Energy Policy 38 (2010) 512–519

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Estimating coal production peak and trends of coal imports in China ☆

Bo-qiang Lin *, Jiang-hua Liu

China Center for Energy Economics Research (CCEER), Xiamen University, No. 422, Siming South Road, Xiamen, Fujian 361005, PR China

ARTICLE INFO

Article history:
Received 23 April 2009
Accepted 23 September 2009
Available online 17 October 2009

Keywords:
Peak coal
Logistic curves
China's net import of coal

ABSTRACT

More than 20 countries in the world have already reached a maximum capacity in their coal production (peak coal production) such as Japan, the United Kingdom and Germany. China, home to the third largest coal reserves in the world, is the world's largest coal producer and consumer, making it part of the Big Six. At present, however, China's coal production has not yet reached its peak. In this article, logistic curves and gaussian curves are used to predict China's coal peak and the results show that it will be between the late 2020s and the early 2030s. Based on the predictions of coal production and consumption, China's net coal import could be estimated for coming years. This article also analyzes the impact of China's net coal import on the international coal market, especially the Asian market, and on China's economic development and energy security.

1. Introduction

Coal has been considered as an affluent non-renewable resource in the world, and this is especially so in China. Just as the first oil crisis sparked many discussions on peak oil, so too have recent surges in coal demand sparked discussions on 'peak coal', attracting much public attention.

Hubbert (1956) predicted that US petroleum production would peak between the late 1960s and the early 1970s and decline thereafter. Although Hubbert (1956) did not provide a precise formula, he proposed that fossil fuel production in a given region, and over time, would follow a roughly bell-shaped curve. Later, Hubbert (1959) first started using logistic curves to simulate historical data and in Hubbert (1974), he further developed his methodology.

The prediction method based on fitting a bell-shaped curve to historical production and to the ultimate recoverable reserves (URR) remains one of the most common approaches in predicting future production of exhaustible natural resources. However, although Hubbert's theory states that oil production in a given region follows a roughly bell-shaped curve over time, the actual production curves are not always bell-shaped. Brandt (2007) showed that some regions under research were better-described by linear and exponential models. Furthermore, when asymmetry was allowed in oil production curves, the asymmetrical exponential model became the most effective model. Also Bardi (2005) indicated that the after-peak downward sloping region of global oil production might turn out to be steeper than the upward sloping region, implying asymmetry.

As Hubbert predicted, a great number of countries' oil productions have reached their peaks, and so has the production of gas. Coal, the main alternative energy to oil and gas, has consequently become increasingly important, and as a non-renewable resource, it will inevitably reach its peak at some point. There are many papers that attempt to predict peak coal for the world and/or various countries. Hubbert (1976) used a bell-shaped curve to global coal production to predict future coal production and estimated that it would peak at between 10 and 24 Gt/year in 2100–2200, depending on the URR. Milici and Campbell (1997) showed, using a life-cycle method, that Virginia's coal production life had entered maturity, and was in a post-peak production (depletion-driven decline) stage. Milici (2000) applied decline rate models based on production decline rates and the decline rate of the estimated potential reserve to indicate that the Appalachian basin's annual coal production would be 200 million tons (Mt) or less by the middle of the next century. Laherrere (2006) concluded that global coal would peak around 2050 using a similar approach. The EWG (2007) found that global coal production would peak around 2025 at 30% above the present production in the best case, and that China would reach coal production peak within the next 5–15 years (around 2015), given that current data on China's coal reserves are accurate (114.5 billion tons). Kavalov and Peteves (2007) showed similar results. His article suggested that the world's proven reserves of coal were depleting fast and coal production costs were increasing globally, due to the need to develop new fields, increasingly difficult geological conditions and additional infrastructure costs associated with the exploitation of new fields. Höök and Aleklett (2009) also used established analytical methods such as logistic curves to create

☆ The paper was supported by Cheung Kong Scholar Fund and National Natural Science Foundation (70841025).

* Corresponding author. Tel.: +86 13906051957.
E-mail address: bqlin@xmu.edu.cn (B.-q. Lin).

0301-4215/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2009.09.042

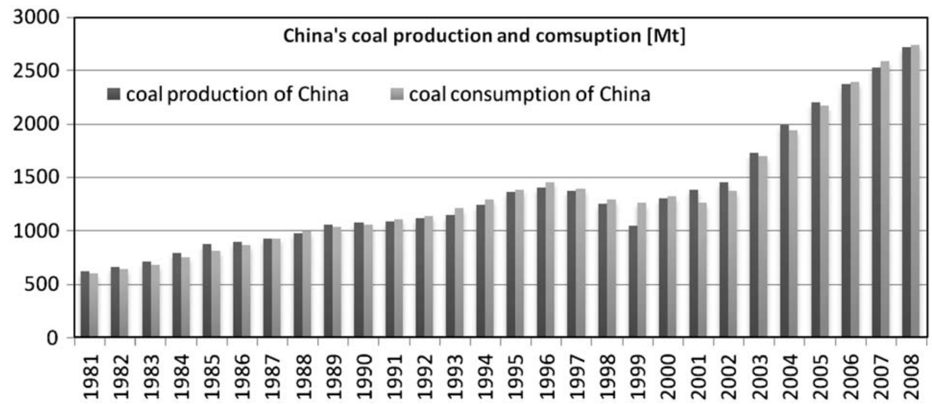

Fig. 1. Trends for China's coal production and consumption. *Source*: National Bureau of Statistics of China *China Energy Statistical Yearbook*.

future outlooks for US coal production. Mohr and Evans (2009) used a model that took into account supply and demand fundamentals, and concluded that worldwide coal production would peak somewhere between 2010 and 2048 on a tonnage basis, and somewhere between 2011 and 2047 on an energy basis when world coal in terms of URR was estimated at between 700 and 1243 Gt. Tao and Li (2007) used the generic STELLA model to simulate the Hubbert peak. In Section 5 of this paper, there will be a comparison of the results of this article and that of the STELLA model.

