RECONCILING CONTROL OF CARBON AND AIR POLLUTION WITH ECONOMIC GROWTH IN CHINA[1]

——An integrated assessment of the economic, environmental, and health costs and benefits of national emission control policies

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Abstract

The rapid economic growth in China over the past 30 years brings parallel degradation of the environment. Recently, China has adopted stringent environmental targets under the 11th Five Year Plan (FYP) for 2005-2010. In this paper, we develop links between a multi-sector economic CGE model, a detailed emissions inventory, an advanced atmospheric model (GEO-CHEM model), and a environmental health assessment tool (BenMAP model) to assess the costs and benefits of such 11th FYP policy measures, and then compare them with a hypothetical carbon tax. We find that, the 11th FYP SO_2 policy appears to be an effective policy success for SO_2 control over the time horizon of our assessment, leading to very large avoided damages to public health, and doing so at a sizable net benefit to Chinese consumption, investment, and GDP. A modest carbon tax, though achieving less SO_2 reductions, it would substantially reduce carbon emissions, as well as other local air pollution as a broader multi-pollutant control policy than the11th FYP policies. There is a cost to GDP from a carbon tax policy; however, if the revenue is recycled back by reducing existing tax rates rather than the lump-sum transfer, the negative impact on GDP would be relatively smaller.

Keywords: Five Year Plan (FYP), Carbon Tax, CGE Model, GEOS-CHEM, BENMAP

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1. Introduction

Concerns over energy security and domestic air quality have led the Chinese government to reduce the country's overwhelming dependence on fossil fuels and to shift a more energy- and resource-efficient development trajectory. This goal now has added emphasis on carbon intensity given the international pressures from climate negotiations. As is now well known there are policies mandating increased vehicle fuel efficiency, expanding renewable energy supply, and imposing energy standards for buildings and appliances. The 11th Five-Year Plan set explicit targets in energy efficiency and pollutant emissions and has led to a number of ambitious implementing measures, and Chinese government recently also sets a carbon intensity target of 40-45% reduction in 2010 compared to 2005 baseline. Despite the current global economic slowdown, partly due to the strong fiscal stimulus plan in 2009, the growth of the Chinese economy and its resource demands, however, is so swift that it is overwhelming many of these efforts, most notably in emissions of carbon dioxide (CO_2), the leading greenhouse gas (GHG).

How to achieve these goals, while maintaining rapid growth to benefit hundreds of millions of Chinese living at low income levels, is essential for the welfare of China's people, as well as for the rest of the world. The urgency of this task has led to numerous studies and conferences devoted to understanding the relation between China's energy growth, energy use, local pollution and cross-border pollution, and to devise policies that can reduce pollution damages while sustaining a rise in the low living standards. Saikawa et al. (2009), Song and Woo (2008), Aunan et al. (2007) and Ho and Nielsen (2007) are some examples of these studies.

The link between the poor air quality causing severe health damages, energy security and GHG is simple in that they all relate mainly to fossil fuel use, but is complex in that efforts to improve one dimension often worsen the situation along another dimension. For example, reducing SO2 emissions with the use of desulfurization equipment raises energy use and CO2 emissions. Improving energy security by reducing oil imports may mean a greater use of domestic coal which worsens air pollution. These complex linkages are embedded in the bigger national objective of raising living standards for all regions, that is, policies to address the energy and environmental issues should be consistent with the national economic goals. Many analysts have written about various aspects of this complex web, however, given the great difficulty in quantifying these tradeoffs there is no single satisfactory comprehensive analysis.

For the above reasons, our study has two goals here. First, we coordinate a group of researchers over a multi-disciplinary team in economics, atmospheric chemistry, public health and others, to develop methods and tools for analyzing environmental policies that recognizes the main elements of this complex web of interactions in an integrated research framework. The second is to apply this methodology to examine and compare the present policies such as China's 11^{th} Five Year Plan environmental measures, and potential future policies such as carbon tax, and how these SO_2 control and energy policies might affected the environment and economic performance.

There are four main components in our approach: (i) a economic model of China that allows us to discuss inter-industry linkages and economic growth; (ii) an emissions inventory that link the output of the various industries with a large set of emissions that is crucial for determining air quality; (iii) a global atmospheric model that estimates how changes in emissions affect air quality in China on a relatively fine scale; (iv) a benefit analysis module that estimates the health and environmental impacts on the same geographic scale. This methodology certainly cannot address all the questions that are of interest, for example, the economic model is for the national economy and cannot examine how regions are affected and respond differently by policies. It only concerns the co-benefits, but has not yet addresses the climate benefits of reducing GHG emissions, i.e. the benefits of limiting climate change. Nevertheless, we believe the estimates we do make provide critical elements for discussing the types of policies to implement.

1.1 Recent energy use and environmental outcomes

Our projections of the future economic growth and energy use are based on the performance of the last 30 years, a period of remarkable growth and changes in policies. The high rate of GDP growth is well known (officially 9.8% per year during 1978-2007), but the more complicated changes in energy use deserves some discussion here. Figure 1 gives the energy consumption in standard coal equivalents (SCE) for the three main fossil fuels and other sources (mostly hydro and nuclear). This shows that even though the oil share rose to a peak 23% in 2001, it has since fallen, leaving a share for coal at 70% that is close to its share in 1978. This is a remarkable stability given the enormous changes in the economy. The growth rates of GDP energy use, and emissions are given in Table 1.

Figure 2 gives the total primary energy use per unit of GDP (this is a simple sum of the SCEs of the fossil fuels excluding biomass and ignores the big differences in yuan prices of a SCE of these fuels). The energy intensity fell almost continuously at a rate of 5.1% per year, until it bottomed at 0.130 kg SCE/yuan in 2002, and then rose to 0.143 in 2005 before falling again. Many analysts have discussed this rapid decline, including the possible data anomalies around year 2002 (e.g. Sinton and Fridley 2003). It is highly debated about the sources of this decline and rise in intensity. Cao and Ho (2009) survey the relevant literature and highlighted the slightly increasing carbon intensity growth during 2002-05 after continuously decline in energy intensity for two decades since early 80s. This debate will continue but for now we should note the unusual characteristics of the economy during 2002-05. First, the investment share of GDP rose to 43% in 2005 from an average of 37% during 1997-2003 with the boom in Construction. The current account surplus rose sharply, from an average of 2% during 1997-2004 to 11% in 2007 with a corresponding sharp rise in the savings rate. These changes shifted the composition of output from consumption to investment goods, from agriculture and consumer manufacturing to construction, heavy industry and export related manufacturing. This growth of construction and heavy manufacturing (cement, iron & steel, motor vehicles) meant a big growth in energy consumption (Figure 1), and pollution emissions.

Figure 3 gives the official estimates of the emissions of sulfur dioxide and particulate matter. There is a break in the series in 1997 due to the statistical method changes, however, the pattern of SO2 emissions clearly follow the overall coal consumption, falling between 1997 and the early 2000s, rising between 2002 and 2006 before falling again during the 11^{th} Five-year Plan period. Particulate matter emissions fell almost throughout this period, with a sharp fall after 2005. In sum, over the 1997-2007 period when GDP was growing at 9.1% per year, SO2 emissions rose at 0.5% on average, and TSP fell at 7.0% per year. There is no official estimate of emissions nitrogen oxides but Zhang et al. (2007) and Zhang et al. (2009) provide a calculation that is reproduced in Figure 4. This shows that NOx emission has risen much faster than SO_2, at 6.6% per year between 1997 and 2006. The major contributor to NOx is the combustion of liquid fuels in transportation and Figure 4 also reports the consumption of gasoline plus diesel oil for a longer time series for comparison[2]. The growth rate of NOx is similar to the 6.2% growth of oil consumption during 1997-2007 (Table 1).

These emissions have resulted in high levels of pollution measured in the major cities of China. While the level of TSP concentration has fallen substantially since 1990, the average of the major cities is still 282 $\mu g/m^3$ in 2004 (even higher in the northern cities). The SO2 concentration map simulated by our GEOS-Chem model shows the high concentrations are located along the Yangtze River and in the Beijing-Tianjin area. These high levels of air pollution are estimated to cause a high rate of premature mortality and morbidity. There are a number of such studies but this is not our aim here[3]. We are focused on the health impacts of policies – how much would mortality be reduced by a particular policy.

1.2 Previous policy analysis

Before we describe our approach we briefly review other related analysis of environmental policies. Aunan et al. (2007) estimate the effects of China taking on CO_2 targets using a 2-region model of the economy and including the air pollution effects on agriculture and human health. The air pollution levels are estimated using a reduced form linear relation between emissions and concentrations (WHO 1989), and using the CTM photochemical tracer/transport model. The study estimated that a carbon tax that reduce CO2 emissions by up to 17% may have negative costs, i.e. the health and agriculture productivity benefits is higher than the economic costs.

The earlier study by the Harvard-Tsinghua group reported in *Clearing the Air* (Ho and Nielsen 2007) examined the effects of green taxes on fuels using the "intake-fraction" approach which uses the ISCLT air dispersion model and population maps to generate reduced form relations between emissions and exposures. They find that a tax on fossil fuels proportional to the damages caused will reduce health damages by a few times more than the loss of GDP.

The US-China Strategic Economic Dialogue led to a Joint Economic Study of Energy Pollution Abatement Policies in 2007 by the US EPA and China SEPA that focused on the 11th FYP policies for the electric power sector (summarized in JES 2007[4] and Cao, Garbaccio and Ho (2009)). That study used information on the electricity sector from SEPA and the Energy Research Institute, and the CMAQ model to estimate the change in pollution concentrations due to the requirements for flue-gas desulfurization equipment and small-plant shutdown policies. The Harvard China economic model was used to estimate the economy-wide impact. The JES estimate that by 2010 annual SO2 emissions will be reduced by 5.4 million tons and PM2.5 concentration will be reduced by an average of 5% nationally from the FGD policy alone. The benefits to health and environment are valued at 35 billion yuan, or a 5 to 1 benefit-to-cost ratio. The shutdown policy is estimated to not only reduce coal consumption (for the same amount of electricity generated) but also to reduce SO2 emissions by 2.1 million tons annually.

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[2] The oil consumption data is from the China Energy Statistical Yearbook 2008, Tables 4-10 and 4-12.

[3] The recent large studies include World Bank (2007), Ho and Nielsen 2007(Chapter 9) and Hirschberg et al. (2003).

[4] JES. 2007. U.S.–China joint economic study: Economic analyses of energy saving and pollution abatement policies for the electric power sectors of China and the United States (summary for policymakers). Washington, DC, and Beijing: U.S. EPA and SEPA.

2. An integrated framework to analyze environmental policies

The pollution causal chain we use builds on the analytical framework described in detail in *Clearing the Air* edited by Ho and Nielsen (2007). Here we highlight some new elements to improve this framework by applying a comprehensive integrated framework for assessing costs and benefits. The framework is illustrated in Figure 5. There are four major components:

i) A model of the economy that estimate the energy consumption for each of 34 sectors, for each year, tracking how GDP and technologies might evolve.

ii) An emissions inventory covering all the main pollutants, with special detail for the most polluting sectors, estimated at a fairly fine spatial resolution.

iii) An atmospheric chemistry and transport model covering the whole globe with the same detailed resolution over China.

iv) A health risk model that estimates the health impact using population distribution data over the same grid, and estimates the value of such impacts.

We discuss these main elements in turn beginning with the energy use of the 33 economic sectors and residential sector identified.

2.1 Industry output and energy use

The economic model is based on the input-output table for 2005 that gives the inter-industry flow of commodities. In particular it gives the yuan value of each fossil fuel and electricity input. We estimate the quantity of fuel consumed from this value data and the results are given in Table 2.

