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**Peak Energy and the Limits to
China's Economic Growth:
Prospect of Energy Supply and Economic
Growth from Now to 2050**

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Abstract

This paper evaluates the prospect of China's energy supply and its impact on economic growth from now to 2050. After considering China's domestic potential of coal, oil, and gas production, potential of energy imports from the rest of the world, as well as potential developments of renewable and nuclear energy, the paper finds that China is likely to face an insurmountable energy crisis beyond 2020 and even with optimistic assumptions, drastic declines of economic growth rate and the eventual end of economic growth cannot be avoided.

Key Words

Peak Oil; Peak Coal; Energy Crisis; Limits to Growth; Chinese Economy

JEL Codes

O40; O53; Q40

According to the World Bank (2008), measured by purchasing power parity, China now accounts for 10 percent of world GDP, about half of the current size of the US economy. Since 2000, China's share in world GDP has been growing at about 0.5 percentage point a year while the US share has been falling at about 0.3 percentage point a year. Under these trends, China could overtake the US and become the world's largest economy by around 2020.

China's economic growth has been heavily energy intensive and arguably the single most important factor behind the rapid growth of global energy demand and greenhouse gases emission in recent years. China now accounts for 15 percent of the world's primary energy consumption and under the current trend could overtake the US to become the world's largest energy consumer by 2010. China has already overtaken the US to become the world's largest carbon dioxide emitter and now accounts for one-fifth of the global emissions.

Is China's economic growth sustainable from an energy and environmental perspective? If not, how will the energy and environmental constraints shape the future of China and the rest of the world? China's energy consumption, like that of the rest of the world, depends heavily on the nonrenewable fossil fuels. Now there is a growing body of evidence suggesting that the global production of fossil fuels is likely to peak in the not very distant future and this will happen even without taking into account the environmental constraints on greenhouse gases emissions. This paper evaluates the prospect of China's energy supply and its impact on economic growth from now to 2050. After considering China's domestic potential of coal, oil, and gas production, potential of energy imports from the rest of the world, as well as potential developments of renewable and nuclear energy, the paper finds that China is likely to face an insurmountable energy crisis beyond 2020 and even with optimistic assumptions, drastic declines of economic growth rate and the eventual end of economic growth cannot be avoided. These outcomes could have major implications for the political and social development within China and in the rest of the world.

Peak Energy: World Production of Oil, Natural Gas, and Coal

In 1956, M. King Hubbert, an American geologist who worked for the Shell Oil Company, predicted that the US oil production would peak around 1970, a prediction that was later confirmed by the actual trajectory of the US oil production (see Heinberg 2004: 87-92). Since then, many other important oil producers have reached the peak and their production has been in decline. The two most important European producers, Britain and Norway, peaked in 1999 and 2001 respectively. Mexico, which was the world's fifth largest producer, peaked in 2004. The current evidence suggests that Russia, the world's second largest producer, is likely to have peaked in 2007.

Colin J. Campbell, an Irish petroleum geologist, conducted a detailed study of the world's oil discovery history and pointed out that the world oil discoveries peaked in the 1960s (Campbell 2005). In a recent research report, the German Energy Watch Group argued that the world oil production might have peaked in 2006 (Energy Watch Group 2007). The Association for the Study of Peak Oil and Gas Ireland now estimates the world oil production peak to take place in 2008 (ASPO 2008).

Dave Rutledge, chair of the Division of Engineering and Applied Science at California Institute of Technology, studied the historical series of world oil and natural gas production and concluded that about one-third of the world's ultimately recoverable resources of oil and gas have already been exploited, implying a peak of the world total production of oil and gas around 2015 (Rutledge 2007a).

A common technique used in predicting the ultimate recoverable amount of a nonrenewable resource is known as "Hubbert Linearization." As the production level approaches the peak, a linear relationship is likely to be formed between the growth rate of the cumulative production of the resource (that is, the ratio of the current annual production over the cumulative production from all previous years) and the cumulative production. The horizontal intercept of the linear function would indicate the ultimate recoverable amount and the peak

production is likely to take place when about half of the ultimate recoverable amount has been depleted (Korpela 2005).

