Acid Rain in a Regional Context 13-15 June 1995

Recommended Citation

Peter Hayes and Lyuba Zarsky, "Acid Rain in a Regional Context 13-15 June 1995", Special Reports, June 15, 1995, https://nautilus.org/napsnet/napsnet-special-reports/acid-rain-in-a-regional--ontext-13-15-june-1995/

1.0 Introduction

Note: this text refers to 19 overheads which are graphics not contained in this electronic version of the text. These overheads are available in hard copy from the Institute

In section 1 of this paper, we provide a definition of the acid rain problem in Asia in technical as well as policy terms. In section 2, we review what is known about emissions in the region, and describe the current state of knowledge concerning calculated and measured deposition of acid rain. In section 3, we consider the transboundary transport and deposition of acid rain with particular reference to Northeast Asia. Finally, in section 4, we present some estimates of the technological cost of controlling emissions to a level which do not exceed calculated critical loads for the region. We conclude with a brief discussion of the next critical steps that should be considered in tackling the acid rain problem in this region.

1.1 Defining the Acid Rain Problem

Acid rain is a lay term for a widely recognized environmental affliction caused by chemical reactions in the atmosphere of emissions of polluting species such as SO_x and NO_x with water and oxygen. The term covers wet and dry deposition (gaseous SO_2) onto ecosystems. The relationship between primary emissions of precursors and ultimate acid deposition is the result of multiple, complex chemical processes and cannot be determined exactly at this time.

[OH1, acid rain flow diagram]

The sulfur and nitrogen containing species along with reactive hydrocarbons are mixed, transported, reacted and finally removed from the air back to the surface. Sulfur dioxide can react quickly with hydroxyl radicals in the atmosphere to produce SO_3 which reacts in turn with water to become sulfuric acid; or it may be moved hundreds of kilometers downwind before such reaction. Some may be deposited directly onto the surface; some may be absorbed in clouds to become sulfuric acid via various chemical pathways in the liquid phase. This acid may be removed via precipitation, or injected into the gas phase via evaporation.

These processes of wet sulphate deposition interact in complex ways with limiting factors determined partly by the fate of NO_x and changes in reactive hydrocarbon levels. Transport and deposition models necessarily simplify these processes, and uncertainties about the rates, magnitudes, and interactions of the various pathways make it difficult to determine the likely efficacy of control strategies--especially when the temporal and spatial distribution of emissions also vary.

Acid rain precursors are not only anthropogenic, but include a variety of natural sources such as volcanoes. But emissions of precursors from human activities have become significant relative to local and regional natural flows, and a variety of environmental damages have been attributed to these emissions. Such emissions result largely from the combustion of fossil fuels as fuels, particularly coal.

Acid rain has been a concern at the regional level in North America and Europe for nearly two decades. The precise scope and scale of the deleterious impacts remain contentious at scientific and political levels. But scientists and policymakers concur on the basic facts: precursor emissions injected into the atmosphere change into strong acids, viz, sulfuric and nitric acid which eventually return to Earth in rain unless neutralized by alkaline compounds in the atmosphere. Normal pH levels in unpolluted areas are slightly acidic (between 5.5 and 6.5) due to the combination of water and carbon dioxide into carbonic acid. But over much of the Northeast United States, the pH of rain has dropped to less than 4 (at which many vegetal types are severely affected). Similar values have been measured in much of northern Europe. These falls of pH correlate closely with sulfur emissions and atmospheric transport and dispersion of the resulting acids. Impacts of acid rain are poorly understood as ecological degradation is usually the result of multiple, simultaneous, interdependent and often non-linear causal relationships. But generally, acid rain is believed to modify the rate of nutrient leaching from soils and biomass; diminish or destroy fish populations in flowing water or lakes; affect soil bacteria and fungi; increase uptake of heavy metals such as cadmium; and exacerbate other pre-existing stresses such as pesticide contamination. Large-scale forest degradation has been attributed to acid rain in Europe, as well as more localized impacts on urban structures.

Acid rain is not a "stand-alone" problem. It relates intimately with energy, land use, urban, transport, and other socioeconomic issues. It interacts with other stresses on ecosystems which are already poorly endowed in terms of fertility, sunlight etc, and on species at the limits of their natural range. Acid rain also has major ramifications for commercial and cultural values including forests, agriculture, and tourism.

But acid rain is firmly on policy agendas in these two regions. Moreover, control strategies adopted in these regions have made a difference. In Europe, for example, 24 of the 33 parties to the Convention on Long-Range Transboundary Air Pollution have reduced their net emissions relative to those of 1980, and 12 have reduced them by 30 percent or more--with much larger, long-range reductions in the offing

1.2 Acid Rain in Asia

Scientists and policymakers--including ordinary citizens--have long suspected that acid rain is also a problem in the Asian region. Localized impacts in Asian megacities, high economic and associated energy consumption growth rates, and apparent transport of acid rain across national borders have generated a perception that acid rain affects Asia as badly (or worse) than in Europe or North America.

Indeed, one early estimate suggests that Asian SO2 emissions may surpass those of Europe and US combined early in the next millenia, rising to 75 million tonnes in 2010.

