ECONOMY AND ENVIRONMENT PROGRAM
FOR SOUTHEAST ASIA

Marginal Cost Pricing for Coal Fired Electricity in Coastal Cities of China: The Case of Mawan Electricity Plant in Shenzhen, Guangdong Province

Zhang Shiqiu and DuanYanxin

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April 1999

TABLE OF CONTENTS

LIST OF TABLES

MARGINAL COST PRICING FOR COAL FIRED ELECTRICITY IN COASTAL CITIES OF CHINA: THE CASE OF MAWAN ELECTRICITY PLANT IN SHENZHEN, GUANGDONG PROVINCE

Zhang Shiqiu and DuanYanxin[1]

ABSTRACT

By developing a model to estimate the environmental externalities associated with electricity generation, this project provides a detailed analysis of the damages and costs caused by different pollutants at varying distances from the Mawan Electricity Plant in Shenzhen, China. The major findings of this study are that (1) environmental damages caused by electricity production are large and are mainly imposed on regions far away from the electricity plant; (2) air pollution is the most significant contributor to the total damages, and SO2, NOx, and particulate matter are the three major pollutants with highest damages; (3) the damages caused per unit of particulate, NOx, and SO2 emissions are much higher than pollution treatment and prevention costs. The research results of this project show that China needs to have a more effective levy system on SO2, and a more manageable electricity tariff mechanism to internalize the environmental externalities. The results have also implications for pollution control strategies, compensation schemes as well as emission trading arrangements.

1.0 ISSUES AND PROBLEMS

China is currently in the process of transition from a planned to a market economy. In a market economy, the allocation of scarce resources between competing uses is a problem that is solved through market pricing of resources. A precondition for the optimal functioning of this allocation process is that the market prices reflect all costs involved in production. The market mechanism cannot secure an optimal macroeconomic allocation if substantial costs of production are not reflected in the market price because they are passed on to third parties not involved as consumers or producers of a product (in the instance of external or social costs).

1.1 Background

China has experienced remarkable economic growth in recent years. The gross domestic product (GDP) increased an average of 10.1% per year during 1981-1996, and 11.6% per year during 1991-1996. It was projected that China's economy would grow 8% per year during 1996-2000 and beyond (State Planning Commission, 1996). In some regions, particularly along the coast, the rates of growth have been higher than these national averages. China's struggle to meet its enormous energy needs is a key element of the nation's development strategy (Administrative Centre for

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China's Agenda 21 1994) and is perhaps the single most important variable shaping the future of China's environment. By 1990, China's energy demand had surpassed 1 billion tons (standard coal equivalent, SCE). It has been projected that China's energy demand will increase to somewhere between 2.7 and 4.4 billion tons (SCE) by 2050 under a "business as usual" scenario (ADB 1994). The choice of technology and fuel used to meet the growing energy demand will have tremendous environmental consequences. Finding ways to achieve rapid economic growth and simultaneously implement pollution prevention and control policies that will mitigate the associated environmental damages represents a critical challenge for China and developing countries throughout the world.

China's power plants depend largely on coal. In 1995, the power sector was responsible for 32.2 % of China's total coal consumption (China Statistical Bureau 1997). The thermal power output accounted for 80.2 % of the total electricity produced in 1995. Of the thermal power produced, 86.8 % was produced using coal (China State Statistical Bureau 1994, 1997, Zhang et al 1995). Given the government's plans to continue depending heavily on coal to meet the increasing demands for power, it is unlikely that coal's use in the power sector will be declining. As a consequence, it is expected that China's air pollution will increase substantially.

This pricing policy study of coal-fired electricity plants in China's coastal cities will therefore provide important insights for policy makers and the public on the efficient management of energy and environmental sectors.

1.2 Major Problems Facing the Power Sector's Development in China

The major problems facing the power sectors development in China can be summarized as follows:

First, there are problems with the supply mix. Electricity supply depends primarily on coal-fired generation plants and the use of coal in electric power plants continues to expand. This dominance of coal has significant environmental implications. For example, in Southwest China, where high sulphur coal is commonly used, the electricity sector is one of the major contributors to air pollution and this region is one of the highest sulphur emission areas in China.

Second, there is a shortage of electricity. The shortage is due to problems on both the supply and demand sides. On the supply side, the capacity of power generation cannot meet the needs of rapid economic development and increased living standards. On the demand side, the use of electricity is inefficient, particularly in industry, which is still the main sector responsible for China's high-energy intensity. Marked inefficiencies in China's existing pattern of electricity use are due to centralised planning and the continuing practice of providing massive subsidies in the form of electricity prices that are below the long run supply cost. Such inefficiencies are examples of market failure and government (policy) failure (Pearce and Warford 1993). The severe shortage of electricity in China affects virtually all provinces, as reflected in endemic blackouts and breakouts. Li and Johnson (1994) estimate that electricity shortages cost China $24.5 billion in 1993, based on a cost of $0.175 per kilowatt-hour.

Third, there is a serious problem with price distortion (which is discussed in detail in next section). As noted above, without the proper market signals in the power sector, there is little to encourage efficient production, consumption and conservation of electricity. Until recently, government-defined output goals have been the principal incentive in production, while electricity was highly subsidised for both industrial and residential consumers. The net effect was wasteful energy consumption that widened the gap between energy demand and supply. In addition, price distortion and constraints discouraged investment in electricity conservation and in the development of alternative sources of electricity supply. Price distortions in the electricity market have been reduced in successive price reforms since 1979, especially since 1985 (Yang and Tian 1991).

1.3 Major Problems Related to Electricity Pricing in China

China has made progressive steps towards the liberalisation of electricity prices, which has created a pricing structure that more accurately reflects the production costs (although not the externalised environmental costs). However, further measures to rationalise energy prices and reform product markets are still needed. The major problems related to electricity price in China can be summarised as follows:

First, the current price system is the result of a number of incremental *ad hoc* changes instead of being the product of a well-designed long-term price reform program. The electricity pricing system remains too complex and cumbersome in spite of the major reforms initiated in 1993. Important distortions and major inequities continue to exist. While prices remain partly regulated for state-operated power plants, the price of electricity for new investor-operated plants (operated by industrial users, semi-private corporations, or local government) is, in theory, based on the calculation of a profitable rate of return on capital and operating costs. Other plants sell electricity at negotiated prices substantially above state prices or simply charge customers a processing fee for the conversion of fuels. Pricing policies vary by region, supplier, and customer. Furthermore, municipal, provincial, and county governments frequently impose added fees to raise funds for electricity development, and cost classifications are poorly defined (Yang and Tian 1991; ADB 1994). Major efforts are still needed to rationalise the power pricing system so that it can better meet the demands of the emerging market economy and changing macroeconomic conditions (World Bank 1994).

The state regulated electricity price is too low and has resulted in the power industry operating largely under deficit. Since 1979, the adjustment for the prices of production materials led to the increase of fuel prices, transportation costs, equipment costs and so on. Although the electricity price has been adjusted several times, the rate of increase in electricity prices is still lower than the rate of increase in the costs of inputs. In Guangdong Province, for example, the accumulated deficit reached 1 billion yuan by the end of 1993 (Guan et al 1995).

Second, there is an internal distortion of electricity pricing. The price for commercial industries, service sectors, and hotels is set too low. Preferential prices for industry and agriculture are also too low. Furthermore, the current prices poorly reflect differentiation in peak-load use.

Third, there is a problem with inefficient management in the electricity sector. The roles of the various administrative departments (agencies) are not clearly defined which is a major obstacle to co-ordinating efforts between different departments. As a result, there is not a very strong scientific basis behind the calculation and classifications of electricity prices or in the determination of rational profit rates.

Fourth, electricity prices do not reflect the full social cost, such as environmental damages produced by electricity generation. This tends to discourage firms from adopting efficient pollution prevention and treatment measures. Moreover, the price of coal resources in China does not reflect the full social cost either. Without including the full social costs of raw materials and power generation, there will be less effort put towards developing alternative electricity supplies or considering economies of scale in power production. Estimates of the total cost of environmental damage in China are limited and unreliable. In part, this is because it is difficult to assign value to environmental damages since accurate valuation depends on (1) understanding the relationship between pollutants and public health, property, ecological, and aesthetic effects; (2) determining the degree of harm; and (3) ascertaining who suffers losses and the value of their damages. Values in turn depend on individual or social preferences, which may vary across cultures, income levels, and at different stages of economic development (see, Pearce and Warford 1993).

In summary, electricity pricing in China is affected by many different factors, such as regulations and economic policies. There are three policy principles underlying the current system:

- Higher prices are charged for electricity from new power plants since the new investment for these plants is comparatively high (since most of the inputs are purchased on the free market);

- The price is composed of three parts: operating cost, returns on investment, and profit to the investors. Pricing is further complicated by the variety of surcharges and miscellaneous fees along with the discounts on coal price and transportation that are often set on a plant by plant basis.

- The price is often negotiated between the local and central governments.

In sum, the current price system is still very much a product of central planning. It does not internalise all the environmental costs and user costs of coal (although the user costs of coal in China is quite low). Under the current pollution charge system, charges are collected at a very low rate and only take into account part of the operating costs (within the firm) associated with environmental prevention and treatment. Such a price distortion sends misleading signals to producers and consumers which leads to lower investments in alternative energy, improved efficiency in electricity production, the installation of environmental pollution prevention facilities, and the use of clean inputs (such as cleaner coal with lower sulphur and ash content).

1.4 Objectives of the Study

The main objective of this research project is to provide policy-makers with an empirical basis for internalizing environmental costs in energy pricing using the actual situation in a coastal region of southern China. The model developed for this study will be used to determine the cost of damages associated with electricity production. The data used is for a coal-fired electricity plant in Shenzhen, which is called Mawan

Electricity Plant.[2] The findings will be based on specifications of the plant together with socio-economic and environmental data from the surrounding regions.

1.5 Definition of Marginal Opportunity Cost (MOC) Pricing for this Study

1.5.1 Definition of Coal Fired Electricity Price

In this study, the electricity price is defined as *the firm-gate price of electricity* produced by the coal fired power plants.

1.5.2 Components of the Electricity Price at Firm Gate

Pricing plays an important role in the allocation of resources. The price that leads to a more efficient allocation is the one that reflects not only the production costs, but also the environmental and user costs. Therefore, the electricity price (MOC at firm-gate) should include MPC, MUC and MEC.