The existing research on peak coal has mainly used the Hubbert methodology for prediction, and has mainly focused on the US or on the world. There is little research conducted on China with this regard. This article uses both logistic curve fits and Gaussian curve fits to estimate future coal production. Based on the estimated coal production, this article will estimate net coal import of China and discuss its implications on the international coal market, especially the Asian market, and on China's economic development.

2. Background

2.1. Reserves

It is well known that different international energy institutions have different classifications and definitions of coal reserves. For instance, the concept of proved reserves used by the International Energy Agency (IEA) and British Petroleum (BP) is equivalent to proved recoverable reserves defined by the World Energy Council (WEC). According to the definition of the WEC, proved recoverable reserves are the tonnage within the proved amount that can be recovered in the future under present and expected local economic conditions, with existing and available technologies. A full discussion of coal resource and reserve terminologies of IEA, WEC and BP can be found in EWG (2007). China's proved coal reserves, in almost all the international energy institutions including IEA, WEC and BP, is 114.5 billion tons, which has been unchanged since 1992. The Ministry of Land and Resources of China stated this number was actually 188.6 billion tons by the end of 2002 (www.ChinaCoal.org.cn). It is hard to tell why data of IEA, WEC and BP have not been updated. One possible reason may be that the Chinese government might have not submitted the new figures to these international institutions as yet.

In the new Chinese Classification, resources are classified on the basis of geological knowledge, project economics and the project (feasibility) study status. The details of the new Chinese Classification could be found in Bucci et al. (2006) and Stoker (2009). The proved reserves defined by the *solid mineral resources/reserves classification (1999 version)* are calculated from ensured coal reserves, which equal proved mineral reserves (including industrial and prospective reserves) minus extracted parts and underground losses. This calculation shows the current condition of the coal resources of a country multiplied by the mining coefficient. The mining losses, recovery rate and other factors have been taken into account in the calculation process, so the proved reserves of 188.6 billion tons could be used directly under present and expected local economic conditions with existing and available technology.

2.2. Production

From 1999 to 2008, the average growth rate of coal production of China was 11.37%, which was almost twice as much as that of 5.8% from 1982 to 1996 (BP, 2008). In 2008, coal production in China rose to 2716 million tons (40% of global coal production), driven by the high coal prices and tight domestic supply and demand conditions (Fig. 1). Coal production in China has been rising since 1981, and is likely to continue rising, due to increasing demand.

2.3. Consumption

Fig. 1 shows that coal consumption in China had experienced a rapid and continuous increase with an annual average increase rate of 5.08% from 1980 to 1996. In 2007, the volume of China's coal consumption amounted to 2580 Mt and accounted for 41% of the global coal consumption (2.28 times that of America, and 6.30 times of that of India). Almost 94.83% of coal of China was consumed in the industrial sector in 2007, and about 50% was consumed in the electricity sector alone (China Energy Statistical Yearbook, 2008). Coal has played a crucial role in China's economic growth. More than 80% of China's power was generated by coal and 55% of China's freight railway transportation was used in energy transportation, in which coal transportation took 49% and oil transportation covered only 6% in 2007 (Lin, 2009).

To predict future coal consumption, the demand of China's primary energy and the structure of primary energy will need to be forecasted. We use the available results from China Center for Energy Economics Research (CCEER). The demand of China's primary energy is predicted using a co-integration model, while the structure of primary energy is forecasted using a stochastic process model (Markov probability analysis).

The co-integration model of the demand for primary energy is as follows:

$$\operatorname{Log} Q = c + \beta_1 \operatorname{Log} Y + \beta_2 \operatorname{Log} M + \beta_3 \operatorname{Log} C + \beta_4 \operatorname{Log} EF + \beta_5 P \quad (1)$$

where Q is the consumption of the primary energy of China, Y the GDP and M the percentage of value-added of heavy industry to

GDP. It is an indicator of industrial structure. C is the percentage of the urban population to the China's total population. It stands for urbanization level; EF is the result of value-added of industry divided by energy consumption of industry, representing energy efficiency; P is the coal price index.

From the working paper Lin et al. (2008) at CCEER, the results are as follows:

$$\text{Log}\,Q = 0.009\,\text{trend} + 0.738\,\text{Log}\,Y + 0.469\,\text{Log}\,M + 0.769\,\text{Log}\,C - 0.976\,\text{Log}\,EF + 0.008P \quad (2)$$

To forecast the consumption of China's primary energy, we have to make some assumptions for the abovementioned variables.