[OH2, E/NA/Asia comparison]

Systematic monitoring of forests in Japan, South Korea (hereafter ROK), North Korea (DPRK), China (hereafter PRC) has revealed already degradation that is prima facie evidence of direct damage from acid rain. Preliminary assessments by regional institutions such as the Asian Development Bank surmised that acid rain is already a major problem, but could muster little hard data to press the case for action to mitigate the driving emissions. Early data from monitoring show that acidity of rainfall has indeed risen in some areas, but some Asian ecosystems may be less susceptible to such deposition than European or North American ecosystems.

Moreover, determining liability--that is, ascertaining whose acid rain is responsible for the damage--is a highly political issue that has slowed the pace of regional cooperation on the issue.

1.3 Acid Rain In Northeast Asia

As we argue below, the definition of a region used in assessment of environmental impacts is driven by purpose rather than by "natural" boundaries. As is well known, Northeast Asia (NEA hereafter) is not a political region per se. Given deep and abiding animosities between the states of NEA, the region could be well termed the NEA "anti- region." Indeed, the national political cultures of NEA largely defines themselves by virtue of their differences and in relation to their opposition against their neighbors. Relatedly, security dilemmas at the geopolitical level bind the states of NEA into on-going conflicts over a variety of issues including territorial disputes, ethnic issues, military threat projection, etc.

Transborder air pollution in Northeast Asia has the potential to add to these already existing problems as well as to promote cooperation between states to solve them. Acid rain is the single most important regional air pollution affecting interstate relations. (Greenhouse gas emissions, "yellow dust," and radioactive contamination are other actual or potential regional air pollution issues.) Moreover, sub-regional economic integration in NEA around what have been called "natural economic territories" imply an increasing level of environmental as well as political-economic interdependence within NEA.

The main sources of acid rain in NEA are high levels of sulfur emissions from coal- burning power plants and factories in the PRC, DPRK, and elsewhere in the region. The north and south eastern regions of the PRC have especially high levels of sulfur dioxide emissions. One study of the PRC's largest coal-fired power plant, for example, showed that sulfur dioxide concentrations frequently exceed the legally permissible releases because the coal that is burned contains more than two percent sulfur. Even low sulfur coals can result in high levels of sulfur dioxide emissions when the coal is burned in inefficient plants. Acid rain may decrease biomass productivity and thereby reduce its carbon uptake, degrading existing forests and causing the recipient country's carbon emissions to increase.

Many scientists in the ROK, DPRK, and Japan believe that they suffer from transfrontier acid rain originating from northeastern PRC. Some have also noted that Mongolia may receive acid rain originating over its northwestern border with Russia. Depending on the time of year, some countries may be originators and recipients of acid rain, especially the DPRK. In winter (January), the air flows are generally from the Asian land mass to the ocean, while in summer (July), the opposite is the case.

[OH3, summary map]

According to an early study by the Asian Development Bank and recent interim reports of the RAINS-ASIA project, Northeast China, Japan and the two Koreas are relatively vulnerable to acid rain degradation due to the combination of high deposition and sensitive soils, vegetation, and materials.

The scale and impact of transfrontier acid rain deposition remains unclear, in part due to the lack of monitoring stations and ecological studies. Initial studies indicate, however, that the levels may be on a par with Europe. China itself has noted the possibility that acid rain may be transmitted long distances and has seriously affected areas of China. In the area adjacent to the Yellow Sea, Chinese industry has been estimated to emit about 700,000 tonnes of sulfur dioxide per year, some of which could be transported across the Yellow Sea to Korea by the predominantly northwesterly winds. Fortunately, the problem is amenable to technological controls at source: a modern power plant with glue-gas desulfurization equipment can remove more than 90 percent of the emissions. Countries in the region are also establishing facilities to monitor acid rain deposition. Much remains to be done, however, in terms of establishing common monitoring methodologies, comprehensive baseline monitoring, and ecosystem impact studies.

1.4 Conceptual and Analytical Framework

Analysis of the acid rain issue is a problem that demands multi-disciplinary, transnational, and multi-institutional analytical capabilities. But beyond the scientific, technological, and economic methods normally brought to bear on the acid rain problem are a set of broader conceptual concerns.

What, for example, is the domain of regional environmental cooperation over responding to the acid rain threat? What can--and should--governments accomplish through joint action at a regional level that they could not accomplish by acting unilaterally or in global concert in relation to a problem such as acid rain? In broad terms, we argue that the domain embraces three broad categories of environmental management:

1) governance of common pool, transboundary regional resources and ecosystem services;2) management of the trade-environment interface. High levels of regional economic interdependence, especially in the context of rapid economic growth, subject within- border resources to common pool pressures through competitive markets; and3) capacity-building, that is, joint welfare gains through cooperation in enhancing human and technological capacities to manage within-border resources and to respond to global environmental problems.

Before proceeding much further, it is important to note that the term "region" is also elastic. Common pool resources such as the atmosphere do not respect political boundaries, whether of one nation singly or many nations collectively. Seen through the lens of eco- system governance, a nation is not located in one geographical "region" with a fixed number of other nations. Rather, nations (and sub-regions within them) may be simultaneously part of many regions as defined by a common sea, watershed, desert, forest, air current system, etc. The governance of each common pool resource requires the participation of those who use it.

Likewise, nations and sub-national areas are part of multiple economic regions. The United States, for example, and especially the state of California, are simultaneously part of the Asia-Pacific and North American trading areas. Depending on the analytical or political problem to be examines, the boundaries of a "region" could be drawn on functionalist and bio-physical, as well as geographical, cultural, economic and political determinants.