MPC (marginal production cost) is the cost of production for an incremental unit of electricity (capital investment and operating cost).

MUC (marginal user cost) is the depletion cost of the coal that is used as fuel. In theory, either the domestic marginal opportunity cost (MOC) price of coal or world market price of coal can be used, as the cost of coal, which means the MUC will be considered in the MPC[3].

MEC (marginal external cost) is the external costs related to the production and consumption of electricity. It consists of MEC1, the external (environmental) costs (damages) caused by electricity generation and MEC2, the external (environmental) costs (damages) associated with electricity consumption. Since the electricity price for this study is the firm gate price, the MEC used here includes only the external costs of production, MEC1.

Thus, the electricity price at firm gate for this study can be described as:

$$P = MOC = MPC + MEC = MPC + MEC1 \qquad [1]$$

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[2] The plant is located in the west of Shenzhen (Mawan Bay), 25km away from the downtown area. The first phase of this plant has the capacity of 2×300 MW and was constructed between January 1992 and September 1994. The coal used comes mostly from northern Shanxi. Some also comes from Australia. The domestically supplied coal is transported from Shanxi to Qinhuangdao by Da-Qin railway then is shipped south to the ports of the electricity plant.

[3] Based on the results of a research project done by Peking University on MOC pricing for coal in China (CCICD, 1997), the MUC of domestic produced coal at the coal mine-mouth of Datong in Shanxi Province was 3.5 yuan/ton, while the MOC price of coal was 77.84 yuan/ton to 110.27 yuan/ton in 1992. Including transportation costs, the coal MOC price in Qinghuangdao Port was 111.44 yuan/ton to 143.87 yuan/ton. During this same period the average international coal price was about 315 yuan/ton, which is much higher than the domestic price. The free market price at Shenzhen for the coal from Datong is 240 yuan/ton and about 300 yuan/ton for coal from Australia. Since the MOC price of domestic coal is lower than the world market price, the local MOC price of coal should be used as the price of coal inputted. Given this, there is no need to further correct the MUC of coal inputted.

2.0 METHODOLOGY USED

2.1 Comparison of Methodology

There are two ways to value environmental damages.

First, one can estimate the damages by comparing economic performance indicators for a given regional economic system before and after damages occurred. To use this method, certain conditions are necessary:

- the statistical data regarding the region concerned needs to be complete, and the structure of the economy should not have changed substantially;

- the source and effects of the pollution being studied can be isolated from other sources and effects of pollution.

The advantage of this method is that it does not require information on the diffusion and specific effects of pollution. The disadvantages are: (1) it is difficult to isolate effects when multiple impacts are involved; (2) non-market damages cannot be evaluated; (3) it is not possible to predict the future impact of damages.

An alternative method for determining the value of environmental damages is to estimate the damages by identifying the relationships between pollution, its transport and the resulting environmental effects. The value of damages can be determined systematically. There are certain requirements for this method:

- the pollution emissions and related diffusion models are known
- the environmental effects of different pollutants are known
- the environmental effects can be assigned monetary value

The advantages of this method are that: (1) the evaluations process and results are clear; (2) it allows for the prediction of future damages. The disadvantage is that it requires tremendous amount of data and information drawn from empirical studies. There are also some damages that are difficult to value in monetary terms.

Between these two different methods for evaluating the environmental damages produced by Mawan Electricity Plant, we selected the latter method. This decision was based on the following:

- enough data and information about pollution sources is available and the air pollution diffusion model and other transmission models can be developed or introduced from previous research;

- there is information available regarding pollution dose-response relationships of environmental effects;

- the regional market in southern China is relatively liberalized in comparison with other parts of China;

- it would be difficult to isolate the losses caused by the Mawan Electricity Plant since there are a large number of other pollution sources in the region.

2.2 Determining the Value of Environmental Damages

The major focus of this study is the estimation of the environmental costs (MEC1) associated with coal-fired electricity production. To do this we first identify the environmental stressors and then use dispersion and transformation models to estimate the possible environmental changes caused by the different stressors. The physical impacts and damages caused by these changes are assessed and quantified, and finally monetary values are assigned to the damages. The steps involved in this process of MEC1 estimation are summarized below and illustrated in Figure 1.

Step 1: Determine the pollutants and emissions, and identify the type and size of associated environmental impacts.

In this step, the pollution sources and emission intensities are determined based on information about the fuel used and production process. Using previous research, the environmental impacts are then identified. After bringing together this information, we identify those potential stressors and impacts that will be quantitatively assessed in this study.

Step 2: Identify and assess the changes in environmental quality.

Based on literature review as well as pollution dispersion and transformation models, the incremental changes of each pollutant in the environment is simulated and calculated. For air pollutants and pollution, the following methodology is introduced:

$$\Delta C_i = F(Q_i), \text{ and } \Delta C_{i'} = F'(Q_i) \qquad [2]$$

In which,

ΔC_i	the concentration changes of pollutant i
$\Delta C_{i'}$	concentration changes of secondary pollutant i' of pollutant i
Q_i	intensity of pollutant i

Once the atmospheric dispersion and transformation models are established, the spatial distribution of the pollutants emitted by the point source can be calculated. Typically, receptor cells will be defined for the effected regions. The concentration at the central point of each receptor cell can be calculated using the model and this central point value will serve as a proxy for the concentration of the whole receptor cell. Due to the dependence on socioeconomic data in this model, receptor cells must often be defined as administrative units (e.g., counties or districts).

The concentration of pollutant i in each receptor cell k is thus approximated by formula [3]:

$$\Delta C_{ik} = A_{ik} \times Q_i \qquad [3]$$

In which,

ΔC_{ik}	incremental concentration of pollutant i in receptor cell k
A_{ik}	transformation coefficient of pollutant i in receptor cell k
Q_i	intensity of pollutant i

A_{ik} is a parameter determined by the atmospheric dispersion models. Its value is dependent on the type of pollutant i as well as the location, topographic features, and meteorological conditions of receptor cell k.

Step 3: Calculate the physical damages caused by pollutants by establishing dose-response relationships.

Using a dose-response relation and ΔC_i, the physical damages caused by each pollutant can be calculated. Each pollutant will affect several receptors within a receptor cell. The degree of damage, D_{ijk}, in each receptor cell is the function of C_i and the number of receptors. Previous studies show that the dose-response relations of pollutants have different shaped curves. Although most of the D_{ijk} functions are non-linear, to simplify calculation, a linear function can be used for simulating the real D_{ijk} at certain levels of concentration.

The linear dose-response function used in this study is shown in formula [4].

$$\begin{aligned} &D_{ij} = D(\Delta C_i) && \\ &D_{ijk} = B_{ij} \times \Delta C_{ik} \times T_{ijk} && C_{ik} \geq C_{i0} \\ &D_{ijk} = 0 && C_{ik} \langle C_{i0} \end{aligned} \qquad [4]$$

In which,

D_{ij}	physical damage j caused by pollutant i
D_{ijk}	physical damage j in receptor cell k caused by pollutant i
ΔC_{ik}	concentration changes of pollutant i in receptor cell k
C_{i0}	threshold for damage caused by pollutant i
B_{ij}	coefficient of dose-response of pollutant i and impact j
T_{ijk}	number of receptors in cell k for impact j caused by pollutant i

Step 4: Valuation of physical damage in receptor cells identified above.

The valuation methodology for the various types of physical damage will vary depending on the characteristics of the damage. There are many valuation techniques that have been developed. However, due to the limited information and data currently available, the "benefit transfer technology" technique is used in this study. We used existing research results from China and abroad.

Formula [5] is used to calculate the monetary value of the physical damages.

$$E_{ijk} = P_{ij} \times D_{ijk} \qquad [5]$$

In which,

E_{ijk}	monetary value of the impact j in receptor cell k produced by pollutant i
P_{ij}	monetary value of impact j in one year produced by pollutant i
D_{ijk}	physical damage j in receptor cell k caused by pollutant i

Step 5: Summary and analysis of the computational results.

The following formula [6] summarises the computation of damage effects:

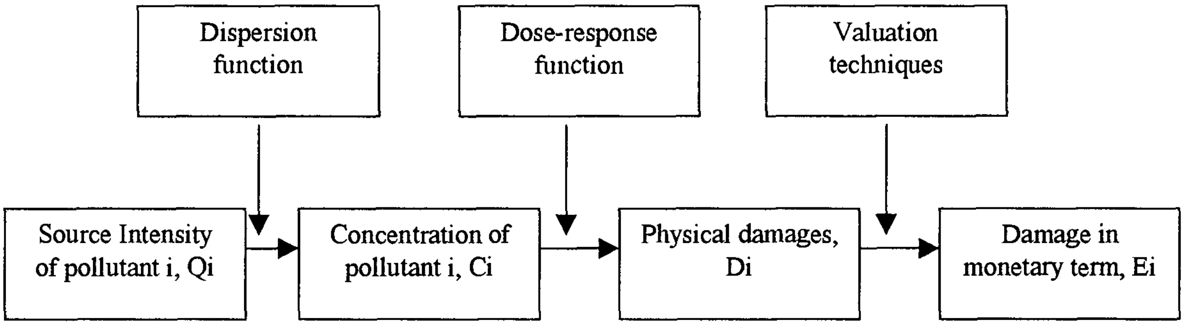
$$E=\sum_{i}\sum_{j}\sum_{k}[P_{ij}\times(A_{ik}\times Q_{i})\times B_{ij}\times T_{ijk})] \qquad [6]$$

In which,

E represents the annual value of total environmental damages caused by electricity generation.

Since the production processes used in the electricity industry vary little, coefficients of pollution emission and the environmental damage functions from other models can be used. This allows for the use of computer programs to calculate the damages and determine the monetary value the damages. Based on the program EXMOD[4] created for the "New York State Environmental Externalities Cost Study", we developed a GDMOD, which is computer model to estimate the environmental costs produced by the Mawan Electricity Plant in Shenzhen.

Figure 1. Process of damage valuation for estimation of MEC1



3.0 ESTIMATION OF MEC1

As mentioned above, MEC1 is the external (environmental) cost (damages) produced by electricity generation. In order to estimate MEC1, we designed the GDMOD model.

