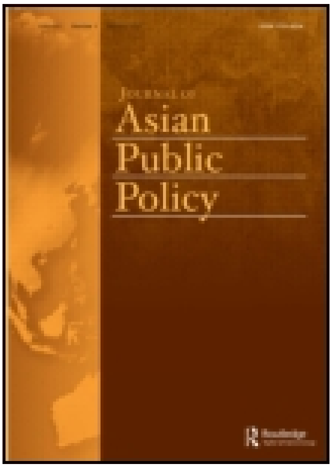

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Investigating economic growth, energy consumption and their impact on CO_2 emissions targets in China

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RESEARCH ARTICLE

Investigating economic growth, energy consumption and their impact on CO_2 emissions targets in China

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This article aims to analyse economic growth, energy consumption and carbon dioxide (CO_2) emissions data in China comparing with the US and Japanese data. Then, we try to evaluate the Chinese government's targets in reducing energy use and carbon intensity. Economic growth is a key factor that determines the Chinese's ability to meet these targets. If we suppose that China's economic growth is maintained at 9.54% per year, and total primary energy supply (TPES) growth is stabilized at 3.82% on average, the country would be able to cut energy consumption per unit amount of gross domestic product (GDP) by 23.5% in 2010: if carbon-GDP intensity could decrease by 4.5% on average, China would be able to achieve a reduction in carbon-GDP emissions target by 49.87% or above the target in 2020. We suggest that China needs to stabilize CO_2 per total primary energy supply intensity. This target can also push government to implement clean coal technology and promote renewable energy target more seriously. Finally, we argue that binding target on CO_2 emissions has worked effectively in the case of Japan, but we have to be careful when analysing economic-energy-CO_2 emissions in Japan due to 'the lost decade' of Japan's economy. Finally, we expect that developed countries such as Japan and the United States can help China not only in transferring technology but also in strengthening the institutional capacity such as in harmonizing regulations, in energy planning and in developing human capability.

Keywords: economic growth; energy consumption; primary energy supply; carbon dioxide emission; China; Japan; the United States

1. Introduction

As the country with the largest population in the world, China has shown impressive and consistent economic growth since the last three decades. In terms of purchasing power parity (PPP), China was the second largest economy in the world, sharing 15% of the world gross domestic product (GDP) in 2006 (International Energy Agency (IEA) 2007a). China has now become important as an essential engine of world economic growth. However, there is an ongoing debate on growth sustainability and sustainable development. Bergsten *et al*. (2009) argued that China has experienced an unbalanced economic growth. The authors contend that promoting energy-intensive heavy industry and investment-led growth has aggravated income inequality, undermined employment gains, heightened trade tension and contributed to serious energy and environmental problems for both China and the rest of the world. The rebalancing of China's economic growth was formally announced in

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December 2004 during the annual Central Economic Work Conference held by the Chinese Communist Party (Bergsten *et al*. 2009).

According to the Chinese government's 11th 5-Year Plan (2006–2010), economic growth in China will slow down and reach about 7.5% per year during that period. This step is taken to minimize the overheating of the economy. Further, the Chinese government aims to cut energy use per unit of GDP by 20% in 2010 compared with the 2005 level (IEA 2007a). The plan also states that the government needs to diversify energy resources, protect the environment, enhance international cooperation and ensure a stable supply of affordable and clean energy in support of sustainable economic and social development (IEA 2007a). This programme is well known as *jieneng jianpai* or energy efficiency and pollution abatement. Zhu Rongji in 1998 also stated that China should find some constructive role to play on the issue of climate change (Economy 2010). Similarly, the President of PR China Hu Jintao at the 15th Asia-Pacific Economic Cooperation (APEC) leaders meeting on 8 September 2007 stated the importance of 'low carbon economy'. Even China has predicted that global warming has direct impact on the country's temperature. Gang (2009) mentioned that 'annual average air temperature has increased by 0.5°C to 0.8°C during the past 100 years, which was slightly larger than the average global temperature rise'. Thus, it is apparent that the Chinese government puts more weight on green growth rather than high economic growth.

The analysis of the economic, energy, carbon dioxide (CO_2) emission issue in China needs to consider before and after controlling the number of population. China's GDP per capita, energy production per capita and total primary energy supply per capita (TPES) are still below world average, even for CO_2 emissions per capita are slightly above the world's level (see Table 1). Currently, China's population covers about 20% of the world population, whereas Organization for Economic Cooperation and Development (OECD) countries cover about 18%: Japan and the United States comprise 1.9% and 4.6%, respectively. A large population also has implications on the quantity of resources that have to be supplied, such as energy. As a result, measuring economic and energy indicators by controlling the population will indicate a huge gap between China and the developed countries.

However, without controlling the population, special attention needs to be addressed on China because China has influenced power in terms of economic, energy and CO_2 emissions. In 2008, China emitted 6508 Mt of CO_2 or about 22% of the world's emissions or China is the largest source of CO_2 emissions in the world (Table 1). If we measure CO_2

Table 1. Key economic, energy and CO_2 emissions indicators in 2008.

Economy	GDP per capita	TPES per capita	CO_2 per capita	GDP – PPP (billion 2000 USD)	TPES (Mtoe)	CO_2 emissions	CO_2 per GDP (PPP) (kg CO_2 per 2000 USD)
China	8,150	1.60	4.91	10,803.84	2,116.43	6,508	0.6
Japan	28,175	3.88	9.02	3,597.63	495.84	1,151	0.32
The United States	37,658	7.50	18.38	11,742.29	2,283.72	5,596	0.48
OECD	27,620	4.56	10.61	32,868	5,422	12,630	0.38
World	9,549	1.83	4.39	63,866	12,267	29,381	0.46

Notes: GDP per capita = gross domestic product (purchasing power parity (PPP) – 2000 USD) in USD; energy production per capita (tonnes oil equivalent); total primary energy supply (TPES) in tonnes oil equivalent; CO_2 emissions from fuel combustion only (Mtoe of CO_2).
Source: Calculated from Key World Energy Statistics (2010) and International Energy Agency (2010).

emissions with respect to GDP at PPP and constant price, China has the highest value, much higher than the world's value. This indicates that the economic growth in China will also rapidly increase the world's CO_2 emissions level, because China's economy is more carbon intensive compared with other countries.

China's rapid economic growth also increases the energy demand of the world. As seen in Table 1, TPES in China is approaching the US level. According to IEA's estimates, there was an increase in global primary energy demand between 2000 and 2006, and about 45% was generated by China (IEA 2007a). Bergsten *et al*. (2009) attributed the dramatic increase in China's energy consumption to a rise in its heavy industries, for example, flat glass, cement, steel and aluminium. These industries have developed because of several factors: low operating cost, low labour cost, high profits, economic incentives from local governments and the ease of obtaining credit from the banks (Bergsten *et al*. 2009).

Thus, an impressive economic growth in China not only obtains benefits for China and the world but also poses a challenge and a dilemma in dealing with energy and environmental problems, especially CO_2 emissions. This article aims to investigate quantitatively the impact of China's rapid economic growth on the country's energy and CO_2 emission profile comparing with the US and Japan cases. More specifically, this article also attempts to evaluate the Chinese government's targets with respect to reducing energy use in 2010 and carbon intensity in 2020. This article contributes to two groups of existing studies. First, there is still a deadlock dialogue between developed and developing countries to measure global warming; especially developed countries want China to take serious action to reduce CO_2 emissions. In this article, we investigated that China also has several policies to reduce CO_2 emissions, while there is also a growing support from the world to China. Second, we offer an alternative approach on how emerging economies such as China can set a target on reducing CO_2 emissions intensity by controlling primary energy supply.

This study focuses on China, but we compare Chinese data with those of Japan and the United States for three reasons. First, we may argue that stages of economic development between China, Japan and the United States are incomparable. But, now China has become the new economy giant that pushes a global economic growth with rapid energy consumption and CO_2 emissions. Thus, to what extent do those countries share similarities and differences? Second, as an emerging economy, we believe that China also has responsibility to measure CO_2 emissions. By comparing China with Japan and the United States, decision-makers will be able to obtain some ideas on to what extent China has followed the path of green growth. Third, Japan is part of the Annex I parties in the Kyoto Protocol; on the other hand, the United States has not ratified the Kyoto Protocol. We consider that it is interesting to analyse the difference in terms of carbon footprint between two countries. Thus, this may bring some interesting ideas on how China needs to respond to the post-Kyoto Protocol framework.

The analytical framework is based on the interdependency between economic, social, energy and environment. This framework follows a new paradigm on green economy. According to the United Nations Environmental Program's green economy report entitled *Towards a Green Economy: Pathways to Sustainable Development and Poverty eradication*, 'a green economy as one that results in improved human well being and social equity, while significantly reducing environmental risks and ecological scarcity' (UNEP 2011).

This article is divided into six sections. Section 2 investigates historical trends of economic growth and energy data. Then, we try to elucidate on the interrelationship between economic and energy data in Section 3. In Section 4, we apply mathematical modelling techniques to both economic and energy data. In Section 5, we try to evaluate the Chinese

CO_2 emissions strategy in relation to economic and energy data. Finally, the conclusion and policy recommendations are provided in Section 6.

