The Future of Natural Gas vs. Coal Consumption in Beijing, Guangdong and Shanghai: An assessment utilizing MARKAL

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The Program on Energy and Sustainable Development at Stanford University is an interdisciplinary research program focused on the economic and environmental consequences of global energy consumption. Its studies examine the development of global natural gas markets, reform of electric power markets, international climate policy, and how the availability of modern energy services, such as electricity, can affect the process of economic growth in the world's poorest regions.

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About the PESD Study: Natural Gas in the Energy Futures of China and India

PESD has been studying the emerging global market for natural gas through a series of closely integrated research projects. The topics of these studies range from focusing on the geopolitical implications of a shift to a global gas market, the factors that affect gas pricing and flows as LNG links the U.S. and European markets across the Atlantic basin, and how gas projects fare in privately-owned independent power projects (IPPs) in emerging markets.

One of the open questions in all these studies concerned China and India--both countries use relatively small amounts of gas now but could be very large in the future. The role of natural gas in Chinese and Indian economies is of critical import both domestically and for global energy and environmental issues. The competition between coal and natural gas in these two markets has tremendous implications for local air pollution and for climate change. Rising demand for imported gas in China and India will also shape the LNG market in the Pacific Basin and could lead to the construction of major international pipeline projects to monetize gas supplies in Russia and the Middle East. The present paper is one in a series that looks at the Chinese market in detail.

Disclaimer

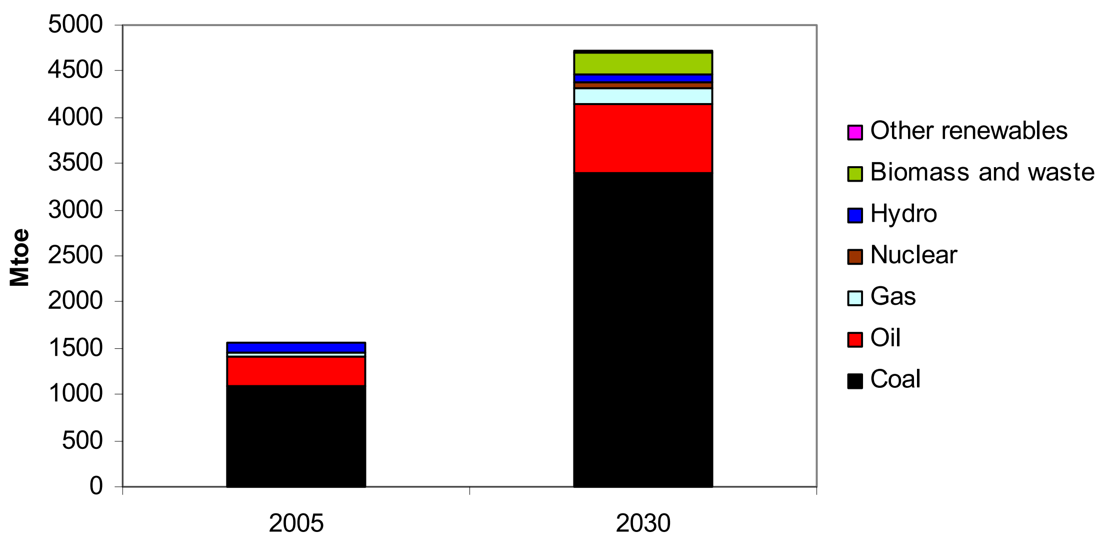
This paper was written by a researcher (or researchers) who participated in the PESD study *Natural Gas in the Energy Futures of China and India*. Where feasible, this paper has been reviewed prior to release. However, the research and the views expressed within are those of the individual researcher(s), and do not necessarily represent the views of Stanford University.

I. Introduction

The world's natural gas market is rapidly globalizing. Traditionally, gas supplies have been delivered entirely within regional markets—usually with little geographical distance between the source of gas and its ultimate combustion. However, a significant and growing fraction of world gas is traded longer distances via pipeline and, increasingly, as LNG. The rising role of LNG is interconnecting gas markets such that a single global market is emerging.[1]

Within this increasingly integrated gas market, the role of China remains highly uncertain. Today, China's share of the global gas market is tiny, with a natural gas market that is smaller than California's[2], but the future demand for natural gas in China is potentially enormous. With an average gross domestic product (GDP) growth of 9.6% for the last twenty years[3] and no signs of slowing down, demand for energy commodities—coal and oil, notably—has been expanding rapidly. With appropriate policies, natural gas could also grow rapidly.

Figure 1: Primary Energy Consumption in China for 2005 and 2030



Source: BP Statistics Review 2006, IEA WEO 2005

This study explores potential drivers for increased natural gas demand within the Chinese energy system and focuses on three regions—Beijing, Shanghai and Guangdong. This regional model reflects that natural gas sourcing and the downstream natural gas market vary greatly by region due to climatic and geographical barriers. For example,

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[1] Jensen, Jim. (2004) "The Development of a Global LNG Market." Oxford Institute for Energy Studies.
[2] China data from: ISI Emerging Markets, CEIC Database, (2007). Indian data from: Government of India, Ministry of Petroleum and Natural Gas (2007). "Petroleum Statistics."
[3] China National Bureau of Statistics, 10 January 2006

Guangdong receives no pipeline gas and is dependent on LNG imports (at present from Australia), while Beijing and Shanghai's gas demands are principally supplied by domestic pipelines. The major off-takers for the gas differ between regions as well. In Shanghai, for example, the industrial sector consumes almost all of the gas, while peaking power plants are major off-takers in Guangdong. The regional organization of this study also reflects the political realities of decision-making in China. While there are national policies on energy in China, most decisions that affect the usage of natural gas are made at the provincial and local level and driven by the economics and consumption patterns of each locale. A regional focus is therefore useful to model the nuances unique to each area.

Analyzing the drivers of gas demand in China is crucially important for three reasons. First, understanding the increasingly global gas market requires some assessment of the demand for natural gas in major emerging markets, such as China and India. Second, China's gas demand has repercussions for global geopolitics. State-owned China National Petroleum Company (CNPC) is already earnestly acquiring assets and building relationships in oil and gas fields abroad. For example, high level negotiations between China, Turkmenistan, and Kazakhstan are aimed at securing natural gas supplies from the Bagtyiarlyk gas fields, via a pipeline through Kazakhstan[4]. CNPC is also engaged in a worldwide search to secure more LNG supplies. If natural gas demand soars, CNPC will be under increased pressure to seek out new supplies. This competition for resources could lead to a realignment of alliances globally.

Third, a significant increase in natural gas use could result in a decrease of CO_2 emissions by displacing more carbon-intensive fuels such as coal. This issue is especially pressing since China is projected to be the top emitter of greenhouse gases in the world by the end of 2007.[5] Gas could play a role in stemming the emissions which are dominated by coal.

In analyzing the energy systems of Beijing, Guangdong, and Shanghai, we used three separate, regional MARKAL models. Given a projected level of total energy demand services, each MARKAL model solves for a least cost optimal solution[6] over the course of twenty years (2000-2020), utilizing a menu of technologies that is provided as an input for the models. The specific types of energy and emissions control technology are characterized by performance and cost parameters. The model solves by selecting a combination of technologies that minimizes the total system cost and meets the estimated energy demand.[7] Our goal is not necessarily a robust prediction of future gas use, since key input assumptions, such as the level of demand services, are highly uncertain. Rather, such models are particularly well suited to reveal how sensitive natural gas demand is to key factors. In addition, because the models allow the system to meet energy demand in the most cost effective manner, the results of the study can also help illuminate financially viable options for constraining emissions.

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[4] "China announces details of its second West-East gas pipeline project." Interfax, 19 August 2007

[5] U.S. Carbon Dioxide Information Analysis Center, U.S. Department of Energy (2007).

[6] Noble, Ken et. al.(2005) MARKAL Training Workshop Support Notes, The Australian Bureau of Agricultural and Resource Economics, June 30, 2005.

[7] Energy Technology Systems Analysis Programme, "http://www.etsap.org/markal/main.html"

For this study, we identified some of the major factors that are likely to affect future demand for gas. These include:

- Rate at which more efficient end-use technology is made available;
- Stringency of local and regional environmental constraints;
- Financial reforms that affect the cost of capital for different sectors of the economy (i.e., power, industry, residential, commercial, transportation)
- Pricing and availability of gas.

The findings of the report show that the most important drivers (apart from polices that influence the price of natural gas relative to other fuels) which affect the consumption of natural gas are the implementation of SO_2 controls in the system and, unexpectedly, financial reforms. For very tight limits on SO_2 emissions, the model shows that a switch to natural gas in the power and industrial sectors becomes the economically optimal alternative to other fossil fuels in many cases. When the rise in gas demand is in the industrial sector, this gas displaces oil; in the power sector, where gas competes with coal, it is much harder in our baseline scenario for gas to gain a substantial share of the market. We also find that a side benefit to SO_2 emissions reduction policies is a corresponding decline in CO_2 emissions on the order of 100 million tons CO_2 for some locales (equivalent to about half of the entire stock of Clean Development Mechanism projects in China[8]). This suggests that a leverage point for governments in developing countries like China to start addressing global concerns about climate change is through regulation of local pollutants that yield visible and immediate benefits while also fortuitously limiting growth of CO_2.

As for the effects of financial policies on energy consumption, we found that, with differentiation of the cost of capital by sector as effectively occurs in China today, the consumption of coal is particularly favored. Under current conditions in China, the power sector has access to cheaper capital than other sectors within the economy, providing an incentive to build power plants with a high ratio of capital to operating costs. This arrangement favors large coal facilities, which are expensive to build and cheap to operate, over natural gas plants, which are cheap to build but expensive to operate because of the higher price of gas. While the situation is now changing due to financial reforms, it may help explain why gas has had a particularly difficult time making inroads in the power sector. This also suggests that financial reforms could have a big impact on the country's CO_2 emissions.

[8] UNEP Riso Centre, Capacity Development for the Clean Development Mechanism, http://www.cdmpipeline.org

II. Overview: Supply and Demand for Natural Gas in China

1. Background

The story of China's ascent in the global marketplace is well-known. Rapid economic growth has been fueled by massive domestic and foreign investments in the heavy industrial and manufacturing industries. Cheap labor, availability of raw materials, and loosely enforced environmental regulations serve as strong incentives for the development of energy intensive industries in China, mostly fueled by coal burned directly or after conversion to electricity. The government is now beginning to realize the external costs that it must pay for this mode of development. The type of technology and fuel with which the economy is powered has a strong bearing on the consequences of energy consumption now and in the future. While carbon dioxide (CO_2) emissions are not likely to be regulated in the near-term future, the government has already moved in the direction of regulating local and regional pollutants such as sulfur dioxide (SO_2), which have undeniably taken a toll on the health and environment of the country. One third of the land mass of China is affected by acid rain, and the treatment and loss of productivity from respiratory illnesses caused by air pollution cost the economy more than 7% of GDP.[9] Since natural gas is the cleaner burning alternative to other fossil fuels, encouraging the increased use of natural gas is one strategy that the government is evaluating (and deploying in some areas) to ameliorate the negative consequences of energy consumption.

Creating the right incentives for increased natural gas use is a challenging proposition, however. Gas has always been an integral part of the state-owned oil industry in China. PetroChina is the largest upstream player and is also responsible for the construction of the majority of the domestic pipelines. There is no separate company that deals exclusively in natural gas, and there is no policy that regulates the use of natural gas for any industry. The only mention of a unified goal for natural gas is in the 11th Five-Year Plan on Energy Development developed by the National Development and Reform Commission (NDRC) of the central government. The stated goal is to increase the share of natural gas in the primary energy mix from 2% to 5.3% by 2010, and reach 10% by 2020. However, there are no guidelines for how such ambitious goals can be achieved. As a result, provinces sometimes are expected to reach unrealistic targets without assistance from the central government. The lack of structure and support for the development of natural gas usage is partly responsible for the small part that gas plays in China's energy mix.

NDRC sets gas prices based on an affordability criterion utilizing the cost-plus approach to pricing.[10] These are the prices that the gas distribution companies have to pay. Fees

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[9] Peng, ChaoYang et. al. (2002) "Urban Health Quality and Health in China" Urban Studies, Vol. 39, No. 12, 2283-2299.

[10] Well-head [regulated] + pipeline mark up cost + local distribution mark up cost = sales price to customer

charged by gas distribution companies to end users are approved by the local pricing bureaus. The price for natural gas therefore varies by province and sector. Residential users pay the highest price, followed by chemical producers, then power generators, and finally fertilizer manufacturers. Consequently, the suppliers (Sinopec and PetroChina) typically prefer to sell at a higher price to the residential sector rather than to the subsidized industries, especially in a tight market. An overall goal of the NDRC is to increase gas prices by an average of 8% annually to balance out the increasing dependence on foreign imports of energy resources such as gas.[11] At the same time, there is some tension between this goal and the objective of boosting natural gas use to increase fuel diversity and reduce environmental impacts.[12] There are plans to change the natural gas pricing mechanism to be 40% weighted on the international crude oil prices, 20% on international LNG prices, and 40% on international coal prices. While this does not bode well for an increased consumption of natural gas, the rising price of coal may blunt the effects of these changes.

Demand

The major off-takers of natural gas in China are the chemical and fertilizer, industrial, power generation, and residential sectors (Figure 2). In time, IEA predicts that the power sector will become a larger off-taker, consuming 39% of the gas in 2020 compared to 11% in 1997. Residential consumption is also estimated to increase to 25% of total gas off-take in 2020 from 11% in 1997. The consumption of gas by the chemicals and fertilizer sector is predicted to fall from 43% to 16%. Although these numbers describe the national market, regional demand can look quite different. For example, the chemical/fertilizer natural gas demand is non-existent for the fairly urbanized areas in and around Beijing, Guangdong, and Shanghai. The regional demand will be detailed in later sections.

