Energy and Acid Rain Projections for Northeast Asia – Full Text

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2020, under BAS conditions, emissions of nitrogen oxides are projected to increase to 38.9 mt, 3.5 times the 1990 value. This is an even more rapid growth than for sulfur dioxide, primarily because of the very large projected growth in transportation in the region. In 2020, Northeast China will be responsible for 69% of total NOx emissions, South Korea 13%, Japan 12%, and North Korea 6%. Thus, Northeast China's growing power and transportation sectors will outstrip Japan's in the next 30 years. Increasing NOx emissions also indicate an increase in generation of ozone, which will place an added burden on human health and the environment, especially in urban areas., "Energy and Acid Rain Projections for Northeast Asia – Full Text", NAPSNet Policy Forum, June 17, 1997, https://nautilus.org/napsnet/napsnet-policy-forum/energy-and-acid-rain-projections-for-n-rtheast-asia-full-text/

Energy and Acid Rain Projections for Northeast Asia

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Introduction

Northeast Asia is one of the most dynamic and diverse regions of the world. It contains one of the richest and most highly developed countries of the world, Japan, as well as some of the poorest and most backward areas in North Korea and rural China. It contains regions of extremely rapid growth in population, economic development, and industrial productivity: South Korea and Shanghai, for example. Millions are living in relative luxury; millions are near starvation. As the poorer regions strive to catch up to the more developed ones, the environment is often ignored or given only cursory attention. It often seems that national wealth is a prerequisite for pollution control. But in a region like Northeast Asia, where the rich live and work alongside the poor, all share the burden of environmental degradation. Increasingly, the need for regional cooperation in solving environmental problems becomes apparent. And none more so than with air pollution and acid rain, where the problems do not respect physical or geopolitical boundaries.

Background

For the purposes of this paper, Northeast Asia is defined to include Japan, South Korea, North Korea, and Northeast China. It is inappropriate to include all of China in Northeast Asia, so a region called Northeast China has been established, bounded on the West by the provinces of Inner Mongolia (eastern half), Shanxi, Henan, Anhui, and Zhejiang. The major sources of emissions that influence the Korean peninsular and Japan are located within this part of China. Although Chinese sources outside this region also exert some influence, as do sources as far away as Southeast Asia under certain large-scale cyclonic wind patterns, their effects are generally small and diminish rapidly with distance.

Figure 1 identifies the constituent regions of Northeast Asia used in this paper. Though some early parts of this paper refer to all of China (in discussions of population growth and economic growth, for example), the energy and emissions calculations specifically relate to Northeast China, as highlighted in Figure 1. Mongolia is not included in this analysis. That portion of the Russian Far East bordering the Sea of Japan is discussed only briefly, and no analysis of its impact is presented due to lack of data.

Figure 1 The Northeast Asia Region

The quantitative portions of this paper use results from the RAINS-Asia model described below. The Northeast Asia region precisely encompasses 23 RAINS-Asia "subregions." These include 16 geographical areas that are either individual or combinations of provinces and prefectures and seven major municipalities: Beijing, Pusan, Seoul-Inchon, Shanghai, Shenyang, Taiyuan, and Tianjin. The RAINS-Asia identification codes for each of the 23 subregions are shown in Figure 1 and in Table 1.

The RAINS-Asia model is a comprehensive analytical tool constructed by an international team of experts and sponsored by the World Bank and the Asian Development Bank (Bhatti *et al.*, 1992; Foell *et al.*, 1995; World Bank, 1995). Its purpose is to trace the causes of acid deposition in Asia--from population, economic development, energy use, and emissions, through atmospheric transport and deposition, to effects on sensitive ecological receptor systems. The computer model covers 23 countries of Asia, including all countries east of Afghanistan. The entire region is disaggregated into 94 subregions, of which 24 are large metropolitan areas. As indicated above, 23 of these subregions have been amalgamated into Northeast Asia for the purposes of this paper. The RAINS-Asia model provides the capability to examine the effects of alternative energy pathways and emission control strategies on emissions to the atmosphere, and it is this capability that is used in the present analysis to provide a quantitative framework within which to discuss the energy and emission issues facing Northeast Asia. When no citation is given, data were developed by the author using the RAINS-Asia model, Version 7.01.

Table 1 Regional Summary of Emissions (mt/y)

Region	Code	SO_2		NO_x	
		1990	2020	1990	2020
Beijing	BEIJ	0.27	0.68	0.24	0.92
Hebei-Anhui-Henan	HEHE	3.08	8.44	1.70	6.06
Inner Mongolia	IMON	0.69	1.42	0.36	1.41
Jiangsu	JINU	2.11	6.28	0.85	3.92
Northeast Plain	NEPL	2.49	6.72	1.68	6.25
Shanghai	SHAN	0.51	1.48	0.40	1.51
Shenyang	SHEN	0.10	0.30	0.04	0.29
Shandong	SHND	1.06	2.52	0.60	1.80
Shanxi	SHNX	0.63	1.56	0.49	1.43
Taiyuan	TAIY	0.20	0.73	0.10	0.66
Tianjin	TIAN	0.23	0.74	0.20	1.10
Zhejiang	ZHEJ	0.53	1.65	0.27	1.41
Chugoku-Shikoku	CHSH	0.16	0.19	0.47	0.62
Chubu	CHUB	0.16	0.21	0.37	0.81
Hokkaido-Tohoku	HOTO	0.11	0.15	0.30	0.50
Kanto	KANT	0.17	0.26	0.62	1.36
Kinki	KINK	0.13	0.17	0.40	0.72
Kyushu-Okinawa	KYOK	0.11	0.14	0.42	0.63
North Korea	KORN	0.34	1.35	0.52	2.43
North [S.Korea]	NORT	0.25	0.94	0.25	0.98
Pusan	PUSA	0.61	1.09	0.27	1.28
Seoul-Inchon	SEOI	0.50	2.92	0.30	1.94
South [S.Korea]	SOUT	0.29	0.58	0.23	0.88