2. Trend analysis based on economic and energy indicators

2.1. GDP, economic structure and population

China's GDP has grown smoothly and has increased tremendously during the last three decades from about 183 billion USD in 1980 to about 3243 billion USD in 2010, an increase of more than 17.7 times (Figure 1). Japan's GDP and the United States's GDP increased by about 1.9 times and 2.3 times, respectively. Similarly, China's GDP per capita has increased from about 186 USD to about 2423 USD between 1980 and 2010. The rapid economic growth in China has a positive impact on narrowing the income gap in nominal terms between China and the countries being compared. In the 1980s, the GDP per capita gaps between China and Japan and China and the United States were both around 121 times while those were 16.4 and 15.6 times, respectively, in 2010. Since the mid-1990s the United States's GDP per capita has been approaching Japan's level. One of the reasons is the tendency of the United States's GDP to increase while Japan's GDP slightly increases. Japan's economy has been discussed by Hayashi and Prescott (2002) and Blanchard (2003), as cited in Leigh (2009). They argued that Japan entered a liquidity trap in the mid-1990s and this came to be known as the 'lost decade'. This terminology reflects three indicators: slow growth, deflation and output below the potential level.

A look at the literature provides some insights into the rapid economic growth in China. Hu and Khan (1997) argued that capital accumulation and increasing labour productivity are the driving forces of growth, but they said that the latter is more important, because the problem on capital is deepening in China. Further, they said that economic reforms have created more incentives to engage in rural collective enterprises (Sun and Pannell 1999). Economy (2010) said that the new incentives such as fiscal autonomy, the ability to approve capital construction projects and foreign joint ventures and greater leeway to appoint an

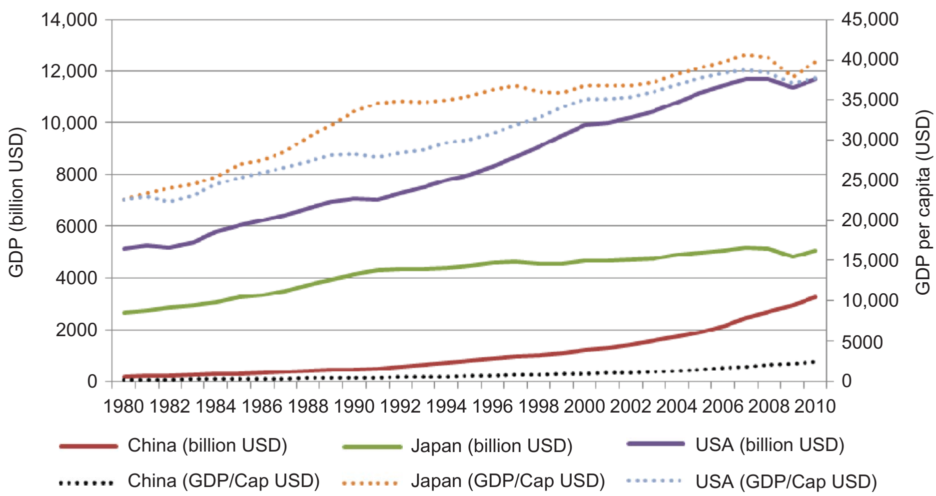

Figure 1. Gross domestic product (GDP) and GDP per capita in China, Japan and the United States.
Source: World Development Indicators.
Note: Measured at constant 2000 USD.

official at the provincial level have boosted entrepreneurial spirit among the local governments and the Chinese Communist Party leaders. Qin (2004) attributed the rapid growth in the services sector to industrialization and urbanization. He further explained that the labour shift from the agricultural sector which has low productivity to the services sector has a positive contribution to China's economy. Similarly, Wu (2002) pointed out that from the analysis of panel data at the provincial level, growth of physical capital, infrastructure, labour productivity, human capital and foreign investment were positively related to China's economic growth in the 1980s and 1990s.

However, there are risks on rapid economic growth in China due to the global financial crisis. Huang (2008) argued that slowdown of the US economy, elevated oil prices and normalization of domestic costs will challenge economic growth and inflation. Similarly, Tyers and Bain (2008) said that with exports almost half of China's GDP and most of these directed to Europe and North America, negative financial shocks in those regions might be expected to retard China's growth.

As seen in Figure 2, China has experienced a rapid economic transition. The agricultural value added as percentage of GDP decreased from 42% in 1968 to about 10.3% in 2009, whereas the share of the services sector increased from 26.7% to about 43.4% in the same time frame. Although the share of the manufacturing sector tended to fluctuate, since the last 10 years, its share to GDP was between 30% and 35%.

Similarly, Bergsten *et al*. (2009) concluded that, in the last three decades, the source of China's economic growth has shifted from consumption to investment. The share of consumption to GDP in the 1980s was about 50%, decreasing to about 45% in the 1990s and now reaching about 35%. At the same time, the share of investment increased from 37% in the 1980s to about 42% in 2007. In addition, Hu and Khan (1997) and Shane and Gale (2004) pointed out that China's open door policy led to a big capital inflow to China, driving technology transfer and strong export growth. Although foreign direct investment (FDI) becomes an important driver of economic growth in China, the distribution of FDI is very unequal across the regions (Graham and Wada 2001). About 71% of total FDI was concentrated in the coastal region, while the western part of China received less than 2% (Graham and Wada 2001). This also indicated a potential GDP gap among

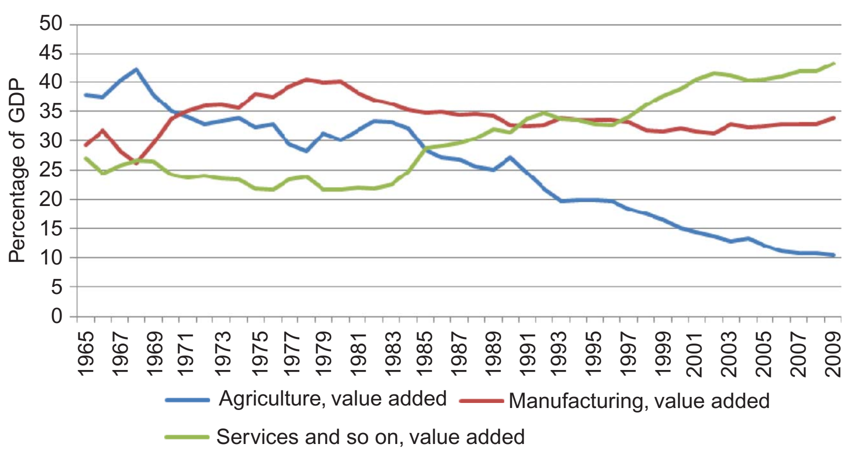

Figure 2. Trends in structural economic change in China.
Source: World Development Indicators.

the regions in China. Next, Fu (2006) argued that exports and FDI have played an important role in the increasing regional disparities in China. Further, a study conducted by Lyons (1998) in Fujian province, which implements special economic zone, indicated huge income disparities inside the province.

China is classified as a lower middle-income country.[1] The rapid increase in income per capita is also driven by the sharp decline in population growth. One of the reasons why China was able to approach Japan and the United States in terms of GDP per capita is its population control policy. Figure 3 illustrates China's reduction in population growth: from about 1.5% in the mid-1980s to about 0.5% in 2009. Since the early 1990s, the US population growth has been higher than China's. In contrast, Japan's population growth was −0.14% in 2010.

In the early 1970s, the Chinese government introduced the one-child policy and this reduced drastically the fertility rate. Currently, the fertility rate is about 1.7, similar to that of the Netherlands; at the same time, life expectancy has approached 71 years for men and 74 for women (UNFPA 2007, as cited in IEA 2007a). The one-child policy had negative impacts, for example, widespread female infanticide, a lopsided sex ratio, mass sterilization and forced abortion (*The Economist* 2009). On the other hand, slowing the fertility rate is better than population control for three reasons (*The Economist* 2009). First, it increases the size of workforce age relative to the number of children and old people. Second, it gives women a chance to work and this can increase the size of the labour force. Finally, low fertility rate accumulates capital per person.

The World Bank (2009) has pointed out that China's rapid economic growth is important for poverty reduction. Every 10% increase in per capita GDP contributed to reduction in the incidence of poverty by 9% (World Bank 2009). However, because of China's large population, by using international poverty standards (i.e. people consuming less than $1.25 per day in 2005 PPP dollar), the number of poor people in China is the second highest, after India (World Bank 2009). Similarly, the World Bank (2009) argued that the responsiveness of poverty to economic growth has decreased, from 2 between 1980 and 1985 to about 1 between 2000 and 2005.[2] Further, income inequality in China also tends to rise among

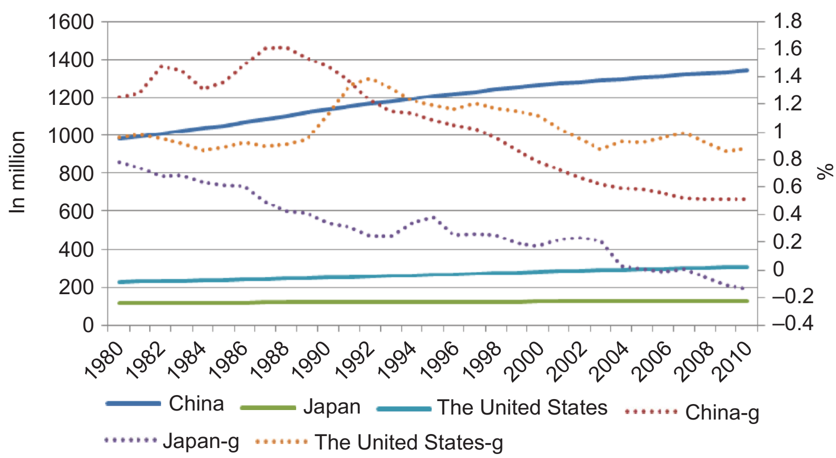

Figure 3. Dynamics of population for China, Japan and the United States.

Source: World Development Indicators.

Note: g indicates yearly growth rate in percentage.

income groups. Similarly, Long (1999) said that income inequality has deteriorated since the 1990s. According to the World Bank (2009), the Gini coefficient in China increased from 30.9% in 1981 to 45.3% in 2003. Even after adjusting for the rural–urban cost of living, the Gini index increased from 32.9% in 1990 to about 44.3% in 2005 (World Bank 2009). This indicates that the income gap between the richest and the poorest groups has been getting wider and wider in the last 20 years. Keidel (2007) also pointed out increasing inequality among regions and also between rural and urban areas in China.