Beijing

In Beijing, end-use consumption of gas is dominated by space heating (60%), residential use (22%), commercial use (14%), industry (3%), and automobiles (1%).[13] Because space heating is such a large component of the consumption needs, one of the challenges for the system is how to accommodate the seasonality of the demand and how to deal with the extra supply in the summer. However, because Beijing is particularly motivated to rid the air of pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NOx), and total suspended particulate matter (TSP) before the 2008 Olympics, the government is likely to support policies which encourage the use of natural gas. Although no firm polices are in place to do this, the Beijing government has forecasted optimistic future natural gas consumption levels (12% of end-use energy mix by 2020; the current level is 7%).[14]

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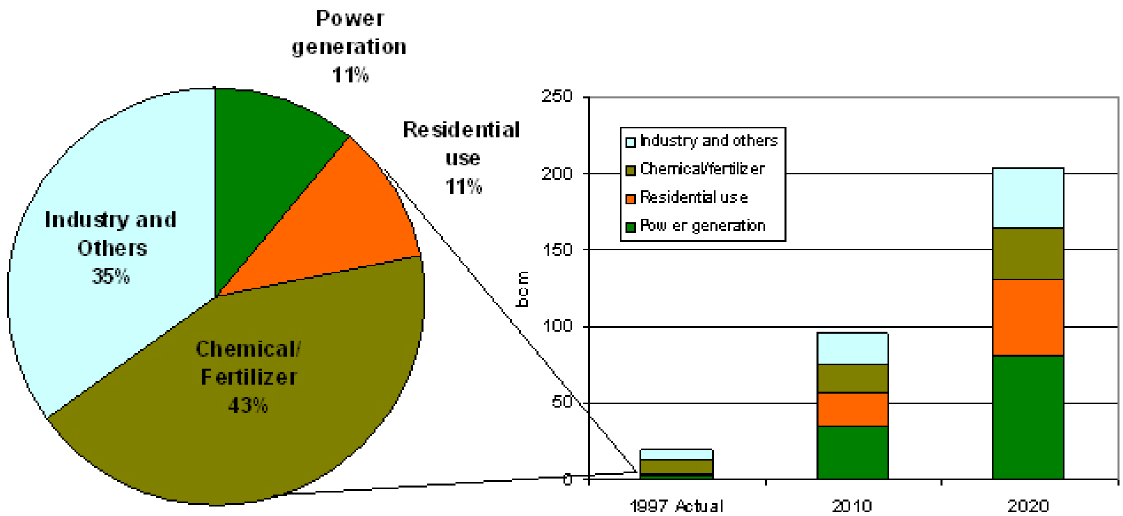
[11] "China to rasie natural gas prices by 10 percent this month." Interfax. 11 April 2007

[12] Interfax. 11 April 2007

[13] Chen, W. et. al. "Beijing Natural Gas Report." Program on Energy and Sustainable Development, Stanford University, Working paper #63. 4 June 2007.

[14] Chen, W. et. al. "Beijing Natural Gas Project Report." Working Paper #63, Program on Energy and Sustainable Development, Stanford University. June 2007. pp. 7-8

Figure 2: National natural gas consumption in China by sector



Source: *IEA, "World Energy Outlook." 2006*

Guangdong

Guangdong's situation is especially affected by the scarcity of local coal resources. This province is thus poised to become the biggest natural gas demand center in China. It faces high costs and unreliability associated with the transportation of coal from remote areas. Consequently, Guangdong is often the first to explore alternative energy supply options. China's first LNG terminal, Guangdong Dapeng, was completed in 2006. Guangdong has also initiated several nuclear power plant projects. The major consumers of natural gas in this region include peaking power plants that would otherwise be run by expensive diesel generators.[15] Industrial and residential/commercial demand is also projected to increase. The high level of development and income in the region means that its residents and officials have the financial and infrastructural capacity to put a premium on environmental protection. Natural gas is a more attractive fuel option for this region than in other parts of China due to these factors.

Shanghai

About 32% of the natural gas demand in Shanghai comes from six energy intensive industries[16]. Industry is therefore poised to be the largest user of natural gas in this region, although some construction of natural gas-fired power plants is under way. Shanghai experienced a rapid increase in residential and commercial natural gas consumption in recent years due to the fact that much of the infrastructure that is needed

[15] Zeng, L. et al. "Development of the Guangdong Natural Gas Market Report." Working Paper #64. Program on Energy and Sustainable Development, Stanford University. June 2007, pp. 13-17.

[16] Yu, Y. et. al. "Shanghai Energy Situation and Natural Gas Development." Working Paper #65. Program on Energy and Sustainable Development, Stanford University. June 2007, pp. 36-38. Figure calculated by author from data from Yu Yuefeng, Zhang Shurong, and Hu Jianyi. using the total natural gas demand, percentage of natural gas in total gas use, and the total gas consumed in industry.

to bring gas to each household was already in place (This network of pipes enabled the distribution of synthetic gas, also known as town gas, before natural gas was available). Shanghai also has the most comprehensive policies in support of natural gas market development. For example, the municipal government was the first in the country to subsidize the cost of natural gas conversion. Simultaneously, fees for SO_2 emissions have tripled from 0.20 RMB/kg to 0.60 RMB/kg in 2005.[17] However, with its cheaper fuel prices and entrenched infrastructure, coal remains dominant in the energy sector.

Table 1: Natural gas demand in three regions

Region	Dominant uses in status quo	Current natural gas demand	Availability of competing fuel alternatives	Existing gas infrastructure
Beijing	Space heating; Residential and commercial use	2.4 bcm	High (coal)	West –East Pipeline (WEP)
Guangdong	Power generation; residential/commercial use; industrial processes	3.5 bcm	Low	LNG terminal
Shanghai	Power generation; co-generation, transition from city gas for residential/commercial uses	4.3 bcm	High (coal)	West –East Pipeline (WEP); existing residential city gas pipe system

Source: Chen et. al., Zeng et. al., Yu et. al. 2006

Supply

Most of the onshore gas supplies are controlled by PetroChina, a listed subsidiary of China National Petroleum Company (CNPC), China's largest state-owned enterprise (The offshore supplies are controlled by the China National Offshore Oil Company, CNOOC-another state-owned company.)

In addition to piped natural gas, imported liquefied natural gas (LNG) is another source of natural gas that China has tapped into and is planning to rely more upon in the future. Only the Dapeng Shenzhen LNG terminal in Guangdong is operational currently; two more in Shanghai and Fujian have been approved by the government and are likely to go forward. There is no foreseeable barrier to the construction of the other LNG terminals if demand continues to grow, although the growth in demand is slower than predicted originally[18]. A third source is international pipelines from Turkmenistan, Russia and

[17] Yu et. al.
[18] "Blazing a new path", Petroleum Economist, August 2007, pp. 16-17

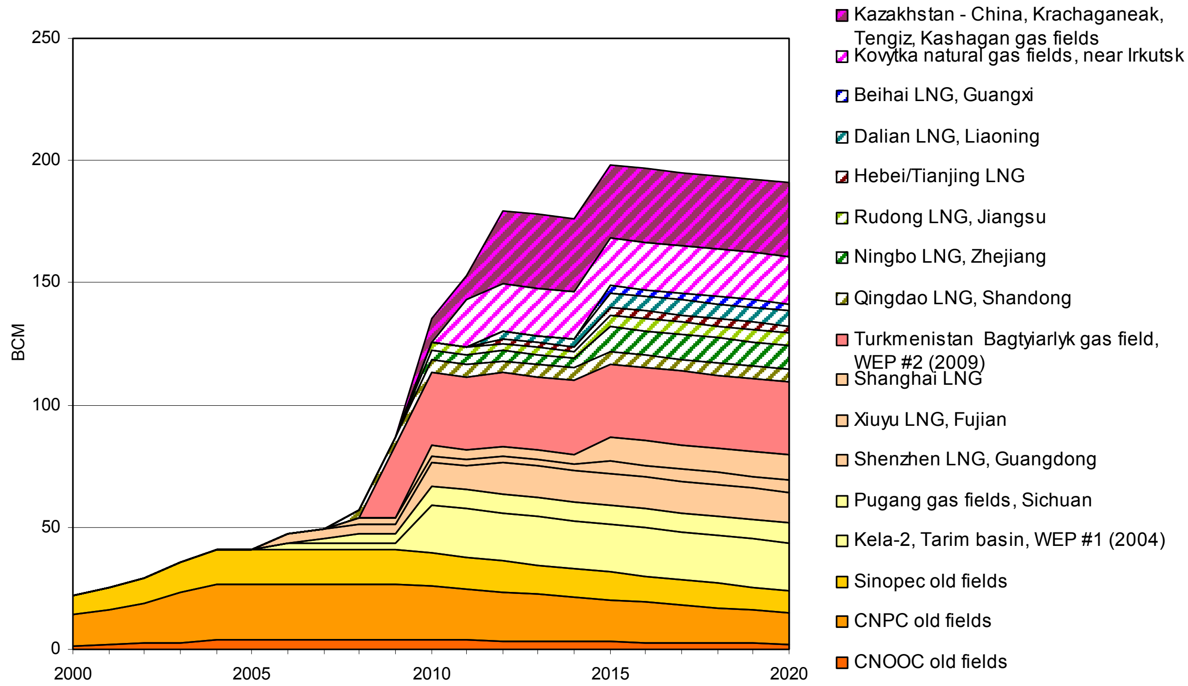
Kazakhstan. Of these, the pipeline to connect Turkmenistan and Xinjiang seems to be the most promising option, although talks have stagnated on the question of gas prices. The Kazakh and Russian supplies appear less likely to be realized at the moment. Supply from Russia's Kovykta gas field are a perennial source of interest yet also perennially stalled due to lack of strategy and commitment by Russia's Gazprom.

The top graph in Figure 3 "stacks" the supplies, with the most likely on the bottom and shaded in solid and the more speculative on top and hatched in shading. The bottom chart indicates country wide demand estimates from official Chinese agencies (such as the National Development and Reform Commission (NDRC), China National Petroleum Company (CNPC), and China National Offshore Oil Company (CNOOC)) and western sources overlaid on top of the supplies. The Chinese sources all arrive at similarly high estimates for natural gas use, perhaps due in part to a desire to approach government targets, while outside sources show lower and more varied projections. They suggest that the full range of plans to develop major international gas projects are based on overly optimistic demand projections. Uncertainty surrounding the gas demand estimates makes infrastructure planning difficult. The 100 billion cubic meters (bcm) difference between the highest and lowest estimates for gas demand is more than nine times the capacity of the West-East pipeline. This is the essential dilemma of developing a natural gas market. As earlier studies have shown, one of the major challenges in developing large-scale gas infrastructures is assuring adequate demand.[19] The study at hand does not look at the whole country, and thus our projections are only a subset of the national total, but the projections are consistent with the full range of demand projections for the country.

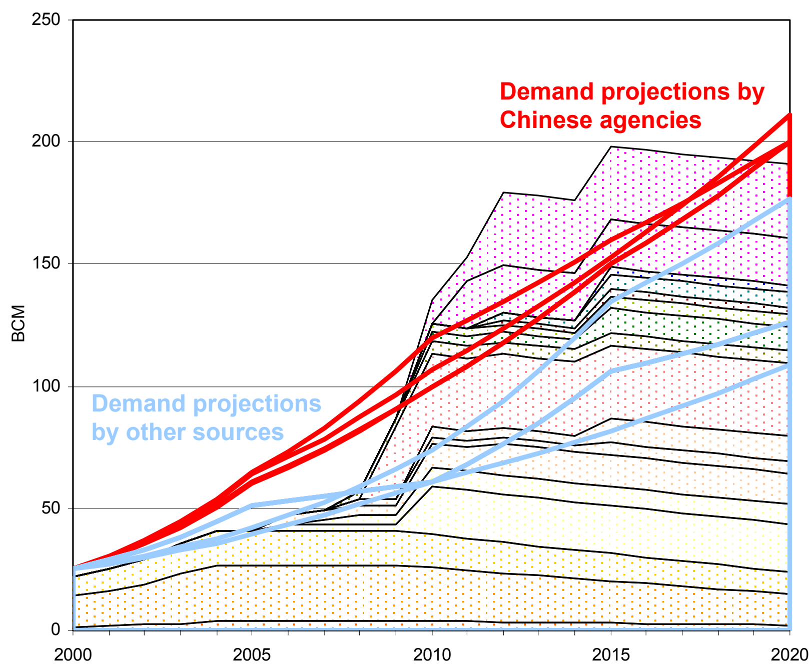
[19] Victor, D., Jaffe, A., Hayes, M. *Natural Gas and Geopolitics: From 1970 to 2040*, Cambridge University Press (2006)