Results are presented primarily for the base year of 1990 and a single future year, 2020. The thirty-year time horizon is chosen to give a long-term view of pathways for energy and the environment that dramatically illustrate the potential consequences of present-day practices. Because the region is changing so rapidly, however, the results for 2020 are subject to a high degree of uncertainty and should be viewed simply as potential endpoints for different kinds of policy decisions. They are not meant to be definitive, "crystal-ball" predictions of the future. Where space permits, results for 2010 are also presented to add a mid-term perspective.

It needs to be emphasized that much of the data needed to create emission inventories for Asian countries is unreliable. In many countries there are no administrative bodies charged with collecting national statistics on such parameters as energy production, fuel characteristics, and combustor types. Only for Japan can such data be considered to be comparable with western data. Some of the more sophisticated data needed to convert emissions into air quality--such as point-source stack heights, diurnal emission variations, and plume rise--are simply unavailable. Within the RAINS-Asia model, some data are derived from Asian experience and some are extrapolated from western experience, as fully documented in the final project report (World Bank, 1995).

Socioeconomic Driving Forces

The roots of the acid rain problem can be traced back to human activities. People need to produce and consume energy in order to meet their basic needs. If that energy is provided in the form of uncontrolled combustion of fossil fuels, then contamination of the atmosphere occurs through the release of a variety of chemical species. In this paper, the focus is on those species that lead to acid deposition: sulfur dioxide (SO_2) and nitrogen oxides (NO_x). Clearly, the more people there are, the more energy is needed, and the greater the atmospheric pollution.

Northeast Asia is one of the most densely populated regions of the world. In 1990, the populations of the countries of the region were as follows: Japan (124 million), South Korea (43 million), and North Korea (22 million). The total population of China was about 1.17 billion, though the breakout for Northeast China is not readily available. Large populations, high population density, and high population growth rates are all well-known characteristics of the Asian situation. In broad terms, it is projected that the population of Asia will continue to grow at a fast pace, but gradually decelerate after the turn of the century. The RAINS-Asia study assumes annual average population growth rates over the entire continent of 1.66% (1990-2000), 1.47% (2000-2010), and 1.33% (2010-2020). By 2020, the population of Asia is projected to reach 4.6 billion, an increase of 55% over 1990 levels.

Population growth is by no means uniform across the region, however. The more highly developed countries are expected to achieve the lowest population growth rates, commensurate with present-day levels in the West. Thus, Japan's population is expected to be 127 million in 2020, essentially stable after the turn of the century. The population of South Korea is expected to grow to about 51 million by 2020, representing an annual average growth rate of about 0.5%. North Korea is expected to grow faster (1.8% between 1990 and 2000, 1.2% between 2000 and 2010, and 0.9% between 2010 and 2020), reaching 32 million by 2020. Despite its historically high population growth rates, China has instituted strong population control measures that will curb growth after the turn of the century (1.2% between 1990 and 2000, 0.9% between 2000 and 2010, and 0.5% between 2010 and 2020).

Northeast Asia has experienced phenomenal economic growth since the end of the second World War. Japan and South Korea sustained annual average economic growth rates of between 8% and 10% for long periods in the 1960s, 1970s, and 1980s. In the last decade, China has joined the ranks of the booming Asian economies. Nevertheless, there remains considerable variation in economic strength across the region. Gross Domestic Products of the four countries in 1990 were Japan ($2,400 billion), China ($320 billion), South Korea ($250 billion), and North Korea ($28 billion)--all in 1990 U.S. dollars. On a *per capita* basis, the GDP disparity is even more marked: Japan ($19,400), South Korea ($5,900), North Korea ($1,300), and China ($270). Typical values for western countries in 1990 were $15,000-20,000.

Economic growth is expected to continue in the region at a fast pace, as Japan and South Korea strive to maintain their economic competitiveness with the West, China seeks to strengthen its economic base, and North Korea struggles to combat the dire economic straits in which it presently finds itself. After the turn of the century, as the countries of the region mature and evolve into more highly developed nations, the economies are expected to cool down. The RAINS-Asia study forecasts annual average economic growth rates of 6.5% (1990-2000), 3.9% (2000-2010), and 3.7% (2010-2020) Asia-wide. These levels of growth will quadruple the 1990 continental GDP by the year 2020.

Japan's GDP is expected to grow relatively slowly compared to the other countries, reaching a level of $7,400 billion by 2020--an annual growth rate of about 2.6% after the turn of the century. South Korea's economy is expected to grow at a faster pace (4-5% after 2000), reaching $1,200 billion by 2020. Similarly, China will continue its rapid rate of growth (5-6% after 2000), growing eight-fold to $2,400 billion by 2020. The economy of North Korea is projected in the RAINS-Asia study to continue to be troubled by internal problems and an inability to penetrate western markets, maintaining a stable 2% per year GDP growth rate and reaching a value of $51 billion by 2020. The*per capita* GDP estimates for 2020 signify greater prosperity in all parts of the region except North Korea: Japan ($58,200), South Korea ($24,300), North Korea ($1,600), and China ($1,500).