Income disparities, rising demand for labour in the cities and significant wage gap between urban and rural in China have driven migration. Rural–urban migration has served as an important fuel for China's economic growth (Gong *et al*. 2008). Further, the massive rural–urban migration has served as a crucial contributor to total factor productivity (TFP) growth (Gong *et al*. 2008). The World Bank reported that the amount of net migration out of China decreased from 491,960 in the 1980s to about more than 1.7 million in 2010. Migration has a positive impact on poverty reduction (World Bank 2009). The probability of households with migrant workers to becoming poor is 30% less than households without migrant workers (World Bank 2009). We found that in the early 1980s, the share of urban population to rural population was 24%, but in 2009, the share was 78.6%. Further, Shan (2002) also suggested that any policies that attempt to reduce unemployment and more equal fiscal spending across the provinces can reduce income inequality in China.

2.2. Energy production, primary energy supply and consumption

Rapid economic growth in China has a direct consequence on more demand for resources such as energy. Migration also leads to a rapid increase in energy consumption in two ways (IEA 2007a). First, it increases demand for housing in the city, leading to an increase in consumption of energy such as electricity. Second, a reduction in the use of non-commercial energy source and an increase in the use of commercial energy source when having more people in the city result in a greater demand for energy such as that from the transportation sector. According to Bai and Qian (2010), from 1978 to 2007, the annual growth rate of electricity installed capacity and the amount of electricity generated were 9.1% and 9.2%, respectively, while annual growth of real GDP was 9.8%. Rapid growth in electricity production is due to strong investment incentives from the Chinese government (Bai and Qian 2010). Bai and Qian (2010) said that incentives created overinvestment, for example in 1997, thus the Chinese government suspended investment in electricity generation for 3 years. However, rapid economic growth increased demand for electricity and a surplus of electricity supply was shortly changed to shortage of power a few years later.

One of the most important parts of China's energy dynamics in the last three decades is its transformation from a self-sufficient energy consumer to the third largest net oil importer after the United States and Japan (IEA 2007a). Generally speaking, coal is the backbone of China's energy sector (IEA 2007a).[3] Data from IEA (2007a) showed that the contribution of coal to total primary energy is about 60%. IEA (2007a) also points to the industrial sector as the largest final user of energy; in recent years its share has gone back up to levels seen a decade ago. In the electricity sector, according to Kahrl *et al*. (2011), coal still accounted for 78% of China's generation mix in 2009. Industrial sector consumes more than 70% of China's net electricity demand and heavy industry dominates industrial load, accounting for 83% of industrial electricity consumption in 2009 (Kahrl *et al.* 2011).

Two terminologies are important in analysing the energy sector – total production of energy (TPE) and TPES (OECD 2009). TPE refers to a country's endowment in producing energy. By the definition, we can conclude that TPE is a function of the fuels extracted.

Thus, for a net energy importer country, TPE can be lower than the TPES, because TPES includes energy import. Four conclusions can be obtained from Figure 4. First, China's TPE increased rapidly compared with Japan and the United States. In 2006, China's TPE was higher than that of the United States. This indicates that China has experienced growing exploration activities for oil, gas and coal during the last three decades. Thus, China's mining and quarrying have boomed. Second, in terms of fuel extraction, Japan has lower energy resources than China and the United States. Similarly Oyama (1986) observed that about 90% of Japan's TPES was imported and that could affect Japan's economy if political and economic shocks from exporting countries occurred. For example, Takase and Suzuki (2010) pointed out that more than 80% of Japan's oil imports came from the Persian Gulf and over 60% of its natural gas imports as liquefied natural gas (LNG) came from southeast Asia. Third, TPE in Japan and the United States has remained constant during the last three decades.

Fourth, in terms of TPES, the lowest values were observed in Japan (Figure 4). Although in terms of TPES China approaches the US level, we see that China level is ahead of the United States when it comes to TPE in 2006. Since the mid-1990s, TPES in Japan has remained at the same level around 500 Mtoe. One of the reasons for this is the economic stagnation in Japan. In contrast, the primary energy supply tends to increase in the United States and China. Thus, TPES in Japan is expected to increase when the economy starts to grow. TPES in China started to grow much higher in 2001, more than 5%. The high demand for crude petroleum explains the very fast growth on TPES in China.

Comparing TPES per capita among China, Japan and the United States, we see that the gap between the United States with the highest TPES and China with the lowest has been becoming smaller (Figure 5). The gaps in TPES and TPE per capita among these countries tend to decrease. It is interesting to look at TPES per capita in Japan, which tends to increase in the same magnitude as China. There are two reasons for this. First, Japan's energy import tends to increase. Second, Japan's TPE also tends to increase, while that of the United States tends to decrease. Between 1980 and 2006, the average TPES per capita in China was about 0.827 toe, whereas those in Japan and the United States were 3.62 and 7.77 toe, respectively. In the same period, TPES in China and Japan increased by 137.38% and 39.78%, respectively, while that in the United States decreased by 2.56%.

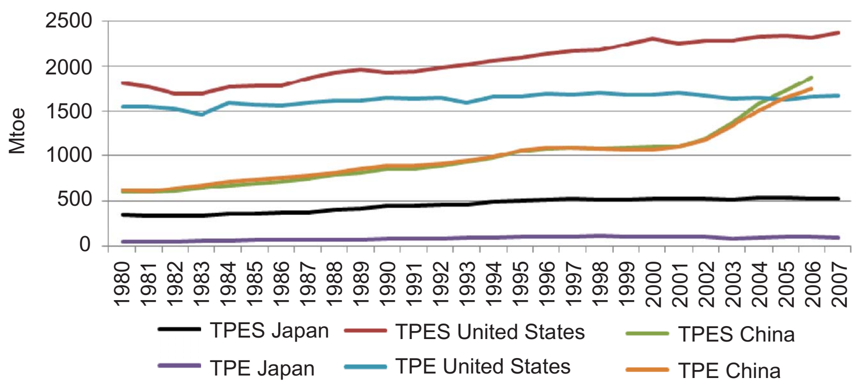

Figure 4. TPE and TPES in the three countries.

Source: Calculated from http://stats.oecd.org/Index.aspx?DatasetCode=CSP2009.
Notes: TPES, total primary energy supply; TPE, total production of energy. The latest figure for China is 2006 while for Japan and the United States is 2007.

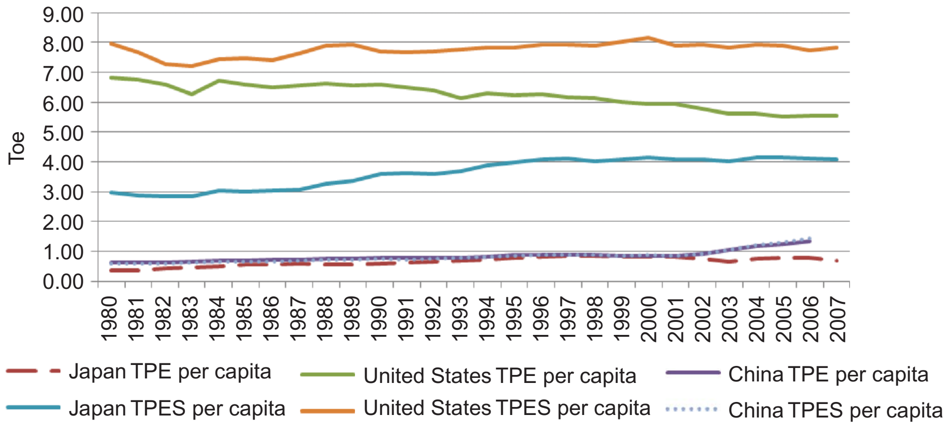

Figure 5. TPE and TPES per capita in China, Japan and the United States.

Source: Calculated from http://stats.oecd.org/Index.aspx?DatasetCode=CSP2009.
Note: TPES, total primary energy supply; TPE, total production of energy.

Thus, although China was higher than Japan in terms of TPES, the former was lower than the latter in terms of per capita primary energy supply.

The information on TPE and TPES has important implications on the net export and import of energy. As seen in Figure 6, between 1980 and 1997, China was a net energy exporter; after that, it became net energy importer. On the other hand, between 1980 and 2007, Japan and the United States were net energy importers, while the US energy import was larger than that of Japan's. Although China exports energy, the share of exports to TPE was relatively less than 3.35% between 1980 and 1997, while the share of import

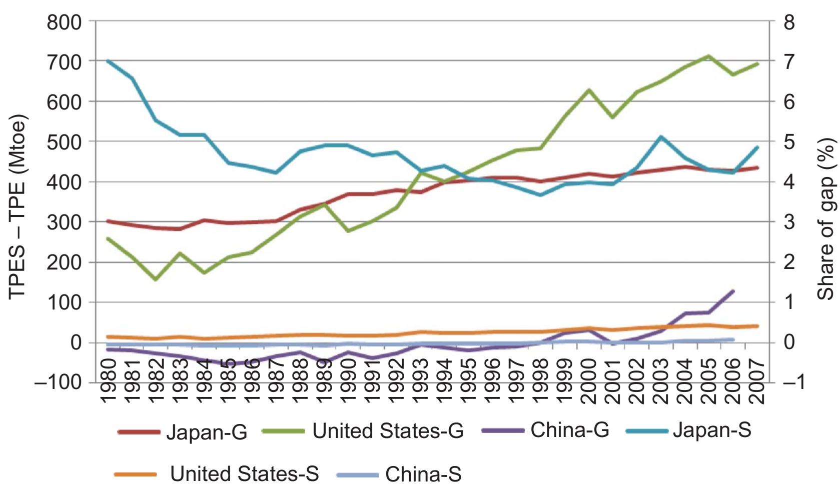

Figure 6. Energy gap and share of energy gap to total energy production.