Figure 3: Potential Natural Gas Supplies and National Demand Projections

Supply



Demand

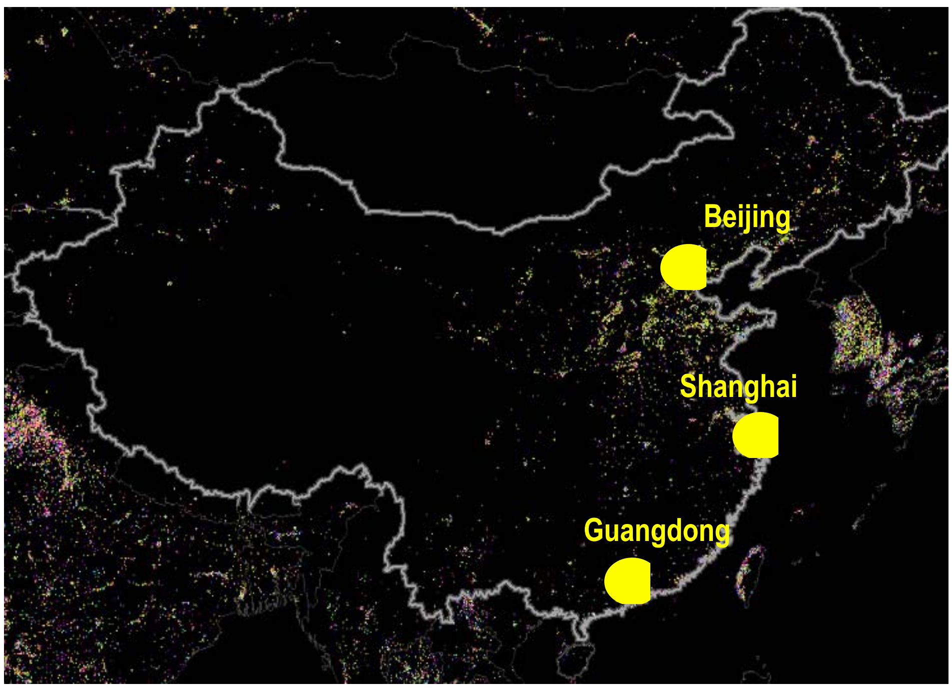


Source: PESD estimates 2007, CNPC/Sinopec/CNOOC company reports 2007, ERI, IEA 2004
Chinese agencies: NDRC, China Energy Development Report 2003, CNPC, CNOOC
Western sources: BP, EIA/DOE 2003, AIE/WEO 2002

2. Scenarios

The pivotal policy driver for each of the scenarios within the study in China is the implementation of sulfur dioxide (SO_2) constraints upon the energy system. We use SO_2 as a proxy for the full range of local pollutants and future studies might model those other pollutants. SO_2 is a reasonable target due to local governments' concern with proximate pollution. The governments of Beijing, Shanghai, and Guangdong have already voiced their commitment to controlling this pollutant. Additionally, the at present data for SO_2 is the most complete and accurate of all the pollutants that are monitored in China (compared to data for NOx, PM 10, PM 2.5, CO_2).

Figure 4: Research Locations



Source: NASA photo modified by PESD.

To examine the influence of SO_2 constraints, we developed three "core" scenarios. In the base case reference scenario (R), we assume no changes are made to the status quo. The model operates on a least cost optimization paradigm so that it solves for the most economically favorable solution. In this situation, we expect coal to out-compete gas in all sectors due to the lower fuel cost. Some emissions control programs are already in place on the national and regional levels; the reference case scenario only includes policies that were already implemented by the year 2000 as well as highly likely extensions of those policies. From this starting point, there are two main scenario developments. Scenario P is the case in which the output SO_2 emissions are reduced by 40% from the reference case and is defined as the "plausible" scenario. This scenario can be viewed as a reflection of what the future may look like if newly proposed emissions control legislation is effectively implemented (at 40% reduction from status quo). Scenario "Ag" is the case in which SO_2 emissions are reduced by 75% from the baseline.

This is defined as the "aggressive" scenario and is less likely to represent the future than scenario "P", but is not entirely out of the question.

Table 2: Summary of Scenarios in this Study

<table>
<tr><th>Primary Runs</th><th>Assumptions</th><th>Secondary Runs</th><th>Assumptions</th></tr>
<tr><td>Reference ("R")</td><td>Status quo emissions control</td><td></td><td>1.5% annual market share growth of new demand technology

10% discount rate for all sectors

No gas supply from Russia (LNG availability unconstrained)</td></tr>
<tr><td rowspan="4">Plausible ("P" scenarios)</td><td rowspan="4">40% SO_2 reduction</td><td>P: Reference Assumptions</td><td>Same as reference</td></tr>
<tr><td>P_Fast: Faster Penetration of Demand Technologies</td><td>3%, 5% annual market share growth of new demand technology</td></tr>
<tr><td>P_Diffcost: Different costs of capital</td><td>5.8% for power sector
10% for industrial
25% for residential and commercial</td></tr>
<tr><td>P_Moregas: High availability of cheap gas</td><td>Gas supply from Russia available (LNG availability unconstrained)</td></tr>
<tr><td rowspan="4">Aggressive ("Ag" scenarios)</td><td rowspan="4">75% SO_2 reduction</td><td>Ag: Reference Assumptions</td><td>Same as reference</td></tr>
<tr><td>Ag_Fast: Faster Penetration of Demand Technologies</td><td>3%, 5% annual market share growth of new demand technology</td></tr>
<tr><td>Ag_Diffcost: Different costs of capital</td><td>5.8% for power sector
10% for industrial
25% for residential and commercial</td></tr>
<tr><td>Ag_Moregas: High availability of cheap gas</td><td>Gas supply from Russia available (LNG availability unconstrained)</td></tr>
<tr><td rowspan="3">Plausible w/ more gas availability ("C" scenarios)</td><td rowspan="3">40% SO_2 reduction + Moregas</td><td>M_Fast: Faster Penetration of Demand Technologies</td><td>3%, 5% annual market share growth of new demand technology
+
Gas supply from Russia available (LNG availability unconstrained)</td></tr>
<tr><td>M_Diffcost: Different costs of capital</td><td>5.8% for power sector
10% for industrial
25% for residential and commercial
+
Gas supply from Russia available (LNG availability unconstrained)</td></tr>
<tr><td>M_Exp: More expensive oil and gas</td><td>Gas supply from Russia available (LNG availability unconstrained) at a more expensive price</td></tr>
</table>

Having developed the core scenarios we then developed the "MoreGas" scenarios ("M"). The goal is to find out how the system would react to sensitivity parameters with a plausible SO_2 constraint and more gas supply available to the region (such as might be available from a successful effort to develop international pipelines and price gas favorably). With the "MoreGas" scenarios, it is possible to determine the relative effects of gas availability and pricing versus the other drivers in the model.

Within each of the core scenarios, we also wanted to find out how gas demand would vary with two other factors. First, we changed the rate at which efficient, advanced technology is allowed to enter the market (the "Fast" scenarios). Second, we wanted to find out if specifying different costs of capital for each of the sectors would make an impact in consumption patterns (the "Diffcost" scenarios). We also combined the factors with each other in ways shown in Table 2.

In all, we looked at twelve scenarios. These scenarios allow us to explore four broad hypotheses:

A. Policies which constrain total SO_2 emissions from the entire system lead to increased natural gas consumption.
B. The rate of technological diffusion significantly influences the amount of natural gas consumed within the system.
C. Varying the cost of capital for different sectors has an effect on energy consumption patterns.
D. Gas prices and the availability of gas are important factors in determining which sector consumes what volume of natural gas.

Below, we organize the results of the study according to the four hypotheses.

III. Results

A. Constraints on SO_2 emissions

Figure 5 shows projections of natural gas consumption for the reference (R), plausible (P, 40% reduction in emissions), and aggressive (Ag, 75% reduction) scenarios from 2000 to 2020 in all three areas. The estimates for consumption vary widely depending on which SO_2 constraint is implemented in the system. From 2000 to 2020, natural gas consumption increases by about six times in Beijing and fifty times in Shanghai. Guangdong goes from zero gas consumption to around 5 bcm.

The natural gas consumed in 2020 in the aggressive scenario for all three regions is close to 50 bcm greater than the amount consumed in the reference scenario. These results suggest that a tighter SO_2 constraint leads to more gas demand. While these results shed some light on the sensitivity of the model to SO_2 policies, a deeper understanding of the system comes from looking at the projections within each of the three city-regions.

Table 3: Natural gas consumption by region, year, and scenario (in billion cubic meters, bcm)

	Reference "R0"		40% reduction "P"		75% reduction "Ag"	
	2000	**2020**	**2000**	**2020**	**2000**	**2020**
Beijing	1.2	6.2	1.2	7.7	1.2	10.3
Guangdong	0	5.1	0	21.2	0	21.3
Shanghai	0.2	10.4	0.2	23.9	0.2	36.6
Total	**1.2**	**21.7**	**1.2**	**52.8**	**1.2**	**68.2**

Source: Year 2000 MARKAL inputs from Chen, Yu, Zeng et al. (2006), year 2020 output from MARKAL model

In general, we found that provincial government targets were reasonably close to those projections. Before making this comparison, we hypothesized that the projections made by each government would far exceed calculated numbers since official targets are based on an ideal rather than a plausible set of assumptions. Beijing targets appeared slightly optimistic, falling about 1 bcm higher than the most aggressive model projections in 2020. In both Guangdong and Shanghai, the government projections are within the bounds of our highest and lowest scenarios. This shows that official provincial targets appear to be feasible goals for the most part if sufficient efforts are made to encourage gas use. However, at the same time, the government projections for the country as a whole are still seen as overly optimistic (See Figure 3).

Figure 5: Natural gas consumption for all study areas: Comparison of results for reference and SO_2 constrained scenarios

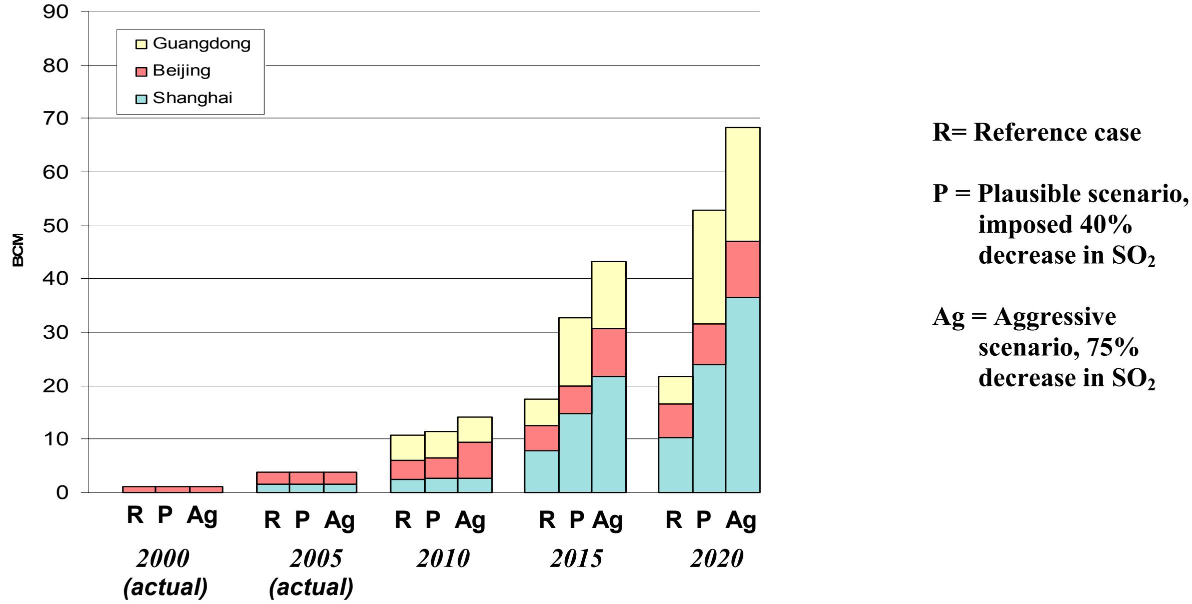
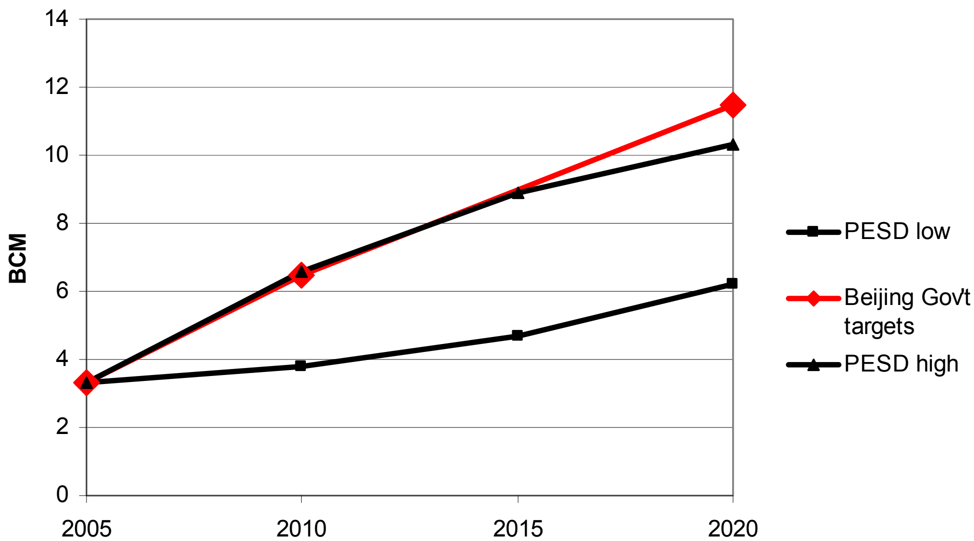
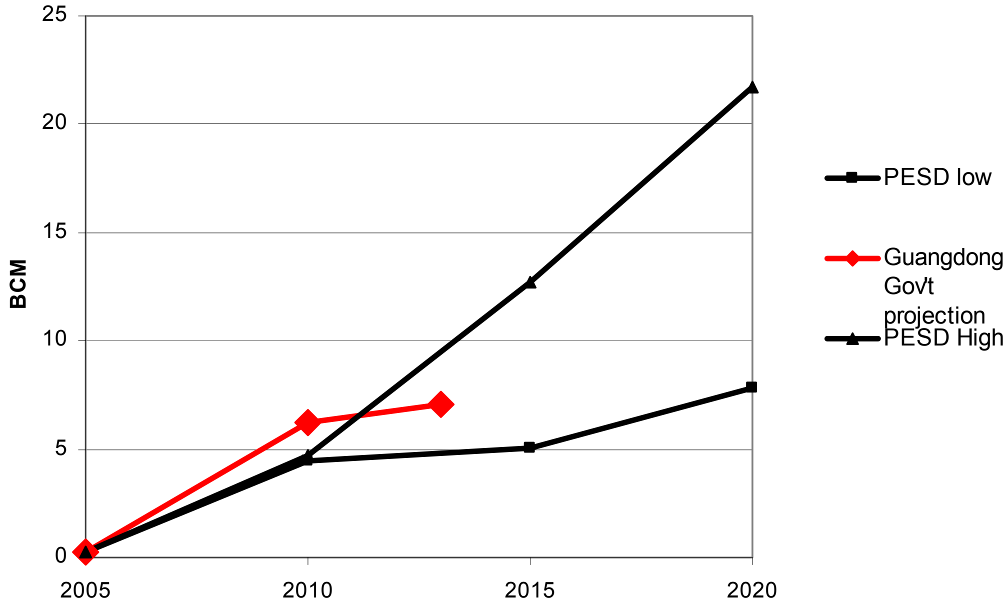