Energy Consumption

With populations and economies growing so rapidly in Northeast Asia, one might expect energy consumption to skyrocket in the 21st century. However, there are several ways in which energy growth can be decoupled from economic and population growth. For example, economic growth will not be equally apportioned across economic sectors. It is expected that the highly energy-intensive industrial sector will grow at a slower rate than the services sector, which has relatively light energy demands. Thus, for example, between 2000 and 2010, the services sector of China is expected to grow at an annual rate of 8.4%, while the industrial sector grows by 6.2% and the agricultural sector by 3.0%. A similar situation is projected in Japan, though industrial growth is still expected to dominate the South Korean economy. Sectoral shifts such as these can help to moderate growth in energy demand, as, of course, can other things such as improvements in energy intensity.

Total energy consumption in Northeast Asia was 43 EJ (exajoules or 10^{18} joules) in 1990. This represents almost exactly half of all energy use in Asia. This was distributed among the countries of the region as follows: Northeast China (45%), Japan (42%), South Korea (8%), and North Korea (4%). Table 2 shows the base-year energy consumption estimates by country. Note again that these energy figures (and those that follow) refer specifically to Northeast China, not all of China. As Table 3 shows, energy was principally consumed in the industrial sector (45%) in 1990, with lesser amounts going to power generation (19%), domestic use (16%), and transportation (10%).

Table 2 Energy Consumption in Northeast Asia by Country (EJ)

Country	1990	2010		2020	
		BAS	HEF	BAS	HEF
Northeast China	19.4	44.5	35.6	61.0	45.0
Japan	17.9	25.7	20.9	28.8	21.5
South Korea	3.6	9.5	7.8	13.4	9.7
North Korea	1.8	5.0	3.9	7.9	5.5
Total	**42.7**	**84.7**	**68.2**	**111.1**	**81.7**

Coal was the principal fuel used to meet these energy demands, supplying 48% of primary energy needs (see Table 4). Smaller contributions were provided by heavy and medium fuel oils (20%), light fuel oils and gasoline (15%), natural gas (7%), and nuclear (7%). This heavy reliance on coal is a major contributing factor to the high levels of emissions.

Table 3 Energy Consumption in Northeast Asia by End-Use Sector (EJ)

Sector	1990	2010		2020	
		BAS	HEF	BAS	HEF
Industrial Fuel Combustion	19.3	36.0	28.7	45.0	33.9
Domestic/Commercial	6.9	12.8	11.1	16.1	12.8
Transportation	4.1	10.3	8.0	15.5	9.9
Power Generation	8.2	17.5	13.7	24.4	17.3
Nonenergy Uses	1.8	3.4	3.0	4.2	3.8
Other (Conversion and Loss)	2.3	4.7	3.6	5.9	4.1
Total	**42.7**	**84.7**	**68.2**	**111.1**	**81.7**

Table 4 Energy Consumption in Northeast Asia by Primary Fuel Type (EJ)

Fuel Type	1990	2010		2020	
		BAS	HEF	BAS	HEF
Coal	20.6	44.8	34.1	58.8	39.8
Heavy and Medium Oil	8.7	15.1	11.8	19.3	13.3
Light Fuel Oil	6.6	10.6	8.8	12.6	9.2
Natural Gas	3.0	6.1	5.3	8.8	7.5
Renewables	0.1	0.2	0.2	0.3	0.3
Hydroelectric	0.8	2.7	2.7	3.8	3.8
Nuclear	2.8	5.2	5.2	7.6	7.6
Total	**42.7**	**84.7**	**68.2**	**111.1**	**81.7**

In order to understand the potential for acid-rain damage in Asia in the future, it is necessary to project future energy consumption. One of the major drivers of energy consumption is economic growth, as discussed above. Another important factor is the rate at which energy will be consumed in meeting the demands of economic growth. In many parts of the Asian economy, energy is presently used very inefficiently. Therefore, if energy efficiency can be improved, energy consumption need not grow as fast as economic productivity. This decoupling of energy and economy will be an important component of any regional policy to protect the environment.

In 1990, the industrial energy intensity in Japan was about 4.8 GJ/$\$10^3$ US. This is comparable with the best values observed in the West. In South Korea, the value was 12 GJ/$\$10^3$ US. In North Korea and China, however, industrial energy intensity values were extremely high at 86 GJ/$\$10^3$ US and 110 GJ/$\$10^3$ US, respectively. This means that it takes China 20 times as much primary energy to produce a dollar of economic product as it does Japan. Some of this difference can be attributed to the type of economic good produced; for example, China tends to produce basic materials that inherently require large amounts of energy as input, such as steel and cement, whereas Japan produces a lot of finished goods with lighter energy demands. Nevertheless, inefficient equipment and outmoded practices contribute much to high energy intensity in China and North Korea.

Energy intensity is improving all the time in the developing nations of Asia. China, in particular, has made tremendous strides in the past decade to reduce its energy needs in the face of rapid economic growth. Thus, the RAINS-Asia project forecasts that industrial energy intensity in China will have improved to 44 GJ/$\$10^3$ US by 2020. With similar levels of improvement occurring in other sectors of the Chinese economy, energy consumption growth can be moderated in comparison with economic growth. However, this same type of improvement is not expected for North Korea, where industrial energy intensity may actually worsen in the future.