Source: Calculated from http://stats.oecd.org/Index.aspx?DatasetCode=CSP2009.
Notes: Energy Gap = TPES – total production of energy (TPE) = import – export – international marine bunkers ± stock changes. Share of gap indicates the ratio of energy gap to total energy production; G, gap; S, share.

between 1997 and 2006 was about 2.80%. Japan's energy import with respect to TPE tended to fall from about 698.6% in 1980 to about 485% in 2007. In the case of the United States, the share of imports to TPE increased from 16.6% in 1980 to about 41.4% in 2007. Interestingly, we can conclude that Japan is relatively more successful in reducing its import dependency ratio compared with the United States, especially on oil consumption. IEA (2007b) reported that share of oil to TPES decreased from 52% in 1990 to about 43% in 2005 while share of coal increased from 17% to about 21%. Further, coal has been the principal replacement for oil in power generation, but in the future coal-fired generation plants are expected to be replaced by nuclear plants. On the other hand, between 2002 and 2006, China's energy imports increased rapidly from 11.2 Mtoe to about 129.4 Mtoe, an increase of about 1055%. This rapid increase resulted from dramatic increase in oil consumption.

Figure 7 shows the trend in the ratio of TPE to consumption in China between 1981 and 2008. A ratio above 1 means that consumption is larger than production and vice versa. Between 1981 and 1993, China had a positive energy gap in terms of oil, but between 1994 and 2008, China became a net oil consumer,[4] which means that China's consumption of crude petroleum is higher than its production, and the ratio between oil consumption and production increased from 1.021 in 1994 to about 1.895 in 2008. According to IEA (2007a), the demand for oil increased from about 1.9 million barrels per day in the 1980s to about 7.1 million barrels[5] per day. Oil imports increased from about –0.2 million barrels per day in the 1980s to about 3.5 million barrels per day.[6] Kambara (1984) and Smil (1998) pointed out problems on ageing fields that led to a small increase in oil production. Thus, Kambara (1984) emphasized that new exploration was needed. The Chinese government focused on the production side because China lacked in advanced technology, capital and personnel. Now, China aggressively looks for new wells and actively participates in oil extraction activities of other countries such as Canada, Russia, Mongolia, Thailand, Papua New Guinea, Iraq, Sudan, Peru and Venezuela (Smil 1998).

Furthermore, after decomposing the trend of China's energy production and consumption into three periods (Table 2), we see that, in the 1980s, the average energy production was much higher than energy consumption, thus China had a negative energy

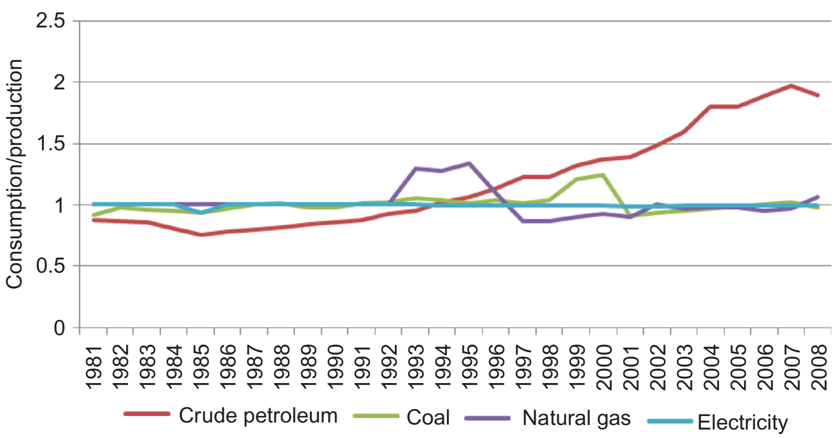

Figure 7. Ratio between energy consumption and production in China.

Source: Calculated from Asian Development Bank (ADB) – Key Indicators for Asia and the Pacific 2009.

Table 2. Average yearly energy production and consumption in China.

Energy	Crude petroleum (million t)	Coal (million t)	Gas (billion m^3)	Electricity (billion kWh)
1981–2008				
Production	149.00	1325.11	26.04	1216.11
Consumption	185.18	1329.75	26.09	1211.04
Gap	36.18	4.64	0.05	−5.07
1981–1989				
Production	121.00	840.00	13.22	431.44
Consumption	99.11	814.78	13.22	429.33
Gap	−21.89	−25.22	0.00	−2.11
1990–1999				
Production	150.10	1209.90	19.10	944.80
Consumption	160.50	1256.90	20.05	942.80
Gap	10.40	47.00	0.95	−2.00
2000–2008				
Production	175.78	1938.22	46.56	2302.22
Consumption	298.67	1925.67	45.67	2290.78
Gap	122.89	−12.56	−0.89	−11.44

Note: Gap = consumption – production.
Source: Calculated from ADB – Key Indicators for Asia and the Pacific 2009.

gap. However, since the 1990s, the average energy consumption has become larger than its production and the energy gap tended to increase, except for electricity. Between 2000 and 2008, the energy gap in crude petroleum became higher than that for the entire period, while for coal, gas and electricity production was higher than consumption. Rapid production of electricity was driven by the electricity shortage in the 1990s and the goal was to achieve a target electrification ratio. According to IEA (2007a), China was very successful in achieving the electrification ratio in 2005, as it reached 99%. However, Kahrl (2011) argued that China's current electricity system lacked the flexibility in demand, generation, transmission and pricing necessary to integrate renewable energy and reduce CO_2 emissions on a large scale at an acceptable level of cost and reliability.

3. Relationship between economic growth and energy consumption

This section makes a comparative analysis between China, Japan and the United States in terms of TPE and TPES in relation with GDP. Four important findings can be gleaned from Figure 8. First, China has shown rapid growth in primary energy supply and GDP growth, while in Japan and the United States, GDP grew faster than primary energy supply. Second, the ratios of TPES and GDP in Japan and the United States have not changed much since the 1980s. In China, the ratio tended to increase. Third, China's economic growth was relatively more energy intensive than those of Japan and the United States. This means that the energy requirement to produce one unit of GDP in China is relatively higher than those needed in Japan and the United States. Finally, China seemed to approach the United States in TPES, while the level of TPES in Japan remained almost the same.

Figure 9 shows the relationship between TPES per capita and GDP per capita for the three countries. There are two important findings. First, China lagged behind Japan and the United States in terms of TPES per capita and GDP per capita. During that period, per capita income in Japan and the United States increased at a much higher pace than TPES per capita. Meanwhile, in China, TPES per capita seemed to increase much higher

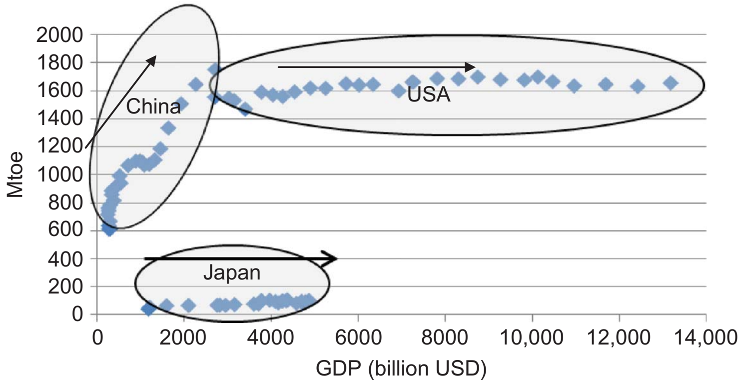

Figure 8. Total production of energy (TPE) (Mtoe) and gross domestic product (GDP) between 1980 and 2006.

Source: Calculated from http://stats.oecd.org.

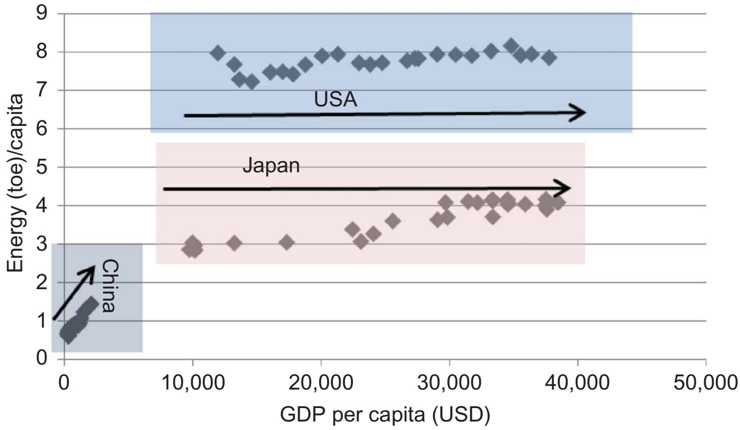

Figure 9. Total primary energy supply (TPES) per capita and gross domestic product (GDP) per capita between 1980 and 2006.

Source: Calculated from http://stats.oecd.org.

than GDP per capita. Second, although GDP per capita in Japan and the United States was growing, TPES per capita in the United States was much higher than that in Japan. On the other hand, TPES per capita in Japan tended to grow while that in the United States remained constant.

From mapping of energy cluster among China, Japan and the United States, it is clear that TPE per capita in China has more opportunities for further increase. Rapid economic growth, increasing standard of living and migration lead to an increase in per capita energy consumption and the government has to accommodate this by increasing energy production or TPES. Thus, the inequality in primary energy supply per capita between China, Japan and the United States tends to decrease. This leads to the new idea that controlling the energy growth between China and the controlling countries will be unfair, but further discussion to find the normative standards for energy per capita after considering economic, social and environmental conditions will be more constructive and important.