The growth rate of GDP: According to Huang and Yang (2006), China would keep developing at a rapid growth rate, and the average growth rate would be about 8% in the next 5 years, 7–8% in the 5 years from 2010 to 2015, and 6–7% in the 5 years from 2016 to 2020. As China's economy expanded by 6.1% year on year in the first quarter in 2009, against the background of the global financial crisis, some economists believe that the month of March 2009 has been a turning point with retail sales and industrial output both improving markedly. This indicates to some extent that China may be stepping out of the current economic slump, and the assumption of average GDP growth rate of 8% is therefore reasonable and our assumptions of GDP growth rates are made accordingly, as shown in Table 1.

Table 1
Assumption of Chinese economic development growth rates.

Year	High (%)	Mid (%)	Low (%)
2007–2010	10	9	8
2011–2015	9	8	7
2015–2020	8	7	6
2021–2030	7	6	5

Table 2
Forecasts of Chinese coal demand based on assumption in Table 1.

Year	Coal demand ($\times 10^2$ Mt)		
	Low	Mid	High
2010	29.40	30.10	31.00
2015	34.70	37.00	39.40
2020	40.10	44.30	48.90
2025	43.50	49.90	57.00
2030	48.40	57.50	68.00

M, the percentage of the value-added of industry to GDP would be 51.5%, 50%, 48% and 45% in years 2010, 2020, 2030 and 2040, respectively (China Macro Economic Information Network, 2001); C, according to forecasts made by the State Statistical Bureau, the urbanization level of China would be 48%, 60%, 65% and 70%, respectively, in the years 2010, 2020, 2030 and 2040, and these forecasts will be used in the model directly; EF, based on historical data, we could make assumptions that the EF increases by 3% annually from 2007 to 2010, 2.5% from 2011 to 2015, 2% from 2016 to 2020 and then decline by 0.5% every 10 years following 2020; P, influenced by various factors including economics, politics and climate, the coal price is controlled by the government in China. Therefore we choose not to take it into account in our forecast.

Applying these assumptions to the model, the demand of primary energy is forecasted in Eq. (2), and the structure of primary energy can be predicted by a stochastic process model using Markov probability analysis. Finally, we can calculate the demand for coal by multiplying the demand of the primary energy by the share of coal in the structure of primary energy as shown in Table 2.

2.4. Export and import

Fig. 2 shows that the exports and imports of China's coal have fluctuated substantially from 1995 to 2008 (State Bureau Statistics; General Administration of Customs of People's Republic of China). From 1995 to 2003, China had taken favorable measures to boost coal exports and in 2001 the volume reached 90 Mt which increased 64% over the previous year. However, because of the tight supply and demand of domestic coal, the export amount decreased significantly after 2004. Coal imports to China remained nearly static at a few million tons until 2001, and then rose sharply since.

Factors that influence the trend of coal exports and imports mainly include the following: the soaring growth of coal demand, policy changes in coal trade, and a gap between domestic and overseas coal prices as stated in Sagawa and Koizumi (2008).

From 2003 on, there was a trend of decreasing volumes of coal exports and increasing coal volumes of coal imports, as shown in Fig. 2. The Chinese government has taken several effective measures to discourage coal exports, such as gradually abolishing the value-added tax refund for coal exports from 2004 and implementing a 'Coal Export Allotment Control Law' in July 2004 (www.China.com.cn). Also, an export tax of 5% was levied on coking coal from November 1, 2006, and import tax of coal was gradually abolished.

In conclusion, the volume of exported coal tends to decrease further while the import volume would continue rising as a result of the increasing domestic coal demand and the present policy changes that favor this trend.

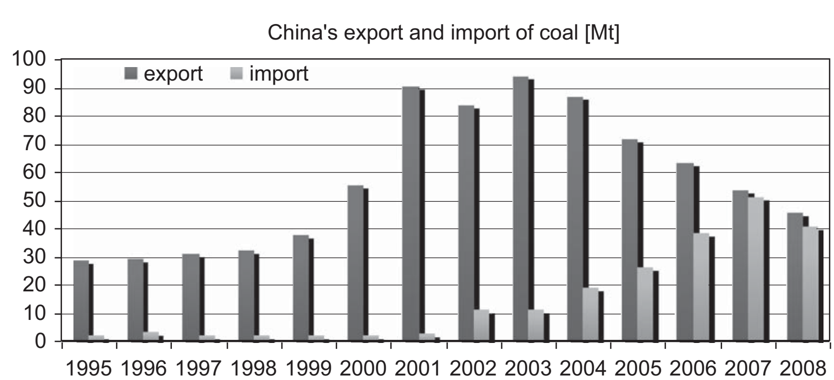

Fig. 2. Trends of coal export and import. *Source*: General Administration of Customs of the People's Republic of China.