Using detailed assumptions about economic growth and sector-specific technology development, the RAINS-Asia project developed energy forecasts out to the year 2020. These are detailed below for the Northeast Asia region. Under a base-case forecast (BAS), total energy consumption in Northeast Asia is projected to grow from 43 EJ in 1990 to 111 EJ in 2020 (see Tables 2-4 and Figure 2). This increase is largely taken up by an expansion in coal use from 21 EJ to 59 EJ. All other forms of energy supply grow as well, but from small bases. Japan shows only a modest (61%) growth in energy demand over the 30-year period, whereas the other three regions grow by factors of 3-4. Thus, for example, Northeast China's share of regional energy use in 2020 climbs to 55% (Table 2).

There is growth in energy consumption in all economic sectors (see Table 3), but most noteworthy are the transportation sector, which grows from 4 EJ in 1990 to 16 EJ in 2020 as demand for private vehicles grows and restrictions on vehicle ownership are lifted; and the power generation sector, which grows from 8 EJ to 24 EJ as electricity penetrates increasingly remote rural areas and ownership of electrical appliances grows rapidly in urban areas.

The energy scenario developed above represents the base-case (BAS) projection of the RAINS-Asia study. Its premise is that energy development and energy efficiency improvements will continue in accordance with official energy projections made by the countries themselves, but that no special measures will be undertaken to improve the quality of the environment by instituting additional energy efficiency measures or fuel substitution measures intended to steer away from the profligate use of fossil fuels in large power and industrial facilities.

Figure 2 Total Energy Consumption for Northeast Asia

In order to simulate the effects of a stronger effort to protect the environment, an alternative energy pathway was constructed, which is termed here the Higher Efficiency Forecast (HEF). Under this scenario, energy consumption in 2020 is expected to reach 82 EJ. Figure 2 illustrates the differences between the BAS and HEF pathways. The HEF scenario considerably moderates the expected increase in energy consumption, but does not prevent it. Growth between 1990 and 2020 is 91% under the HEF scenario, compared with 160% under the BAS scenario. Most of this improvement is achieved by a reduction in 2020 coal use from 59 EJ to 40 EJ (see Table 4). This is obtained through reduced energy demand and a concerted effort to replace coal use in power generating facilities by additional hydro, nuclear, and natural gas.

Coal Use in Northeast Asia

If the additional energy required in Asia between 1990 and 2020 were to be supplied by nuclear power or renewable energy sources, there would be no great threat to the atmospheric environment--though these alternative energy sources come with their own sets of environmental and economic problems. However, the fact is that coal will be called upon to supply the majority of future energy needs. Moreover, demand for liquid fuels will predominantly be met by various types of refined oil products, including gasoline, all of which release acid-rain precursors in one form or another.

Coal will continue to be the dominant fuel for energy supply in Asia because it is readily available, easy to extract and use, and relatively cheap. This is particularly true of Northeast Asia. China has extensive coal supplies in the Shanxi/Hebei/Shandong area, amounting to something in excess of 700 GT (Walker, 1993). This coal is very variable in sulfur content, ranging from about 0.3% to more than 3%. In Heilongjiang Province are an estimated 40 GT of coal reserves averaging about 0.4% sulfur. Inner Mongolia is the next big coal field to be exploited. China's coal industry has expanded rapidly in recent years to where it is now the leading coal producer in the world, producing about a billion tons annually, mostly for domestic needs. Production levels are expected to level out at about 2.2 billion tons during the next century, because of lack of capital to further expand production, transportation, and utilization facilities (Siddiqi *et al*., 1994). Nevertheless, the coal needed for Northeast Asia out to 2020 is not expected to be limited by physical or economic factors. Table 5 summarizes the regional coal picture for 1993, with projections made for 2010 by Intarapravich *et al.* (1996).

Table 5 Summary of Regional Coal Trade (mt/y) in Northeast Asia

Country	1993			2010		
	Produc-tion	Consump-tion	Net Trade[a]	Produc-tion	Consump-tion	Net Trade[a]
China (all)	1,141	1,123	+18	2,000	1,975	+25
Japan	7	118	-111	1	150	-149
South Korea	9	40	-31	4	77	-73
North Korea	34	35	-1	50	58	-8
[Australia]	-	-	+132	-	-	+230
[Indonesia]	-	-	+18	-	-	+37
[Vietnam]	-	-	+2	-	-	+7

[a]A positive value indicates net exports; a negative value indicates net imports. Not all exporters and importers are included in this table: only the four major countries of Northeast Asia and the major exporters to Northeast Asia. Source: Intarapravich *et al*., "Asia-Pacific Energy Supply and Demand to 2010," *Energy*, 21, 1017-1039, 1996.

Japan has limited coal reserves in the northern island of Hokkaido and the southern island of Kyushu. Total resources are estimated to be about 10 GT, with recoverable reserves less than 1 GT. Although the coal is of high quality, the Japanese coal industry is on a long decline, and almost all future needs will be met by imports. Japanese coal imports are expected to grow from about 111 mt/y in 1993 to 149 mt/y in 2010 (Intarapravich *et al*., 1996). Australia is the largest supplier at present, with Canada, the United States, and other countries supplying lesser amounts; this situation is expected to continue. South Korea has few natural energy resources, and its coal reserves are limited, of poor quality, and difficult to extract. Like Japan, the bulk of future coal supplies will be provided by imports from the same suite of countries, led by Australia. It is likely in the future that both Japan and South Korea will increase their coal imports from China.

North Korea has rather larger coal reserves, estimated at 12 GT, with some indications that still larger reserves may be awaiting discovery. Information about the coal industry in North Korea is difficult to obtain. It is believed that the general economic woes that have hit the country in recent years also plagued the coal industry, with domestic production perhaps being cut in half in the early 1990s. With the industry in present disarray, it is hard to predict its future. If foreign companies can be persuaded to invest in extraction of the better quality coals, attracted by the country's very low labor rates, North Korea could become a significant exporter in the next century. Otherwise, the country will likely drift along on domestic production, with some small exports to China and imports of coking coal (Daniel, 1995).