3.1 Design of the GDMOD Model

The GDMOD model greatly simplifies the valuation of environmental damages. The model was developed based on the characteristics of pollution produced by coal-fired electricity plants. The production process and types of pollutants are quite similar for different electricity plants, and so it is easy to determine the actual pollutant emission intensities. Also, the dispersion and transmission of pollutants are well understood and there are numerous models available. The key factors considered as we designed the GDMOD were:

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[4] EXMOD model is a computer model for estimating environmental externalities associated with electric resource options in New York State. The environmental externalities from electric resources options are environmental costs and benefits to society that result from the production and consumption of electricity, or from demand side management activities, that are not accounted for in electricity prices. For detail, see Robert D. Rowe et al, The New York Electricity Externality Study, Oceana Publications Inc. 1995

- There are many different types of pollutants emitted from coal-fired electricity plants and they can affect the air, water and soil. The impact on atmospheric environment is however the more significant one (R. Rowe, 1995).
- Of the air pollutants emitted, smoke, soot, SO2, and NOx are the greatest in volume. Other toxic pollutants emitted, such as heavy metals and toxic organic chemicals, though less in volume, can still produce significant impacts.
- With the introduction of high stacks, air pollution affects a wider area.

3.2 Scope of the Analysis

The analytical parameters for GDMOD are defined as:

- The regional focus of this study is Guangdong Province. Though areas on the border of Guangdong are also included in the analysis.
- 1992 was selected as the base year for the study and all data was converted into 1992 values using a discount rate of 12%.
- The model developed here only considers the environmental damages produced by electricity generation and does not include the external costs associated with the transportation of coal and consumption of electricity.

3.3 Receptor cell definition

The model uses spatial units called ***receptor cells***. These are the basic units for calculation. The affected area is divided into139 receptor cells that are categorised based on their distance from the facility site. The four geographic classifications used are:

1. *Local Community:* locations in Guangdong within 30 km of the facility site
2. *Rest of the Region:* locations in Guangdong between 30 and 80 km from the facility site
3. *Rest of Province*: locations in Guangdong more than 80 km from the facility site.
4. *Out of Province:* Locations in provinces neighbouring Guangdong.

Within Guangdong (categories 1-3), the receptor cells are defined to be county-level units such as urban districts and rural counties. Outside of Guangdong, receptor cells are defined to be the neighbouring counties (except for Hong Kong, Macao, and Hainan, each of which is wholly treated as a single receptor cell). Each receptor cell is assumed to be internally undifferentiated vis-a-vis pollution levels, population density and the relevant economic indicators. For each cell, the central point is used for distance from source measurement.

3.4 Air Quality Models Used in GDMOD

Air Quality models are used to calculate changes in ambient air quality and pollution deposition using stack emissions data. The ambient concentration of emissions from a power plant can be predicted for both short and long distances from the stack. The atmospheric dispersion models can predict the transport, dispersion, deposition, chemical transformation, and visibility effects of emissions from a power plant.

This study uses the same air quality models used in EXMOD, though they have been adjusted based on related parameters in Guangdong Province. The following major models are used:

- ISC2LT model: Used for short range modeling, the Industrial Source Model (ISC2LT) is used to calculate the air quality changes with 50 km of the power plant. It uses the Gaussian sector-average plume equation. This model can be used to calculate the incremental concentration of SO2, NOx, TSP and other pollutants.

- SCREEN2 model: Since the ISC2LT model can only calculate the annual averages of ambient concentration, for short-term averages we used the US EPA SCREEN2 model. It is used to calculate the short-term average concentration of PM-10 for a maximum of 24 hours and Nox (an O3 precursor) for a maximum of 1 hour. The SCREEN2 model is an easy method for predicting maximum ground level of concentration from a single emission source.

- SLIM2 model: Developed for the New York Electricity Externality Study, this model is used to calculate annual average impacts at long range (greater than 50 km from the power plant).

- OLM: US EPA's Ozone-limiting Model is used to calculate changes in ambient ozone concentrations resulting from power plant emissions of NOx.

3.5 Case Creation

With this model, it is necessary to specify the facility location (including elevation), production specifications (type of plant and production process), as well as the characteristics of the receptor cells.

For the facility, the emissions and concentration amounts are determined based on information regarding the production process, facilities and operation parameters as well as the pollution prevention measures for the Mawan Electricity Plant. The electricity generating equipment used at the Mawan Electricity Plant is a pulverised steam boiler with a capacity of 2×300 MW. The plant uses high quality domestic and imported coal. Pollution prevention measures taken at the plant include the use of high stack (210 M) emissions, low NOx emission boilers, electrostatic dust precipitators with 99% dust removal efficiency, and wastewater treatment facilities.

For the receptor cells, the data inputted include: (1) information for each receptor cell, such as place name, latitude, longitude, altitude, area, population, sex and age structure of the population; (2) environmental concentration monitoring data in each receptor cell (collected prior to plant operation); and (3) meteorological data (joint frequency distribution of wind speed and direction).

Once the characteristics of the facility and receptor cells have been established, the dose-response functions must be specified. By modifying the parameters used for the EXMOD, appropriate functions for the GDMOD can be produced for the region being studied. The monetary value for physical damages must also specified before the model can be run.

3.6 The Output of Calculation Results

Using the above mentioned data for the facility, surrounding regions, pollution characteristics and effects, the GDMOD will generate the following information:

- value of damages based on regional proximity
- value of damages for each major type of pollutant
- value of damages within environmental category (such as air, water, land, etc.)
- value of damages per unit of each major pollutant

4.0 IDENTIFICATION AND CLASSIFICATION OF POLLUTION DAMAGES PRODUCED BY MAWAN ELECTRICITY PLANT

Coal-fired electricity plants emit various pollutants that when released into the environment impact the health and well being of humans and other forms of life. The major impacts can be summarised as:

- Impacts on Human Health
- Impacts on Human Welfare
- Impacts on Environmental Resources
- Impacts on Global Change

4.1 Potential Stressors and Impacts

The Environmental Impact Statement for the Mawan Electricity Plant provides valuable data such as pollution emission levels. Table 1 below shows the potential stressors and impacts identified for the Mawan Electricity Plant.

Table 1. Potential stressors and impacts for the Mawan Electricity Plant.

Stressors	Potential Impacts	Emission Data from EIS	Note
Emission/burden on air: *Hazardous chemicals*			
1. inorganic	Human health	N/A	Emission levels are probably low
2. metals	Human health Environmental resources	N/A	Emission level of Hg and Pb are low
3. organic	Human health	N/A	Emission levels are probably low

Emission/burden on air: *Gases*			
1. CO	Human health	N/A	Emission levels are probably low
2. SO2	Human health, Welfare Environmental resources	22,500 tons/year	use lower sulfur content coal from Shanxi' and Australia to reduce the SO2 emission; The 2nd phase uses seawater desulfurization May have large impact on litchi forest
3. NOx	Human health, Welfare Environmental resources	4,710 tons/year	Use low NOx generating boiler.
4. Oxidants	Human health Human welfare	N/A	Secondary pollutant from NOx and SO2, not directly emitted
5. GHG	Global change	740,000 tons of C/year	There is no limitation on CO2 emission
6. aerosols/ particulate (PM-10)	Human health, Welfare Environmental resources	N/A	Secondary pollutant from NOx and SO2, not directly emitted Can use the TSP emission then transfer to PM-10
7. particulate (>PM-10)	Human health human welfare	299 tons/year	4th class of electrical precipitator was installed with 99% removal
8. electro-magnetic radiation	Human health Environmental resources	N/A	From the transmission line of the plant
9. noise	Human health Aesthetics	90dB inside,<60dB outside	Adopt various measures to reduce the noise on workers
Potential Emission/ Burden to Water: *Hazardous Chemicals*			
1. inorganic (non metals)	Human health	Waste water from chemical salt elimination 14,804 tons/year	From boiler cleaning, can be treated separately
2. metals	Human health Environmental resources	From chemical salt elimination No concentration data	From boiler cleaning, can be treated separately
3. organic	Human health Environmental resources	Oil contaminated water 1,000 tons/year	Treated separately
4. BOD/COD	Environmental resources	Domestic waste water 14,400 tons/year	To municipal drainage works to the sea by preliminary treatment
5. exotics	Human welfare Environmental resources	Possible heavy metals and sulfate from desulfurization waste water	
6. acides/bases	Environmental resources	Desulfurization waste water Acid cleaning waste water	
7. waste products	Environmental resources	N/A	-
8. acid deposition	Human health	N/A	Secondary pollutant from NOx and SO2, not directly emitted
9. particulate /sedimentation			
10. water diversion/withdraw	Environmental resources	1.785million tons/year of fresh water	Reduce the consumption on fresh water by improving the recycling
11. thermal alteration	Environmental resources	About 7°C rise, 48 tons/sec of delivery	Thermal plume to ocean (Lingding Sea) from cooling system by sewage

Potential emissions/Burdens to Land: *Hazardous Chemical*			
1. inorganic (non-metals)	Human health Environmental resources	(psychrometer ash ponds transportation of coal dust)	Treat the ash in ash ponds, potential leakage to marine environment
2. metals	Human health	(psychrometer ash ponds transportation of coal dust)	Related to the contents of coal, some metals may leach out of the coal ash
3. Organic	Environmental resources	N/A	Emission is low
4. acids/bases	Environmental resources	166,600 tons of coal ash/year	The diffuse of coal ash shows alkalinity
5. waste product	Human health	N/A	
6. acid deposition	Resources	N/A	Secondary pollutant from NOx and SO2, not directly emitted
7. coal gangues	Environmental resources	84000 tons/year	Landfill and so on
8. soil erosion	Environmental resources	N/A	
9. coal ash	Environmental resources	166,600 tons/y	use anti-leakage measures for landfill
10. land use	Welfare	391,000 m2 site 3,100,000 m2 for ash ponds	

4.2 Impacts Screening

Based on data collected for this study and on results from previous research, the different stressors listed in Table 1 were reviewed and categorized in terms of their potential impacts (see Table 2). Through this screening process, each stressor was assigned one of four classifications (S1-S4). These classifications are used to select the applicable externalities for the study. The criteria used in assigning categories were:

- The impact can be mitigated (S1)
- The impact is relatively small (S2)
- There is not enough scientific information available for a quantitative assessment (S3)
- A quantitative assessment can be completed (S4)

Table 2. Potential impacts for stressors identified for the Mawan Electricity Plant and screening analysis results.

