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August 16, 1999

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FROM: Joe Aldy

SUBJECT: China paper

We understand that some individuals had difficulty downloading and/or opening the Word document of the China paper on Friday. In addition, some charts were inappropriately linked into that document. Attached please find a hard copy of the China paper with all charts in the appropriate order. We apologize for the delay in sending out this revised version.

8/13/99 Preliminary Draft; For Use in International Negotiations; Do Not Cite; Close Hold

The Economics of Greenhouse Gas Emissions Abatement in China

Over the past two decades, China has experienced an impressive rate of economic growth. Between 1980 and 1997, the size of the economy increased from the 16th largest to the 7th largest in the world, per capita incomes increased by nearly 400%, and energy consumption grew 112%. Like virtually all countries in the world, economic growth also resulted in the growth of greenhouse gas emissions, especially carbon dioxide.

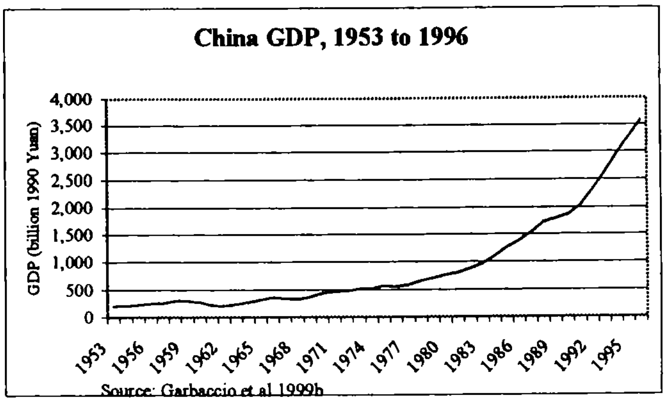
Emissions of greenhouse gases from all countries pose a risk to the global climate. International efforts to address these risks in Rio in 1992 and Kyoto in 1997 recognize the need to abate greenhouse gas emissions while sustaining economic development. Specifically, the Kyoto Protocol calls for the design of markets that will facilitate the transfer of capital and technology to the countries where emissions can be abated at least cost. A country that can abate greenhouse gas emissions at lower cost than others has the opportunity to attract investment for climate-friendly technology that abates emissions and can then sell emissions credits or allowances to higher cost countries. Effectively, Kyoto provides the potential for low-cost abating countries to create an export industry – whose export products are emissions abatement – which would be financed through foreign direct investment.

What is the potential for a fast-growing economy such as China's to create and benefit from such export industries? The economic literature indicates that China has the opportunity to abate more greenhouse gas emissions at a lower cost than any other country. Selling these abated emissions through the Kyoto mechanisms could attract billions of dollars of investment per year that would finance some technology leap-frogging in the energy generation and industrial production sectors. In addition, abating carbon dioxide, for example by improving combustion efficiency of coal power plants, would reduce emissions of local air pollutants that carry significant economic costs through lost worker days, additional health care expenses, and premature mortality. The potential is clearly available for China to be better off economically through the promotion of an emissions abatement export industry.

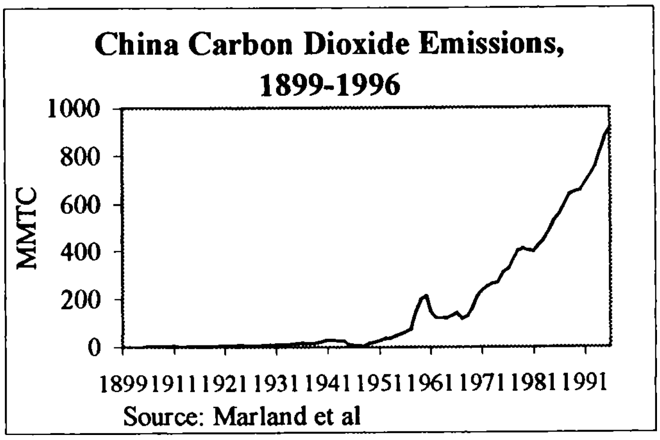
This paper provides an overview of this potential drawing from economic research on China conducted by academic, industry, and government analysts from around the world. First, the paper summarizes recent energy and economic trends as well as various projections of the Chinese economy under business as usual. Second, the paper presents a description of the trade-oriented mechanisms in the Kyoto Protocol that will promote capital and technology flows for emissions abatement. Third, it reviews the extensive economic modeling literature on the potential economic gains associated with participation in the Kyoto mechanisms. Fourth, the report discusses in detail some of the advanced technologies that would likely play an important role in improving the efficiency of the energy system while abating emissions. Finally, it describes the potential improvement in public health associated with abating emissions of local air pollutants that usually accompany carbon dioxide abatement.

I. Overview of China's Economic, Energy, and Environmental Trends

Historical Trends

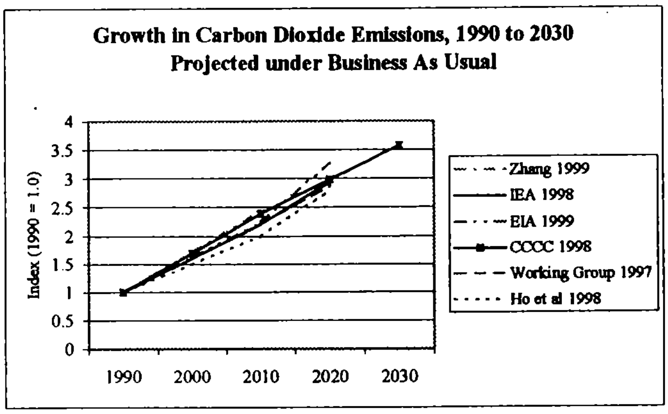


China's economy has grown at a very rapid rate over the past two decades (Figure X), averaging 10% growth per year between 1978 and 1997 (Zhang 1999). China achieved this economic growth through impressive productivity gains (cite?). Further, China has played a significant role in international trade, with exports as a share of GDP increasing from X% in 1978 to X% in 1996. Moreover, foreign direct investment has increased from X% in 1978 to X% in 1996, and has been concentrated in China's larger export industries, such as X, Y, and Z (true?; cite?).

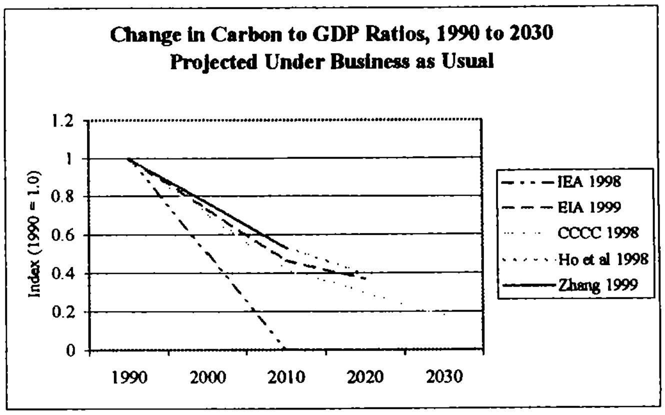


At the same time that China's economy has grown remarkably, its emissions of greenhouse gases has also increased substantially (figure X). While carbon dioxide emissions tend to increase when GDP rises, and decrease when GDP fall, the rate of emissions growth depends not only on GDP growth, but also on structural change (which varies through a country's economic development) and explicit government policies that affect the energy efficiency and carbon-intensity of energy supply in the economy.