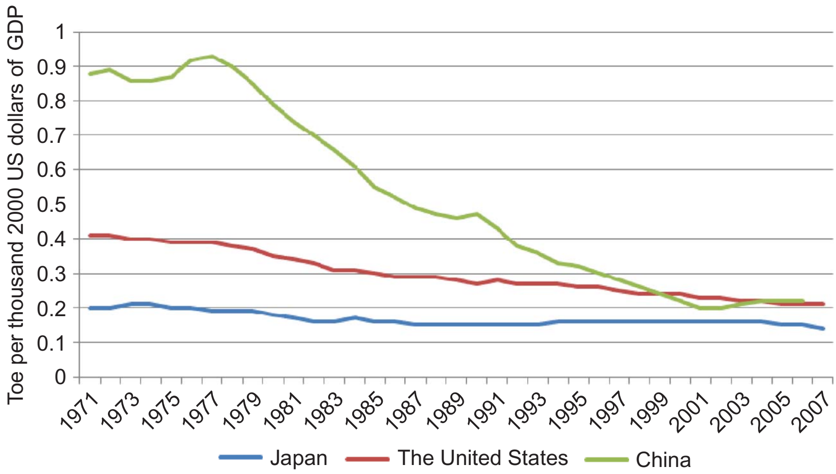

Figure 10. Ratio of total primary energy supply (TPES) to gross domestic product (GDP) in the three countries.

Source: http://stats.oecd.org/Index.aspx?DatasetCode=CSP2009.
Note: Tonnes of oil equivalent (toe) per thousand 2000 USD of gross domestic product (GDP) calculated using purchasing power parities (PPPs).

Figure 10 shows how much primary energy supply is needed in order to produce USD 1000 of GDP. The trend for China has been decreasing sharply since the mid-1980s and since 1999 it has been similar to the US level. Japan is more efficient in using energy, because for one unit of energy, its output is higher than those of China and the United States. Comparing energy production and GDP also reflects the stage of industrialization. A high-technology industry can produce high-value products compared with low–medium technology content by using the same amount of energy.

Reduction in energy intensity can be caused by several factors, for example, production shift to high-value added products, improvement in technology and changes in government policy towards energy use. Five policies were found to have a positive impact on increasing energy efficiency in China (IEA 2007a). First, in 1998, the Chinese government enacted the Energy Conservation Law. Second, in late 2004, the National Development and Reform Commission (NDRC) released a Medium and Long Term Plan for Energy Conservation, which required some sectors such as the industrial, transportation and construction sectors to achieve a specific target on energy efficiency target. Third, it was mandated that the performance of major industrial equipment, the performance of appliances and motor vehicles need to meet international standards. Fourth, contracts were made and targets were set with the top 1000 enterprises under the Energy Efficiency Program. Finally, since June 2007, the government has implemented the Program on Comprehensive Action Plan for Energy Saving and Emissions Reduction.

The economic and energy data analyses became the bases of four major conclusions. First, in terms of energy indicators such as TPE and TPES, China is relatively 'bigger' than Japan. Intuitively, the energy use in Japan and the United States has been devoted to high-value added products, while China is still in the early stage of deepening economic structure. However, the rising services sector in China leads to less energy intensity in China. Second, technology capacity in Japan and the United States is more advanced than in China as 'technology deepening' is related to the economic structure. Third, in terms of the relationship between energy and population, China is 'small sized' compared with Japan and the United States. However, we need to consider distribution issues in the case of China. For example, most of the petroleum consumption goes to the industry and transportation sectors. This means that most of the petroleum is consumed in urban area. The Chinese government needs to work hard to improve the energy efficiency at the industrial level while promoting mass rapid transport, which is necessary to reduce fuel demand from rapid urbanization. Thus, urbanization has created a demand not only for electricity but also for fossil fuel. Finally, energy production in China will tend to increase and the level may approach that of Japan or the United States. Under this condition, China will be the largest producer of energy, the largest primary energy supplier and the largest energy importer in the world.

4. Modelling analysis for economic and energy data

We apply the following mathematical model for investigating the time trend of economic and energy data:

$$y = Ke^{\lambda t} \tag{1}$$

where y is a dependent variable, which can be GDP, GDP per capita, primary energy supply or primary energy supply per capita; K and λ are parameters; and t indicates year. Parameter estimates for GDP and GDP per capita are given in Tables 3 and 4, respectively, for each period in each country. Those for primary energy supply (TPES) and primary energy supply (TPES) per capita are given in Tables 5 and 6, respectively, for each period in each country.

Four important findings are reflected in Table 3. First, conducting an exponential growth analysis for China we can conclude that GDP growth in China has been 9.54% during the

Table 3. Parameter estimates for gross domestic product (GDP) growth.

	Period I	Period II	Period III
China			
K	7.2066	7.2456	7.2173
λ	0.09693	0.09429	0.09545
SE	0.002206*	0.001831*	0.000731*
R^2	0.9928	0.9947	0.9983
Japan			
K	7.8400	8.2583	7.9892
λ	0.04031	0.009170	0.02087
SE	0.001754*	0.001285*	0.001549*
R^2	0.9760	0.7843	0.8623
The United States			
K	8.5025	8.6245	8.5175
λ	0.03127	0.02564	0.03000
SE	0.001375*	0.001794*	0.000644*
R^2	0.97550	0.9358	0.9868

Notes: Period I (1980–1994), period II (1995–2010) and period III (1980–2010). GDP in Japan and the United States measured in constant 2000 USD; GDP in China measured at constant local currency unit.
*Significant at 5%.

Table 4. Parameter estimates for gross domestic product (GDP) per capita growth.

	Period I	Period II	Period III
China			
K	7.2395	7.1595	7.2203
λ	0.08282	0.08748	0.08489
SE	0.002289*	0.002036*	0.000816*
R^2	0.9894	0.9925	0.9973
Japan			
K	9.9956	10.3478	10.1194
λ	0.03381	0.008045	0.01802
SE	0.001749*	0.001269*	0.001387*
R^2	0.9639	0.7416	0.8534
The United States			
K	10.00111	10.10229	10.01561
λ	0.020517	0.015672	0.019239
SE	0.001380*	0.001676*	0.000618*
R^2	0.9404	0.8619	0.9709

Notes: Period I (1980–1994), period II (1995–2010) and period III (1980–2010). GDP per capita in Japan and the United States measured in constant 2000 USD; GDP in China measured at constant local currency unit.
*Significant at 5%.

Table 5. Parameter estimates for total primary energy supply (TPES) growth.

	Period I	Period II	Period III
China			
K	5.9635	5.9621	5.9787
λ	0.04056 (0.00265)*	0.03876 (0.00158)*	0.0382 1 (0.0009)*
R^2	0.9475	0.9837	0.9872
Japan			
K	5.7485	6.1790	5.8215
λ	0.02825 (0.00192)*	0.003270 (0.00084)*	0.01941 (0.0013)*
R^2	0.9436	0.5810	0.8909
The United States			
K	7.4309	7.2693	7.3920
λ	0.004269 (0.0027)	0.01505 (0.0012)*	0.009371 (0.0009)*
R^2	0.1603	0.9461	0.7912

Notes: For China, period I (1980–1994), period II (1995–2006) and period III (1980–2006). For Japan and the United States, period I (1980–1994), period II (1995–2007) and period III (1980–2007). Figures in parentheses indicate SEs.
*Significant at 5%.

last three decades. Second, comparing GDP growth in each decade, GDP growth tended to decrease during the period 1995–2010. This indicates that China has failed to achieve the 11th 5-Year Plan's (2006–2010) target to reduce the economic growth to about 7.5% although the reduction strategy had started to work. Third, economic growth in Japan and the United States also tended to decrease in the second period. Fourth, it is interesting to compare GDP growth and GDP per capita in China between period II and period III. We conclude that due to low population growth in period II, GDP per capita growth in period II was higher than that of period III, but GDP growth in period II was lower than that of period III.

Table 6. Parameter estimates for total primary energy supply (TPES) per capita growth.

	Period I	Period II	Period III
China			
K	–0.5308	–0.2777	–0.5719
λ	0.02216 (0.0016)*	0.04158 (0.00715)*	0.02763 (0.0026)*
R^2	0.9625	0.7452	0.8916
Japan			
K	0.9883	1.3700	1.0549
λ	0.02298 (0.002)*	0.001687 (0.0008)**	0.01623 (0.0012)*
R^2	0.9064	0.2766	0.8757
The United States			
K	2.0101	2.0933	2.0167
λ	0.002753 (0.0017)	–0.001164 (0.0009)	0.002204 (0.00055)*
R^2	0.1669	0.1288	0.3786

Notes: For China, period I (1980–1994), period II (1995–2006) and period III (1980–2006). For Japan and the United States, period I (1980–1994), period II (1995–2007) and period III (1980–2007). Figures in parentheses indicate SEs.
* and **Significant at 5% and 10%, respectively.

Comparing Japan with the United States in terms of GDP and GDP per capita growth, we noted three important findings (Tables 3 and 4). First, for the whole period, the US economy can grow faster than Japan because in the 1995–2010 period Japan's economic growth was below that of the US level. Thus, 'the lost decade' has made Japan's economic performance lag far behind the United States. Second, GDP per capita in Japan and the United States grew less than that in China. Third, because population and GDP growth in the United States are higher than in Japan, the growth of GDP per capita between the countries is not much different compared with the GDP growth.

In the second period, the GDP growth in all countries tended to be lower than those in the first period. In the case of China, reduction in economic growth can be explained by its tight monetary policy in the domestic market. Narayana *et al*. (2009) said that in the mid-1990s the government adopted a tight monetary policy to control inflation, while the Asian economic crisis in 1998 caused a downward pressure on the price level because of excess supply of traded goods. They also said that the severe acute respiration syndrome has had a negative impact on output. Thus, internal and external factors have reduced the speed of economic growth in the countries observed.