A new player in the Northeast Asian energy market is the Russian Far East. According to Tang and Khartukov (1996), this region may become a marginal supplier of coal and oil products early in the next century. More significantly, however, it is likely to have a large, sustainable surplus of natural gas for export to Asian markets by the year 2000. If some of this natural gas could be used to replace coal in the power sector or industrial sector, it could drastically reduce atmospheric emissions of sulfur dioxide. If the Russian Far East becomes a serious supplier of energy to the region, it will alter both the political and environmental balance. An urgent need is to develop emission estimates for this region and incorporate them into analytical models such as RAINS-Asia.

The problems caused by extensive uncontrolled combustion of coal in Northeast Asia are by no means underappreciated in the region. There is extensive work in progress to develop appropriate technologies for China. Many research and development groups in China, Japan, and other countries are working cooperatively on such technologies as coal cleaning, briquette manufacture, more efficient small boilers, low-cost emission controls with moderate-to-good removal efficiency, etc.

Emissions of Sulfur Dioxide

With knowledge of the quantities of fossil fuels burned, their sulfur contents, and the amounts of sulfur retained in ash, it is possible to calculate uncontrolled emissions of sulfur dioxide. Only Japan had any stack-gas control technology in place in 1990 and this is reflected in the RAINS-Asia date base. Thus, 1990 estimates of sulfur dioxide emissions are presented by country in Table 6 and for each of the 23 subregions in Table 1.

Total emissions of sulfur dioxide in Northeast Asia in 1990 are estimated to be 14.7 million metric tonnes (mt). Northeast China was responsible for 11.9 mt (81%), South Korea 1.7 mt (12%), Japan 0.8 mt (5%), and North Korea 0.3 mt (2%). The use of large amounts of fossil fuels by Japan is offset by the widespread deployment of emission controls. The majority of sulfur dioxide emissions comes from the industrialized regions of China: the Northeast Plain, Hebei-Anhui-Henan, and Jiangsu/Shanghai. The locations of these emitting sources are conducive to transboundary flow across the Korean peninsular to Japan and the Northern Pacific Ocean.

Table 6 Emissions in Northeast Asia by Country (mt/y) under BAS Scenario

Country	SO_2			NO_x		
	1990	2010	2020	1990	2010	2020
Northeast China	11.9	25.3	32.5	6.9	N.A.	26.8
Japan	0.8	1.0	1.1	2.6	N.A.	4.6
South Korea	1.7	4.1	5.6	1.1	N.A.	5.1
North Korea	0.3	0.9	1.3	0.5	N.A.	2.4
Total	**14.7**	**31.3**	**40.5**	**11.1**	**N.A.**	**38.9**

N.A. = Values not calculated by van Aardenne (1996).

Under the BAS energy scenario, emissions would rise to 31.3 mt in 2010 and 40.5 mt in 2020. Recall that this scenario assumes continuation of current energy policies and no additional environmental controls beyond those required under existing regulations. In essence, this means that only Japan requires any post-combustion flue-gas treatment on major coal-burning facilities. In 2020, Northeast China would emit about 32.5 mt, maintaining its 80% share of the total. Emissions become increasingly concentrated in the industrialized areas of Northeast China. Emissions in South Korea are also expected to increase significantly from 1.7 mt in 1990 to 5.6 mt in 2020, driven by extensive coal-based industrial growth.

Under the HEF energy scenario, which increases energy efficiency and encourages fuel substitution away from fossil fuels, sulfur dioxide emissions grow to "only" 24.7 mt in 2010 and 28.8 mt in 2020. Even so, emissions would still double in the next 30 years. This situation is in stark contrast to the situations in Europe and North America, where sulfur dioxide emissions are projected to decline from 24 mt in 1990 to about 17 mt in 2020 (North America) and from 37 mt in 1990 to about 16 mt in 2020 (Europe). In both cases, recognition of the acid rain problem has triggered environmental action and associated emission restrictions. Without the same steps in Asia, reversal of the global pattern of emissions will occur, and Asia will become the dominant emitting continent.

Sulfur Dioxide Emission Reduction Scenarios

The BAS projection is best viewed as an upper bound on future emissions, presuming that the countries of Northeast Asia will value the environment no more in the future than they do today. This is a pessimistic forecast. Countries such as China and South Korea are beginning to establish regulations to curb emissions in the regions of highest emissions or where ecosystems are most sensitive. Japan has had such regulations for many years. And, as discussed earlier, advanced technologies with improved performance are starting to penetrate the energy supply market.

A lower bound on future emissions can be established by assuming that all major point sources (existing and new, industrial and power) install state-of-the-art flue-gas desulfurization (FGD) systems and that all other users of fossil fuels switch to lower-sulfur fuels. The RAINS-Asia study terms this the Best Available Technology (BAT) scenario. Under these assumptions, 1990 emissions in Northeast Asia would be reduced by 69% to a 2020 value of 4.6 mt. This scenario also has an air of unreality about it; the capital is simply not available to implement such a stringent level of control over such a wide region.

Thus, the pathway for future sulfur dioxide emissions in Northeast Asia can realistically be bounded by the BAS and BAT scenarios, as illustrated in Figure 3 for the year 2020. This broad range of possible emission futures represents an enormous opportunity and a challenge to policymakers in the countries of the region, as they weigh options for investment in economic development and environmental protection.