Of the 33 industries identified, Construction has the highest level of gross output in 2005 at ¥4256 billion, followed by Agriculture with 3936 billion and Metals Smelting with 3143 billion. This reflects the unusual nature of the 2005 economy with the huge investment boom. Of these big 3 industries only Metals Smelting is a substantial direct consumer of energy. The biggest user of coal is Electricity, Steam and Hot Water followed by Metals Smelting and Nonmetal Mineral Products. The biggest users of oil for combustion are Transportation, Chemicals and Metals Smelting (the estimate for combustion excludes a portion estimated for feedstock use, however, no estimate for feedstock use of oil in Chemicals were available). The biggest users of natural gas by far are Electricity, Steam and Hot Water and Chemicals.

The big coal users are the biggest contributors to SO2 emissions, with the Nonmetal Mineral Products (mostly cement) responsible for the majority of process (non-combustion) emissions. By our estimates the Electricity, Steam and Hot Water sector alone was responsible for 16241 kilotons of the total 29439 kilotons of SO2 emissions in 2005 prior to the implementation of the 11th Five-year Plan. Unlike SO2 emissions in 2005, TSP emissions are not simply linked to fossil fuel use, the emission factors depends on the boiler types and control equipment. The MEP estimates that the biggest emitter of TSP is the Nonmetal Mineral Products industry followed by Electricity.

Using this energy data for 2005, Cao and Ho (2009) estimated the carbon content of output for each of these 33 industries. The results are reproduced in Figure 6, ranked in order from the highest carbon intensity to the lowest (in kg. of carbon per yuan of gross output). Electricity is by far the most carbon intensive (0.445 kg/yuan), followed by Gas Utilities (0.193) and Metal Smelting (0.162). For comparison we also calculated the carbon intensity for the U.S. using the 2002 Input-Output table. The US$ values are converted to yuan using a PPP rate of 3.4 yuan/US$ (World Bank 2007). In all but 3 industries the Chinese intensity is higher than the U.S., the most important exception is the Electric Utilities. This may appear surprising given the big role of coal in Chinese power plants, however, the intensities are not in terms of kWh, but in terms of yuan values, the U.S. power is cheap relative to the price of other goods and so more kWh and carbon is embodied per dollar of power.

2.2 Emissions inventory.

The emissions inventory for this integrated assessment analysis cover both detailed point source information, coal-fired power plants, cement plants, and iron and steel smelting plants , and area sources including both mobile and stationary source types in China. The benchmark activity levels in 2005 were mainly obtained from actual statistics data published by a variety of government agencies in China. The current emission inventory covers a wide range of pollutants (x), such as SO_2, NO_X, NMVOC, PM, BC, OC, NH_3 and CO_2. For the policy simulations, such as the 11th FYP case, we assume implementation of official measures to save energy and abate emissions in the power sector, thus the closest to the actual energy and emission path from 2006-2010. It estimates that approximately 59 GW of small, inefficient units were shut down (exceeding the original expectation of 50 GW), and the total installed capacity of coal-fired thermal power reached 651 GW. The application rate of FGD is estimated to have reached 76% (measured by installed capacity). In this case, because it concerns a command-and-control policy in the power sector, analyzing the effect of the policy on activities began with that sector. The economic model was then used to determine how resulting changes in the price of electricity would affect the demand and supply of energy and emission-related activities in all other sectors of the economy, including their interactions with each other.

Emission factors were determined for each of the species, sectors, and fuel types from an array of both published studies and unpublished field measurements. The formula for the emission inventory is given in equation (1). Taking PM as example, $\boldsymbol{ef}_{y,z}$ is the emission factor of PM of size y at year z; $\boldsymbol{EF}_{TSP}$ is the emission-output coefficient, $\boldsymbol{f}_y$ gives the share of PM of certain size y of total PM; $\boldsymbol{C}_{n,z}$ denotes the share of control technologies used of total production in year z, $\eta_{n,y}$ denotes the reduction rate from using end-pipe control technologies. Similar analysis has been conducted to other pollutants as well.

$$\boldsymbol{ef}_{y,z} = \boldsymbol{EF}_{TSP}\, \boldsymbol{f}_y \sum_n \boldsymbol{C}_{n,z}(1-\eta_{n,y}) \tag{1}$$

The spatial resolution of the inventory of emissions (EM_{jxs}) is 0.5°×0.667°, matched to the nested grid of the GEOS-Chem model. This was done using spatial administrative boundaries matched to the categorization of underlying data, the location of large point sources, and social and economic characteristics to guide allocation of results aggregated at provincial level.

Figure 7 shows China's PM and SO_2 Emissions by Sector in 2005. Total primary PM emissions were estimated to be 32.3 Tg in 2005, and mainly come from the cement, domestic residential and other manufacture industries, while PM from the coal-fired power plants only count for 10%. SO_2 emissions in China are quite different; 55% comes from the coal-fired power plants, and 15% from the other manufacture industries. The total SO_2 emissions were estimated to be 29.4 Tg, and NO_X emissions were estimated to total 18.8 Tg in 2005.

2.3 Estimating pollutant concentrations with GEOS-CHEM-CHINA model.

In this study, we apply an updated version of the ensted-grid capability in the global GEOS-Chem model (Wang et al. 2004; 2009) using the newest version of GEOS-assimilated meteorological data (GEOS-5), which allows for higher spatial resolutions over the nested domain, i.e. a better resolution of 0.5° x 0.667° with 15 hybrid eta levels below 2km for the nested domain over East Asia, in particular China (see figure 8). This China domain is nested within the global GEOS-Chem model at resolution 4°×5° (Wang et al. 2009; Chen et al. 2009). In forward mode, GEOS-Chem takes the gridded emissions inventory and assimilated meteorological fields for a given time period, simulating atmospheric chemistry and transport to yield concentrations for a full complement of trace gases and aerosols at each grid cell. It includes interactions of all pollutant gases & aerosols, primary & secondary: 80 chemical species, >120 reactions. With the atmospherical modeling in such a nested framework, we can simulate China's air quality in full regional and global context.

Pollutant estimation of GEOS-Chem China may be stronger than that of other regional models now used in China, for several reasons. These include: (a) built-in inclusion of background and boundary concentrations, essential both to accurate chemistry and policy-relevant source attribution, through nesting in a global model; (b) rigorous validation of simulations against observations of scientific ground stations, aircraft campaigns, and satellites; and (c) we can not only estimate concentrations but to analyze problems and unexpected results with thorough knowledge of the chemical and physical processes behind both observations and the model results. Given our primary focus on health, the pollutants of interest are SO_2, NO_X, VOCs, O_3, and aerosols of many forms. The last can be reasonably classified as PM_{10} or $PM_{2.5}$ on the basis of chemical composition.

2.4 Assessing damages on health and agriculture.

Based on the modeling results of air quality improvement, we estimated the health benefits and the relevant value from better air quality using U.S.EPA's Benefit Mapping and Analysis Program (BenMAP). It is a population risk assessment model takes the change in concentrations estimated by the atmospheric components, and estimates the effect on human health across the country. It provides also an economic valuation of this health risk, in this case *yuan* valuations of reductions in mortality and morbidity due to pollution control. The key elements are: (a) population by age in each grid cell corresponding to the grid of GEOS-Chem China; (b) concentration-response functions for various endpoints and pollutants, e.g. the change in the incidence of chronic bronchitis due to an increase in the concentration of PM_{10} by 1 $\mu g/m^3$; (c) valuation of each health endpoint derived from surveys of "willingness to pay" for health risk reduction; these individual responses are then aggregated to form a national average valuation of, for instance, avoiding a case of chronic bronchitis.

In this integrated study, we build on existing BenMAP model to apply for China. The flow diagram is given in figure 9. We first incorporate of improved concentration-response information based on World Bank and SEPA (2007), Levy and Greco (2007), Aunan and Pan (2004), and HEI (2004). Then we update the population distribution based on post-census estimates. Then we rely on new studies on domestic willingness-to-pay studies to monetize pollution health damages, including those reviewed by World Bank and SEPA (2007) and Hammitt-led studies in the Harvard China

Project (Zhou and Hammitt 2007; Guo and Hammitt 2007; and Guo, Hammitt, and Haab 2007). The dose-response and valuation of health effects based on literature review are summarized in Table 4 and 5. We also include the agricultural damages from ozone pollution in our calculation.

2.5 Assessing economic effects with economic growth model

In this study, we applied a multi-sector CGE model of China's economy and energy use to assess various environmental policies (11^{th} FYP policy measures vs. carbon tax), in particular the policy impacts on the Chinese economy and energy use. Growth is mainly driven by labor force growth, capital accumulation and productivity growth, additional drivers include improvements in the quality of labor and capital. The main agents are the household, producers, government and rest-of-the-world. Household savings and government funded investment are the main sources of investment unlike developed economies where the government role is smaller. The model recognizes that the central Plan still plays some role in setting some prices and quantities.

The household sector maximizes a utility function that has all thirty-three commodities as arguments. The demand for consumption goods is allowed to change over time to represent the "income effect"; the share of total expenditures allocated to income inelastic goods such as food falls as income rises while the share allocated to services rises. The projection of this change is described in the next section. Household income is derived from labor, capital, and land, supplemented by transfers from the government. Labor is supplied inelastically by households and is mobile across sectors.

The model is a "Solow model" where the private savings rate is set exogenously. Total national savings is made up of household savings and retained earnings of enterprises. These savings, plus allocations from the central plan, finance national investment. They also finance the government deficit and the current account surplus. The investment in period *t* increases the stock of capital that is used for production in future periods.

The capital stock is partly owned by households and partly by the government. The plan part of the stock is immobile in any given period, while the market part responds to relative returns. Over time, plan capital is depreciated and the total stock becomes mobile across sectors.

The government imposes taxes on value added, sales, and imports, and also derives revenue from a number of miscellaneous fees. On the expenditure side, it buys commodities, makes transfers to households, pays for plan investment, makes interest payments on the public debt, and provides various subsidies. The government deficit is set exogenously and projected for the duration of the simulation period. This exogenous target is met by making government spending on goods endogenous.

Finally, the rest of the world supplies imports and demands exports. World relative prices are set exogenously as described in section 3.2 below. The current account balance is set exogenously in this one-country model, and an endogenous variable for terms of trade clears this equation. On the production side, 33 industries are identified including 6 for energy. Each of the producers uses capital, labor and intermediate goods to produce output, and a constant returns to scale cost function is used to determine the choice of inputs. The production technology changes over time, there is a term for "neutral" productivity growth and changes in certain parameters represent "biased" growth. Biased technical change refers to changes in input mix that happens over time that are not caused by price changes. Such a change in energy use is often referred to as the AEEI (autonomous energy efficiency improvement).

There are 33 markets for the commodities, that is, there are 33 endogenously determined prices that equate supply with demand for the domestic commodities identified in the model. The total supply consists of domestically produced goods and imported varieties and the endogenous terms-of-trade (e_t) clears the international market. There are 3 markets for the factors of production – land, capital and labor – and 3 prices to clear them. Finally, the government budget constraint is met by the endogenous level of government purchases. The model is a standard constant returns-to-scale model and is homogenous in prices, that is, doubling all prices leaves the economy unchanged. We are free to choose a price normalization.

The base case simulation is determined by the exogenous variables projected as explained in the previous section, and the initial stocks of debt, capital and labor force. The main aim of the model is to study the impact of policies, that is, to estimate the percentage change in variables of interest between a counterfactual simulation and the base case. The base case itself is not the primary interest and most of these percentage changes are affected in only a minor fashion by the levels in the base case. Here we document the main outcomes of the base case projection for completeness and for those who may have an independent interest in it. Given the initial stock of capital and labor force, we solve for the 3 factor prices and the 33 commodity prices that clear the markets in the first period. This gives us all the quantities for the first period, including investment which augments the stock of capital for use in the next period. The solution process is repeated for each period in the simulation horizon.