Stressor	Impact[a]	Screening result (assigned S1-S4)
Potential emission/stressors to air		
Hazardous chemicals Inorganic Metals	Human health: Premature morbidity, mortality	*Health impacts probably small(S2)*: emission will be partially mitigated with an electrostatic precipitator that will remove at least 99% of the particles and toxics emitted. Health risks are low for toxics relative to other air pollutants because of limited exposure pathways.
	Environmental resources: Terrestrial ecosystems	*Impacts on environmental resource are unknown (S3)*
Gasses CO	Human health: increased morbidity	*Impacts probably small(S2)*:Although emission levels are not in EIS, CO emissions should be low
Gasses SO2	Human health: increased morbidity	*Impacts be small (S2)*: the standard be met, and health data show that the chances of morbidity effects are small (may have impacts on respiratory system) at ambient air levels below the standards.
	Environmental resources	*Impacts are unknown (S3)*: it is uncertainty for the degree of impacts on local environmental resources. May have impacts on litchi forest and Lingding Sea Natural Reserves.
Gasses Nox	Human health: increased morbidity	*Impacts be small (S2):* The standards be met, and health data show that the chances of morbidity effects are small
	Environmental resource	*Impacts are uncertain (S3):* may contribute to the photochemical smog and greenhouse effects
Gasses Oxidants (ozone)	Human health: increased mortality and morbidity	*Health impacts are uncertain but may be quantified (S4):* the concentration of ozone has not been estimated, but NOx emissions could increase them. Evidence suggest that some health effects can occur at levels below the ozone standards, and these effects can be quantified
	Human welfare: material damages, resource use (damage on production)	*human welfare impacts can be quantified and valued(S4):* Oxidants can degrade some material. Elevated ozone levels can reduce crop and forest yields
	Environmental resources: Terrestrial ecosystems	*impacts are unknown (S3):* there is no literature about the damage on terrestrial ecosystems by ozone, although there may be some damages
Gasses GHG CO2	Global Climate Change	*impacts are uncertain, but can be estimated (S4):* may use the research results of other studies, but the results are highly uncertain.
Aerosols/ particulate (PM-10) from TSP,SO2, NOx emission	Human health: increased morbidity, mortality	*Health impacts can be quantified and valued (S4)*: Ambient concentration is below China's standards. There are some data on the concentration and total amount of emission
	Human welfare: aesthetics, materials damages	*welfare impacts can be quantified and valued (S4)*: Fine particulate can reduce visual range. The impacts can be quantified using US values, but visibility may not have value in developing countries. Materials damage can also be quantified, but US values may not be transferable to developing countries
	Environmental resource:	*impact on environmental resource are uncertain (S3)*
Particulate> PM-10 TSP	Human welfare: aesthetics, materials soiling	*impacts will be mitigated (S1)*: the installation of high efficient electrostatic precipitator will mitigate these damages
	Environmental resources	*impacts are probably small (S2)*
Electro-magnetic radiation (EMR)	Human health: increased morbidity Human welfare: resource use	*impacts are uncertain(S3):* Scientific evidence is inconclusive for health or welfare effects related to EMR exposure.
Noise	Human welfare	*impacts are mitigated (S1)*

Potential emission/Stressor to water		
Hazardous chemicals Inorganic Metals	Human health: increased morbidity, mortality Environmental resources: freshwater ecosystems	*impacts are mitigated (S1):* by wastewater treatment and proper plant operation
waste product	Human health: increased morbidity Environmental resources: aquatic ecosystem	*impacts are mitigated (S1):* by proper operation of the wastewater treatment system
Acid deposition	Human welfare: resource use Environmental resources: freshwater ecosystem	*impacts are uncertain (S3):* impacts are not quantified at EIS, may be significant if sensitive fisheries are affected *impacts are uncertain (S3):* impacts are not quantified at EIS, may be significant if sensitive water body are affected
Water diversion/ withdraw	Environmental resources: freshwater ecosystems	*Impacts are uncertain or small (S3):* if water being heavily withdraw and used, the impacts may be big
Thermal alteration	Human welfare: resource use Environmental resources: marine ecosystems	*Impacts are uncertain, but can be quantified (S3,S4):* can be based on mitigation costs *Impacts are uncertain(S3):* the impacts are not quantified in EIS
Potential emission/Stressor to land		
Hazardous chemicals Inorganic Metals	Human health: increased morbidity, mortality Environmental resources: groundwater	*Impacts are mitigated (S1):* properly built managed and monitored ash pond will minimize the impacts from coal ash leakage
waste products	Human health: increased morbidity	*Impacts are mitigated (S1):* proper disposal of the wastes
Acid deposition	Human welfare: resource use Environmental resources: terrestrial ecosystems	*Impacts are mitigated (S1):* low sulfur content coal will minimize acid deposition formation. But the impacts on agriculture, forest and so on should be paid attention since this area has been acid rain affected area *Impacts are uncertain (S3):* need to identify whether sensitive areas exist near Mawan Electricity Plant
Erosion	Human health: resource use Environmental resources: terrestrial ecosystems	*Impacts are mitigated (S1):* a retaining wall built
Land use: shoreline destruction	Environmental resources: biodiversity	*Impacts are unknown, mitigation measures are adopted(S1)*
land use: change from agriculture to industrial land use	Human welfare: social/cultural	*Impacts are unknown (S3)*

Note: [a] list of impacts on human health, welfare and environmental resources, and global system

Based on the screening classifications (S1-S4) shown in Table 2, the impacts of category S4 will be assigned full or partial economic valuation; category S3 impacts will be qualitatively assessed and analysed separately; S2 impacts will be deleted from further analysis; and the costs associated with mitigation of S1 impacts will be included in calculations of pollution prevention cost (P_e).

Based on the identification and analysis of impacts described above, Table 3 shows the different models selected for this study.

Table 3. Models required for carrying-out quantitative analysis.

End Point Model Groups Selected
Air Quality Modeling
Air, Acid Deposition & Fishing
Air, Lead Emissions & Human Health
Air, Mercury & Human Health Effects
Air, Other Impacts
Air, Ozone & Crop Damage
Air, Ozone & Human Health Effects
Air, Particulate(PM-10) & Human Health
Air, Pollutants & Materials Damages
Air, Toxics & Human Health Effects
Air, Visibility Effects
Fuel Acquisition
Other Resource Impacts
Resource Security Impacts
Siting Impacts of Facilities
Waste Disposal
Water, Chemicals/Metals & Fisheries
Water, Chemicals/Metals & Human Health
Water, Consumption
Water, Impingement / Entrainment
Water, Other Impacts
Water, Thermal Discharges

5.0 ESTIMATION OF DOSE-RESPONSE FUNCTION AND MONETARY VALUATION PARAMETERS FOR POLLUTANTS

5.1 Estimation of Damages by Air Pollutants

5.1.1 Human Health Effects of Air Pollutants

Human Health Effects of PM-10

With regards to human health effects, particulate that cause the greatest damage are those under 10 microns in aerodynamic diameter (PM-10) since they are small enough to enter into the airways of the lungs. PM-10 comes from the smoke and soot directly emitted, or indirectly as the secondary pollutants of SO_2 and NOx. Although the Mawan coal-fired electricity plant uses dust deducting equipment, when one considers the region as a whole, the removal is not that effective. Therefore, smoke and soot pollution is still a major source of pollution damages on human life and health.

China uses TSP as the regular monitoring indicator for dust. However, many studies show that PM-10 is the major factor causing health problems. Therefore, PM-10 is more accurate to indicate the dose for damages. In the model we run, we use PM-10 instead of TSP. Abbey and others (1993) studied the conversion factor for TSP and PM-10, and use a factor of 0.5-0.6. Brook (1997) studied data collected over a 10-year period from 19 monitoring stations and also determined the conversion coefficient for PM-10 and TSP to be 0.5-0.6. These studies are consistent with the research findings of the New York Study (R. Rowe, 1995). In this model we use 0.55 as the conversion factor. Therefore $C_{PM10} = 0.55 \times C_{TSP}$ [7]

The human health effects of PM-10 include mortality and respiratory disease. Studies show that the health problems and impacts related to PM-10 include: chronic bronchitis (CB), respiratory hospital admissions (RHA), asthma (AA), restricted activities days (RAD), acute respiratory symptoms (ARS), emergency room visits (ERV), and asthma for children. Formula [8] is used to calculate the dose-response of health effects of PM-10.

$$\Delta D_a = R \times \Delta PM10 \times POP \times N \quad [8]$$

In which,

ΔD_a	annual incremental cases of disease due to PM-10
R	dose-response coefficient (case/(day·ug/m^3))
ΔPM10	annual concentration change of PM-10
POP	affected population
N	days of PM-10 exceeding standards in one year

The dose-response coefficient estimation is therefore the key issue for estimating the health effects. There have been a number of studies conducted by Chinese researchers on the human health damages caused by air pollution (see Wang et al 1989; Wang et al 1993; Zhang et al. 1994, Chu 1993), and there appears to be no significant difference from findings of studies conducted in other countries. A recent joint research project between Chinese and international researchers examined human health effects of air pollution in China's urban areas (World Bank 1997). Dose-response functions were derived based on data collected in three case study cities (Beijing, Shenyang and Chongqing) and it was found that the functions were also very similar to those found in other countries. Given the similarities, we decided to use the dose response functions developed for the New York Study (EXMOD). These functions were developed based on the most comprehensive review of related research conducted in the US during the 1990's. The dose-response functions we used are shown in Table 4.

Table 4. Damage functions of health effects of PM-10.