Figure 6: Comparison of official and MARKAL natural gas consumption projections for Beijing



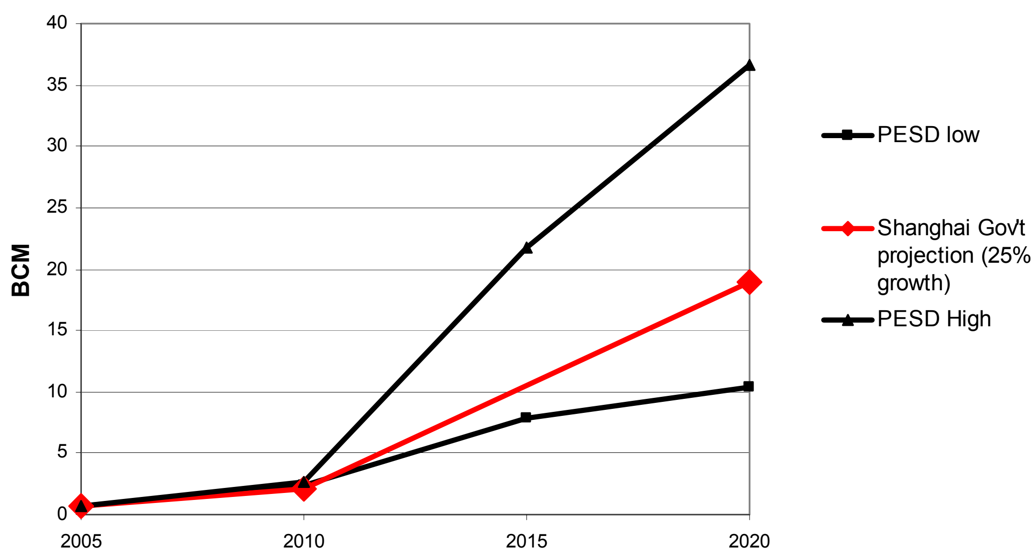
Sources: Beijing City Master Plan 2004-2020

Figure 7: Comparison of official and MARKAL natural gas consumption projections for Guangdong



Source: National Statistical Bureau 2004, MARKAL results from study

Figure 8: Comparison of official and MARKAL natural gas consumption projections for Shanghai



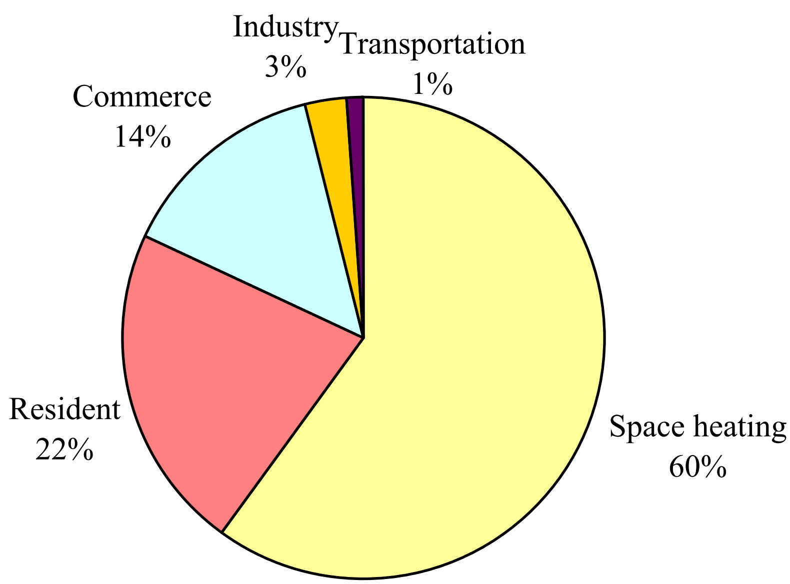
Sources: 2004 Shanghai Statistical Yearbook

Beijing

The natural gas fields near Beijing were developed before supplies were made available to Shanghai and Guangdong. The result was that Beijing residents had connections to natural gas supplies before either of the other two regions. However, the model results suggest that Beijing will consume less gas in 2020 than the other two regions for all scenarios. What stands in the way of rapid development of the natural gas? First, natural gas demand is highly seasonal. Figure 8 shows that 60% of the consumption (in 2003) comes from space heating, which is not required during the summer. Expensive infrastructure to deliver gas continuously is especially costly to operate when it is under-utilized for significant periods of time during the year. The Shanghai government has engaged with this problem by encouraging the use of natural gas air conditioners to sustain the level of natural gas consumption during the summer when heating demand does not exist, but no such measures have been implemented in Beijing.

Second, reductions in pollutants thus far have been accomplished largely by closing down coal-fired power plants and installing generators in neighboring cities. ESP and FGD have also been installed in coal-fired power plants. Due to such efforts, the low hanging fruit in decreasing local SO_2 emissions has already been picked, and further decreases in SO_2 emissions could be achieved through continuing the current, cheaper option of desulfurization and importing electricity from outside regions rather than by forcing a fuel switch from coal to natural gas. It is for this reason that there is very little difference in gas consumption between the reference scenario and the plausible scenario in Beijing (Figure 9).

Figure 9: Beijng natural gas demand in 2003



Source: Beijing Statistics 2004, Beijing Statistic Bureau, China Statistic Publishing Company, 2004

Starting in 2010, natural gas fired power plants account for all of the additional gas consumed in scenario "P" compared to the reference case scenario, with demand 24% higher than the levels consumed for the reference case scenario by 2020. This tells us that when the system is forced to reduce its SO_2 emissions by 40%, the most cost efficient sector in which to implement fuel switching is the power sector. For scenario "P", the increased gas use comes from the Taiyanggong electric and thermal plant. The relative increase of gas use for this scenario is minor compared to other scenarios because, overall, the main strategy for controlling emissions is to clean existing fuel systems.

Table 4: Beijing natural gas consumption by sector in the reference case scenario ("R", no reduction in SO_2 emissions)

(in bcm)	2000	2005	2010	2015	2020
Residential	0.2	0.5	1.1	1.1	1.4
Power Plants	0.1	0.2	1.8	2.7	3.7
Industrial	0.3	0.3	0.4	0.5	0.5
Commerical	0.7	1.2	0.5	0.5	0.5
Total	**1.2**	**2.2**	**3.8**	**4.7**	**6.2**

Table 5: Beijing natural gas consumption by sector in plausible scenario ("P", 40% reduction in SO_2 emissions)

(in bcm)	2000	2005	2010	2015	2020
Residential	0.2	0.6	1.2	1.1	1.4
Power Plants	0.1	0.1	1.9	3.1	5.2
Industrial	0.3	0.3	0.4	0.5	0.5
Commerical	0.7	1.2	0.5	0.5	0.5
Total	**1.2**	**2.2**	**3.9**	**5.2**	**7.7**

The system does start to change more drastically when the SO_2 constraint becomes tighter. In scenario "Ag", the gas consumption in the industrial and residential sectors increases along with demand in the power sector. In addition to Taiyuangong, a combined cycle natural gas plant comes online, and more gas is consumed in existing gas power plants that were already operating in the plausible scenario ("P"). For 2010 and 2015, the power plants are still the main source of fuel switching in Beijing. In 2020, industrial coal and oil boilers, used primarily for process heat, are replaced by natural gas boilers. For more lenient SO_2 emissions standards, it is cheaper to desulfurize coal-fired power plants rather than fuel switch from coal to gas. The opportunities for cost-effective desulfurization are exhausted by 2020.

Figure 10: Natural gas consumption in Beijing for reference, plausible, and aggressive SO_2 constraint scenarios

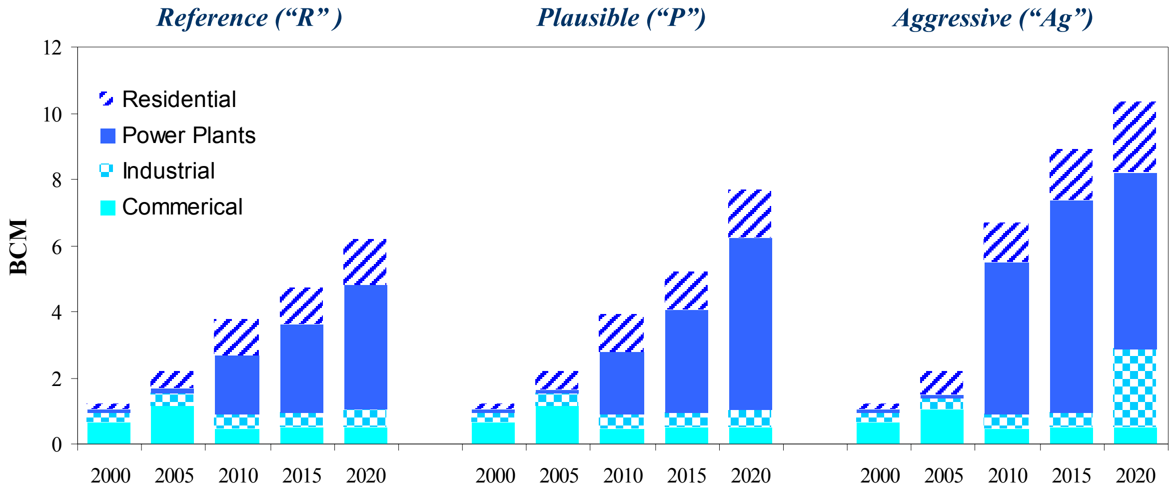


Table 6: Beijing natural gas consumption by sector in aggressive scenario ("Ag", 75%% reduction in SO_2 emissions)

(in bcm)	2000	2005	2010	2015	2020
Residential	0.2	0.7	1.2	1.5	2.1
Power Plants	0.1	0.1	4.6	6.4	5.3
Industrial	0.3	0.3	0.4	0.5	2.3
Commercial	0.7	1.0	0.5	0.5	0.5
Total	**1.2**	**2.2**	**6.6**	**8.9**	**10.3**

Although there is pressure for the government to reduce pollutants such as SO_2 and NOx and to increase energy efficiency for the upcoming 2008 Olympics in Beijing, there are no specific policies to promote natural gas use, although the Beijing Gas Supply Group, who is responsible for supplying natural gas to the area, is partially subsidized by the government. Despite the lack of official orders, the Beijing government is still optimistic about the future of natural gas use, assuming that natural gas will account for 12% in end-use consumption by 2020, according to the Olympic Energy Action Plan and the Beijing City Master Plan 2004-2020. For comparison, our "R" and "P" scenarios yielded 8% and 9% gas penetration, respectively. The "Ag" scenario, which reduces SO_2 by 16% from the baseline, is the most extreme case and goes far beyond the Olympic Games for pollution control. The implication of these results is that while the goal set by the government is not impossible to achieve, such an outcome will not be realized without much tighter environmental policies that are well-enforced and specific policies to promote gas.

Guangdong

Guangdong is the southernmost of the three regions, where, in contrast to Beijing, space heating is rarely needed. Its economic growth is the most rapid in China, and it emits more pollutants than any other region. Guangdong, unlike Beijing and Shanghai, does not have easy access to coal. There are no indigenous sources, so all coal must be imported from other regions of China or from abroad, resulting in high prices. This poses a special opportunity for the use of natural gas. Guangdong also is currently not able to intercept piped natural gas from the West-East Pipeline (WEP) due to geographic constraints. Guangdong therefore relies on LNG to meet some of its energy demand and is home to China's first LNG terminal (completed in 2006).