In a base case we project that GDP will grow at an annual rate of 7.6% over 2005-2030. During these 25 years, total primary energy use is projected to rise only 3.7% per year, with coal use growing slowly at 3.4% per year, oil use at 3.9%, but natural gas use at a rapid 7.2%. These projections are similar to the International Energy Agency forecasts in the *World Energy Outlook 2008*. Due to the change in energy mix, the CO_2 emissions from fossil fuels are projected to grow slightly slower than energy use. Over 1990-2006, the carbon intensity in China fell from 179 tons of carbon per million *yuan* of GDP (constant 2000 *yuan*) to 95 tons, declining at 4.0% per year. The above projection gives a similar rate of decline in intensity. The carbon intensities per *yuan* of output for individual sectors in China are very high compared to the U.S., indicating prospects for improved carbon efficiency in China's future.

3. Assessing the 11th Five-year Plan energy and SO2 policies

3.1 Environmental Targets and Policies under China's 11th Five-Year Plan

The 11th Five Year Plan, covering the years 2006-2010, grew out of a broad consultative process that included some of the most highly regarded economists in China (Naughton 2005), and specify both "compulsory" (strong target) and "expected" (weak target) targets[5]. This plan includes two compulsory targets directly affecting the atmospheric environment. One requires that national sulfur dioxide (SO_2) emissions in 2010 be 10% lower than 2005 levels. The second mandates that energy consumption per unit GDP in 2010 be 20% lower than the value in 2005. Achieving these compulsory environmental targets at low cost is important not just for the success of the current FYP but also useful to compare with potential market-based instruments, such as carbon tax. Such a policy assessment study may shed some light on the 12th Five Year

[5] Even the Chinese terminology for the plan has changed. Although both *guihua* and *jihua* can be translated as "plan" in English, *guihua*, the Chinese term now used, connotes a more flexible guidance document than the more rigid *jihua* used for previous Five-Year Plans.

Plan target setting and policy designs. However, cost-and-benefit assessment of policies is a difficult analytical task given the complex relations between economic activity, emissions, air quality, and public health. The main aim of our research project is to conduct the most complete accounting possible of costs and benefits of key emission control policies, advancing a range of research capacities in an interdisciplinary research framework. In this section we provide a more detailed description of the methodologies we used to analyze these 11th FYP policies described in detail as follows.

Small Unit Shutdown Policy

At the end of 2005, almost one third of China's thermal power generation capacity was provided by small scale power generation units, where small scale is defined as a unit with capacity of less than 100 MW.[6] Most of these small scale units are coal-fired, but some are oil and diesel units serving localities which had in the past experienced severe electricity shortages. These small units are generally inefficient in their use of energy and also highly polluting. The average total cost per kilowatt hour for small plants is almost three times the cost for large plants. This is due mostly to smaller plants' higher fuel requirements per kilowatt hour of electricity, with diesel-fired plants being particularly inefficient. As noted above, as part of the 11th Five-Year Plan's emphasis on energy efficiency and pollution control, 50 GW of small scale power plant capacity has been targeted for closure by the end of the plan period (2010). Implementing this shutdown policy requires that replacement capacity be built. However, since this policy is being implemented gradually over five years, the individual units shut down are proportionately small and widely spread geographically, and electricity connected to the grid is fungible, the actual cost of this replacement capacity can be assumed to be an average for all new capacity installed over the plan period. Thus the direct cost of the shutdown policy would be equal to the cost of producing the replacement electricity, less the operating and maintenance costs that would have been incurred by operating the small units plus decommissioning costs.[7] The decommissioning costs could include the shutdown of the small plants themselves and perhaps the retraining and relocating of displaced workers. The value of any scrap materials and the land the plant was located on should be accounted for as negative costs (Cao, Garbaccio, and Ho, 2009).

FGD Installation Policy

At the end of 2005, FGD equipment had been installed on 46.2 GW of coal-fired electricity generation capacity – 12 % of the total. In order to meet the SO_2 reduction target of the 11th Five-Year Plan, an additional 167 GW of FGD equipment is scheduled to be installed on existing power generation units by 2010.[8] Moreover, all new power generation units constructed during the 11th Five-Year Plan – estimated in the JES (2007) at 250 GW of capacity – are mandated to have FGD equipment. According to the 11th FYP target, it is expected that in 2010 the FGD would be installed on almost 85% of total coal-fired capacity.

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[6] The NDRC's Energy Research Institute estimates that in 2006 there was about 115 GW of capacity provided by coal and oil fired units under 100 MW, out of a total of 391 GW of thermal-fired capacity.

[7] The location of the replacement plants may also mean higher transmission costs.

[8] This 167 GW of FGD includes 39 GW carried over from the previous Five-Year Plan and 128 GW of installation newly mandated.

The costs of the FGD installation policy can be divided into two types: direct and economy-wide. The direct costs[9] of the FGD policy include the capital costs of the FGD equipment and operation and maintenance costs, which include additional electricity for the operation of the equipment and thus an increase in fuel inputs. Capital costs for FGD units manufactured in China have fallen by more than half since the 1990s, these costs now range from 150 *yuan*/kW for a 600 MW plant to 180 *yuan*/kW for a 100 MW plant, and the addition of FGD equipment represents about a 3.8% increase in capital costs. The unit operating cost of the FGD equipment (per ton of SO_2 removed) depends on the size of the plant and sulfur content of the coal used, and ranges from 1,244 *yuan*/ton of SO_2 for a 100 MW plant to 800 *yuan*/ton for a 1000 MW plant (for coal with a sulfur content of 1%). Low sulfur coal raises the cost per ton removed, from 1,020 *yuan*/ton for 1% sulfur coal to 1,840 *yuan*/ton for 0.5% sulfur coal. The Chinese Academy for Environmental Planning (CAEP 2007) reports that coal with a sulfur content of less than 0.5% makes up 30 percent of coal combusted in the power sector, with coal having a sulfur content of 0.5-1% making up another 35 percent. Averaging over plant sizes and coal types, CAEP estimates that running FGD equipment raises operating costs by 2.4 percent. In terms of the price of delivered electricity, which includes transmission costs, the additional cost of running FGD equipment is only 1.5 percent (Cao, Garbaccio, and Ho, 2009).

3.2 Simulation Results

In order to analyze the impacts of the small unit shutdown and FDG policies on the rest of the economy, we first establish a base case, or "business-as-usual" (BAU) scenario. The BAU scenario includes previous environmental policies, but not the SO_2 policies in the 11th Five-Year Plan. It is assumed that the FGD units already installed in 2005 continue to operate, but that no additional FGD equipment is installed. The base case scenario projection is presented in Section 2.1. We then perform simulations of the shutdown and FGD policies using the cost estimates described in the previous section.

Impacts of the Small Unit Shutdown Policy

Because the small unit shutdown policy is a non-market intervention made by the central government, simulation of the policy in a CGE model requires some departure from a more standard analysis. Also, while the power sector comprises a single sector in the input-output table and in our model, the power generation sector in China is in reality composed of many different types of technology, including small (higher cost) thermal-fired plants, larger (lower cost) thermal-fired plants, hydro, and nuclear power. Some of this market segmentation is the result of implicit and explicit government subsidies. Thus we represent the power sector differently from other sectors in the model. More specifically, instead of having demand for capital in the power sector determined endogenously, based on the market price of capital, we set the capital stock exogenously and derive an endogenous sectoral rate of return that differs from the economywide rate of return.

According to the plan for SO_2 control, approximately 50 GW of new power generation capacity will be installed per year from 2006 to 2010 while approximately 10 GW of small thermal power units will be shut down each year. In the simulation, we represent the reduction

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[9] The economywide impacts of both the FGD and shutdown policies are estimated in the next section.

in inputs of coal and oil (per kWh of electricity) resulting from this change in the generation technology mix by reducing the energy intensity parameter and shifting the power sector cost function down. Table 6 gives the average total cost for small plants is 0.704 *yuan* per kWh compared to 0.286 *yuan* per kWh for large and median plants, which are cited from the ERI electricity survey , the changes in energy cost shares and unit cost are modest, with the energy cost share falling to 33.2 percent in 2010, compared to 33.8 percent in the base case, and the unit cost falling by 8.8 percent in 2010 (see Table 7).

The higher-cost small generation units exist in part because of implicit and explicit subsidies from the government. In our simulation, we represent the reduction in coal and oil input costs resulting from the shutdown policy as a reduction in subsidies, but we leave the price of electricity unchanged. We then hold all other government expenditure at the same level as in the base case. The reduction in total government expenditure due to the reduction in subsidies is recycled back by proportionally reducing all other taxes in the economy system. In accordance with our assumptions, the price and demand for electricity are essentially unchanged following the shutdown of the small units (see Table 8). The fact that the shutdown policy results in the production of a kWh of electricity with fewer inputs is equivalent to a small positive productivity shock to the economy. Aggregate GDP rises slightly in each year, which in turn results in higher investment. By the end of the Five-Year Plan period in 2010, the combined change in productivity and the larger capital stock results in an increase in GDP of 0.77 percent from the baseline. Household consumption rises by 0.51 percent and total investment by 1.12 percent (see Table 8). As discussed above, government expenditure is assumed to be held constant. Since the effect of the tax reduction is larger for enterprises than for households, the percentage rise in investment is greater than the rise in consumption. This shifts the overall composition of output slightly, with, for example, higher growth in the construction and cement industries than in the service sector.

The reduction in the amount of coal and diesel fuel required to generate an average kWh of electricity results in a decline in total coal and oil consumption, with coal use declining by 5.35 percent and oil use declining by 0.53 percent in 2010 (see Table 8). Part of the reduction in oil use by the electricity sector is offset by a small increase in consumption in other sectors, such as transportation. With the reduction in coal and oil use due to the small unit shutdown, SO_2 emissions fall by 7.6 percent. In the same year, emissions of particulate matter fall by 4.0 percent. Changes in emissions differ from changes in fuel demand because emissions factors differ by industry and because of shifts in the structure of output.

Impacts of the FGD Installation Policy

In 2006, 16.7 percent of total electricity output (by kWh) was produced by generation units equipped with FGD (see Table 9). In keeping with the projected level of capacity and our estimate of total output, the amount of electricity produced by units with FGD installed and operating should increase to 61.9 percent in 2010. Because, as discussed above, operating an FGD unit raises the delivered electricity cost by 1.5 percent, the average cost of all electricity generated rises by approximately 0.25 percent (16.7% x 1.5%) in 2006 and 0.91 percent (61.9% x 1.5%) in 2010 (see Table 9). We represent this as an upward shift of the cost function, which is equivalent to a negative productivity shock. That is, the installation and operation of the FGD equipment increases the inputs (capital, labor, and energy) required to generate the same amount of electricity.

When this small increase in costs is simulated in the CGE model, the net effect – including general equilibrium adjustments – is to raise electricity prices, by 0.27 percent in 2006, rising to 1.26 percent in 2010. Given our unit elasticity assumption, this reduces overall electricity use by approximately the same (absolute) percentage as the rise in price. The higher cost of electricity leads to a small decline in the output of energy intensive industries such as chemicals, non-metal mineral products, and primary metals. The use of FGD also increases the amount of coal required to generate a kWh of deliverable electricity. However, this is offset by the reduction in the demand for electricity and the reduction in the demand for coal by energy intensive industries, which leads to a small net decline (0.17 percent) in coal consumption in 2010.

This small negative productivity shock results in a slight decline in GDP, with corresponding reductions in the consumption and investment components of GDP (see Table 8). The lower amount of investment in each period results in a smaller capital stock in the subsequent periods. By the end of the Five-Year Plan period, the smaller capital stock and lower productivity results in GDP being about 0.11 percent below the baseline. There is also a slight change in the composition of output with, as noted above, the electricity intensive sectors declining the most. Output of less electricity intensive industries such as agriculture and services fall by a smaller amount.