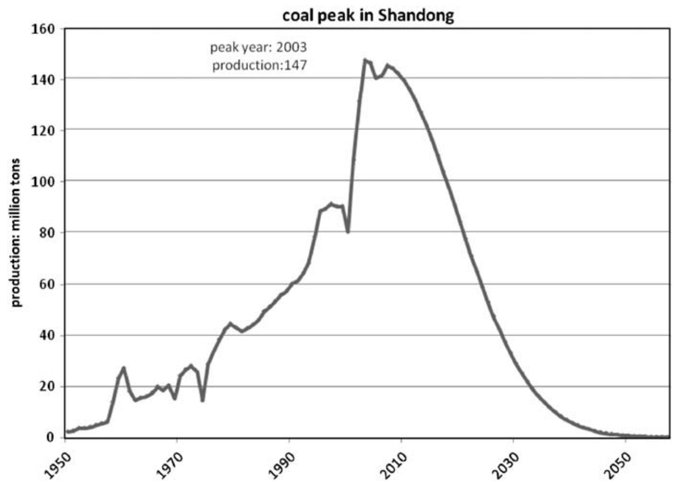

Fig. 3. The Coal peak in Shandong China. *Source*: National Bureau of Statistics of China. The data after 2007 are estimated with logistic growth model.

3. The concept of peak coal

Coal is a fossil fuel and a finite resource that would eventually be exhausted, which also applies to oil and other non-renewable resources. Peak coal is the point in time when the maximum coal production is reached, after which the production will enter irreversible decline. The contemporary concept of peak coal follows from M. King Hubbert's peak-oil theory, and was originally raised by Jevnos (1865). The concept of peak coal is similar to the concept of peak oil with the only difference being the amount of available reserves and extraction methods. Some countries have already passed their 'peak coal' stage, such as the United Kingdom, Japan and Germany. The US, being the second largest coal producer, had already passed peak production of high-quality coal in 1990 in the Appalachia and the Illinois basin, and global coal production would peak around 2025, at 30% above the present production in the best case (EWG, 2007). In China, there are some provinces that have passed the peak coal stage. To give an example, Fig. 3 shows that the Shandong province in China reached its coal peak in 2003.

4. Methodology

4.1. Logistic growth model

Logistic growth curves are used to simulate the historical data of coal production and predict coal production in the future.

$$Q=\frac{URR}{1+e^{-(t-t_{\max})/w}}$$

where Q is the cumulative coal production, URR the ultimate recoverable resources, t the year, $t_{\max}$ the year of coal peak and w a parameter that varies to least the residual sum of squares of fitted values and observed values.

A disadvantage of using such a model is that it is estimated on the assumption that economic factors, such as coal price, are non-relevant in the long term. This model is a purely theoretical production model that neglects the impact of economic cycles, policy changes and other factors.

4.2. Gaussian model

Gaussian curves can also be used to simulate the historical data of coal production and predict coal production in the future:

$$P=-dQ/dt=[Q_{\infty}/(S(2p)^{1/2})]\exp[-(t_{\max}-t)^2/(2S^2)]$$

where P is the annual coal production; Q is the available reserves unexploited; Q_{∞} is the cumulative coal production when $t\to\infty$, or, ultimate recoverable resources (URR):

$$W=[(8\ln 2)^{0.5}S]=2.355\ldots S$$

where S is a wideth coefficient commonly used.

The disadvantage of this model is the same as that of the logistic growth model, in that it ignores economic factors.

The logistic curve has been widely used to model population growth, and M. King Hubbert used it to model oil production. The Gaussian curves share a similar theoretical basis and the Central Limit Theorem states that the sum of a sufficiently large number of independent random variables, each with finite mean and variance, will be approximately normally distributed (Rice, 1995). The huge number of mines and mining operations, making up a global or national production, may be seen large enough a sample to justify the use of these models. Bartlett (2000) used both logistic curves and Gaussian curves to fit historical data on oil production in the US and the world.

In both models, one of the most important variables is coal reserve, which is denoted by the URR.

5. Coal peak of China

5.1. The estimated results

Fig. 4 shows the logistic curves and Gaussian curves according to the models. The detailed results and the comparison with the STELLA model of Tao and Li (2007) are listed in Table 3. Using the logistic growth model, the coal peak of China is estimated to be reached in 2025 and the peak production would be 3.83 billion tons. However, using the Gaussian model the coal peak year and peak production would be 2027 and 3.67 billion tons, respectively. Compared with the STELLA model (Tao and Li, 2007), the results are very similar. As a conclusion, using the aforementioned models, China's coal peak would occur between the late 2020s and the early 2030s. These results are also in

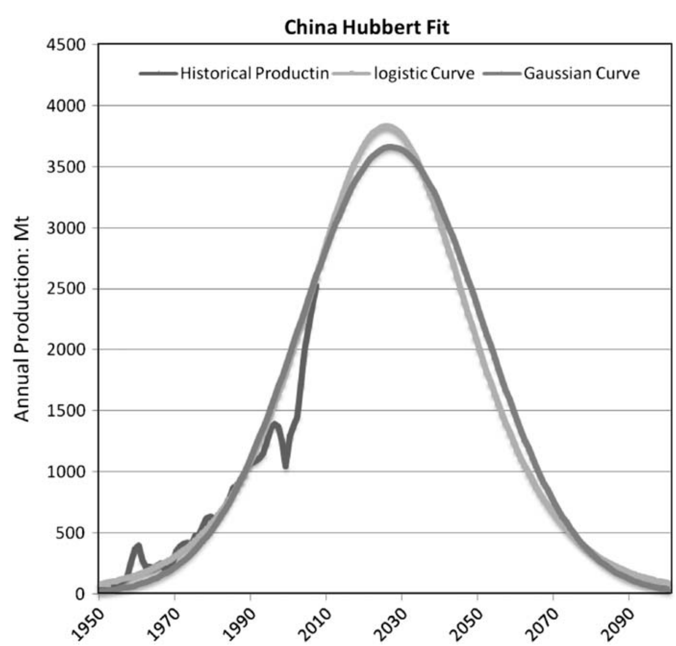

Fig. 4. The coal peak of China. *Source*: National Bureau of Statistics of China.