The economy grew more slowly in the second period than in the first period, but energy supply moved differently. Between 1980 and 2006, TPES in China grew annually by 3.82%. But between 1995 and 2006, the TPES grew by 3.88% (Table 5). This indicates the Chinese government's attempt to increase growth in the energy supply sector. As previously shown, between 2002 and 2006, China's energy imports increased dramatically, especially for crude petroleum. Because of reduction in population growth and the increase in primary energy supply, we can infer that the ratio of primary energy supply per capita will also increase. Further, we can see that the growth of TPES per capita in China between 1980 and 1994 was about 2.2% and that between 1995 and 2006 was about 4.1% (Table 6). We cannot apply the model for the United States because its primary energy supply seems to be constant over the years, thus we had low coefficient of determination.

In contrast, the growth in TPES in Japan and the United States tended to be lower in the second period. This trend is parallel to what economic growth analysis showed. There are three possible reasons for the tendency of the primary energy supply to increase in

China, with lower economic growth in the second period. First, the rapid economic transition, improvements in standards of living, urbanization and growth of energy-intensive industries demand more energy. Second, there is limited room to improve energy efficiency in some sectors such as the transportation sector. Third, the government aims to achieve a high electrification ratio.

It is important to analyse energy elasticity too. We apply the following mathematical model to measure energy elasticity:

$$y = Kx^{\lambda} \quad (2)$$

where y is GDP; x is primary energy supply; and K and λ are parameters. Parameter estimates for the above model (Equation (2)) are given in Table 7.

Table 7 shows that, in the case of China, between 1980 and 2006, 1% increase in TPES leads to 2.45% increase in GDP. This means that economic growth and primary energy supply has a positive relationship. Between 1980 and 2007, energy elasticity in Japan was lower than that of the United States. In the period 1980–1994, estimated energy elasticity between the United States and Japan was almost the same, with China having the highest value. In the second period, energy elasticity in China grew higher than that of the United States, and it was approaching Japan's level. We need to analyse more carefully in the case of Japan due to relatively low value of coefficient of determination.

The Chinese government attempts to cut energy use per unit of GDP by 20% in 2010 compared with 2005. The calculation showed that economic growth and TPES were 9.54% and 3.82%, respectively. In 2005, TPES was 1720.1 Mtoe, while GDP was 8243.1 billion renminbi. Thus, energy use per unit of GDP in 2005 was 0.20867 toe/1000 renminbi. In 2010, the ratio is expected to be 0.1596 toe/1000 renminbi, a 23.5% decrease. Thus, based on this condition China can still reduce its energy intensity by more than 20% while the economy can grow fast. If the economy grows by 7.5%, the ratio will be 0.1753 toe/1000 renminbi; energy used per unit of GDP decreases by 15.98%, way below the target ratio. The assumption related to economic growth is a key factor that determines whether the Chinese target of reducing energy intensity will be achieved in short terms. Thus, if the

Table 7. Parameter estimates for energy elasticity.

	Period I	Period II	Period III
China			
K	–6.3376	–5.8651	–7.4077
λ	2.2769 (0.01143)*	2.2261 (0.092)*	2.4499 (0.0475)*
R^2	0.9682	0.9832	0.9907
Japan			
K	0.056532	–4.6761	1.1267
λ	1.3567 (0.099)*	2.1020 (0.572)*	1.1758 (0.0532)*
R^2	0.9301	0.5515	0.9495
The United States			
K	–1.3709	–5.5411	–11.3249
λ	1.3561 (0.73259)**	1.9392 (0.1657)*	2.6945 (0.0262)*
R^2	0.2086	0.9257	0.8027

Notes: For Japan and the United States, period I (1980–1994), period II (1995–2007) and period III (1980–2007). For China, period I (1980–1994), period II (1995–2006) and period III (1980–2006). Figures in parentheses indicate SEs.
* and **Significant at 5% and 10%, respectively.

Chinese government is able to reach 7.5% economic growth per year, the target on energy intensity will be difficult to achieve, except when extraordinary efforts are exerted to attain energy efficiency, as Hu *et al*. (2011) argued that Chinese government must transform its output structure from energy intensive (e.g. manufacturing industry) to less energy consuming (e.g. services sector).

We can expect that China will continue to reduce energy elasticity. Further, the era of knowledge economy has inspired decision-makers in China to promote the cultural industry since 2000. Cultural industry has four basic characteristics (Shoguang and Yunpeng 2011): low resource consumption and less environmental pollution; high economic returns with long benefits; competitive and labour intensive; and tight correlation with other sectors of economy. However, share of cultural industry to GDP is still relatively small, that is about 2.6% of GDP, but China has great potential to develop this industry in the future (Shoguang and Yunpeng 2011).

In Section 5, we argue that reducing energy intensity and energy elasticity need to be accompanied by reducing carbon intensity.

5. Analysing economic and energy data for evaluating CO_2 emissions targets

Climate change has been one of the hottest issues since the Kyoto Protocol in 1997. Weighing the advantages and disadvantages of cutting down CO_2 emissions, one has to consider economic, social and cultural, environmental and even political matters. From the scientific perspective, the general consensus is that there is a rapid increase in global temperature compared with pre-industrial period. However, there is no general agreement on what kind of short-term action to take due to the high degree of uncertainty. Instead of cutting down CO_2 emissions that will reduce economic growth, urgent issues must be addressed, for example, clean technology, protecting the forests and improving energy savings. CO_2 emissions grew drastically in the case of China and gradually the United States (Figure 11). Interestingly, the emissions appeared to be constant between 1996 and 2007 in the case of Japan.

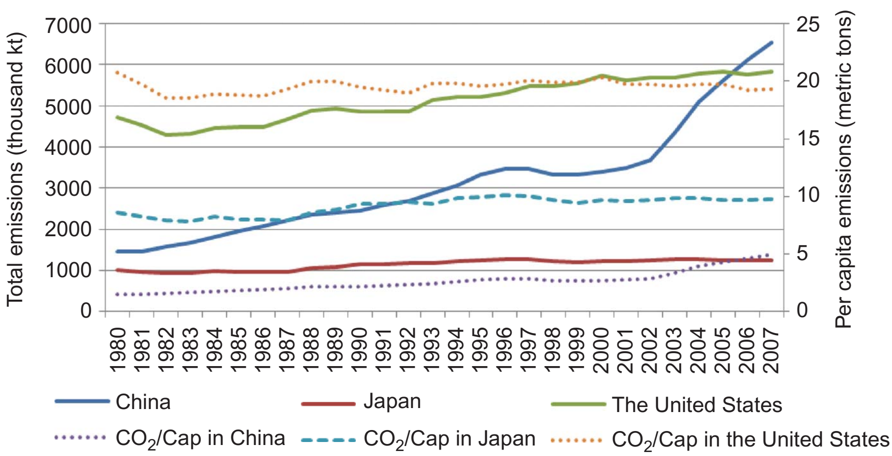

Figure 11. Total CO_2 emissions in China, Japan and the United States.
Source: World Development Indicators.

Looking at CO_2 per capita with respect to population data, we see that it is almost stable in the case of the United States, but it tends to increase in the case of Japan and China (see Figure 11). In terms of CO_2 emissions per capita, we can make two conclusions. First, in the case of the United States, although CO_2 emissions increase much higher than Japan, these are stable in terms of CO_2 emissions per capita. This is because population size and population growth in the United States are higher than in Japan. Second, in the case of China, although CO_2 emissions are much higher than in Japan (and they are almost approaching Japan's), in terms of CO_2 emissions per capita, the values are far below the US and Japan levels. Thus, merely measuring the CO_2 emissions per capita will not reflect the true size of CO_2 emissions, especially when we try to compare among several countries. It will be useful if the basis of CO_2 emissions per capita is also controlling the level of economic development, and it will be an alternative to a binding target. This result attempts to elaborate on the recommendations from Srivastave and Oyama (2009).

Further, there is also a concern that decreasing population will decrease CO_2 emissions in the future. On June 2007, the Chinese government issued the first national climate change policy. This policy is a compilation from four policies such as energy efficiency, renewable energy, reforestation and family planning (Seligsohn 2008). According to Seligsohn (2008) China contended that reduction in population growth can reduce not only demand for energy but also CO_2 emissions in the future. However, Seligsohn (2008) argued that this idea may not work because CO_2 emissions are mainly driven by industrial sector. Seligsohn's argument may be right because in the case of Japan, although population growth shows a decreasing trend, even negative, CO_2 emissions per capita in the 1980s were lower than in 2007. We argue that demographic transition towards low population growth may have some impacts on energy demand and CO_2 emissions in the future, but this idea will work effectively if there is some change in society's behaviour on energy conservation.

As seen in Figure 12, the CO_2 to GDP ratio in China has declined since the early 1990s, but it is still high compared with Japan and the United States. The drastic reduction in the CO_2 to GDP ratio in China is mainly due to rapid economic growth. Further, this figure shows that energy supply in China is still highly carbon-intensive (Figure 13). This argument is supported by the increasing value of the CO_2 to TPES ratio in China, as the ratio in Japan is slightly increased compared with the mid-1990s and in the United States it tends to remain constant. Our results confirm that reducing energy intensity does not necessarily cause a fall in CO_2 emissions. The case may be true for developed countries such as Japan and the United States because they can develop less carbon intensity in its energy mix, but in the case of China, it does not work. Figure 13 also shows the model that assumed carbon intensity of energy use (CO_2 per TPES) stays broadly constant in China, such as Garnaut *et al*. (2008), needs to be revised.