Effects	Unit	Damage function					
		L	*P*	C	*P*	H	*P*
Mortality>=65	case/day*person*1μg/ m^3	10.1*10^{-8}	*33*	16.9*10^{-8}	*34*	25.4*10^{-8}	*33*
Mortality <65	case/day*person*1μg/ m^3	0.14*10^{-8}	*33*	0.23*10^{-8}	*34*	0.35*10^{-8}	*33*
CB (>=25)	case/year* 1μg/m^3	3.0*10^{-5}	*25*	6.1*10^{-5}	*50*	9.3*10^{-5}	*25*
RHA	case/day* 1μg/m^3	1.8*10^{-8}	*25*	3.3*10^{-8}	*50*	4.8*10^{-8}	*25*
ERV	case/day*1μg/m^3	3.2*10^{-7}	*25*	6.5*10^{-7}	*50*	9.7*10^{-7}	*25*
AA	day/day*1μg/m^3	0.9*10^{-4}	*33*	1.6*10^{-4}	*50*	5.4*10^{-4}	*17*
RAD (>=18)	day/day* 1μg/m^3	0.8*10^{-4}	*33*	1.6*10^{-4}	*34*	2.5*10^{-4}	*33*
ARS	day/day*1μg/m^3	2.2*10^{-4}	*25*	4.6*10^{-4}	*50*	7.0*10^{-4}	*25*
Asthma for children (<18)	case/year* 1μg/m^3	0.8*10^{-3}	*25*	1.6*10^{-3}	*50*	2.4*10^{-3}	*25*

Note: L refers to low value; C refers to central value; H refers high value; P refers to probability (%).
Source: A.D. Rowe, 1995; Schwardz, 1992.

Since some double counting may exist between the indicators shown in Table 4, we adjust the functions in the GDMOD as following:

The average days for staying in hospital for a RHA case is 9.5 days (based on China's Health Statistical Year Book 1996);

$\text{ERV}_{adjusted}$ = ERV-RHA

$\text{RAD}_{adjusted}$ = [RAD-(r·9.5days·RHA) – (r·$\text{ERV}_{adjusted}$) - r·AA], in which, r refers to the proportion of population over age 18;

$\text{ARS}_{adjusted}$ = ARS - RAD

Human Health Effects of Ozone

Ozone has some obvious impacts on human health, including morbidity, respiratory hospital admissions (RHA), asthma (AA), minimum restricted activities days (MRAD), and acute respiratory symptoms (ARS). Formula [9] is used to calculate the human health effects of ozone.

$$\Delta D_a = R \times \Delta O_3 \times POP \times N \qquad [9]$$

In which,

ΔD_a annual incremental cases of disease due to PM-10

R dose-response coefficient (case/(day·ug/m^3)

ΔO_3 annual average of daily changes in high-hour ozone

POP affected population

N days of ozone exceeding standards in one year

Since there is no study on human health effects by ozone available in China, we use the functions used in EXMOD which are shown in Table 5. Due to the possibility of double counting, the following adjustments were made:

$\text{MRAD}_{adjusted}$ = MRAD – AA

$\text{ARS}_{adjusted}$ = ARS - MRAD

Table 5. Dose-response functions of human health effects of O_3.

Effects	Unit	Dose-response					
		L	*P*	C	*P*	H	*P*
Mobility	Case/day*1ppm	0.0	*33*	$3.3*10^{-6}$	*34*	$6.6*10^{-6}$	*33*
RHA	Case/day*1ppm	$8.4*10^{-6}$	*33*	$13.7*10^{-6}$	*34*	$19.0*10^{-6}$	*33*
AA	Case/day*1ppm	$1.06*10^{-1}$	*33*	$1.88*10^{-1}$	*50*	$5.20*10^{-1}$	*17*
MRAD	Day/day*1ppm	$1.93*10^{-2}$	*25*	$4.67*10^{-2}$	*50*	$7.40*10^{-2}$	*25*
ARS	Day/day*1ppm	$0.73*10^{-2}$	*25*	$1.37*10^{-2}$	*50*	$2.04*10^{-2}$	*25*

Note: L refers to low value; C refers to central value; H refers high value; P refers to possibility (%).
Source: A.D. Rowe, 1995; Schwardz, 1992.

Human Health Effects of Lead and Mercury

Lead and mercury are emitted into the air with soot produced during coal combustion. Exposure can occur through breathing and ingestion (foods and liquids). Epidemiological studies have found that PbB levels can lead to higher rates of hypertension, nonfatal heart attacks, nonfatal strokes and risks of premature death for adult men. In children age 1-7, potential effects include reduced stature, impaired hearing, behavioral changes, interference with nervous system development, metabolic effect, impaired heme synthesis, anemia, and possible cancer. Mercury is a common heavy metal found in coal and is very volatile. Uptake of mercury at elevated levels may cause paraesthesia of the extremities, psychomotor retardation in prenatal exposed infants, neuro-response in young children and other adverse health effects. Effects of mercury exposure are quite complex and difficult to quantify. As a result, we use the damage value per unit of pollutant used in the New York Electricity Externality Study, after adjusting for per capita GDP values, to directly calculate the damages (see Table 6).

Formula [10] and [11] are used to calculate the human health effects of lead and mercury.

$$E_{il} = R_{jl} \bullet POP \bullet C_{il} \qquad [10]$$

in which,

E_{li} damages due to health effects of lead

POP population exposed to lead

C_{il} incremental lead level produced by electricity plant

R_{il} damage function of lead

$$E_{ik} = R_{jk} \bullet C_{ik} \qquad [11]$$

in which,

E_{ik} damages due to health effects of mercury

C_{ik} incremental mercury level produced by electricity plant

R_{i} damage function of mercury

Table 6. Damage functions for human health effects of lead and mercury.

Effects	Unit	Damage function					
		L	*P*	C	*P*	H	*P*
Health effects of lead	$/(person*μg/dl)	0.53	*33*	1.61	*34*	8.6	*33*
Health effects of mercury	$/Kg	0.35	*25*	6.95	*50*	41.0	*25*

Note: 1) L refers to low value; C refers to central value; H refers high value; P refers to probability (%).
2) The value here is subjected to adjust by GNP ratio
Source: A. D. Rowe, 1995; Schwardz; 1992.

Human Health Effects of Radiation

Radiation can cause various health effects. The dose received by an individual can be used as an indicator of the damage caused by radiation. Formula [12] is used to estimate the health effects of radiation.

$$E_R = R \bullet r \bullet POP / 1000 \qquad [12]$$

in which,

E_R	value of damages caused by radiation
R	value of damages per unit radiation
r	radiation exposure/person/year due to 1000MW electricity plant
POP	affected population

It is estimated in the EXMOD model that the incremental radiation produced by a 1000 MW coal fired electricity on local area is $1.33 \cdot 10^{-3}$ rem/(person·year·1000MW).

Human Health Impacts of Air Toxics

Air toxics included here are the suspected carcinogenic air emissions such as As, Be, Cd, Cr, Nickel, and POMs□BaP□. Uptake of these pollutants can happen through breathing and ingestion (food and liquids).

According to the US EPA's Integrated Risk Information System (IRIS) (see USEPA 1992), the dose response functions of air toxics are:

$$\Delta D_i = POP_i \cdot \Delta C_i \cdot RF_i / 70 \qquad [13]$$

In which,

ΔD_i	incremental case of cancer by pollutant *i*
ΔC_i	incremental concentration of pollutant *i*
RF_i	cancer risk factor for inhalation for chemical *i* (which refers to 1 incremental concentration exposure in one's life time, 70 years)
POP	affected population

The value we used of RF_i is shown in Table 7[5].

Table 7. Damage functions of selected toxic chemicals.

Pollutants	Damages	Rfi (μg/m3)
As	Respiratory	0.004
Cd	Respiratory	0.002
Cr	Lung	0.012
Ni	Respiratory	0.001
Bap	Respiratory	0.017

Source: USEPA 1992.

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[5] Most of the Chinese studies focused on BaP (see Chen Bingyan 1992).

Valuation for Human Health Effects

There are several different ways to estimate the economic costs of human health effects. The Willingness to Pay (WTP), Cost of Illness (COI) and Human Capital Approaches are three common methods. However, given the difficulties associated with data and information collection, for this study we use the technology transfer methodology to estimate the human effects in monetary terms.

Usually, the estimation based on WTP is much higher than on COI (Pearce and Markandya 1989; R. Rowe 1995). According to research conducted by the Chinese Academy of Social Sciences, the monetary value assigned to human life in 1992 for China was about 160,000 yuan (World Bank 1997). In the affected areas of the Mawan Electricity Plant, the per capita GDP is higher than the national average. We therefore adjust the average life value using GNP ratios and values calculated in other countries to assign life values for the areas around the Mawan Plant (see Table 8 and Table 9). Given the arguments for and against benefit transfer approach as well as the value of human life approach, we present final results two ways -- once with costs of deaths included in total damages and once with deaths left out of the cost calculation.

Table 8. The estimation for life value (converted by GNP ratio).

Effects	Population	Life value(10,000 yuan/person, 1992 RMB)		
		L	C	H
Mortality	>age 65	23	47	94
Mortality	<age 65	31	62	126
Mortality	All population	29	58	106
Mortality	Children	31	62	126
	Probability Weight	33%	50%	17%

Sources: Calculated based on Cropper 1991; Fisher 1989; Miller 1989; Moore 1988.

Table 9. The cost estimation for illness (converted by GDP).

Illness	Unit	Yuan,1992 RMB			Primary resource	Type of Estimate
		L	C	H		
CB (adult)	yuan/person	1,980	3,309	5,200	Cropper et al, 1991; Miller, 1989	WTP
RHA	yuan/case	1,100	2,200	3,300	Viscusi et al, 1991	Adjusted COI
ERV	yuan/case	42	83	125	Krupnick et al, 1992	Adjusted COI
CB (children)	yuan/case	21	42	64	Viscusi et al, 1991	Adjusted COI
RAD (>=18)	yuan/case	5.5	11	16.5	Abbey et al, 1993	WTP & adjusted COI
AA	yuan/day	1.9	5.3	8.7	Loehman et al, 1979	WTP
MRAD	yuan/day	2.4	3.8	6.5	Abbey et al, 1993; Rowe et al, 1986	WTP
ARS	yuan/day	0.8	1.6	2.4	Abbey et al., 1993; Rowe et al., 1986	WTP
Probability weight		33%	34%	33%		

5.1.2 Damage to crops by SO2 and acid deposition

Studies on the dose-response functions for SO2 and acid deposition for agricultural crops have been done in China (see Cao et al. 1991, Zhang 1997). Cao et al focused on Guangdong and Guangxi Province, making their results most appropriate for use in this study. Given that there is a direct relationship between SO2 emissions and acid deposition, we use the following formula to calculate the damages to various crops. The calculated results are shown in Table 10.

$$\Delta Qi = \Sigma Ri \cdot \Delta C_{SO2j} \cdot Qij$$

$$\Delta Vi = \Delta Qi \cdot Pi = Pi \cdot \Sigma Ri \cdot \Delta C_{SO2j} \cdot Qij = \Sigma Ri \cdot \Delta C_{SO2j} \cdot Vi \qquad [14]$$

In which,

ΔVi	losses to crop i
ΔQi	production loss of crop i
Pi	market price of crop i
Ri	damage functions for crop i
ΔC_{SO2j}	incremental value of SO2 at region j
Qij	total production of crop i at region j
Vij	total output value of region j.

