# Least-Cost Approaches to Reducing Acid Emissions

*The costs of meeting sulfur emissions targets can be high. It is essential, therefore, that countries adopt policies which minimize the net economic and social costs of reducing emissions to the agreed target levels and maximize the overlap between measures designed to reduce acidifying emissions and those addressing other forms of air pollution. This chapter discusses alternative approaches to reducing acid emissions cost-effectively, identifies possible mechanisms for international assistance, and describes the health and ecological damages caused by acid emissions and acid rain.*

Considerable work has been undertaken on the comparison of alternative mechanisms for meeting given emissions targets. Among the *market-based* systems are emissions charges and tradable permits. Possible *regulatory* systems range from the imposition of uniform emissions standards to the negotiation of plant-specific emissions permits. All raise practical problems of implementation, as well as issues of designing a system of incentives that induces emitters to reduce their emissions in the most efficient, i.e., least-cost, manner.

The use of geographic differentiation in charges or emissions standards, to take account of the fact that emissions from sources in one region may be more damaging than those from sources elsewhere in the country, adds a further layer of complication. However, introducing a spatial element may be essential in any system if the basic objective of reducing the damage caused by acid rain—as represented by exceedances of deposition rates over critical loadings—is to be met at an acceptable total cost.

It is possible to identify combinations of actions that may be used to reduce emissions of sulfur and nitrogen oxides at least cost, subject to constraints on monitoring and institutional feasibility. The list of possible actions includes energy conservation, the use of low-sulfur fuels, fuel switching, changes in levels or patterns of equipment operation, installation of controls to mitigate or eliminate emissions, and changes in combustion or other technologies. These actions may be mandated by specific regulations or may be adopted in response to economic or other incentives such as differentiated fuel taxes, pollution charges, permit trading, and investment subsidies. For large stationary emissions sources, a considerable range of alternative actions can be considered, but small or area sources, including households and small industrial and commercial boilers, should not be neglected, although they cannot be treated at the same level of detail.

## Sample Terms of Reference for a Study

- Prepare a countrywide database of large stationary sources of sulfur and nitrogen oxide emissions, with information on location, current emissions, and options for controlling emissions (including modifying combustion processes, switching to alternative fuels, and fitting abatement equipment).
- Collect data on the marginal and average costs of fuel use and operation for the alternative methods of reducing emissions for a sample of sources and generalize to the full range of stationary sources in the country database.
- Where applicable, investigate the impact of economic and regulatory instruments on the merit order for operating power stations to meet a given load curve and level of aggregate electricity demand in each country.
- Examine evidence on the “local” damage to human health, ecosystems, economic productivity, and amenity caused by air pollutants in

the areas surrounding emissions sources. Use this evidence to prepare approximate estimates of the benefits of reducing such air pollution in order to estimate the net cost of adopting alternative measures to reduce emissions of sulfur dioxide ($SO_2$) and nitrogen oxides ($NO_x$), from both large and small sources.

- Compare the total and marginal costs of meeting different targets for reducing emissions using different policy instruments, allowing for the "local" benefits of improving ambient air quality near the emissions sources. The comparisons should take account of the feasibility and costs of monitoring and enforcing the different systems of control.
- Investigate the scope for introducing regional differentiation to take account of the greater damage caused by depositions from some sources than from others. This analysis should be extended to take account of the benefits of reducing concentrations of particulates in the neighborhood of the sources as a result of the control measures and changes in utilization induced by the alternative instruments.
- Examine the institutional and administrative aspects of using alternative regulatory and economic instruments to reduce acidifying emissions, with particular attention to requirements for monitoring and enforcement.

In identifying the least-cost strategies for reducing emissions in each country, considerable attention should be paid to the administrative or regulatory issues that arise in implementing the alternative actions. Whatever the theoretical advantages or disadvantages of different instruments of environmental policy, it is crucial to base the analysis on a realistic assessment of the costs and performance, in practice, of the various mechanisms available.

## Transboundary versus Local Effects

The analysis should assess the net costs of implementing each alternative action after allowing for the associated health and other benefits to the country. For example, the net economic cost of switching households and small boilers from burning coal to gas may be small or even negative because this change will also reduce the population's exposure to high levels of particulates or sulfur dioxide and thus lower the health damage caused by such pollution. Such a study can identify the net costs of actions to reduce sulfur emissions as a basis for agreements between countries or for donor assistance designed to meet emissions reduction targets. In the future, Activities Implemented Jointly (AIJ) arrangements, as provided for in the Kyoto Protocol, might be one way of developing more cost-effective strategies.