Further, Zhang *et al.* (2009) studied the decomposition of energy-related CO_2 emissions in China between 1991 and 2006 into four effects such as CO_2 intensity effect, energy intensity effect, structural changes effect and economic activity effect. The results showed that the economic activity effect dominated the largest increase in CO_2 emissions, while energy intensity effect contributed negatively to CO_2 emissions growth. However, the contribution of CO_2 intensity and structural changes was relatively small. Zhang *et al.* (2009) argued that structural changes only exhibit positive effect to the CO_2 mitigation in agricultural sector, and CO_2 intensity just contributes to the decrease in CO_2 emissions in transportation sector. The results imply that broad-based policy to promote energy conservation, clean energy utilization and energy efficiency needs to be enhanced.

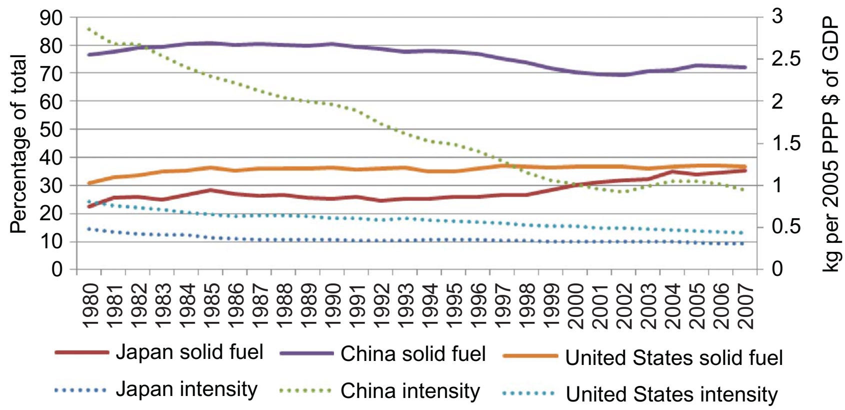

Figure 12. CO_2 intensity and CO_2 emissions from solid fuel.

Source: World Development Indicators.

Note: Solid fuel (CO_2 emissions from solid fuel consumption percentage of total) mostly consists of coal; intensity CO_2 emissions (kilograms per 2005 purchasing power parity (PPP) $ of gross domestic product (GDP)).

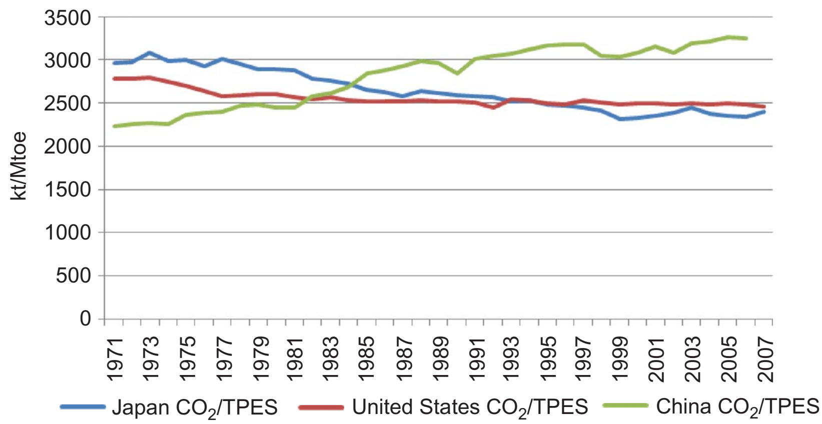

Figure 13. Share of CO_2 to total primary energy supply (TPES) in China, Japan and the United States.

Source: Author's calculation.

For China, reducing energy intensity is more preferable than reducing carbon intensity. Gang (2009) said that coal has dominated China's energy structure and this will prevent the country from accepting mandatory emissions reduction in the current stage. Changing the primary energy structure to less carbon used types may slow down the economic growth and this is not desirable because China's economy is still below the world level and the country also needs to reduce unemployment, poverty and income inequality, which are still relatively high. Similarly, Gang (2009) said that the mindset of the Chinese government is 'development first' because the ruling party still needs economic growth to legitimize its governance.

Thus, China's economic growth will continue to increase and so will energy consumption too. When economic growth can go faster than energy consumption and production, energy intensity in China will decrease, but CO_2 emissions will increase much higher than the TPES if China cannot develop clean energy sources and improve energy efficiency.

Further, following the case of Japan, Takase and Suzuki (2010) said that recently carbon intensity tends to increase due to the decrease in the ratio of non-fossil fuel energy use relative to fossil fuel energy use. They argued that this is because more coal is used, and slightly less use of nuclear power, as a fraction of overall energy supply. Further, this is also due to efforts to reduce dependency on oil. A similar situation may arise in China, if the government fails to control the growth of CO_2 emissions.

To obtain a more precise analysis, we applied the following mathematical model for dealing with CO_2 emissions data:

$$y = Ke^{\lambda t} \tag{3}$$

where y is the dependent variable, which can be CO_2, CO_2 per GDP and CO_2 per capita, primary energy supply or primary energy supply per capita; K and λ are parameters; and t indicates year. Parameter estimates for CO_2, CO_2 per GDP and CO_2 per capita are given in Table 8, respectively, for each period in each country.

The findings reflected in Table 8 can be the basis of these four conclusions. First, CO_2 emissions growth in China is much higher than those in Japan and the United States for the whole period, before and after the Kyoto Protocol; even after the Kyoto Protocol, CO_2 emissions grew higher in China. Second, CO_2 emission growth in Japan and the United States after the Kyoto Protocol is much lower than before the protocol and Japan has a relatively lower growth of emissions compared with the United States. Third, generally speaking, CO_2 emissions per GDP growth show a negative sign, meaning that, relatively, GDP grows much higher than the CO_2 emissions. Fourth, the application of model for CO_2 emission per capita in the case of China shows robust results, but this is not so for Japan and the United States. CO_2 emission per capita in the case of China tends to increase after the Kyoto Protocol. Because CO_2 emission per capita in Japan has remained constant post-Kyoto Protocol, the model could not explain clearly the situation in Japan.

Thus, the decreasing trend of carbon intensity (CO_2 per GDP) has been happening in China since the early 1990s or before the Kyoto Protocol. Similarly, Hu *et al*. (2011) said that China has adopted a low carbon pathway since 1980. But, we showed that carbon intensity in terms of CO_2 per TPES has risen since the 1980s. It is possible for CO_2 per TPES to decrease in the future. There are three reasons for this. First, the response to high economic growth is a drastic increase in TPES that is higher than CO_2 emissions. Second, China can change its energy mix from coal to less carbon intensity energy sources. Third, China can develop clean coal technology. Thus, a target on reducing carbon intensity with respect to TPES, in the case of China, is preferable to a binding target on CO_2 emissions. Thus, the short-term target in China is to stabilize CO_2 per TPES intensity that has showed increasing trend since the last 30 years.

According to the letter from the Department of Climate Change, NDRC of China to the executive secretary of the UNFCCC Secretariat regarding autonomous domestic mitigation on climate change on 28 January 2010, China will reduce CO_2 emissions per unit of GDP by 40–45% by 2020 compared with the 2005 level. Our results suggest that on average China can reduce carbon intensity with respect to GDP by 4.5% per year, and since China produced 2457 thousand metric ton per billion USD in 2005, in 2020 China can reduce CO_2 per GDP by 49.87%. Economic growth and government policy to reduce carbon intensity will be the key points for further reduction in carbon intensity in China.

Table 8. Parameter estimates for CO_2, CO_2 per gross domestic product (GDP) and CO_2 per capita.

	China			Japan			The United States		
	Period I	Period II	Period III	Period I	Period II	Period III	Period I	Period II	Period III
CO_2									
log *K*	14.138	13.266	14.157	13.705	13.944	13.766	15.269	15.415	15.274
λ	0.0534	0.0858	0.0495	0.0196	0.0035	0.012	0.0123	0.006	0.0119
	(0.0014)*	(0.008)*	(0.002)*	(0.0019)*	(0.0014)*	(0.0012)*	(0.0015)*	(0.0012)*	(0.0007)*
R^2	0.9887	0.931	0.9578	0.874	0.439	0.7935	0.8125	0.7498	0.9252
CO_2 per GDP									
log *K*	2.1425	1.2749	2.139	−1.071	−1.087	−1.1055	−0.143	−0.109	−0.1347
λ	−0.044	−0.0096	−0.045	−0.016	−0.115	−0.011	−0.0187	−0.021	−0.0197
	(0.0013)	(0.0068)	(0.0018)*	(0.0026)*	(0.0021)*	(0.0012)*	(0.0014)*	(0.0009)*	(0.0006)*
R^2	0.9864	0.2040	0.9596	0.6983	0.794	0.7715	0.9138	0.9858	0.9763
CO_2 per population									
log *K*	0.3528	−0.6446	0.351	2.033	2.2192	2.084	2.952	3.070	2.958
λ	0.0398	0.0793	0.038	0.015	0.0023	0.0088	0.00157	−0.0037	0.00098
	(0.0014)*	(0.0084)*	(0.002)*	(0.002)*	(0.0013)	(0.0011)*	(0.0014)	(0.0012)*	(0.00063)
R^2	0.9805	0.9175	0.925	0.785	0.267	0.700	0.0709	0.5649	0.087

Notes: Period I (1980–1997 or before the Kyoto Protocol), period II (1998–2007 or after the Kyoto Protocol) and period III (1980–2007). Figures in parentheses indicate SEs.
*Significant at 5%.