The focus of this paper is on NEA as defined by the political boundaries of six particular nation-states: China, Japan, North Korea, South Korea , the Russian Federation, and Mongolia. This designation reflects the UN propensity to draw regional boundaries in politico-geographical terms and to promote within them cooperative relations across a broad spectrum of issues. It also reflects the interests of central governments in Northeast Asia to maintain control over foreign relations. Many environmental issues involving China and Russia concern primarily the Russian Far East and the Northeast Chinese provinces. But considered on an ecological basis, the border of the "region" would bifurcate these two countries.

Finally, the designation reflects political and security interests in excluding the United States, even though Alaska stretches well into geographical proximity. Nurtured by the UN Economic and Social Commission on Asia and the Pacific and the UN Development Program, the primary initiatives toward regional environmental cooperation have embraced these six countries. Yet existing efforts to address acid rain in "Asia" have covered East Asia (minus Russia, Canada, and the United States), Southeast Asia, and South Asia, apparently because this region conforms to that of international financial institutions as much as because of any political, economic, or environmental logic. Such a "region" may be convenient to international agencies, but has no grounding in environmental realities. Thus, there is no reason to restrict regional analysis to broad concepts of region.

Returning now to the conceptual framework in which we believe the acid rain problem should be situated, we address the primary characteristics in three dimensions.

1.4.1 Governance of Common Pool Transboundary Resources

Common pool resources are those which are not exclusively utilized by a single agent or source. Generally, such resources are considered common pool if de facto or de jure property rights to them are communal. Property rights consist of formal and informal norms, rules and institutions which specify who can utilize a resource, including who can appropriate income streams from it, as well as how they can utilize it, that is, user obligations. Examples of common pool resources include air, oceans, and atmosphere, as well as communal forests, pasturelands, fisheries, and local water management associations. In the context of international relations, common pool resources are those which extend across national boundaries; or which are not claimed exclusively by any nation.

Formal and effective forms of collective governance are required to ensure that common pool resources are utilized in ways which promote longterm sustainability. Without collective governance, common pool resources are "open access:" private welfare- maximizing decisions, especially to maximize income, will generate over-use and resource depletion. Individual users have no pecuniary or non-pecuniary incentive to limit their use and to invest in the long-term provisioning of the resource. Without use limits and investment, the resource will be undermined.

In short, without effective governance, common pool resources can generate a "prisoner's dilemma" paradox , in which "individually rational strategies lead to collectively irrational outcomes." Some researchers have concluded that any resource held in common inevitably generates a "tragedy of the commons" because of the free rider problem (i.e. those who conserve and invest in the resource cannot exclude others from enjoying the benefits of their investments). The solution, they believe, is either for the state to act as a leviathan to appropriate and control the resource; or to transform communal into private property by assigning private property rights to communal resources. In the context of state-centered international relations, this would suggest either that one state appropriate and regulate a transboundary common pool resource; or that states collectively allocate all resource rights to private citizens. Neither strategy is attractive or feasible.

Unlike prisoner's dilemma games in economic theory, however, humans can voluntarily cooperate in designing and enforcing collective governance mechanisms: incentive structures which promote the sustainability of common pool resources. Rather than carve up or appropriate common pool resources, states can cooperate in establishing Common Pool Regimes (CPRs). CPRs specify property rights and create mechanisms to enforce them. CPRs are needed whenever non-excludable, transboundary resources are subject to prisoner's dilemma-type resource degradation problems.

Some transborder common pool resources are global in nature and require international CPRs, including the atmosphere and ozone layer, the oceans, space, and biodiversity. Other resources span across a limited set of national territories, that is, a region. The domain of regional environmental cooperation encompasses the creation of CPRs for all transboundary common pool resources within the region, such as atmospheric systems, watersheds, seas, and habitats.

1.4.2 Economic Interdependence and the Trade-Environment Interface

A second category of collective action environmental problems emerges when national economies, especially resource-intensive sectors, become highly integrated in trade, investment and capital flows. Economic integration subjects states to two kind of pressures:

1) competitive market pressures which create prisoner's dilemma-type problems for local resource and ecosystem management; and 2) regulatory pressures to converge toward the environmental standards and policies of large-market countries. In the absence of collective governance, environmental standards governing trade-exposed sectors will gravitate either towards those of the most competitive producer or the largest market country.

Economic integration means that firms compete across jurisdictional boundaries. Property rights and regulatory regimes in different countries specify different rights and obligations of resource users, including firms. Regulatory regimes, in turn, affect competitiveness. Yet, firms compete in common markets. Through competitive markets, producers with the lowest private costs of production win the sale. Higher private cost producers go out of business. Yet the difference between high and low cost producers may reflect, at least in part, differences in the property rights regimes under which they operate. Low-cost producers, for example, may create social costs including pollution, resource depletion, and irreversible ecological losses.

International market competition, in other words, is not just between firms but also between systems of rules including property rights regimes. Ceteris paribus, the rules which generate the lowest private costs will dominate. Rules systems in other countries delimit national control over resources. Through economic integration, ecological resources within national boundaries acquire common pool characteristics. Rational decisions by individual firms to maximize profits or market share can result in irrational social outcomes if longterm resource productivity is undermined. When there are net private costs to sustainable resource management, competitive, cross-border market pressures will promote resource depletion.