A variety of researchers have made projections of China's carbon dioxide emissions, some as far into the future as 2030 (figure X). While the absolute levels of emissions in a given year in these forecasts may appear to vary somewhat, much of this appears to be due to different estimates of 1990 emissions. Emissions growth rates through 2010 across six different business as usual projections appear to be fairly similar. The differences in projections also appear to be influenced by different economic growth rate assumptions.



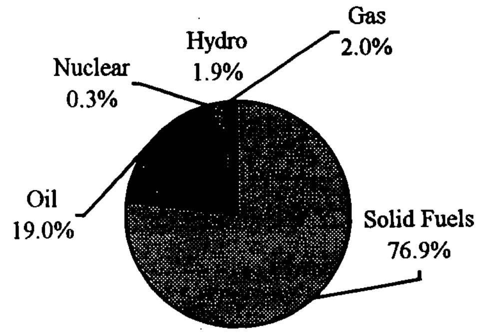
The carbon-to-GDP ratios across five of the China business as usual projections appear to follow similar rates of improvement (figure X). These forecasts illustrate that the recent decoupling of carbon emissions and economic growth will likely continue into the future.



Projected Trends

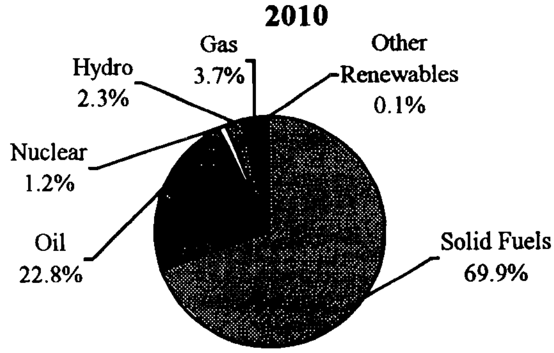
Solid fuels (coal) comprised approximately ¾ of China's total primary energy supply in 1995, and under business as usual will continue to serve as the largest source of energy in 2010 (see Figures 5 and 6). As a share of energy, natural gas is projected to nearly double, and nuclear will quadruple, but combined these will comprise only 5% of total energy supply in 2010. Hydropower will increase by approximately 20%, and surpass oil as the second largest source of energy by 2010. Non-hydro renewable power sources will increase through 2010, but play only a minor role in the energy supply system.

China Total Primary Energy Supply 1995



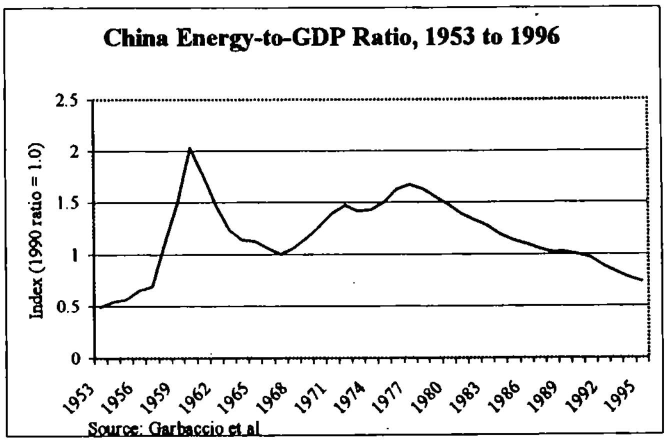
Total: 864 million tons oil equivalent
Source: International Energy Agency 1998

China Total Primary Energy Supply 2010



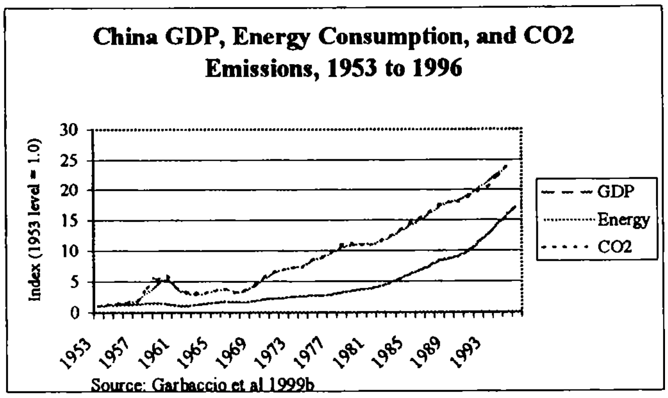
Total : 1559 million tons oil equivalent
Source: International Energy Agency

Prior to the late 1970s, the relationship between energy consumption and GDP was not stable over time (Figure X). However, since the implementation of market reforms in the late 1970s, the energy-to-GDP ratio has fallen significantly despite rising economic growth. While most developing economies have income elasticities of energy consumption of approximately 1.0 (or higher), China's over the past twenty years has averaged about 0.5 (Zhang 1999; IEA 1998). The current energy-to-GDP ratio is at its lowest point in China since the late 1950s (Garbaccio et al 1999b). Recent analysis of this trend in the energy-to-GDP ratio indicates that most of the improvement reflects within-industry technological change as opposed to structural change (Garbaccio et al 1999b).



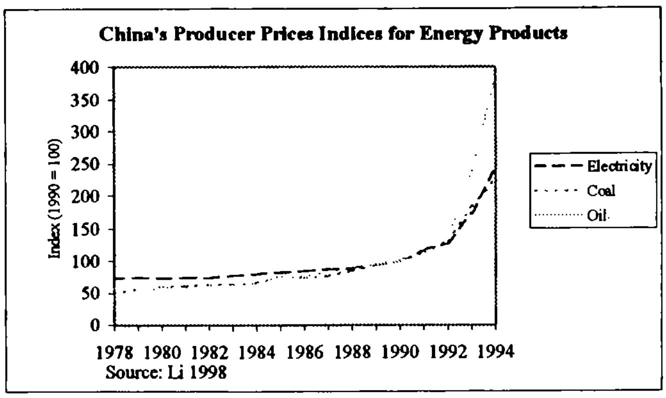
China Energy-to-GDP Ratio, 1953 to 1996

Over the past 45 years, energy use and carbon dioxide emissions have grown more than GDP (Figure X). Specifically, carbon dioxide emissions and energy consumption track each other very closely. However, as reflected in Figure X, the improvement in the energy-to-GDP ratio over the past two decades reflects the much faster growth rate in GDP than in energy use and carbon dioxide emissions since 1978.