In the reference scenario "R", the level of natural gas consumption stays constant from 2010 onwards. Consumption is capped at the level corresponding to the volume of LNG imported from Australia under a cheap contract (approximately $3/mmbtu, compared with the $5 to $7 typical of current LNG contracts). Any volume of gas above this amount would be sold at the new, higher price. Since there is no incentive for the system to spend more money than what is necessary in the reference scenario, the amount of gas consumed stops at the volume limit of the contract. Gas is unable to compete with coal and nuclear in meeting new demand for power. In the reference scenario, nonetheless, most of the gas is consumed by power plants, with the residential sector taking a miniscule portion. When a 40% mandatory decrease in SO_2 emissions is imposed on the system in the plausible scenario, the consumption of gas increases for 2015 and 2020, although there is no increase in uptake before 2015. For this plausible scenario, the amount of gas consumed is no longer constrained by the volume of LNG under the Australian contract because the system has no choice but to pay higher prices in order to meet the SO_2 constraint. All of the increased gas demand comes from power plants. In particular, gas-fired combined cycle plants replace oil. Gas also finds use in co-generation and replaces coal in two ways: small, inefficient peaking coal plants that are less than 135 MW, and one large coal-fired baseload power plant. The environmental constraints also push forward the construction of an integrated coal gasification combined cycle (IGCC) plant.

At the same time that gas consumption is increasing, nuclear power is also on the rise. Nuclear provides baseload generation, while gas is used for peaking, so there is no direct competition between the two. Nuclear generation increases 14 times above 2020 reference scenario levels. Nuclear power development is uniquely far along in Guangdong, with a few plants that are already under construction in the area. However, without a policy push to decrease SO_2 emissions, coal is still the preferred fuel since a coal plant facing modest limits to SO_2 is cheaper to build than a nuclear unit.

Figure 11: Natural gas consumption in Guangdong for reference and plausible SO_2 constraint scenarios

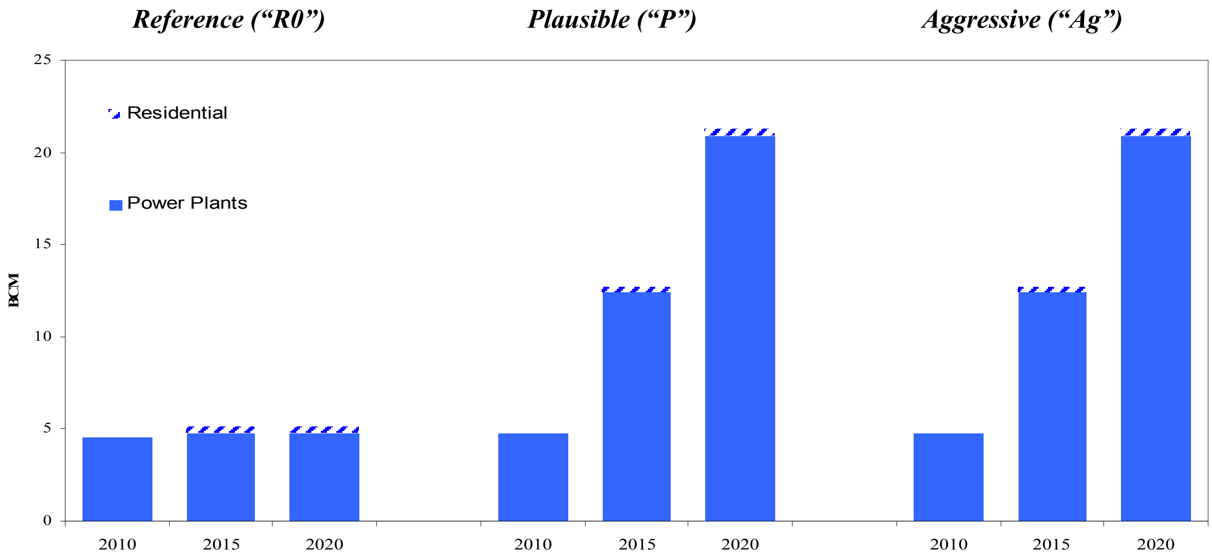
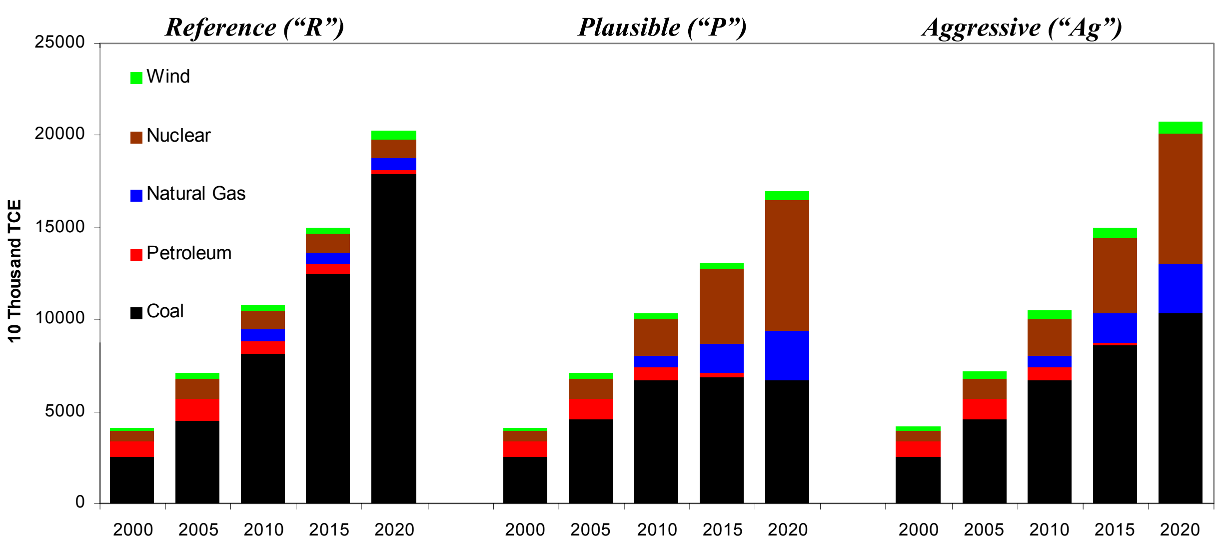


Figure 12: Fuel consumption in Guangdong Power Sector for reference and plausible SO_2 constraint scenarios



Natural gas consumption does not increase when a more stringent limitation is applied to the system (75% SO_2 reduction, scenario "Ag") due to the operation of a new IGCC unit in Guangdong starting in 2010. The additional energy demand in the model is therefore met by coal rather than natural gas. This suggests that even though the coal prices in Guangdong are higher than in other parts of China, it is still cheaper than natural gas, which makes clean coal operations competitive. The caveat to this outcome is that the actual cost of IGCC units may be higher than the one assumed in the study ($1400/kW), which is much cheaper than western estimates, although twice the cost of conventional coal plants. In reality, construction of IGCC units may be delayed due to the unavailability of the technology. If so, our estimation is that advanced (ultra-supercritical) coal along with pollution control equipment, and some expansion in nuclear, would be favored over gas for baseload power.

Shanghai

Shanghai's economy is dominated by energy intensive industries that thrive in and around the city. Six industries comprise 50% of the city's total energy demand—smelting/rolling of ferrous materials, oil processing, coking, nuclear fuel processing, textiles, and chemical production. In contrast to Guangdong, not much natural gas is used for power plants. This is mostly due to the fact that there is an abundant and relatively cheap supply of coal available for firing baseload plants. When the 40% SO_2 constraint is imposed on this system, there is an increase in the consumption of natural gas appearing in 2010. Almost all of this growth stems from the industrial sector. Rather than building new power plants that run on cleaner burning gas, it is much less costly in Shanghai to meet the SO_2 constraint by switching existing boilers in the industrial sector from higher sulfur heavy fuel oil and coal to natural gas. Similarly, many of the coal boilers and kilns in the six energy intensive industries get switched to natural gas fuel to meet SO_2 constraints. Replacing old, inefficient coal technology with natural gas boilers minimizes the cost of fuel switching. In addition, Shanghai has access to domestic piped natural gas which is priced lower (for now) than LNG, which f opposed to being exclusively dependent on LNG, facilitating the switch to natural gas.

Comparing Table 7 and Table 8, it is clear that when there is a stricter SO_2 constraint, gas consumption continues to increase for the industrial sector. Additionally, power plant gas demand is higher in scenario "Ag" compared to scenario "P". It seems that investing in fuel switching in the power sector becomes attractive only after gas demand in the industrial sector is saturated. This is because the barriers to fuel switching in the power sector are present even after emissions limits are tightened.

Figure 13: Natural gas consumption in Shanghai for reference and plausible SO_2 constraint scenarios

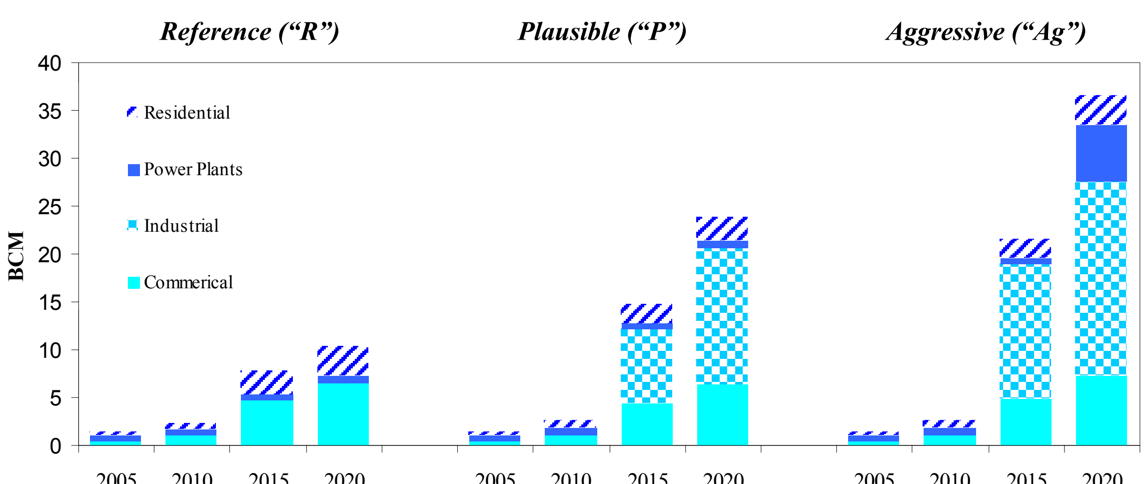


Table 7: Shanghai natural gas consumption for plausible scenario ("P")

Bcm	2000	2005	2010	2015	2020
Commerical	0.0	0.4	1.1	4.4	6.3
Industrial	0.0	0.0	0.0	7.8	14.3
Power Plants	0.0	0.6	0.8	0.6	0.7
Residential	0.0	0.4	0.8	2.0	2.4
Transportation	0.0	0.1	0.1	0.1	0.1
Total	0.0	1.5	2.7	14.8	23.9

Table 8: Shanghai natural gas consumption for aggressive scenario ("Ag")

Bcm	2000	2005	2010	2015	2020
Commercial	0.0	0.4	1.1	4.8	7.3
Industrial	0.0	0.0	0.0	14.1	20.4
Power Plants	0.0	0.6	0.8	0.6	5.8
Residential	0.0	0.4	0.8	2.1	3.1
Transportation	0.0	0.1	0.1	0.1	0.1
Total	0.0	1.5	2.7	21.7	36.6

Section Summary

In summary, each of the regions is responsive to environmental regulation as a driver of natural gas consumption. In Beijing, power plants are the main consumers of natural gas, but the gas demand is lower than in the other two areas. This is due to the fact the power plants are able to utilize desulfurization equipment to reduce SO_2 at a lower price than fuel switching. In Guangdong, natural gas is also mostly consumed by the power sector, but gas consumption is more sensitive to the 40% SO_2 reduction of scenario "P". Natural gas consumption levels stay uniform at less than 5 bcm unless there is an external policy that forces a reduction in emissions. When that does happen in scenario "P", natural gas use increases more than fourfold by 2020, accompanied by substantial nuclear baseload buildup. However, there is no additional increase in gas consumption moving to scenario "Ag" with the model using IGCC to achieve the additional SO_2 cuts. The caveat to this finding is that the prices for IGCC units are likely to be more expensive than predicted, in which case fuel sources such as natural gas could play a bigger role. In Shanghai, industry is the main driver of increased gas consumption. This sector replaces coal boilers with natural gas-fired boilers; power plants switch fuels only under the most stringent regulatory conditions. While implementing environmental controls can lead to increases in natural gas consumption, it is apparent that the sectors in which this occurs differ between regions.

B. Effects of the rate of technological diffusion in demand technologies

It is instructive to consider how the rate at which advanced, efficient demand side technologies diffuse into the market can affect natural gas demand. For our study, there are two assumptions for the size of the initial market share of demand technologies in different sectors. For "new" demand technologies that have longer life cycles and are more expensive to purchase, such as industrial equipment and mass transportation infrastructure (boilers, kilns, and buses), we assume a 5% share of the entire market in 2010. A 7% initial share of market is assigned to demand technology in the commercial and residential sectors, such as air conditioners, cooking stoves, heating appliances, and lighting.[20] We created different scenarios by changing the rate at which this initial share grows. After consulting a range of sources[21], a 1.5% annual growth market share starting in 2010 seemed reasonable for the reference case. For the scenario in which a faster rate of technological diffusion is expected, we used a 5% annual share growth. A 3% annual share growth was also tested to approximate the sensitivity of the model but there were no significant changes in fuel consumption in any of the regions so the results are not included in the study. The table below lists the runs that are discussed in this section.