Beyond competitive market forces, convergence in environmental standards among trade and investment partners is driven by national regulatory policies. Large market countries set product requirements for imports, including environmental, health and safety requirements. Large market countries also tend to be foreign investors. Many multinational firms find it cheaper to maintain the same production and management standards and practices in all international operations, standards typically generated in home countries. Import requirements and foreign investment act as transmission belts for standards set in the large market country.

Large market states have also taken initiatives to institutionalize convergence in environmental policy in the context of negotiations over trade liberalization, including in the European Union and North America. Convergence lowers transactions costs of trade which stem from a patchwork of differing national environmental requirements. It also reduces the potential that environment policies will be used as a protectionist device. As with market- driven convergence, however, policy-driven convergence may not promote sustainable resource use. Trading partners, especially at the global level, tend to be highly diverse economically, socially, politically and ecologically. Social and ecological diversity suggests that appropriate environment management policies should differ across and within nations. The issue is not so much whether standards will come "up" or "down" as what the specific local/national priorities, problems and requirements are and whether following standards developed elsewhere will address them.

These are issues of governance and they can and most likely will be taken up at the global level by the World Trade Organization. The WTO has established a Committee on Trade and Environment which is considering, inter alia, the scope of national trade- impacting environment policy. However, these issues also fall within the domain of regional environmental cooperation whenever regions are highly integrated or when particular sectors are highly integrated within a region. Regional cooperation is easier and cheaper than global cooperation because there are far fewer negotiating partners and the partners tend to have cultural, linguistic, ideological, or political affinities. Regional initiatives can thus act to lead, rather than follow, global negotiations. Nonetheless, regional and global initiatives need to move generally in similar paths.

Experience and empirical data increasingly show that the costs of environment-blind economic growth are likely to be higher than development paths which build in environmental protection. The experience of the Philippines and South Korea, for example, shows that "grow now, pay later" imposes high financial, social and ecological costs. Development strategies which promote income growth while preventing or minimizing pollution and ecosystem degradation could generate an entirely different relationship between economic growth and environmental quality. It could be less negative or even positive if strong environment protection policies promote product and process innovation and enhance investment in environmental infrastructure.

The point is not that trade openness is itself necessarily "good" or "bad" for the environment. Rather, it is that economic interdependence generates pressures which make within-border resources take on common pool characteristics. Sustainable management of the trade-environment interface requires collective governance, including at the regional level.

1.4.3 Building Capacities for National and Global Environment Management

The domain of regional environmental cooperation extends beyond managing common pool resources to the capture of joint welfare benefits in building domestic environment management capacities. The costs of capacity-building can be reduced through regional cooperation in three ways: 1) pooling of resources, including knowledge, information, and technology; 2) economies of scale and agglomeration in investment in environmental infrastructure; and 3) knowledge spillovers and accelerated learning curves. Increased domestic management capacities enhance capacities to respond to global environmental problems.

Environmental management is extremely information-intensive and knowledge- intensive. Few countries in the world have yet created a baseline ecosystem information base at a national level: biodiversity resources have not yet been mapped, pollution monitoring stations are not yet in place, etc. Pooling of resources can reduce the cost of creating an information management system, as well as collecting, storing, updating and disseminating information. Moreover, cooperation to standardize and intercalibrate information would increase the net benefits of information systems.

In some cases, there may be scale and/or agglomeration economies in creating joint management capacities across regional boundaries. For example, the costs of training environmental professionals may be reduced by creating a regional environment management training center or programs rather than many national centers. Regional cooperation can also accelerate learning by providing opportunities for people to communicate. Exchanges among scientists, businesspeople, environment organizations, educators, and policymakers could be especially fruitful.

Let us turn now to a review of the state of the art of acid rain knowledge in Asia and NEA.

2.0 Emissions Analysis

2.1 Underlying Variables

The foundation of a sulfur emissions analysis is the construction of an inventory of spatial and temporal allocation of emissions generated by energy use, especially but not only of fossil fuels. The starting point is the construction of a standard, disaggregated energy supply/demand balance at a geographical resolution consistent with the atmospheric circulation models. In work to date in Asia, the inventory has distinguished between large point sources (of which about 300 have been identified) and area sources of emissions.

[OH4, LPS map]

To these sources are applied standard emission factors which are simply technical coefficients of the amount of emissions per unit energy used over time. The locational issues surrounding emission sources are critical as the deposition is determined by the downwind plume which transports the chemical compounds through the atmosphere and back to Earth.

A recent energy supply/demand balance is used as a baseline against which reference future scenarios are developed--in the case of the RAINS-ASIA study of acid rain, two scenarios were constructed over a thirty year time horizon. The first was an energy "business as usual" scenario; the second was a "low" energy scenario based on variations on economic intensity of GNP, greater energy efficiency in end use, etc.

Such an approach is rather data-intensive as information is needed on a disaggregated, multi-sectoral basis for provinces, megacities, big plants, diffuse end users (such as household coal burning stoves), and shipping lanes including ports. Moreover, such data is rarely collected on a consistent basis across countries. Yet the foundation of analysis of a regional environmental problem such as acid rain is necessarily cross national. Even the consistency of technical terminology and calibration practices can reduce the utility of such data as exist on energy use and monitored emission rates and deposition levels. Consequently, even the "simple" science is fraught with loaded political and cultural issues (whose terminology, what calibration standards will be used?).