Conferences of the Parties 15 held in Copenhagen produced the 2009 Copenhagen Accord. There were three major points from the accord. First, all parties agreed that an increase in global temperature should be below 2°C. Second, both developed and developing countries agreed that by 31 January 2010, Annex I parties will be submitting their target emissions, while non-Annex I parties were requested to submit their mitigation actions on CO_2 emissions. Third, the accord also mentioned that developed countries provided a new resource fund, namely, the Copenhagen Green Climate Fund that has been allocated for mitigation and adaptation. Most of the adaptation funds would go to vulnerable countries, while the mitigation funds will be devoted to developing countries. Furthermore, the accord also mentioned that the fund can be allocated for the development and transfer of technology as part of adaptation and mitigation strategies. We consider China should make use of this opportunity to develop clean coal technology and to increase the share of renewable energy in its primary energy mix. Economy (2010) also mentioned that China plans to increase the role of renewable energy within the primary energy mix to 15% in 2020.

China with the help of global community has done a lot to control CO_2 emissions. Following explanation from Economy (2010), we share five examples. First, up to September 2009, about 35% of the world's clean development mechanism (CDM) projects under the auspices of the Kyoto framework were in China. Further, Gang (2009) argued that China has obtained the largest share of CDM market due to two reasons. First, the marginal cost for emissions reduction is relatively low compared with many other developing countries. Second, with support and help from developed and international organizations, government establishes CDM service centre to help local Chinese department with technical services. China with the help of UNDP establishes a national CDM fund to offer aid for local projects.

Second, European Union, Singapore and California have established eco-city or province partnership in Jilin, Chongqing, Guandong, Tianjin and Jiangsu. Third, British Petroleum (BP) has established a clean energy research centre at Qinghua University in Beijing. Wall-Mart has also launched a campaign to reduce the energy use. Fourth, China also announced $1.5 billion research subsidy for automakers to improve their electric vehicle technology. Fifth, the World Bank during 2007–2008 provided more than $700 million of loans for projects on such environmental problems. Between July 2007 and April 2009, the World Bank's International Bank for Reconstruction and Development, along with the Global Environment Facility, had approved project funds totalling over $4.6 billion, and 30% of the total is allocated to environmental project. Similarly, Xiaowei *et al*. (2011) said that China is the first country to use carbon and capture storage technology and clean coal technology.

However, the Chinese government also needs to address three institutional challenges that may reduce effectiveness of policy implementations (Ma and Ortolano 2000). First, government sets low prices for fuel and energy. This reduces incentive to improve energy efficiency. Second, institutional framework is segmented among government levels such as national and local, and these government units affect how enterprises respond to environmental rules. Furthermore, Gang (2009) also mentioned the potential of interagency conflicts. For example, in China, the NDRC has an important role in the decision-making process. Even State Environmental Protection Administration pushed central government to introduce Euro III (car standard) on 1 July 2007, and NDRC has more authority to delay the programme for up to 2 years. Further Gang (2009) also argued that Foreign Ministry and Ministry of Science and Technology support NDRC, and 'development first' will dominate negotiation in both national and international talks.

Third, most day-to-day implementation of a national environmental law occurs at the local level, and local people's congresses and the executive branches can produce their own versions of national regulations, notice and so on. But the laws and regulations issued by subnational people's congresses and executive branches of people's governments must be consistent with national legal enactment. Economy (2010) also argued that local officials in China have taken advantage of China's weaker laws and enforcement capacity and some of the multinational companies obtained benefits from this situation. Alternatively, Hu *et al*. (2011) suggested that besides the administrative measures, China can apply several instruments such as more use of economic and financial incentives, the integration of energy efficiency target into industrial policies and greater efforts to encourage a change of behaviour and expectation amongst the citizens.

Finally, due to the importance of high economic growth, segmented policies between central and local governments and lack in green policy solidity among the central government agencies, we expect that China will adopt the gradual approach to control its CO_2 emissions, instead of the big bang approach.

6. Conclusions and policy recommendations

6.1. Conclusions

This article shows that China has shown remarkable economic progress since the last three decades. The average economic growth was maintained at 9.54% per year, while GDP per capita grew by 8.5%. Both internal and external factors have contributed positively to the rapid economic growth. However, based on international standards, the number of poor people in China is still high and there is also evidence of rising income inequality in China. Thus, the Chinese government needs to pursue more balanced economic growth across the regions.

Further, China's economic growth is more carbon intensive compared with the world's average. In China, there is no conflict between rapid economic growth and reducing energy intensity or the ratio of TPES with respect to USD 1000 of GDP. But the long-term issue for China is how to reduce the intensity rapidly following the level in Japan and the United States. Further, reduction in energy intensity does not necessarily mean decrease in TPES or TPE. In the case of China, rapid economic growth has driven down the intensity level. This is due to the structural change such that the role of manufacturing and services sector has been increasing the value added. However, energy conservation policy, upgrading of technology capability and promoting knowledge economy need to be enhanced to further energy intensity reduction in the future.

In the case of Japan and the United States, TPE and TPES also tended to increase at lower rate and due to decreasing population growth in Japan, growth of TPES in Japan tended to be lower than TPES per capita. Japan is also very successful in reducing energy dependency ratio especially on imported oil. On the other hand, in China, import of oil has been increasing. Although share of energy import to total energy production is low, China has attempted to develop oil exploration outside the country.

Economic growth assumption will become the key determinant on how the Chinese government can cut energy consumption per unit of GDP by 20% in 2010 compared with 2005. For example, if the Chinese government want to reach 7.5% economic growth per year and assume TPES increases by 3.82%, energy used per unit of GDP would decrease by 15.98%, or below the target ratio. However, if economic growth can be maintained at 9.54%, China can reduce the energy intensity by 23.5%. Thus, rapid economic growth can help China to achieve a target on energy-GDP intensity.

Rapid economic growth will make China become the largest energy producer, the largest primary energy supplier and the largest energy importer in the world. However, reducing energy intensity needs to be balanced with decreasing CO_2 emissions. Currently, it will be very difficult for China to reduce carbon intensity because the energy structure in China depends on coal. But, this study shows that China can reduce CO_2 emissions per unit of GDP by 40–45% that of the 2005 level by 2020, if economic growth can be maintained at 9.54% on average and if the government effectively pursues policies to reduce carbon intensity. We argued that reducing energy intensity and improving the primary energy supply need to be done in parallel to reducing carbon intensity because it is possible to reduce energy intensity in the face of increasing CO_2 emissions.

Now, the CO_2 intensity with respect to TPES in Japan and the United States is about 2500 kt/Mtoe, while in China it is about 3250 kt/Mtoe. We expect in the future, China can reduce this gap, because since the last 25 years the gap has become wider compared with Japan and the United States. Experience from Japan and the United States showed that although growth of CO_2 emissions tends to decrease after the Kyoto Protocol, absolute emission from Japan remains constant, while in the United States, it showed increasing trend. Thus, binding target on CO_2 emissions can push the countries to be more disciplined and responsible to control CO_2 emissions. Thus, cooperation on binding target emissions needs to be enhanced post-Kyoto Protocol.

Finally, comparing Japan and the United States in terms of economic and energy indicators, three points can be raised. First, although we can conclude that Japan is relatively more successful in reducing its import dependency ratio compared with the United States, the low economic growth and reduction in population growth in Japan have to be considered in investigating this factor. Second, Japan is more efficient in energy use (energy intensity) because for one unit of primary energy supply, a relatively higher output can be produced compared with the United States; on the other hand, Japan needs more primary energy supply than the United States to increase GDP by 1% (energy elasticity). This has happened because the economic condition in Japan is not as good as that in the United States. Third, Japan has showed decreasing rate of CO_2 per TPES and since the mid-1990s, the level has been lower than the United States.

6.2. Policy recommendations

This study has policy impacts both on the Chinese government and the global community. Quality of growth is more important than quantity of growth. Nowadays, the fruits of economic development growth need to be clearly reflected by high economic growth, low levels of inflation, unemployment and income inequality and disparity, low energy intensity and elasticity and low carbon intensity with respect to TPES. Thus, a key issue for China is how the country can reduce carbon intensity and at the same time achieve a reasonable level of economic growth that can improve the quality of growth.

It will be too risky for China if it just depends on economic growth to reduce energy intensity and CO_2 intensity. Global economic crises will affect long-term projection of China's economic growth. Further, rising oil price can push China to use coal more intensively. Several polices have been implemented to show promptly commitment from the Chinese government to reduce CO_2 emissions. As this research suggested, the Chinese government can implement target on the ratio of CO_2 emissions to TPES to control CO_2 emissions as one of policy goals, for example, at 2500 kt/Mtoe approaching Japan and the US levels. TPES can increase while CO_2 emissions decrease if China can develop clean coal technology and increase the share of new and renewable energy in its energy mix.

We agree with McKibbin *et al*. (2008) who said that cooperation among nations must be enhanced to address clean energy needs such as in energy planning. For example, Duffield and Woodall (2011) argued that according to a new Basic Energy Plan 2011, Japan places more emphasis on fighting climate change than energy security in several ways such as to reduce energy-related carbon emissions and to set more ambitious and detailed targets for renewable energy sources. The Copenhagen Accord offers developing countries an opportunity to narrow the gap in technology capability building by harnessing the Copenhagen Green Climate Fund. We also hope that support from developed countries such as Japan and the United States can help China not only in transferring technology but also in strengthening the institutional capacity such as in harmonizing regulations, in energy planning and in developing human capability.

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Notes

1. The World Bank uses the atlas method and economies are divided according to 2008 gross national income (GNI) per capita.
2. This indicates the growth in real GDP per capita associated with reduction in poverty headcount rate.
3. Coal reserves of China are the third largest in the world after the United States and Russia (Smil 1998). Further, coal from China has fairly high heating content (Smil 1998).
4. Most of China's oil exports came from the Daqing oil field in Heilongjiang province (north-east); the coal came from Shanxi province and the Inner Mongolia Autonomous Region in the north (Kambara 1992).
5. Preliminary estimates.
6. (–) indicates exports.

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