Because it is not electricity intensive, transportation is only slightly affected by the FGD policy. The net effect of reductions in manufacturing and transportation is a 0.08 percent decline in oil consumption in 2010. The effect of the FGD policy on natural gas consumption is small, as most natural gas use is in industry, such as chemical manufacturing. As targeted in the Five-Year Plan, the installation and operation of FGD equipment in the power sector results in an economywide decline in SO_2 emissions of more than 20 percent by the end of the Plan period. In addition to the abatement carried out through the FGD equipment, part of the reduction in emissions comes about because of an overall reduction in electricity output. Particulate and NO_x emissions fall slightly, in line with the small declines in manufacturing output and transportation.

Combined Impacts of the FGD and Shutdown policies

Our final simulation combines the small unit shutdown and FGD installation policies. It is thus our best estimate of the overall impacts of the 11th Five-Year Plan's SO_2 reduction policies – if they are fully implemented. As shown in Table 8, the impacts are essentially additive. In our simulation, GDP in 2010, the last year of the plan, is 0.66 percent above the baseline. This is due primarily to the productivity improvement and increase in capital stock resulting from the small unit shutdown, which offsets the slight decline in GDP resulting from the installation of the FGD equipment.

The combined effect of the policies on SO_2 is a reduction of emissions in 2010 of 28.4% from the baseline, which would achieve the Five-Year Plan target. The small net increase in transportation results in an increase in NO_x emissions of 0.38 percent. These results demonstrate some of the value of analyzing policy in an economywide framework, as the net environmental effects of a policy differ from the estimated effects on individual sectors. Given concerns about China's contribution to greenhouse gas emissions, we also calculated the effect of the two policies on CO_2 emissions, which are estimated to fall by 4.5 percent (see Table 8). We should note that our model does not currently incorporate endogenous feedback of damages to human health and ecosystems from exposure to pollution. If we included the effects of pollution on labor productivity and agricultural output, the two Five-Year Plan policies might have further positive effects on the economy.

4 How Carbon Taxes affect local pollution and economic growth

In this study, we also consider an alternative carbon tax policy, which is likely to be implemented by the Ministry of Finance in recent years, though it may take quite different form such as increasing current gasoline tax, reform on the resource tax or put as general environmental tax reform. Considering the 12th Five Year Plan China is likely to impose further environmental constraints on air pollutions, we believe the time table for carbon tax is tickling now.

4.1 Modeling Strategy

We model carbon tax as a direct unit tax on energy use, and tax base is the carbon contents of the fossil fuel use. More specifically, the unit carbon tax rate (US dollar per unit of fuel) is calculated by multiplying the exogenous carbon tax rate tx^u (expressed in US dollar per ton of carbon content), with the carbon content (XU_i) per unit of fuel *i*. The unit carbon tax is calculated as:

$$tc_i^u = tx^u XU_i \quad (i = \text{coal, oil, gas}) \tag{2}$$

The carbon tax rate per ton of carbon content tx^u is exogenously set in the model. Carbon prices in the European Trading Scheme were about $25-30 per ton of CO2 in 2007, or 210 *yuan*/ton. The U.S. EPA analysis of the Waxman-Markey bill projects an initial carbon price of $13-17/ton. As the price of coal in China is much lower than the world price, we start with a tax of 100 *yuan*/ton C, about 27 *yuan*/ton CO2. With a mine mouth price of coal in 2005 of 360 *yuan*/ton, this is a substantial tax of about 14% on the price of China's primary energy source.

The policy simulation consists of imposing a 100 *yuan*/ton C tax on use of coal, oil and gas, including imported fuels. This tax is imposed every year from 2006 to 2010. How the tax revenue is used affects the impact of the policy, as emphasized by many other analysts. Our first scenario recycles the revenue in lump sums back to households to maintain the base case level of government spending. A second scenario uses the revenue to cut existing distortionary taxes, an approach often shown to be better for economic growth. For the recycling regime in terms of reducing pre-existing distorted taxes, for simplicity we assume that all the tax cuts are at the same fraction ξ_t compared to their benchmark rate, therefore the counterfactual tax rates are given by:

$$t_t^k = \xi_t t_{t0}^k, \quad t_t^{VAT} = \xi_t t_{t0}^{VAT}, \quad t_t^S = \xi_t t_{t0}^S, etc. \tag{3}$$

where t_t^k is the capital income tax, t_t^{VAT} is the value-added tax, and t_t^S is the sales tax. The fraction coefficient ξ_t is endogenously determined by setting the government expenditure fixed to the base case government expenditure. Another alternative is to give the tax revenue back to the households – lump-sum transfer.

In both revenue recycling regimes, the constrained revenue neutrality condition is expressed as:

$$GG(t) = GG_{base}(t) \quad (4)$$

where *GG(t)* is the quantity index of government purchases. In later sections, the fuel tax simulation and output simulation also adopt the same revenue neutrality condition.

4.2 Carbon Tax Results and Comparison with 11th FYP Policies

Table 11 presents a comparison between the 11th Five Year Plan policy impacts and carbon tax with revenue recycling through household lump-sum transfer or through reducing pre-existing distorted taxes.

The carbon tax raises the price of coal by 14% and the price of oil by 2% in the first year. This reduces the demand for these fuels proportionately. It raises the costs of producing carbon-intensive products such as primary metals, cement, and transportation services, and thus reduces their output. These products are also the biggest emitters of PM, SO2 and NOX, and these emissions are thus sharply reduced. There is also a second effect that is due to the changes over time: investment goods (e.g., buildings, machinery) are more carbon-intensive, so their price rises relative to the price of consumption goods. This reduces investment in each period, leading to a 0.1% smaller stock of capital by 2010. The revenue from this new tax comes to 3.1% of total government revenue. It is transferred back to households as lump sums in the first scenario, raising consumption at the expense of investment, or reducing pre-existing distorted taxes, thus stimulate investments and have smaller impacts on GDP.

The smaller stock of capital and the distortions due to the carbon tax lead to a 0.19% fall in 2010 GDP. Coal use in 2010 is 14.6% lower due to the lower GDP and the price-induced lower demand. CO2 emissions fall by 12.2%, less than the fall in coal use due to the switch to other fuels. Electricity use falls by 4.1% due to the higher price of electricity and the reduced demand from lower output of carbon-intensive products. The output of the refining sector falls by 2.0%.

The lower use of fossil fuels, and lower output of highly polluting sectors, reduces national emissions of PM10 by 11%, of SO2 by 14%, and of NOx by 11%, compared to the base case (also see figure 10). We then use our GEOS-Chem model to estimate the reduction in concentrations of the various pollutants: for PM2.5, the reduction in some areas is more than 7.7 μg/m3, and for ozone the peak reduction is 1.1 ppb (Figure 11-12 as sample results for SO_2 and Ozone). Then we match our concentration map with the population map (figure 13 and 14). As table 13 shows, we estimate that this will reduce the number of cases of acute mortality (premature deaths) due to PM by 18,400 a year, reduce hospital admissions for cardiovascular reasons by 32,200, and reduce outpatient visits by 7.1 million. The reduction in ozone concentrations reduces acute mortality by an additional 1700 cases. Acute mortality is estimated by studies of population exposures over days and weeks, while chronic mortality is estimated by studying a cohort of people over years. The chronic effect is believed to be much higher than the acute effect, but estimating it for China is more speculative as no Chinese cohort studies have been completed. If we use chronic effect estimates imported from western literature—which some epidemiologists warn against—the carbon tax would have reduced PM premature mortality by 110,000 deaths per year by 2010.

We also translate these health effects into economic terms using best-available valuation estimates. The acute mortality figures imply a reduction in total health damages of 13.8 billion *yuan* in 2010 (in 2005 *yuan*) as a side-benefit of the tax; this is mapped spatially in Figure 15. The more uncertain chronic mortality effect yields a monetized health benefit of 59.8 billion *yuan*, or 0.18% of GDP in 2010 (see table 13).

If the revenues from the carbon tax are used to cut existing taxes instead, reducing the distortions in capital allocation, then the cost to GDP is much lower. In our second simulation, the reduced taxes on enterprise income allow a greater rate of retained earnings and investment. The cumulative effect of the higher investment, and lower consumption, leads to a higher GDP by 2013 and a smaller reduction in emissions. This simulation is not to argue that enterprises should benefit at the expense of consumption by households, but to spotlight that choices on use of revenues matter. This recycling regime is economically beneficial, but is generally more difficult politically.

The comparison of the carbon tax and SO_2 policy is given in figure 15 and table 14. The SO_2 policy is clearly a major policy success if not counting for temporary adjustment costs on laidoff workers by plant shutdowns, it will reduce premature mortality by around 12,400 cases in 2010 (or as many as 73,900 cases under alternative assumptions). The FGD component of the policy helps produce this health benefit, at a small positive cost to the economy. Effects of the small-plant shutdowns, however, lead to sizable net economic benefits (negative costs) for the policy as a whole, on GDP, investment, and consumption. The plant shutdowns also reduce coal use, leading to a small net reduction in CO_2 emissions overall vs. the base case. Under the 2-part policy, PM_{10} and NO_X emissions decrease slightly, and changes in ozone concentrations are mixed.

Regarding a hypothetical 100 yuan/ton carbon tax implemented during the same years as the SO_2 policy, 2006-2010, and beyond. It would have reduced emissions of all pollutants analyzed—CO_2, PM_{10}, SO_2 and NO_X—in 2010 by large amounts compared to business-as-usual. It would have reduced net concentrations of $PM_{2.5}$ substantially, and ozone somewhat. Along with the large intended benefit in carbon control, avoided premature deaths from reduced air pollution would have totaled 18,600 cases in 2010 (or as many as 103,000 cases under other assumptions). Our simulations suggest compared to the SO_2 policy, carbon tax is a broader base multi-pollutant control instrument, can can be a highly effective forms of emission control.

In sum, the 11th FYP SO_2 policy demonstrates the effectiveness of well-targeted technology mandates for pollution control in major industries. This is encouraging for the prospect of effective NO_X-control technology mandates in the 12th FYP, although matching the scale of the health and economic benefits of the 11th FYP SO_2 control policy may be more difficult. The use of tax mechanisms may not only be a cost-effective way to lower the carbon intensity of the Chinese economy over time, but a potent multi-pollutant strategy. It could integrate China's primary objectives in domestic air quality (regarding $PM_{2.5}$, ozone, and potentially acid rain) with those to protect global climate.

5. Conclusion

The rapid economic growth in China over the past 30 years brings parallel degradation of the environment. In recent years, China has adopted stringent environmental targets under the 11th Five Year Plan (FYP), such as the 10% reduction for SO_2 target (focusing on power sector), and 10% energy intensity reduction target for 2010, both are compared to the 2005 level. Meanwhile Ministry of Finance, National Development and Reform Commission of China and other agencies are studying how to initiate an environmental tax to curb the environmental degradation and cut carbon intensity, especially after the national government announced to adopt a new carbon intensity target, that is to reduce carbon intensity by 40-45% by 2020, also compared to 2005 level.

In this paper, we develop links between a multi-sector economic CGE model, a detailed emissions inventory, an advanced atmospheric model (GEO-CHEM model), and health assessment tools (BenMap model) to assess the cost and benefit of current adopted policy measures to meet the 11^{th} FYP targets, and compare them with a hypothetical carbon tax. For both types of policies the benefits include reduced emissions of CO_2 and avoided health damages from reduced local pollutants [SO_2, particulate matter (PM), nitrogen oxides (NO_X), and ozone]. In our cost and benefit calculation, the costs include both direct costs such as installation and operation costs of FGD equipments, but include the indirect economy-wide effects of higher electricity prices affecting the rest of the economy.