Two intermediate levels of control are simulated in the RAINS-Asia study: an advanced control technology (ACT) scenario, in which FGD is applied to all new power plants (not existing ones) and a moderate level of fuel switching is achieved in the industrial, domestic, and transportation sectors; and a basic control technology (BCT) scenario, in which more modest pollution control systems, such as limestone injection, are applied to new power-generating facilities in China, but ACT controls are used in other countries and sectors. The limestone-injection technology achieves only 50% reduction in sulfur dioxide emissions, compared with 95% for the flue-gas desulfurization (FGD) technology assumed in the BAT and ACT scenarios. Table 7 summarizes the 2020 emission forecasts for each of these scenario options; Figure 3 illustrates them.

Figure 3 Alternative Future SO2 Emission Scenarios

Table 7 Sulfur Dioxide Emissions (mt/y) under Alternative Future Scenarios

Scenario	Year	Sectoral Emissions				
		Industry	Power	Domestic	Other	**Total**
	1990	7.8	4.3	1.9	0.7	**14.7**
BAS	2020	20.7	14.2	3.2	2.2	**40.3**
HEF	2020	15.9	8.8	2.7	1.4	**28.8**
BCT	2020	15.7	6.3	1.8	1.6	**25.4**
ACT	2020	15.7	1.6	1.8	1.6	**20.7**
BAT	2020	1.4	0.8	1.6	0.8	**4.6**

The ACT scenario results in a 40% increase in sulfur dioxide emissions over 1990 levels by 2020 (to 20.7 mt); the BCT scenario results in a 73% increase by 2020 (to 25.4 mt). These two scenarios are equally effective in curbing emissions in the nonpower sectors, but the ACT scenario greatly increases the reduction in emissions from major power plants. Note that both of these emission control scenarios are more effective than the HEF scenario, which permits a 95% increase in emissions by 2020. Of course, combinations of additional energy efficiency improvements and pollution controls are possible and can be simulated with the RAINS-Asia model.

Table 8 shows how the 2020 emission reductions would be distributed among the countries of the region. Emissions in Japan are relatively unaffected by the control scenarios, because current regulations are at least as stringent; it is only the BAT scenario that forces additional emission reductions in Japan. The effect of the scenarios on emissions in Northeast China is the major determinant of total regional emissions. Even in China, it is clear that the control of major new power plants and industrial plants is limited in its effectiveness, because of the increasing number of small industrial emitters and the growth of the domestic and service sectors. Either a radical realignment of industrial production or the rapid penetration of advanced technology is necessary to control environmental pollution.

Table 8 Regional Sulfur Dioxide Emissions (mt/y) under Alternative Future Scenarios

Scenario	Year	Country				
		NE China	Japan	S. Korea	N. Korea	**Total**
	1990	11.9	0.8	1.7	0.3	**14.7**
BAS	2020	32.5	1.1	5.5	1.4	**40.5**
HEF	2020	23.7	0.8	3.7	0.8	**28.9**
BCT	2020	22.3	1.0	1.5	0.7	**25.5**
ACT	2020	17.4	1.0	1.5	0.7	**20.7**
BAT	2020	3.7	0.4	0.6	0.1	**4.7**

Emission Control Costs

The costs of emission control technologies are high. This is discussed in greater depth in a subsequent paper. Only Japan had significant expenditures for pollution controls in 1990, estimated at $2.1 billion per year. Table 9 summarizes the costs of each scenario. The BAT scenario, which achieves the greatest emission reductions, would require the phenomenal expenditure of $35.5 billion annually by 2020 (levelized capital and operating expenses). The more modest ACT scenario would incur annual costs of about $14.1 billion by 2020. The BCT scenario costs are anomalously high at $14.2 billion. Although the capital costs of the assumed BCT technologies are significantly lower than in the ACT case, larger quantities of solid wastes are generated, and the model assumes waste disposal costs that are typical in western countries. In Northeast Asia, it is likely that the costs for disposing of these wastes would be considerably less, pricing the BCT scenario in the more likely region of $8-10 billion per year. This aspect of the RAINS-Asia methodology is presently under review.

Abatement costs under the HEF scenario decline to $1.7 billion in 2020. This is a reflection of decreased demand for energy and the need to construct fewer new generating facilities. Note that neither this paper nor the RAINS-Asia study estimates the cost of the additional energy efficiency improvements and fuel substitution measures embodied in the HEF scenario.

Table 9 Sulfur Dioxide Abatement Costs ($\$10^9$ US/y) under Alternative Future Scenarios

Scenario	Year	Country				
		NE China	Japan	S. Korea	N. Korea	**Total**
	1990	0.0	2.1	0.0	0.0	**2.1**

BAS	2020	0.0	3.5	0.0	0.0	**3.5**
HEF[a]	2020	0.0	1.7	0.0	0.0	**1.7**[a]
BCT	2020	6.4	3.5	3.2	1.1	**14.2**
ACT	2020	6.3	3.5	3.2	1.1	**14.1**
BAT	2020	22.5	6.1	3.8	3.1	**35.5**

[a]Does not include the cost of the additional energy efficiency measures, only the cost of the pollution abatement equipment.

The question remains as to whether these scenarios are "affordable" by the emerging economies of Northeast Asia, which have so many demands placed on them. The intervention of international lending organizations will almost certainly be required. This might also be an area in which the more highly developed economies (Japan and South Korea) could subsidize pollution controls in the other two countries (China and North Korea), especially because they would be the recipients of benefits in terms of reduced deposition. Note that under the ACT scenario, for example, annual abatement costs in Northeast China are projected to increase from zero in 1990 to $6.3 billion in 2020; on the other hand, annual abatement costs in Japan would increase from $2.1 billion in 1990 to $3.5 billion in 2020, a relatively small increment.