Applying Hubbert Linearization to the historical data of world oil and natural gas production, the regression results suggest that the world oil production peak is likely to take place in 2008 and the world natural gas production peak in 2031.¹

Since 2000, global coal production has been growing at about 5 percent a year, making a larger contribution to the net increase in global energy supply than any other energy resource. Since the industrial revolution, the world's total cumulative production of coal has been about 300 billion metric tons (Rutledge 2007b). The world's official coal reserves now stand at about 850 billion metric tons (BP 2008), suggesting an ultimate recoverable amount of about 1.2 trillion metric tons. The world currently produces nearly 7 billion metric tons of coal a year. If the current growth rate of world coal production is sustained, the world's cumulative coal production would reach 600 billion metric tons by around 2030, suggesting the world production peak by that time.

However, the German Energy Watch Group (2007b) believes that the remaining recoverable coal resource is in fact much less than is suggested by the official reserves and the world coal production peak could take place in 2025. Rutledge (2007a) estimates that the

¹ Historical data of world oil and natural gas production are from Rutledge (2007b). Since 1965, the data are available from the *BP Statistical Review of World Energy* (BP 2008). A regression of the cumulative production growth rate over the world's cumulative oil production over the period 1983-2007 indicates an remaining recoverable resource of 170 billion metric tons (compared with the world's official reserves of 168.6 billion metric tons), regression R-square being 0.955. A regression of the cumulative production growth rate over the world's cumulative natural gas production over the period 1995-2007 indicates an remaining recoverable resource of 250 billion metric tons of oil equivalent (compared with the world's official reserves of 177.4 trillion cubic meters or 160 billion metric tons of oil equivalent), regression R-square being 0.895.

world's remaining recoverable coal is likely to be 440 billion metric tons, suggesting the peak within ten years. An application of Hubbert Linearization finds that the world (excluding China) production of coal could peak by 2018.²

Peak Energy: China's Production of Coal, Oil, and Natural Gas

Domestic coal production accounts for 72.2 percent of China's primary energy supply. Domestic oil, domestic natural gas, hydro, and imports and stock change (mostly oil) account for 10.4, 3.5, 2.3, and 11.3 percent respectively. Nuclear energy and non-hydro renewables together account for only 0.3 percent.³

According to China's Ministry of Land and Natural Resources, China's remaining recoverable coal amounts to 200 billion metric tons (Cui, ed. 2008:33). China's cumulative coal production has been about 50 billion metric tons. China's annual coal production reached 2.5 billion metric tons by 2007 and has been growing at an annual rate of 10 percent since 2000. At this rate, China's cumulative coal production would have passed 125 billion metric tons by around 2020.

² Historical data of world coal production are from Rutledge (2007b) and BP (2008). A regression of the cumulative production growth rate over the world's cumulative coal production (excluding China) over the period 1950-2007 indicates a remaining recoverable resource of 330 billion metric tons (compared with the world's official reserves of 730 billion metric tons and Rutledge's estimate of 350 billion metric tons), regression R-square being 0.817.

³ Data for China's coal, oil, natural gas, nuclear, and hydro production are from BP (2008). Imports and stock change are derived by subtracting the total domestic production of coal, oil, and natural gas from their total consumption. Renewable contribution is estimated by this author. Hydro, nuclear, and renewable contributions are measured by the electrical energy they represent. Traditional biomass (such as wood burning in the rural areas) is excluded from the total primary energy supply.

The *BP Statistical Review of World Energy* reports China's coal reserve to be only 114.5 billion metric tons, about half of the Chinese official estimate (BP 2008). The German Energy Watch Group (2007b) argues that China's coal production could peak as early as 2015. An exercise of Hubbert Linearization over the period 1970-2007 suggests China's remaining recoverable coal to be 110 billion metric tons (with annual production peaking in 2021).