Our study finds that, the 11^{th} FYP measures and carbon tax policy have substantial differences but, depending on policy objectives, each has each own merit. The 11^{th} FYP SO_2 policy appears to be an impressive policy success over the time horizon of our assessment: achieving its primary objective of SO_2 control, leading to very large avoided damages to public health, and doing so at a sizable net benefit to Chinese consumption, investment, and GDP. Our analysis suggest that FGD policy would in general cause a loss in the economy; however it is mostly offsetted by the environmental benefits. The shutdown policy would have very large impact since it phases out many inefficient small-size powerplants, and this is due primarily to the productivity improvement and increase in capital stock resulting from replacing small units with big efficient power plants. Overall, the combined 11^{th} FYP policy would increase GDP by 0.66 percent above the baseline.

A modest carbon tax, mainly by inducing energy conservation, would not only reduce CO_2 emissions substantially, but also by local air pollution by an amount greater than that estimated for the 11FYP policies. There is a cost to GDP from a carbon tax policy, especially in the initial years after launching the reform. However, if the revenue is recycled back by reducing existing tax rates rather than the lump-sum transfer, the negative impact on GDP would have been smaller. However, the environmental benefits under the lump-sum transfer regime are slightly larger.

In sum, a modest carbon tax, mainly by inducing energy conservation, would reduce emissions of CO2 by as much as 12% vs. business-as-usual, and also reduce China's local air pollution. The reduction in health damages alone—ignoring additional benefits, notably to agricultural productivity—may be worth as much as 0.2% of GDP. The costs of the tax to the economy are not large or even zero, depending on how the revenues are used. In any case they appear much smaller than the health benefits.

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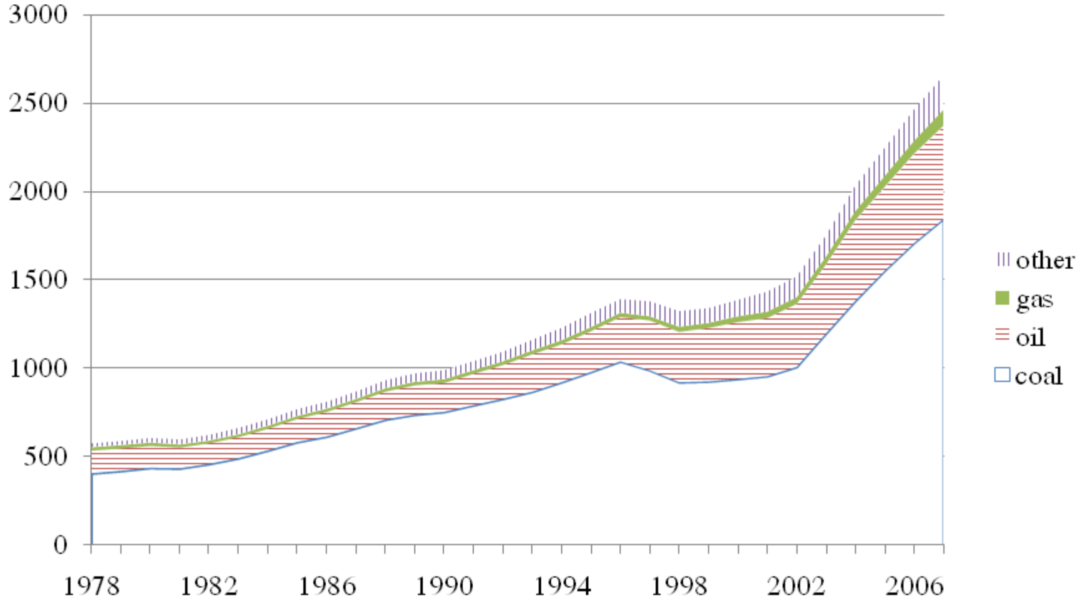
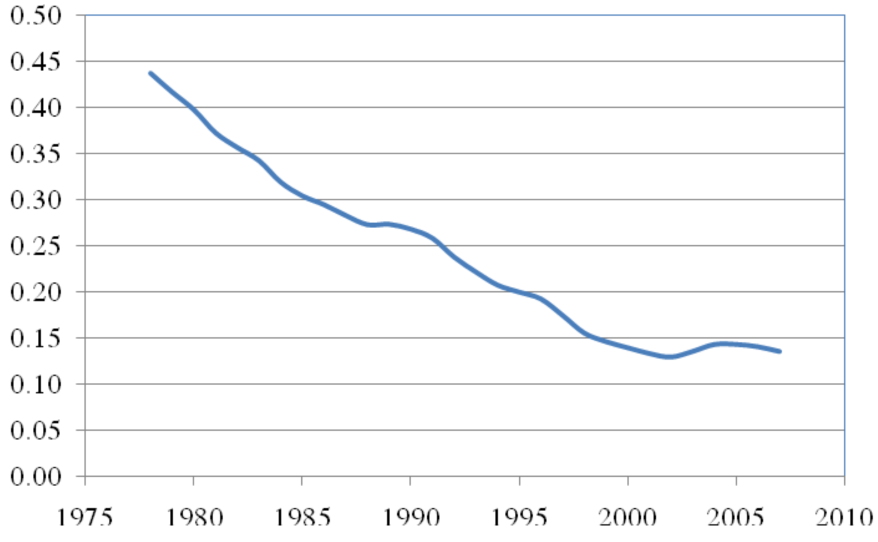
Fig



SCE=standard coal equivalent. Source: China Statistical Yearbook (2008).

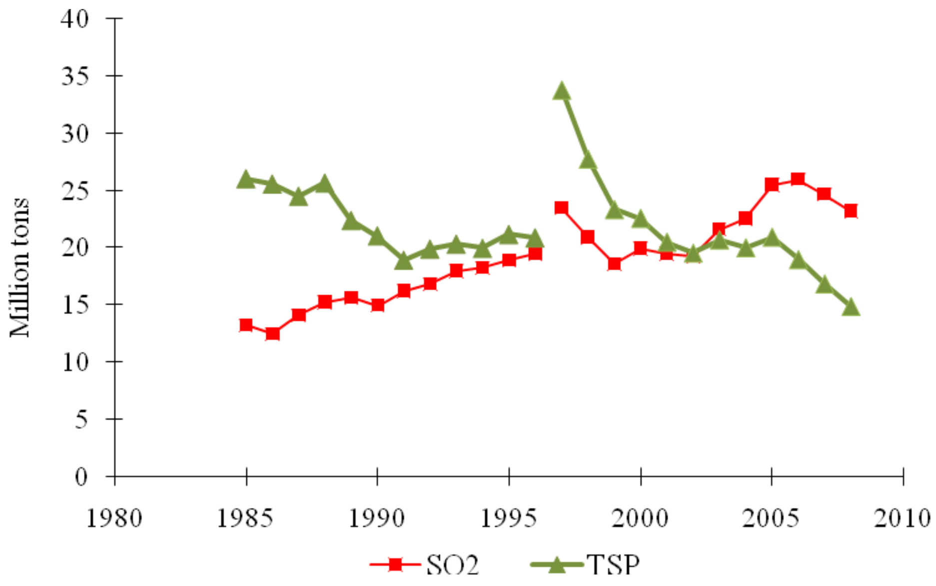
ption in China (mil. ton SCE)

Figure 2. Energy Consumption per unit GDP (kg SCE/yuan 2000)



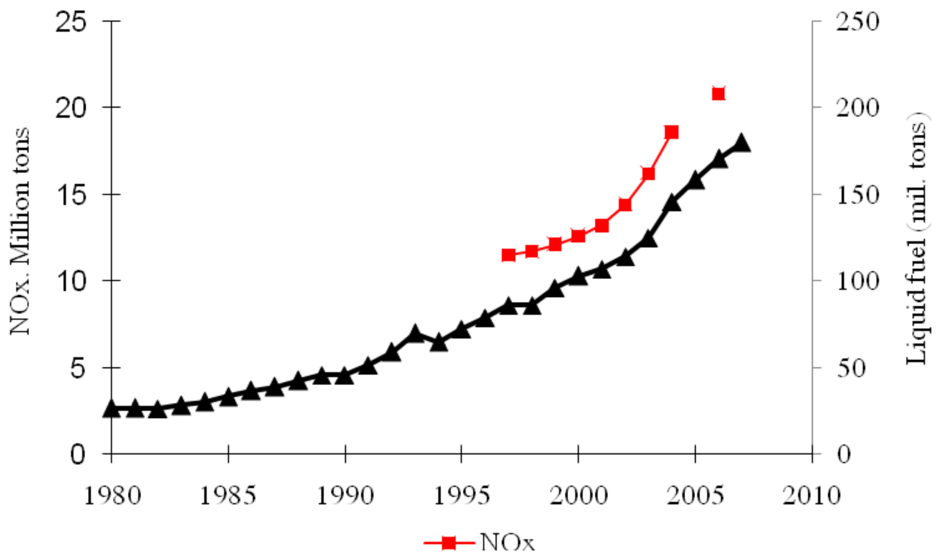
Source: Chinese Statistical Yearbook and China Energy Databook v7.

Figure 3. SO_2 and TSP Emissions (official China MEP estimates)



Note: TSP includes combustion and process emissions. These are estimates from the Minsitry of Environmental Protection.

Figure 4. NOx Emissions in China



Note: Emission estimates from Zhang et al. (2009). “Liquid fuel” is the sum of gasoline and diesel consumption.

Figure 5. Framework to Analyze Costs and Benefits of Alternative Emission Control Policies

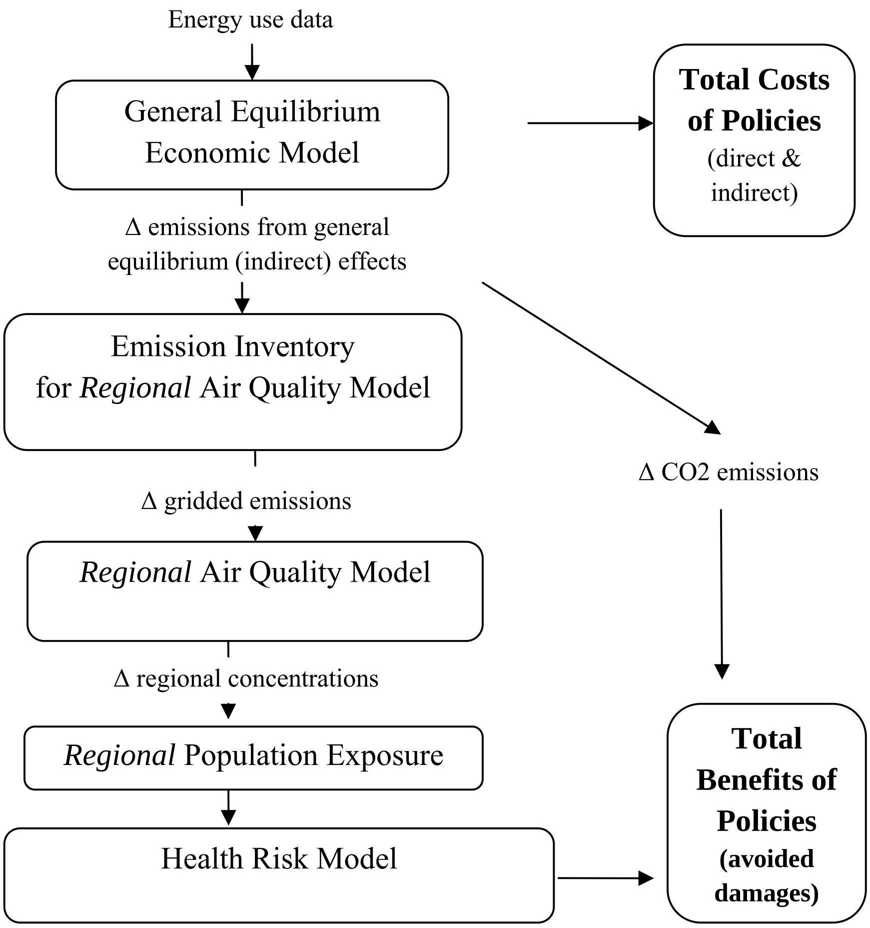


Figure 6. Carbon Intensity (China vs US; kg carbon per ppp yuan of output)