China GDP, Energy Consumption, and CO2 Emissions, 1953 to 1996

Energy subsidies in China have fallen over the past two decades, and the increase in energy prices is evident in the producer price indices for oil, coal, and electricity (see figure X). Zhang (1999) notes that the subsidy for coal has fallen from 61% in 1984 to 29% in 1995, while the petroleum subsidy has fallen from 55% in 1990 to 2% in 1995. However, the World Bank (1997b) estimated that for 1995-1996, China's energy subsidies averaged 20%. Li (1998) reports that the government still sets a plan energy price for industrial users that supply energy through the state plan, but market prices for other users. This transition to energy prices that better reflect supply and demand has helped contribute to China's improving energy efficiency (Zhang 1999).



China's Producer Prices Indices for Energy Products

II. Opportunities to Participate in Kyoto Flexibility Mechanisms

The Kyoto Protocol establishes three mechanisms that, if designed and implemented efficiently, could provide the foundation for a global emissions market. Through international emissions trading (Article 17), joint implementation (Article 6), and the Clean Development Mechanism (Article 12), an economic value would be assigned to an emissions reduction through a market.

Since greenhouse gas emissions have the same climatic consequences regardless of where in the world they occur, the least-cost approach to addressing the risks of climate change would be to reduce emissions wherever such reductions are cheapest. This uniform climatic effect of an emissions reduction implies that emissions abatement has the economic property of a commodity. This facilitates the evolution of a market, where entities that demand emissions abatement (e.g., those with high abatement costs) can funnel capital and/or technology to suppliers of abatement. In such a market, countries with low emissions abatement costs could take advantage of the opportunity to "produce" emissions abatement and to export these abated emissions, as certified emissions reductions or tradable allowances, at lower costs than other, higher-cost countries. Just as in the production of other commodities, low-cost producers could attract foreign direct investment to finance their export industry.

This potential evolution of an international emissions market reflects some of the experiences and lessons learned from the international trade in a variety of goods and services. The concept of gains from trade in emissions allowances is the same as it is for trade in goods and services. For example, Frankel (1999) notes that developing countries could "specialize in installing clean new-technology power-generation capacity, while industrialized countries specialize in producing the capital goods that go into those plants" (p. 4). Toman et al (1998) also note that "[t]hose countries which find themselves with lower abatement costs and more generous emission ceilings can generate a valuable commodity to export" (p. 3). Thus, developing countries would export emissions abatement, and use their export revenues to import, among other things, these new energy technologies.

The gains from trade in emissions allowances occur as a result of the large differences in marginal abatement costs across countries. Weyant and Hill (1999) note that "if the marginal cost in any country participating in a trading regime is higher than in any other participating country, it is advantageous to both countries for the higher cost country to buy emissions rights at a price that is between the two marginal costs" (p. xvii). However, before reviewing the estimated marginal costs across countries, it is important to understand how the Kyoto Mechanisms, specifically international emissions trading and the Clean Development Mechanism, could serve as the necessary foundation of an international emissions market.

A. International Emissions Trading

Articles 3 and 17 of the Kyoto Protocol allow countries with binding targets to lower the cost of meeting their targets by participating in international emissions trading. These binding targets take the form of an "assigned amount" – the number of metric tons of greenhouse gases (counted in carbon dioxide equivalent) that may be emitted by sources within the country during the five-year commitment period running from 2008 through 2012. In emissions trading, one country transfers part of its assigned amount to another. This transfer of assigned amount lowers the number of tons of greenhouse gases that the first country may emit between 2008 and 2012, and raises the number of tons that the second country may emit by an equal amount. It is useful to think of each one-ton unit of assigned amount as a tradable allowance for one ton of emissions that may be transferred between countries.

Because the cost of controlling greenhouse gases differ by many times from country to country, emissions trading will allow substantial gains from trade in meeting the Kyoto targets. Countries that have relatively inexpensive ways to control greenhouse gases have incentives to reduce emissions by more than their targets require, because they can sell tradable allowances that they will not need to others. Countries facing the most expensive control measures have incentives to buy less costly allowances from others, and thereby increase the amount they may emit. Since greenhouse gases are global pollutants, the environmental impact of reducing them is the same no matter where the reductions take place. The same overall reduction is achieved, total costs are reduced, and both buyers and sellers gain from the savings allowed by trading.

A country that wants to increase the number of tons of greenhouse gases that it is allowed to emit would seek out other countries that are willing to sell some of their tradable allowances. Buying and selling countries could arrange their transactions directly or use brokers or exchanges. Because of the voluntary nature of trading, a selling country would engage in a trading transaction only if it makes that country better off.

In addition to trading at the governmental level, some countries (including the United States) plan to use both domestic and international emissions trading at the company level as part of their program to meet their Kyoto commitments. Companies and other legal entities subject to these domestic trading programs (integrated with the international trading system) would have strong incentives to look constantly for innovative ways to abate their greenhouse gas emissions. Those who found inexpensive opportunities to abate their emissions could sell the allowances they do not need to other companies or countries who face higher costs. Further, some companies that have climate-friendly technology may find it cost-effective to transfer this technology to facilities in a low-cost abatement country in return for tradable allowances. These tangible rewards for innovation should provide the incentive for research and development and subsequent technological breakthroughs (Petsonk et al 1998).

As stated above, the Kyoto Protocol stipulates that countries must have an emissions target to engage in international emissions trading. Since the Kyoto Conference, several non-Annex I countries have expressed an interest in adopting emissions targets. Consistent with the Framework Convention on Climate Change, targets for non-Annex I countries should help promote their sustainable development. To do so, such targets should accommodate emissions growth. Unlike most Annex

B targets, which were set below most countries' current emissions levels, such a target for non-Annex I countries would be set above current emissions levels. To contribute to the international effort to address climate change risks, it would also be desirable for such targets to result in real abatement in emissions below levels that would otherwise occur during the commitment period – that is, below the projected business as usual (BAU) emissions level. This kind of target, often referred to as an emissions growth target, would provide for continued economic development but with a lower emissions growth rate.

If developing countries were to agree to binding limits, even if they involved only small cuts below Business as Usual (BAU) in the first budget period, then such targets, with trading, would imply gains for their economies and gains for the environment. Figure X provides an illustration of an emissions growth target. Such a target could be expressed as some percentage of a base year, in a similar fashion to Annex B targets, but with a different base year and a percentage greater than 100% to account for emissions growth.