Table 9: Technological Diffusion Scenario

Name of run	Annual share growth
P	1.5% (Reference)
P_Fast	5%
Ag	1.5%
Ag_Fast	5%

In Beijing, under modest environmental constraints, faster technology diffusion reduces coal consumption by 6% and natural gas consumption by about 57% in 2020 relative to the base case diffusion scenario. Natural gas use decreases when more advanced technologies are introduced into the market because greater end use efficiency affects energy demand where gas tends to be used, such as in cooking, heating water, and space heating. In the scenarios with technology diffusion, these natural gas using technologies are replaced by newer technologies that do not utilize natural gas, such as a heating network for cooking and heating water (fueled by coal-fired sources). The main assumption driving these outcomes is that advanced coal utilizing demand technology is likely to flood the market before natural gas equipment gets there. The speculation is that because coal-powered technologies have been out on the market for a longer period of time, there has been more time to develop more efficient versions of this equipment that

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[20] U.S. National Energy Modeling System database (NEMS), A joint study between the Energy Foundation and China National Institute of Standardization (EF/CNIS), A joint study between Guan Fu Min in Qingdao, China and Lawrence Berkeley Laboratory (Guan/LBL). Our assumptions came from a study that numerated the initial market shares of fluorescent light bulbs.

[21] U.S. National Energy Modeling System database (NEMS), A joint study between the Energy Foundation and China National Institute of Standardization (EF/CNIS), A joint study between Guan Fu Min in Qingdao, China and Lawrence Berkeley Laboratory (Guan/LBL)

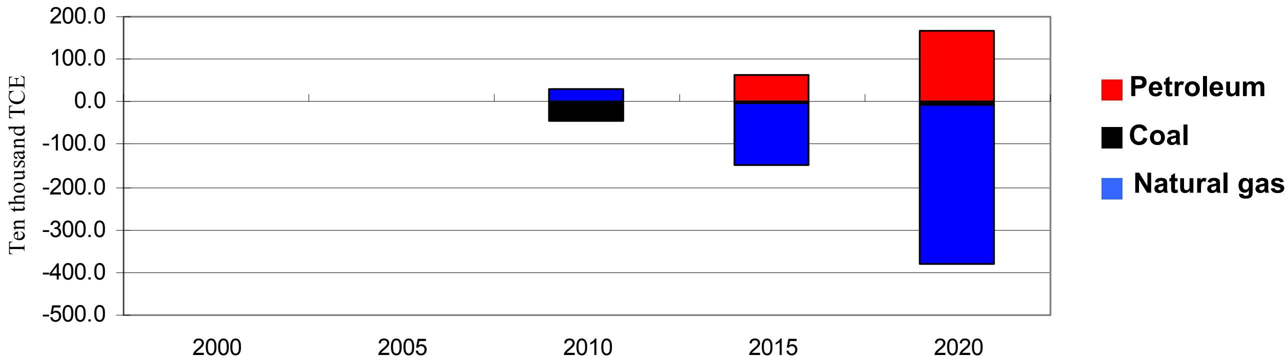
can reach the market before new gas consuming technologies are introduced. Thus the availability of efficient technologies which are not fueled by natural gas is detrimental to the expansion of the gas market. As expected, the residential sector was especially affected by the fast scenarios due to the assumption of higher initial market share of advanced end-use technologies.

In Guangdong, under modest environmental constraints, coal consumption increases when the rate of technology penetration is increased. This is due not only to the replacement of old equipment with more advanced commercial coal stoves and boilers but also to increased consumption by these technologies. In the industrial sector, new coal boilers and kilns replace older versions and also contribute to the increased consumption of coal. Higher efficiency for coal makes this fuel more competitive. Oil consumption decreases slightly as improved LPG stoves and heaters that require less fuel to do the same amount of work in the residential sector replace older models. Electricity and natural gas consumption do not change much between the reference penetration (P) and the high technology penetration rates (P_Fast). The technology diffusion trends are further magnified when the system is placed under a stringent environmental constraint (Ag, Ag_Fast).

In Shanghai, starting in 2010 there is a small decrease in the consumption of coal within the residential sector and a slight increase in the consumption of gas as old, inefficient coal burning appliances are retired. In 2015, we see natural gas consumption decrease within the residential sector as more efficiency in end use cuts demand and oil products became more competitive. The same trend on a greater scale occurs in 2020. We were surprised by the increased share of oil. Although in open markets oil is more expensive than gas (by heat content), refined oil products are made available to the domestic market at a subsidized cost supported by the central government, which could explain the system's overall reliance on oil in the residential sector. While this resilience for oil is interesting, it is useful to keep in mind that the total change in energy consumption between P and P_FAST here is only about 2.5% of the total amount of energy consumed within the system. In short, technology is not a significant factor in determining fuel consumption patterns.

Overall, increasing the rate of technological diffusion may help to reduce the overall energy intensity of a system, but it does not generally encourage natural gas consumption. In fact, in all three regions, we find that natural gas consumption, especially in the residential sector, actually decreases. This is because most of the new technologies utilize coal (or oil in the case of Shanghai) rather than natural gas. Thus when the technology penetration rate is increased, more efficient demand favors coal and oil.

Figure 14: Differences in Primary Energy Consumption in Shanghai (P vs. P_FAST)



Source: Yu, 2007, Shanghai Jiaotong University/PESD study

C. Effects of Differing Costs of Capital across Sectors

An often overlooked aspect of the Chinese energy system is that different sectors are offered different lending rates by banks and pursue different strategies for financing investments that, in practice, yield highly varied costs of capital. In particular, the cost of capital for building state-owned power plants has been much lower than for private projects and business. The purpose of this section is to simulate varying costs of capital reflective of the past reality of the Chinese financial system (P_Diffcost) and to compare that with a behavior under a uniform cost of capital across all sectors. For our reference runs, we replicate what has done many times in other models, which is to assume that there is a uniform discount rate across all sectors (10%) reflecting the assumption that the cost of capital is uniform. For the scenarios that vary the cost of capital, however, we attempt to simulate the actual differentiated lending rate system under which the Chinese economy has been operating under by assigning different lending rates for each sector in MARKAL. Taking into account these different discount rates should, we expect, lead to a significantly different energy system.

The power sector is viewed as a "pillar" industry by the government, which affords the industry special treatment such as indirect subsidies and access to political favors. One way indirect subsidies are distributed is via the China Development Bank, which at the time of the model runs was providing capital to government connected enterprises at a rate of 5.8%[22]. This same arrangement is not extended to the industrial sector, which is still given a 10% discount rate. The residential and commercial sectors experience significant barriers to obtaining loans at all – which we simulate by applying a 25%

[22] Discussions with Pan Jiehua (CASS), Kejun Jiang (ERI), and Tao Wang (BP), November 2006, People's Bank of China website (www.pbc.gov.cn), Global Financial Data (www.globalfinanicaldata.com)

discount rate.[23] One rationale that the government uses to justify preferential relative treatment of the large industrial players is that many are state-owned enterprises employing large numbers of people. The manufacturing companies within the industrial sector have also been the driving force behind China's economic development. The government therefore has a stake in maintaining the financial health of this important sector, and these enterprises (especially owned by the state) reinforce this view through their political connections. This multi-tiered cost of capital system is reflective of the reality of the Chinese economy and representative of the strategy that the Chinese government has employed since making a transition from a planned to a market economy: "Let go of small enterprises and engage with large enterprises.[24]" Smaller players in the market are always allowed to privatize first while larger entities are carefully "guarded" by government subsidies and regulations. The exact effective discount rates vary constantly, but after consulting experts, official statistics, and various rules and regulations of the People's Bank of China, we chose these tiers as more or less representative of the differentiated cost of capital structure that may be plausible in China.

Table 10: Different assumed costs of capital by sectors

Sector/Industry	**Effective Lending Rate**
Power plants and other public service entities	5.8%
Industrial sector	10%
Residential	25%
Commerical	25%

In Beijing, coal consumption in the modest environmental constraints scenario is higher in the case of differentiated costs of capital between sectors. That is because gas-fired power plants have low fixed costs and high O&M costs, whereas coal-fired power plants require high fixed investments but have low O&M costs.

Table 11: Investment Costs for Various Types of Power Plants in China (2006)[25]

	$/kW (300MW)
Pulverized coal-fired power plant	600-676
PC w/ FGD	620-1100
Combined cycle natural gas	500 – 600
Ultra supercritical coal	1000-1100
IGCC	1000-1300

Source: Chen et. al, Yu et. al., Zeng et. al., 2006

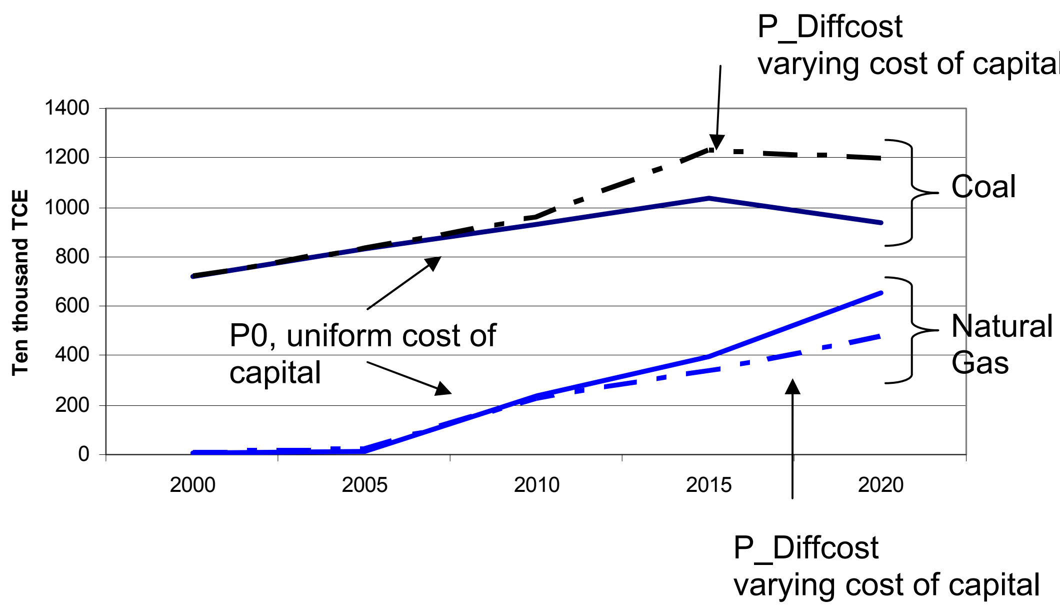
23 Discussions with Pan Jiehua (CASS), Kejun Jiang (ERI), and Tao Wang (BP), November 2006

24 Zhang, Jin. (2006) *Catch-up and Competitiveness in China: The Case of Large Firms in the Oil Industry.* Routledge-Curzon Studies on the Chinese Economy

25 Costs for projects in Beijing, Guangdong, and Shanghai

Thus coal consumption increases by about 17%, while natural gas consumption decreases by about the same percentage. The same story holds true when environmental controls are set tighter for Ag0 and Ag_Diffcost scenarios. The SO_2 constraints are not sufficient to induce fuel switching in favor of natural gas because cheap capital makes advanced coal technology such as flue gas desulfurization (FGD) even more economical (prices for FGD are already low in China).

Figure 15: Coal and Natural Gas Consumption in the Beijing (Power Sector)



A similar story plays out in Guangdong. Coal consumption is higher under differentiated costs of capital representing the status quo. Advanced coal plants with pollution control equipment (FGD, ESP) are built at the expense of LNG-fired power plants. In fact, the real situation is already playing out in this way due to rising LNG prices in recent years.[26] In Guangdong, the coal consumption is a dramatic 88% higher under differentiated costs of capital, with natural gas consumption decreasing by about 40%. For illustration, Figure 16 shows the results.

By contrast, there was little change in the amount of coal consumed as a function of capital cost assumptions in Shanghai. This is explained by the fact that the vast majority of natural gas consumed there is within the industrial sector, for which the cost of capital does not change between the reference case and the "Diffcost" runs.

We are mindful that China is in the midst of accelerating reforms that are making state enterprises more competitive and also improving access to capital across the economy. It is possible to see a future where the varied cost of capital are less extreme than shown here, but our results help illustrate the sensitivity of the models and also help explain the capital intensive nature of the industrial energy development so far.