Clearly, the cost effectiveness of emission control actions, measured in terms of dollars per ton of pollutant removed, varies widely across the region. Table 10 summarizes the cost effectiveness of emission reductions under the BAT scenario--essentially very stringent emission reductions in all sectors in all regions. The cost effectiveness of such reductions in Japan is estimated at $3,600 per ton of sulfur dioxide reduced in 2020. This high value is a reflection of the stringency of current regulations in Japan and the need to apply additional controls chiefly to small, dispersed facilities--an expensive proposition. In North Korea, the cost effectiveness is estimated to be $2,400 per ton. This is relatively high, perhaps because of the lack of large point sources where emissions control is most cost effective. In South Korea, the value is $760 per ton, and throughout Northeast China the value is in the range of $400-800 per ton. In both South Korea and China, the number of large point sources, both existing in 1990 and projected to be built before 2020, offers the most cost-effective control opportunities.

Table 10 Cost Effectiveness of SO_2 Emission Reductions in Selected Regions

Region	Abatement Cost in 2020(10^9/y)			Emissions in 2020(10^6 t/y)			Cost Effect.($/t)
	BAT	BAS	delta	BAT	BAS	delta	
Japan	6.13	3.50	2.63	0.39	1.12	0.73	3,600
N. Korea	3.09	0.00	3.09	0.08	1.35	1.27	2,400
S. Korea	3.77	0.00	3.77	0.55	5.53	4.98	760
NECh: HEHE	6.03	0.00	6.03	0.94	8.44	7.50	800
NECh: JINU	3.38	0.00	3.38	0.89	6.28	5.39	630
NECh: SHAN	0.63	0.00	0.63	0.12	1.48	1.36	460

Because of the variation in cost effectiveness across the region, there are likely to be significant economic benefits to the region as a whole of coordinating emission control strategies and achieving the emission reductions where they would cost the least and have the greatest environmental benefit. This variation also suggests that a market-oriented approach, such as that recently introduced in the U.S., would achieve overall economic benefits. In either case, cooperation among the countries of the region would be necessary to secure the economic benefits.

Emissions of Nitrogen Oxides

Thanks to the work of van Aardenne (1996), preliminary estimates of nitrogen oxides emissions are available under base-case conditions. He has introduced NO_x emission factors for each of the fuels and utilization sectors in the RAINS-Asia model. Table 11 summarizes NO_x emissions by country and sector for 1990 and 2020. Table 1 provides the complete summary for each of the 23 subregions.

Emissions of nitrogen oxides in Northeast Asia in 1990 are estimated to be 11.1 mt. This is about three-quarters of the corresponding value for sulfur dioxide. In general, emission factors for nitrogen oxides are lower than for sulfur dioxide, but this is counterbalanced by the fact that combustion of oil and natural gas releases much more NO_x than SO_2. Thus, the sectors that use these fuels assume relatively more importance for NO_x: the transportation and domestic sectors, especially. It is clear that the more highly developed countries and regions of Northeast Asia, such as Japan, Seoul-Inchon, and Shanghai, which have more extensive transportation systems and more western-style residential areas, have greater contributions to NO_x emissions than the heavily industrialized areas of the region. For these reasons, Japan's share of total regional NO_x emissions in 1990 was 23%, compared with 6% for sulfur dioxide.

Table 11 Sectoral Growth in Nitrogen Oxides Emissions (mt/y) under BAS Scenario

Region	1990					2020				
	IND	DOM	TRA	POW	**TOT**	IND	DOM	TRA	POW	**TOT**
NEChin	2.68	0.39	0.30	3.49	**6.93**	6.58	0.79	6.21	12.99	**26.76**
Japan	0.54	0.11	1.35	0.56	**2.57**	0.54	0.16	2.19	1.70	**4.63**
SKorea	0.26	0.07	0.47	0.23	**1.05**	0.88	0.09	1.94	2.14	**5.09**
NKorea	0.25	0.00	0.09	0.16	**0.52**	0.68	0.00	0.23	1.44	**2.43**
Total	**3.73**	**0.57**	**2.21**	**4.44**	**11.07**	**8.68**	**1.04**	**10.57**	**18.27**	**38.91**

By 2020, under BAS conditions, emissions of nitrogen oxides are projected to increase to 38.9 mt, 3.5 times the 1990 value. This is an even more rapid growth than for sulfur dioxide, primarily because of the very large projected growth in transportation in the region. In 2020, Northeast China will be responsible for 69% of total NO_x emissions, South Korea 13%, Japan 12%, and North Korea 6%. Thus, Northeast China's growing power and transportation sectors will outstrip Japan's in the next 30 years. Increasing NO_x emissions also indicate an increase in generation of ozone, which will place an added burden on human health and the environment, especially in urban areas.

The situation regarding growth in nitrogen oxides emissions is potentially more serious than for sulfur dioxide. Emissions come from a wider variety of sources, the sources tend to be smaller and more dispersed, and emission control technologies are relatively less well developed. In addition, there is little experience of the performance of NO_x emission control technologies in Asian situations, except in Japan, which has been one of the world leaders in the development of such technologies. Because of the absence or the uncertainty of available data, no analysis has yet been performed of the cost or effectiveness of additional emission controls to reduce NO_x emissions. Performance is so sensitive to combustion conditions and type of combustion system, that field testing in the region is really the only way to know how effective NO_x reduction techniques will be.