Table 10. Damage functions for agricultural losses caused by SO2 and acid deposition

Crops	Unit	Damage function					
		L	*P*	C	*P*	P	*P*
Rice, soybeans, ground nuts, etc.	%/μg/m3	0.018	*33*	0.021	*34*	0.025	*33*
Wheat, fruits, etc.	%/μg/m3	0.025	*33*	0.029	*34*	0.033	*33*
Vegetables	%/μg/m3	0.038	*33*	0.048	*34*	0.063	*33*

Source: Calculated based on Cao et al., 1991.

5.1.3 Material damages by acid deposition

An empirical study conducted by Yang Zhiming et al (1997) provides dose-response functions for various materials, such as covering materials, marble, galvanized steel, and steel. Based on the findings of this study, the relevant damage functions for materials can be estimated. We use formula [15] to estimate the cost of materials damages caused by acid deposition.

$$E = \sum R \cdot \Delta C_{so2i} \cdot HH_i \qquad [15]$$

In which,

E	material damages cost by SO2 and acid deposition
R	damage function
ΔC_{so2i}	incremental concentration of SO2 at receptor cell k
HH_i	number of households at receptor cell k

Yang (1997) developed the following dose-response functions that we used as the input for R in formula [15].

For covering materials: $R = 5.61 + 2.84SO_2 + 0.74 \times 10^4[H^+]$

For marble: $R = 14.53 + 23.81SO_2 + 3.8 \times 10^4[H^+]$

For galvanized steel: $R = 0.43 + 4.47SO_2 + 0.95 \times 10^4[H^+]$

For steel: $R = 39.28 + 81.41SO_2 + 21.2 \times 10^4[H^+]$

In which, R refers to the speed of the corrosion (um/year); SO2 refers to the concentration of the SO2; [H^+] refers to the concentration of [H^+] of rainfall (mol/L).

5.2 Estimation of Damages by Waste Water Pollution

The wastewater discharged by the Mawan Electricity Plant includes mainly domestic wastewater; cleaning wastewater, wastewater from ash flushing, and thermal wastewater. The wastewater has been treated primarily before discharging. However, the heavy metals and toxics in cleaning wastewater and wastewater from ash ponds may have an impact on the environment and it is difficult to quantify these impacts. Large amounts of thermal water discharged may also have impacts on the ocean ecological system.

In this study, we use the cost for water treatment (outside of the plant) to estimate the environmental cost of wastewater pollution. Specifically, we use the secondary treatment cost for urban wastewater to calculate the losses produced by the wastewater released by the Mawan Plant. Based on Shanghai Monitoring Institute (1996), the treatment costs are: 1.2 yuan/ton for domestic wastewater,2 yuan /ton for rinsing water, 1 yuan/ton for ash flushing water and 0 yuan for thermal water[6]. Table 11 shows the treatment costs of wastewater.

Table 11. Wastewater discharges and treatment costs.

	Annual discharge (1,000 tons)	Treatment cost (yuan/ton)	Total loss (yuan1000)
Domestic waste water	14.4	1.2	17.3
Rinsed water	24.0	2.0	48.0
Ash sewage	3,600.0	1.0	3,600.0
Thermal water	13,000.0	0.0	0
Total			3,665.0

5.3 Environmental Impacts Valuation Results for the Mawan Electricity Plant

Using the procedures and parameters described in the previous sections, we developed and ran the GDMOD. In this section we present the valuation results first by region then by type of pollutant.

5.3.1 Damages based on geographic division

Table 12a and Table 12b summarize the annual average total costs calculated for each environmental externality group, broken down into 4 subregions. The total

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[6] The Environmental Impact Assessment Report for the Mawan Plant states that the thermal water will not produce significant impacts.

environmental externalities produced annually, if mortality valuation is included, is $3.8 million to $6.7 million (see Table 12a). If mortality numbers are not monetarily converted then the total annual externalities total from $2.4 million to $ 4.9 million with the number of deaths ranging from 4.4 to 26.2. The results also show that pollution produced by the Mawan Electricity Plant imposed significant impacts on remote areas (rest-of- province and out-of-province). These remote areas account for 78.4% to 84.1% of the total environmental damages. Such a situation is perhaps due to the use of high stacks for emissions, which will increase pollution dispersion towards more remote regions.

Table 13a and Table 13b show the annual average externality cost per kWh of power generation, similarly broken down by externality group and geographic region. The environmental cost for generating one kWh of electricity ranges from $\$1.028\times10^{-3}$ to 1.832×10^{-3} (1992 prices). Converted to 1997 prices, the cost would be $\$1.8117\times10^{-3}$/kWh to $\$3.2286\times10^{-3}$/kWh, which is 0.015 yuan/kWh to 0.027 yuan/kWh. Currently, the electricity price at firm gate is 0.52 yuan/kWh. Therefore, the costs associated with environmental damages range from 2.9% to 5.2% of the current price of electricity.

Table 12a. Annual average total externalities by geographic divisions (Monetary valuation for mortality is included).

Geographic Division	Externality Group	Damages ($1,000)[7]		
		Low (20%)	Central (average)	High (80%)
Local				
	Air	17.171	31.514	48.234
	Water	287.946	575.893	863.839
	Land / Waste	22.500	52.200	81.300
	Other	0.000	0.000	0.000
	Local Subtotal	327.618	659.607	993.373
Rest-of-Region				
	Air	272.579	369.900	462.832
	Water	0.000	0.000	0.000
	Land / Waste	0.000	0.000	0.000
	Other	0.000	0.000	0.000
	Rest-of-Region Subtotal	272.579	369.900	462.832
Rest-of-Province				
	Air	1,268.054	1,695.433	2,102.519
	Water	0.000	0.000	0.000
	Land / Waste	0.000	0.000	0.000
	Other	0.000	0.000	0.000
	Rest-of-Province Subtotal	1,268.054	1,695.433	2,102.519

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[7] Low and high totals may not sum because of Central Limit Theorem.

Out-of-Province				
	Air	1,914.204	2,563.237	3,179.375
	Water	0.000	0.000	0.000
	Land / Waste	0.000	0.000	0.000
	Other	0.000	0.000	0.000
	Out-of-Province Subtotal	1,914.204	2,563.237	3,179.375
Total Externalities		**3,782.455**	**5,288.177**	**6,738.100**

Table 12b. Annual average total externalities by geographic divisions (Monetary valuation for mortality is excluded).

Geographic Division	Externality Group	Damages ($1,000)		
		Low (20%)	Central (average)	High (80%)
Local				
	Air	21.051	31.942	44.514
	Water	287.946	575.893	863.839
	Land / Waste	22.500	52.200	81.300
	Other	0.000	0.000	0.000
	Local Subtotal	331.498	660.035	989.653
	Mortality(deaths)	*0.006*	*0.033*	*0.098*
Rest-of-Region				
	Air	161.179	225.900	295.832
	Water	0.000	0.000	0.000
	Land / Waste	0.000	0.000	0.000
	Other	0.000	0.000	0.000
	Rest-of-Region Subtotal	161.179	225.900	295.832
	Mortality (deaths)	*0.311*	*0.812*	*1.273*
Rest-of-Province				
	Air	766.054	1,067.433	1,387.519
	Water	0.000	0.000	0.000
	Land / Waste	0.000	0.000	0.000
	Other	0.000	0.000	0.000
	Rest-of-Province Subtotal	766.054	1,067.433	1,387.519
	Mortality (deaths)	*1.275*	*5.972*	*10.305*
Out-of-Province				
	Air	1,132.204	1,653.237	2,189.375
	Water	0.000	0.000	0.000
	Land / Waste	0.000	0.000	0.000
	Other	0.000	0.000	0.000
	Out-of-Province Subtotal	1,132.204	1,653.237	2,189.375
	Mortality (deaths)	*2.771*	*8.992*	*14.731*
Total Externalities		**2,390.935**	**3,606.605**	**4,862.380**
Total Mortality(deaths)		***4.364***	***15.743***	***26.212***

Table 13a. Annual average externality per kWh generated (monetary valuation for mortality is included).

Geographic Division	Externality Group	Damages ($mills/kWh)*		
		Low (20%)	Central (average)	High (80%)
Local				
	Air	0.005	0.009	0.013
	Water	0.078	0.157	0.235
	Land / Waste	0.006	0.014	0.022
	Other	0.000	0.000	0.000
	Local Subtotal	0.089	0.179	0.270
Rest-of-Region				
	Air	0.074	0.101	0.126
	Water	0.000	0.000	0.000
	Land / Waste	0.000	0.000	0.000
	Other	0.000	0.000	0.000
	Rest-of-Region Subtotal	0.074	0.101	0.126
Rest-of-Province				
	Air	0.345	0.461	0.571
	Water	0.000	0.000	0.000
	Land / Waste	0.000	0.000	0.000
	Other	0.000	0.000	0.000
	Rest-of-Province Subtotal	0.345	0.461	0.571
Out-of-Province				
	Air	0.520	0.697	0.864
	Water	0.000	0.000	0.000
	Land / Waste	0.000	0.000	0.000
	Other	0.000	0.000	0.000
	Out-of-Province Subtotal	0.520	0.697	0.864
Total Externalities		**1.028**	**1.437**	**1.832**

Note: * 1 mill = $0.001

Table 13b. Annual average externality per kWh generated (monetary valuation for mortality is excluded).