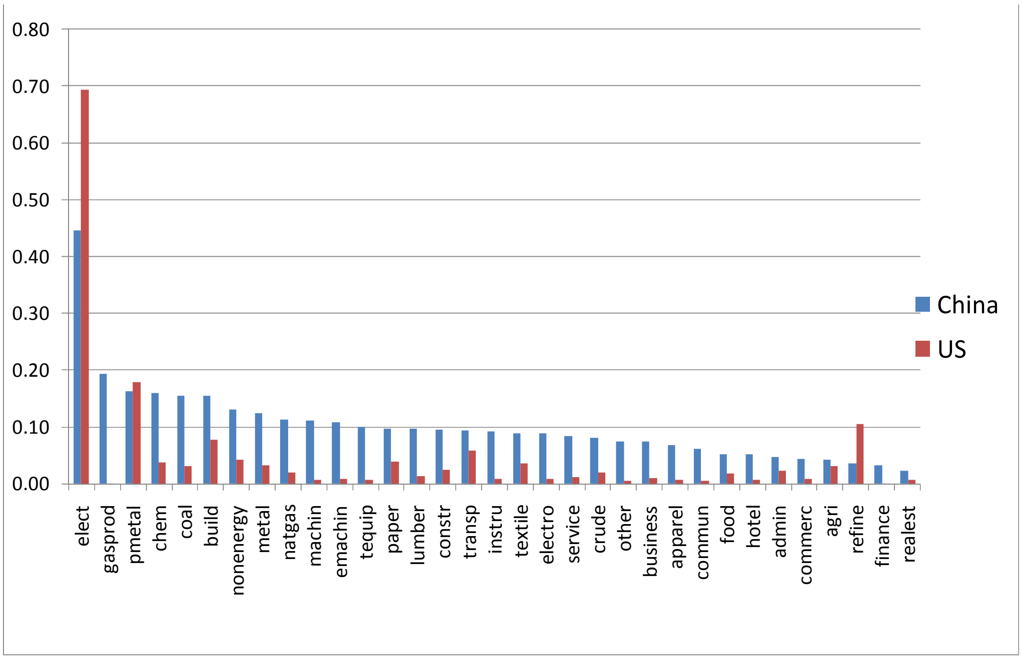


Figure 7. Emission Inventory in China

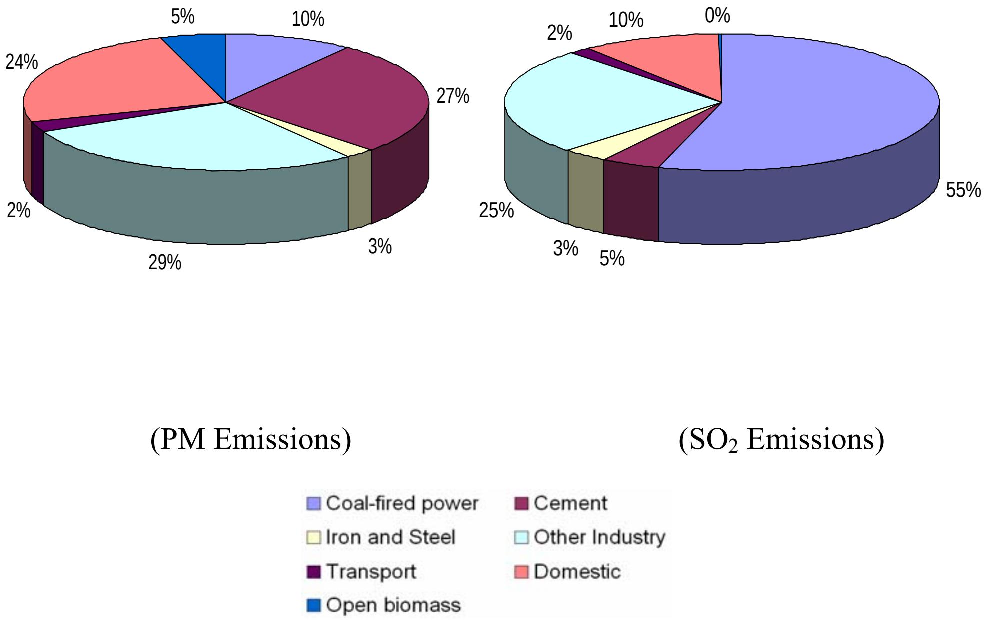


Figure 8. China's Atmosphere: Nested Window over China in GEOS-Chem

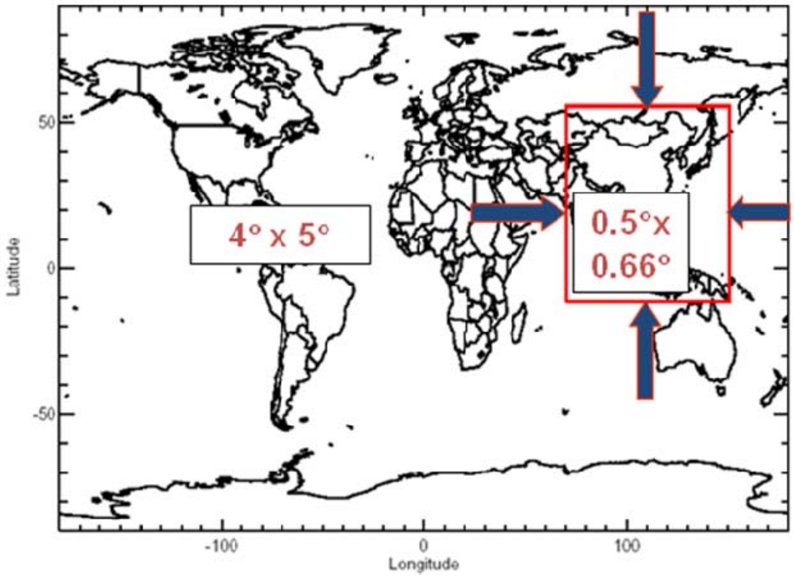


Figure 9.BENMAP Flow Diagram

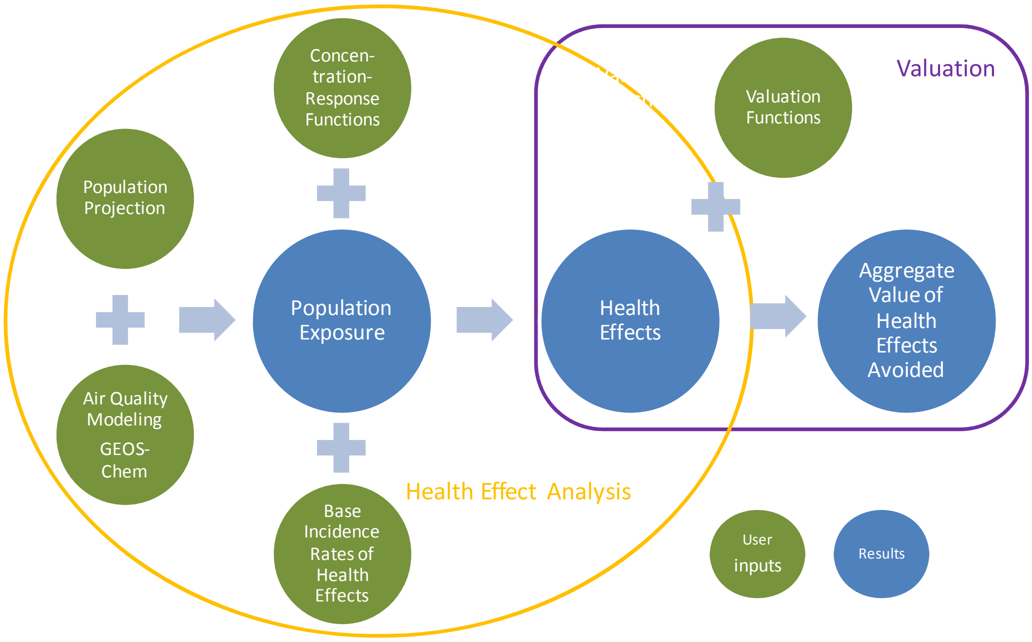


Figure 10. Effects of Polices on Emissions, 2005-2010

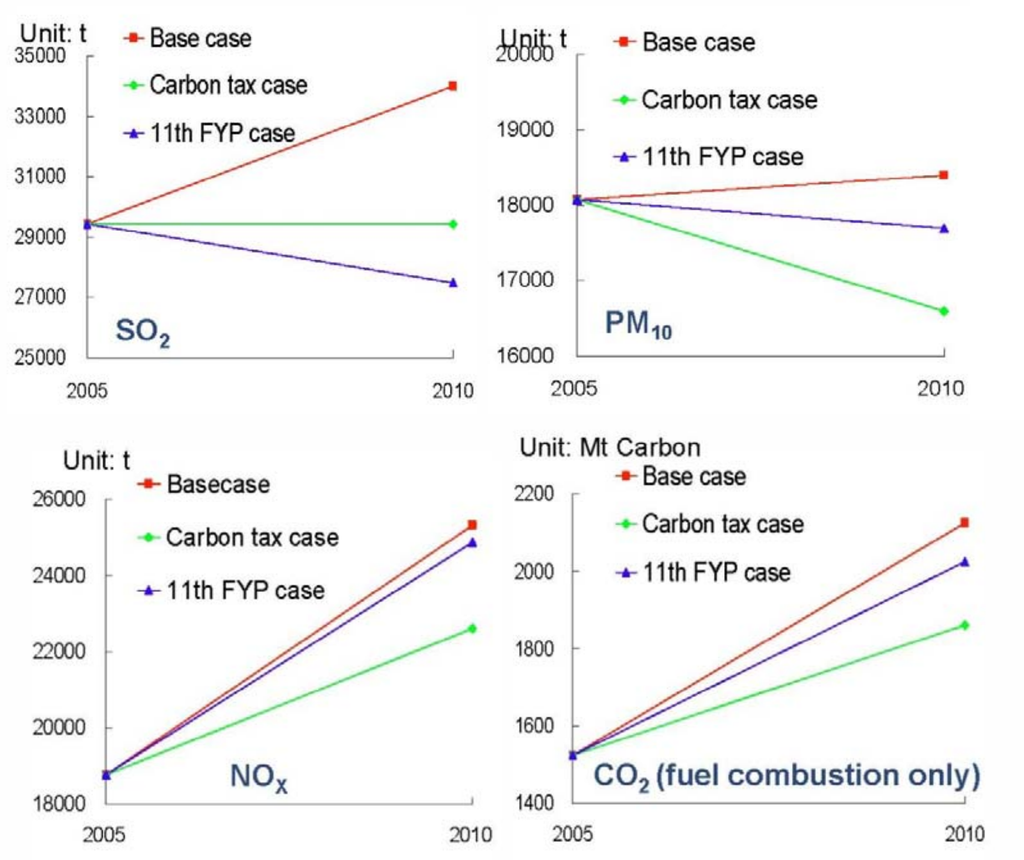
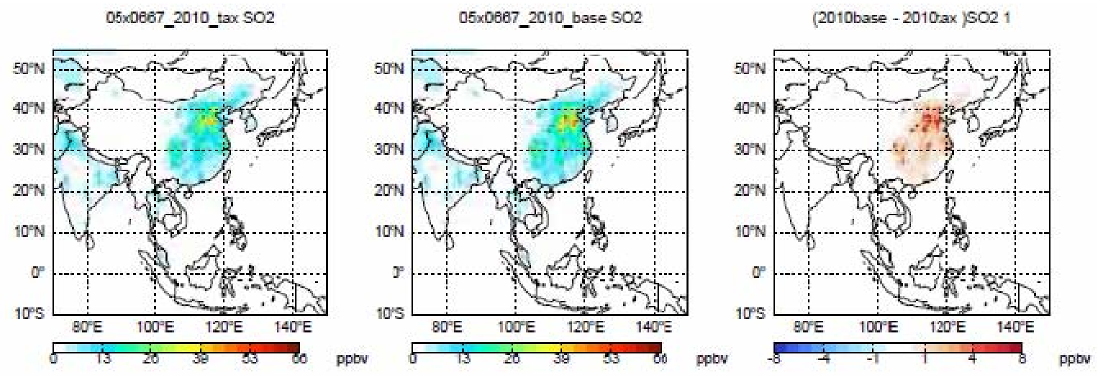