[OH5, RAINS ASIA Regions]

In addition, official projections of future energy use are often prove to be too high as they are collected from agencies that are innately optimistic given that such figures serve as the basis for budgetary allocations. RAINS-ASIA used standard, simple extrapolation of existing sectoral energy use supplemented by socioeconomic growth rates of GNP/capita and population growth to determine their "base" and "low" energy use scenarios.

[OH6, RAINS ASIA OH Base Energy Case] [OH7, RAINS ASIA OH Low Energy Case]

In the former, average per capita energy use increases by about 2.3 to 65 GJ/capita by 2020 (still only 50 % of current European and 20% of current US per capita energy use).

The latter, low energy use scenario results in about a 25 % reduction relative to the base case. In both cases, coal predominates in supply, although gas, hydroelectricity and nuclear energy are all projected to increase, while the contribution of biomass decreases due to the transition to more efficient fuels in poor countries.

The net result of these computations is that the "Asian" region as a whole emitted about 34 million tonnes of SO2 in 1990 from area and large point sources, of which the NEA "five" (PRC, Japan, two Koreas and Mongolia) were responsible for about 75 % (plus a substantial fraction of the trade-related emissions from sea lanes).

[OH8, RAINS Qe 1990 LPS and area sources, p. 4/20]

3. Transboundary Transport

3.1 Estimated Acid Rain Transport and Deposition

Lacking detailed field data, modelling to date in Asia has focused on the dominant acid rain precursor emitted in the course of energy use, namely, wet and dry deposition of aerosol sulfate and gaseous SO2. These emissions of the latter come from the following sources: natural sources refer to active volcanoes; anthropogenic sources comprise of: regional shipping in port and sealanes; large point sources (>300 MWe power plants; >900 MWt industrial facilities; and >20 kT SO2/year emitters); and area sources (including industrial, domestic, and transportation emissions, the latter provided on a one by one degree resolution).

The atmospheric module used in the RAINS-ASIA model calculates the concentrations and deposition of sulfate and SO2 on a one by one degree resolution, using a multi-layer advection model bound by night/day and time (five days or until the plumes depart from the modelling region) whereby the initial release branches into different trajectories. The modelling employed collected values for 1990 observed wind speeds and temperature from upper air sondings, or interpolated from these points to positions required by the model, as well as precipitation data. The modelling is hampered by lack of data for oceans in Northeast Asia.

[OH9, Met Stations, 5/17]

3.2 Estimated Deposition and Concentrations

As might be expected, calculated sulfur deposition is closely correlated with spatial distribution and density of emissions. The regions in eastern and southern PRC and the ROK clearly show elevated sulfur deposition in the RAINS-ASIA model. The strong continental outflow of air from east Asia results in a high deposition latitudinal band 20-40o over virtually the whole western Pacific ocean. Accumulated annual deposition is also heavily related to the annual precipitation patterns in southeastern China and Southeast Asia. In most areas, wet deposition of aerosol sulfate dominates the sulfate deposition process, whereas in the case of gaseous SO2, the dry and wet removal mechanisms are about the same in importance.

Deposition varies strongly according to season because of wind and precipitation seasonality; high emissions due to residential heating in winter months in northern Asia; and changes in chemical processes and rates due to season. Heavy precipitation occurs over Northeast Asia in December-January-February; and the rainy season occurs in June-July- August. More than 30 percent of cumulative annual wet deposition over the East Sea of Korea/Sea of Japan occurs during winter. Volcanoes are also important, accounting for nearly 30 percent of total deposition in Japan, for example.

The calculated annually-averages surface concentrations of aerosol sulfate and gaseous SO2 reveal elevated values throughout Asia. Direct damage to sensitive crops and forest ecosystems can occur at levels of 20-30 æg/m3--levels exceeded in large areas of the PRC and Korea. Japanese deposition measured levels reveal high values in Kyushu, on the East Sea of Korea/Sea of Japan side of Honshu, and large urban areas. These values (ranging from an annual 2-55 g-sulfate/m2) being higher than predicted by modelling work (1-4.8 g- sulfate/m2). Perhaps this difference is due to the coarse resolution of modeling, and the fact that monitoring may be biased toward and by urban areas. In the course of the RAINS- ASIA project, 43 sampling sites were established in 11 countries using low-cost passive samplers to collect weekly or monthly SO2 levels during 1994 at sites chosen for distance from major emitter sources and or in sensitive areas.

[OH10, monthly av. SO2 concentrations, 5/40] [OH11, monthly av. sulfate surface concentration, 5/41] [OH12, 5/42, observed/predicted sulfate deposition in Japan] [OH13, 5/46, SO2 sampling sites]

Calcium deposition ("yellow rain") is an important dimension to acid rain in Asia which is absent in North America and Europe. East Asia experiences large-scale dust storms which come from strong cold fronts and strong winds which lift up dust high into the atmosphere from the PRC and Mongolia. The dust contains alkaline substances such as Ca, Mg, K, and Na which likely neutralizes some of the acid rain. Indeed, although sulfate levels in Asia are similar to those found in North America and Europe, the pH values of the rain are much higher--due it seems to the availability of excess calcium in the wind-blown dust the calculated values of which correlate closely with observational data.

The deposition rates calculated in the RAINS-ASIA modelling are highly uncertain. Adjusting some parameters in the model showed it to be sensitive to emissions inventory (and particularly weak in relation to biomass fuels), the dispersion formula, the location of sources within the grid, wet removal rate constants, spotty or surrogate data for winds and rain temporal and spatial variation--all these factors need to be validated, refined, and tested.