[26] "LNG is too expensive for power generation." Interfax. 4 April 2007

Figure 16: Coal and Natural Gas Consumption in the Guangdong (Power Sector)

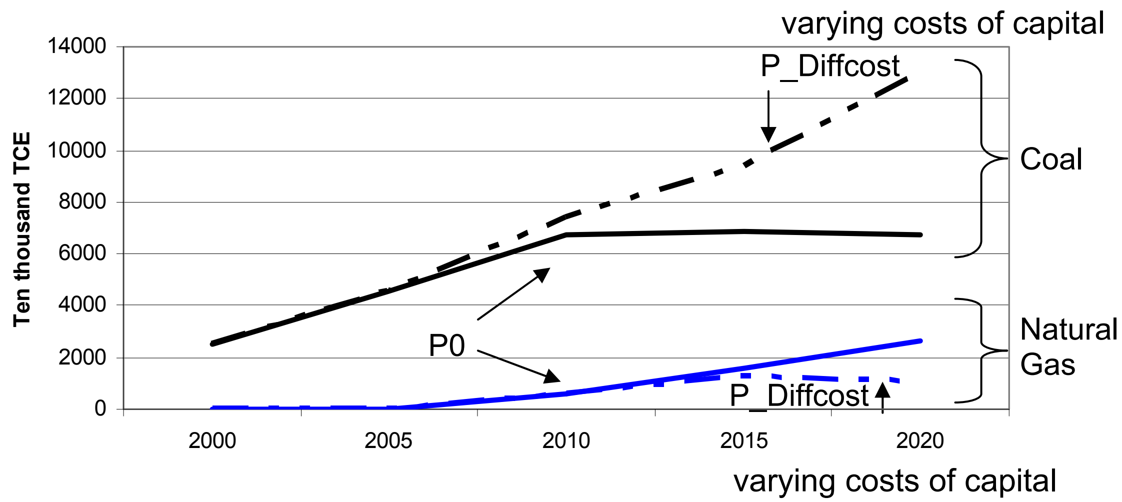
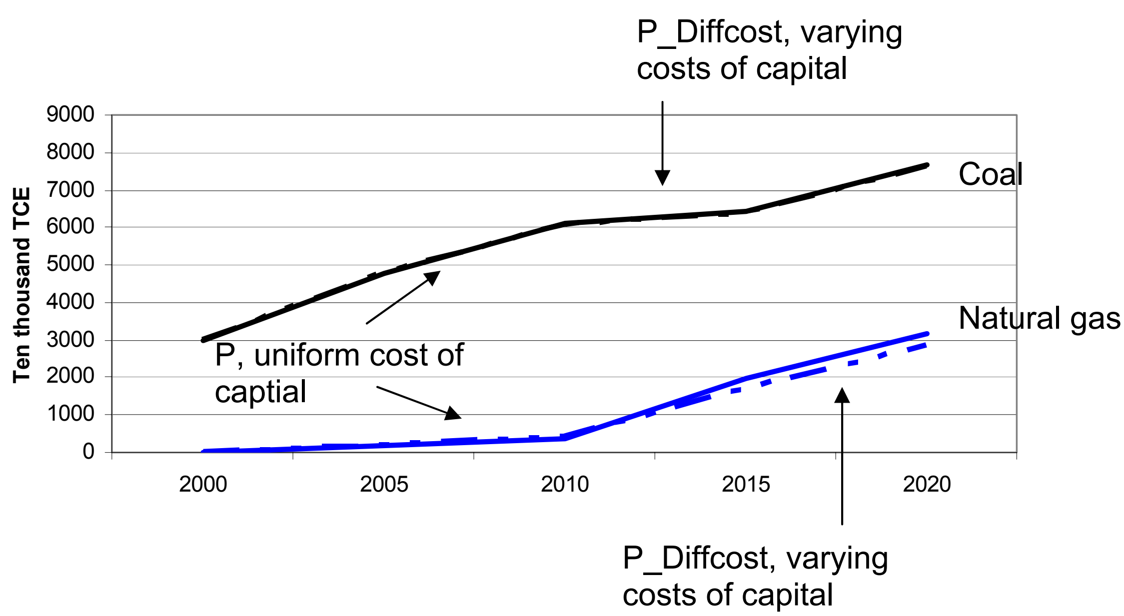


Figure 17: Coal and Natural Gas Consumption in the Shanghai (Power Sector)



D. Effects of gas supply

Obviously, gas cannot be consumed unless supply can be assured. Figure 3 showed that some of the potential natural gas sources are international pipelines. While China and Russia signed an agreement in March 2006 to develop potential pipelines between China National Petroleum Company (CNPC) and Gazprom,[27] and similar plans with Kazakhstan and Turkmenistan were codified in August 2007, it is not certain that these plans will actually be carried out. International projects are inherently challenging to complete because they are rarely motivated purely by economics and are sensitive to political moods and relationships between the relevant governments.[28] China also has a plethora of LNG terminal projects planned, seven of which have been approved. In the following scenarios, we explore gas consumption patterns in a world where international gas does not get piped to China and one in which there is additional international gas supply available. The availability of gas supplies affect the price of gas and thus, in turn, affect demand.

Table 12: Gas Availability Scenario

Name of run	Gas supply
Ag	Only domestic pipeline and LNG terminal in Guangdong
Ag_Moregas	Domestic pipeline, international pipeline, LNG terminal in Guangdong

Beijing is not sensitive to the availability of gas in either the plausible or aggressive scenarios. This presumably indicates that the use of natural gas is not hindered by the availability of the supply. Indeed, because there is a domestic pipeline that supplies the city, and also because Beijing is the capital, it already gets preferential treatment when gas is allocated. The relatively low demand for natural gas in this area, as indicated by Figure 4, is also relatively easy to satisfy.

Guangdong is more responsive to the availability of gas only if additional gas (and lower gas prices) combines with tight rules on SO_2. Figure 18 shows the major consumers of natural gas by sector in both the Ag and Ag_Moregas scenarios (there is no movement for this scenario under the plausible SO_2 constraint conditions). Along with this, the black bars also indicate bounds for different types of supplies available to Guangdong. The main difference between Ag and Ag_Moregas is that for Ag_Moregas, an additional source of piped gas becomes available to Guangdong at a cheaper price than expensive LNG.

Even though the amount of expensive new LNG that is consumed does not decrease in "Ag_Moregas", the major consumers of gas change in this scenario. What we see here is that the additional cheaper supply of gas allows major off-takers *outside* of the power

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[27] Interfax, 5/24/06

[28] Andrews-Speed, P. *The Strategic Implications of China's Energy Needs.* Oxford University Press for the International Institute for Energy Studies (2002)

sector to consume gas. The transportation, residential, industrial, and commercial sectors all dip into the natural gas supply once it becomes available. When cheap gas supplies are limited, almost all of the gas is funneled into power generation in order to meet the requirements of the SO_2 emission constraints.

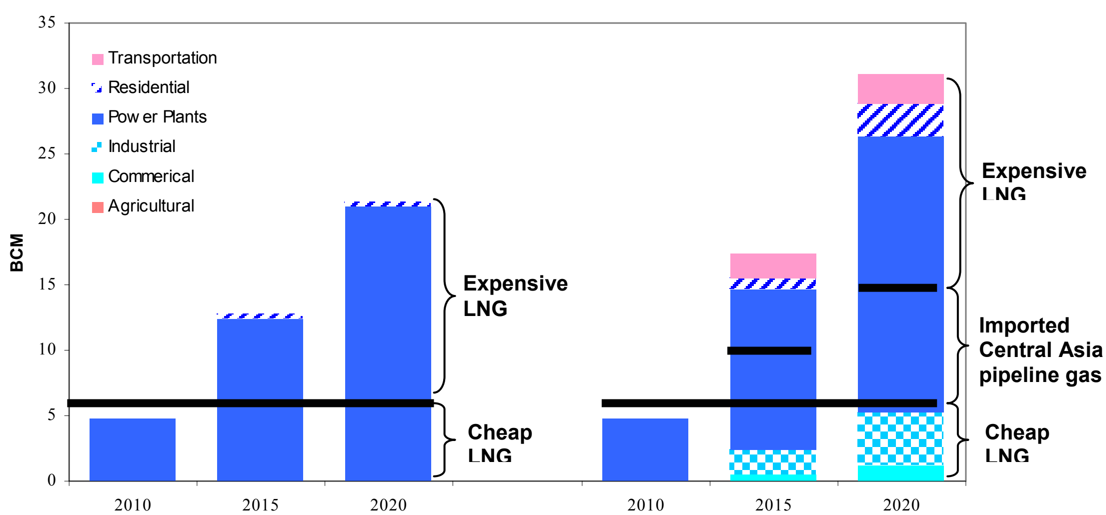
Table 13: Gas prices and supplies for in Moregas Scenario

Gas supply	Price[29]	Supply limit
Cheap LNG	\$5.50/MMBtu (regasified to delivery)	5.1 bcm
Imported Central Asia pipeline	\$7.12/MMBtu	5 bcm in 2010 10 bcm in 2020
Expensive LNG	\$9/MMBtu (regasified to delivery)	No limit

Figure 18: Gas Supply Options for Guangdong and Natural Gas Demand by Sector

Aggressive ("Ag")

Aggressive w/ more gas supply("Ag_Moregas")



Source: Gas volume estimates for MARKAL model, Mark Hayes, 2007

In Shanghai, greater availability of cheap gas does not significantly change the consumption patterns (<0.1%) in the industrial sector. Given Shanghai's abundant domestic gas supply (Shanghai, like Beijing, has access to gas from the West-East pipeline) at favorable prices, it was not expected that supply constraints would drive scenarios in this situation.

[29] Present day prices

In summary, as a supply-constrained market, Guangdong is the only region that is sensitive to the availability of new supplies of gas. This sensitivity hinges on a set of assumptions—notably the availability of a piped natural gas from the second West-East pipeline from Central Asia in 2010 that will face political, financial, and geographic challenges. When new sources become available, there is a diversification in the use of the natural gas that extends beyond the original power plant off-takers. If an international gas pipeline is built for Guangdong, the fuel will be cheaper than any new LNG contracts that the government will be able to obtain and will have a significant impact on energy consumption patterns. The gas demand in Beijing and Shanghai, on the other hand, is not affected by additional sources of gas because these regions are already connected to existing pipelines which deliver adequate gas supplies.

E. Implications for CO_2

Next we explore how some of the factor may affect emissions of CO_2. In particular, we explore the hypothesis that limits on SO_2 could yield, incidentally, some reduction in CO_2 due to greater use of natural gas. CO_2 emissions reductions in response to SO_2 limits are greatest in Guangdong. If we take the case of the aggressive scenario, about 99 million tons less of coal would be used in 2020 compared to the reference case.

Figure 19: Energy Use in Guangdong for Reference, Plausible, and Aggressive Scenarios

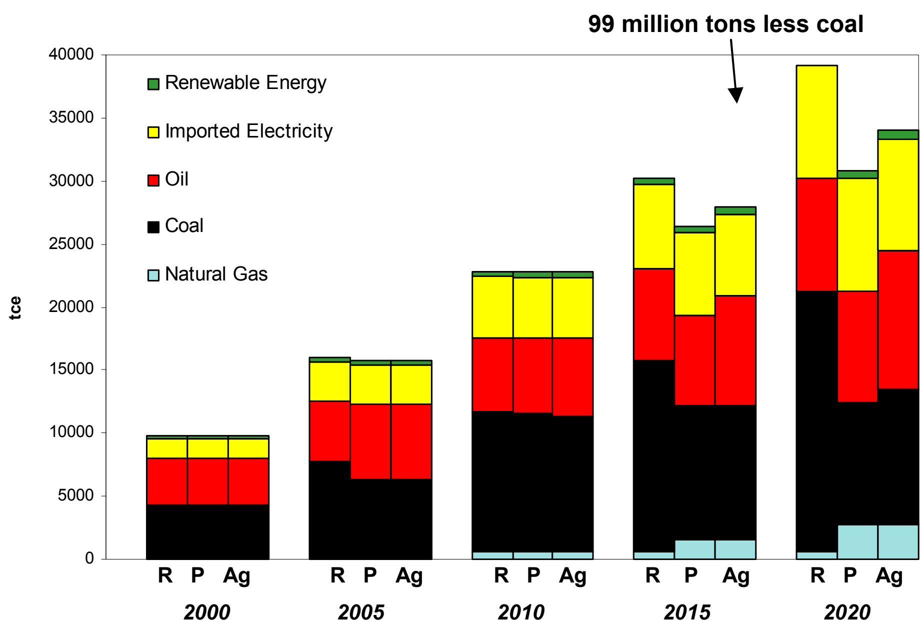


Figure 20 explains the carbon consequences of this fuel switch for Guangdong. About 57 million tons of carbon dioxide emissions can be averted by imposing a 75% emissions cap on SO_2 emissions. For comparison, 50 million tons is about a quarter of the CO_2 saved by the entire stock of Clean Development Mechanisms (CDM) projects in China in

2006.[30] It is also a quarter of Europe's Kyoto commitment.[31] While in absolute numbers these savings alone will not alter the global trajectory of climate change, they do suggest new ways of thinking about the climate issue, especially with regard to how to bring developing countries to the climate negotiation table. Developing countries are wary of emission caps that may hinder economic growth. However, they are more strongly motivated to engage in discussions related to local and regional pollution. Perhaps a stringent SO_2 policy could be a more acceptable scenario compared with one that addresses CO_2 emissions directly.

Figure 20: CO_2 Emissions from Guangdong in the Reference, Plausible, and Aggressive Scenarios

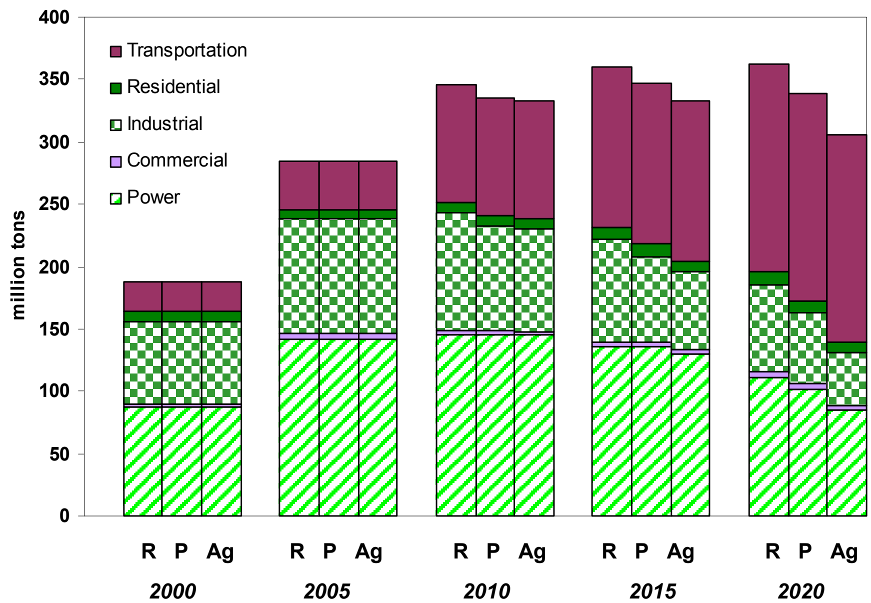


Table 14: CO_2 emissions reductions for Guangdong for two scenarios (million tons CO_2)

Scenarios	2010	2015	2020
Plausible	11	15	24
Aggressive	16	28	57

The caveat to these results is that while the carbon dioxide savings come from fuel switching in a particular region, there is no guarantee that demand could not also be met by importing electricity from power plants outside the city, particularly if emissions

[30] DOE, 2006
[31] Victor, D., Cullenward, D."Making Carbon Markets Work" 24 September 2007 Scientific American.com

controls are less stringent elsewhere. Most likely, any imported electricity will be coal-fired – although in the past Guangdong has imported substantial quantities of electricity from large government hydroelectric projects. This implies that while carbon dioxide emissions are decreasing in one area, they could be increasing in another, diluting any benefit. We do not expect that this effect will be significant in the cases modeled here, it could become a much more important issue in the future, particularly if imported electricity becomes cheaper than developing regional energy resources.