By comparison, there is a consensus regarding China's oil production potential. The consensus among the Chinese researchers is that the domestic oil production is likely to peak around 2015, with the peak production level unlikely to be above 200 million metric tons (the current annual production is about 190 million metric tons) (Cui, ed. 2008:33).

China's natural gas production now makes a small contribution to China's energy supply, but has been growing at 14 percent a year since 2007. The current annual production is about 70 billion cubic meters. The Chinese researchers estimate China's ultimate recoverable natural gas to be 10-13 trillion cubic meters (Cui, ed. 2008:33). With a 10 percent growth rate of annual production, China's natural gas production could peak by 2030.

China's Nuclear and Renewable Energy Potential

China currently has a nuclear electricity generating capacity of 7 giga-watts. The Chinese government plans to expand the nuclear electricity capacity to 40 giga-watts by 2020 (Cui, ed. 2008:309).

Nuclear electricity generation uses uranium, which is a nonrenewable resource. The German Energy Watch Group (2006) points out that the world's proved and possible uranium resources could last only 30-70 years at the current rate of consumption. China's economically recoverable uranium is estimated to be 650,000 metric tons (Cui, ed. 2008:34). If China's nuclear electricity capacity is expanded to 40 giga-watts, China's annual consumption of uranium will need to rise to about 9,000 metric tons. At this rate, China's domestic uranium resource will be exhausted in about 70 years.

Hydro electricity now accounts for about 15 percent of China's total electricity generation. The Chinese government plans to expand the hydro electricity generating capacity from the current 100 giga-watts to more than 200 giga-watts by 2020. China's long-term technical potential of hydro electricity is estimated to be 500 giga-watts (Cui, ed. 2008:34).

By 2020, the Chinese government plans to expand China's wind electricity generating capacity to 100 giga-watts and biomass electricity generating capacity to 30 giga-watts. By 2030, China's solar photovoltaic electricity generating capacity is projected to increase to 100 giga-watts (Cui, ed. 2008:308-309).

China's long-term onshore and offshore wind electricity potential is estimated to be 1,000 giga-watts (Cui, ed. 2008:273). By comparison, China's solar electricity potential is likely to be limited. Solar photovoltaic electricity is much more expensive than wind electricity, is limited to daytime generation, and suffers from substantial seasonal variations. The more promising solar electricity technology is known as the solar thermal technology or concentrated solar power. With the solar thermal technology, it is possible to store solar energy as heat and thus has less of a problem of intermittency. However, the solar thermal technology works best in tropical or subtropical deserts. China does not have access to comparable geographical areas.

In recent years, China's ecological footprint has been growing rapidly. According to the *Living Planet Report* (WWF et al. 2006), China's ecological footprint now doubles China's own biological capacity. In fact, China's ecological footprint would be greater than its biological capacity even if the effects of energy consumption were excluded. That is, China's biological capacity has already been stressed to the limit just to provide food for the population. China is also confronted with a potentially devastating water crisis. Given the severe constraints imposed by China's limited biological capacity and water shortage, biomass is unlikely to make a major contribution to China's future energy supply.

The Limits to Growth: Prospect for China's Energy Supply and Economic Growth from Now to 2050

Figure 1 presents China's historical and projected primary energy supply from 1950 to 2050. China's remaining recoverable coal is assumed to be 200 billion tons (the same as China's official estimate) and China's coal production is projected to peak in 2030. The oil production is projected to peak in 2015 and the natural gas production is assumed to peak in 2047.

By 2050, China's hydro electricity technical potential is assumed to be fully exploited. China's long-term potential of nuclear electricity generating capacity is assumed to be 100 gigawatts, comparable to the present US nuclear generating capacity.

China's long-term potential of non-hydro renewable electricity generating capacity is assumed to be 2,000 gigawatts (including 1,000 gigawatts of wind electricity and 1,000 gigawatts of solar and other renewable electricity). Half of this potential is projected to have been exploited by 2050. By comparison, China's current total electricity generating capacity from all sources amounts to about 700 gigawatts.