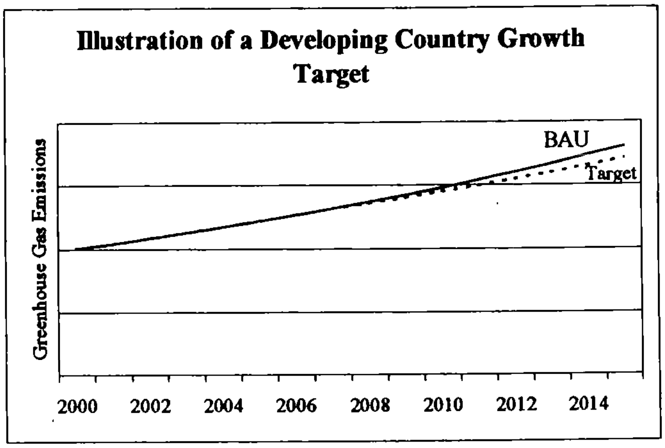


Illustration of a Developing Country Growth Target

An emissions target could also take alternative forms. Some have expressed concerns about the uncertainty associated with business as usual emissions projections (Baumert et al 1999). A country that takes on a commitment for the 2008-2012 period that is fixed *now*, faces the risk, for example, that its economy will grow more rapidly than expected, resulting in an inadvertently stringent target. Alternatively, a country's economy could grow less rapidly than expected, resulting in an inadvertently lax target. There are, however, ways of designing targets to reduce uncertainty and mitigate these risks. In particular, targets could be indexed to future values of economic and other, possibly demographic, variables.

A target could, for example, be indexed to a country's economic performance between now and the start of the 2008-2012 commitment period (Frankel 1999). This approach is used in the private sector, where contracts are frequently indexed. This approach is also used in the public sector (e.g., the U.S. government provides cost-of-living adjustments for social security recipients). A target could then be specified in a way that depends on the future values of economic variables, such as GDP. For example, Baumert et al (1999) have argued for a carbon-to-GDP intensity measure as an appropriate form of developing country commitment. Zhang (1999) has specifically discussed a greenhouse gas emissions per unit GDP measure as the basis for a voluntary commitment by China around 2020.

Such targets would avoid the risk of inadvertent stringency associated with higher than projected economic growth between now and the beginning of the commitment period in 2008. Non-Annex I countries would face only the much smaller risk that emissions would be higher than expected, *given* the economic conditions realized in 2007. Similarly, such targets would also avoid the risk of inadvertent laxness associated with lower than expected economic growth between now and the start of the commitment period.

B. The Clean Development Mechanism

The Clean Development Mechanism was incorporated in the Kyoto Protocol to 1) promote sustainable development; 2) contribute to the Framework Convention's climate objective; and 3) to assist Annex B parties in complying with their commitments (Toman et al 1998). The CDM allows for developed and developing countries to work together to design and implement projects in developing countries that abate greenhouse gas emissions from what they would have been otherwise. These projects must undergo a review process to certify the emissions reductions. In addition, a portion of the proceeds from the project must be used for an adaptation fund for low-income countries especially vulnerable to climate change and for administrative costs of the CDM.

An example, step-by-step, of a CDM project design, approval, and implementation process

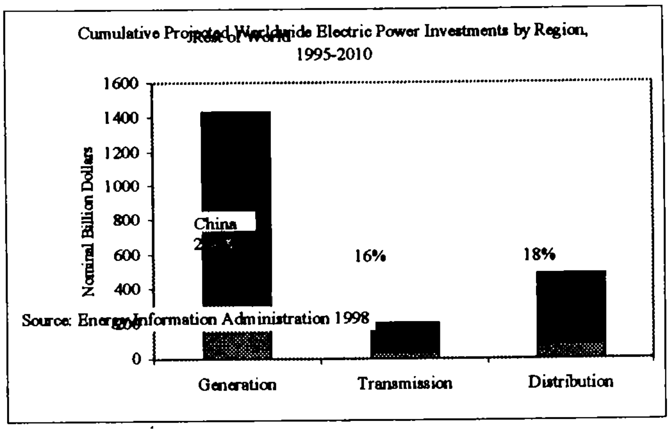
In addition to firms in developed and developing countries working together to design and implement specific projects, some have suggested that governments could cooperate to design project "fast-track" processes, or even sector-oriented efforts (Chayes 1998). To reduce some of the transaction costs associated with participating in the CDM, two countries could design a fast-track process that makes the project approval process more transparent to the private sector and simplifies the rules for approval. Alternatively, a developing country could consider designating an entire sector a CDM "project". For example, a country could identify a business as usual emissions forecast for its power sector, set this as an implicit sector-wide emissions target, and attract investment for projects and policies that abate the emissions from electricity generation.

However, even these efforts to promote sustainable development by increasing the number of CDM projects probably would not compare to the likely volume of capital and technology flows expected for a country with an emissions target that is actively participating in international emissions trading. The CDM carries with it several transaction costs, such as project approval and certification, the adaptation charge, and a charge to cover administrative expenses, that reduce the potential cost-effectiveness of this approach relative to a less-burdened trading system. It should also be noted that non-Annex I countries that adopt emissions targets could be able to participate as a host to CDM projects until the beginning of the commitment period, at which time, it would participate in international trading.

III. Economic Gains from Clean Development Mechanism and Emissions Trading

A variety of economic models have been developed throughout the world that can evaluate the potential economic gains from trade in emissions allowances. These economic tools effectively model trade in emissions as if they were any other internationally tradable commodity where both production costs and demand vary across countries. However, before reviewing the summary of model results for China, it may be useful to consider some relevant statistics regarding China's projected energy trends. These data will facilitate an understanding of and provide some context for the model results presented below.

A. Illustrative Energy and Economic Statistics



While China's economy is not expected to grow as fast in the future as it has in the past twenty years, it is still expected to grow at a strong pace. The International Energy Agency (1998) projects China's economy will grow 5.5% for the 1995-2020 period, and X projects economic growth of Y, while IEA projects OECD countries GDP to grow on average about 2% over this time period. Because of the higher growth rate, China has more opportunities than many OECD countries to reduce emissions relative to baseline projections by installing new carbon-efficient plants and adopting other new technologies. In contrast to retrofitting existing plants, new investment in carbon-efficient plants is a less costly approach to abate emissions.

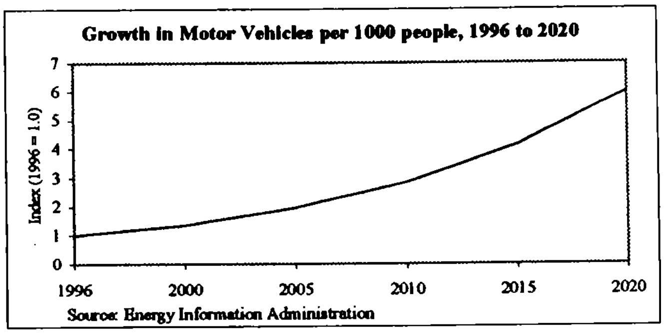
The faster economic growth expected in China implies a higher rate of investment than most OECD countries. For example, investments in electric power generation in China are projected to comprise nearly ¼ of total world generation investment between 1995 and 2010 (see figure X). Many of these Chinese investment projects are likely to increase total generation, while a larger share of OECD investments will likely replace existing power plants. Current Chinese coal plants are about 25 to 33% less efficient than developed countries' coal plants (Fang et al 1998). Investing in power technologies with comparable efficiencies to developed countries' plants could significantly reduce Chinese emissions per unit of electricity generated. Further, one out of every six dollars expected to be invested in transmission systems around the world will be spent in China through 2010. Improving transmission efficiency in China – where transmission losses are twice those found in developed countries and can range up to 30% (Ni and Nien 1998) – through these investments can further reduce emissions per unit of energy consumed.