For reference, in Figure 21 we show the similar effect of SO_2 controls in Shanghai and Beijing. The total emissions of these two cities are lower than Guangdong and contribute to the less dramatic reduction of CO_2 as a result of putting in SO_2 controls.

Figure 21: CO_2 Emissions from Shanghai in the Reference, Plausible, and Aggressive Scenarios

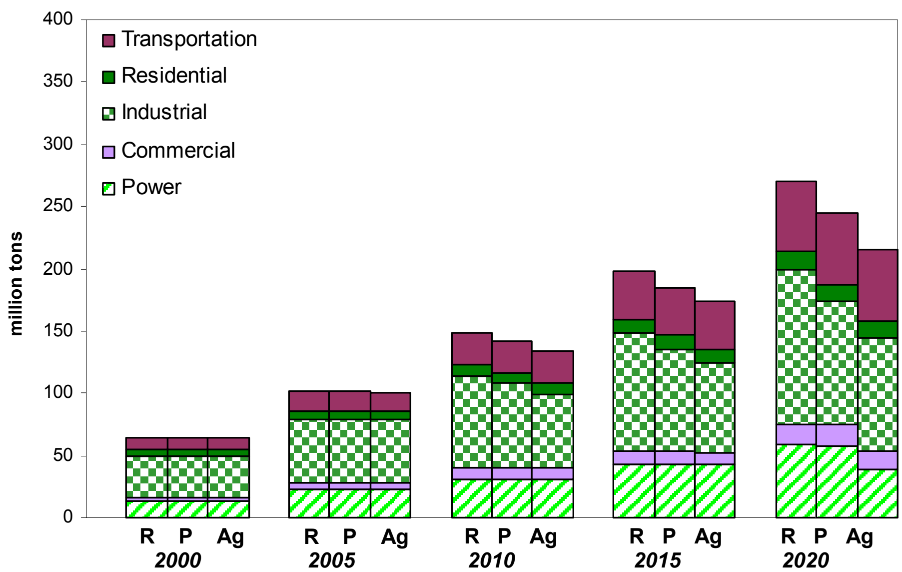
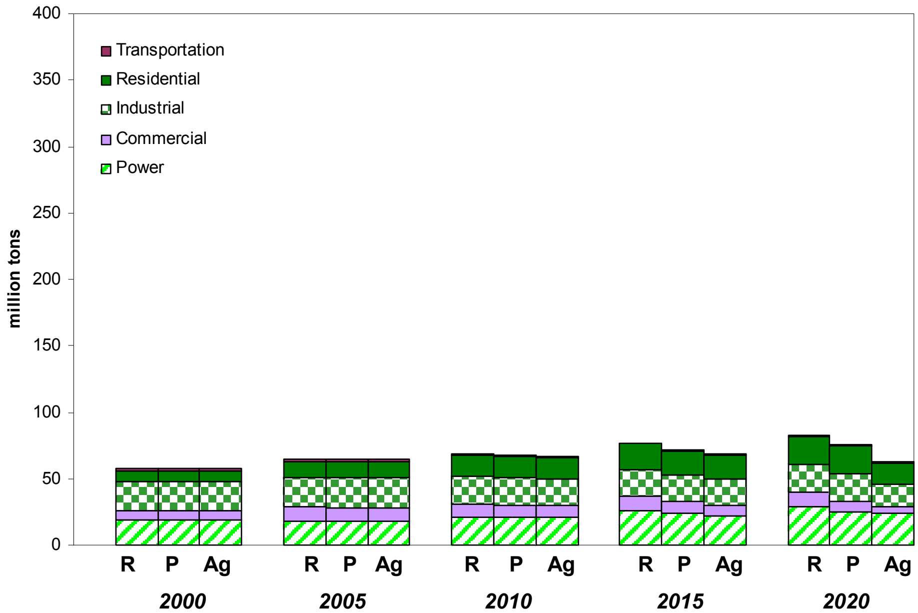


Figure 22: CO_2 Emissions from Beijing in the Reference, Plausible, and Aggressive Scenarios



The effect of financial reform on CO_2 levels is also striking. When the cost of capital is made uniform across sectors, the amount of CO_2 reductions that occurs in the system is close to that of when *aggressive* SO_2 constraints are implemented. This reinforces the idea that there are alternative ways of thinking about controlling CO_2 emissions other than forcing developing countries to put restrictions on their factories and power plants. Standardizing lending rates across sectors, for example, is already a goal that the Chinese government is moving towards because it is in line with the greater goal of moving the economy towards a stable market economy. Utilizing leverage points such as this one to negotiate with China and other developing countries on the carbon emissions will be the key to creating a practical climate regime.

IV. Conclusions

The study suggests five key findings on the competitiveness of natural gas in China over the next two decades:

First, demand size and uncertainty influence supply infrastructure. Growth in gas demand in China could lead to a surge of natural gas imports as demand is likely to far outstrip domestic supplies in certain parts of the country. Guangdong province is a particularly extreme case that relies completely on imports. This supply constraint provides an impetus for the Chinese government to seek out new supplies, such as a large international pipeline from Russia, Kazakhstan, or Turkmenistan, and more LNG regasification terminals. At the same time, demand is highly uncertain, making it challenging to determine the appropriate rate at which to build out infrastructure.

Second, gas demand is highly dependent on financial policies. The current Chinese financial system provides extremely low costs of capital for the power sector. This makes the construction of capital intensive coal-fired power plants especially attractive. Because coal and natural gas are in direct competition as the fuel source in most cases, this diminishes the opportunity for more natural gas combined cycle plants to be built. In Guangdong, for example, the MARKAL model would predict almost 50% lower coal consumption by 2020 if a 10% lending rate were available to all sectors. While policies related to the banking system do not usually factor into considerations for planning an energy system, our study shows that this is an important aspect to consider in creating the right incentives for a sustainable energy plan.

Third, the industrial sector can in some cases be more attractive for fuel switching than the power sector. The study found that looking outside of the power sector for fuel switching opportunities could prove to be a cost effective option. According to the model, a switch from coal to natural gas boilers would be cheaper than forcing a switch in power plants in the case of Shanghai where the industrial sector is currently dependent on inefficient coal boilers. Replacing an inefficient coal boiler requires much less upfront capital than converting a power plant from coal to natural gas. When there are enough boilers in the industrial sector to make a difference in emissions, this is an especially attractive alternative.

Fourth, the fuel mix for electricity generation is unlikely to change dramatically. In all of the scenarios that were tested in the model, coal remains the dominant fuel in the energy mix. Coal is simply too cheap and abundant to leave unused (China has the world's third largest coal reserves). Aggressive sulfur reductions do shift the electricity mix somewhat towards a greater role natural gas, but sulfur reductions can often be met more cheaply through fuel shifts in the industrial sector and by installing end-of-pipe solutions on coal plants.

Fifth, non-climate policies could have a large impact on carbon emissions. While China is unlikely to accept binding carbon dioxide emissions reductions targets in the near future, very large CO_2 reductions might be realized as a side benefit from other policies enacted for reasons other than climate concerns. For example, in the case of China, a cap on SO_2 emissions could have a significant effect on CO_2 reductions by promoting the use of cleaner burning fuels and more advanced technology. An SO_2 policy might be more palatable to the Chinese government because it addresses immediate local concerns about air quality and health which directly affects its citizens. Such issues are much more likely to gain immediate traction and spur change in the near term.

Appendix I: Fuel costs assumptions for MARKAL

Description		2000	2005	2010	2015	2020	2025	2030
International oil price (RMB/tce)	-	1,111	2,168	1,724	1,647	1,724	1,839	1,915
Domestically produced natural gas, domestic average (RMB/tce)	-	805	1,052	1,111	1,062	1,111	1,185	1,234
Natural gas from Russia, Central Asia; China border price (RMB/tce)	-	805	1,572	1,250	1,194	1,250	1,333	1,389
Regasified LNG, in local market (RMB/tce)	-	1,000	1,444	1,539	1,476	1,539	1,635	1,698
Coal price, OECD Border avg. (RMB/tce, 12,601 Btu/lb)		242	524	427	427	435	435	444

Description	Multipliers	Model Price						
Export Diesel (Beijing)	1.18	1,310.86	2,558.44	2,034.10	1,943.69	2,034.10	2,169.70	2,260.11
Export Gasoline (Beijing)	1.33	1,477.50	2,883.67	2,292.67	2,190.77	2,292.67	2,445.51	2,547.41
Domestic coal (Beijing, Shanghai)	0.90	217.74	471.78	384.68	384.68	391.94	391.94	399.20
Domestic coal (Guangdong)	0.90	337.74	591.78	504.68	504.68	511.94	511.94	519.20
Australian coal (Guangdong)	1.00	361.94	644.20	547.42	547.42	555.49	555.49	563.55
Watered hard coal (Beijing, Shanghai)	1.00	401.94	684.20	587.42	587.42	595.49	595.49	603.55
Coke (Beijing, Guangdong)	2.75	665.33	1,441.55	1,175.42	1,175.42	1,197.60	1,197.60	1,219.77
Diesel (Beijing, Guangdong, Shanghai)	1.18	1,310.86	2,558.44	2,034.10	1,943.69	2,034.10	2,169.70	2,260.11
Gasoline (Beijing, Guangdong, Shanghai)	1.33	1,477.50	2,883.67	2,292.67	2,190.77	2,292.67	2,445.51	2,547.41
Kerosene (Beijing, Guangdong, Shanghai)	1.68	1,866.31	3,642.53	2,896.00	2,767.29	2,896.00	3,089.07	3,217.78
Domestic natural gas (Beijing, Shanghai)	1.00	805.40	1,052.00	1,110.90	1,061.53	1,110.90	1,184.96	1,234.33
Russian natural gas (Beijing, Shanghai)	1.00	805.40	1,571.92	1,249.76	1,194.22	1,249.76	1,333.08	1,388.63
Australia gas (Guangdong)	1.00	805.40	1,571.92	1,249.76	1,194.22	1,249.76	1,333.08	1,388.63
LNG (Beijing, Guangdong, Shanghai)	1.00	999.81	1,444.17	1,539.39	1,475.91	1,539.39	1,634.61	1,698.09
Domestic gas (Guangdong)	1.00	905.40	1,152.00	1,210.90	1,161.53	1,210.90	1,284.96	1,334.33
LPG (Guangdong)	1.11	1,233.10	2,406.67	1,913.43	1,828.39	1,913.43	2,040.99	2,126.03
Crude oil (Beijing, Shanghai)	1.00	1,110.90	2,168.17	1,723.81	1,647.20	1,723.81	1,838.73	1,915.35
Other petroleum products (Beijing, Shanghai)	1.18	1,310.86	2,558.44	2,034.10	1,943.69	2,034.10	2,169.70	2,260.11
Fuel oil (Beijing, Guangdong, Shanghai)	0.74	822.07	1,604.45	1,275.62	1,218.93	1,275.62	1,360.66	1,417.36

Appendix II: Power Plant Technology for MARKAL (Beijing)

Description	**Investment cost** (M$/GW) 2005	**SO2 Emissions** (kt per PJ electricity output) 2005
Coal-fired, <=100MW	676	3.8985
Coal-fired, 100-200MW	650	3.6249
Coal-fired, 200-300MW, ESP	625	3.0384
Coal-fired, >=300MW, ESP	600	3.0384
Coal-fired, >=300MW, ESP, Dry FGD	709	1.2521
Coal-fired, >=300MW, ESP, Wet FGD	764	0.3130
Coal-fired, >=300MW, ESP, Sox/NOx	788	0.3130
Coal pulverized, 500 MW, with FGD	1090	0.1278
AFBC	900	0.4558
PFBC	1025	0.4558
Coal ultrasupercritical	1114	0.1278
IGCC electricity, quench	1334	0.0208
Coal LTH & Power	721	3.026
Coal LTH & Power-new tech	750	0.1278
PCC steam el + PRH	1530	0.1474
IGCC electricity + PRH	1678	0.0234
Heating plant - Coal central boiler	115	1.435
Coal steam/heat, advanced	493	0.052
Traditional oil-fired plant	530	0.417
Oil-fired combined cycle plant	600	0.275
NG turbine peaking plant	543	0
NG CC - cogen, advanced	485	0
NG Fuel cell CHP	2000	
Biomass FBC power	427	0
Biomass – cofire	241	0
Biomass - direct fire	1571	0
Biomass – gasification	1650	0
Residential PV	5750	0
Central PV	4000	0
Wind power plant - local	825	0
Wind power plant - remote & trans	860	0
Hydropower (>25MW)	1400	0
Small Hydropower (<25 MW)	1300	0
Geothermal power generation	1809	0
Nuclear	2000	0