general public about the safety of nuclear power is another challenge, particularly after the 2011 Tōhoku earthquake and tsunami disaster in Japan.

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