3.21 Acid Rain Import/Export

The atmospheric modeling and resultant deposition patterns provide suggestive figures for intra-regional (internal to each country) and transboundary deposition patterns. In the PRC, for example, the modelling done by RAINS-ASIA indicates that 82 percent of the sulfur deposition arising from its emissions are deposited in the PRC, about 2 percent on Japan and the Korean Peninsula, and the other 15 percent on the oceans (except for a tiny fraction on Taiwan and Indochina).

In Table 1, for example, take Japan. Reading along the row, one finds that a total of about 400,000 tonnes of sulfur were deposited on Japan in 1990, of which about half came from Japan itself about 7 percent from the ROK, about 10 percent from the PRC, and about 30 percent from volcanoes. Of the cross-border deposition onto national territories in Northeast Asia in 1990 (about 292,000 tonnes according to the model), the PRC was responsible for 47 percent, the ROK about 29 percent, the DPRK about 23 percent, and Japan only about 1 percent.

[OH14, Table 1]

Table 1: Northeast Asian Recipients/Sources of Sulfur Deposition, 1990

Source: G. Carmichael and R. Arndt, "Long Range Transport and Deposition of Sulfur in Asia," RAINS-ASIA unpublished work in progress, March 1995, p. 11.

3.3 Critical Loads and Levels

As noted earlier, sulfur deposition causes acidification. The highest level deposition before tolerance to acidification-related effects is exceeded is the critical load for that ecosystem. Given an ecosystem's characteristics, the critical load is a function of the aerial concentration of the pollutants that damages the ecosystem. The concentration at or above which damage occurs is known as the critical level. The higher the critical load, the less sensitive the ecosystem is to increased acidity; and conversely, the lower the critical load, the more sensitive it is to increased acidity.

Both these concepts attempt to define the level of stress imposed by the assaulting pollutant that threatens the ecological integrity of a natural system, that is, its structural and functional attributes. The former relate to aspects such species composition, diversity, ratios between trophic levels, etc. The latter relates to nutrient transfer, energy flows, rate processes, maintenance efficiency, and ecological efficiency. The damage that can occur to these ecosystem characteristics are direct and immediate, especially at a local level from gaseous plumes; direct but occasional excessive levels that result in immediate damage but not in an irreversible, long term way; and long term, chronic excessive deposition that changes soil chemistry to the point that ecosystem sustainability is threatened or irreversibly damaged.

Various methods have been developed to estimate critical loads for specific ecosystems in Europe and North America given lack of field data. These include: 1) the relative sensitivity approach which is based on parameters such as climate, geology, soil, land use, and vegetation type; and 2) the Steady State Mass Balance Model which concentrates on the ability of soils (from weathering and other processes) to buffer the acidity, thereby relating vegetation types and tolerances to soil chemistry.

At the macro-level of regional acid rain analysis, the first objective is to establish broad categories of critical loads at a low resolution compatible with the overall transport/deposition model. The critical loads are driven by ecosystem considerations, and can be used to evaluate emission control strategies. Where emissions can be shown to impose excess loads given a current or projected control strategy, the excess can be defined in terms of area or areal fraction of protected versus vulnerable ecosystems; and excess values over critical loads for each area (at whatever resolution is the foundation of the analysis--one by one degree in the case of RAINS-ASIA). At this stage, ecosystem recovery (or restoration if recovery is not feasible) is not integrated into assessments of acid rain control strategy.

3.4 Ecosystem Sensitivity and Critical Load Exceedance

The sensitivity of a given ecosystem is determined by multiple variables and cannot be determined a priori. Certainly, vegetation types may occur on sites with typical acidity buffering rates. But the buffering itself will vary as a function of soil chemistry response, in turn a function of multiple chemical and physical factors. Thus, an ecosystem may be highly sensitive to increased acidity even though it has vegetation types that are highly tolerant of increased acidity--because the background buffering rate is low. Conversely, ecosystems with vegetation types that are highly intolerant of increased acidity nonetheless may be insensitive to higher acidity because high buffering rates. The RAINS-ASIA project used six factors to classify vegetation types into six sensitivity classes: soil buffering ability; soil moisture; flooding; nutrient circulation, rooting depth, and organic matter type; stresses such as temperature; and tolerance of Al (see Table 2).

[OH15, table 2] [OH16, sensitivity according to vegetation type only 6/26]

Work to date in Asia has relied on detailed studies of the sensitivity of indicator species to acidification. This approach simplifies greatly the complex interdependence of species in actual ecosystems, and the existence of numerous limiting conditions and thresholds which may not be represented prudently in the acidity level defined as "acceptable" to the indicator species. Thus, it is crucial that detailed ecological studies be conducted in a range of sensitive and significant ecosystems to identify indicator species which capture the complexity and set conservative limits with respect to the whole ecosystem, not just the dominant or indicator species in the ecosystem.
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At the low level of resolution used in RAINS-ASIA, continental data sets for these classes have been combined with three other major variables which together determine overall relative sensitivity (climate, soil, geological data) have been mapped for Asia by GIS manipulation. Once amalgamated, these maps show Northeast Asia to have a ecosystems that are relatively highly sensitive to acidic deposition, especially in Japan and Korea where soils are already acidic and ecosystems have a low ability to buffer chronic increases in acidity. (Note that at this level of resolution, local areas of low sensitivity such as paddy fields in areas containing highly sensitive ecosystems are not distinguished; however, the RAINS-ASIA approach does compute the extent to which critical loads are exceeded for different ecosystems contained in a mapping cell, allowing different risk levels of imposing damage to determine sensitivity. The areas found in Northeast Asia by

Table 2: Sensitivity of Ecosystem Types by Vegetation Type Only in Asia

Source: J.P. Hettelingh et al, "An Assessment Model for Acid Rain in Asia," work in progress, RAINS-ASIA, April 1995.