Despite these optimistic assumptions, between now and 2020, China will have to rely upon rapid increase in energy imports to sustain rapid economic growth. From now to 2020, it is assumed that China's energy imports will grow sufficiently rapidly so that China could maintain an annual economic growth rate of 8.5 percent.

Between 2000 and 2007, China's energy consumption grew at an average annual rate of 10 percent. Between 2007 and 2020, it is assumed that rapid improvements in energy efficiency allow China's energy consumption growth to slow down to 3.9 percent a year. Nevertheless, China's energy imports will have to grow from 200 million metric tons of oil equivalent to nearly 600 million metric tons (and will keep growing if rapid economic growth continues). China's energy imports as a share of the rest of the world's total production of fossil fuels would

have to increase from 2.5 percent to 7 percent.⁴ By comparison, the US energy imports in 2007 were about 700 million metric tons of oil equivalent. Beyond 2020, it is assumed that China's energy imports will account for 7.5 percent of the rest of the world's fossil fuels production.

According to the World Bank (2008) measure of GDP and *BP Statistical Review of World Energy*, China's current level of energy efficiency (measured by purchasing power parity of GDP per unit of primary energy consumption) is about \$3.7 per kilogram of oil equivalent. By comparison, the US energy efficiency is \$5.9 per kilogram, Japan's energy efficiency is \$8.6 per kilogram, the German energy efficiency is \$9.0 per kilogram, and the world average is \$6.0 per kilogram. In the current projection, it is assumed that China's energy efficiency would more than triple and reach \$13 per kilogram of oil equivalent by 2050.

According to the *Annual Report of China's Energy Development*, the average physical efficiency of China's energy system is about 36 percent (Cui, ed. 2008:332). This result, if reliable, would suggest that China's long-term energy efficiency potential at most would be about three times of the present level. The above projection assumes that this potential would be more than fully exploited by 2050. Figure 2 compares China's projected energy efficiency with the historical energy efficiency performance of the world average as well as the world's largest economies.

With energy supply and energy efficiency projected, one can then proceed to project economic growth, as GDP is simply the product of primary energy supply and energy efficiency. Figure 2 presents China's historical and projected economic growth rates from 1980 to 2050.

It is assumed that the Chinese economy will continue to grow at 8.5 percent a year until 2020. After 2020, however, it is extremely unlikely that China's energy imports from the rest of

⁴ The world (excluding China) production of coal is projected to peak in 2018. The rest of the world's oil and gas production is derived by subtracting the projected China's production from the projected total world production.

the world could grow any further. As energy imports start to decline, economic growth rate plunges below 6 percent.

It turns out that the rapid growth of renewable energy and energy efficiency will fall far short of what is necessary to compensate the decline of fossil fuels. Figure 1 shows that China's total energy supply peaks around 2030 and declines at an accelerating pace from 2030 to 2050. By 2050, the Chinese economy sinks into negative growth and permanent decline.

Could there be anything wrong with these projections? The above assumptions are between optimistic and wildly optimistic. The coal projection is based on the highest estimate of China's remaining recoverable coal. The oil and natural gas projections are fairly uncontroversial. The hydro electricity is expanded to the limit. Barring unexpected technological miracles, there is little scope for further expansion of nuclear electricity. Both the renewable and energy efficiency projections are on the optimistic side. Energy imports are allowed to grow to the point beyond which the rest of the world would be forced into energy starvation. What else could one do to save China's economic growth?

Therefore, it seems impossible to avoid the conclusion that the availability of energy resources is likely to impose an insurmountable limit to China's future economic growth. It is obvious that such a finding, if confirmed by the actual development of future events, will be of enormous significance for the global political and social development.

First of all, as the US imperialism has been in secular decline, many have expected or hoped that China would replace the US to become the next leader of the capitalist world system, leading a successful systemic reconstruction. However, given the findings of this paper, by the mid-21st century, the Chinese economy will probably find itself in permanent decline (if not complete disintegration) and China will be in no position to lead the restructuring of the existing world system.