Table 3
Detailed results and comparison with the STELLA model.

Model	Unit	Logistic curve	Gaussian curve	STELLA		
Reserves	$\times 10^2$ Mt	1886	1886	Scenario 1	Scenario 2	Scenario 3
t_{max}	Year	2025	2027	2033	2029	2027
P_{max}	$\times 10^2$ Mt	38.30	36.65	33.39	37.84	42.29

Table 4
Results of sensitivity analysis of changes in the URR.

Model	Reserves	2086	1986	1886	1786	1686	1145
Logistic growth curve	Peak production ($\times 10^2$ Mt)	41.31	39.85	38.30	37.08	36.35	30.46
	Peak year	2027	2026	2025	2024	2023	2016
Gaussian growth curve	Peak production ($\times 10^2$ Mt)	38.51	37.58	36.65	35.72	34.79	30.10
	Peak year	2029	2028	2027	2026	2025	2017

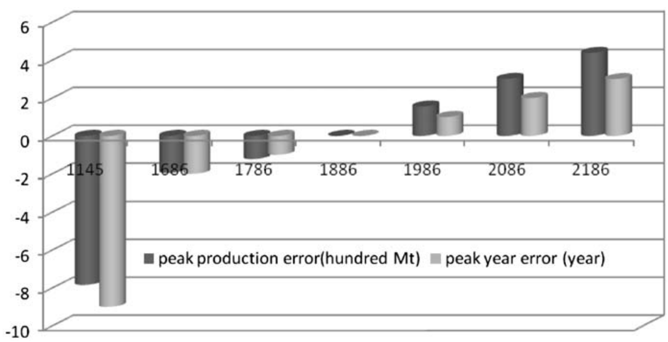

Fig. 5. The error bars of the peak production and peak year as a result of URR changes.

agreement with the EWG (2007), that is, China would reach coal peak in 5–15 years.

The similarity across results is unsurprising. As a matter of fact, almost all the models used by the previous researchers are dependent on the sensitivity of the URR. This will be demonstrated in Section 5.2.

5.2. The sensitivity analysis for the URR

For the URR, sensitivity analysis is necessary for two reasons. First, different international institutions use different classifications and data for China's reserves, and it is difficult to justify which ones are more useful and/or reliable. Second, the most important variable in both models is the URR. Thus, the sensitivity analysis is applied to show how the results of the models will change with the URR and this will demonstrate the reliability of the results.

In Table 4, results show that the peak production would change by 0.1 billion tons and the peak year would change by about 1 year when the URR varies by 10 billion tons. Furthermore, all the changes are in the same direction. Table 4 also presents the results using 114.5 billion tons as the URR (the same used by international energy institutions). Using the logistic growth model, a peak year of 2016 and peak production of 3.05 billion tons are estimated. Using the Gaussian model, these results become 2017 and 3.01 billion tons for year and quantity, respectively. In Fig. 5, we obtain the errors between the peak production and peak year of changed reserves. Fig. 5 could help us understand how the URR influences the peak production and peak year directly and visually.

The above analysis indicated that China's coal production will continue to increase, arrive at a peak, and then decline, as the general production pattern for non-renewable energy resources that Hubbert predicted. The sensitivity analysis implies that, although the results of this study, like all others, depend heavily on the assumption of the URR, China's coal production peak will not change significantly with additional coal reserves. China's long-term energy reliance on coal will be unsustainable, unless there are dramatic increases in coal reserves. Given the results in Table 4 and the demand forecast, it is likely that China's coal import would increase substantially over time.

6. Trends of China's net import of coal and the impact

6.1. The trends of China's net import of coal

Since we have the predictions for coal consumption and production, the net coal import can be calculated. The coal consumption data come from Table 2 and the coal production data from the logistic growth model in Section 5.

Whether the growth rate of coal demand is low, mid or high, the volume of net coal imports will increase and the coal import dependence will be high. By 2030, the coal import dependence will be about 23% under the low growth situation and 45% in the high growth situation.

Table 5 indicates that the amount of net coal import for China would be 99 Mt in 2010, accounting for 10% of the global coal exports in 2007 (909 Mt in 2007), nearly 50% of the total coal exports of Australia, more than 50% of the total coal exports of Indonesia, and three times of the total coal exports of Vietnam.

The conclusions coincide with the report of MIT (2007). MIT estimated that half of the increment of global coal production and global coal demand would come from China in the next 25 years. Our results indicated that China's coal import will be 1.9×10^2 Mt in 2010, similar to 1.5×10^2–2.3×10^2 Mt forecasted by the Coal Industry Association of China (www.chinagate.com.cn).

6.2. The impact of China becoming a net coal importer

The transformation of China from being a coal exporter to a significant coal importer will be inevitable and will have a great impact on the international coal markets, especially Asian markets.

As shown in Table 6, by 2015, the volume of net coal imports to China would account for 11–34% of the world coal trade and by

2030 that would be 41–54%, as predicted. That means that about 50% of the total world coal would be traded with China. If this is the case, a slight change in China's coal market would have a great impact on international coal markets, especially on international coal prices.