Undoubtedly, there are a lot of cheap emission reductions possible through improved burner technology and firing conditions. How much and at what cost is presently unknown. Higher levels of reduction (on a percentage basis) would be available through selective catalytic reduction (SCR) or selective noncatalytic reduction (SNCR) technologies. Japan, South Korea, and some western countries have begun to transfer these more sophisticated technologies into China, but present experience is extremely limited. In view of the projections made in this paper, high priority needs to be given to investigation of NO_x emission reduction possibilities. Of course, one of the advantages of higher energy efficiency approaches, such as those embodied in the HEF scenario, is that they are effective at reducing emissions of both sulfur dioxide and nitrogen oxides simultaneously.

Conclusions

The prospects for acid rain and its detrimental effects on human health and the environment in Northeast Asia are serious. With the economies in the region growing rapidly, energy consumption is expected to increase significantly after the turn of the century. Coal is expected to supply the bulk of the additional energy needs, leading to an increase in emissions of the acidifying pollutants, sulfur dioxide and nitrogen oxides. In the absence of additional control measures, sulfur dioxide emissions are projected to increase from 14.7 mt in 1990 to 40.5 mt in 2020. Emissions of nitrogen oxides are projected to increase from 11.1 mt in 1990 to 38.9 mt in 2020.

Various possibilities for curbing these increases are available. They include a stronger effort to improve energy efficiency, shifting away from fossil fuels wherever possible, reducing the sulfur content of fuels used, and requiring emission controls on the larger energy and industrial facilities. For sulfur dioxide, the use of emission controls is effective but expensive. For nitrogen oxides, the use of emission controls is less effective, expensive, and largely untested in the Asian situation.

Emissions are concentrated largely in the major industrial regions of China, in the form of large coal-burning power plants and industrial manufacturing facilities. No emission controls are presently used, though regulatory initiatives have begun in China to identify acid-rain control zones where controls on new sources would be required in the future. Because of the location of these facilities and the prevailing meteorological conditions, they are primarily responsible for deposition throughout the Northeast Asian region. They also represent the most cost-effective sources to control.

Where there is a large difference in cost effectiveness of emission controls across a region, there are benefits to be gained by coordinated emission control programs. It may be, for example, that Japan would find that it could obtain greater incremental environmental benefit by spending one million yen in China than spending one million yen in Japan. There are precedents for this, such as Sweden's financing of emission controls in Poland. Certainly, it will be in the interests of all countries of the region to investigate cooperative solutions to the acid-rain threat. With other countries outside the region, such as the United States, interested in helping to alleviate problems through supply of low-emitting energy technologies, pollution control technologies, and low-sulfur fuels, a broader constituency can be developed.

Strategies that might be considered by a regional consortium include:

- establishing a joint fund, including contributions from the multilateral lending institutions, to provide loans to cover the capital cost of abatement technology on those facilities where the greatest benefit would be achieved;
- establishing a regional monitoring network to develop and share high-quality information on acid deposition trends;
- joint sponsorship with industry of technology demonstrations at approved facilities or at technology parks and dissemination of results to other power companies and industries in the region;
- convening regional meetings of regulatory representatives from each country to begin discussions of a regulatory framework to limit emissions of acidifying species throughout the region; and
- investigation of *quid pro quo* arrangements whereby, for example, China might agree to install

some pollution controls in return for Japan increasing its purchases of Chinese coal.

All of these strategies are, to one degree or another, being tested in Northeast Asia, but the scale is small and the pace is slow. The biggest obstacles to progress in this area are the cultural and institutional barriers to regional cooperation. Establishment of a regional forum, analogous to the Economic Commission for Europe, at which debate on these matters could begin, would be perhaps the single biggest step forward. Perhaps the U.N. Economic and Social Commission for Asia and the Pacific (ESCAP) could perform this function.

References

Bhatti N., Streets D.G. and Foell W.K. (1992) Acid rain in Asia. *Environmental Management* **16**, 541-562.

Daniel M. (1995) Asian coal prospects to 2010. IEA Coal Research Report Number IEAPER/18. IEA Coal Research, London, UK.

Foell W., Amann M., Carmichael G., Chadwick M., Hettelingh J.-P., Hordijk L. and Zhao D. Rains-Asia: An Assessment Model for Air Pollution in Asia. Final Report to The World Bank (December 1995).

Foell W., Green C., Amann M., Bhattacharya S., Carmichael G., Chadwick M., Cinderby S., Haugland T., Hettelingh J.-P., Hordijk L., Kuylenstierna J., Shah J., Shrestha R., Streets D. and Zhao D. (1995) Energy use, emissions, and air pollution reduction strategies in Asia. *Water Air Soil Pollut.* **85**, 2277-2282.

Intarapravich D., Johnson C., Li B., Long S., Pezeshki S., Prawiraatmadja W., Tang F. and Wu K. (1996) Asia-Pacific energy supply and demand to 2010. *Energy* **21**, 1017-1039.

Siddiqi T., Streets D., Wu Z. and He J. (1994) National response strategy for global climate change: People's Republic of China. Final report of project (TA 1690-PRC) for the Asian Development Bank.

Tang F. and Khartukov E. (1996) China and the Former Soviet Union. *Energy* 21, 1041-1046.

Van Aardenne J. (1996) NOx emissions from fossil fuel combustion in Asia in the period 1990-2020. Internship report S-306 of the Department of Air Quality, Wageningen Agricultural University, the Netherlands.

Walker S. (1993) Major coalfields of the world. IEA Coal Research Report Number IEACR/51. IEA Coal Research, London, UK.

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