RAINS-ASIA to be most in excess of critical loads for acidity due to sulfur deposition in 1990 (at a 25 percentile critical load exceedence such that 75 percent of the ecosystems are protected) were Korea, and southern Japan.

The RAINS-ASIA modeling of sensitivity and critical load exceedence estimates are highly uncertain, however. The range of environmental conditions and ecosystems in Asia is far greater than in Europe, along with related soil types and land uses. The calculated results require urgent validation and refinement based on fieldwork. The crude, low resolution identification of sensitive ecosystems in the RAINS-ASIA project should be used to identify the range and location of sample sites for such field work to identify the impacts of acid deposition, and to ensure consistency of approach and comparability of results across these studies.

Two such reports work are available so far, one in Japan, and one in China. The Japanese study applied a variety of steady-state model formulae for calculating critical load to data collected for Gunma Prefecture (northwest of Tokyo). They found that each formula resulted in different levels and spatial distribution of critical loads (in some cases, negative) for the same area and that much better estimates of vegetation-specific, base cation uptake and site-specific information on mineralogy and weathering rates are needed as well as monitoring of acid deposition. In addition, local and widespread forest decline has been reported over the last two decades at many locations in Japan. Causes include air pollution, wind and drought damage, insects and pathogens, and the direct and indirect effects of acid deposition. Detailed, controlled studies are needed, therefore, to determine the contribution of acid deposition to this decline.

The Chinese study examined current and prospective emissions in Guizhou Province in southwest China relative to a map combining critical loads and critical levels. The study showed that a province-wide, even reduction of emissions was unnecessary so long as emissions from three big cities are reduced, or the large point sources in these cities are relocated to areas capable of absorbing more air pollution.

Meanwhile, the modeling presents a prima facie case that future deposition levels present a major potential environmental problem for the region.

4.0 Control Costs and Economics

4.1 Control Options and Costs

Since the first and second generation scrubbers for SOx and NOx became available in the 1970s, utilities and industries have accumulated a vast operational experience with abatement technologies. In Germany today, for example, all relevant emission sources have been regulated and in general, are required to be constructed and operated according to best available practices.

A comprehensive inventory of technological controls will include: 1) desulfurization of fuel oil, coal, and diesel fuel before combustion; 2) desulfurization of fuels during combustion by additive processes such as injecting limestone into the furnace with Su removal rates of 50-60 percent at moderate costs albeit with a large waste stream, and fluidized bed combustion; and post combustion capture by flue gas treatments, the most popular of which are wet limestone scrubbers which can now remove 95 percent or more of the sulfur without imposing much higher costs, and even offset cost by recycling captured Su to the chemical industry (Wellman-Lord process). Typical investment and operating cost functions are shown in Table 3 and can be simplified into a reduction cost curve as shown in Table 4.

[OH17, table 3, 4/35] [OH18, table 4]

Two other important policy measures are: 3) changes in fuel mix toward those containing less or no sulfur; and 4) increased efficiency of energy use on the supply and demand sides. These approaches reduce the emissions to be cleaned in the course of energy use; and they abate the emissions in the first place by reducing the emitting activities. They may be substantially cheaper than the control technological options and will be adopted often for non-acid rain motivations (such as lower cost of energy services, reducing greenhouse gas emissions, modernization of plant, etc.).

Table 4: Emission Cost Control Curve

Source: D. Streets et al, "Emissions and Control," work in progress, RAINS ASIA, April 1995, Table 4.19

Many of the control technologies used in the OECD and listed above--and related costs-- can be transposed to the Asian region as broadly the same technological fixes are available. But use of OECD cost data--which reflect higher emission standards at this time--mean that actual costs in Asian countries may be overstated as the requirements are less stringent; and in many cases, local inputs such as labor and materials for such technologies may be substantially cheaper than in OECD countries.

In addition, technological controls on Asian energy conversion systems no longer used in OECD countries including coal briquettes and wet particle scrubbers, low cost adaptations of OECD technologies, and technologies appropriate to local fuels (such as lignite, high ash coals as in the DPRK, etc) reflecting local labor and materials as costs, would diversify the technological options and shift the cost functions.

4.2 Economics of Emission Reductions

Using baseline and projected emission scenarios, the RAINS ASIA project developed cumulative cost estimates for controlling SO2 emissions. The unabated projected SO2 emissions in 2020 in the "business as usual" scenario with no further controls than those present today are 110 million tonnes, compared with about half that figure for the "best available control technology" scenario. The latter reduction rate requires an estimated $42 billion in the year 2000, rising to about $80 billion per year in 2020. Adopting energy efficiency measures to reduce emissions (and assumed to not be charged to the SO2 account, thereby relieving SO2 controllers of this responsibility), these costs fall to about $37 billion and $58 billion respectively.