Differences in energy efficiency between China and developed countries also exist in various industrial sectors. Table X illustrates some of these differences in industrial production activities. As these industrial sectors in China evolve, new investment could be leveraged by the value derived from generating emissions abatement to install more advanced, higher efficiency production technologies.

Table X. Comparison of Physical Energy Efficiency in Industrial Production between China and Western Countries

Production Activity	China	Western Countries
Industrial Boiler	55-60%	75-80%
Industrial Furnaces	20-30%	50-60%
Thermal Electrical Power	25-30%	35-40%
Steel Industry	1.0 tce/ton of output	0.7 tce/ton of output
Synthetic Ammonia	2.1 tce/ton of output	1.15 tce/ton of output
Cement	0.2 tce/ton of output	0.13 tce/ton of output

Source: Fang et al 1998, p. 125.



As per capita incomes continue to rise in China, the number of motor vehicles per capita is projected to increase much faster. Between 1996 and 2010, motor vehicles per capita is projected to triple, and then double again by 2020 (EIA 1999). Since Chinese fuel intensity in highway transport is 25% higher than in developed countries, and domestic-made vehicles consume 30-40% more fuel than comparable import vehicles (Lin and Polenske 1998), this growth in vehicle usage could significantly increase emissions. However, this differential in fuel economy also illustrates another potential opportunity to improve energy efficiency as the transportation sector continues to expand.

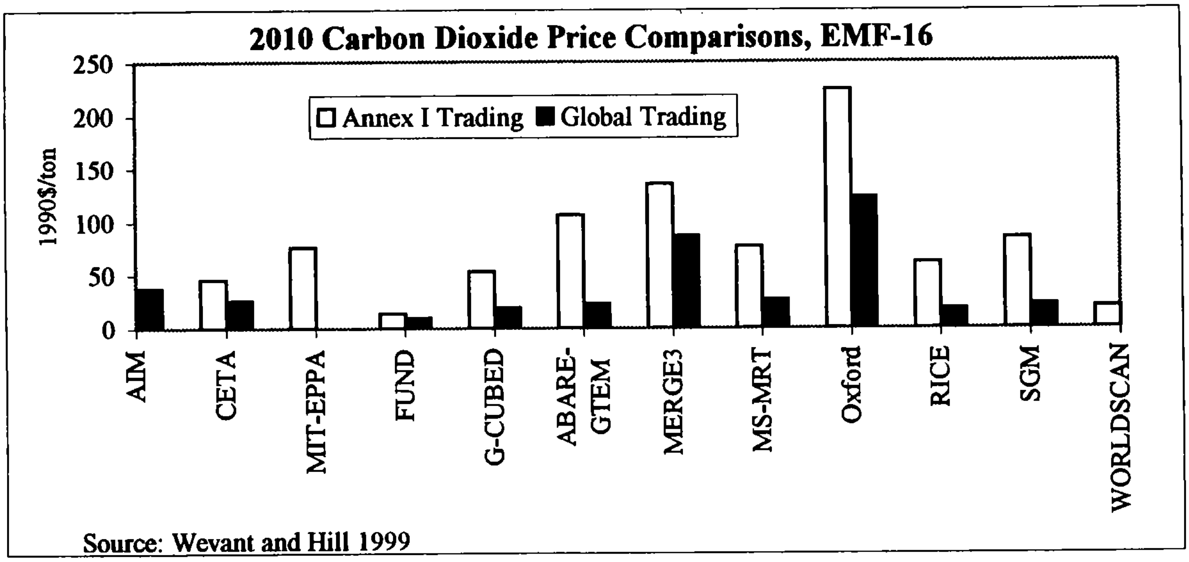
These various economic and energy statistics for China illustrate some of the differences between China's and developed countries' energy economies. This sample of statistics demonstrates qualitatively the potential opportunities for investment in China, through international emissions trading and the Clean Development Mechanism, to abate greenhouse gas emissions. For a more formal overview of these potential opportunities, results from economic models are presented.

A variety of international energy-economic models have been used to evaluate the potential economic implications of the Kyoto Protocol. For example, the Stanford University Energy Modeling Forum coordinated a modeling comparison exercise involving 13 models developed by teams in Europe, the United States, Asia, and Australia. Further, the Organisation for Economic Cooperation and Development (OECD) hosted a workshop in 1998 where 9 modeling teams presented their assessments of the Kyoto Protocol. These models assess the projected marginal cost of abating carbon dioxide across countries and then estimate the extent of buying and selling in an international emissions market until no further economic gains can be achieved through subsequent trades – i.e., they find the market clearing price for an emissions allowance. These models provide estimates of marginal cost (e.g., the price of a tradable allowance or a CDM certified emission reduction), emissions abatement by country, capital transfers by country, and measures of total economic cost (or benefit for some countries that are net exporters of emissions allowances).

B. Illustrative Modeling Results

A large number of energy-economic models have evaluated the potential economic effects of an international emissions market under the Kyoto Protocol. Most of these models evaluate the potential emissions abatement in a country by assuming that such abatement occurs at least-cost. This effectively represents the effects of a domestic tradable permit system or a domestic emissions tax. In the case of China, emissions abatement is assessed in these models assuming that the incentive to abate is provided through an instrument comparable to the U.S. sulfur dioxide trading system, but where carbon dioxide is traded, or some of China's pollution discharge fees (Panayotou 1998), but where carbon dioxide is taxed. Since a project-oriented approach may not deliver least-cost abatement first like a tradable permit or tax system, some have argued that model results of emissions abatement at a given price for developing countries can serve at best as an upper bound on the volume of emissions abatement produced by these countries through the CDM (MacCracken et al 1999). Indeed, given the complexity of the CDM, some have made the assumption that a developing country would only be able to generate 15% the emissions abatement through the CDM that it would by adopting an emissions target set at 2010 business as usual and engaging in international emissions trading (Manne and Richels 1999). Thus, the model results presented below represent the potential under an efficient international trading system and serve as an upper bound on the potential volume of emissions abatement that could occur through the Clean Development Mechanism.

To evaluate the international emissions market under Kyoto, energy-economic models are designed to assess marginal costs across countries given the emissions targets established in Annex B of the Protocol. These models then estimate market clearing prices for an emissions allowance (the economic value of a ton of carbon) in various trading scenarios. In scenarios involving non-Annex I countries, these models assume that developing countries adopt emissions targets set at 2010 business as usual emissions levels and participate in international trading. Figure X presents results from 12 models that participated in the Stanford University Energy Modeling Forum Kyoto Protocol exercise (EMF-16).