## Environmental Damage from Acid Emissions

### *Health Impacts*

Sulfur dioxide is an irritant that, in high concentrations, can cause acute respiratory problems. In conjunction with high levels of exposure to particulates, it is implicated in the excess mortality observed during severe smogs, and it worsens the morbidity associated with chronic respiratory problems.

Sulfur dioxide also reacts with other substances in the atmosphere to form sulfate aerosols that may have an important health impact. Moreover, sulfate aerosols can be transported long distances through the atmosphere before deposition occurs.

Exposure to high levels of nitrogen oxides can also worsen the health of those with pre-existing respiratory problems. It is, however, through its contribution to the generation of photochemical smog and ozone (another respiratory irritant that aggravates the condition of people with asthma and heart disease) that $NO_x$ emissions have their main effect on health.

### *Other Impacts*

High levels of $SO_2$ and $NO_x$ emissions can damage buildings and other structures because of relatively high concentrations of acid and of sulfur particles in rainfall. Much concern has been expressed about damage to cultural artifacts and especially historic buildings in cities in Eastern Europe. It is, however, difficult to disentangle this damage from that caused by poor maintenance and mistaken attempts at restoration in the past. While the scale of the damage to materials caused by acid emissions is uncertain, emissions undoubtedly give rise to amenity costs because they reduce visibility. The presence of sulfate and nitrate particles and of acid aerosols, as a result of either direct emissions or their secondary formation in the atmosphere, leads to light scattering. Furthermore, gaseous nitrogen dioxide absorbs light at the high end of the spectrum, giving the atmosphere a reddish-brown tinge. The result is a haze that may extend over a large region, or topographical features may concentrate the haze over a city.

*Acid Rain*

Depositions of sulfur and nitrogen, or "acid rain," are primarily associated with the long-distance transport of acid aerosols formed in the atmosphere from a mixture of dilute hydrochloric, nitric, and sulfuric acids, plus ammonium sulfate and nitrate. Rainfall gives rise to wet deposition, which rapidly infiltrates soils, groundwater, rivers, and lakes. Both dry and wet depositions may cause direct damage to trees and other vegetation by affecting their plant chemistry and pathology. Acidification of soils leads to leaching of plant nutrients and to mobilization of aluminum that would otherwise be bound up in rocks and mineral particles. Excessive levels of aluminum damage roots, reduce the capacity of plants to take up necessary trace elements such as calcium and magnesium, and interfere with water transport within trees, which increases their sensitivity to drought. Acidification of rivers and lakes can result in drastic changes in their ecosystems, including the complete loss of fish stocks.

The dose-response relationships between acidic emissions and damage to forests, crops, and lakes are complex and are still poorly understood. Recent evidence suggests that nitrogen compounds may be more damaging to ecosystems than sulfur compounds. Rainwater has not become significantly more acidic in Central Europe over the last 50 years, but the area covered by highly acid rainfall has increased greatly. Evidence from Germany and other western European countries suggests that forest loss may be linked to the long-term effects of acid depositions but that other (often site-specific) stress factors are also involved.

The nature of the damage to ecosystems caused by acid rain means that it is necessary to distinguish between the "stock" and "flow" aspects of the problem. Long-term acidification of soils is a "stock" problem that cannot be quickly reversed by reducing the level of current depositions, although applications of lime and nutrients and changes in silvicultural practices may mitigate its consequences. At the same time, it is possible to define "critical loads" representing the maximum "flow" of acid depositions that can be absorbed by specific soil types without provoking a tendency to acidification. These critical loads define a measure of long-run sustainability that can be used in setting the ultimate goals of environmental policy. However, in setting priorities for short-term actions, countries must also consider how much immediate measures to reduce acid emissions will affect the amount of damage that will occur over the next few years.

## Conclusions

The implication is that short-term priorities should focus on the local, health-related, damage caused by acid emissions, while damage to ecosystems should be the basis for a longer-term reduction in emissions from those sources and regions that have contributed most to acidification in the past. Any measures to alleviate the local damage caused by sulfur dioxide and other emissions should be consistent with achieving a declining trend in emissions, which would not, for example, be the case with a policy of constructing tall stacks to extend the area over which acid emissions are deposited.