[OH19, Foell Figures 4 and 5, p. 8]

In the base "business as usual" case with no further controls, the cost falls to only about $3 billion per year (or only $2 billion/year for the low energy scenario)--mostly from control costs adopted in Japan.

Only under the "best available control technology" scenario does excess deposition fall to levels that might be regarded as even minimally acceptable in the RAINS-ASIA models. The cost of the control technology options may be compared with the funds required to develop electric power in APEC countries. Between 1991-2000, for example, one study estimates that an average of (1992)$55 billion/year will be needed for power generation, transmission, and distribution, rising to (1992)$92.7 billion/year between 2000- 2010. Of this total, China will demand 62 percent in 1991-2001, rising to 60 percent over 2000-2010; the NICs 19 falling to 14 percent; and ASEAN states, 19 falling to 17 percent.

Due to the absolute scarcity of investment capital, it is not surprising that the PRC is reluctant to spend funds on sulfur emission controls--especially when (as we saw earlier) a substantial fraction of the eventual deposition is either on international commons (the oceans) or on other states. Indeed, the PRC reportedly has rejected Japan's efforts to fund emission controls with aid funds as unwarranted "green conditionality" and prefers to spend aid on expanded coal-fired generation. Although the PRC has emphasized the adaptation of environmental management technology, it is unlikely that cooperative projects such as the adaptation in Shanxi Province of Japanese limestone-gypsum wet flue gas desulfurization will be replicated widely enough to achieve significant reductions of projected emissions.

[OH20, Foell p. 10]

Unfortunately, the costs associated with the damage arising from exceeding critical loads today or as projected in the future have not been estimated. Consequently, it is not possible to quantify the benefits of avoiding the damage imposed by acid rain by investments on the scale referred to above.

Nor can the issue of who should pay to stop acid rain be elevated from a political tussles rooted in scientific uncertainty, not to mention connections with preexisting regional animosities over unrelated issues that preclude even serious dialogue over such issues as acid rain--let alone cooperative action to address the problem.

What are the aesthetic and ecological values of forests worth to the Japanese people? Are they and others willing to pay a price commensurate with the cost of avoiding these emissions in the PRC and elsewhere to preserve elements of their environment which are central to their national identity?

5. Conclusion

Assuming that 1) the acid rain issue can be extricated from political gridlock due to high level geopolitical (and geoeconomic) issues in the region; and 2) assuming further that not only is the political will is forthcoming in wealthy states to invest substantial resources in an international effort but that 3) the major acid rain exporting states are willing to accept aid on a scale commensurate with the problem that they are creating--what then?

Returning to the conceptual framework outlined in section 1.4, we believe that at least five steps must be taken to address effectively the nexus between energy, development, and environmental impacts that is embodied in the regional acid rain problem.

First, a much expanded political commitment and scientific effort must be made at a regional level to monitor acid rain emissions, transport, deposition, and impacts analysis. This enterprise itself requires major investment in technical assistance, training, provision of equipment, information exchange, and education based on the results to ensure that awareness of the issue is not confined to a narrow strata of scientists but reaches all sectors of society. An effective capacity building program in each country and via the creation of regional networks is needed to achieve this outcome.

Second, states in Northeast Asia might consider the utility of negotiating a subregional convention on long range transboundary air pollution, adapting the European and North American experience to local circumstances. This convention would provide the framework for on-going governance of a common pool resource--the atmospheric system and terrestrial absorptivity of deposited acid rain. As economic integration proceeds apace in Northeast Asia, we believe that the environmental "subtext" will require explicit agreements to regulate and manage the impacts implied by such growth in sub-regional trade and investment. Acid rain is only one such dimensions of such sub-regional cooperation. But it is a crucial one because the solutions entailed in solving the acid rain are needed badly to address a number of other regional environmental problems including oceans management, integrated coastal zone management, and wetlands and critical habitat maintenance for migratory birds.

As in Europe, such a convention would require states to increase greatly the transparency of their emissions and control programs by such obligations as 1) submitting annual reports and periodic reviews by independent scientific panels, combined with monitoring programs of actual emissions and deposition, including transboundary fluxes; 2) development of special manuals and guidelines for emission inventories and uniform calculation of pollution control costs; 3) widespread dissemination of the documents and reports to media, schools, and universities; 4) specialized information exchange and increased scientific cooperation and expertise; 5) establishment and participation in specialized working groups on topics such as impacts, assessment modeling, economic aspects, control technologies, abatement strategies, etc.; 6) eventual expansion of the convention beyond SOx and NOx to issues such as transboundary transport of persistent organic compounds and emissions of heavy metals.

Third, "no regrets" measures such as energy efficiency and fuel switching to achieve abatement of emissions at zero, low, or even negative marginal cost should be implemented immediately, along with institutional and pricing reforms which will also reduce emissions.

Fourth, informed debate needs to be stimulated in the public in Asian states via better coverage in the media, specific education and outreach programs, and opening the political and scientific dialogues a much higher degree of non-governmental participation-- something to which all governments in the region committed themselves to at the 1992 UNCED conference. Unless such broad-based constituencies emerge, one can predict confidently that little will be achieved.

Finally, the availability of financing will make or break the ability of states to control emissions that lead to acid rain. Much more attention needs to be given to creative and innovative ways of levering public and private capital into environmental concerns, including abatement of acid rain.

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