Geographic Division	Externality Group	Damages ($mills/kWh)*		
		Low (20%)	Central (average)	High (80%)
Local				
	Air	0.006	0.009	0.012
	Water	0.078	0.157	0.235
	Land / Waste	0.006	0.014	0.022
	Other	0.000	0.000	0.000
	Local Subtotal	0.090	0.179	0.269
	Mortality (deaths/million kWh)	*0.000*	*0.000*	*0.000*
Rest-of-Region				
	Air	0.044	0.061	0.080
	Water	0.000	0.000	0.000
	Land/Waste	0.000	0.000	0.000
	Other	0.000	0.000	0.000
	Rest-of-Region Subtotal	0.044	0.061	0.080
	Mortality (deaths/million kWh)	*0.0001*	*0.0002*	*0.0003*
Rest-of-Province				
	Air	0.208	0.290	0.377
	Water	0.000	0.000	0.000
	Land / Waste	0.000	0.000	0.000
	Other	0.000	0.000	0.000
	Rest-of-Province Subtotal	0.208	0.290	0.377
	Mortality (deaths/million kWh)	*0.0003*	*0.0016*	*0.0028*
Out-of-Province				
	Air	0.308	0.449	0.595
	Water	0.000	0.000	0.000
	Land / Waste	0.000	0.000	0.000
	Other	0.000	0.000	0.000
	Out-of-Province Subtotal	0.308	0.449	0.595
	Mortality (deaths/million kWh)	*0.0008*	*0.0024*	*0.0040*
Total Externalities		**0.650**	**0.980**	**32**
Mortality (deaths/million kWh)		***0.001***	***0.004***	***0.007***

Note: * 1 mill = $0.001

5.3.2 Damages produced by each major pollutant

By breaking down the external costs in terms of pollutant type, the environmental costs imposed by each major pollutant can be compared and the key pollutants and environmental impacts can be identified.

The annual average externalities produced by major pollutants are presented in Table 14.a, 14.b and the present value of total externalities of major pollutants are shown in Table 15.a and Table 15.b. From the tables, one will find that air pollutants are the major sources of environmental externalities. They account for 86.0% to 91.9% of the total damages, while SO2, NOx, and particulates (PM-10), the three major pollutants, alone account for 80.5% to 90.0% of the total damages. SO2 is the largest contributor among the air pollutants, with the damages accounting for 66.6% to 70.3% of the damages caused by air pollution and accounts for 56.4% to 64.0% of total damages. The second largest contributor is NOx, with the damages accounting for 22.2% to 22.7% of the damages caused by air pollution and 19.5% to 20.4% of total damages; the third largest contributor is PM-10, which accounts for 5.2% to 5.3% of the damages by air pollution and 4.6% to 4.8% of the total damages.

Table 14a. Annual average externalities produced by major pollutants (Monetary valuation for mortality is included).

Externality Group	Damages ($1,000)		
	Low (20%)	Central (average)	High (80%)
Air			
Greenhouse Gas / CO2	N/A(1)	N/A	N/A
Lead	48.900	148.000	231.000
Mercury	0.158	0.406	0.626
Nitrogen Oxides	755.000	1,060.000	1,330.000
Particulate (PM10)	177.000	248.000	312.000
Radioactivity	0.002	0.010	0.017
Sulphur dioxide	2,388.409	3,136.474	3,898.750
Toxic	28.000	58.500	84.500
Air Subtotal	*3,397.469*	*4,651.390*	*5,856.893*
Water			
Sewage	287.946	575.893	863.839
Toxic in Ash	0.000	0.000	0.000
Water Subtotal	*287.946*	*575.893*	*863.839*
Land / Waste			
Land Use / Noise / Terrestrial	13.100	25.000	36.500
Volume / Land Use	0.000	27.200	53.900
Land / Waste Subtotal	*13.100*	*52.200*	*90.400*
Total Externalities	**3,698.515**	**5,279.483**	**6,811.133**

Note: Due to the arguments and large uncertainty related to the damages of climate change, we did not include the CO2 effects.

Table 14b. Annual average externalities produced by major pollutants (Monetary valuation for mortality is excluded).

Externality Group	Damages ($1,000)		
	Low (20%)	Central (Ave.)	High (80%)
Air			
Greenhouse Gas / CO2	N/A	N/A	N/A
Lead	1.470	4.430	6.940
Mercury	5.260	13.500	20.900
Nitrogen Oxides	365.000	547.000	730.000
Particulate (PM10)	78.400	128.000	177.000
Radioactivity	0.002	0.010	0.017
Sulphur Dioxide	1,653.409	2,276.474	2948.750
Toxic	1.560	3.520	5.190
Air Subtotal	*2,105.101*	*2,972.934*	*3,888.797*
Water			
Sewage	287.946	575.893	863.839
Toxic in Ash	0.000	0.000	0.000
Water Subtotal	*287.946*	*575.893*	*863.839*
Land / Waste			
Land Use / Noise / Terrestrial	13.100	25.000	36.500
Volume / Land Use	0.000	27.200	53.900
Land / Waste Subtotal	*13.100*	*52.200*	*90.400*
Total Externalities	**2,406.147**	**3,601.027**	**4,843.037**
Total Mortality (deaths)	***4.364***	***15.743***	***26.212***

Table 15a. Present value of total externalities of major pollutants (Monetary valuation for mortality is included)

Externality Group	Damages ($1,000)		
	Low (20%)	Central (Ave.)	High (80%)
Air			
Greenhouse Gas / CO2	N/A	N/A	N/A
Lead	398.697	1,206.692	1,883.417
Mercury	1.288	3.310	5.104
Nitrogen Oxides	6,155.758	8,642.522	10,843.919
Particulate (PM10)	1,443.138	2,022.024	2,543.837
Radioactivity	0.016	0.082	0.139
Sulphur Dioxide	19,473.467	25,572.683	31,787.767
Toxic	228.293	476.969	688.956
Air Subtotal	*27,700.658*	*37,924.281*	*47,753.139*
Water			
Sewage	2,347.714	4,695.427	7,043.141
Toxic in Ash	0.000	0.000	0.000
Water Subtotal	*2,347.714*	*4,695.427*	*7,043.141*
Land / Waste			
Land Use / Noise / Terrestrial	106.808	203.832	297.596
Volume / Land Use	0.000	221.770	439.463
Land / Waste Subtotal	*106.808*	*406.602*	*737.058*
Total Externalities	**30,155.187**	**43,045.325**	**55,533.359**

Table 15b. Present value of total externalities of major pollutants (Monetary valuation for mortality is excluded).

Externality Group	Damages ($1,000)		
	Low (20%)	Central (average)	High (80%)
Air			
Greenhouse Gas / CO2	N/A	N/A	N/A
Lead	11.985	36.119	56.584
Mercury	42.886	110.070	170.404
Nitrogen Oxides	2,975.955	4,459.855	5,951.909
Particulate (PM10)	639.219	1,043.622	1,443.134
Radioactivity	0.016	0.082	0.139
Sulphur Dioxide	13,480.740	18,560.770	24,042.050
Toxic	12.719	28.700	42.316
Air Subtotal	*17,163.520*	*24,239.220*	*31,706.530*
Water			
Sewage	2,347.714	4,695.427	7,043.141
Toxic in Ash	0.000	0.000	0.000
Water Subtotal	*2,347.714*	*4,695.427*	*7,043.141*
Land / Waste			
Land Use / Noise / Terrestrial	106.808	203.832	297.596
Volume / Land Use	0.000	221.770	439.463
Land / Waste Subtotal	*106.808*	*406.602*	*737.058*
Total Externalities	**19,618.040**	**29,360.250**	**39,486.730**
Total Mortality (death)	***130.915***	***472.282***	***786.347***

Damages by SO2

As stated above, SO2 is the major contributor to the environmental externalities associated with power production at the Mawan Plant. Table 16 and Table 17 show the different types of damage in physical and monetary terms produced by SO2. SO2 emissions result in the deaths of about 5-13 persons per year, while the costs of other damages totals from $1.65 million to $2.95 million a year. Of these costs, damages to crops total $0.79 million to $1.16 million or 39.3% to 47.7% of the damages caused by SO2.

Table 16. The annual damages caused by sulphur dioxide.

Damage	Unit	Low (20%)	Central (average)	High (80%)
AA	10^4 Occurrence-Day	0.297	0.684	0.977
CB (Child)	10^3 Person	0.304	0.594	0.862
CB (Adult)	10^2 Person	0.438	0.855	1.240
ERV	10^3 Visit	0.249	0.487	0.707
ARS	10^6 Occurrence-Day	0.130	0.257	0.375
RHA	10^2 Admission	0.137	0.261	0.377
RAD	10^5 Occurrence-Day	0.491	0.995	1.458
Visibility Loss	10^5 Dollars	1.685	2.906	4.068
Materials Soiling	10^6 PM-10 ug/m3*households	0.495	0.826	1.157
Mort Over 65 (Part.)	Death	3.990	7.610	10.940
Mort Under 65 (Part.)	Death	0.922	1.799	2.606

Table 17. Valuation of damages caused by SO2.

Damage	Damages ($1,000)		
	Low (20%)	Central (average)	High (80%)
AA	2.970	6.770	9.170
Child CB	2.030	4.580	6.780
CB	25.000	54.700	80.200
ERV	3.270	7.380	10.900
Materials Soiling	90.100	174.000	252.000
ARS	157.000	585.000	1,010.000
RHA	4.730	10.500	15.500
RAD	85.700	199.000	296.000
Visibility	169.000	291.000	407.000
Crop Damage	788.410	946.500	1,158.800
Total	**1,653.410**	**2,276.500**	**2,948.800**
Mortality (deaths)	***4.912***	***9.409***	***13.546***

Damages by Nox

Table 18 and Table 19 show the annual damages caused by Nox, both in physical and monetary terms. NOx emissions result in the deaths of 2-8 persons a year, while the cost of other damages ranges from $0.37 million to $0.73 million. Damages due to acute respiratory symptoms (ARS) cost $0.16 million to $ 0.52 million and account for 44.4% to 71.1% of damages associated NOx.

Table 18. Annual damage caused by NOx.

Damage	Unit	Low (20%)	Central (average)	High (80%)
AA	10^4 Occurrence-Day	0.607	1.137	1.557
CB (Child)	10^3 Person	0.066	0.123	0.177
CB (Adult)	Person	0.950	1.780	2.540
ERV	10^3Visit	0.054	0.101	0.145
ARS	10^6 Occurrence-Day	0.099	0.149	0.197
RHA	10^2 Admission	0.129	0.200	0.266
RAD	10^4 Occurrence-Day	0.107	0.207	0.299
MRAD(Ozone)	10^4 Occurrence-Day	0.198	0.381	0.554
Visibility Loss	10^4 Dollars	0.407	0.674	0.929
Materials Soiling	10^4 PM10 ug /(m3*hholds)	1.065	1.722	2.378
Mortality Over 65 (PM10)	Death	0.877	1.605	2.276
Mortality Under 65 (PM10)	Death	0.200	0.374	0.534
Mortality (Ozone)	Death	1.010	3.510	5.740

Table 19. Valuation of damages caused by NOx.