While the price of a ton of carbon may vary across models, several common lessons can be drawn from these results. First, gains from trade, especially in expanding trading from Annex I countries to all countries, can be substantial. All the models found that marginal and total costs fell going from Annex I to global trading, because developing countries can undertake low-cost emissions abatement and sell their emissions abatement to OECD countries. Second, higher rates of economic growth in OECD countries increase demand for emissions allowances, while higher rates of economic growth in developing countries create more opportunities to substitute carbon-lean technology, and thus increase supply of low-cost emissions abatement. Third, countries with larger coal shares of total energy have more opportunities to abate emissions through energy efficiency and fuel switching that countries with smaller coal shares do not have. Including these countries with larger coal shares in international emissions trading can further reduce the cost of a ton of carbon (Bernstein et al 1998).

These model results provide illustrations of the possible characteristics of an international emissions market. What kind of role can China play in this emissions market? Many of these models indicate that substantial emissions abatement can occur at very low cost in China. For example, Garbaccio et al (1999a) completed a recent evaluation of a carbon tax on the Chinese economy. Such a tax could mirror other emissions and pollutant charges in China. Garbaccio et al designed a X-sector computable general equilibrium model based on China's 1992 I-O tables. They estimated three streams of carbon taxes necessary to abate emissions 5%, 10%, and 15% below business as usual over a 40-year period (see table X). Revenues from the carbon tax were recycled to the economy by proportional reductions in labor and capital taxes, although given the higher rates of taxation on capital than labor, this recycling promotes investment. While GDP falls below projected business as usual in the first year of these three simulations, the investment induced by recycling results in GDP growth above BAU after the first year in all scenarios. In this model, China's emissions could be abated by 15% below business as usual at a cost less than $10 per ton, which is well below the estimated Annex I emissions allowances prices in the EMF-16 model results. In this analysis, before

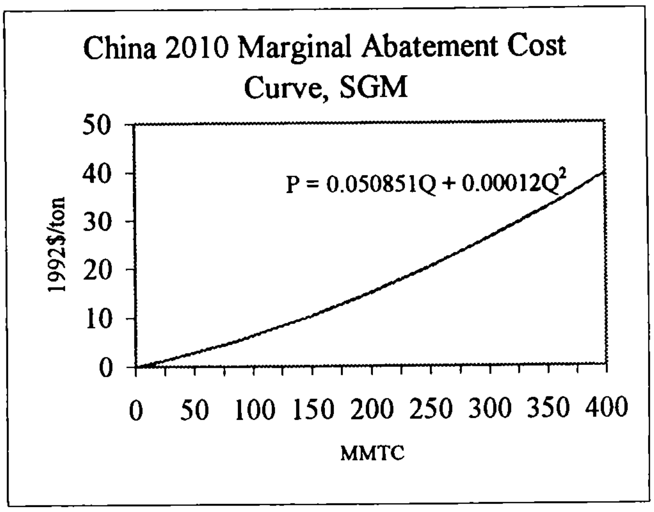
China exports one unit of emissions abatement, its economy is no worse off than before. Moreover, given the low marginal cost of abatement, every unit of abatement exported to an Annex I country under the 15% scenario would be profitable.

Table X. Garbaccio et al 1999a Results

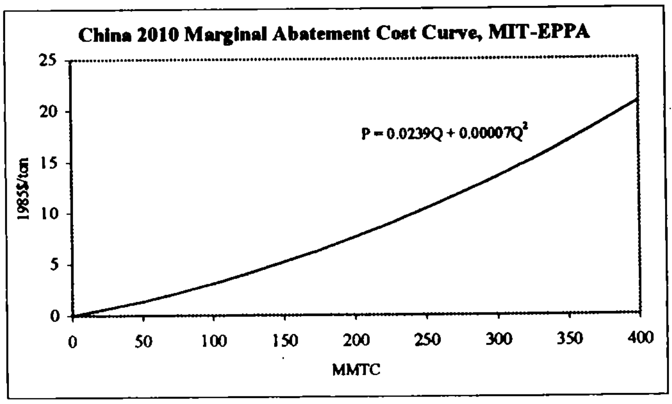
Emissions Abatement	5% below BAU	10% below BAU	15% below BAU
Price of Carbon	9 yuan/ton ($1.40/ton)	19 yuan/ton ($3/ton)	31 yuan/ton ($5/ton)
% Change in GDP	+%	+%	+%

A previous study by Zhang (1996) found that significant emissions abatement could also occur with relatively low carbon prices. Zhang designed a computable general equilibrium model of the Chinese economy, organized in 10-sectors based on 1987 I-O tables. While Garbaccio et al modeled the Chinese economy as a hybrid planned-market economy, Zhang modeled China as a fully market economy. He found that emissions could be abated to 20% below 2010 business as usual with a carbon tax of 205 yuan/ton ($18/ton), and 30% below 2010 business as usual with a carbon tax of 400 yuan/ton ($35/ton). These modest carbon prices generated very high GNP losses in Zhang's model, ranging between 1.5 and 2.8%. These results likely reflect only a partial, and less than optimal, recycling of carbon tax revenues to the economy, the more aggregated nature of the model (10 sectors versus 29 in the Garbaccio et al model), the full market nature of the representation of the Chinese economy (which would then not account for such characteristics of the energy sector as coal subsidies), and the older I-O table data. Other assessments of the Chinese economic potential to abate emissions illustrate that the costs are small, and clearly outweighed by export revenues.

For example, MacCracken et al (1999) employed the Second Generation Model (SGM) to evaluate the international emissions market assuming global participation. The SGM includes a China module, developed in coordination with Chinese energy-economic experts (see Figure X). They found that under global participation in the international emissions market, the price for a ton of carbon would be $26/ton (1992$), and China would find it profitable to abate 341 MMTC in 2010. With a target assumed to be set at 2010 business as usual, these 341 MMTC of abatement would be exported generating revenue equal to 0.3% of GDP.



Ellerman et al (1998) have also developed a global energy-economic model with a separate China module (see Figure X). In their assessment of global trading, they found that the market price for a ton of carbon would be $23.80 (1985$). At this price, China would find it economic to abate 436 MMTC in 2010. This estimate of emissions abatement is larger in absolute terms than the MacCracken et al estimate, but because Ellerman et al project a higher emissions growth rate for China, the projected abatement as a percentage of BAU is rather similar between these two models. If China had a target set at 2010 BAU, Ellerman et al estimate that it could export $10.4 billion in emissions allowances which would generate gains from trade of $6.2 billion.