China's coal consumption is concentrated on electricity generation, cokes production and industrial uses. The import volume of anthracite coal, steaming coal and coking coal in 2007 was 28.41 million tons, 13.30 million tons and 6.22 million tons, respectively (Beijing WEFore Investment Consulting Co. Ltd, 2008). If China keeps the structure of coal imports unchanged, the import volume of the abovementioned three types of coal would double in 2015. In 2004, the price of Chinese coking coal has doubled compared to 2003 because there was a remarkable decrease in export volumes. Undoubtedly, the doubling of import volumes will have substantial impacts on China's coal market, as well as the international coal market.

China will likely become the largest coal importers in Asia and will dominate the Asian coal market. Currently, China's coal market is relatively independent of the Australian coal market, with coal prices mainly subject to domestic supply and demand. However, if China increases its coal import as predicted, it will dominate the Australian coal market and, via trade channels, have greater impacts on other international coal markets.

Regarding its impact on Asian coal markets specifically, the large increase in China's coal exports in 2000 and 2001 had led to an oversupply of coal in Asia and had resulted in a coal price slump from 2002 to 2003.As China has gradually become a net importer of coal in the region, price hikes (such as in 2007) have reflected China's impact on Asia coal market.

At present, China's main coal exporters include Australia, Vietnam, Indonesia, Mongolia, North Korea, Russia and Canada. Amongst them, coal imports from Vietnam and Indonesia, which are near the southern coastal areas of China, have been soaring. In 2007, the coal imported from Vietnam accounted for nearly 50% of coal imports, and from Indonesia, about 28% (Beijing WEFore Investment Consulting Co. Ltd, 2008). However, Vietnam has enjoyed high GDP growth, with a growth rate of over 8% in 2008. With increasing domestic coal demand, the Vietnamese government has taken measures to reduce coal exports. This may have impact on China's coal import. For example, in January 2008, coal exporters in Vietnam boosted coal's price by 40% and Chinese coal consumers, especially those in Guangdong and Guangxi provinces, suffered a great deal. Indonesia also faces a similar problem of increasing domestic coal demand and may reduce the amount of coal exported to China as well. In Australia, import volumes are restricted by limited port capacity, which will not change in the short term. Although Mongolia might prove to be an alternative source of coal imports, it is geographically far from the coal consumption sites of China. As coal expert Jim Brock of Cambridge Energy Research Associates pointed out, Mongolia is not likely to be a major coal exporter to China in the next two decades (Coal.IN-En.com). Compared to oil and gas, the cost of coal transportation is much higher, and could account for up to 50% of the total coal price.

Two State-Owned Enterprises, China Shenhua Energy Co. and China State Grid Corp., who are the main implementers of coal strategy in China, are actively trying to reduce the possible insecurity surrounding the China's future coal situation. China Shenhua Energy Co. is actively looking for acquisition targets in Asia while China State Grid Corp. actively promotes the construction of ultra-high voltage in order to import electricity directly from neighboring countries (www.GOV.cn).

China's coal resources are mainly located in the northern parts of China, whereas the demand for coal is concentrated in the southeastern coastal areas. It is therefore likely that future coal trade will follow the current pattern, that is, exporting coal in the north and importing coal in the south. It is also likely that the coal import volume for the south will be much larger than the number predicted for China as a whole. According to the results in Table 5, in 2030 the China coal import dependence could be about 45%. If one province, or even one company in southern China, has to rely on imports for more than half of its coal consumption, its vulnerability to international market fluctuations would be significant, implying greater risks and substantially less energy security. Taking important measures to reduce this vulnerability, such as building sufficient railway capacity to help transport coal from the north to the south, or investing more in power networks to help transport electricity from the north to the south, is crucial.

The high coal import dependence threatens not only China's energy security but also that of the whole world. When China found itself compelled to notably increase its consumption of coking coal in 2004, the availability and prices of coking coal in other areas of the world were significantly affected. A scenario whereby China imports 1 billion tons of coal from abroad would not only have tremendous upward pressures on coal prices but also pose a difficult question vis-à-vis the transport logistics of such quantities.

Furthermore, with high coal import dependence, Chinese authorities would likely have to increase interventions in the domestic and international markets, like have been done with oil. This could lead to an increase in other countries' energy rivalry, especially Asian countries like Japan and South Korea. If that happens, China will face stressed political and economic relations, and undoubtedly its energy security and even national security

Table 5
Forecast of China's coal import ($\times 10^2$ Mt).

Year	Coal demand			Coal production	Net coal import		
	Low	Mid	High		Low	Mid	High
2010	29.4	30.1	31	29.17	0.29	0.99	1.89
2015	34.7	37.0	39.4	34.00	1.03	3.33	5.73
2020	40.1	44.3	48.9	37.67	3.14	7.34	11.94
2025	43.5	49.9	57.0	39.47	5.20	11.60	18.7
2030	48.4	57.5	68.0	39.01	11.00	20.10	30.6

Table 6
Amount of net coal imports and its proportion of World coal trade in 2015 and 2030.