Figure 11. Effects on Atmospheric Concentration (SO_2, 2010)



2010 SO_2,
carbon tax case

2010 SO_2,
base case

2010 SO_2 benefit
base case – carbon tax case

Figure 12. Effects on Atmospheric Concentration (Ozone, 2010)

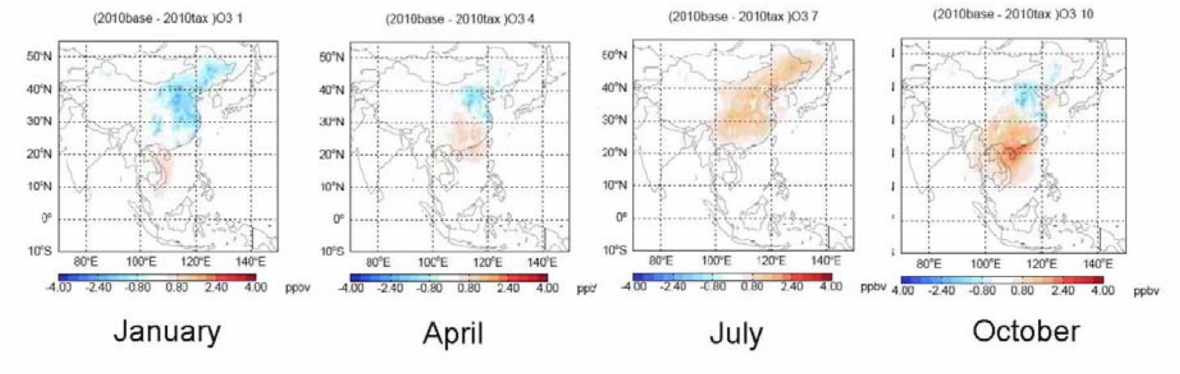


Figure 13. Health Co-benefits (PM2.5 Avoided)

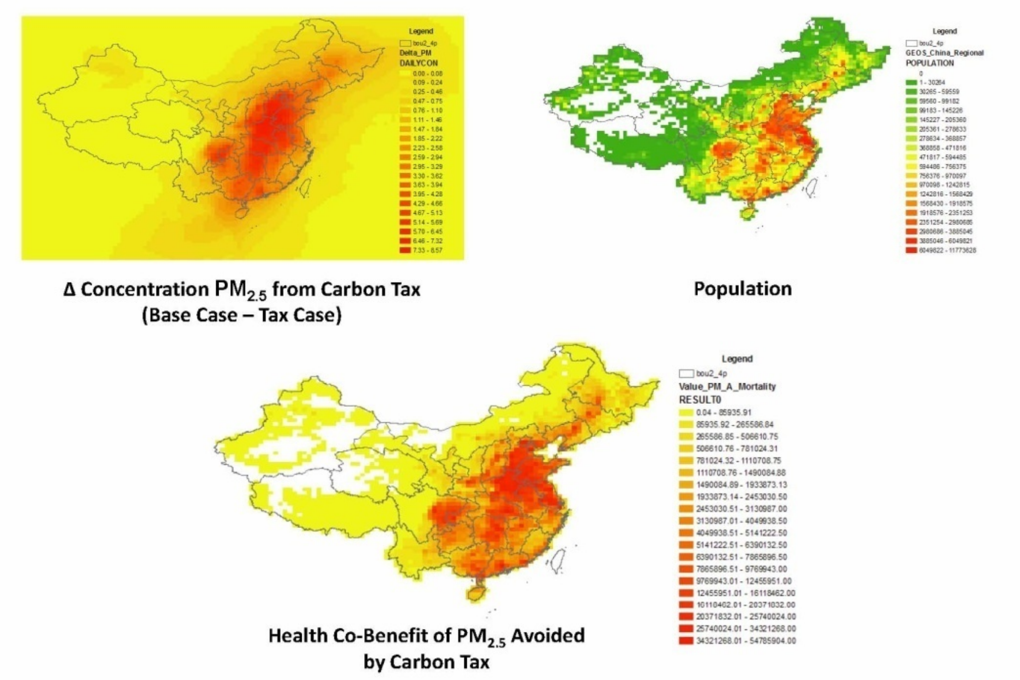


Figure 14. Health Co-benefits (Ozone Avoided)

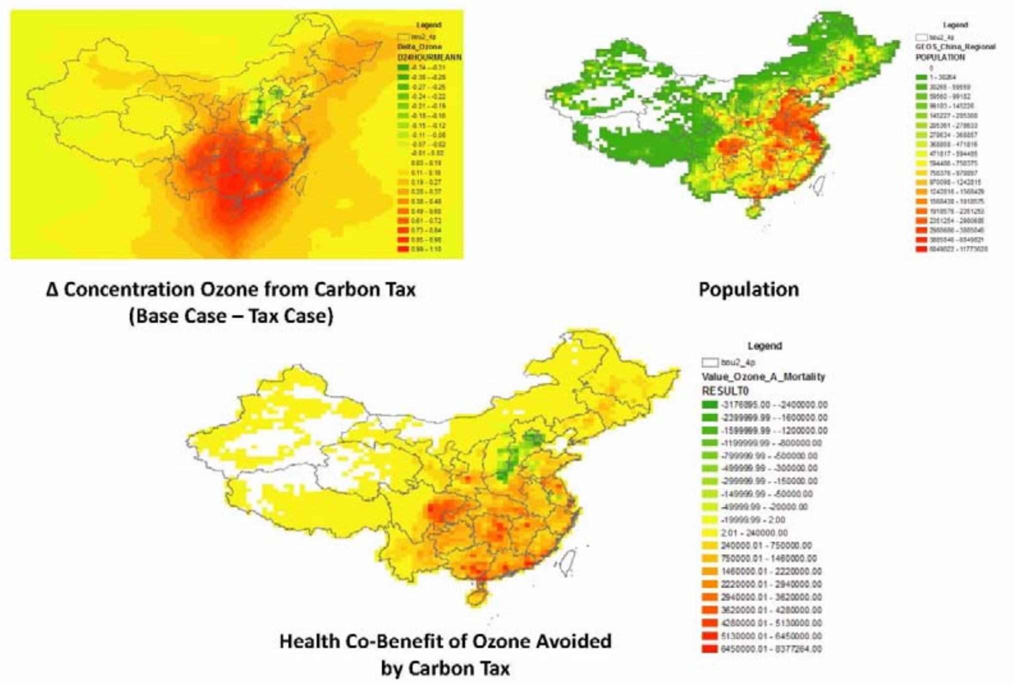


Figure 15. Total Monetized Health Benefits in 2010 for Carbon Tax Policy and SO_2 Control Policy (11th FYP Policy)

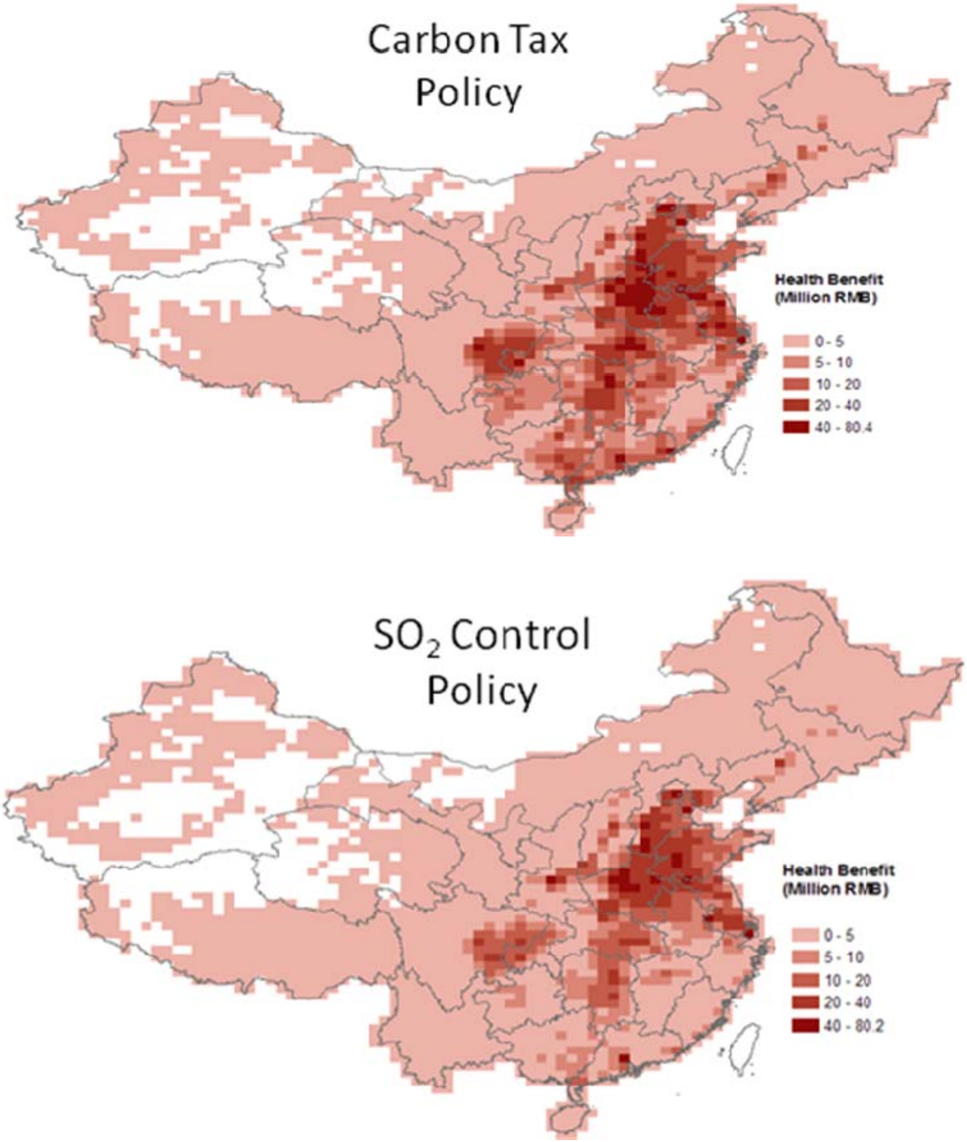


Table 1. China Historical economic growth, energy use and emissions

	1997-2007	1985-2007
GDP	9.10%	9.33%
Total commercial energy	6.56%	5.65%
Coal	6.25%	5.25%
Oil	6.21%	6.29%
Gas	13.78%	7.76%
Other primary energy	8.19%	7.46%
SO2 emissions	0.51%	2.08%
TSP emissions	-6.96%	-4.36%
NOx emissions	6.58%	

Sources: All series from official data except NOx is from Zhang et al. (2009)

Table 2: Major Targets in 11th Five-Year Plan for Environmental Protection

	Indicator	2005 Actual	2010 Target	% Change to Achieve Target
1	Chemical Oxygen Demand (mil. tons)	14.14	12.7	-10%
2	SO_2 (mil. tons)	25.49	22.95	-10%
3	Percentage of river sections under national monitoring program failing to meet Grade V National Surface Water Quality Standard (%)	26.1	<22	-4.1 percentage points
4	Percentage of sections of 7 major rivers under national monitoring program meeting Grade III National Surface Water Quality Standard (%)	41	>43	-2 percentage points
5	Number of days in which urban air quality of key cities is superior to Grade II National Air Quality Standard exceeding 292 days (%)	69.4	75	5.6 percentage points

Source: SEPA (2007).