Van der Mensbrugghe (1998) conducted several analyses of the Kyoto Protocol with the OECD's GREEN model. GREEN also includes a distinct China module. Van der Mensbrugghe found that under global trading, the international market price for a ton of carbon would be $19/ton (1985$). At this price, China would find it profitable to abate 228 MMTC. China would be able to export $4.3 billion in allowances under a 2010 BAU target. In this analysis, Van der Mensbrugghe assumed that China provided the incentive for in-country abatement through a carbon tax, revenues of which would comprise 1.4% of GDP. Moreover, by participating in the international emissions market, he found that China's GDP would increase 0.4% above 2010 BAU.

While not an explicit modeling exercise, the China Climate Change Country Study (CCCC; 1998) did evaluate several scenarios for emissions mitigation. The authors found that in its "policy" case, emissions could be abated over the next 3 decades such that 2030 "policy" emissions were 30% below 2030 business as usual emissions levels. Without accounting for any potential gains from exporting this emissions abatement, the authors found that this mitigation would not reduce economic output from the projected level.

While the modeling results reflect an efficient international emissions market, they do provide an upper bound on the potential from the CDM. As noted above, the CDM is project-oriented, and several of its attributes generate transaction costs relative to an efficient trading system. One international model developed by several Dutch analysts, WorldScan, has been modified to account for some of the characteristics of the CDM (Bollen et al 1999). While the analysts did not include an adaptation or administrative charge, or costs associated with project review and certification, they designed the model so that it would mimic the efforts of private firms to cost-effectively invest in large energy projects. Thus, CDM projects were analyzed only in the form of investments that alter the input intensities of existing production capacity or replace existing capital. With this assumption, and assuming no trading among Annex I countries, Bollen et al found that China could profitably abate approximately 150 MMTC annually during the first commitment period through the CDM. The WorldScan model estimates that the price for the certified emission reduction would be $X/ton.

IV. Technology Diffusion with Kyoto Mechanisms

[Note: this section is still a work in progress. We would like to provide examples of technologies that could be deployed through participation in CDM and/or trading. These below are just some examples – ideas are solicited for which technologies to highlight and how to frame them.]

clean coal technology

Atmospheric Fluidized Bed Technology achieves thermal efficiency rates of 34-37% by combusting a circulating mixture of coal and gas. By injecting limestone directly into this process, the same amount of SO2 can be removed as will a traditional scrubber but at lower power costs (Fang, 1998).

Integrated Gasification Combined Cycle employs coal gasification along with gas turbines to achieve efficiency rates of 38-45% with SO2 removal technology in place (Fang, 1998).

renewable energy sources

China has extensive potential for the development of wind power especially along the coastline and in the north. Large scale wind projects could directly replace coal plant and can usually be brought on line within a year. China has at least two wind projects in effect now. One is an effort begun in the 1980s to subsidize rural elecrification which has generated 140,000 small systems, 15,000 technichians, and 42 Chinese enterprises engaged in wind power development. (Fang 1998)

Known geothermal reserves amount to approximately 3000 Mtce. The Yangbajing station of Tibet demostrates the potential of this technology. The plant takes advatages of underground water temperatures of 150-172C to generate an installed capacity of 25.2MW. The station supplies 60% of the electricity for the Tibet's capital Lhasa. (Fang 1998)

end-use energy efficiency technology

Before 1992, the Dalian Steel Plant in the Liaoning Province "newly cast ingots were allowed to cool to ambient temperature before being discharged into a soaking pit for the next stage" of production called blooming. The company carried our a project to discharge the ingots in a "hot state" for 750,000 yuan. The innovation saved 27% of the ingot heat and allowed a reduction in oil use of 2,000 tons of heavy oil annually. The project paid for itself in 6 months (Fang, 1998), but under a trading mechanism, this innovation would also generate emission credits.

coalbed methane recovery

transportation sector (?)

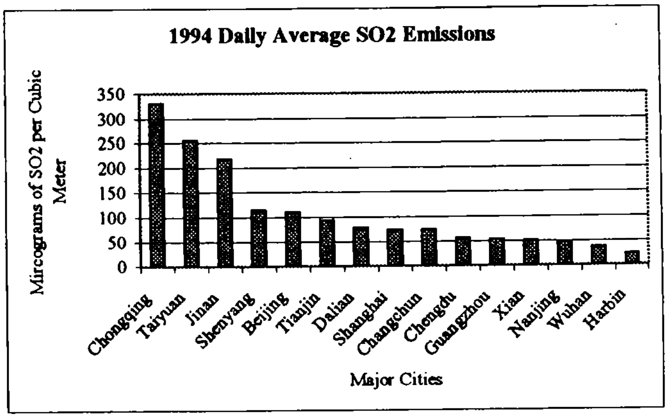
forestry project (?)

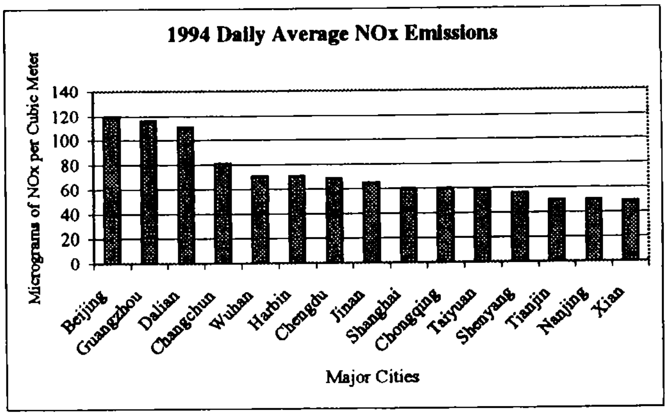
V. Local Air Quality Benefits from Abating Greenhouse Gas Emissions

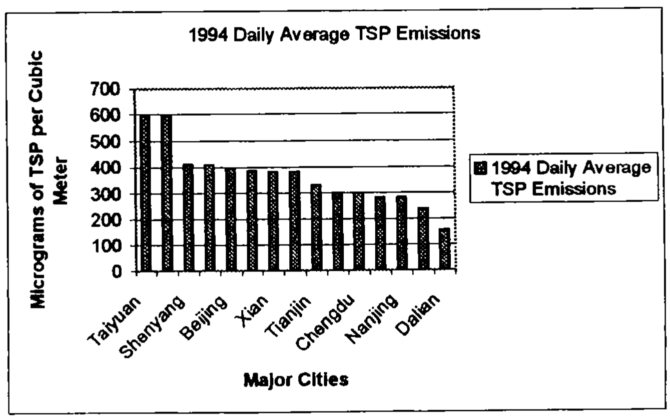
The same combustion processes that emit carbon dioxide and other greenhouse gases also generate numerous local air pollutants like sulfur dioxide and particulate matter. In its Report on the State of the Environment in China, the State Environmental Protection Administration noted that "atmospheric pollution results mainly from coal-burning" (SEPA 1998, p. 8). This is true for both global and local pollutants. By reducing carbon emissions through the use of coal substitutes and the adoption of more efficient coal combustion methods, China can simultaneously generate emission credits and improve the immediate quality of life of its citizens.