Within China, until now, the Chinese ruling elites have relied upon rapid economic growth to alleviate or divert various social conflicts and tensions. However, beyond 2020, as the

Chinese economy falls into increasingly deeper economic crisis, it will become impossible for the ruling elites to contain the unfulfilled economic, social and political aspirations from the broad masses of the population. Thus, in all likelihood, economic crisis will be followed by political and social explosions.

Finally, the limits to China's economic growth could turn out to coincide with the limits to global economic growth. The capitalist world system is one based on endless drive for profit and capital accumulation. After centuries of ruthless accumulation, we have by now reached the point where the global ecological system is on the verge of total collapse. The global energy crisis and other aspects of the global environmental crisis represent the strong signals that the nature sends to the humanity: the existing social system has reached its historical limit and the future survival of the humanity and the civilization depends on the building of a new, equitable, and sustainable society as soon as possible.

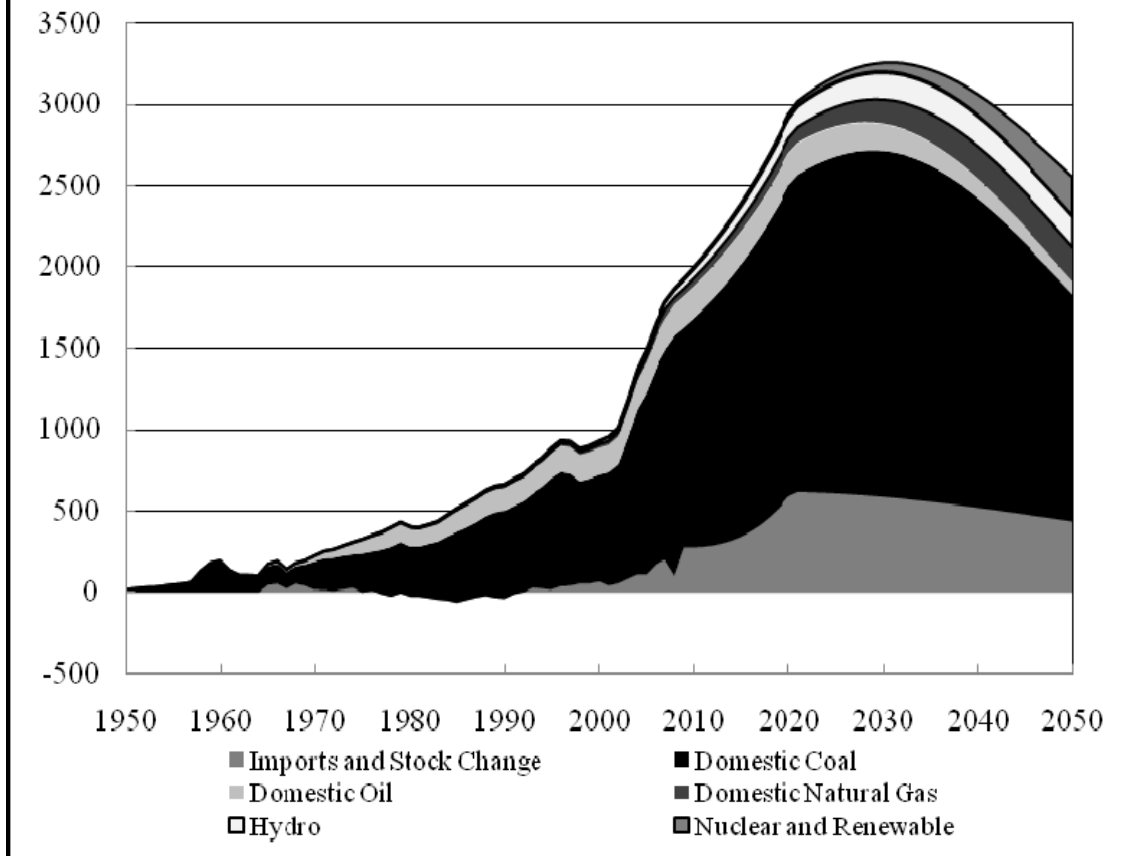
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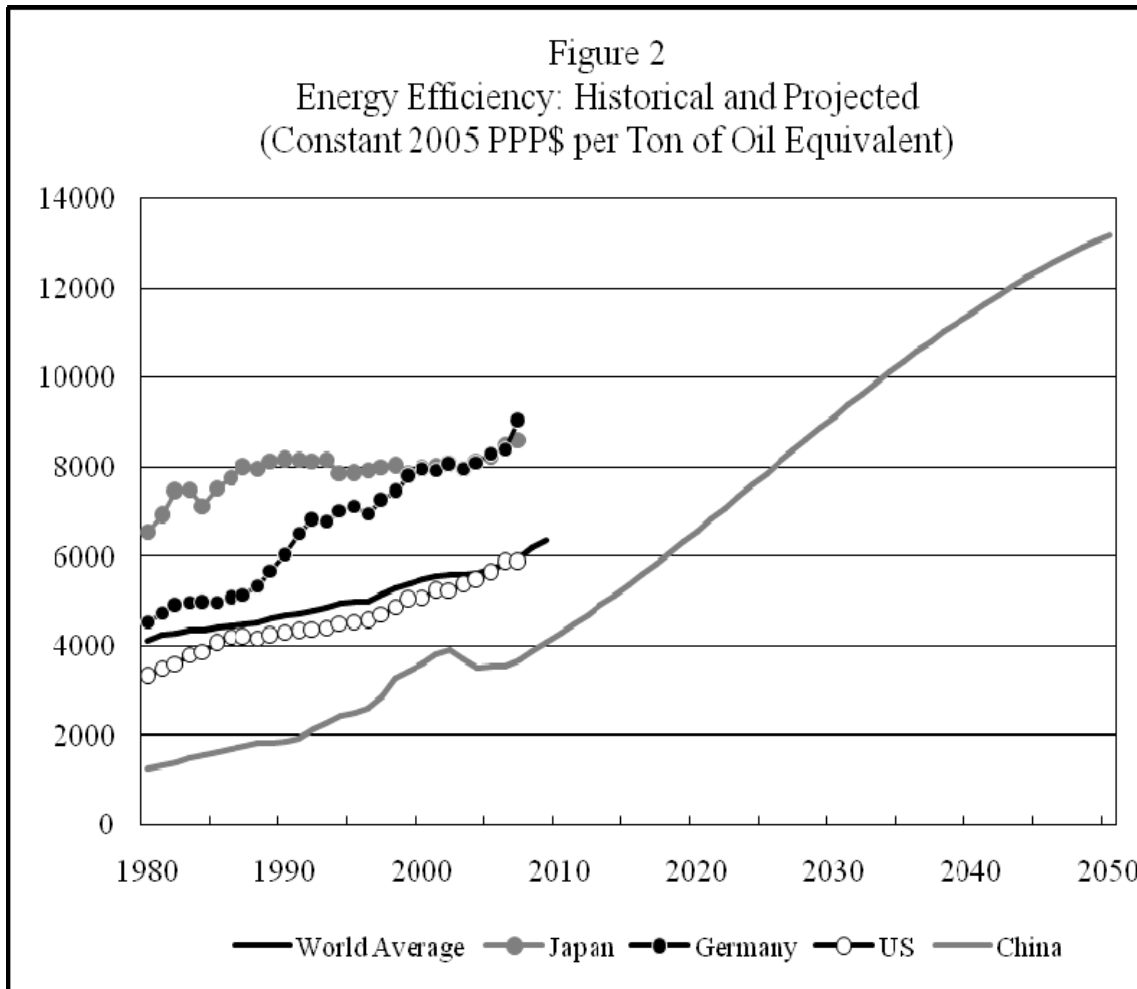