Table 3. Emissions, Fuel Use, and Output in 2005

	Sector	SO2 (kiloton)	Gross Output (bil *yuan*)	Coal Use (mil tons)	Oil Use (mil tons)	Gas Use (mil m^3)
1	Agriculture	73	3935.7	43.29	7.16	0.0
2	Coal mining and processing	296	792.4	75.03	2.85	0.0
3	Crude petroleum mining	44	567.4	12.43	5.51	2.0
4	Natural Gas Mining	1	36.3	0.07	0.28	247.0
5	Nonenergy mining	238	550.9	9.21	7.96	16.3
6	Food products, tobacco	519	2587.8	26.27	1.37	87.6
7	Textile goods	416	1586.0	26.20	1.83	211.6
8	Apparel, leather	51	1222.2	3.93	0.70	0.0
9	Sawmills and furniture	72	602.4	16.29	1.24	0.0
10	Paper products, printing	613	1085.2	23.17	1.75	30.3
11	Petroleum refining & coking	996	1262.0	30.24	17.35	0.0
12	Chemical	1982	2872.0	131.50	52.31	12900.6
13	Nonmetal mineral products	1948	2667.1	200.82	12.63	2891.1
14	Metals smelting & pressing	1694	3143.4	247.34	21.14	1803.7
15	Metal products	36	1063.2	11.09	2.56	361.9
16	Machinery and equipment	124	2509.6	47.89	4.94	1189.1
17	Transport equipment	58	1757.4	21.03	1.97	1160.6
18	Electrical machinery	38	1657.1	8.00	2.30	214.2
19	Electronic & telecom. equip	24	2804.9	4.76	1.78	212.2
20	Instruments	18	359.6	0.75	0.21	1.2
21	Other manufacturing	378	496.5	14.51	0.87	0.1
22	Electricity, steam, hot water	16241	1845.3	1183.10	19.45	14337.8
23	Gas production and supply	26	74.4	11.81	3.23	97.9
24	Construction	308	4256.4	12.45	13.15	0.0
25	Transportation	545	2445.8	25.91	74.69	58.7
26	Communications	70	1060.3	6.39	0.38	0.0
27	Trade	154	2908.5	10.69	7.63	0.0
28	Accomodation & Food	146	1028.3	13.22	1.03	1333.9
29	Finance and insurance	21	1026.2	1.55	0.87	0.0
30	Real estate	116	1025.0	10.73	0.48	6.8
31	Business services	296	1820.0	25.15	5.16	417.2
32	Other Services	918	2873.3	83.77	3.73	185.6
33	Public administration	143	1281.4	12.18	2.63	28.6
	Households	835	0.0	53.53	4.16	3284.1
	Total	29439		2404	285	41080

Notes: Fuel use is combustion, excluding the transformation to secondary fuels and products.
Source: Input-output table, authors' calculations.

Table 4. BenMAP Health Effects Parameters

Health endpoint	$PM_{2.5}$	Ozone
Mortality, acute effect	0.65	1.17
Mortality, chronic effect	4	
Hospital admissions, cardiovascular	1	4.96
Hospital admissions, respiratory	2.68	8.5
Outpatient visits, all cause	0.39	

Note: Values represent the relative risk of the health endpoints if concentration of $PM_{2.5}$ increases by $10ug/m^3$ or ozone increases by 10 ppb

Table 5. Valuation of health effects, based on literature review

Health endpoint	Value in 2010 (RMB)	Estimation method	Inflation factor
Mortality	517,765	Wiliness-to-pay	Wage index
Hospital admissions, cardiovasc.	11,312	Cost of illness	Medical cost index
Hospital admissions, respiratory	5,202	Cost of illness	Medical cost index
Outpatient visits, all cause	239	Cost of illness	Medical cost index

Table 6. Cost Structure for Thermal Power Plants, 2005 (*yuan*/kWh)

	Large &	Small Plants		
Costs	Median Plants	Total	Coal	Diesel
Average Total Costs	0.286	0.704		
Operating & Maintenance Costs	0.057	0.068		
Fuel Costs	0.189	0.596	0.23	2.52

(Source: Energy Research Institute.)

Table 7. The Economics of small power plant (<100MW) shutdown policy

	Total output (bil kWh)	Thermal output (bil kWh)	Small plant output (bil kWh)	Original energy cost share	Energy cost share after shutdown	Reduction in cost per kWh
2005	2494	2047	400	37.0%	37.0%	
2006	2859	2370	400	36.3%	36.2%	-2.30%
2007	3271	2723	400	35.7%	35.4%	-4.11%
2008	3486	2938	400	35.0%	34.6%	-5.87%
2009	3716	3172	400	34.4%	33.9%	-7.44%
2010	3960	3424	400	33.8%	33.2%	-8.84%

Sources: IEA (2007), Chinese Statistical Yearbook (2008, 2009) and authors' calculations (based on 2005 SAM table and other power sector data).

Table 8. The effects of environmental policies, percent change in 2010

	Base case 2010	Shutdown effect % change	FGD policy effect % change	combined policy effect % change
GDP (bil. 2005 yuan)	30955	0.77%	-0.11%	0.66%
Consumption (bil. yuan)	11891	0.51%	-0.10%	0.40%
Investment (bil. yuan)	12468	1.12%	-0.09%	1.01%
Government demand (bil yuan)	3625	0.00%	-0.07%	0.00%
Coal Use (mil. tons)	2802	-5.35%	-0.17%	-5.53%
Oil Use (mil. tons)	449	-0.53%	-0.08%	-0.61%
Carbon Emissions (mil. tons)	1836	-4.42%	-0.15%	-4.57%
Electricity output (bil. kWh)	3245	-1.03%	-1.25%	-2.29%

Table 9. Economics of the FGD policy

	Total output (bil kWh)	Thermal output (bil kWh)	11th Plan FGD additions (GW)	FGD Stock (GW)	11th Plan FGD-covered output (bil kWh)	11th Plan FGD as share of total kWh	Increase in average cost
2005	2544	2083		46			
2006	2742	2247	83	130	459	16.7%	0.25%
2007	2956	2424	83	213	917	31.0%	0.46%
2008	3187	2616	83	296	1376	43.2%	0.63%
2009	3435	2824	83	380	1835	53.4%	0.78%
2010	3703	3048	83	463	2294	61.9%	0.91%

Table 10. Effects of policies on the energy sectors (% change from base case)

	Electricity Use	Electricity Price	Coal Use	Coal Price	Oil Use	Oil Price
Shutdown policy						
2006	-0.28%	0.00%	-1.14%	-0.34%	-0.10%	-0.15%
2007	-0.55%	0.01%	-2.31%	-0.61%	-0.18%	-0.32%
2008	-0.76%	0.00%	-3.44%	-0.79%	-0.27%	-0.45%
2009	-0.92%	0.00%	-4.62%	-0.85%	-0.48%	-0.48%
2010	-1.03%	-0.01%	-5.50%	-0.98%	-0.53%	-0.60%
FGD policy						
2006	-0.27%	0.27%	-0.04%	0.04%	-0.02%	0.02%
2007	-0.52%	0.52%	-0.08%	0.08%	-0.03%	0.04%
2008	-0.76%	0.77%	-0.11%	0.11%	-0.06%	0.06%
2009	-1.00%	1.01%	-0.14%	0.14%	-0.06%	0.08%
2010	-1.25%	1.26%	-0.17%	0.17%	-0.08%	0.10%
Combined Shutdown and FGD policy						
2006	-0.55%	0.27%	-1.19%	-0.29%	-0.12%	-0.13%
2007	-1.07%	0.53%	-2.39%	-0.53%	-0.22%	-0.27%
2008	-1.52%	0.77%	-3.56%	-0.68%	-0.33%	-0.38%
2009	-1.92%	1.02%	-4.77%	-0.71%	-0.54%	-0.40%
2010	-2.29%	1.26%	-5.69%	-0.81%	-0.61%	-0.50%

Table 11: Effect of 11th FYP SO_2 Policies in 2010, Compared to Carbon Tax

	11th FYP SO_2 policy	Carbon Tax with lump-sum transfer	Carbon Tax with reducing distorted taxes
In % Change vs. the Base Case:			
GDP	0.66	-0.19	-0.03
Consumption	0.4	0.13	-0.14
Investment	1	-0.25	0.28
Energy Use	-4.3	-11	-11.3
Coal Use	-5.5	-15	-14.4
CO_2 Emissions	-4.6	-12	-12
PM_{10} Emissions	-3.7	-11	
SO_2 Emissions	-20	-14	
NO_X Emissions	-1.4	-11	
Pollution tax revenue / Total tax revenue		3.07%	3.09%
In Reductions vs. the Base Case:			
PM Acute Mortality Only (cases)	12,300	17,200	
PM Acute Mortality Only (billion yuan)	6.4	8.9	
PM Chronic Mortality Only (cases)	73,900	103,000	
PM Chronic Mortality Only (billion yuan)	38.3	53.5	
PM and Ozone, All Effects (billion yuan)	39.9	56.5	
Reduction in Damages/GDP (%)	0.13%	0.18%	

Table 12: Effect of Carbon Tax on Sector Emissions

	From **2005** to **2010 base case**			Of **2010 tax case** vs. **2010 base case**		
	SO_2	NOx	PM_{10}	SO_2	NOx	PM_{10}
Power	-6.50%	38.10%	-0.40%	-14.50%	-14.50%	-14.50%
Cement	-19.90%	62.80%	-63.40%	-12.40%	-12.00%	-12.70%
Iron and Steel	18.20%	29.40%	11.10%	-8.30%	-8.30%	-8.30%
Other Industry	40.90%	40.90%	40.90%	-13.90%	-13.90%	-13.90%
Transport	53.70%	16.70%	-3.60%	-2.20%	-2.20%	-2.20%
Households	79.00%	45.40%	27.70%	-13.00%	-8.20%	-4.60%

Table 13. Total Health Co-Benefit of Air Pollution Avoided by Carbon Tax

Health Endpoint	Avoided Cases	Economic Benefit (Million RMB) Acute Effect Mortality Only	Economic Benefit (Million RMB) Chronic Effect Mortality Only
PM2.5			
Mortality, acute effect (Concentration-Response from Chinese time-series study)	18,428	9,541	
Mortality, chronic effect (CR US cohort study)	110,985		57,464
Hospital admissions, cardiovascular	32,193	364	364
Hospital admissions, respiratory	57,644	300	300
Outpatient visits, all cause	7,101,438	1,697	1,697
Total		**11,903**	**59,825**
Ozone			
Mortality, acute effect (CR Chinese study)	3,265	1,691	
Hospital admissions, cardiovascular	15,416	174	
Hospital admissions, respiratory	17,575	91	
Total		**1,956**	

Table 14. Comparing of SO_2 Control Policy and Carbon Tax Policy

Variable		Effect of SO2 Policy vs. Base Case in 2010	Effect of C Tax Policy vs. Base Case in 2010
GDP		0.0066	-0.0019
Consumption		0.004	0.0013
Investment		0.01	-0.0025
Energy Use		-0.043	-0.11
Coal Use		-0.055	-0.15
CO2 Emissions		-0.046	-0.12
Primary Particulate (PM10) Emissions		-0.037	-0.11
SO2 Emissions		-0.2	-0.14
Avoided Premature Deaths from Air Pollution	Acute effect PM2.5 (PRC evidence)	12,300 cases	17,200 cases
	Acute effect ozone (PRC evidence)	123 cases	1,380 cases
	Chronic effect PM2.5 (US evidence)	73,900 cases	103,000 cases
Value of Avoided Health Damages from Air Pollution	Acute PM2.5 mortality only (PRC evidence)	Yuan 6.4 billion	Yuan 8.9 billion
	All health effects, PM2.5 (including chronic mortality, US) and ozone (acute, PRC)	Yuan 39.9 billion	Yuan 56.5 billion