Year	World coal trade[a] ($\times 10^2$ Mt)			Net coal import of China ($\times 10^2$ Mt)			Coal import's proportion of world coal trade		
	Low	Mid	High	Low	Mid	High	Low (%)	Mid (%)	High (%)
2015	9.25	13.74	16.63	1.03	3.33	5.73	11	24	34
2030	27.04	43.14	57.12	11.00	20.10	30.60	41	47	54

[a] The data of world coal trade are obtained from adjusting the world coal trade of Energy Information Administration's IEO 2008 according to the prediction of coal import of this article.

may be challenged.

7. Conclusions and policy suggestions

If the Chinese economy and coal consumption continue to expand the way they have, China's coal imports would be unavoidable. With a coal-dominated energy structure, it is clear that China's future economic growth would not be sustainable, in light of coal supply and environmental capacity. Based on the results of this article, we make the following policy suggestions:

(1) China should develop renewable energy to help reduce future coal consumption. In addition to escalating emission problems, potential coal shortage could be also a significant threat to China's energy security. The Government should introduce more incentives to promote renewable energy development. There is a good prospective for renewable energy development in China as technology costs of renewable energies have dropped dramatically in recent years.
Developing nuclear power could be an option to reduce coal consumption and CO_2 emissions in China. China has recently made great efforts to encourage the development of nuclear power. According to the long-term development plan of nuclear power issued by the State Council, China's nuclear power capacity will increase from 8.7 GW (currently) to about 80 GW by 2020 (National Development and Reform Commission, 2007). However, it is unlikely that nuclear power will significantly change the coal-dominated energy structure. Even with 80 GW nuclear capacity, it will account only for about 6% of China's total power capacity in 2020.

(2) Energy conservation is a fundamental solution to China's energy problem and should be prioritized. The main policy options to encourage energy conservation include the following. First, removing energy subsidies that depress energy prices could provide a significant incentive to investments for energy efficiency improvement. Second, Chinese government should try to solve energy efficiency problems via market forces, rather than administrative measures. Because market forces are much more effective than administrative measures in improving energy efficiency. Finally, China should invest more in promoting technologies for energy efficiency improvements. With government's control on energy pricing, efficiency improvements need to be assessed in light of possible rebound effects, as in the Jevons paradox and Khazzoom–Brookes postulate.

(3) In addition to strategic oil reserves, China should consider establishing a strategic coal reserve to ensure energy supply security. To avoid large reserve costs, the coal reserve could simply be identified as deposits in the ground and in strategic locations, as what has been done in other countries.

(4) China should try to find ways to improve awareness among the people towards more effective energy consumption. The energy and environmental problems are both results of human behavior in energy consumption and the solutions should also be rooted in improving human behavior. Seeking energy-efficient technology, the mainstream path of choice in China, is an insufficient means to achieving a sustainable energy future, as consumption bundles must also be altered accordingly.

(5) Taking into consideration the coal production peak forecasted in this study, China will maintain a coal-dominated energy structure for a long period of time. To address climate change brought about by coal consumption, China will need to put CO_2 emission as constraint to its energy structure and promote clean coal technology. There are many policy tools available that can be used, such as preferential taxes and subsidies for clean coal technology.

(6) Recently, domestic coal enterprises in China are increasing their investments globally in coal exploration and production, as what oil enterprises have been doing. It seems like a double-edged sword, because if China encourages foreign exploration and production the coal import dependence would rise consequently while if China explores domestic coal the coal depletion problem comes. Of two evils, the least should be taken. It is a long-term strategic consideration for China to reserve domestic coal. Although coal reserves in a foreign country are less reliable than domestic reserves, it is, however, more reliable than importing coal directly from international markets, as China's coal enterprises could have a greater degree of control on volume and prices.

(7) Given the high transportation cost of coal, China should try establishing closer ties with neighboring countries that possess large coal resources such as Australia, Mongolia and Russia. In addition to importing coal from these countries, China should consider importing electricity, if feasible. This could reduce the number of additional coal-fired power plants in China.

In conclusion, at present few people in China are willing to acknowledge China's peak coal production and most of them believe that China's coal is inexhaustible. China's peak coal issue has not been taken seriously, even though in the past few years, China has had to face a rapid rise in coal prices. The recent coal-power confrontation in not signing long-term coal supply contracts highlights the continuing conflicts between coal enterprises and power plants, and serious coal pricing problems in China. Overall, the current high coal consumption growth in China is unsustainable, in terms of both coal resources and increasing emissions.

Acknowledgements

We wish to thank the anonymous reviewers and editor for their helpful suggestions.