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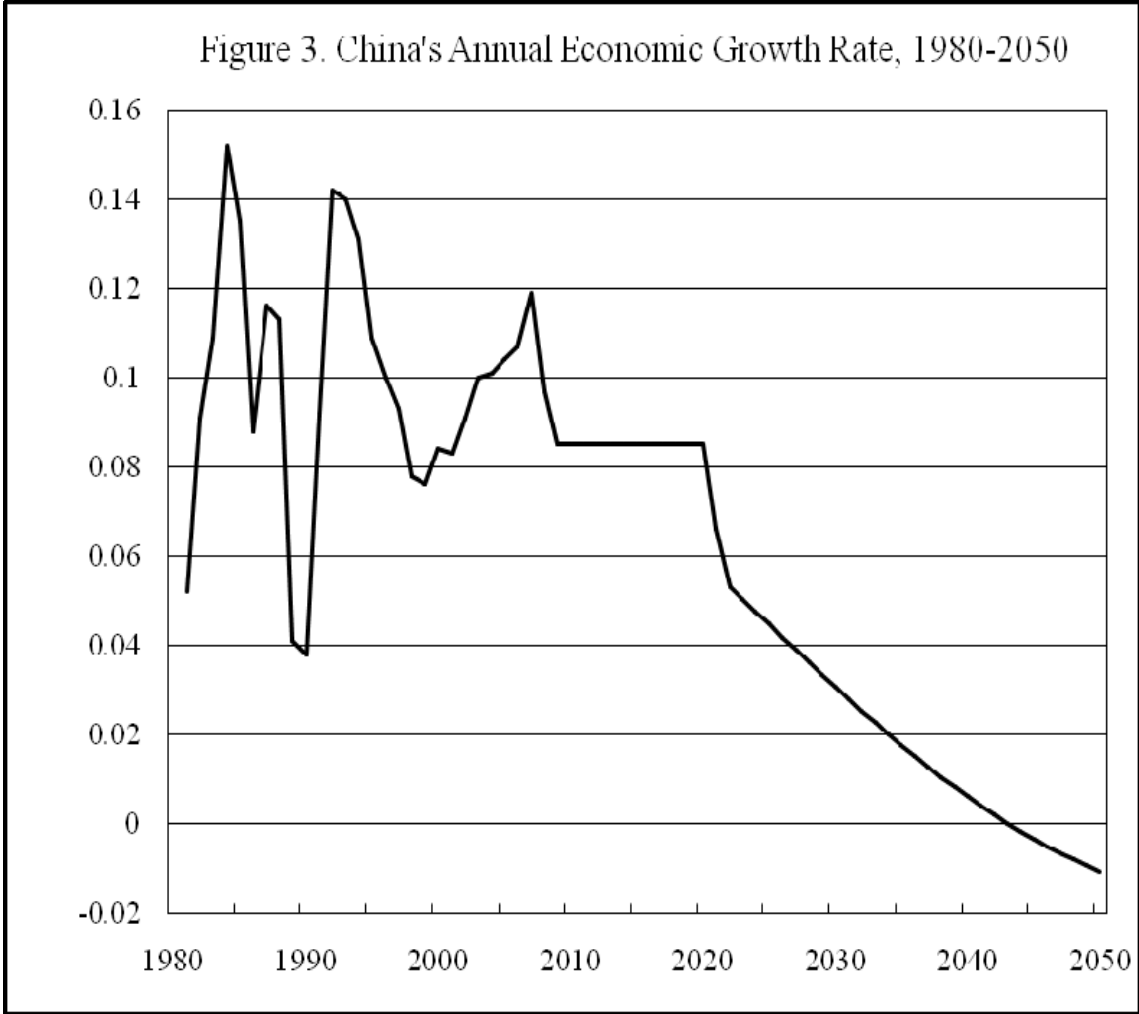
Figure 1. China's Primary Energy Supply
(million metric tons of oil equivalent, 1950-2050)



Sources: Historical data of energy production are from Rutledge (2007b) and BP (2008). Renewable electricity generation data from 1994 to 2005 are from the US Energy Information Administration.



Sources: Energy efficiency is calculated as the ratio of GDP (measured by constant 2005 purchasing power parity dollars) over primary energy supply. Historical GDP data are from World Bank (2008). Historical energy data are from BP (2008).



Sources: Historical growth rates are from World Bank (2008).