Damage	Damages ($1,000)		
	Low (20%)	Central (average)	High (80%)
AA	5.830	11.300	15.000
CB (Child)	0.449	0.955	1.390
CB (adult)	5.500	11.400	16.500
ERV	0.723	1.540	2.240
Materials Soiling	19.600	36.200	51.600
MRAD (O3)	13.200	29.100	42.800
ARS	162.000	340.000	519.000
RHA	4.710	8.010	10.900
RAD	19.000	41.500	60.700
Visibility	40.700	67.500	92.900
Total	**365.000**	**547.000**	**730.000**
Mortality (deaths)	***2.087***	***5.489***	***8.559***

Damage by Particulate

Table 20 and Table 21 shows the annual damages by particulate both in physical and monetary terms. Particulate emissions result in the deaths of 0.7-1.9 persons a year, while the cost of other damages ranges from $78,400 to $177,000. Damages due to ARS is $23,100 to $ 117,000 and accounts for 29.5% to 66.1% of the damages caused by particulate.

Table 20. Damages caused by particulate.

Damage	Unit	Low (20%)	Central (average)	High (80%)
AA	10^4 Occurrence-Day	0.039	0.081	0.114
CB (Child)	10^3 Person	0.039	0.071	0.100
CB (Adult)	10^2 Person	0.056	0.102	0.144
ERV	10^3 Visit	0.032	0.058	0.082
ARS	10^6 Occurrence-Day	0.016	0.030	0.043
RHA	10^2 Admission	0.017	0.031	0.044
RAD	10^5 Occurrence-Day	0.064	0.119	0.169
Visibility Loss	10^5 Dollars	0.019	0.031	0.043
Materials Soiling	10^5 PM10 ug/m3*hholds.	0.628	0.990	1.352
Mortality Over 65	Death	0.592	1.108	1.584
Mortality Under 65	Death	0.118	0.213	0.300

Table 21. Valuation of damages caused by particulate.

Damage	Damages ($1,000)		
	Low (20%)	Central (average)	High (80%)
AA	0.394	0.812	1.070
Child CB	0.270	0.549	0.790
CB	3.300	6.560	9.350
ERV	0.434	0.885	1.270
ARS	23.100	70.000	117.000
RHA	0.626	1.250	1.800
RAD	11.400	23.900	34.500
Visibility	1.930	3.150	4.300
Materials Soiling	11.700	20.800	29.300
Total	**78.4**	**128**	**177**
Mortality (deaths)	***0.710***	***1.320***	***1.880***

5.3.3 Damages per physical unit of emissions

Table 22a and Table 22b summarise the total emissions and damages per unit emissions of major pollutants. Although the particulate emissions is not much in comparison with SO2, it has the highest damages per unit at $592/ton to $1040/ton; while SO2 damages per unit emission is from $106.24/ton to $173.50/ton. The treatment cost for SO2 in China is currently estimated to be less than $100 per ton. This difference between damage and treatment costs for SO2 should provide further evidence in support of increasing levels of SO2 levies or charges to encourage polluters to reduce SO2 emissions. Further efforts to control pollution is cost effective since the marginal cost of damages is higher than the marginal treatment cost.

Table 22a. Annual damages per physical unit emissions (Monetary valuation for mortality is included)

Air Pollutant	Annual Emissions	Damages			
		Unit	Low (20%)	Central (average)	High (80%)
Particulate	299.00 Tons	$/ton	592.000	830.000	1,040.000
Nitrogen Oxides	4,710.00 tons	$/ton	160.000	226.000	282.000
Sulphur Dioxide	22,500.00 tons	$/ton	106.240	139.670	173.500
Lead	1,010.00 lbs.	$/lb	1.460	4.410	6.910
Mercury	340.00 lbs.	$/lb	15.400	39.800	61.400
Arsenic	693.00 lbs.	$/lb	0.060	0.200	0.310
Beryllium	69.50 lbs.	$/lb	0.020	0.040	0.040
Chromium	208.00 lbs.	$/lb	0.070	0.180	0.270
Nickel	243.00 lbs.	$/lb	0.000	0.000	0.000
POMs	104.00 lbs.	$/lb	13.200	32.000	48.000

Table 22b. Annual damages per physical unit of emissions (Monetary valuation for mortality is excluded)

Air Pollutant	Annual Emissions	Damages			
		Unit	Low (20%)	Central (average)	High (80%)
Particulate	299.0 Tons	$/ton	262.00	428.00	591.00
		Mortality (death/ton)	*0.0060*	*0.0110*	*0.0150*
Nitrogen Oxides	4,710.0 tons	$/ton	77.40	116.00	155.00
		Mortality (death/ton)	*0.0003*	*0.0005*	*0.0008*
Sulphur Dioxide	22,500.0 tons	$/ton	73.44	101.27	131.00
		Mortality (death/ton)	*0.0002*	*0.0004*	*0.0006*
Lead	1,010.0 lbs.	$/lb.	1.46	4.41	6.91
Mercury	340.0 lbs.	$/lb.	15.40	39.80	61.40
Arsenic	693.0 lbs.	$/lb.	0.06	0.20	0.31
Beryllium	69.50 lbs.	$/lb.	0.02	0.04	0.04
Chromium	208.00 lbs.	$/lb.	0.07	0.18	0.27
Nickel	243.00 lbs.	$/lb.	0.00	0.00	0.00
POMs	104.00 lbs.	$/lb.	13.20	32.00	48.00

5.3.4 Summary

Table 23 summarizes the life cycle damages and damages per physical unit of emissions for each major pollutant. The present value of damages for SO2 is clearly the most significant one, with about $25.6 million in total damages. NOx ranks as second with a total present value of $8.6 million and particulate rank third with a total present value of $2.0 million.

Table 23. Ranking of damages by major pollutants.

Total damages in present value (in central value term)		Annual Emission	Damage per physical unit (in central value term)	
Rank	$1000		**Rank**	$/unit
Sulfur Dioxide	25,572.683	22,500 tons	Particulate (PM10)	830 $/ton
Nitrogen Oxides	8,642.522	4,710 tons	Nitrogen oxides	226 $/ton
Particulate (PM10)	2,022.024	299 tons	Sulfur oxides	139.7$/ton
Lead	1,206.692	1,010 lbs.	Mercury	39.80 $/lb.
Mercury	3.310	1,409 lbs.	Lead	4.41 $/lb.

The major conclusions that can be drawn from the analysis presented in this section are as follows:

- The regions over 80km away from the electricity plant suffer most of the damages, about 78.4% to 84.1% of the total;
- Air pollution is the most significant contributor to the total damages, with 86.0% to 91.9% of the externalities resulting from atmospheric pollutants;
- SO2, NOx, and particulate matter are the three major pollutants with highest damages. Together they account for 80.5% to 90.0% of the total damages, while SO2 accounts for 56.4% to 64.0%, NOx for 22.2% to 22.7%, and particulate for 4.6% to 4.8% of the total environmental costs;
- Damages produced per unit of particulate, NOx, and SO2 are significant with the values of $830/ton, $226/ton, and $139.7/ton respectively;
- Total environmental cost of electricity generation accounts for 2.9% to 5.2% of the current electricity price at firm gate.

6.0 POLICY IMPLICATIONS OF THIS STUDY

In most cities of China the concentrations of particulate matter and SO2 far exceed WHO guidelines of $70ug/m^3$ and $50ug/m^3$ respectively (Sunman et al., 1998). The results of this study suggest the importance and cost-effectiveness of increased control of TSP and SO2 emissions.

6.1 A More Effective Pollution Levy System on SO2 is Needed to Internalize the Externalities

The analysis above shows that the costs of environmental damages is the main factor leading to price distortion and accounts for 2.9% to 5.2% of the current firm gate price of electricity. Taking into account the current production cost of electricity generation at the Mawan Plant, which is about 0.31 yuan/kWh, if the environmental costs are internalized then the cost of electricity generation should be increased from 0.325 yuan/kWh to 0.337 yuan/kWh, which is an increase of 4.8% to 8.7% of the current production cost.

Levies or charges on pollutant emissions are necessary, especially for SO2. This study shows that SO2 emissions produce environmental costs of $106.24/ton to $173.50/ton, (or about 881.8 yuan/ton to 1440.1 yuan/ton), while the SO2 mitigation cost is about $100/ton (830 yuan/ton). China introduced a SO2 charge in 1992 on a trial basis at a rate of only200 yuan/ton emission. This rate is well below the damage costs of SO2, covering only 13.9% to 22.7% of the damages caused. If the levy or charge on SO2 were to reflect the full damage costs, they would help to encourage electricity producers to better mitigate the pollution and would bring greater environmental gains for the whole of society.

6.2 More Manageable Electricity Tariffs Are Needed

An important obstacle to the effective internalization of environmental externalities is the current electricity tariffs structure. More manageable electricity tariffs should be set up which would not only take into account the price at firm gate, but also demand-related issues such as user price, different end-uses and timing (e.g., peak versus off-peak use). A significant problem related to electricity tariffs in Shenzhen (and Guangdong Province) is that, the consumer price of electricity is already very high, with some users paying 1 yuan/kWh to 2 yuan/kWh, which is about 2-4 times the firm gate price, At the same time, the producers complain they earn very their low profits (some even operate at a deficit). The problem is due in part to the complicated and irrational price system, and to the fact that most of the profits are collected by those responsible for the distribution and transmission of electricity.

6.3 Other Implications

This study showed that the environmental damages produced by the Mawan Electricity Plant have greater effects on regions further from the plant. This finding has a number of important policy implications. When one includes all of Guangdong Province and surrounding regions into the damage valuation analysis, it may be necessary to re-examine whether the high stack is the best choice for mitigating pollution or whether other options might be better. Where the high stack strategy is used, a compensation scheme should be considered. If a compensation policy is needed, then the results in Table 12.a, 12.b and table 13.a and 13.b provide a reference baseline rate for the policy design.

The results of this study also have implications for emissions trading of SO2. SO2 emissions have long distance transport characteristics and may affect more than one air shed. With a permit trading scheme, the quota being treated should not only take into account the total emission, but also the geographic location of emissions as well as the potential damages per unit emission.

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