References

Brandt, Adam R., 2007. Testing Hubbert. Energy Policy 35, 3074–3088.
Bartlett, Albert A., 2000. An analysis of US and world oil production patterns using Hubbert-style curves. Mathematical Geology 32 (1) 〈http://www.albartlett.org/articles/art2000jan.html〉.
Bardi, U., 2005. The mineral economy: a model for the shape of oil production curves. Energy Policy 33, 53–61.
Beijing WEFore Investment Consulting Co. Ltd, 2008. The Report on the Risk of Coal Industry in 2008 (2008 Nian Meitan Hangye Fengxian Fenxi Baogao), 〈http://www.pinggu.org/bbs/b90i337327p29.html〉.
BP, 2008. BP Statistical Review of World Energy 2008.
Bucci, Louis A., et al., 2006. JORC and the Chinese Resource Classification Scheme—An SRK View 〈www.cimg.org.cn/cgi-bin/noticeboards/attachments/2282/36859/AusIMM+Bulletin_Jul-Aug06.pdf〉.
China Macro Economic Information Network, 2001. The Report of China's Macro-Economic Situation, 〈http://www.macrochina.com.cn/report/free/detail/xs/008/00001493.shtml〉.
Coal.IN-En.com 〈http://www.in-en.com/coal/html/coal-20072007032675540.html〉.
Energy Watch Group, 2007. Coal: reserves and future production. EWG-Paper No. 1/07.
General Administration of Customs of People's Republic of China. 〈http://www.customs.gov.cn/publish/portal0/〉.
Höök, Mikael, Aleklett, Kjell, 2009. Historical trends in American coal production and a possible future outlook. International Journal of Coal Geology 78 (3), 201–216.
Hubbert, M.K., 1956. Nuclear energy and the fossil fuels. In: Drilling and Production Practice first ed The American Petroleum Institute, New York, pp. 7–25.
Hubbert, M.K., 1959. Techniques of prediction with application to the petroleum industry. In: Published in 44th Annual Meeting of the American Association of Petroleum Geologists. Shell Development Company, Dallas, TX, pp. 43.

Hubbert, M.K., 1974. US energy resources, a review as of 1972; a background paper prepared at the request of Henry M. Jackson, Chairman, Committee on Interior and Insular Affairs, United States Senate, Pursuant to Senate Resolution 45, A National Fuels and Energy Policy Study: Serial No. 93-40 (92-75), Part 1. US Government Printing Office, Washington, 1974, p. 186.
Hubbert, M.K., 1976. Exponential growth as a transient phenomenon in human history. In: WorldWildlife Fund's Conference, The Fragile Earth: Towards Strategies for Survival, San Francisco, 1976.
Huang, Jikun, Yang, Jun, 2006. The forecast of the impacts of China's rise on the security of China's food and energy and the world economics. Forecasting Report. CEFS-06-005. Center for Forecasting Science Chinese Academy of Sciences.
International Energy Agency, 2006. World Energy Outlook 2006.
Jevons, William Stanley, 1865. The Coal Question: An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal-Mines. Macmillan and Co., London.
Kavalov, B., Peteves, S.D., 2007. The Future of Coal. Publication from European Joint Research Center, Institute of Energy, Petten, Netherlands. Supplementary Material: Coal of the Future. Supply Prospects for Thermal Coal by 2030–2050.
Laherrere, J., 2006. Oil and gas: what future?. Groningen Annual Energy Convention 21 〈http://www.oilcrisis.com/Laherrere/groningen.pdf〉.
Lin, Boqiang, Jiang, Zhujun, He, Xiaoping, 2008. The forecast of China's consumption and structure of the primary energy. Working Paper, CCEER.
Lin, Boqiang, 2009. The way to solve China's energy problem: establishing integrated transportation system. 21st Century Business Herald, 2009-5-29.
Mohr, S.H., Evans, G.M., 2009. Forecasting coal production until 2100, The Oil Drum, http://www.theoildrum.com/node/5256.
MIT, 2007. The future of coal, 〈http://web.mit.edu/coal/The_Future_of_Coal.pdf〉.
Milici, Robert C., Campbell, Elisabeth V.M., 1997. A predictive production rate life-cycle model for Southwestern Virginia Coalfields. Geological Survey Circular 1147, p. 1997, 〈http://pubs.usgs.gov/circular/c1147/〉.
Milici, Robert C., 2000. Depletion of appalachian coal reserves—how soon?. International Journal of Coal Geology 44 (3–4), 251–266.
National Bureau of Statistics of China. China Statistical Yearbook China Statistics Press: Beijing, China, 1980–2008. 〈http://www.stats.gov.cn/tjsj/ndsj/〉.
National Bureau of Statistics of China. China Energy Statistical Yearbook China Statistics Press: Beijing, China, 1986–2008.
National Development and Reform Commission, 2007. The long-term development plan of nuclear power (Hedian Zhongchangqi Fazhan Guihua (2005–2020)), 〈http://www.ndrc.gov.cn/gzdt/t20071102_170163.htm〉.
Rice, John, 1995. Mathematical Statistics and Data Analysis, second ed Duxbury Press, ISBN: 0-534-20934-3.
Sagawa, Atsuo, Koizumi, Koichi, 2008. Trends of export and imports of coal by china and its influence on Asian markets. IEE Journal.
Stoker, Peter, 2009. Progress on the revision of the Chinese Mineral Resources and Mineral Reserves Reporting Standard. 〈http://www.jorc.org/pdf/progress_revision_chinese_mineral1.pdf〉.
Tao, Zaipu, Li, Mingyu, 2007. What is the limit of Chinese coal supplies—a STELLA model of Hubbert peak. Energy Policy 35.
〈www.ChinaCoal.org.cn〉, 〈http://www.chinacoal.gov.cn/mtzy/254/390.aspx〉.
〈www.china.com.cn〉, 〈http://www.china.com.cn/chinese/PI-c/485710.htm〉.
〈www.chinagate.com.cn〉, 〈http://cn.chinagate.cn/economics/2008-01/18/content_9553659.htm〉.
〈www.GOV.cn〉, 〈http://www.gov.cn/jrzg/2006-11/29/content_456109.htm〉.