A. Local Air Quality

Local air quality is the most immediate environmental threat facing China. As figure X shows a number of China's cities regularly encounter more than 2 to 3 times the World Health Organization's recommendations for levels of sulfur dioxide (SO_2) and over 3 to 4 times the recommendations for total suspended particulates (TSP). These pollution levels and the health threats they engender make improvements in local air quality coterminous with carbon emission reductions under the Kyoto Protocol a compelling argument for participation in the emissions trading system through an emission cap or in flexibility mechanisms.







In recent years, the level of pollutants has stabilized (Figure X) due primarily to two countervailing effects (Florig 1997). First, more efficient power generation technology and the use of pollution control devices has reduced emissions from industrial sites. Second, household pollution, primarily a result of cooking and heating with coal, has increased substantially, leaving the total pollution levels constant. Estimates from the World Bank, however, expect particulate emissions to increase 39% between 1995 and 2010 and then decrease slowly there after (35% higher in 2020). They further estimate that household smoke will increase 90% between 1995 and 2020 and that SO_2 levels will increase by 150% (World Bank 199#). The difference in the trends between SO_2 and TSP reflect the more widespread adoption of particulate removal technology versus clean coal technology and scrubbers. A more disturbing fact is that levels of indoor pollution are often higher then levels of out door pollution.

B. Costs of Local Air Pollution

A number of studies have analyzed the relationship between current high levels of local air pollutants and health problems. Xu Zhaoyi and associates at the Liaoning Public Health and Anti-Epidemic Station estimated that indoor and outdoor pollution cause 60% of urban chronic obstructive pulmonary disease cases (Florig, 1997). Research by Xu Xiping at the Harvard School of Public Health and his colleagues takes advantage of the unique structure of the Chinese public health system to demonstrate a relationship between levels of TSP and SO_2 and hospital visits (Xu et. al, 1995a; Xu et. al, 1995b). In one study, one-percent increases in SO_2 and TSP levels increased the number of non-surgical visits by 20% and 17% respectively. Xu Zhaoyi and Xu Xiping have also estimated the effects of pollution on mortality rates in Shenyang and Beijing respectively (Xu, 1998). Figures # and # demonstrate this relationship (charts coming). In Beijing, a doubling of SO_2 levels increased the mortality rate by 11% (a positive, but non-statistically significant relationship existed for TSP) while in Shenyang,1 mortality increased by 2% for each 100 $\mu g/m^3$ of SO_2 and by 1% for each 100 $\mu g/m^3$ for TSP. The World Bank estimates that the economic costs from only lost work hours, hospital and emergency room visits, and chronic bronchitis at $20 billion a year.

Researchers have also documented the effects of pollution on children. Liu Yulin of the Institute of Pediatrics in Beijing found that children's chances of contracting pneumonia doubled if they lived in a home with coal stoves or adults who smoked. He Qingci of the Wuhan Environmental Protection Institute showed that children from Wuhan's urban areas had lung capacities 5% smaller than children from the suburbs where outdoor TSP levels are 50% lower (110 $\mu g/m^3$ vs. 251 $\mu g/m^3$). Finally, Xu Zhaoyi found "up to four times more rhinitis, pharyngitis, and tonsillitis (inflammation of the mucous membrane, pharynx, and tonsils respectively) among children living in areas of heavier outdoor pollution" (Florig, 1997).

While these estimates demand consideration, they should be used with caution. This area of epidimiology has a relatively short history compared with other disciplines. As a result, many of the studies ignore the effects of pollution levels over time and may not adequately control for the presence of covariates that may magnify or diminish the effects of pollution levels on public health. This criticism withstanding, the Working Group on Public Health and Fossil-Fuel Combustion (1997) estimates the number of potential lives that could be saved from particulate matter alone through a 10% reduction from business as usual over the 2000 to 2020 period. Using estimates of the distribution of particulate matter in the United States, the authors project that 1.5 million premature deaths could be avoided in Centrally Planned Asia.2 Since the study assumes an immediate reduction

1 Note that Shenyang has the highest levels of TSP of all major cities. See Chart #.

2 Centrally Planned Asia includes China, Laos, North Korea, and Vietnam.

in the mortality rate after a reduction in PM concentrations, the actual number of premature deaths avoided may be beyond 2020. Additionally, the study does not account for other causes of death which brings into question the actual number of life-years these statistical lives represent. By assuming PM distributions similar to the United States, however, the authors underestimate the number of deaths because of China's higher reliance on coal and residential reliance on coal and biomass stoves.

C. Options for Carbon Dioxide Abatement and Local Air Quality Improvement

The future increases in pollution levels reflect the growth of numerous small pollution sources, including new power plants, household heating sources, and automobiles. China has set a goal of 95% electrification by the year 2000, and to that end, electricity capacity has increased by 200% between 1980 and 1994. Because Chinese generators tend to be small, to run for long life spans, and to have low efficiency levels, significant potential exists both to improve ambient air quality and to generate credits for carbon reductions under an emissions target. Even relatively simple policies like washing and screening coal could both improve air quality and generate more efficient power, reducing levels of carbon emissions (Murray and Rogers, 1998).

Similarly, to reduce congestion on public transportation and to improve commercial service, China has begun encouraging the use of automobiles. Between 1983 and 1990, the automobile stock increased from 1.8 million to 8.2 million and road transportation volume increased at an average annual rate of 13.5% for both passengers and freight while rail volume only increased 7.7% and 5.6% for passengers and freight respectively (Lin and Polensky, 1998). China's emissions standards and automotive technology are similar to those of the west in the 1970's; compared to foreign vehicles, Chinese vehicles emit "2.5 to 7.5 times more hydrocarbons, 2 to 7 time more nitrous oxides, and 6 to 12 times more carbon monoxide" (World Resources Institute 1998). These trends also offer substantial opportunities for simultaneous reductions in local air pollutants and carbon dioxide through stricter emissions standards, improved highway infrastructure, and the use of more recent automotive technology.

Finally, most Chinese residents rely on coal and biomass stoves for cooking and heating. These also constitute the main sources of indoor air pollution. If other energy options develop like natural gas or electricity, then the adoption of gas furnaces or electric appliances would provide an obvious route to reducing pollution levels. Absent these developments, however, options still exist. China's cities, for example, are very dense. This may allow a more centralized control of pollution emissions through large scale heating systems that service multiple housing units (Fang et. al, 1998).

The Chinese government could also pursue programs uniquely tailored to the conditions of various areas such as the very successful Chinese National Improved Stove Program. The stove itself featured an ash box to prevent spent fuel from obstructing the combustion of live fuel and a flue designed to remove pollutants from the cooking area. The stove achieved a 50% efficiency gain over standard models. By targeting distribution and advertising efforts at the county level, the government ensured the acquisition of over 120 million stoves (Fang et. al, 1998). Other options include better insulation and promoting the use of honeycomb briquettes that have a 15% greater efficiency than standard coal briquettes (Fang et. al, 1998).

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